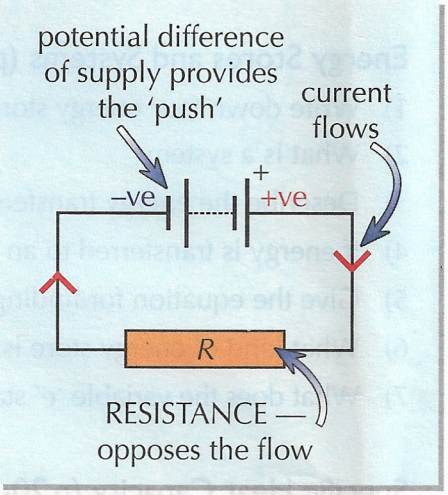
Current and Circuit Symbols

Isn't electricity great? Mind you it's pretty bad news if the words don't mean anything to you...

Current is the flow of Electric Charge

1) Electric current is the flow of electric charge round the circuit. Current will only flow around a complete (closed) circuit if there's a potential difference. So a current can only flow if there's a source of potential difference. Unit of current: ampere, A.
2) In a single, closed loop (like the one on the right) the current has the same value everywhere in the circuit (see p.48).
3) Potential difference (or voltage) is the driving force that pushes the charge round. Unit of potential difference: volt, V.
4) Resistance is anything in the circuit which slows the flow down. Unit of resistance: ohm, Ω.
5) The current flowing through a component depends on the potential difference across it and the resistance of the component (see next page).



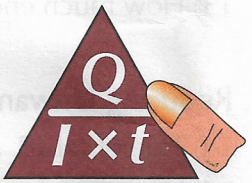
The greater the resistance across a component, the smaller the current that flows through it (for a given potential difference across the component).

Total Charge Through a Circuit Depends on Current and Time

1) The size of the current is the rate of flow of charge. When current (I) flows past a point in a circuit for a length of time (t) then the charge (Q) that has passed is given by this formula:

Charge (C) = Current (A) × Time (s)

$$Q = It$$



2) Current is measured in amperes (A), charge is measured in coulombs (C), time is measured in seconds (s).
3) More charge passes around the circuit when a bigger current flows.

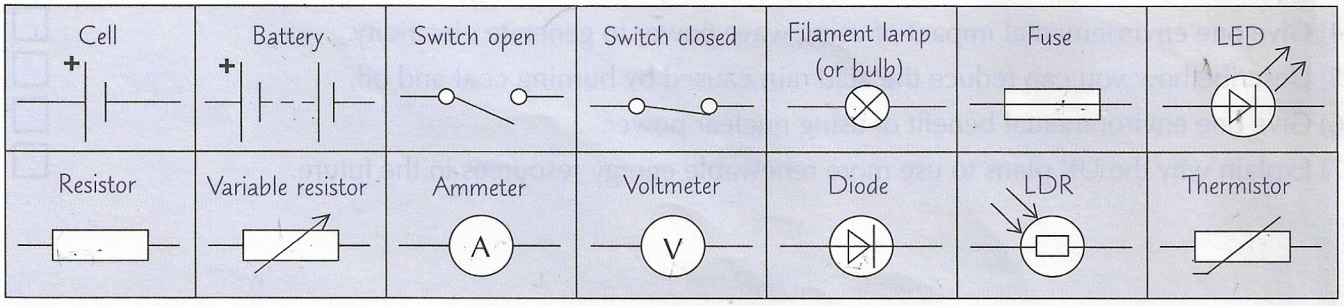
EXAMPLE:

A battery charger passes a current of 2.0 A through a cell over a period of 2.5 hours. How much charge is transferred to the cell?

$Q = It = 2.0 \times (2.5 \times 60 \times 60) = 18\,000$ C

Learn these Circuit Diagram Symbols

You need to be able to understand circuit diagrams and draw them using the correct symbols. Make sure all the wires in your circuit are straight lines and that the circuit is closed, i.e. you can follow a wire from one end of the power supply, through any components, to the other end of the supply (ignoring any switches).



Resistance

Prepare yourself to meet one of the most important equations in electronics. It's all about resistance, current and potential difference... Now if that doesn't tempt you on to read this page, I don't know what will.

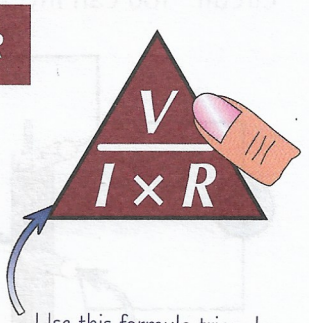
There's a Formula Linking Potential Difference and Resistance

The formula linking potential difference, current and resistance is very useful (and pretty common):

You may see potential difference called voltage.

Potential difference (V)= Current (A) × Resistance (Ω)

$$V = IR$$



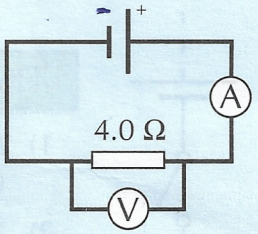
Use this formula triangle to rearrange the equation. Just cover up the thing you're trying to find, and what's left visible is the formula you're after.

EXAMPLE:

Voltmeter V reads 6.0 V and resistor R is 4.0 Ω. What is the current through ammeter A?

1) Use the formula triangle for $V = I \times R$.
2) We need to find I, so the version we need is $I = V \div R$.
3) The answer is then:

$I = 6.0 \div 4.0 = 1.5$ A



Ohmic Conductors Have a Constant Resistance

For some components, as the current through them is changed, the resistance of the component changes as well.

1) The resistance of ohmic conductors (e.g. a wire or a resistor) doesn't change with the current. At a constant temperature, the current flowing through an ohmic conductor is directly proportional to the potential difference across it. (R is constant in $V = IR$.)

2) The resistance of some resistors and components does change, e.g. a filament lamp or a diode.

3) When an electrical charge flows through a filament lamp, it transfers some energy to the thermal energy store of the filament (p.17), which is designed to heat up. Resistance increases with temperature, so as the current increases, the filament lamp heats up more and the resistance increases.

4) For diodes, the resistance depends on the direction of the current. They will happily let current flow in one direction, but have a very high resistance if it is reversed.

Resistance can be temperamental when it comes to temperature...

Remember that ohmic conductors will only have a constant resistance at a constant temperature. In general, resistance increases with temperature (though there are some exceptions, like thermistors — see p.45). So if the temperature is changing, the resistance of your component will be changing too.

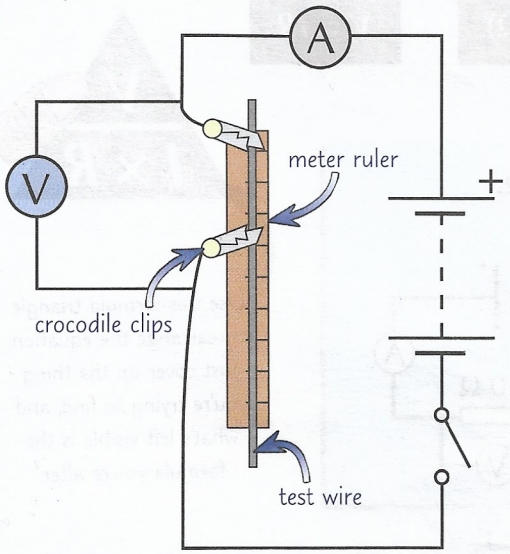
PRACTICAL

Investigating Resistance

Resistance can depend on a number of factors. Here's an experiment you can do to investigate one of them — how the resistance varies with the length of the conductor.

You Can Investigate the Factors Affecting Resistance

The resistance of a circuit can depend on a number of factors, like whether components are in series or parallel, p.50, or the length of wire used in the circuit. You can investigate the effect of wire length using the circuit below.



The Ammeter

1) Measures the current (in amps) flowing through the test wire.
2) The ammeter must always be placed in series with whatever you're investigating.

The Voltmeter

1) Measures the potential difference (or pd) across the test wire (in volts).
2) The voltmeter must always be placed in parallel around whatever you're investigating (p.49) — NOT around any other bit of the circuit, e.g. the battery.

