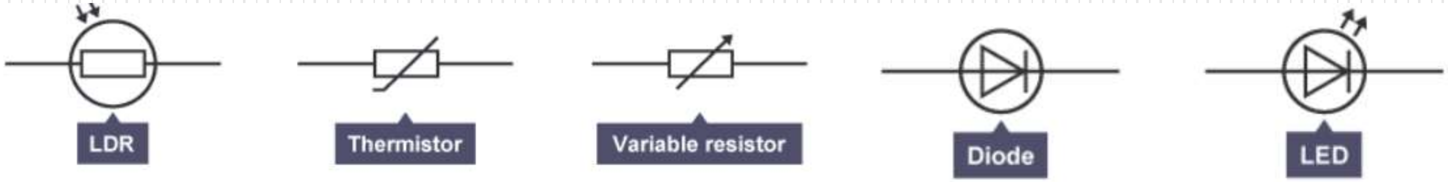
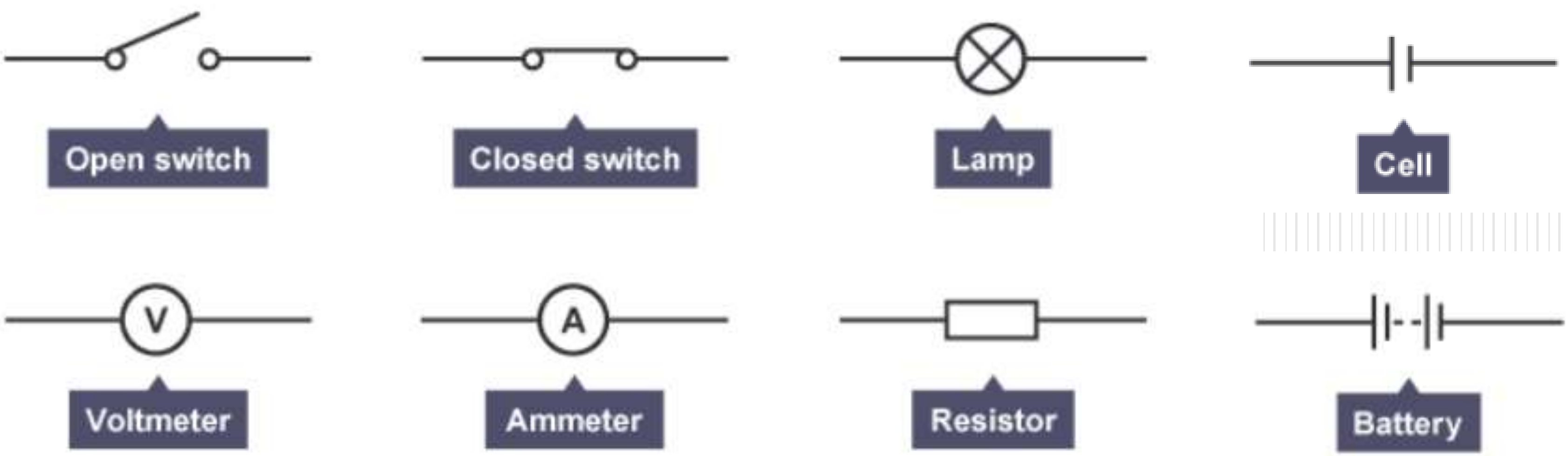


Electric Circuits



Electrical charge and current

- There are two types of **current**: direct and alternating.
- In a **direct current**, the flow of **electrons** is consistently in one direction around the circuit.
- In an **alternating current**, the direction of electron flow continually reverses.

Charge

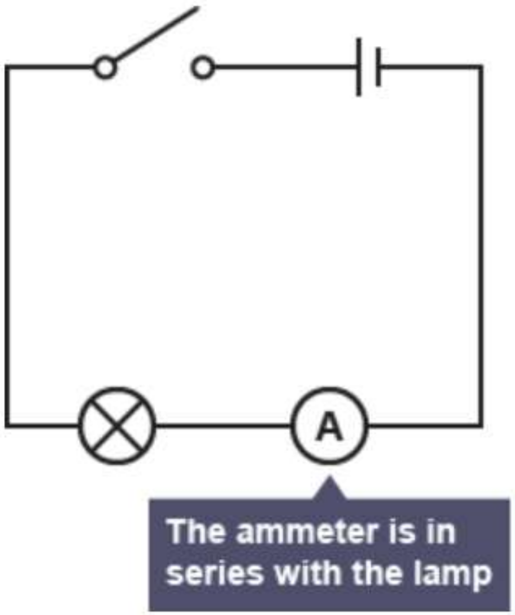
- Electrons are negatively charged particles and they transfer energy through wires as electricity.
- **Charge** is a property of a body which experiences a force in an electric field. Charge is measured in coulombs (C).
- Since electrons are so small and one electron will not have much of an effect anywhere, it is more useful to refer to packages of electrons. One coulomb of charge is a package equivalent to 6,250,000,000,000,000,000 electrons.

Current

- **Electrical current is a flow of electrons.**
- When current flows, electrical **work** is done and energy transferred. The amount of charge passing a point in the circuit can be calculated using the equation: $Q = I \times t$
- This is when:
- charge (*Q*) is measured in coulombs (C)
- current (*I*) is measured in amps (A)
- time (*t*) is measured in seconds (s)
- One amp is the current that flows when one coulomb of charge passes a point in a circuit in one second.

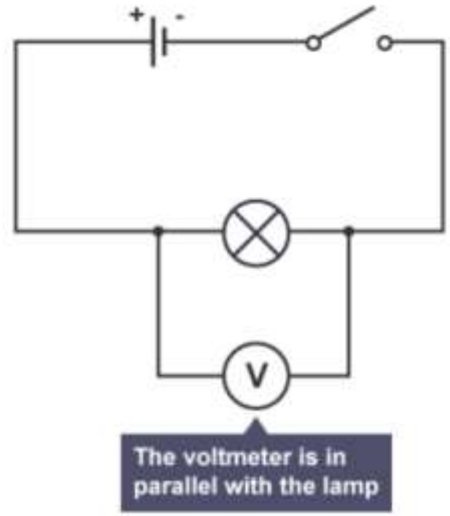
Measuring current

- Current is measured using an **ammeter**. To measure the current through a component, the ammeter must be placed in **series** with that component.



Measuring potential difference

- **Potential difference is a measure of how much energy is transferred between two points in a circuit.**
- To measure the potential difference across a component, a **voltmeter** must be placed **in parallel** with that component in order to measure the difference in energy from one side of the component to the other.
- Potential difference is also known as **voltage** and is measured in volts (V).



Energy, voltage and charge

- When a charge moves through a potential difference, electrical **work** is done and energy transferred. The potential difference can be calculated using the equation: $V = \frac{E}{Q}$

This is when:

- potential difference (*V*) is measured in volts (V)
- energy (*E*) is measured in joules (J)
- charge (*Q*) is measured in coulombs (C)
- One volt is the potential difference when one coulomb of charge transfers one joule of energy.

