Cambridge (CIE) IGCSE Physics

Your notes

Electric Circuits & Electrical Safety

Contents

- Circuit Diagrams & Circuit Components
- Current in Circuits
- EMF & Potential Difference in Circuits
- Combined Resistance
- Potential Dividers
- Electrical Safety

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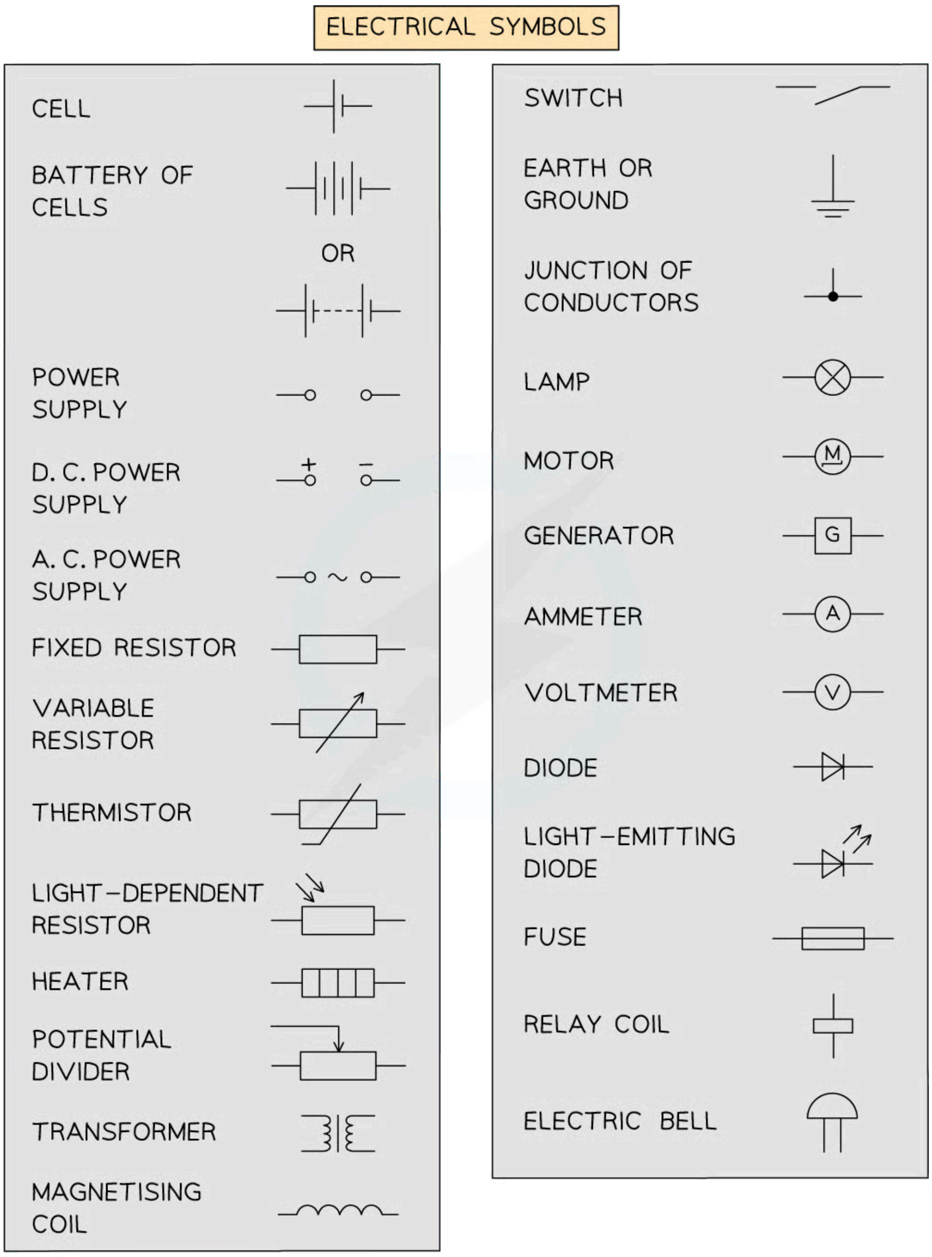
Circuit components

What are circuit symbols?

- The diagram below shows the circuit symbols that could be used in circuit diagrams to represent circuit **components**
  - You will be expected to know **what each component is** and **how it behaves** in a circuit



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Circuit symbols represent these components in circuit diagrams

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Types of circuit components

Power supplies

- Cells, batteries, power supplies and generators all **supply current** to the circuit

Resistors

- Potential dividers, fixed and variable resistors, thermistors and light-dependent resistors (LDRs) are all used to **control current**

Meters

- Ammeters and voltmeters are used to measure the current and potential difference
  - Ammeters are always connected in series whilst voltmeters are always connected in parallel

Switches and functional components

- Switches open and close a circuit and determine whether current can flow
- Functional components perform specific roles when current passes through them:
  - Motors rotate
  - Lamps emit light
  - Heaters transfer thermal energy
  - Bells emit a sound

Electromagnetic components

- Magnetising coils, relays and transformers use electromagnetic effects
  - Relays use a small current in one circuit to switch on a much larger current in another
  - Transformers 'step up' and 'step down' current and potential difference

Fuses

- Protect expensive components from current surges and act as a safety measure against fire

Thermistors

- A thermistor is a **non-ohmic** conductor and a temperature-dependent resistor
- The resistance of a thermistor changes depending on its **temperature**
  - As the temperature **increases** the resistance of a thermistor **decreases** and vice versa