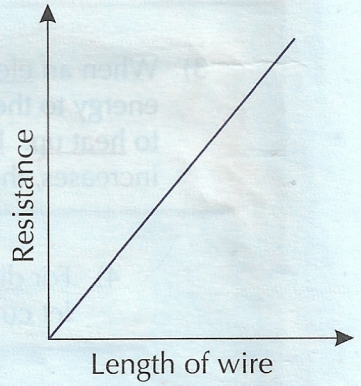
See pages 47-49 for more on series and parallel circuits.

Method

1) Attach a crocodile clip to the wire, level with 0 cm on the ruler.
2) Attach the second crocodile clip to the wire, e.g. 10 cm away from the first clip. Write down the length of the wire between the clips.
3) Close the switch, then record the current through the wire and the pd across it.
4) Open the switch, then move the second crocodile clip, e.g. another 10 cm, along the wire. Close the switch again, then record the new length, current and pd.
5) Repeat this for a number of different lengths of the test wire.
6) Use your measurements of current and pd to calculate the resistance for each length of wire, using $R = V \div I$ (from $V = IR$).
7) Plot a graph of resistance against wire length and draw a line of best fit.
8) Your graph should be a straight line through the origin, meaning resistance is directly proportional to length — the longer the wire, the greater the resistance.
9) If your graph doesn't go through the origin, it could be because the first clip isn't attached exactly at 0 cm, so all of your length readings are a bit out. This is a systematic error (p.7).

A thin wire will give you the best results. Make sure it's as straight as possible so your length measurements are accurate.

The wire may heat up during the experiment, which will affect its resistance (p.41). Leave the switch open for a bit between readings to let the circuit cool down.



PRACTICAL TIP

Be careful with the temperature of the wire...

If a large current flows through a wire, it can cause it to heat up (there's more on this on page 41). So use a low pd to stop it getting too hot and turn off the circuit between readings to let it cool.

I-V Characteristics

PRACTICAL

You've met ohmic conductors already on page 41, but most circuit components aren't ohmic. You can see how circuit components behave by plotting an *I-V* characteristic.

Three Very Important *I-V* Characteristics

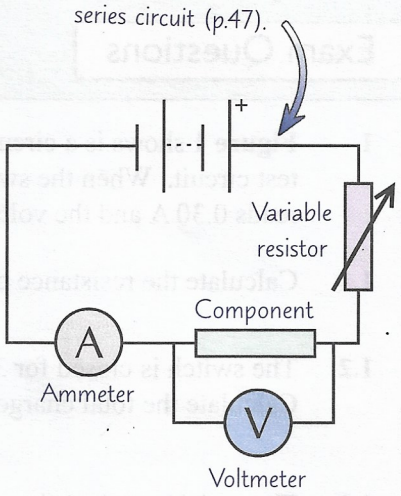
1) The term '*I-V* characteristic' refers to a graph which shows how the current (*I*) flowing through a component changes as the potential difference (*V*) across it is increased.
2) Linear components (e.g. an ohmic conductor) have an *I-V* characteristic that's a straight line.
3) Non-linear components (e.g. a filament lamp or a diode) have a curved *I-V* characteristic.

You can do this experiment to find a component's *I-V* characteristic:

Method

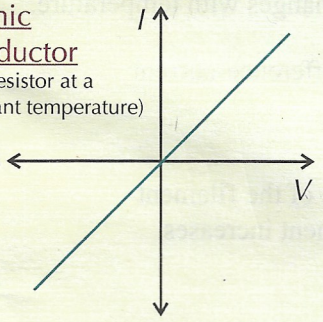
1) Set up the test circuit shown on the right.
2) Begin to vary the variable resistor. This alters the current flowing through the circuit and the potential difference across the component.
3) Take several pairs of readings from the ammeter and voltmeter to see how the potential difference across the component varies as the current changes. Repeat each reading twice more to get an average pd at each current.
4) Swap over the wires connected to the cell, so the direction of the current is reversed.
5) Plot a graph of current against voltage for the component.

This type of circuit uses direct current (dc) (p.52) and is a series circuit (p.47).



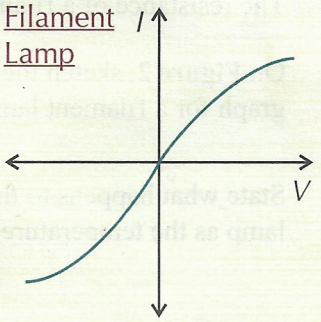
The *I-V* characteristics you get for an ohmic conductor, filament lamp and diode should look like this:

Ohmic Conductor
(e.g. resistor at a constant temperature)



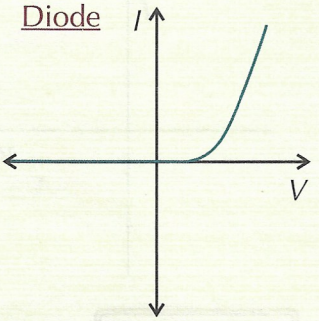
The current through an ohmic conductor (at a constant temperature) is directly proportional to potential difference, so you get a straight line.

Filament Lamp



As the current increases, the temperature of the filament increases, so the resistance increases. This means less current can flow per unit pd, so the graph gets shallower — hence the curve.

Diode



Current will only flow through a diode in one direction, as shown. The diode has very high resistance in the reverse direction.

Since $V = IR$, you can calculate the resistance at any point on the *I-V* characteristic by calculating $R = V \div I$.

EXAM TIP

You may be asked to interpret an *I-V* characteristic...

Make sure you take care when reading values off the graph. Pay close attention to the axes, and make sure you've converted all values to the correct units before you do any calculations.

Warm-Up & Exam Questions

Phew — circuits aren't the easiest thing in the world, are they? Make sure you've understood the last few pages by trying these questions. If you get stuck, just go back and re-read the relevant page.

Warm-Up Questions

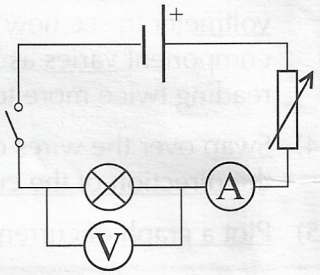
1) What are the units of resistance?
2) How does current through a component vary with resistance for a fixed potential difference?
3) Draw the symbol for a light-emitting diode (LED).
4) Give an example of an ohmic conductor.
5) How should a voltmeter be connected in a circuit to measure the pd across a component?
6) What is an *I-V* characteristic?

Exam Questions

1 **Figure 1** shows is a circuit diagram for a standard test circuit. When the switch is closed, the ammeter reads 0.30 A and the voltmeter reads 1.5 V.

Grade 6-7

Figure 1



1.1 Calculate the resistance of the filament lamp.

[3 marks]

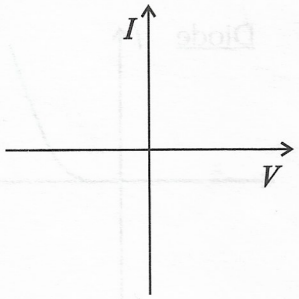
1.2 The switch is closed for 35 seconds.
Calculate the total charge that flows through the filament lamp.

[2 marks]

1.3 The variable resistor is used to increase the resistance in the circuit.
Describe how this will affect the current flowing through the circuit.

[1 mark]

Figure 2



The resistance of a filament lamp changes with temperature.

1.4 On **Figure 2**, sketch the potential difference-current graph for a filament lamp.

[1 mark]

1.5 State what happens to the resistance of the filament lamp as the temperature of the filament increases.

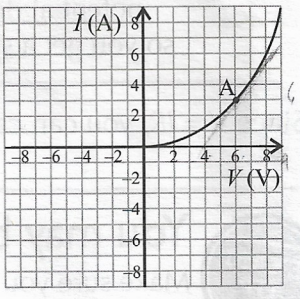
[1 mark]

PRACTICAL

2 A student carried out an experiment using a standard test circuit where she varied the current and monitored what happened to the potential difference across a diode. **Figure 3** shows a graph of her results.