Resistance

- When a charge moves through a potential difference, electrical work is done and energy transferred. The potential difference can be calculated using the equation: $V = I \times R$
- This is when:
- potential difference (*V*) is measured in volts (V)
- current (*I*) is measured in amps (A)
- resistance (*R*) is measured in ohms (Ω)
- One volt is the potential difference when one coulomb of charge transfers one joule of energy.
- **Conductors have a low resistance. Insulators have a high resistance.**

Series circuits

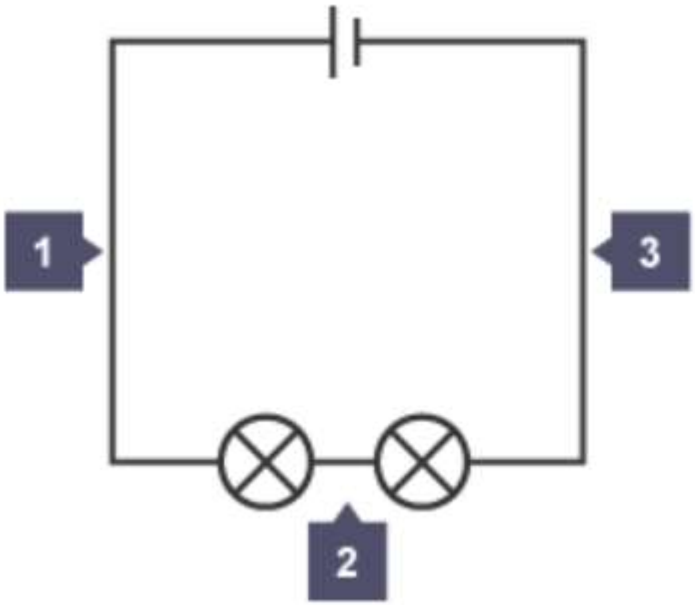
- In series circuits, electrical **components** are connected one after another in a single loop.

Circuit rules

- An **electron** will pass through every component on its way round the circuit. If one of the bulbs is broken then **current** will not be able to flow round the circuit. If one bulb goes out, they all go out.

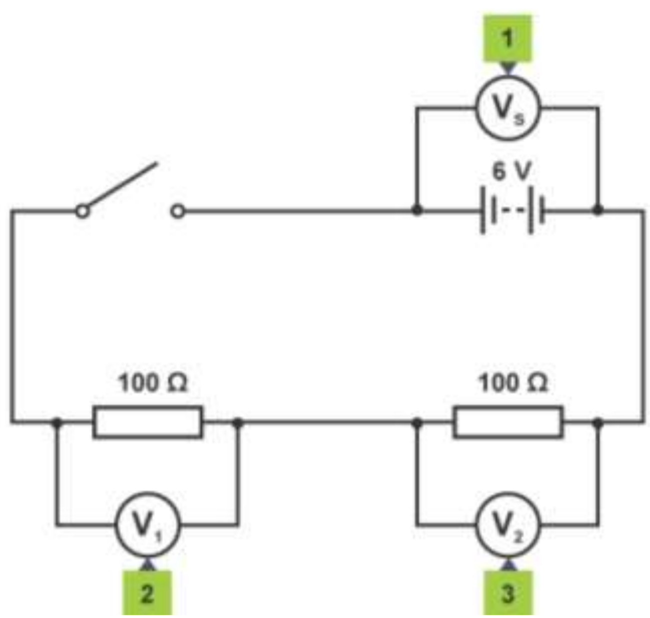
Current in series

- A **series** circuit is one loop; all electrons in that loop form one current. An **ammeter** will measure the same current wherever it is placed in the circuit: $I_1 = I_2 = I_3$



Potential difference in series

- The current will transfer **energy** from the power supply to the components in the circuit. Since energy has to be conserved, all of the source energy is shared between the components. Since **potential difference** is used to measure changes in energy, the potential difference supplied is equal to the total of the potential differences across all other components: $V_s = V_1 + V_2$



Resistance in series

- If **resistors** are connected in series, the current must flow through both of them meaning the **resistances** are added together: $R_{total} = R_1 + R_2$

In series circuits: current is the same through each component

- the total potential difference of the power supply is shared between the components
- the total resistance of the circuit is the sum of individual resistors

Parallel circuits

- In parallel circuits, electrical **components** are connected alongside one another, forming extra loops.

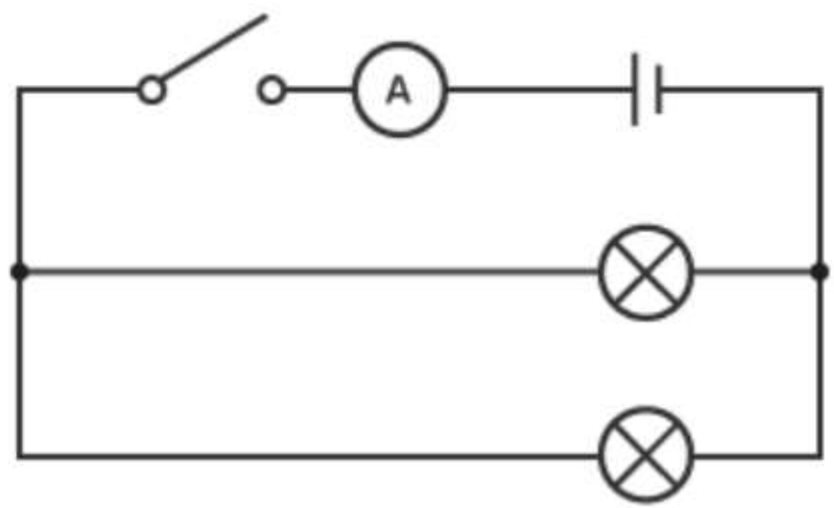
Circuit rules

- An **electron** will not pass through every component on its way round the circuit. If one of the bulbs is broken then **current** will still be able to flow round the circuit through the other loop. If one bulb goes out, the other will stay on.

Current in parallel

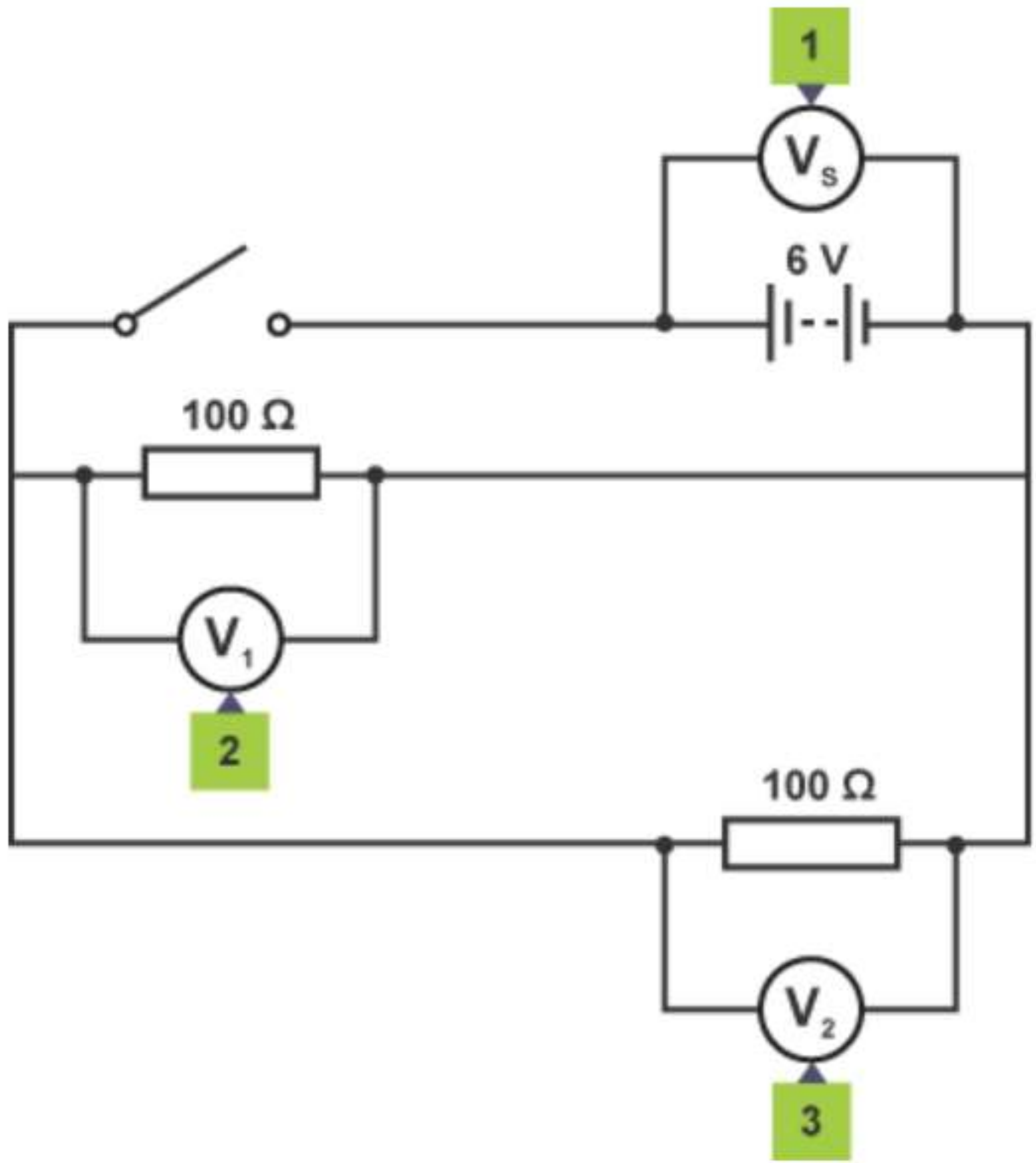
- Since there are different loops, the current will split as it leaves the cell and pass through one or other of the loops. An **ammeter** placed in different parts of the circuit will show how the current splits:

$$I_1 = I_2 + I_4 = I_3$$



Potential difference in parallel

- Since **energy** has to be conserved, the energy transferred around the circuit by the electrons is the same whichever path the electrons follow. Since **potential difference** is used to measure changes in energy, the potential difference supplied is equal to the potential differences across each of the parallel components: $V_s = V_1 = V_2$


1
V_S
6 V
100 Ω
V_1
2
100 Ω
V_2
3

Resistance in parallel

- If **resistors** are connected **in parallel** so that the current will flow through either one or the other, but not both, then the overall **resistance** is reduced as less current is flowing through each.

In parallel circuits:

- the total current supplied is split between the components on different loops
- potential difference is the same across each loop
- the total resistance of the circuit is reduced as the current can follow multiple paths

Energy and power in electric circuits: Heating up wires

- As **electrons** flow through wires, they collide with the **ions** in the wire which causes the ions to **vibrate** more. This increased vibration of the ions increases the temperature of the wire. Energy has been transferred from the chemical energy store of the battery into the internal energy store of the wire.
- The amount of energy transferred each second (**power**) between the **energy stores** can be calculated using the equation: $P = I \times V$

This is when:

- power (*P*) is measured in watts (W)
- **current** (*I*) is measured in amps (A)
- **potential difference** (*V*) is measured in volts (V)

Power can also be written as: $P = I^2 \times R$

This is when:

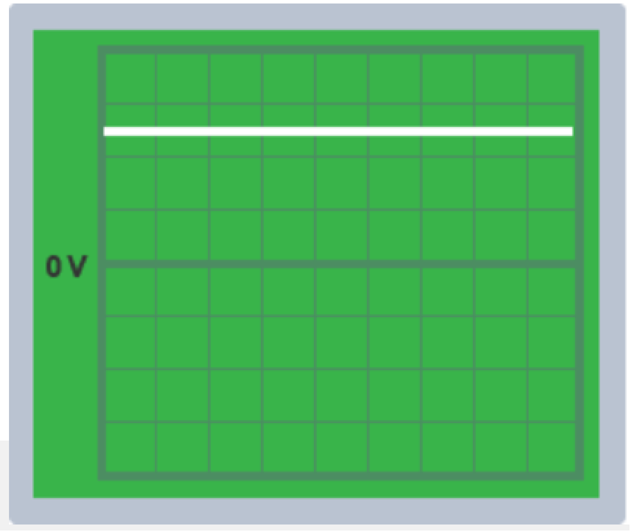
- power (*P*) is measured in watts (W)
- current (*I*) is measured in amps (A)
- **resistance** (*R*) is measured in ohms (Ω)

Efficient transmission of power

- Energy can be transferred by an electrical current; any electrical appliance needs to be given enough energy every second. Electrical power can be delivered as a low current with a high **voltage**, or a high current with a low voltage.
- power = $\text{current}^2 \times \text{resistance}$
- The equation shows that a high current will have a much higher heating effect on the transmission wires than a low current. For this reason, transmitting energy at a high voltage with a low current will keep the wires cooler and waste less energy.

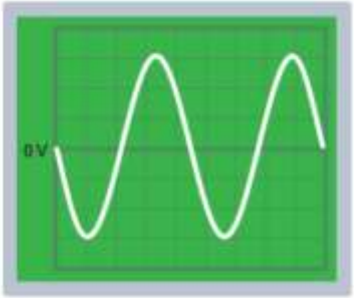
Direct current

- A direct current flows in only one direction.
- On a voltage-time graph this would appear as a straight horizontal line at a constant voltage.
- Car batteries, dry cells and solar cells all provide a direct current (dc) that only flows in one direction.



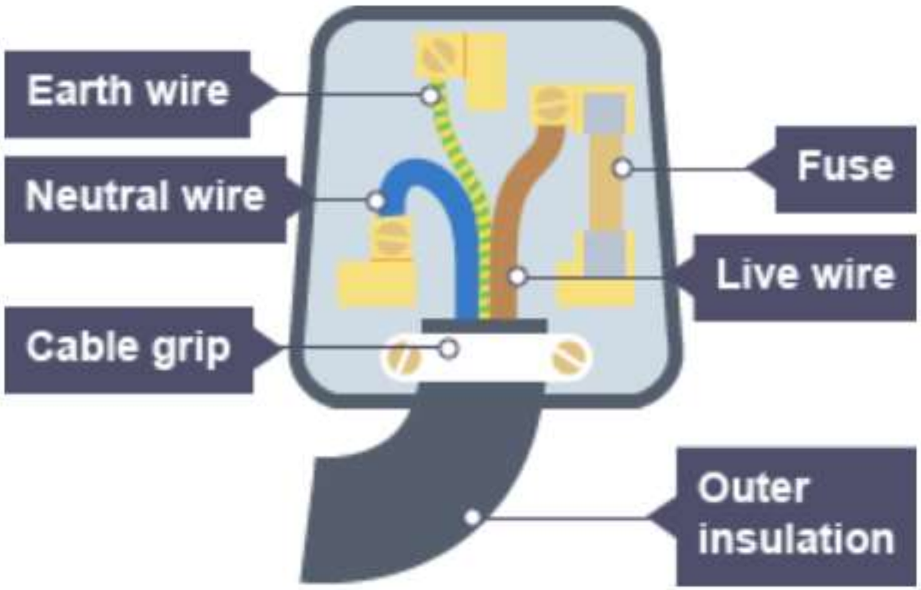
Alternating Current

- An alternating current regularly changes direction.
- On a voltage-time graph, this would appear as a curve alternating between positive and negative voltages. The positive and negative values indicate the direction of current flow.
- Power stations sometimes produce electricity using magnets. This provides an alternating current (ac). In the UK, the **mains electrical supply** is generated at a **frequency** of 50 Hertz (Hz) and is delivered to houses at 230 Volts (V).



