Relative Formula Mass

Calculating relative formula mass is straight forward enough, but things can get a bit more confusing when you start working out the percentage compositions of compounds. Best get cracking, I suppose...

Compounds Have a Relative Formula Mass, M_r

If you have a compound like $MgCl_2$ then it has a relative formula mass, M_r, which is just the relative atomic masses of all the atoms in the molecular formula added together.

You can find the relative atomic mass (A_r) of an element from the periodic table — it's the same as its mass number. See page 97 for more.

EXAMPLE

Find the relative formula mass of $MgCl_2$.

1) Look up the relative atomic masses of all the elements in the compound on the periodic table. (In the exams, you might be given the A_r you need in the question.)
   A_r of Mg = 24 and the A_r of Cl = 35.5.
2) Add up all the relative atomic masses of the atoms in the compound.
   Mg + (2 × Cl) = 24 + (2 × 35.5) = 95 So M_r of $MgCl_2$ = 95

There are two chlorine atoms in $MgCl_2$, so the relative atomic mass of chlorine needs to be multiplied by 2.

You Can Calculate the % Mass of an Element in a Compound

This is actually dead easy — so long as you've learnt this formula:

$$\text{Percentage mass of an element in a compound} = \frac{A_r \times \text{number of atoms of that element}}{M_r \text{ of the compound}} \times 100$$

EXAMPLE

Find the percentage mass of sodium in sodium carbonate, Na_2CO_3.

A_r of sodium = 23, A_r of carbon = 12, A_r of oxygen = 16

M_r of Na_2CO_3 = (2 × 23) + 12 + (3 × 16) = 106

$$\text{Percentage mass of sodium} = \frac{A_r \times \text{number of atoms of that element}}{M_r \text{ of the compound}} \times 100 = \frac{23 \times 2}{106} \times 100 = 43\%$$

You might also come across more complicated questions where you need to work out the percentage mass.

EXAMPLE

A mixture contains 20% iron ions by mass. What mass of iron chloride ($FeCl_2$) would you need to provide the iron ions in 50 g of the mixture? A_r of Fe = 56, A_r of Cl = 35.5.

1) Find the mass of iron in the mixture.
   The mixture contains 20% iron by mass, so in 50 g there will be $50 \times \frac{20}{100} = 10$ g of iron.
2) Calculate the percentage mass of iron in iron chloride.
   $$\text{Percentage mass of iron} = \frac{A_r \times \text{number of atoms of that element}}{M_r \text{ of the compound}} \times 100 = \frac{56}{56 + (2 \times 35.5)} \times 100 = 44.09...\%$$
3) Calculate the mass of iron chloride that contains 10 g of iron.
   Iron chloride contains 44.09% iron by mass, so there will be 10 g of iron in $10 \div \frac{44.09...}{100} = 23$ g
   So you need 23 g of iron chloride to provide the iron in 50 g of the mixture.

Relative mass — when you go to church with your parents...

The best way to get to grips with all this stuff is by practising. Start by having a go at these questions...

Q1 Calculate the relative formula mass (M_r) of: a) H_2O b) LiOH c) H_2SO_4 [3 marks]

Q2 Calculate the percentage composition by mass of potassium in potassium hydroxide (KOH). [2 marks]

Q2 Video Solution

The Mole

Moles can be pretty confusing. It's probably the word that puts people off. It's difficult to see the relevance of the word "mole" to anything but a small burrowing animal.

"The Mole" is Simply the Name Given to an Amount of a Substance

1) Just like "a million" is this many: 1 000 000; or "a billion" is this many: 1 000 000 000, so "the Avogadro constant" is this many: 602 000 000 000 000 000 000 000 or 6.02×10^{23}. And that's all it is. Just a number.
2) One mole of any substance is just an amount of that substance that contains an Avogadro number of particles — so 6.02×10^{23} particles. The particles could be atoms, molecules, ions or electrons.
3) The burning question, of course, is why is it such a silly long number like that, and with a 6 at the front?
4) The answer is that the mass of that number of atoms or molecules of any substance is exactly the same number of grams as the relative atomic mass (A_r) or relative formula mass (M_r) of the element or compound.

5) In other words, one mole of atoms or molecules of any substance will have a mass in grams equal to the relative formula mass (A_r or M_r) for that substance. Here are some examples:

Carbon has an A_r of 12.	So one mole of carbon weighs exactly 12 g.
Nitrogen gas, N_2, has an M_r of 28 (2 × 14).	So one mole of N_2 weighs exactly 28 g.
Carbon dioxide, CO_2, has an M_r of 44 (12 + [2 × 16]).	So one mole of CO_2 weighs exactly 44 g.

6) This means that 12 g of carbon, or 28 g of N_2, or 44 g of CO_2, all contain the same number of particles, namely one mole or 6.023×10^{23} atoms or molecules.

Nice Formula to Find the Number of Moles in a Given Mass:

$$\text{Number of moles} = \frac{\text{mass in g (of an element or compound)}}{M_r \text{ (of the element or compound)}}$$

EXAMPLE

How many moles are there in 66 g of carbon dioxide (CO_2)?

1) Calculate the M_r of carbon dioxide. — M_r of CO_2 = 12 + (16 × 2) = 44
2) Use the formula above to find out how many moles there are. — No. of moles = Mass (g) ÷ M_r = 66 ÷ 44 = 1.5 mol

Easy Peasy.

'mol' is the symbol for the unit 'moles'.