Grade 6-7

Figure 3



2.1 State the dependent variable in this experiment.

[1 mark]

2.2 Explain why the graph in **Figure 3** shows zero current for negative pds.

[1 mark]

2.3 Calculate the resistance of the diode at the point marked A.

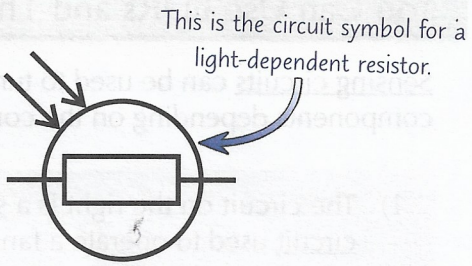
[4 marks]

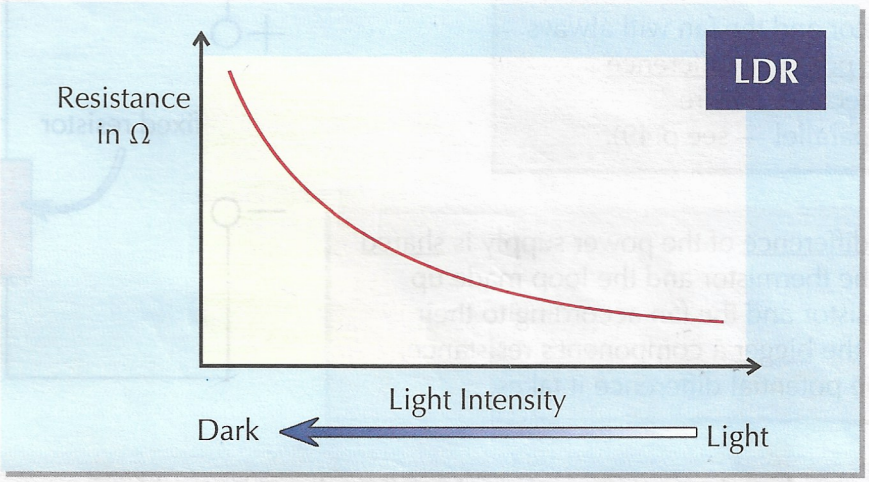
Circuit Devices

You might consider yourself a bit of an expert in circuit components — you're enlightened about bulbs, you're switched on to switches... Just make sure you know these ones as well — they're a bit trickier.

A Light-Dependent Resistor or "LDR"

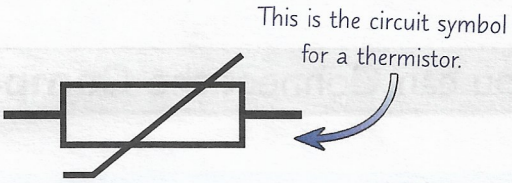
1) An LDR is a resistor that is dependent on the intensity of light. In bright light, the resistance falls.
2) In darkness, the resistance is highest.
3) They have lots of applications including automatic night lights, outdoor lighting and burglar detectors.

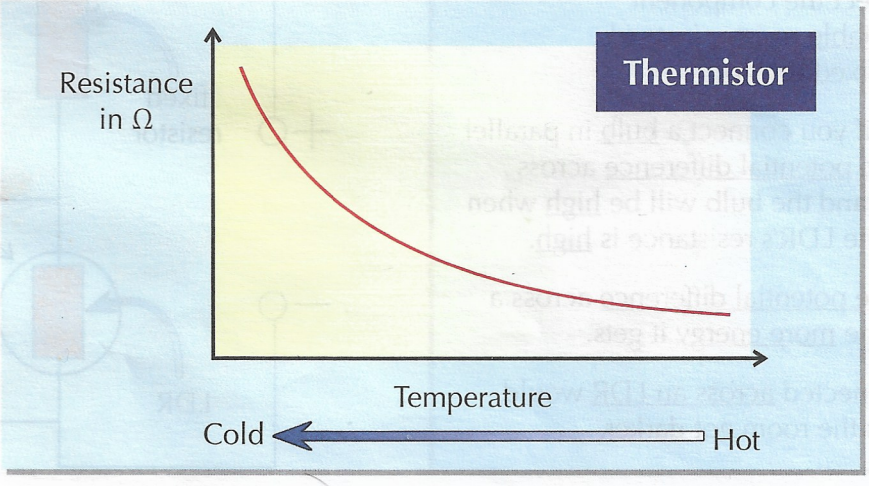




Thermistor Resistance Decreases as Temperature Increases

1) A thermistor is a temperature dependent resistor.
2) In hot conditions, the resistance drops.
3) In cool conditions, the resistance goes up.
4) Thermistors make useful temperature detectors, e.g. car engine temperature sensors and electronic thermostats.





Thermistors and LDRs have many applications...

And they're not just limited to the examples on this page. Oh no. For example, LDRs are used in digital cameras to control how long the shutter should stay open for. If the light level is low, changes in the resistance cause the shutter to stay open for longer than if the light level was higher. How interesting.

Sensing Circuits

Now you've learnt about what LDRs and thermistors do, it's time to take a look at how they're put to use.

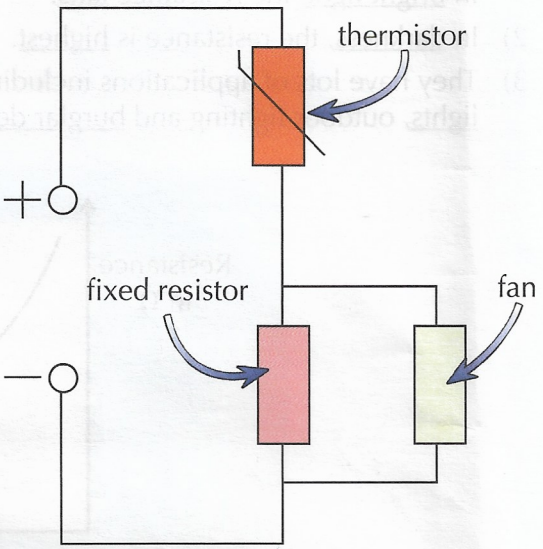
You Can Use LDRs and Thermistors in Sensing Circuits

Sensing circuits can be used to turn on or increase the power to components depending on the conditions that they are in.

1) The circuit on the right is a sensing circuit used to operate a fan in a room.

2) The fixed resistor and the fan will always have the same potential difference across them (because they're connected in parallel — see p.49).

3) The potential difference of the power supply is shared out between the thermistor and the loop made up of the fixed resistor and the fan according to their resistances — the bigger a component's resistance, the more of the potential difference it takes.



4) As the room gets hotter, the resistance of the thermistor decreases and it takes a smaller share of the potential difference from the power supply. So the potential difference across the fixed resistor and the fan rises, making the fan go faster.

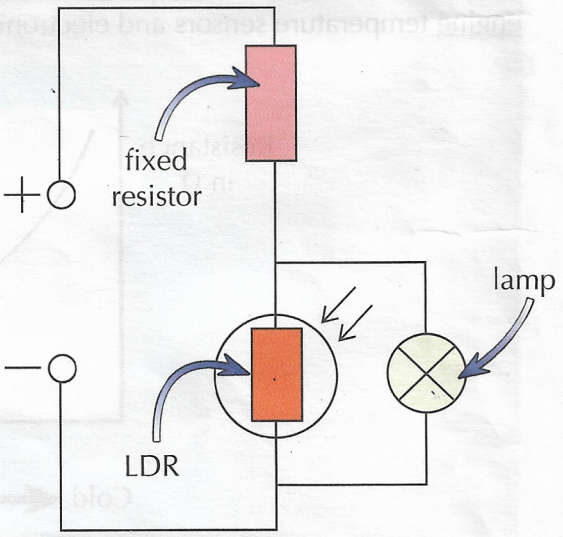
You can Connect the Component Across the Variable Resistor

1) You can connect the component across the variable resistor instead of across the fixed resistor.

2) For example, if you connect a bulb in parallel to an LDR, the potential difference across both the LDR and the bulb will be high when it's dark and the LDR's resistance is high.

3) The greater the potential difference across a component, the more energy it gets.

4) So a bulb connected across an LDR would get brighter as the room got darker.



Sensing circuits react to changes in the surroundings...

Sensing circuits are a useful application of thermistors and LDRs, but they can be tricky to make sense of. They rely on the properties of series and parallel circuits — read on to learn all about them.