Household electricity: plugs

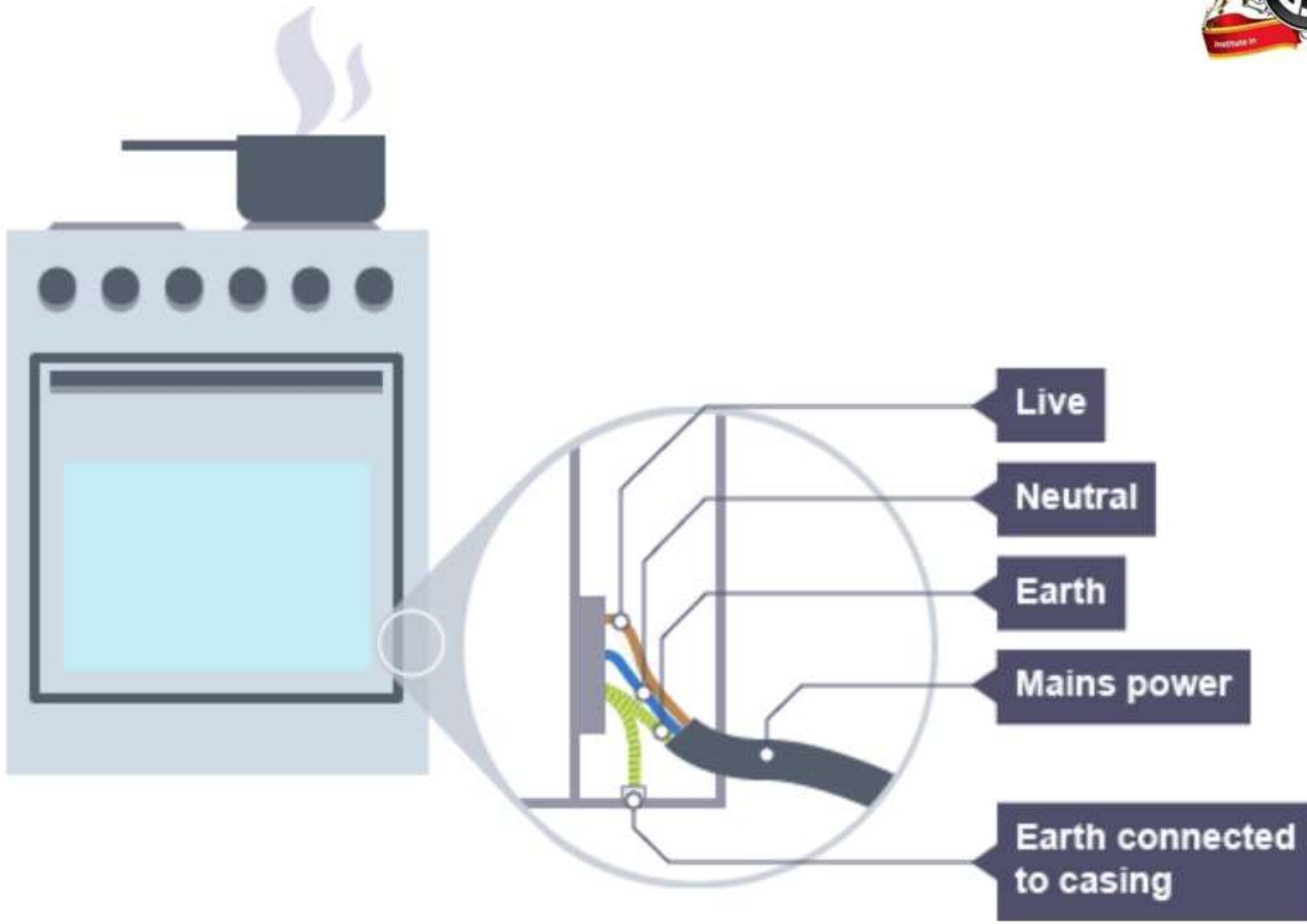
- A plug connects a device to the mains electricity supply. The cable between the device and the three-pin plug contains three copper wires that are coated with plastic.



Features of a plug	Function
Outer insulation	All three wires in the cable are bundled together and there is extra plastic insulation wrapped round them all for safety
Cable grip	This holds the cable tightly in place so that wires do not become loose
Live wire	Copper wire coated with brown plastic along which the current enters the device
Fuse	A glass or ceramic canister containing a thin wire that melts if the current gets too high
Neutral wire	Copper wire coated with blue plastic that also connects to the cable in the wall and completes the circuit
Earth wire	Copper wire coated in striped plastic that provides a path for current to flow from the case of the device to the ground if there is a fault

Earthing

- Without the earth wire, if a fault occurs and the live wire becomes loose, there is a danger that it will touch the case. The next person who uses the appliance could get **electrocuted**.
- The earth wire is therefore connected to the case and is attached to a metal plate or water pipe underground. As the wire is made of copper, the earth wire provides a low **resistance** path to the ground. In the event of a fault, the live current passing through the case will follow this path to the ground instead of passing through a person.


Live
Neutral
Earth
Mains power
Earth connected to casing

Fuses

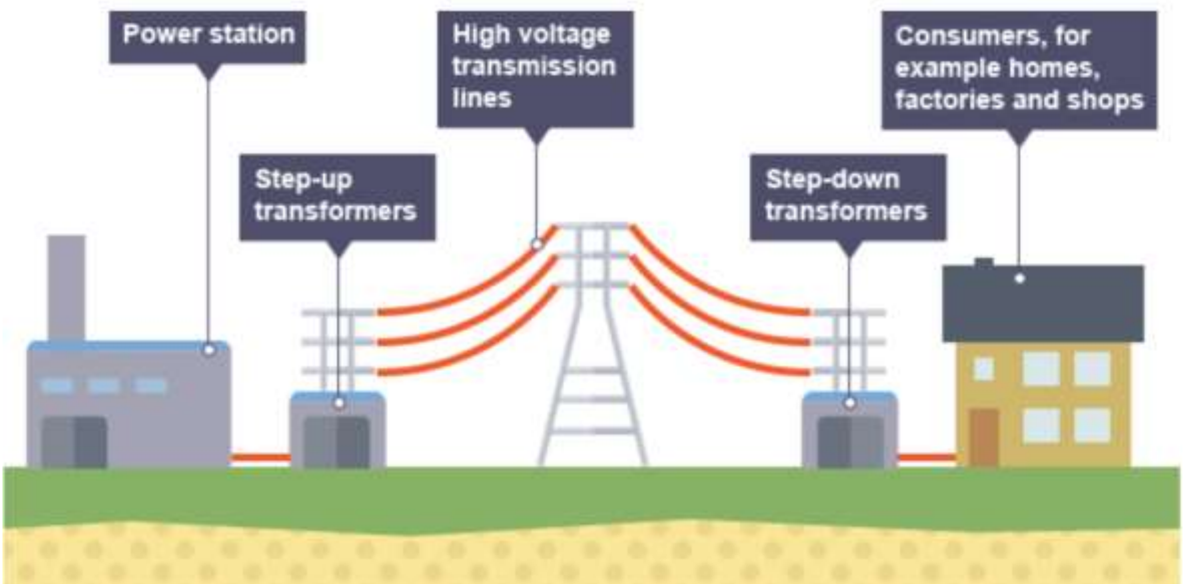
- A fuse provides a built-in fail-safe to the electrical circuit for a device. The fuse contains a thin wire that will melt if the current gets too high. If there is a fault that causes the casing of the device to become live, a large current will flow through the low-resistance earth wire. This high current will cause the fuse to melt.
- Once the fuse has melted, the circuit is broken and no more current flows through the device. This means the case of the device is no longer live and there is no more risk of electrocution.