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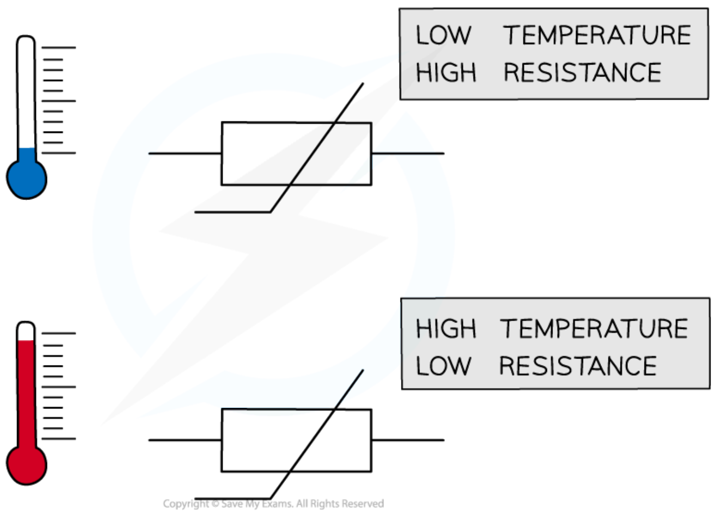
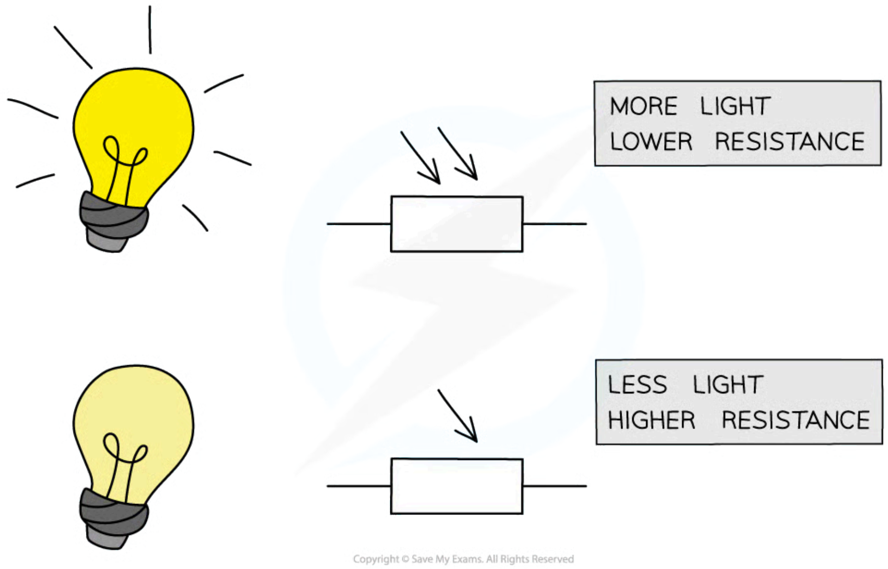


The resistance through a thermistor is dependent on the temperature of it

Light-dependent resistors

- A light-dependent resistor (LDR) is a non-ohmic conductor and sensory resistor
- Its resistance automatically changes depending on the light energy falling onto it (illumination)
- As the **light intensity increases**, the **resistance** of an LDR **decreases**

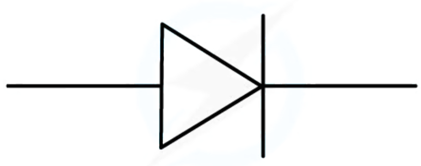


Resistance of an LDR depends on the light intensity falling on it

Diodes

Extended Tier Only

- In addition to the above, you should be able to recognise and draw the circuit symbol for a diode: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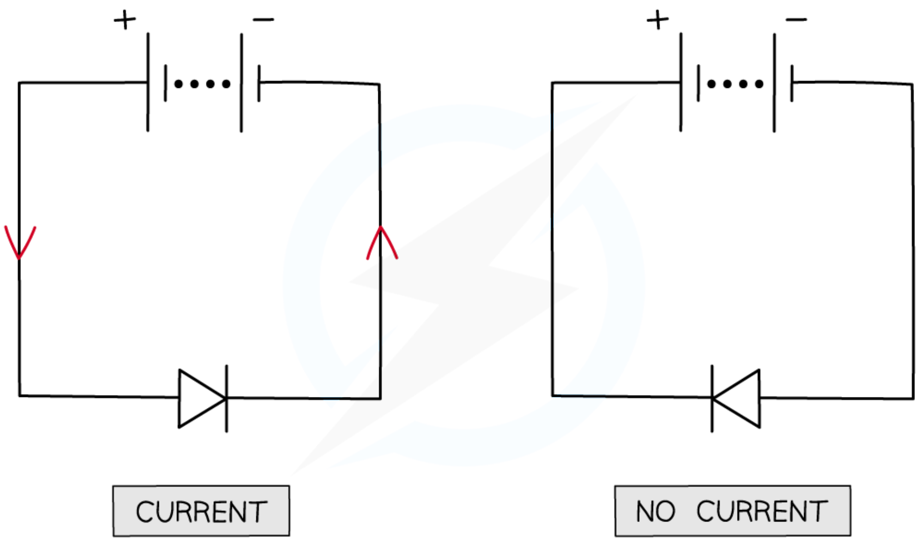
A diode is a component that only allows a current in one direction

- Diodes are occasionally drawn with a horizontal line running through the middle of them
- Diodes only allow current to flow through them in **one** direction (see the diagram below)
  - This is the direction that the triangle points in the diagram



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When travelling in the same direction as the diode, current can flow. If the diode is flipped, it now prevents current from flowing in the circuit

- Light emitting diodes (LEDs) behave the exact same way, but they emit light when current flows through them

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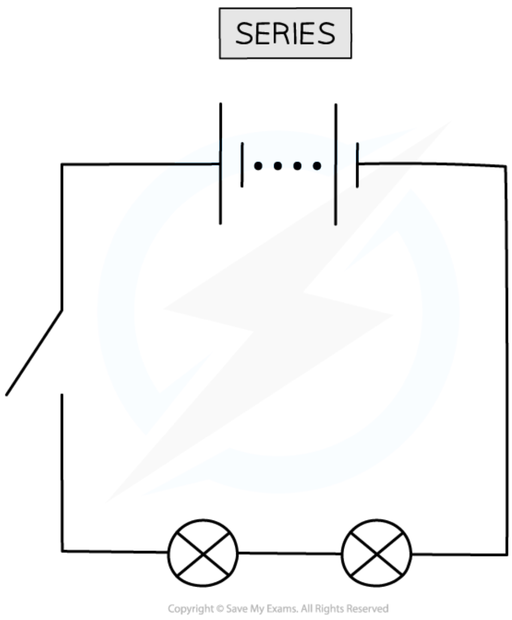
Current in series circuits

What is a series circuit?