Series Circuits

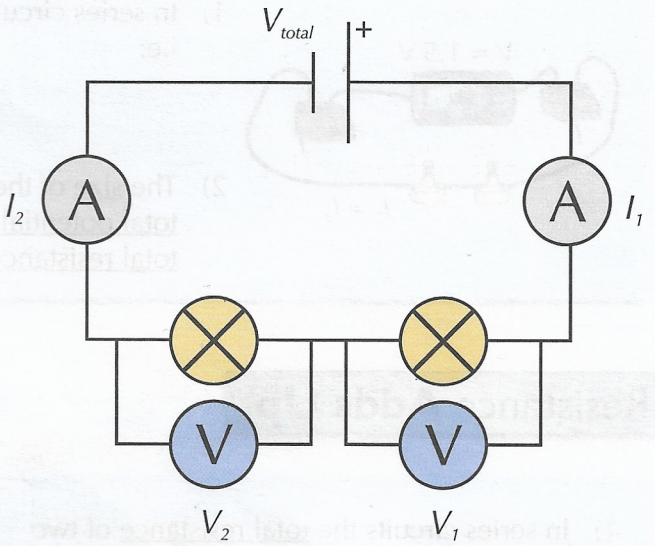
You need to be able to tell the if components are connected in series or parallel just by looking at circuit diagrams. You also need to know the rules about what happens with both types. Read on to find out more.

Series Circuits — All or Nothing

1) In series circuits, the different components are connected in a line, end to end, between the +ve and –ve of the power supply (except for voltmeters, which are always connected in parallel, but they don't count as part of the circuit).

2) If you remove or disconnect one component, the circuit is broken and they all stop. This is generally not very handy, and in practice very few things are connected in series.

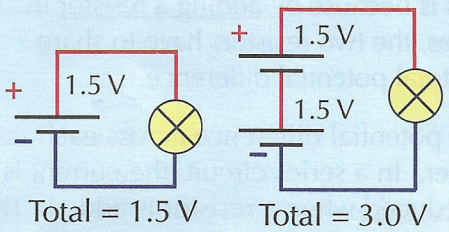
3) You can use the following rules to design series circuits to measure quantities and test components (e.g. the test circuits on p.43 and p.50 and the sensing circuits on the last page).



Cell Potential Differences Add Up

1) There is a bigger potential difference when more cells are in series, provided the cells are all connected the same way.

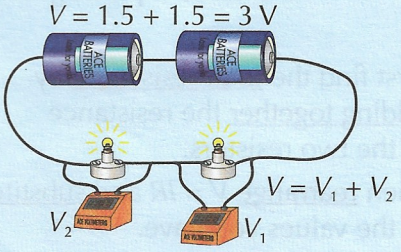
2) For example, when two batteries of voltage 1.5 V are connected in series they supply a total of 3 V.



Total Potential Difference is Shared

In series circuits, the total potential difference of the supply is shared between the various components. So the potential differences round a series circuit always add up to the source potential difference:

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



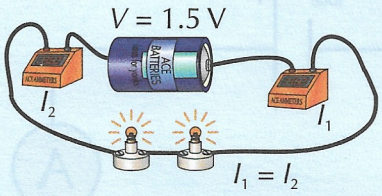
There are two main types of circuit — series and parallel...

Remember, ammeters should always be connected in series, and voltmeters should always be connected in parallel. These components don't count towards how you define a circuit — you can have a parallel circuit (p.49) with ammeters connected in series, or a series circuit with voltmeters connected across components.

Series Circuits

We're not done with series circuits yet. Here's the low-down on current and resistance...

Current is the Same Everywhere



1) In series circuits the same current flows through all components, i.e:

$$I_1 = I_2 = \ldots$$

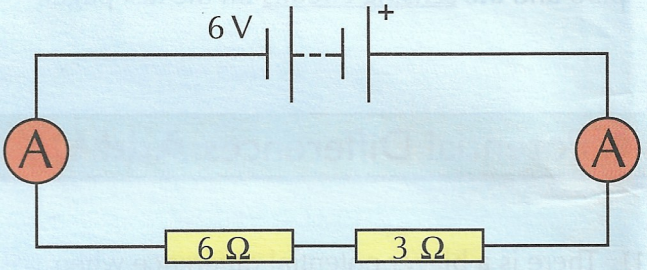
2) The size of the current is determined by the total potential difference of the cells and the total resistance of the circuit: i.e. $I = V \div R$.

Resistance Adds Up

1) In series circuits the total resistance of two components is just the sum of their resistances:

$$R_{total} = R_1 + R_2$$

2) This is because by adding a resistor in series, the two resistors have to share the total potential difference.



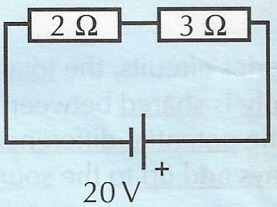
Total resistance = 6 + 3 = 9 Ω

3) The potential difference across each resistor is lower, so the current through each resistor is also lower. In a series circuit, the current is the same everywhere so the total current in the circuit is reduced when a resistor is added. This means the total resistance of the circuit increases.

4) The bigger a component's resistance, the bigger its share of the total potential difference.

EXAMPLE:

For the circuit diagram on the right, calculate the current passing through the circuit.



1) First find the total resistance by adding together the resistance of the two resistors.
2) Then rearrange $V = IR$ and substitute in the values you have.

$R_{total} = 2 + 3 = 5\ \Omega$

$I = V \div R$
$= 20 \div 5$
$= 4\ A$

Series circuits aren't used very much in the real world...

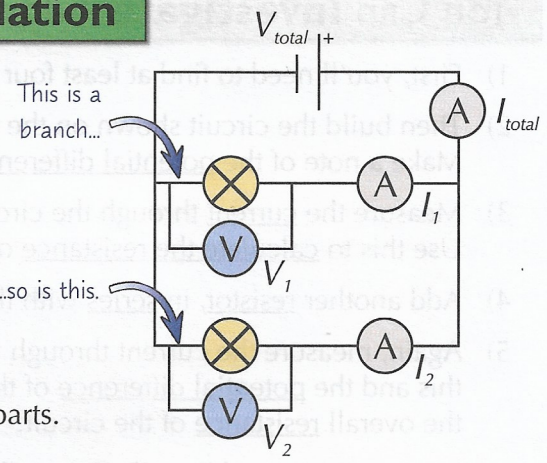
Since series circuits put all components on the same loop of wire, and the current is the same through each component, if one component breaks, it'll break the circuit, and all other components will stop working too. Parallel circuits are much more useful and can avoid this problem — as you're about to find out...

Parallel Circuits

Parallel circuits can be a little bit trickier to wrap your head around, but they're much more useful than series circuits. Most electronics use a combination of series and parallel circuitry.

Parallel Circuits — Independence and Isolation

1) In parallel circuits, each component is separately connected to the +ve and –ve of the supply (except ammeters, which are always connected in series).
2) If you remove or disconnect one of them, it will hardly affect the others at all.
3) This is obviously how most things must be connected, for example in cars and in household electrics. You have to be able to switch everything on and off separately.
4) Everyday circuits often include a mixture of series and parallel parts.



Potential Difference is the Same Across All Components

1) In parallel circuits all components get the full source pd, so the voltage is the same across all components: $V_1 = V_2 = V_3 = ...$
2) This means that identical bulbs connected in parallel will all be at the same brightness.

Current is Shared Between Branches

1) In parallel circuits the total current flowing around the circuit is equal to the total of all the currents through the separate components: $I_{total} = I_1 + I_2 + ...$
2) In a parallel circuit, there are junctions where the current either splits or rejoins. The total current going into a junction has to equal the total current leaving it.
3) If two identical components are connected in parallel then the same current will flow through each component.

Adding a Resistor in Parallel Reduces the Total Resistance

1) If you have two resistors in parallel, their total resistance is less than the resistance of the smallest of the two resistors.
2) This can be tough to get your head around, but think about it like this:

- In parallel, both resistors have the same potential difference across them as the source.
- This means the 'pushing force' making the current flow is the same as the source potential difference for each resistor that you add.
- But by adding another loop, the current has more than one direction to go in.
- This increases the total current that can flow around the circuit. Using $V = IR$, an increase in current means a decrease in the total resistance of the circuit.