Appliances, power and energy

- All electrical appliances transfer energy from one **store** to another, for example **chemical energy** in the fuel in power stations. This is transferred into **kinetic energy** in a fan or heat energy in a cooker.
- The amount of energy transferred depends on the **power** (the energy transferred each second) and the amount of time the appliance is switched on for. The energy transferred by an appliance can be calculated using the equation: $E = P \times t$
- This is when:
- energy (*E*) is measured in joules (J)
- power (*P*) is measured in watts (W)
- time (*t*) is measured in seconds (s)

The National Grid

- The **National Grid** distributes electricity across the country. The National Grid connects power stations to homes, workplaces and public buildings all around the country. The electricity may be produced by a conventional power station turning a **generator** or by another **method**.

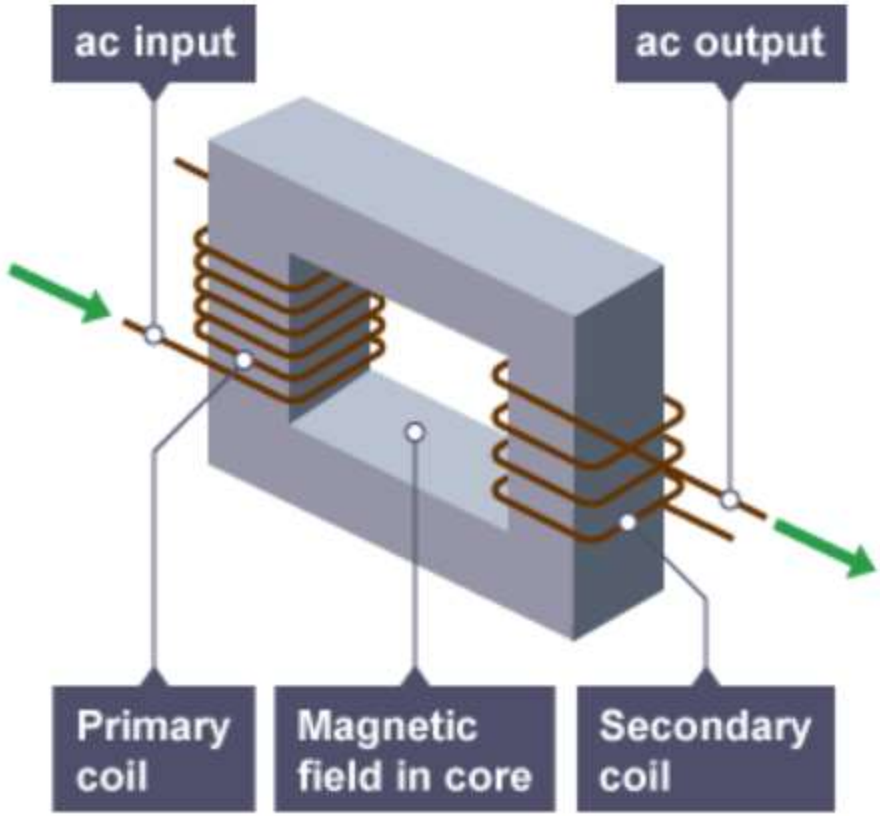


Transformers

- **Transformers** are used to change voltages and **currents** in **transmission lines**. A transformer is formed from two coils of wire around a magnetic core. The number of coils determines whether the transformers will step-up or step-down the voltage

As the power transferred must stay the same:

- increasing voltage decreases current
- decreasing voltage increases current


ac input
ac output
Primary coil
Magnetic field in core
Secondary coil

Transformers

- In the National Grid, a **step-up transformer** is used to increase the voltage and reduce the current. The voltage is increased from about 25,000 Volts (V) to 400,000 V causing the current to decrease. Less current means less energy is lost through heating the wire.
- To keep people safe from these high voltage wires, pylons are used to support transmission lines above the ground.
- Before reaching the end user, a **step-down transformer**, reduces the voltage from the transmission voltage to the safer voltage of 230 V for home use.

Transmission lines

- As an electric current flows through the thick cables held up by the pylons, they will get hotter and dissipate energy to the surroundings. The electrical **power** dissipated depends on current and resistance:

This is when:

- power (*P*) is measured in watts (W)
- current (*I*) is measured in amps (A)
- resistance (*R*) is measured in ohms (Ω)

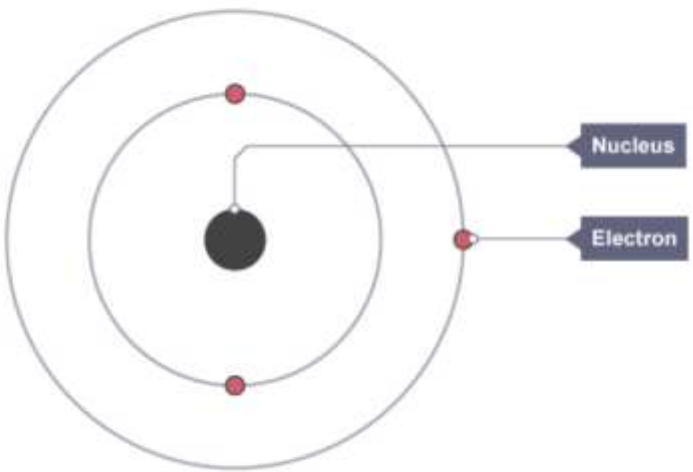
To ensure that the minimum amount of power is lost from the cables:

- the cables are thick so that their resistance is low
- high voltages are used to reduce the current through the transmission lines

- A low resistance and a low current mean that the transmission wires will not heat up as much. As a result, most of the power is delivered to the consumer, and not lost through the wires.