- A series circuit contains a **single** complete loop



In this circuit, the switch, battery and both lamps are in a single loop, making it a series circuit

Current in a series circuit

- In a series circuit, the current is the **same value at any point**
  - This is because the number of electrons per second that passes through one part of the circuit is the same number that passes through any other part
- This means that **all** components in a closed-loop have the same current

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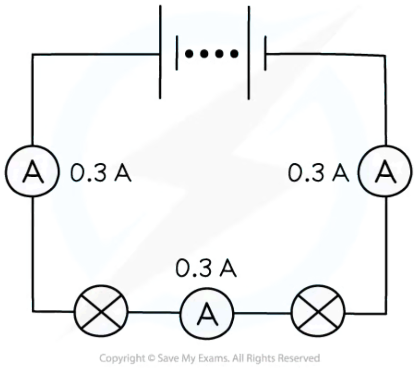
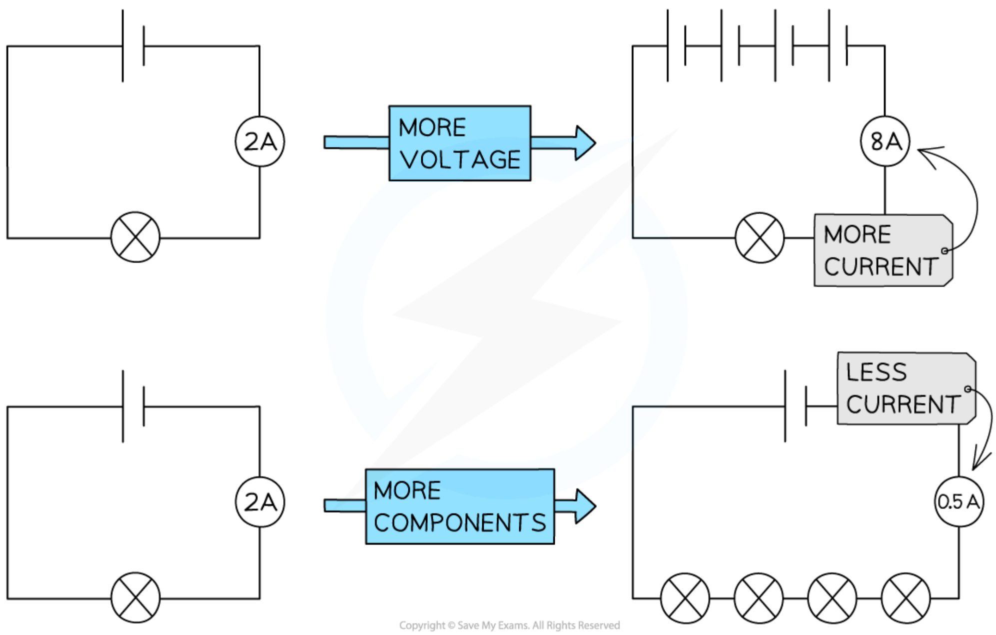


The current is the same at each point in a series circuit

Factors affecting current in a series circuit

- The amount of current flowing around a series circuit depends on two things:
  - The **voltage** of the power source
  - The **resistance** of the components in the circuit
- **Increasing** the **voltage** of the power source drives **more current** around the circuit
  - So, decreasing the voltage of the power source reduces the current
- **Increasing** the **number** of components in the circuit **increases** the **total resistance**
  - Hence **less current** flows through the circuit

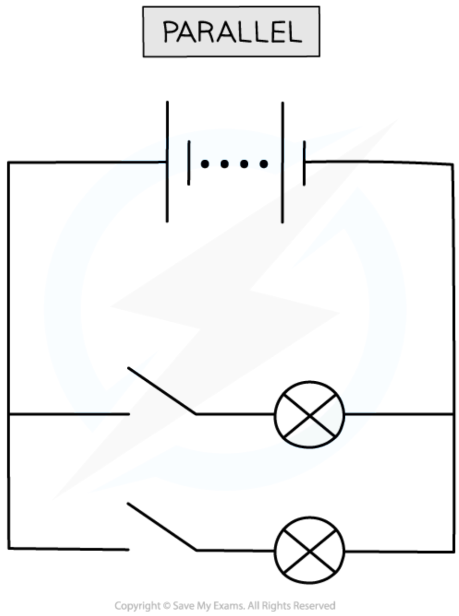


Current will increase if the voltage of the power supply increases, and decreases if the number of components increases (because there will be more resistance)

Current in parallel circuits

What is a parallel circuit?

- A parallel circuit consists of multiple loops containing circuit components



The bulbs are each in a separate loop in this circuit, making it a parallel circuit

What is the rule for current in a parallel circuit?

- In a parallel circuit, the current **splits** along each **branch** at a junction
  - Some of it goes down one branch and the rest goes down the other
- This means that the current from the source is **larger** than the current in each branch

Lighting circuits

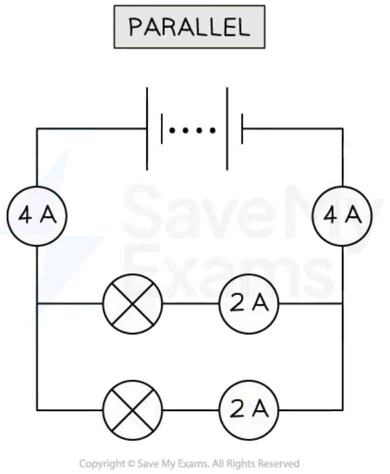
- A lighting circuit is used to supply power to multiple light sources
  - Office lights are a common example, as multiple identical bulbs must have the same brightness
- Lighting circuits are constructed in **parallel** because:
  - Bulb's all have the same potential difference and therefore the same brightness
  - If one bulb breaks, the rest continue to function as current passes along each branch independently
  - This also means lamps can be switched off and on individually without breaking the whole circuit

Your notes

Calculating current in parallel circuits

Extended Tier Only

- The current **before** a junction is equal to the **sum** of currents along each branch **after** the junction



Current from the power supply (4 A) is split along each branch (2 A). These current combine again at the other side

- At a **junction** in a **parallel circuit** (where two or more wires meet) the current is **conserved**
  - This means the amount of current flowing into the junction is equal to the amount of current flowing out of it
- This is because **charge** is conserved
- Note that the current does not always split equally – often there will be more current in some branches than in others
  - The current in each branch will only be identical if the **resistance** of the components along each branch are **identical**
- Current behaves in this way because it is the **flow of electrons**:
  - Electrons are physical matter – they cannot be created or destroyed
  - This means the total number of electrons (and hence current) going around a circuit must remain the same
  - When the electrons reach a junction, however, some of them will go one way and the rest will go the other