You can rearrange the equation above using this handy formula triangle. You could use it to find the mass of a known number of moles of a substance, or to find the M_r of a substance from a known mass and number of moles. Just cover up the thing you want to find with your finger and write down what's left showing.

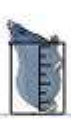
EXAMPLE

What mass of carbon is there in 4 moles of carbon dioxide?

There are 4 moles of carbon in 4 moles of CO_2.

Cover up 'mass' in the formula triangle. That leaves you with 'no. of moles × M_r'.

So the mass of 4 moles of carbon = 4 × 12 = 48 g



What do moles have for pudding? Jam moly-poly...

Calculations involving moles can send some people into a spin. Don't be one of those people — there's really no need to freak out about moles. Go back over this page until you've got your head round it all.

Q2 Video Solution

Q1 Calculate the number of moles in 90 g of water (H_2O). A_r(O) = 16, A_r(H) = 1. [2 marks]

Q2 Calculate the mass of 0.20 mol of potassium bromide (KBr). A_r(K) = 39, A_r(Br) = 80. [2 marks]

Conservation of Mass

You've probably realised by now that you can't magic stuff out of thin air, and you can't make it magically disappear, either. This fact is pretty useful for working out the amounts of substances in chemical reactions.

In a Chemical Reaction, Mass is Always Conserved

1) During a chemical reaction no atoms are destroyed and no atoms are created.
2) This means there are the same number and types of atoms on each side of a reaction equation.
3) Because of this, no mass is lost or gained — we say that mass is conserved during a reaction.
E.g.

$$2Li + F_2 \rightarrow 2LiF$$

In this reaction, there are 2 lithium atoms and 2 fluorine atoms on each side of the equation.

4) By adding up the relative formula masses of the substances on each side of a balanced symbol equation, you can see that mass is conserved. The total M_r of all the reactants equals the total M_r of the products.

There's more about balanced symbol equations on p.99.

EXAMPLE

Show that mass is conserved in this reaction: $2Li + F_2 \rightarrow 2LiF$.

1) Add up the relative formula masses on the left-hand side of the equation.
$2 \times M_r(Li) + 2 \times M_r(F) = (2 \times 7) + (2 \times 19) = 14 + 38 = 52$
2) Add up the relative formula masses on the right-hand side of the equation.
$2 \times M_r(LiF) = 2 \times (7 + 19) = 2 \times 26 = 52$

The total M_r on the left hand side of the equation is equal to the total M_r on the right hand side, so mass is conserved.

If the Mass Seems to Change, There's Usually a Gas Involved

In some experiments, you might observe a change of mass of an unsealed reaction vessel during a reaction. There are usually two explanations for this:

Explanation 1: If the mass increases, it's probably because one of the reactants is a gas that's found in air (e.g. oxygen) and all the products are solids, liquids or aqueous.

- Before the reaction, the gas is floating around in the air. It's there, but it's not contained in the reaction vessel, so you can't account for its mass.
- When the gas reacts to form part of the product, it becomes contained inside the reaction vessel — so the total mass of the stuff inside the reaction vessel increases.

For example, when a metal reacts with oxygen in an unsealed container, the mass of the container increases. The mass of the metal oxide produced equals the total mass of the metal and the oxygen that reacted from the air.

$$metal_{(s)} + oxygen_{(g)} \rightarrow metal\ oxide_{(s)}$$

Explanation 2: If the mass decreases, it's probably because one of the products is a gas and all the reactants are solids, liquids or aqueous.

- Before the reaction, all the reactants are contained in the reaction vessel.
- If the vessel isn't enclosed, then the gas can escape from the reaction vessel as it's formed. It's no longer contained in the reaction vessel, so you can't account for its mass — the total mass of the stuff inside the reaction vessel decreases.

For example, when a metal carbonate thermally decomposes to form a metal oxide and carbon dioxide gas, the mass of the reaction vessel will decrease if it isn't sealed. But in reality, the mass of the metal oxide and the carbon dioxide produced will equal the mass of the metal carbonate that decomposed.

$$metal\ carbonate_{(s)} \rightarrow metal\ oxide_{(s)} + carbon\ dioxide_{(g)}$$

Remember from the particle model on page 120 that a gas will expand to fill any container it's in. So if the reaction vessel isn't sealed, the gas expands out from the vessel, and escapes into the air around.

Not eating your potatoes — that's mash conservation...

Never, ever forget that, in a reaction, the total mass of reactants is the same as the total mass of products.

Q1 Show that mass is conserved in the reaction: $H_2SO_{4(aq)} + 2NaOH_{(aq)} \rightarrow Na_2SO_{4(aq)} + 2H_2O_{(l)}$
$A_r(H) = 1, A_r(O) = 16, A_r(Na) = 23, A_r(S) = 32$ [5 marks]

Q1 Video Solution

The Mole and Equations

This is the moment where the 'number of moles = mass ÷ M_r' equation from page 124 comes into its own.

You Can Use Moles to Calculate Masses in Reactions

Remember those balanced equations back on page 99? Well, the big numbers in front of the chemical formulas of the reactants and products tell you how many moles of each substance takes part or is formed during the reaction.

The little numbers tell you how many atoms of each element there are in each of the substances.

For example:

$$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$$

In this reaction, 1 mole of magnesium and 2 moles of hydrochloric acid react together to form 1 mole of magnesium chloride and 1 mole of hydrogen gas.