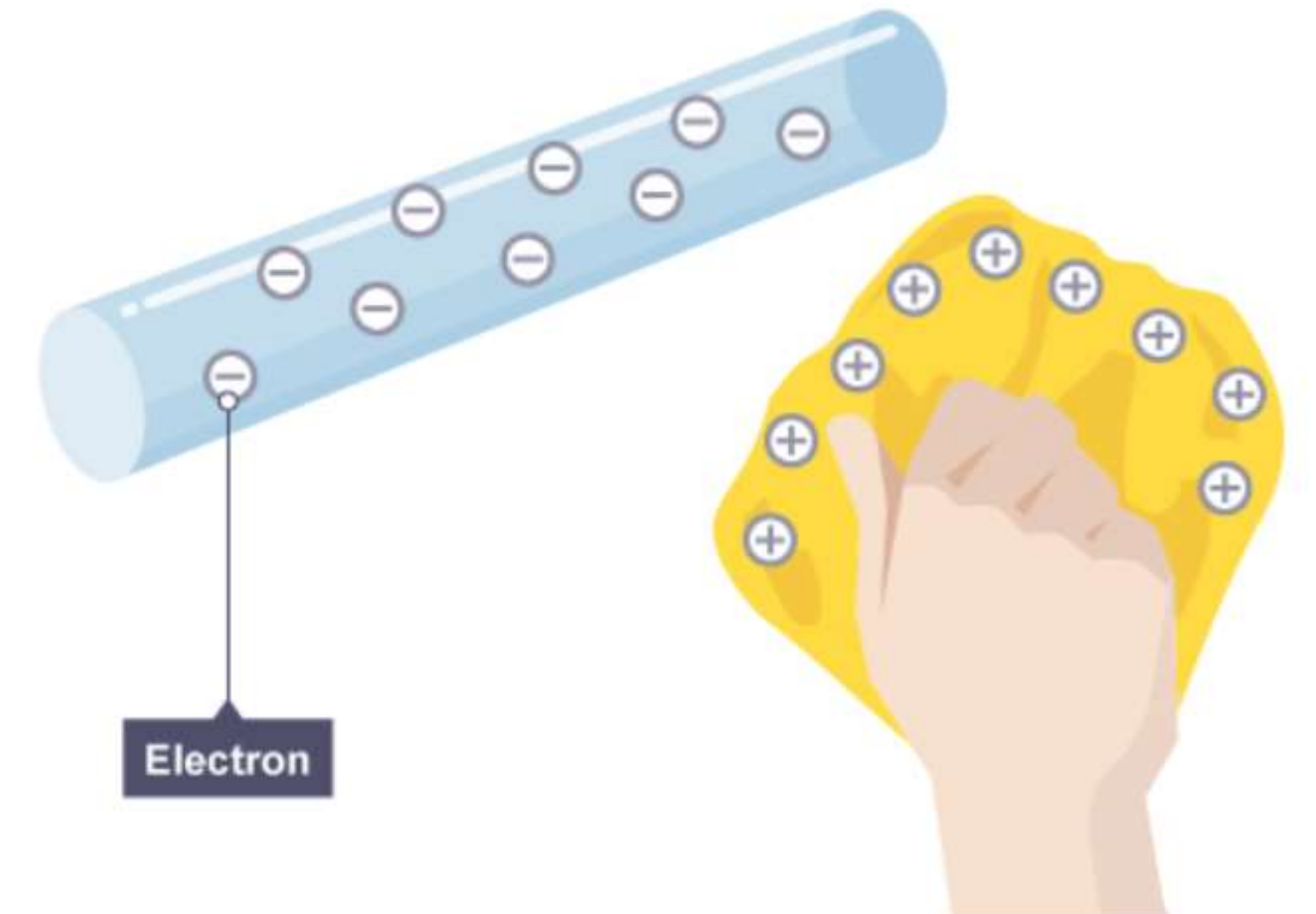
Electrical charges

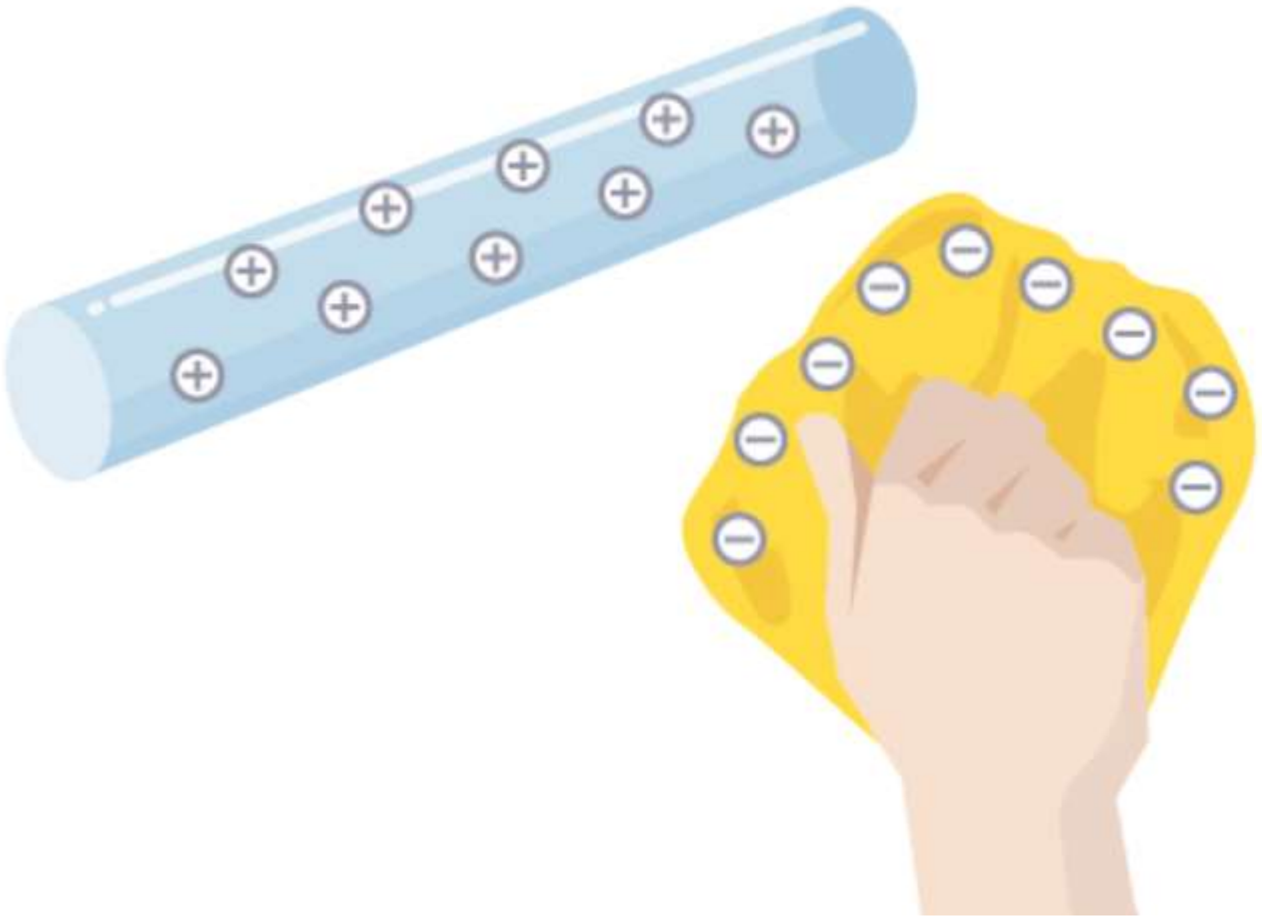
- All matter consists of atoms. Atoms contain three types of smaller particles: **protons**, **neutrons** and **electrons**. Of these three, both the protons and electrons are **charged**.
- **Protons are positively charged. Electrons are negatively charged.**
- Objects that are charged can affect other charged objects using the **non-contact forces** of **static electricity**.



Charging by friction

- When insulating materials rub against each other, they may become electrically **charged**.
- **Electrons**, which are negatively charged, may be 'rubbed off' one material and on to the other.
- The material that gains electrons becomes negatively charged.
- The material that loses electrons is left with a positive charge.