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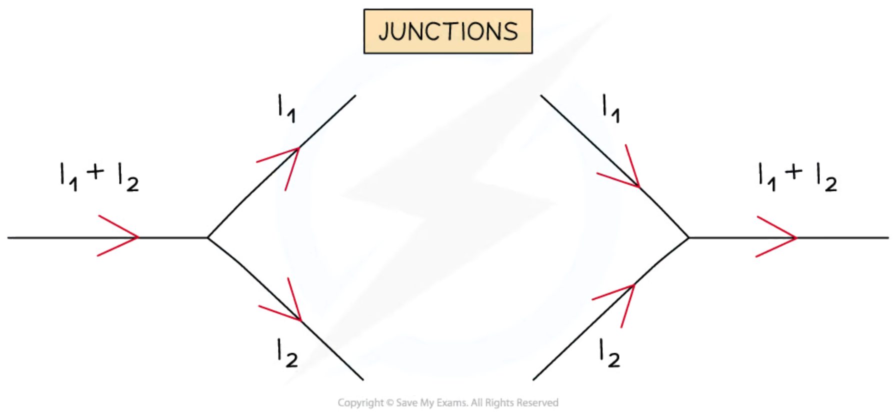
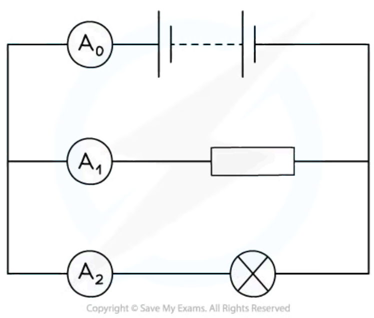


Current is split at a junction into individual branches

Worked Example

In the circuit below, ammeter A_0 shows a reading of 10 A, and ammeter A_1 shows a reading of 6 A.



What is the reading on ammeter A_2?

Answer:

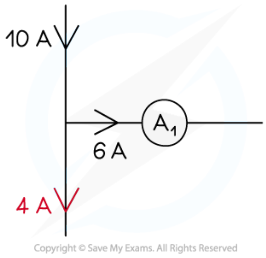
Step 1: Recall that at a junction, the current is conserved

- This means that the total amount of current flowing into a junction is equal to the total amount flowing out

Step 2: Consider the first junction in the circuit where current splits

- The diagram below shows the first junction in the circuit

Your notes



Step 3: Calculate the missing amount of current

- Since 10 A flows in to the junction (the total current from the battery), 10 A must flow out of the junction
- The question says that 6 A flows through ammeter A_1 so the remaining current flowing through ammeter A_2 must be:

$$10\text{ A} - 6\text{ A} = \mathbf{4\text{ A}}$$

- Therefore, **4 A** flows through ammeter A_2

Examiner Tips and Tricks

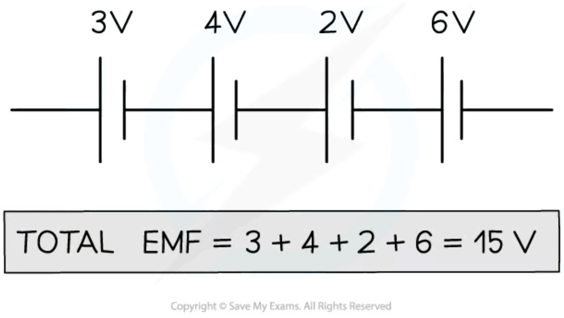
The direction of current flow is important when considering junctions in a circuit. You should remember that current flows from the **positive** terminal to the **negative** terminal of a cell / battery. This will help determine the direction current is flowing round a circuit.

Your notes

Your notes

EMF in series

- When several cells are connected together in series, their combined e.m.f. is equal to the sum of their individual e.m.f.s



The total e.m.f. of these cells is equal to the sum of their individual e.m.f.s

Potential difference in series circuits

Extended Tier Only

- In a series circuit, the sum of potential differences across the components is equal to the total e.m.f. (electromotive force) of the power supply

Potential difference in a series circuit

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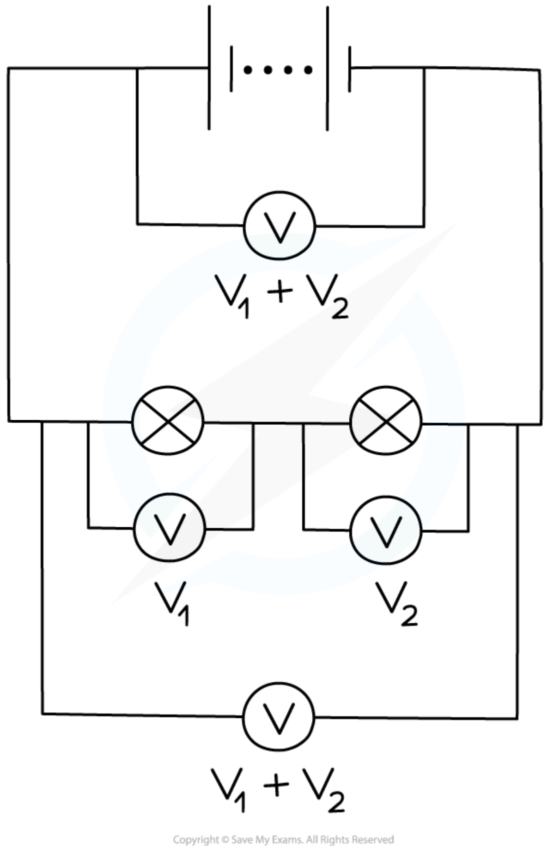
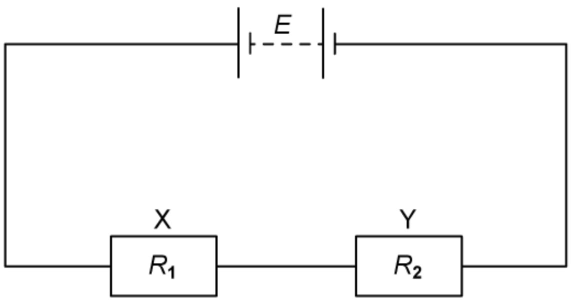


In a series circuit the components share the e.m.f. of the power supply

Your notes

Worked Example

In the circuit diagram below, the power source has an e.m.f., *E*, of 16 V. There is a potential difference of 10 V across component X. Calculate the potential difference across component Y.