You Can Balance Equations Using Reacting Masses

If you know the masses of the reactants and products that took part in a reaction, you can work out the balanced symbol equation for the reaction. Here are the steps you should take:

1) Divide the mass of each substance by its relative formula mass to find the number of moles.
2) Divide the number of moles of each substance by the smallest number of moles in the reaction.
3) If any of the numbers aren't whole numbers, multiply all the numbers by the same amount so that they all become whole numbers.
4) Write the balanced symbol equation for the reaction by putting these numbers in front of the chemical formulas.

EXAMPLE

8.1 g of zinc oxide (ZnO) reacts completely with 0.60 g of carbon to form 2.2 g of carbon dioxide and 6.5 g of zinc. Write a balanced symbol equation for this reaction. $A_r(C) = 12$, $A_r(O) = 16$, $A_r(Zn) = 65$.

1) Work out M_r for each of the substances in the reaction:

ZnO: 65 + 16 = 81 C: 12 CO_2: 12 + (2 × 16) = 44 Zn: 65

2) Divide the mass of each substance by its M_r to calculate how many moles of each substance reacted or were produced:

ZnO: $\frac{8.1}{81} = 0.10$ mol C: $\frac{0.60}{12} = 0.050$ mol

CO_2: $\frac{2.2}{44} = 0.050$ mol Zn: $\frac{6.5}{65} = 0.10$

3) Divide by the smallest number of moles, which is 0.050:

ZnO: $\frac{0.10}{0.050} = 2.0$ C: $\frac{0.050}{0.050} = 1.0$

CO_2: $\frac{0.050}{0.050} = 1.0$ Zn: $\frac{0.10}{0.050} = 2.0$

These numbers give the ratio of the amounts of each substance in the reaction equation.

4) The numbers are all whole numbers, so you can write out the balanced symbol equation straight away:

$$2ZnO + C \rightarrow CO_2 + 2Zn$$

Where do moles live? Edinburrow...

The calculations on this page have lots of steps, so the best way to learn how to do them is by practising. Luckily, here are some questions to get you started. Don't say I don't spoil you. Better get cracking...

Q1 Video Solution

Q1 84 g of N_2 reacts completely with 18 g of H_2 to produce 102 g of NH_3.
$M_r(N_2) = 28$, $M_r(H_2) = 2$, $M_r(NH_3) = 17$.

a) Calculate how many moles of each substance reacted or was produced. [3 marks]

b) Use your answer to part a) to write a balanced symbol equation for this reaction. [2 marks]

Limiting Reactants

Reactions don't go on forever — you need stuff in the reaction flask that can react. If one reactant gets completely used up in a reaction before the rest, then the reaction will stop. That reactant's called limiting.

Reactions Stop When One Reactant is Used Up

When some magnesium carbonate ($MgCO_3$) is placed into a beaker of hydrochloric acid, you can tell a reaction is taking place because you see lots of bubbles of gas being given off.

After a while, the amount of fizzing slows down and the reaction eventually stops...

1) The reaction stops when all of one of the reactants is used up. Any other reactants are in excess. They're usually added in excess to make sure that the other reactant is used up.
2) The reactant that's used up in a reaction is called the limiting reactant (because it limits the amount of product that's formed).
3) The amount of product formed is directly proportional to the amount of limiting reactant. For example, if you halve the amount of limiting reactant the amount of product formed will also halve. If you double the amount of limiting reactant the amount of product will double (as long as it is still the limiting reactant).
4) This is because if you add more reactant there will be more reactant particles to take part in the reaction, which means more product particles.

The Amount of Product Depends on the Limiting Reactant

You can calculate the mass of a product formed in a reaction by using the mass of the limiting reactant and the balanced reaction equation.

You could also use this method to find the mass of a reactant needed to produce a known mass of a product.

1) Write out the balanced equation.
2) Work out relative formula masses (M_r) of the reactant and product you want.
3) Find out how many moles there are of the substance you know the mass of.
4) Use the balanced equation to work out how many moles there'll be of the other substance. In this case, that's how many moles of product will be made of this many moles of reactant.
5) Use the number of moles to calculate the mass.

EXAMPLE

Calculate the mass of aluminium oxide formed when 135 g of aluminium is burned in air.

1) Write out the balanced equation: $4Al + 3O_2 \rightarrow 2Al_2O_3$
2) Calculate the relative formula masses: Al: 27 Al_2O_3: $(2 \times 27) + (3 \times 16) = 102$
3) Calculate the number of moles of aluminium in 135 g: $\text{Moles} = \frac{\text{mass}}{M_r} = \frac{135}{27} = 5$ (You don't have to find M_r of oxygen because it's in excess.)
4) Look at the ratio of moles in the equation: 4 moles of Al react to produce 2 moles of Al_2O_3 — half the number of moles are produced. So 5 moles of Al will react to produce 2.5 moles of Al_2O_3 (If the question asked for the number of moles of aluminium oxide formed, you'd stop here.)
5) Calculate the mass of 2.5 moles of aluminium oxide: $\text{mass} = \text{moles} \times M_r = 2.5 \times 102 = 255$ g

'A Rush of Mud to the Head' — my favourite album by Moldplay...

I've said it before, I'll say it again — practice makes perfect. So before you get distracted by a cute picture of a kitten, or wander off to have a cup of tea, have a go at the question below.