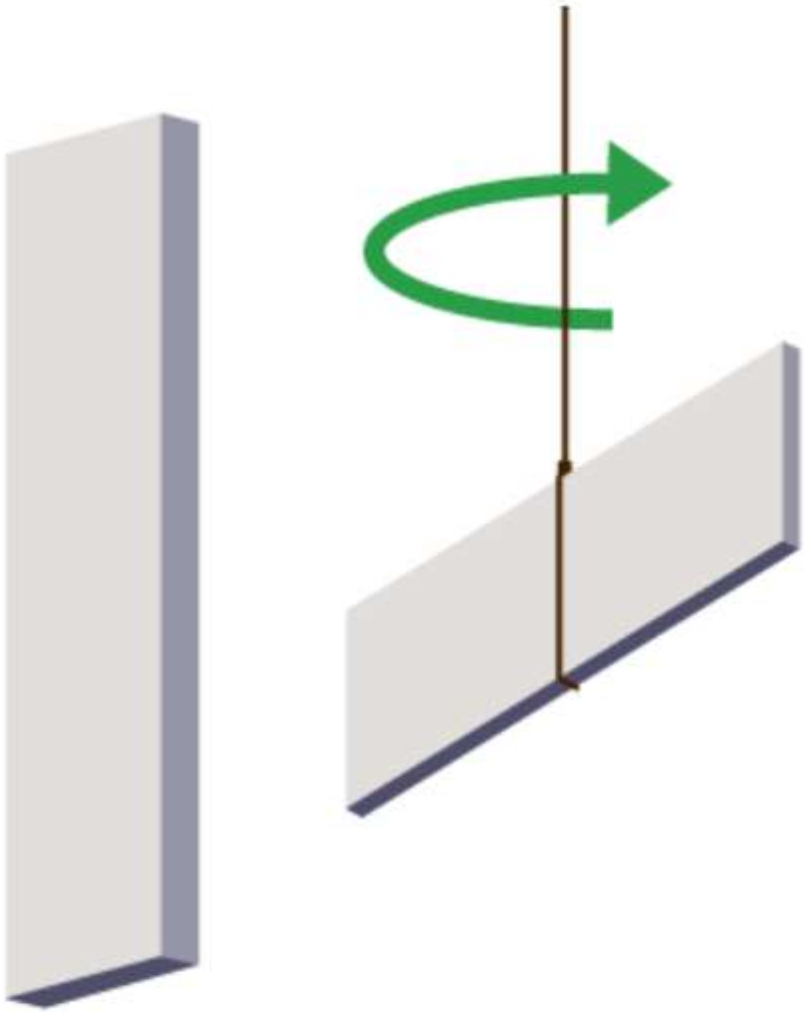

Electron



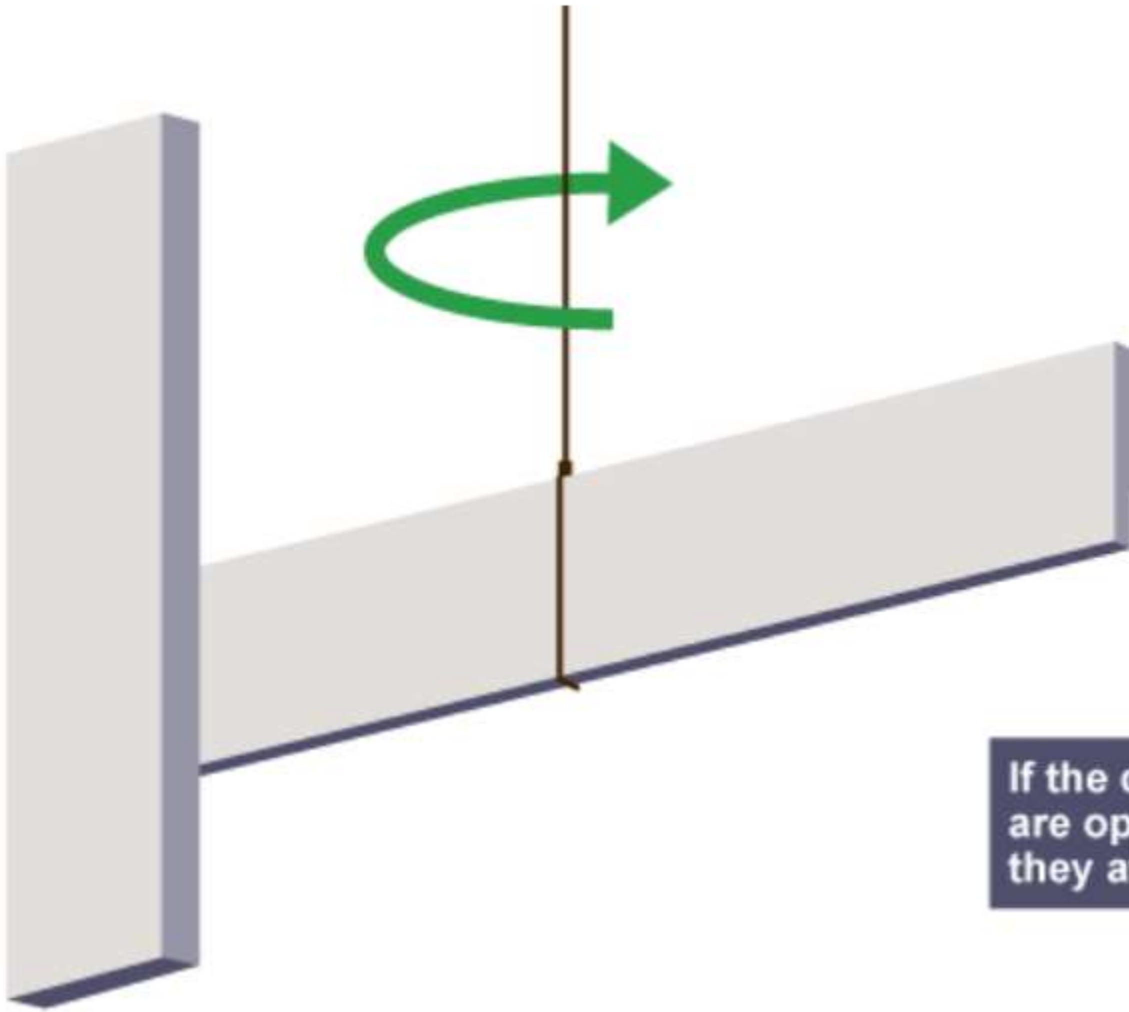
- When a polythene rod is rubbed with a duster, the **friction** causes electrons to gain energy. Electrons gain enough energy to leave the atom and 'rub off' onto the polythene rod.
- the polythene rod has gained electrons, giving it a negative charge
- the duster has lost electrons, giving it a positive charge
- If the rod is swapped for a different material such as **acetate**, electrons are rubbed off the acetate and onto the duster.
- the acetate rod has lost electrons, giving it a positive charge
- the duster has gained electrons, giving it a negative charge
- Both the rods and the duster are made of **insulating** materials. Insulators prevent the electrons from moving and the charge remains **static**. **Conductors**, on the other hand, cannot hold the charge, as the electrons can move through them.

Electrical forces

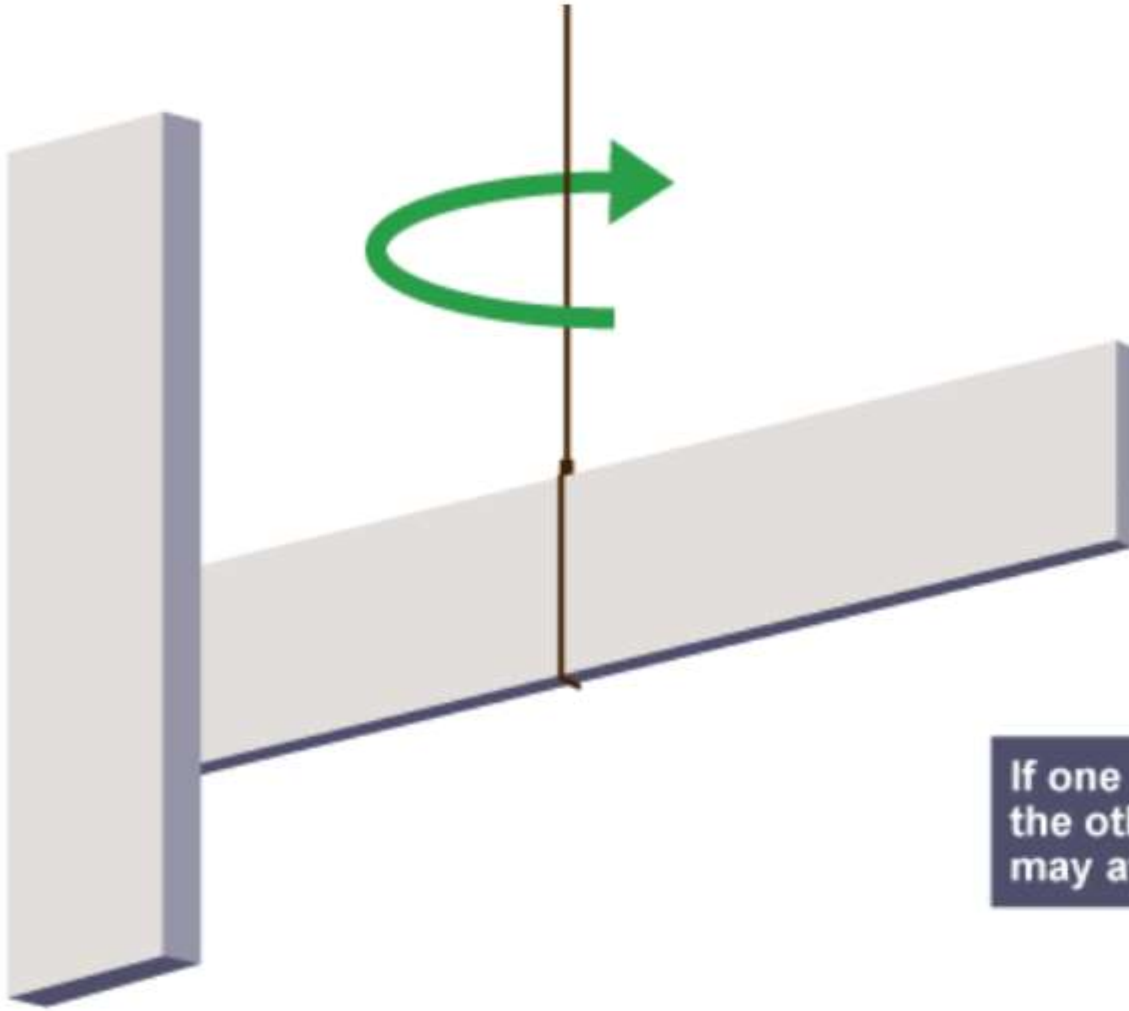
- A charged object will experience **non-contact force** from another charged object. The type of force will depend on the type of charge (positive or negative) on the two objects.
- The properties of **attraction** and **repulsion** are often used to show that an object is charged:
- a charged rod can pick up small pieces of paper
- a charged balloon can stick to the wall by attraction
- a charged rod can pull a stream of water towards it
- **Opposite charges attract. Like charges repel**