Answer:

Step 1: Recall the rule for potential difference in series

- The sum of potential differences across components in series is equal to the e.m.f. across the power source

Step 2: Write an equation to determine the potential difference across Y

$$E = V_X + V_Y$$

- Where:
  - E is the e.m.f. of the power source = 16 V
  - V_X is the potential difference across X = 10 V
  - V_Y is the potential difference across Y
- Recall that:
  - E = 16 V
  - V_X = 10 V

Step 3: Substitute in the known quantities and calculate V_Y

$$16 = 10 + V_Y$$

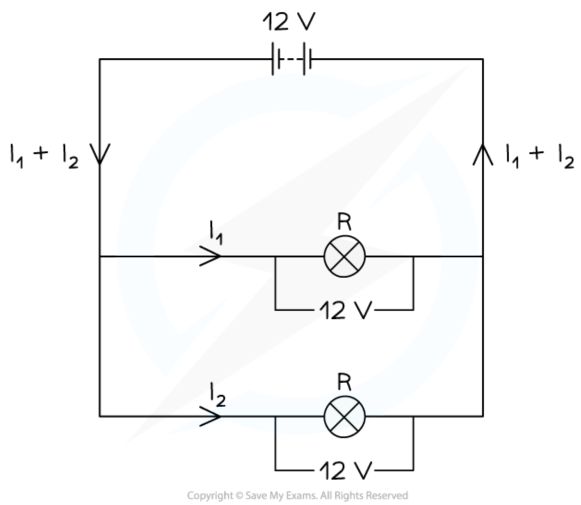
- Therefore, the potential difference across Y is 6 V

Potential difference in a parallel circuit

Extended Tier Only

- The potential difference across **each** branch of a parallel circuit is the same as the e.m.f. of the power source

Potential difference in a parallel circuit



The power source has an e.m.f . of 12 V and there is a potential difference of 12 V across each branch

Your notes

- It is important to notice that the potential difference in a parallel circuit is equal across each **branch**
  - In the example above, if one branch in the circuit contained multiple components, the 12 V would be **split** between the components on that branch

Your notes

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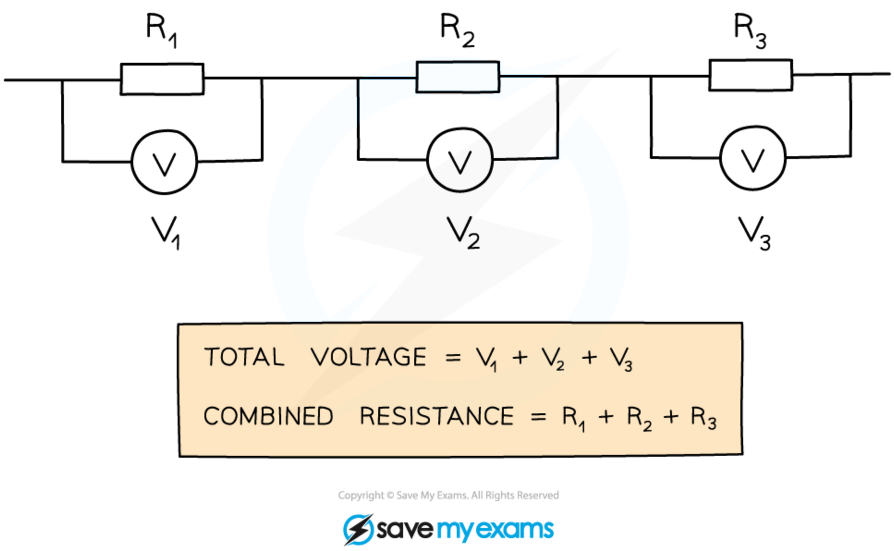
Resistors in series & parallel

Combination of resistance in series

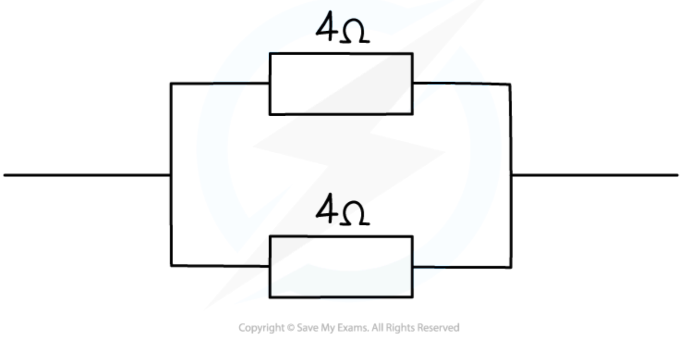
- When two or more components are connected in **series**:
  - The **combined** resistance of the components is equal to the **sum** of individual resistances



When several components are connected in series, their combined resistance is equal to the sum of their individual resistances

Combination of resistance in parallel

- When resistors are connected in parallel, the **combined** resistance is **less than** the resistance of any of the individual components
- If two resistors of equal resistance are connected in parallel, then the combined resistance will halve



The above resistors will have a combined resistance of 2 Ω – half the value of each resistor in this case

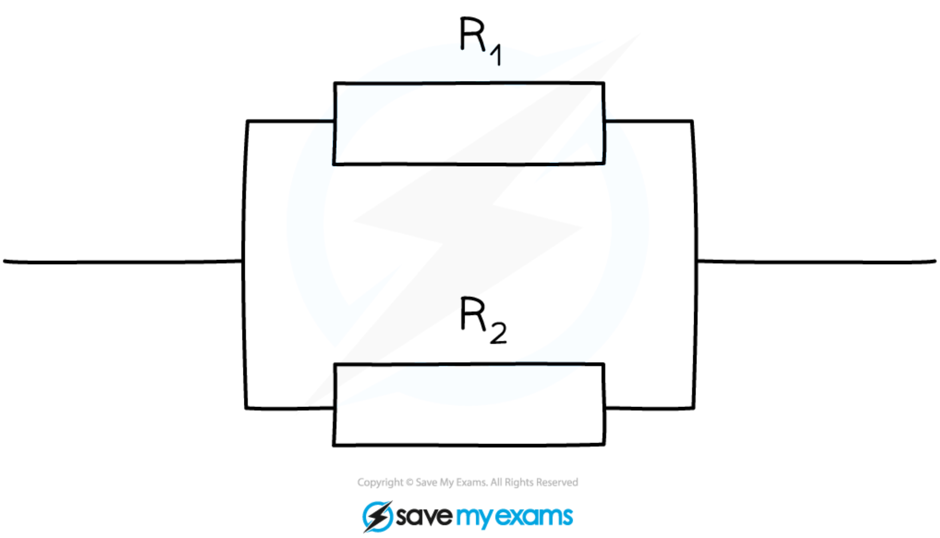
Determining resistance in parallel

Extended Tier Only

- To determine the combined resistance of any combination of two resistors, you must use the equation:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

- Where:
  - R is the combined resistance in ohms, Ω
  - R_1 is the resistance of resistor 1 in ohms, Ω
  - R_2 is the resistance of resistor 2 in ohms, Ω



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$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$$

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The combined resistance is always less than the resistance of either resistor individually

- The method to calculate the resistance:
  - First find the value of $1/R$ (by adding $1/R_1 + 1/R_2$)
  - Next find the value of R by using the reciprocal button on your calculator (labelled either x^{-1} or $1/x$, depending on your calculator)