Q1 The balanced equation for the reaction between chlorine and potassium bromide is:

$$Cl_2 + 2KBr \rightarrow Br_2 + 2KCl$$

Calculate the mass of potassium chloride produced when 23.8 g of potassium bromide reacts in an excess of chlorine. $A_r(K) = 39$, $A_r(Br) = 80$, $A_r(Cl) = 35.5$. [4 marks]

Q1 Video Solution

Concentrations of Solutions

I can't promise that this page has all the answers to life, but there are quite a lot of solutions. Time to discover how you can work out the mass of a solute in a solution. Hold onto your hats and concentrate...

Concentration is a Measure of How Crowded Things Are

1) Lots of reactions in chemistry take place between substances that are dissolved in a solution. The amount of a substance (e.g. the mass or the number of moles) in a certain volume of a solution is called its concentration.
2) The more solute (the substance that's dissolved) there is in a given volume, the more concentrated the solution.

Concentration can be Measured in g/dm^3

1) One way to measure the concentration of a solution is by calculating the mass of a substance in a given volume of solution. The units will be units of mass/units of volume. Here's how to calculate the concentration of a solution in g/dm^3:

$$\text{concentration (in g/dm}^3\text{)} = \frac{\text{mass of solute (in g)}}{\text{volume of solvent (in dm}^3\text{)}}$$

EXAMPLES

Gavin wasn't great at concentration.

1) What's the concentration in g/dm^3 of a solution of sodium chloride where 30 g of sodium chloride is dissolved in 0.2 dm^3 of water?

$\text{concentration} = \frac{30}{0.2} = 150\ g/dm^3$

$1\ dm^3 = 1000\ cm^3$

2) What's the concentration, in g/dm^3, of a solution with 15 g of salt in 500 cm^3?
- Convert the volume to dm^3 by dividing by 1000: $500\ cm^3 \div 1000 = 0.5\ dm^3$
- Now you've got the mass and the volume in the right units, just stick them in the formula: $\text{Concentration} = \frac{15}{0.5} = 30\ g/dm^3$

2) You can rearrange the equation above to find the mass of solute in a given volume of solution if you know its concentration. Here's a handy formula triangle to help with rearranging the equation:

mass (in g)
conc. (in g/dm^3) × volume (in dm^3)

EXAMPLE

What mass of a salt would you need to dissolve in 0.40 dm^3 of water to make a solution with a concentration of 24 g/dm^3?
- Use the formula triangle to rearrange the equation to make mass the subject: mass = concentration × volume
- Use this equation to calculate the mass: mass = 24 × 0.40 = 9.6 g

Remember — all measurements have some uncertainty to them. For repeated measurements, you can calculate the average (mean) and also the range of your results (see page 6). The range can be used to give you an idea of how uncertain the mean value is (see page 10).

CGP Revision Guides — not from concentrate...

Learning that formula could be a useful way to spend a few minutes. As could eating a biscuit. Why not kill two birds with one stone and write out the formula with one hand whilst holding a digestive in the other?

Q1 Calculate the concentration, in g/dm^3, of a solution that contains 0.6 g of salt in 15 cm^3 of solvent. [2 marks]

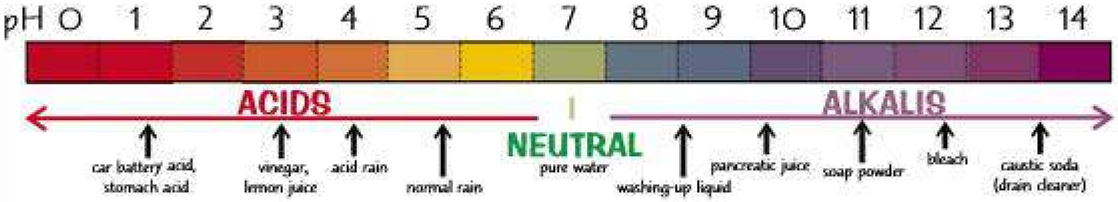
Q1 Video Solution

Acids and Bases

Testing the pH of a solution means using an indicator — and that means pretty colours...

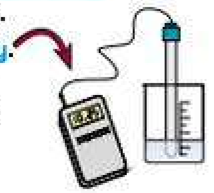
The pH Scale Goes From 0 to 14

1) The pH scale is a measure of how acidic or alkaline a solution is.
2) The lower the pH of a solution, the more acidic it is. The higher the pH of a solution, the more alkaline it is.
3) A neutral substance (e.g. pure water) has pH 7.



You Can Measure the pH of a Solution

1) An indicator is a dye that changes colour depending on whether it's above or below a certain pH. Some indicators contain a mixture of dyes that means they gradually change colour over a broad range of pH. These are called wide range indicators and they're useful for estimating the pH of a solution. For example, universal indicator gives the colours shown above.
2) A pH probe attached to a pH meter can also be used to measure pH electronically. The probe is placed in the solution you are measuring and the pH is given on a digital display as a numerical value, meaning it's more accurate than an indicator.



Acids and Bases Neutralise Each Other

1) An acid is a substance that forms aqueous solutions with a pH of less than 7. Acids form H^+ ions in water.
2) A base is a substance with a pH greater than 7.
3) An alkali is a base that dissolves in water to form a solution with a pH greater than 7. Alkalis form OH^- ions in water.

The reaction between acids and bases is called neutralisation:

$$\text{acid} + \text{base} \rightarrow \text{salt} + \text{water}$$

Neutralisation between acids and alkalis can be seen in terms of H^+ and OH^- ions like this:

$$H^+_{(aq)} + OH^-_{(aq)} \rightarrow H_2O_{(l)}$$

Hydrogen (H^+) ions react with hydroxide (OH^-) ions to produce water.