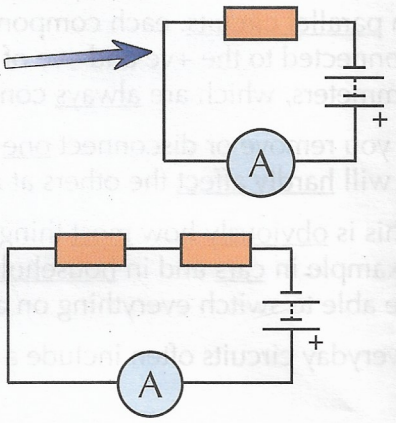
PRACTICAL

Circuits and Resistance

You saw on page 42 how the length of the wire used in a circuit affects its resistance. Now it's time to do an experiment to see how placing resistors in series or in parallel can affect the resistance of the whole circuit.

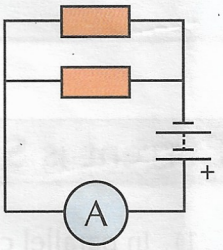
You Can Investigate Adding Resistors in Series...

1) First, you'll need to find at least four identical resistors.
2) Then build the circuit shown on the right using one of the resistors. Make a note of the potential difference of the battery (V).
3) Measure the current through the circuit using the ammeter. Use this to calculate the resistance of the circuit using $R = V \div I$.
4) Add another resistor, in series with the first.
5) Again, measure the current through the circuit and use this and the potential difference of the battery to calculate the overall resistance of the circuit.
6) Repeat steps 4 and 5 until you've added all of your resistors.
7) Plot a graph of the number of resistors against the total resistance of the circuit (see below).



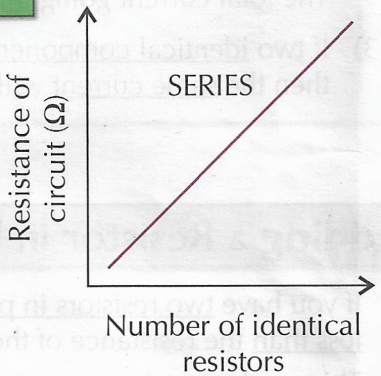
... or in Parallel

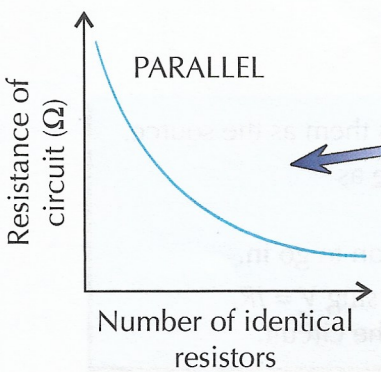
1) Using the same equipment as before (so the experiment is a fair test), build the same initial circuit.
2) Measure the total current through the circuit and calculate the resistance of the circuit using $R = V \div I$ (again, V is the potential difference of the battery).
3) Next, add another resistor, in parallel with the first.
4) Measure the total current through the circuit and use this and the potential difference of the battery to calculate the overall resistance of the circuit.
5) Repeat steps 3 and 4 until you've added all of your resistors.
6) Plot a graph of the number of resistors in the circuit against the total resistance.



Your Results Should Match the Resistance Rules

1) You should find that adding resistors in series increases the total resistance of the circuit (adding a resistor decreases the total current through the circuit).
2) The more resistors you add, the larger the resistance of the whole circuit.





3) When you add resistors in parallel, the total current through the circuit increases — so the total resistance of the circuit has decreased.
4) The more resistors you add, the smaller the overall resistance becomes — as shown by the graph on the left.
5) These results agree with what you learnt about resistance in series and parallel circuits on pages 48 and 49.

Warm-Up & Exam Questions

Time to check and see what you can remember about those circuit devices, parallel and series circuits.

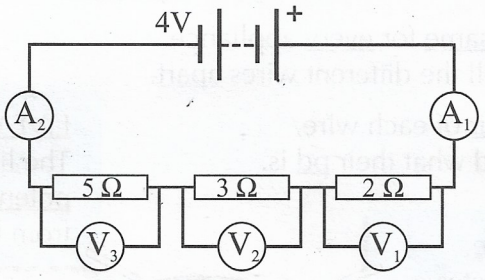
Warm-Up Questions

1) Give one use of a light-dependent resistor (LDR).
2) What happens to the resistance of a thermistor as its temperature increases?
3) Draw a circuit diagram of a sensing circuit where a bulb gets brighter with decreasing temperature.
4) Give one practical disadvantage of series circuits.
5) How do you work out the total resistance in a series circuit?
6) Which has the higher total resistance: two resistors in series, or the same two resistors in parallel?
7) Sketch a graph to show how the number of identical resistors connected together in parallel affects the total resistance in a circuit.

Exam Questions

1 **Figure 1** shows a series circuit. Grade 4-6

Figure 1



1.1 Calculate the total resistance in the circuit.

[2 marks]

1.2 The current through A_1 is 0.4 A.
What is the current through A_2? Explain your answer.

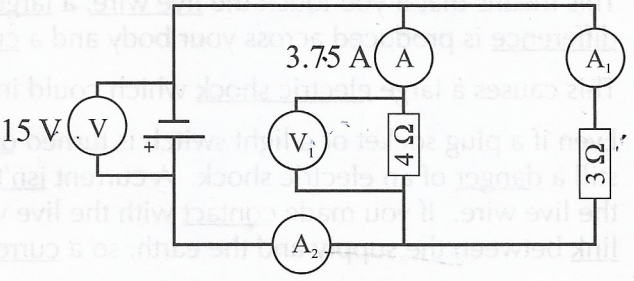
[2 marks]

1.3 V_1 reads 0.8 V and V_2 reads 1.2 V.
Calculate the reading on V_3.

[2 marks]

2 A parallel circuit is connected as shown in **Figure 2**. Grade 7-9

Figure 2



2.1 Give the reading on voltmeter V_1.

[1 mark]

2.2 Calculate the reading on ammeter A_1.

[3 marks]

2.3 Calculate the reading on ammeter A_2.

[2 marks]

Electricity in the Home

Now you've learnt the basics of electrical circuits, it's time to see how electricity is used in everyday life.

Mains Supply is ac, Battery Supply is dc

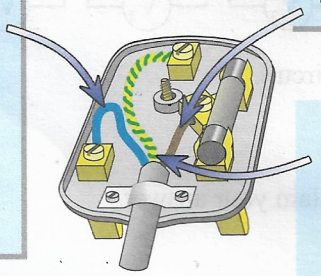
1) There are two types of electricity supplies — alternating current (ac) and direct current (dc).
2) In ac supplies the current is constantly changing direction. Alternating currents are produced by alternating potential difference in which the positive and negative ends keep alternating.
3) The UK mains supply (the electricity in your home) is an ac supply at around 230 V.
4) The frequency of the ac mains supply is 50 cycles per second or 50 Hz (hertz).
5) By contrast, cells and batteries supply direct current (dc).
6) Direct current is a current that is always flowing in the same direction. It's created by a direct potential difference.

Most Cables Have Three Separate Wires

1) Most electrical appliances are connected to the mains supply by three-core cables. This means that they have three wires inside them, each with a core of copper and a coloured plastic coating.
2) The colour of the insulation on each cable shows its purpose.
3) The colours are always the same for every appliance. This is so that it is easy to tell the different wires apart.
4) You need to know the colour of each wire, what each of them is for and what their pd is.

LIVE WIRE — brown.
The live wire provides the alternating potential difference (at about 230 V) from the mains supply.

NEUTRAL WIRE — blue.
The neutral wire completes the circuit and carries away current — electricity normally flows in through the live wire and out through the neutral wire. It is around 0 V.



EARTH WIRE — green and yellow.
The earth wire is for protecting the wiring, and for safety — it stops the appliance casing from becoming live. It doesn't usually carry a current — only when there's a fault. It's also at 0 V.