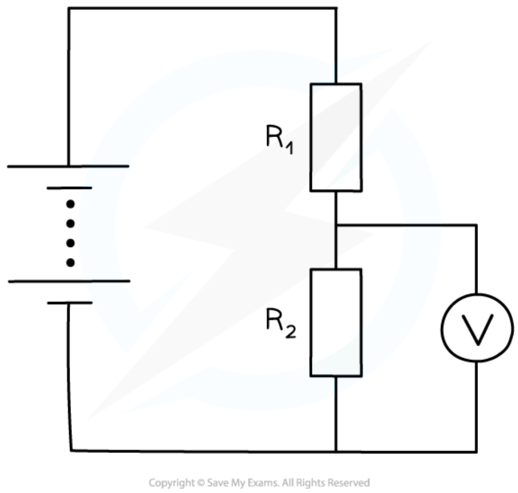
Your notes

Variable potential dividers

Extended Tier Only

- When two resistors are connected in series, the potential difference across the power source is shared between them
- A potential divider is a circuit which **splits** potential difference from a power source, so only a **fraction** goes to a component (a voltmeter, in the diagram below)

Potential divider diagram



A potential divider splits the potential difference of a power source between two components

- The potential difference across each resistor depends upon its resistance:
  - The resistor with the **largest resistance** will have a **greater potential difference** than the other one
  - If the **resistance** of one of the resistors is **increased**, it will get a **greater** share of the potential difference, whilst the **other** resistor will get a **smaller** share
- If one resistor is a **variable resistor**, the potential difference across the other resistor can be **altered**
  - This means the potential difference across any component **in parallel** with that resistor can also be altered

Resistors as Potential Dividers

Extended Tier Only

- When two resistors are connected in series, the power source's e.m.f. is split between the resistors
  - This potential difference splits in the **same ratio** as the resistance of the two resistors
- The ratio of potential differences across each resistor can be found using the following equation:

$$\frac{R_1}{R_2} = \frac{V_1}{V_2}$$

- Where:
  - R_1 is the resistance of resistor 1 in ohms, Ω
  - R_2 is the resistance of resistor 2 in ohms, Ω
  - V_1 is the potential difference across resistor 1 in volts, V
  - V_2 is the potential difference across resistor 2 in volts, V
- Recall that the e.m.f. of the power source will be equal to $V_1 + V_2$

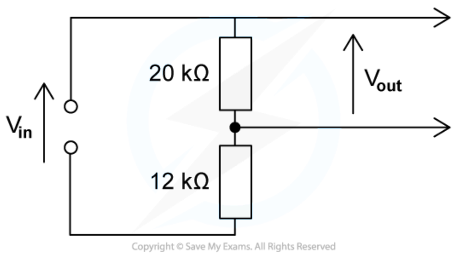
Your notes

Worked Example

The circuit is designed to light up a lamp when the input voltage exceeds a value.

When the lamp lights up, V_{out} is 5.3 V.

Calculate the e.m.f. of the power source required to illuminate the lamp.



Answer:

Step 1: List the known quantities

- Resistance of resistor 1, R_1 = 12 kΩ = 12 000 Ω
- Resistance of resistor 2, R_2 = 20 kΩ = 20 000 Ω

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- Potential difference across resistor 2, $V_2 = V_{out}$ = 5.3 V

Step 2: Recall the equation for a potential divider

$$\frac{R_1}{R_2} = \frac{V_1}{V_2}$$

Step 3: Substitute the known quantities and determine the potential difference across resistor 1

$$\frac{12\,000}{20\,000} = \frac{V_1}{5.3}$$

$$V_1 = 3.18 \text{ V}$$

Step 4: Determine the e.m.f. of the power source, V_{in}

$$V_{in} = V_1 + V_2$$

$$V_{in} = 3.18 + 5.3 = 8.48 \text{ V}$$

- The e.m.f. of the power source when the lamp illuminates is 8.5 V to 2 significant figures

Examiner Tips and Tricks

When thinking about potential dividers, remember that the higher the resistance the more energy it will take to 'push the current through' and therefore the higher the potential difference.

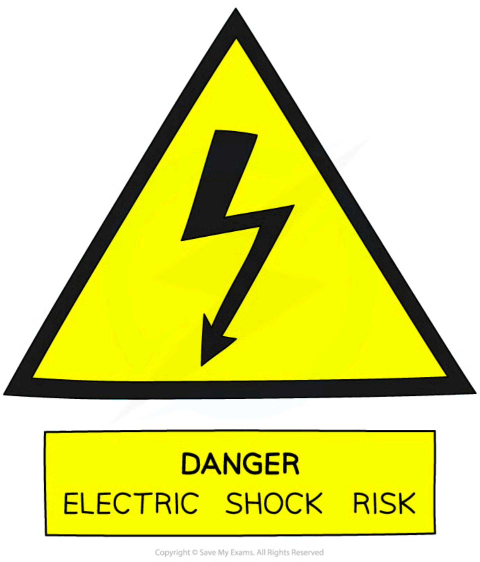
This means that if a component (often shown as a voltmeter in questions) needs to be switched on by a change such as increased light or temperature, then the resistor it is in parallel with needs to become larger **compared to the other resistor.**

Your notes

Electrical hazards

- Mains electricity can be dangerous if safety procedures are not followed
  - Voltages as low as 50 V can pose a serious risk of electrocution
- Common electrical hazards include:
  - damaged insulation
  - overheating cables
  - damp conditions
  - excess current from overloading of plugs, extension leads, single and multiple sockets when using a mains supply

Electrical danger sign



The risk of electrocution is indicated by hazard signs but other risks which would not be signposted are listed below

Damaged insulation

- If the insulation around an electrical cable is damaged, the metal part of the wire may become exposed
- If a person touches the exposed wire, they could be subjected to a lethal electric shock
- There is also a chance that current will flow between the exposed wire and any piece of metal it comes into contact with

Your notes

Overheating of cables

- If an excess of current flows in a wire, this can lead to overheating
- This could cause the insulation to melt, or even cause a fire