When an acid neutralises a base (or vice versa), the products are neutral, i.e. they have a pH of 7. An indicator can be used to show that a neutralisation reaction is over.

This page should have all bases covered...

pHew, you finished the page... This stuff isn't too bad really, and pH is worth knowing about — it's important to the chemistry in our bodies. For example, here's an interesting(ish) fact — your skin is slightly acidic (pH 5.5).

Q1 A student uses universal indicator to test the pH of some lemon juice. What colour would you expect the indicator to turn? [1 mark]

Q2 The pH of an unknown solution is found to be 8. Is the solution acidic or alkaline? [1 mark]

Strong Acids and Weak Acids

I like strong acids, and I also like weak acids. But which is better? There's only one way to find out...

Acids Produce Protons in Water

The thing about acids is that they ionise in aqueous solution — they produce hydrogen ions, H^+. For example:

An H^+ ion is just a proton.

$HCl \rightarrow H^+ + Cl^-$
$HNO_3 \rightarrow H^+ + NO_3^-$

These acids don't produce hydrogen ions until they meet water. So, for example, hydrogen chloride gas isn't acidic.

Acids Can be Strong or Weak

1) Strong acids (e.g. sulfuric, hydrochloric and nitric acids) ionise completely in water. All acid particles dissociate to release H^+ ions.
2) Weak acids (e.g. ethanoic, citric and carbonic acids) do not fully ionise in solution. Only a small proportion of acid particles dissociate to release H^+ ions.
3) The ionisation of a weak acid is a reversible reaction, which sets up an equilibrium between the undissociated and dissociated acid. Since only a few of the acid particles release H^+ ions, the position of equilibrium lies well to the left.
4) Reactions of acids involve the H^+ ions reacting with other substances. If the concentration of H^+ ions is higher, the rate of reaction will be faster, so strong acids will be more reactive than weak acids of the same concentration.

For more on equilibria turn to p.147.

Strong acid: $HCl \longrightarrow H^+ + Cl^-$

Weak acid: $CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$

pH is a Measure of the Concentration of Hydrogen Ions

1) The pH of an acid or alkali is a measure of the concentration of H^+ ions in the solution.
2) For every decrease of 1 on the pH scale, the concentration of H^+ ions increases by a factor of 10. So, an acid that has a pH of 4 has 10 times the concentration of H^+ ions of an acid that has a pH of 5. For a decrease of 2 on the pH scale, the concentration of H^+ ions increases by a factor of 100. The general rule for this is:

$$\text{Factor } H^+ \text{ ion concentration changes by} = 10^{-X}$$

X is the difference in pH. So if pH falls from 7 to 4 the difference is –3, and the factor the H^+ ion concentration has increased by is $10^{-(-3)} = 10^3$.

3) So the pH of a strong acid is always less than the pH of a weaker acid if they have the same concentration.

Don't Confuse Strong Acids with Concentrated Acids

1) Acid strength (i.e. strong or weak) tells you what proportion of the acid molecules ionise in water.
2) The concentration of an acid is different. Concentration measures how much acid there is in a certain volume of water. Concentration is basically how watered down your acid is.
3) The larger the amount of acid there is in a certain volume of liquid, the more concentrated the acid is.
4) So you can have a dilute (not very concentrated) but strong acid, or a concentrated but weak acid.
5) pH will decrease with increasing acid concentration regardless of whether it's a strong or weak acid.

Concentration describes the total number of dissolved acid molecules — not the number of molecules that are ionised to produce hydrogen ions at any given moment.

Weak acid or strong acid? I know which goes best with chips...

Acids are acidic because of H^+ ions. And strong acids are strong because they let go of all their H^+ ions at the drop of a hat... Well, at the drop of a drop of water.

Q1 Name a strong acid. [1 mark]

Q2 A student added strong acid to a weakly acidic solution of pH 6. The pH of the new solution was found to be pH 3. By how many times did the concentration of H^+ increase? [1 mark]

Q2 Video Solution

Reactions of Acids

Remember neutralisation from page 129? Well, there's more stuff on neutralisation reactions coming up...

Metal Oxides and Metal Hydroxides are Bases

1) Some metal oxides and metal hydroxides dissolve in water. These soluble compounds are alkalis. As you saw on page 129, alkalis react with acids in neutralisation reactions.
2) Even bases that won't dissolve in water will still take part in neutralisation reactions with acids.
3) So, all metal oxides and metal hydroxides react with acids to form a salt and water.

Acid + Metal Oxide → Salt + Water   **Acid + Metal Hydroxide → Salt + Water**

The salt that's produced depends upon the acid and the metal ion in the oxide or hydroxide:

hydrochloric acid	+	copper oxide	→	copper chloride	+	water
$2HCl$	+	CuO	→	$CuCl_2$	+	H_2O
sulfuric acid	+	potassium hydroxide	→	potassium sulfate	+	water
H_2SO_4	+	$2KOH$	→	K_2SO_4	+	$2H_2O$
nitric acid	+	sodium hydroxide	→	sodium nitrate	+	water
HNO_3	+	$NaOH$	→	$NaNO_3$	+	H_2O

To work out the formula of an ionic compound, you need to balance the charges of the positive and negative ions so the overall charge of a compound is neutral. For more on ionic formulas, see p.114.

Acids and Metal Carbonates Produce Carbon Dioxide

Metal carbonates are also bases. They react with acids to produce a salt, water and carbon dioxide.