If the charges are the same they repel



If the charges
are opposite
they attract



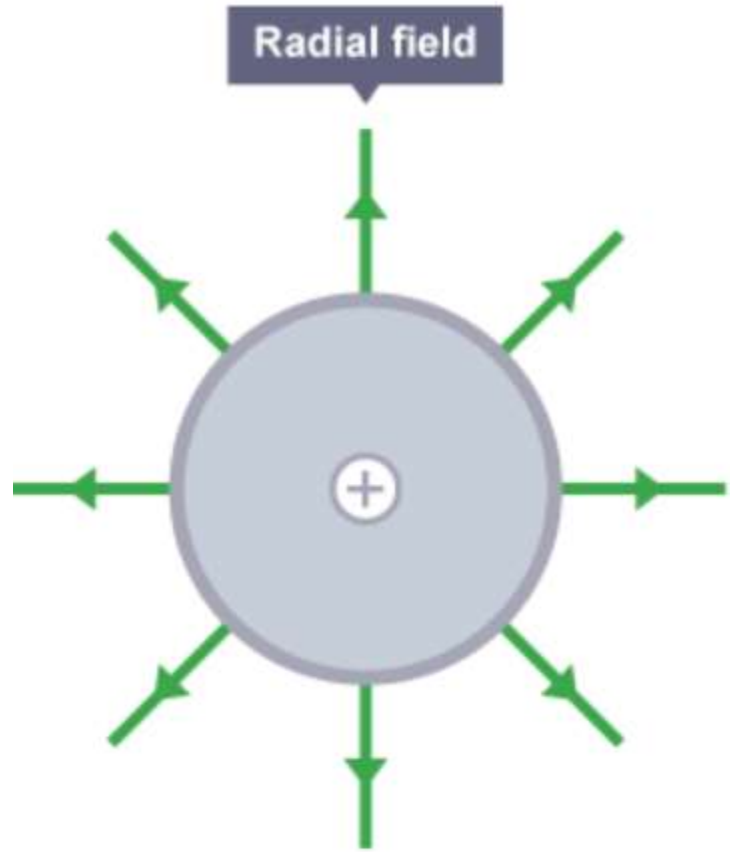
If one is charged and the other is not, they may attract

Electrical Forces

- if electrons are rubbed off the cloth and onto the rod - the cloth will be positively charged and the rod will be negatively charged
- if electrons are rubbed off the rod and onto the cloth - the cloth will be negatively charged and the rod will be positively charged
- In both cases, the opposite charges will attract.
- The forces of attraction or repulsion are greater when the charged objects are closer.

Electric fields

- All charged objects have an **electric field** around them, which shows how they will interact with other charged particles.
- A **Van de Graaff generator** removes electrons to produce a positive charge. A person does not have to touch the Van de Graaff generator to start feeling the effects, as static electricity is a **non-contact force**. This force will act on any charged particle in the electric field around the generator.
- A person touching the dome of the Van de Graaff generator will also lose electrons and become positively charged. The same will happen to each of their hairs. Since the person, their head, and each of the hair follicles are all positively charged, the hairs will repel from the head and from every other strand causing them to stick out from the head in all directions.



A radial field around a positive charge

Electric field shapes

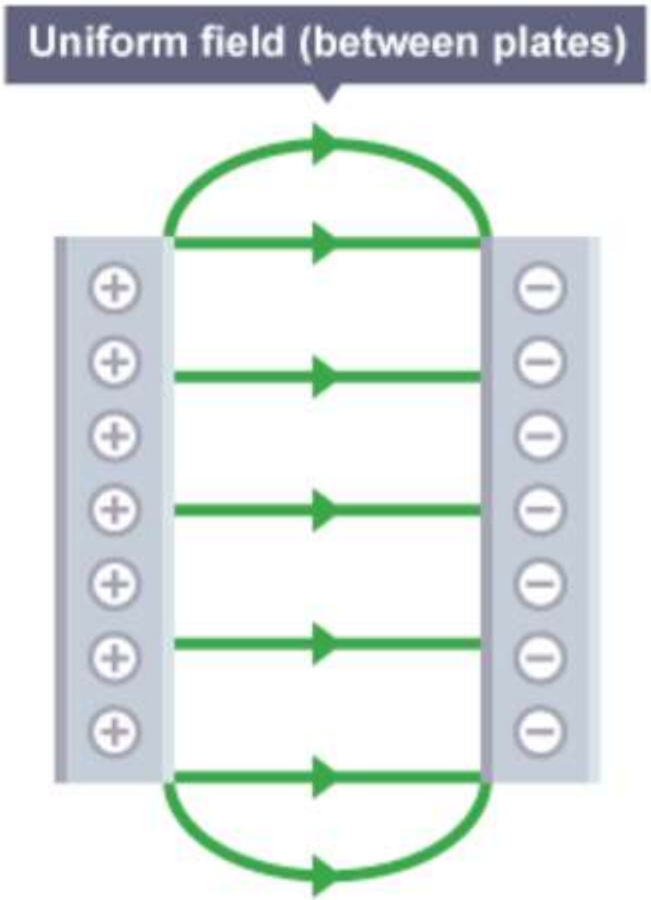
- An electric field is a region where **charges** experience a **force**.

Fields are usually shown as diagrams with arrows:

- The direction of the arrow shows the way a **positive** charge will be pushed.
- The closer together the arrows are, the stronger the field and the greater the force experienced by charges in that field. This means that the field is stronger closer to the object.
- **Field lines point away from positive charges and towards negative charges.**

Electric Field Shapes

- With a **radial field** around a positive charge, other positive charges are repelled away. Therefore, the arrows are pointing away from the central positive charge. This is what happens with the example of the Van de Graaff generator.
- However, if a negative charge is placed in that field, it would attract the positive charge and feel a force in the opposite direction to the field lines.
- The field between two parallel plates, one positive and the other negative, would be a **uniform field**.
- The field lines would be straight, parallel and point from positive to negative.


Uniform field (between plates)