Touching the Live Wire Gives You an Electric Shock

1) Your body (just like the earth) is at 0 V.
2) This means that if you touch the live wire, a large potential difference is produced across your body and a current flows through you.
3) This causes a large electric shock which could injure or even kill you.
4) Even if a plug socket or a light switch is turned off (i.e. the switch is open) there is still a danger of an electric shock. A current isn't flowing, but there is still a pd in the live wire. If you made contact with the live wire, your body would provide a link between the supply and the earth, so a current would flow through you.
5) Any connection between live and earth can be dangerous. If the link creates a low resistance path to earth, a huge current will flow, which could result in a fire.

Power of Electrical Appliances

You can think about electrical circuits in terms of energy transfer — the charge carriers take energy around the circuit. When they go through an electrical component energy is transferred to make the component work.

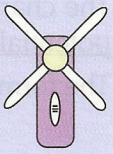
Energy is Transferred from Cells and Other Sources

1) You know from page 17 that a moving charge transfers energy. This is because the charge does work against the resistance of the circuit. (Work done is the same as energy transferred, p.18.)
2) Electrical appliances are designed to transfer energy to components in the circuit when a current flows.

Kettles transfer energy electrically from the mains ac supply to the thermal energy store of the heating element inside the kettle.



Energy is transferred electrically from the battery of a handheld fan to the kinetic energy store of the fan's motor.



3) Of course, no appliance transfers all energy completely usefully. The higher the current, the more energy is transferred to the thermal energy stores of the components (and then the surroundings). You can calculate the efficiency of any electrical appliance — see p.28.

Energy Transferred Depends on the Power

1) The total energy transferred by an appliance depends on how long the appliance is on for and its power.
2) The power of an appliance is the energy that it transfers per second. So the more energy it transfers in a given time, the higher its power.
3) The amount of energy transferred by electrical work is given by:

Energy transferred (J) = Power (W) × Time (s) **$E = Pt$**

This equation should be familiar from page 23.

EXAMPLE:

A 600 W microwave is used for 5 minutes. How long (in minutes) would a 750 W microwave take to do the same amount of work?

1) Calculate the energy transferred by the 600 W microwave in five minutes. $E = Pt = 600 \times (5 \times 60)$ $= 180\,000$ J
2) Rearrange $E = Pt$ and sub in the energy you calculated and the power of the 750 W microwave. $t = E \div P$ $= 180\,000 \div 750 = 240$ s
3) Convert the time back to minutes. $240 \div 60 = 4$ minutes

So the 750 W microwave would take 4 minutes to do the same amount of work.

Remember that the time must be in seconds.

4) Appliances are often given a power rating — they're labelled with the maximum safe power that they can operate at. You can usually take this to be their maximum operating power.
5) The power rating tells you the maximum amount of energy transferred between stores per second when the appliance is in use.
6) This helps customers choose between models — the lower the power rating, the less electricity an appliance uses in a given time and so the cheaper it is to run.
7) But a higher power doesn't necessarily mean that it transfers more energy usefully. An appliance may be more powerful than another, but less efficient, meaning that it might still only transfer the same amount of energy (or even less) to useful stores (see p.28).

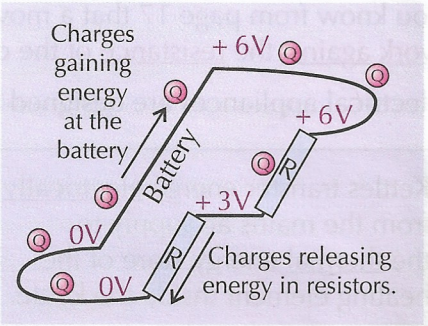
More on Power

As you've seen, the power of a device tells you how much energy it transfers per second. In electrical systems, there are a load of useful formulas you can use to calculate energy and power.

Potential Difference is Energy Transferred per Charge Passed

1) When an electrical charge goes through a change in potential difference, energy is transferred.
2) Energy is supplied to the charge at the power source to 'raise' it through a potential.
3) The charge gives up this energy when it 'falls' through any potential drop in components elsewhere in the circuit.
4) The formula is really simple:

Energy transferred (J) — $E = QV$ — Charge flow (C); Potential difference (V)



5) That means that a battery with a bigger pd will supply more energy to the circuit for every coulomb of charge which flows round it, because the charge is raised up "higher" at the start.

EXAMPLE:

The motor in an electric toothbrush is attached to a 3 V battery. 140 C of charge passes through the circuit as it is used. Calculate the energy transferred.

$E = QV = 140 \times 3 = 420$ J

This energy is transferred to the kinetic energy store of the motor, as well as to the thermal energy stores of the surroundings.

Power Also Depends on Current and Potential Difference

1) As well as energy transferred in a given time, the power of an appliance can be found with:

Power (W) = Potential difference (V) × Current (A) **$P = VI$**

EXAMPLE:

A 1.0 kW hair dryer is connected to a 230 V supply. Calculate the current through the hair dryer. Give your answer to two significant figures.

1) Rearrange the equation for current. $I = P \div V$
2) Make sure your units are correct. 1.0 kW = 1000 W
3) Then just stick in the numbers that you have. $I = 1000 \div 230 = 4.34... = 4.3$ A (to 2 s.f.)

2) You can also find the power if you don't know the potential difference. To do this, stick $V = IR$ from page 41 into $P = VI$, which gives you: **$P = I^2R$** (Resistance (Ω))

Power is measured in watts, W — one W is equal to one J/s...

Remember, the power rating of an electrical appliance is the amount of energy transferred to the appliance per second, not the amount that it transfers to useful energy stores. Two appliances with the same power rating won't necessarily work as well as each other — it'll depend on their efficiencies (see page 28).

The National Grid

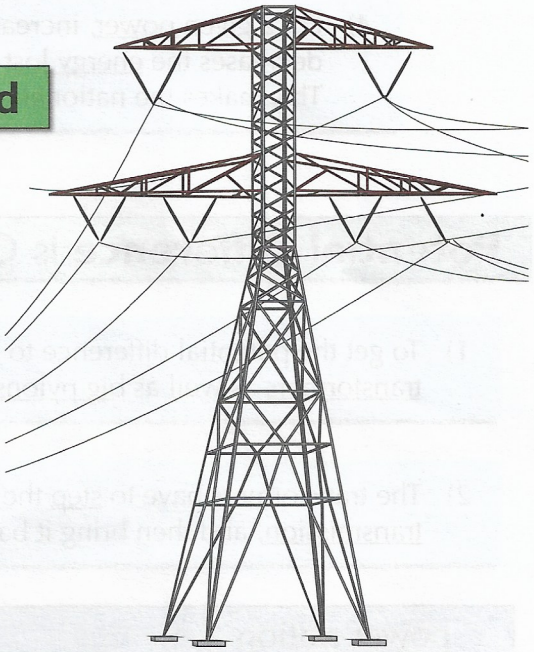
The national grid is a giant web of wires that covers the whole of Britain, getting electricity from power stations to homes everywhere. Whoever you pay for your electricity, it's the national grid that gets it to you.

Electricity is Distributed via the National Grid

1) The national grid is a giant system of cables and transformers (p.171) that covers the UK and connects power stations to consumers (anyone who is using electricity).

2) The national grid transfers electrical power from power stations anywhere on the grid (the supply) to anywhere else on the grid where it's needed (the demand) — e.g. homes and industry.

Electricity Production has to Meet Demand



1) Throughout the day, electricity usage (the demand) changes. Power stations have to produce enough electricity for everyone to have it when they need it.

2) They can predict when the most electricity will be used though. Demand increases when people get up in the morning, come home from school or work and when it starts to get dark or cold outside. Popular events like a sporting final being shown on TV could also cause a peak in demand.

3) Power stations often run at well below their maximum power output, so there's spare capacity to cope with a high demand, even if there's an unexpected shut-down of another station.

4) Lots of smaller power stations that can start up quickly are also kept in standby just in case.

WORKING SCIENTIFICALLY

Energy demands are ever increasing...

The national grid has been working since the 1930s and has gone through many changes and updates since then to meet increasing energy demands. Using energy-efficient appliances and switching unneeded lights off are some ways we might ensure that supply and demand stay in balance. It'll do wonders for your electricity bills too, as I'm sure your parents often remind you.

The National Grid

To transfer electricity efficiently, the national grid makes use of some clever tech called transformers.