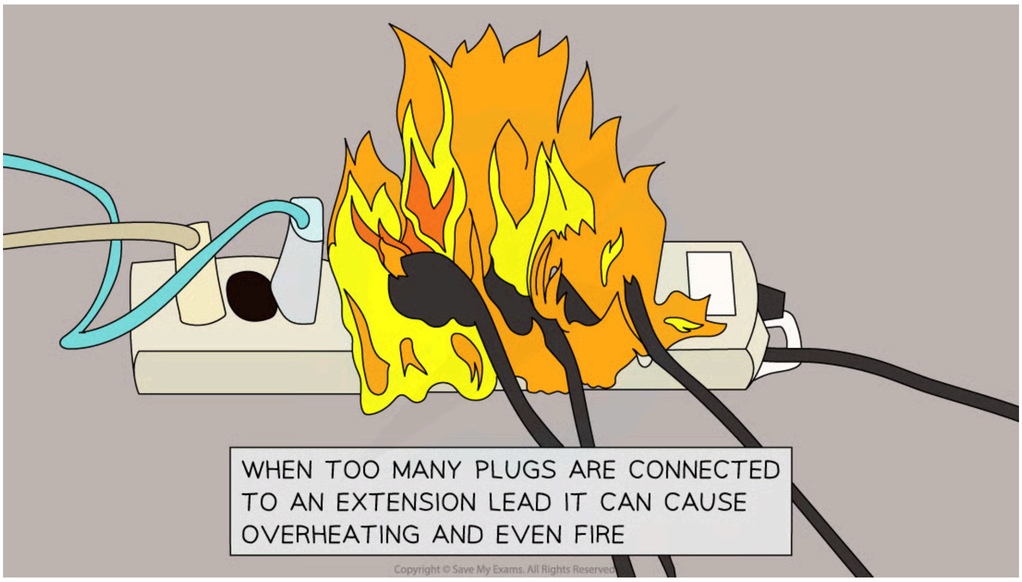
Damp conditions

- Damp conditions can be dangerous in the presence of electricity since water is an electrical conductor
- If moisture comes into contact with a live wire, this could set up
  - a short circuit within the device, which could cause a fire
  - a conductive path for current to flow through a person to the earth, which could cause electrocution

Excess current from overloading

- An excessive current may flow if too many plugs, extension leads or sockets are connected to the mains supply
- The heat created could cause the insulation to melt, or even cause a fire

Electrical fire due to excessive current



Too many appliances plugged into an extension lead can cause overheating and fire

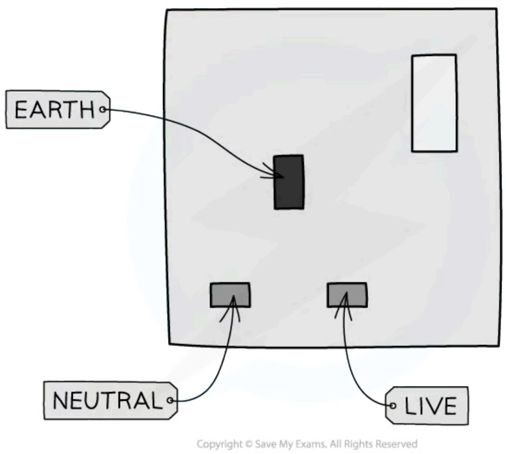
Mains Circuits

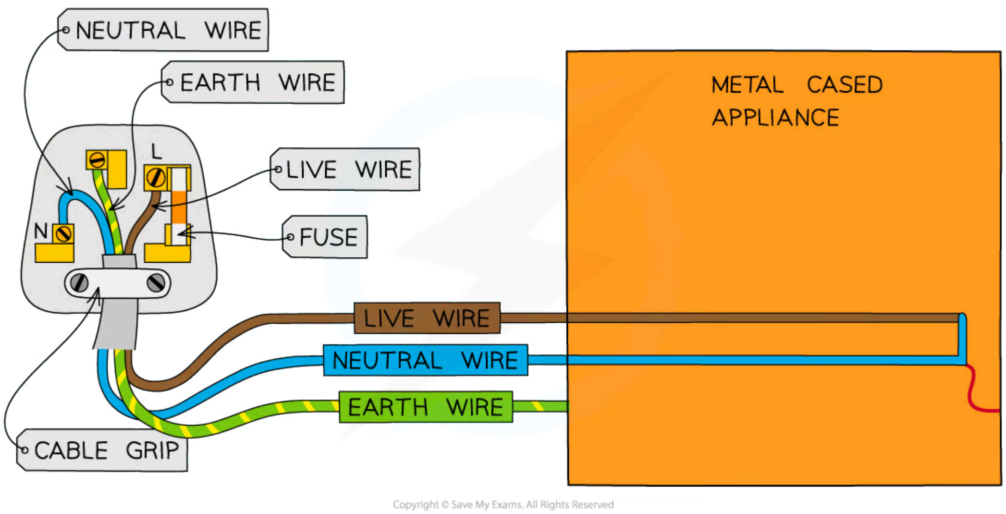
- All electrical appliances are connected to the mains supply
- A mains circuit consists of:
  - a live wire

- a neutral wire
- an earth wire

- The insulation covering each wire is colour-coded for easy identification:
  - Live wire – **brown**
  - Neutral wire – **blue**
  - Earth wire – **green and yellow stripes**

Live, neutral & earth wires





A mains-powered appliance in the UK contains live, neutral and earth wires

- Every country has a slightly different configuration, with many using two-pin plugs and plug sockets such as in the USA and mainland Europe
  - The earth wire is still present in the two-pin plugs, just more hidden
- The three wires have distinct purposes

Your notes

Your notes

The live wire

- The purpose of the live wire is **to carry the alternating current from the mains supply to a circuit**
- It is the most dangerous of the three wires
- If it touches the appliance without the earth wire, it can cause electrocution

The neutral wire

- The purpose of the neutral wire is **to form the opposite end of the circuit to the live wire to complete the circuit**
- Because of its lower voltage, it is much less dangerous than the live wire

The earth wire

- The purpose of the earth wire is **to act as a safety wire to stop the appliance from becoming live**
- This prevents electric shocks from occurring if the appliance malfunctions or the live wire breaks off and touches the case of the plug
- In order to protect the user or the device, there are several safety features built into domestic appliances, including:
  - double insulation
  - earthing
  - fuses
  - circuit breakers

Double insulation

- The conducting part of a wire is usually made of copper or some other metal
  - If this comes into contact with a person, this poses a risk of electrocution
- For this reason, wires are covered with an insulating material, such as rubber