Acid + Metal Carbonate → Salt + Water + Carbon Dioxide

hydrochloric acid	+	sodium carbonate	→	sodium chloride	+	water	+	carbon dioxide
$2HCl$	+	Na_2CO_3	→	$2NaCl$	+	H_2O	+	CO_2
sulfuric acid	+	calcium carbonate	→	calcium sulfate	+	water	+	carbon dioxide
H_2SO_4	+	$CaCO_3$	→	$CaSO_4$	+	H_2O	+	CO_2

You can Make Soluble Salts Using an Insoluble Base

PRACTICAL

1) You need to pick the right acid and insoluble base, such as an insoluble metal oxide, hydroxide, or carbonate. E.g. if you want to make copper chloride, you could mix hydrochloric acid and copper oxide. $CuO_{(s)} + 2HCl_{(aq)} \rightarrow CuCl_{2\,(aq)} + H_2O_{(l)}$

You could also react the acid with a metal.

2) Gently warm the dilute acid using a Bunsen burner, then turn off the Bunsen burner.
3) Add the insoluble base to the acid a bit at a time, until no more reacts (i.e. the base is in excess). You'll know when all the acid has been neutralised because, even after stirring, the excess solid will just sink to the bottom of the flask.
4) Then filter out the excess solid to get the salt solution (see p.101).
5) To get pure, solid crystals of the salt, gently heat the solution using a water bath or an electric heater to evaporate some of the water (to make it more concentrated) and then stop heating it and leave the solution to cool. Crystals of the salt should form, which can be filtered out of the solution and then dried. This is called crystallisation (p.101).

AHHHHH so many reactions...

In the exam you could get asked to describe how you would go about making a pure, dry sample of a given soluble salt. Make sure you understand the method and what reactants to use.

Q1 Calcium carbonate is added to hydrochloric acid.
Write the word equation and the balanced symbol equation for the reaction that occurs. [3 marks]

The Reactivity Series

You can place metals in order of reactivity. This can be a lot more useful than it sounds, promise.

The Reactivity Series — How Well a Metal Reacts

1) The reactivity series lists metals in order of their reactivity towards other substances.
2) For metals, their reactivity is determined by how easily they lose electrons — forming positive ions. The higher up the reactivity series a metal is, the more easily they form positive ions. Make sure you learn this list:
3) When metals react with water or acid, they lose electrons and form positive ions. So, the higher a metal is in the reactivity series, the more easily it reacts with water or acid.
4) If you compare the relative reactivity of different metals with either an acid or water and put them in order from most reactive to the least reactive, the order you get is the reactivity series.

The Reactivity Series

Potassium	K	Very Reactive
Sodium	Na	Very Reactive
Lithium	Li	Very Reactive
Calcium	Ca	Very Reactive
Magnesium	Mg	Fairly Reactive
Carbon	C	Fairly Reactive
Zinc	Zn	Fairly Reactive
Iron	Fe	Fairly Reactive
Hydrogen	H	Not very Reactive
Copper	Cu	Not very Reactive

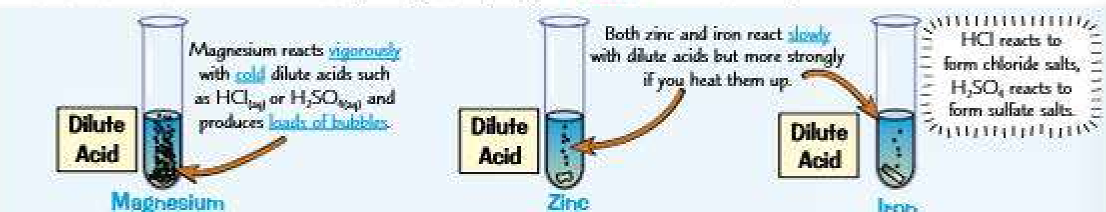
Carbon and hydrogen are non-metals but are often included in the reactivity series.

How Metals React With Acids Tells You About Their Reactivity

Some metals react with acids to produce a salt and hydrogen gas.

Acid + Metal → Salt + Hydrogen

1) The speed of reaction is indicated by the rate at which the bubbles of hydrogen are given off.
2) The more reactive the metal, the faster the reaction will go. Very reactive metals like potassium, sodium, lithium and calcium react explosively, but less reactive metals such as magnesium, zinc and iron react less violently. In general, copper won't react with cold, dilute acids.



$Mg_{(s)} + 2HCl_{(aq)} \rightarrow MgCl_{2(aq)} + H_{2(g)}$

$Mg_{(s)} + H_2SO_{4(aq)} \rightarrow MgSO_{4(aq)} + H_{2(g)}$

$Zn_{(s)} + 2HCl_{(aq)} \rightarrow ZnCl_{2(aq)} + H_{2(g)}$

$Zn_{(s)} + H_2SO_{4(aq)} \rightarrow ZnSO_{4(aq)} + H_{2(g)}$

$Fe_{(s)} + 2HCl_{(aq)} \rightarrow FeCl_{2(aq)} + H_{2(g)}$

$Fe_{(s)} + H_2SO_{4(aq)} \rightarrow FeSO_{4(aq)} + H_{2(g)}$

3) You can also investigate the reactivity of metals by measuring the temperature change of the reaction with an acid or water over a set time period. If you use the same mass and surface area of metal each time, then the more reactive the metal, the greater the temperature change should be.