The National Grid Uses a High pd and a Low Current

1) To transmit the huge amount of power needed, you need either a high potential difference or a high current (as $P = VI$, page 54).

2) The problem with a high current is that you lose loads of energy as the wires heat up and energy is transferred to the thermal energy store of the surroundings.

Remember that power is the energy transferred in a given time, so a higher power means more energy transferred.

3) It's much cheaper to boost the pd up really high (to 400 000 V) and keep the current relatively low.

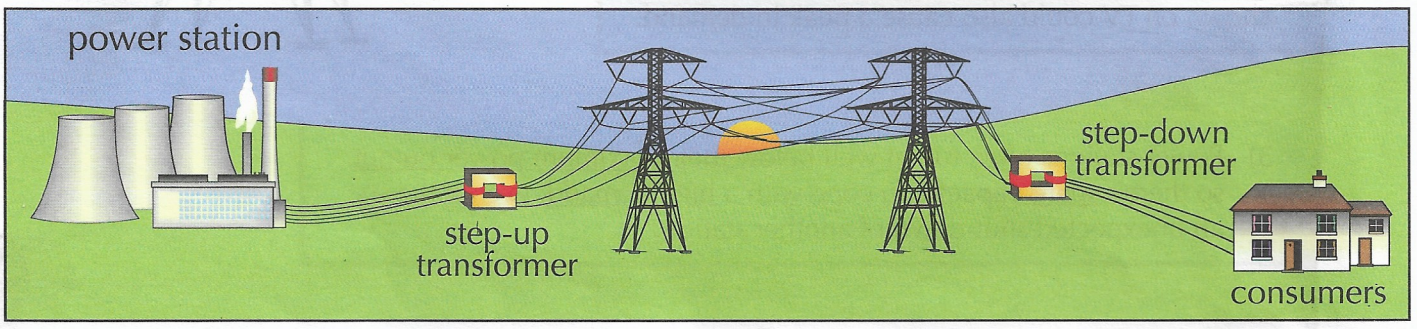
4) For a given power, increasing the pd decreases the current, which decreases the energy lost by heating the wires and the surroundings. This makes the national grid an efficient way of transferring energy.

Potential Difference is Changed by a Transformer

1) To get the potential difference to 400 000 V to transmit power requires transformers as well as big pylons with huge insulators — but it's still cheaper.

For more on how transformers work, including some useful equations, have a look at page 171.

2) The transformers have to step the potential difference up at one end, for efficient transmission, and then bring it back down to safe, usable levels at the other end.



3) The potential difference is increased ('stepped up') using a step-up transformer.

4) It's then reduced again ('stepped down') for domestic use using a step-down transformer.

The national grid — it's a powerful thing...

The key to the efficiency of the national grid is the power equation, $P = VI$ (see page 54). Since power is proportional to both potential difference and current, if you have a constant power, but increase the potential difference using a transformer, the current must decrease. And vice versa.

Warm-Up & Exam Questions

Who knew there was so much to learn about electricity in the home and across the country? See if it's switched on a lightbulb in your brain by trying out these questions.

Warm-Up Questions

1) What are the three core cables that connect electrical appliances to the mains supply?
2) What is the main energy transfer when electric current flows through an electric kettle?
3) What is the equation linking power, current and resistance?
4) What is the national grid?

Exam Questions

1 Appliances with a metal casing are usually connected to the mains using a three-core cable. Grade 4-6

1.1 Mains electricity provides alternating current.
Define alternating current.

[1 mark]

1.2 An electrical cable has become frayed so that the metal part of the live wire is exposed.
Explain why you would get an electric shock if you touched it.

[3 marks]

2 The national grid transmits electricity from power stations to homes and businesses all over the country. Grade 6-7
Explain why the national grid uses step-up transformers.

[3 marks]

3 **Table 1** shows the power and potential difference ratings for two kettles. Grade 6-7

Table 1

	Power (kW)	Potential Difference (V)
Kettle A	2.8	230
Kettle B	3.0	230

3.1 State the equation linking power, potential difference and current.

[1 mark]

3.2 Calculate the current drawn from the mains supply by kettle A. State the correct unit.

[4 marks]

3.3 A student is deciding whether to buy kettle A or kettle B.
She wants to buy the kettle that boils water faster. Both kettles have an efficiency of 90%.
Suggest which kettle she should choose. Explain your answer.

[2 marks]

4 A current of 0.5 A passes through a torch bulb. The torch is powered by a 3.0 V battery. Grade 7-9

4.1 The torch is on for half an hour.
Calculate the amount of energy transferred from the battery in this time.

[4 marks]

4.2 Calculate how much charge passes through the torch in half an hour.

[3 marks]

Tride

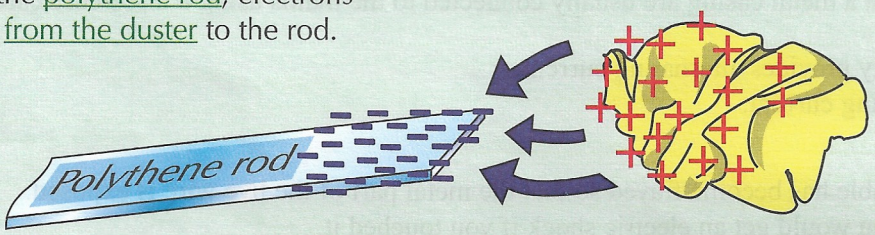
Static Electricity

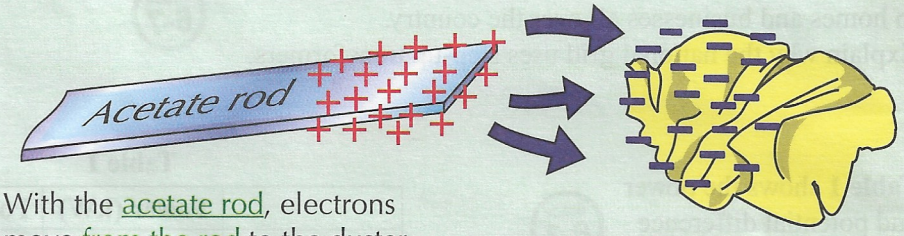
Static electricity is all about charges which are not free to move, e.g. in insulating materials.

Build-up of Static is Caused by Friction

1) When certain insulating materials are rubbed together, negatively charged electrons will be scraped off one and dumped on the other.
2) This will leave the materials electrically charged, with a positive static charge on one and an equal negative static charge on the other.
3) Which way the electrons are transferred depends on the two materials involved.
4) The classic examples are polythene and acetate rods being rubbed with a cloth duster (shown below).

With the polythene rod, electrons move from the duster to the rod.





With the acetate rod, electrons move from the rod to the duster.

Only Electrons Move — Never Positive Charges

1) Watch out for this in exams. Both positive (+ve) and negative (–ve) electrostatic charges are only ever produced by the movement of electrons. The positive charges definitely do not move!

2) A positive static charge is always caused by electrons moving away elsewhere. The material that loses the electrons loses some negative charge, and is left with an equal positive charge. Don't forget.

It shouldn't shock you to learn that static charges are everywhere...

You'll probably be pretty familiar with static charges from your day to day life. Whenever taking off a jumper or brushing your hair makes your hair stand on end — that's static electricity. It's also the reason you can get zapped by the car door after a long journey. The 'zap' is a spark — read on to find out more.

Triple

Static Electricity

When lots of static charge builds up in one place, it often ends with a spark or a shock, as they finally move.

Too Much Static Causes **Sparks**

1) As electric charge builds on an object, the potential difference between the object and the earth (which is at 0 V) increases.

For more on how sparks actually jump across gaps, see the next page.

2) If the potential difference gets large enough, electrons can jump across the gap between the charged object and the earth — this is the spark.