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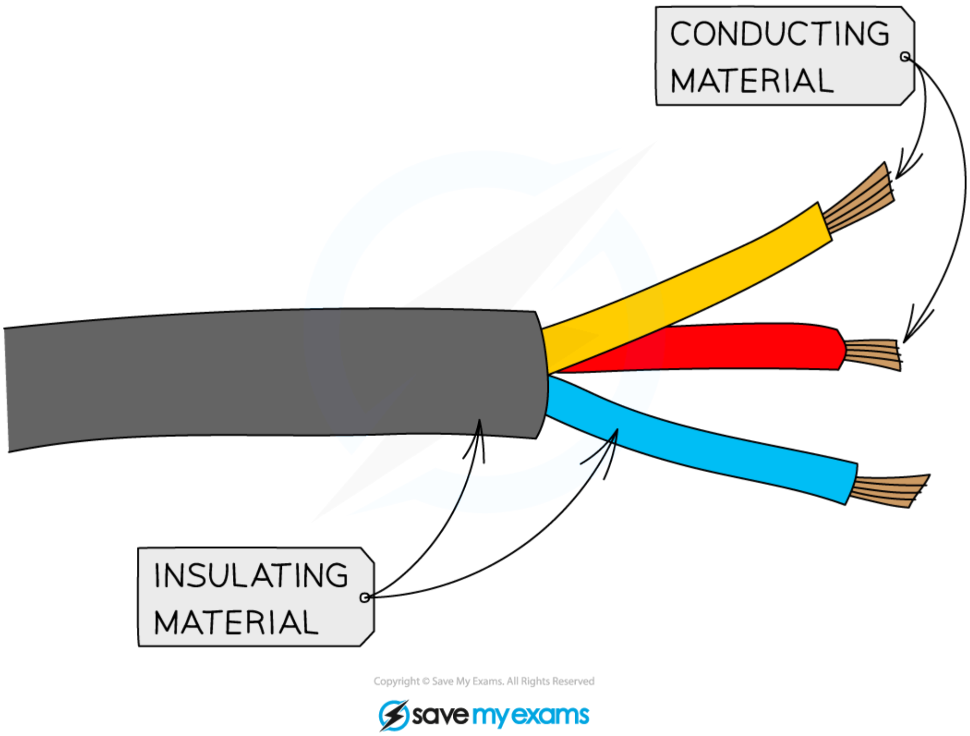


The conducting part of a wire is covered in an insulating material for safety

- Some appliances do not have metal cases and so there is no risk of them becoming electrified
- Such appliances are said to be **double insulated**, as they have two layers of insulation:
  - Insulation around the wires themselves
  - A non-metallic case that acts as a second layer of insulation
- Double insulated appliances do not require an earth wire or have been designed so that the earth wire cannot touch the metal casing

Earthing

- Many electrical appliances have metal cases
- This poses a potential safety hazard:
  - If a live wire (inside the appliance) came into contact with the case, the case would become electrified and anyone who touched it would risk being electrocuted
- The earth wire is an additional safety wire that can reduce this risk
- If this happens:
  - The earth wire provides a **low resistance path to the earth**
  - It causes a **surge of current in the earth wire** and hence also in the live wire

- The high current through the fuse causes it to **melt and break**
- **This cuts off the supply of electricity to the appliance**, making it safe

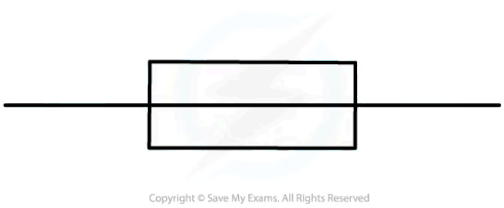
Fuses & trip switches

- **Fuses** and **trip switches** (circuit breakers) are safety devices designed to **cut off the flow of electricity** to an appliance if the current becomes **too large** (due to a fault or a surge)

Fuses

- **Fuses** are used to protect **individual appliances**
- Fuses are located in the **plug**
- Fuses usually consist of a glass cylinder containing a thin metal **wire**
- A fuse without an earth wire **protects** the circuit and the cabling for a double-insulated appliance
- If the current in the wire becomes too large:
  - The wire **heats up** and **melts**
  - This causes the wire to **break**, breaking the **circuit** and **stopping** the **current**

Circuit symbol of a fuse



The circuit symbol for a fuse has a wire running through it (not to be confused with a resistor)

- Fuses have **ratings**, which signify the **maximum current** that can flow through the fuse wire without it melting
- If the current **exceeds** that value, the fuse **wire melts** and the **individual appliance** is **disconnected** from the mains supply
- Fuses come in values of **3 A**, **5 A** and **13 A**
- The correct fuse to use is the value just above the current required for the appliance

Choosing the correct fuse

- Suppose an appliance uses 3.1 amps
  - A 3 amp fuse would be **too small** - the fuse would blow as soon as the appliance was switched on

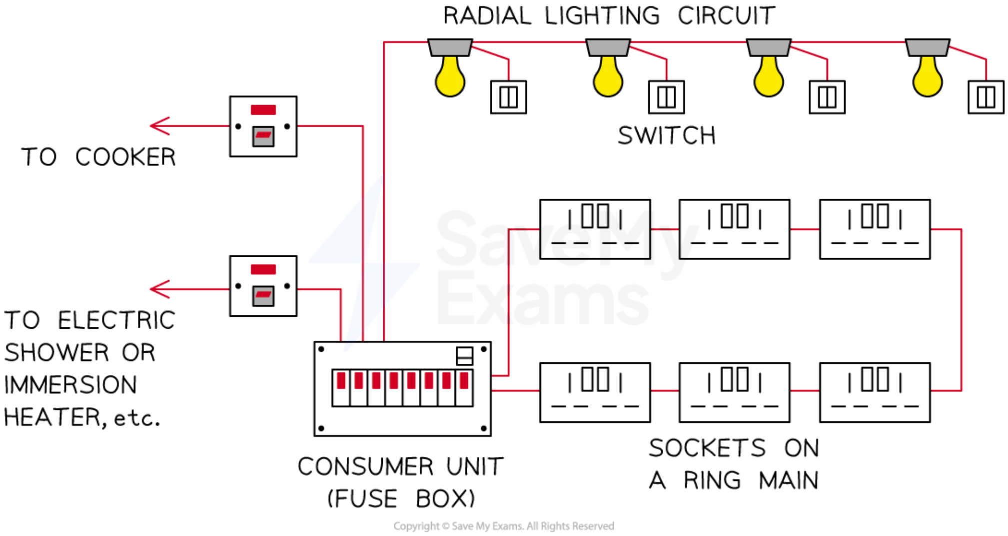
Your notes

- A 13 amp fuse would be **too large** - it would allow an extra 10 amps to pass through the appliance before it finally blew
- A 5 amp fuse would be the **most appropriate** choice, as it is the next size up

Trip switches

- The current enters the house at the **consumer unit** (sometimes referred to as a 'fuse box')
- The consumer unit consists of a series of **trip switches** (or circuit breakers) which control the amount of current supplied to each circuit within the house
  - When the current is too high the switch 'trips' (automatically flicks to the off position)
  - This stops the current flowing in that circuit

Example of a domestic circuit



The consumer unit distributes current to all the circuits in the house

- The main **advantages** of trip switches are:
  - they provide protection from current surges or faults
  - they can be reset when the problem is fixed

Your notes