Metals Also React with Water

The reactions of metals with water also show the reactivity of metals.

You can see more on the reactions of Group 1 metals with water on page 108.

Metal + Water → Metal Hydroxide + Hydrogen

For example, calcium: $Ca_{(s)} + 2H_2O_{(l)} \rightarrow Ca(OH)_{2(aq)} + H_{2(g)}$

1) The metals potassium, sodium, lithium and calcium will all react with water.
2) Less reactive metals like zinc, iron and copper won't react with water.

I AM NOT HIGHLY REACTIVE — OK...

See, experiments aren't just for fun — they can give you an insight into the relative reactivities of elements.

Q1 Give the balanced equation, including state symbols, for the reaction of sodium and water. [3 marks]

Q1 Video Solution

Separating Metals from Metal Oxides

Most metals are not found in the earth as pure lumps. Instead, you have to extract them from a compound meaning more work is required. Thanks for nothing nature...

Metals Often Have to be Separated from their Oxides

1) Lots of common metals, like iron and aluminium, react with oxygen to form oxides. This process is an example of oxidation. These oxides are often the ores that the metals need to be extracted from.
2) A reaction that separates a metal from its oxide is called a reduction reaction.

An ore is a type of rock that contains metal compounds.

FORMATION OF METAL ORE:

Oxidation = Gain of Oxygen

E.g. magnesium is oxidised to make magnesium oxide.

$$2Mg + O_2 \rightarrow 2MgO$$

EXTRACTION OF METAL:

Reduction = Loss of Oxygen

E.g. copper oxide is reduced to copper.

$$2CuO + C \rightarrow 2Cu + CO_2$$

Some Metals can be Extracted by Reduction with Carbon

1) Some metals can be extracted from their ores chemically by reduction using carbon.
2) In this reaction, the ore is reduced as oxygen is removed from it, and carbon gains oxygen so is oxidised. For example...

$2Fe_2O_3$	+	$3C$	→	$4Fe$	+	$3CO_2$
iron(III) oxide	+	carbon	→	iron	+	carbon dioxide

3) The position of the metal in the reactivity series determines whether it can be extracted by reduction with carbon.

- Metals higher than carbon in the reactivity series have to be extracted using electrolysis (p.135), which is expensive.
- Metals below carbon in the reactivity series can be extracted by reduction using carbon. For example, iron oxide is reduced in a blast furnace to make iron.
- This is because carbon can only take the oxygen away from metals which are less reactive than carbon itself is.

The Reactivity Series (More Reactive → Less Reactive)

Extracted using electrolysis.	Potassium	K
	Sodium	Na
	Lithium	Li
	Calcium	Ca
	Magnesium	Mg
	Carbon	C
Extracted by reduction using carbon.	Zinc	Zn
	Iron	Fe
	Copper	Cu

Some metals are so unreactive they are in the earth as the metal itself. For example, gold is mined as its elemental form.

Make sure you can explain how and why different metals are extracted in different ways.

Are you going to revise this page, ore what?

Metals are great aren't they? Loads of uses. Shame extracting them's not always cheap. Make sure you know the difference between reduction and oxidation and why carbon can be used to extract some metals but not others.

Q1 Write a balanced equation for the reduction of lead oxide, PbO, by carbon, C. [2 marks]

Q2 A mining company tried to extract calcium from its ore by reduction with carbon. The process did not work. Explain why. [1 mark]

Q1 Video Solution

Redox Reactions

In chemistry, oxidation doesn't just mean gain of oxygen. No, that would be far too easy.

If Electrons are Transferred, It's a Redox Reaction

1) Oxidation can mean the addition of oxygen (or a reaction with it), and reduction can be the removal of oxygen, but on this page we're looking at oxidation and reduction in terms of electrons.
2) A loss of electrons is called oxidation. A gain of electrons is called reduction. A handy way to remember this is by the mnemonic OIL RIG — Oxidation Is Loss, Reduction Is Gain.
3) REDuction and OXidation happen at the same time — hence the term "REDOX".

- Iron atoms are oxidised to Fe^{2+} ions when they react with dilute acid: $Fe + 2H^+ \rightarrow Fe^{2+} + H_2$
- The iron atoms lose electrons. They're oxidised by the hydrogen ions: $Fe - 2e^- \rightarrow Fe^{2+}$
- The hydrogen ions gain electrons. They're reduced by the iron atoms: $2H^+ + 2e^- \rightarrow H_2$

All reactions of metals and acids on p.132 are redox reactions.

Displacement Reactions are Redox Reactions

1) Displacement reactions involve one metal kicking another one out of a compound. Here's the rule:

A MORE REACTIVE metal will displace a LESS REACTIVE metal from its compound.

2) If you put a reactive metal into the solution of a dissolved metal compound, the reactive metal will replace the less reactive metal in the compound (see the reactivity series on p.132).

If you put iron in a solution of copper sulfate ($CuSO_4$) the more reactive iron will 'kick out' the less reactive copper from the solution. You end up with iron sulfate solution ($FeSO_4$) and copper metal.

iron + copper sulfate → iron sulfate + copper

$$Fe_{(s)} + CuSO_{4(aq)} \rightarrow FeSO_{4(aq)} + Cu_{(s)}$$

In this reaction the iron loses 2 electrons to become a 2+ ion — it's oxidised. The copper ion gains these 2 electrons to become a copper atom — it's reduced.

$$Fe \rightarrow Fe^{2+} + 2e^-$$

$$Cu^{2+} + 2e^- \rightarrow Cu$$

Koalas are more reactive than rucksacks.