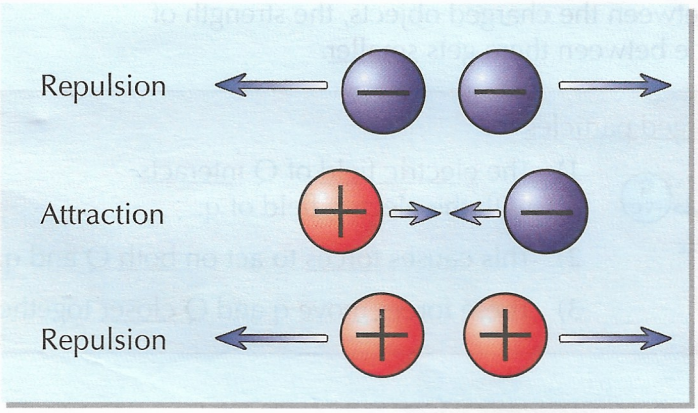
3) They can also jump to any earthed conductor that is nearby — which is why you can get static shocks getting out of a car. A charge builds up on the car's metal frame, and when you touch the car, the charge travels through you to earth.

4) This usually happens when the gap is fairly small. (But not always — lightning is just a really big spark.)

Like Charges Repel, **Opposite** Charges Attract

1) This is easy and, I'd have thought, kind of obvious. When two electrically charged objects are brought close together they exert a force on one another.

2) Two things with opposite electric charges are attracted to each other, while two things with the same electric charge will repel each other.



3) These forces get weaker the further apart the two things are.

4) These forces will cause the objects to move if they are able to do so. This is known as electrostatic attraction / repulsion and is a non-contact force (the objects don't need to touch, p.87).

5) One way to see this force is to suspend a rod with a known charge from a piece of string (so it is free to move). Placing an object with the same charge nearby will repel the rod — the rod will move away from the object. An oppositely charged object will cause the rod to move towards the object.

EXAM TIP

Electrostatic forces — like charges repel but opposites attract...

You could be asked to apply the idea of electrostatic attraction and repulsion in any situation in the exam. So remember, when an object becomes charged by being rubbed against another object, the objects will have equal and opposite charges to each other.

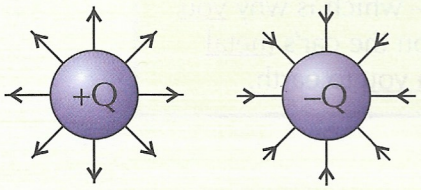
Electric Fields

As you've seen on the last page, electrical charges exert a force on each other. You can explain these forces in terms of electric fields. They can be used to explain things like sparks as well.

Electric Charges Create an Electric Field

1) An electric field is created around any electrically charged object.
2) The closer to the object you get, the stronger the field is. (And the further you are from it, the weaker it is.)
3) You can show an electric field around an object using field lines. For example you can draw the field lines for an isolated, charged sphere:

Isolated means it's not interacting with anything.

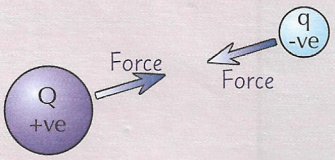


- Electric field lines go from positive to negative.
- They're always at a right angle to the surface.
- The closer together the lines are, the stronger the field is — you can see that the further from a charge you go, the further apart the lines are and so the weaker the field is.

Charged Objects in an Electric Field feel a Force

1) When a charged object is placed in the electric field of another object, it feels a force.
2) This force causes the attraction or repulsion you saw on the previous page.
3) The force is caused by the electric fields of each charged object interacting with each other.
4) The force on an object is linked to the strength of the electric field it is in.
5) As you increase the distance between the charged objects, the strength of the field decreases and the force between them gets smaller.

Two oppositely charged particles



1) The electric field of Q interacts with the electric field of q.
2) This causes forces to act on both Q and q.
3) These forces move q and Q closer together.

Sparking Can Be Explained By Electric Fields

1) Sparks are caused when there is a high enough potential difference between a charged object and the earth (or an earthed object).
2) A high potential difference causes a strong electric field between the charged object and the earthed object.
3) The strong electric field causes electrons in the air particles to be removed (known as ionisation).
4) Air is normally an insulator, but when it is ionised it is much more conductive, so a current can flow through it. This is the spark.

Warm-Up & Exam Questions

Have you been paying close attention to the last three pages? Only one way to tell really — have a go at these delightful warm-up and exam questions. If you get any wrong, go back and read it all again.

Warm-Up Questions

1) What happens to an acetate rod when it is rubbed by a cloth?
2) Two objects are rubbed together and become charged.
What particles move to cause the objects to become charged?
3) Do opposite charges attract or repel each other?
4) What type of objects have electric fields?
5) What happens to the strength of an electric field as you move closer to a charged object?

Exam Questions

1 A student rubbed a plastic sphere with a cloth, and the sphere became negatively charged. The charge on the sphere is –1.6 nC. Grade 4-6

1.1 State the charge on the cloth.

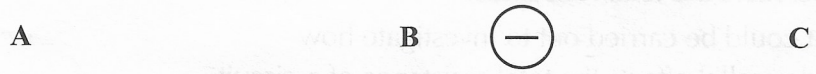
[1 mark]

1.2 Describe the movement of charge which caused the sphere to become charged.

[1 mark]

An image of the charged sphere is shown in **Figure 1**.

Figure 1



1.3 Give the position (A, B or C) where a test charge would feel the greatest force.

[1 mark]

1.4 Draw an arrow on **Figure 1** showing the force a negative test charge would feel at that point.

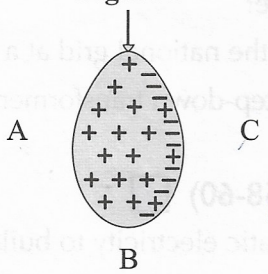
[1 mark]

1.5 Describe how the presence of a strong electric field can cause a spark.

[2 marks]

2 Jane hangs an uncharged balloon from a thread. She brings a negatively charged polythene rod towards the balloon. **Figure 2** shows how the positive and negative charges in the balloon rearrange themselves when she does this. Grade 7-9

Figure 2



In which of the positions labelled A, B and C on the diagram did Jane hold the polythene rod? Explain your answer.

[3 marks]

Revision Summary for Topic 2

You've made it through Topic 2 — time to put yourself through your paces and check it's all sunk in.

- Try these questions and tick off each one when you get it right.
- When you've done all the questions under a heading and are completely happy with it, tick it off.

Circuit Basics (p.40-43) ☐

1) Define current and state an equation that links current, charge and time, with units for each. ☐
2) What is meant by potential difference and resistance in a circuit? ☐
3) Draw the circuit symbols for: a cell, a lamp, a diode, a fuse and an LDR. ☐
4) What is the equation that links potential difference, current and resistance? ☐
5) What is an ohmic conductor? ☐
6) Explain how you would investigate how the length of a wire affects its resistance. ☐
7) Draw a circuit that could be used to investigate how the resistance of a filament bulb changes with the current through it. ☐
8) Name one linear component and one non-linear component. ☐

Circuit Devices and Types of Circuit (p.45-50) ☐

9) Explain how the resistance of an LDR varies with light intensity. ☐
10) What happens to the resistance of a thermistor as it gets colder? ☐
11) True or false? Potential difference is shared between components in a series circuit. ☐
12) True or false? The current is constant in a series circuit. ☐
13) True or false? The potential difference across each component connected in parallel is different. ☐
14) Explain why adding resistors in parallel decreases the total resistance of a circuit, but adding them in series increases the total resistance. ☐
15) Describe an experiment that could be carried out to investigate how adding resistors in series and parallel affects the total resistance of a circuit. ☐

Electricity in the Home (p.52-56) ☐

16) True or false? Mains supply electricity is an alternating current. ☐
17) What is the potential difference and the frequency of the UK mains supply? ☐
18) Name and give the colours of the three wires in a three-core cable. ☐
19) Give the potential differences for the three wires in a three-core mains cable. ☐
20) Explain why touching a live wire is dangerous. ☐
21) State three equations that can be used to calculate electrical power. ☐
22) What is the power rating of an appliance? ☐
23) Explain why electricity is transferred by the national grid at a high pd but low current. ☐
24) What are the functions of step-up and step-down transformers? ☐

Static Electricity and Electric Fields (p.58-60) ☐

25) How does rubbing of materials cause static electricity to build up? ☐
26) True or false? Two positive charges attract each other. ☐
27) In which direction do the arrows on electric field lines point? ☐
28) Using the concept of electric fields, explain how a build up of static electricity can cause a spark. ☐