3) In displacement reactions, it's always the metal ion that gains electrons and is reduced. The metal atom always loses electrons and is oxidised.
4) In the exam you could be asked to write word or symbol equations to show displacement reactions.

Ionic Equations Show Just the Useful Bits of Reactions

1) In an ionic equation only the particles that react and the products they form are shown. For example: $Mg_{(s)} + Zn^{2+}_{(aq)} \rightarrow Mg^{2+}_{(aq)} + Zn_{(s)}$
2) This just shows the displacement of zinc ions by magnesium metal. Here's what the full equation of the above reaction would be if you'd started off with zinc chloride:

$$Mg_{(s)} + ZnCl_{2(aq)} \rightarrow MgCl_{2(aq)} + Zn_{(s)}$$

3) If you write out the equations so you can see all the ions, you'll see that the chloride ions don't change in the reaction — they're spectator ions. They're of no interest here so can be crossed out.

$$Mg_{(s)} + Zn^{2+}_{(aq)} + 2Cl^-_{(aq)} \rightarrow Mg^{2+}_{(aq)} + 2Cl^-_{(aq)} + Zn_{(s)}$$

4) Instead, the ionic equation for this displacement reaction just concentrates on the substances which are oxidised or reduced.

REDOX — great for bubble baths. Oh no, wait..

Ionic equations are hugely important in chemistry. Better practice until you can do them in your sleep.

Q1 The equation for the reaction of zinc and iron sulfate is: $Zn_{(s)} + FeSO_{4(aq)} \rightarrow ZnSO_{4(aq)} + Fe_{(s)}$

a) Write an ionic equation for the reaction. [1 mark]

b) State which species is being reduced and which is being oxidised. [2 marks]

Q1 Video Solution

Electrolysis

Electrolysis uses an electrical current to cause a reaction. It's actually pretty cool. No, really...

Electrolysis Means 'Splitting Up with Electricity'

1) During electrolysis, an electric current is passed through an electrolyte (a molten or dissolved ionic compound). The ions move towards the electrodes, where they react, and the compound decomposes.
2) The positive ions in the electrolyte will move towards the cathode (-ve electrode) and gain electrons (they are reduced).
3) The negative ions in the electrolyte will move towards the anode (+ve electrode) and lose electrons (they are oxidised).
4) This creates a flow of charge through the electrolyte as ions travel to the electrodes.
5) As ions gain or lose electrons, they form the uncharged element and are discharged from the electrolyte.

An electrolyte is just a liquid or solution that can conduct electricity. An electrode is a solid that conducts electricity and is submerged in the electrolyte.

Electrolysis of Molten Ionic Solids Forms Elements

The electrodes should be inert so they don't react with the electrolyte.

1) An ionic solid can't be electrolysed because the ions are in fixed positions and can't move.
2) Molten ionic compounds can be electrolysed because the ions can move freely and conduct electricity.
3) Molten ionic liquids, e.g. lead bromide, are always broken up into their elements.
4) Positive metal ions are reduced to the element at the cathode: → $Pb^{2+} + 2e^- \rightarrow Pb$
5) Negative non-metal ions are oxidised to the element at the anode: → $2Br^- \rightarrow Br_2 + 2e^-$

Metals can be Extracted From Their Ores Using Electrolysis

If a metal is too reactive to be reduced with carbon (page 133) or reacts with carbon, then electrolysis can be used to extract it. Extracting metals via this method is very expensive as lots of energy is required to melt the ore and produce the required current.

1) Aluminium is extracted from the ore bauxite by electrolysis. Bauxite contains aluminium oxide, Al_2O_3.
2) Aluminium oxide has a very high melting temperature so it's mixed with cryolite to lower the melting point.
3) The molten mixture contains free ions — so it'll conduct electricity.
4) The positive Al^{3+} ions are attracted to the negative electrode where they each pick up three electrons and turn into neutral aluminium atoms. These then sink to the bottom of the electrolysis tank.
5) The negative O^{2-} ions are attracted to the positive electrode where they each lose two electrons. The neutral oxygen atoms will then combine to form O_2 molecules.

Cryolite is an aluminium based compound with a lower melting point than aluminium oxide.

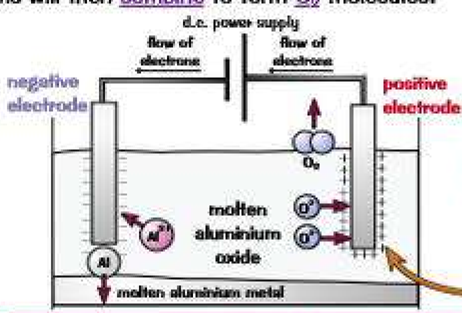
At the negative electrode:

Reduction — a gain of electrons

$Al^{3+} + 3e^- \rightarrow Al$

Metals form positive ions, so they're attracted to the negative electrode.

Aluminium is produced at the negative electrode.



At the positive electrode:

Oxidation — a loss of electrons

$2O^{2-} \rightarrow O_2 + 4e^-$

Non-metals form negative ions, so they're attracted to the positive electrode.

Oxygen is produced at the positive electrode.

The anode is made of carbon and needs to be replaced regularly as it reacts with oxygen to produce carbon dioxide.

Overall Equation:

aluminium oxide → aluminium + oxygen

$2Al_2O_{3(l)} \rightarrow 4Al_{(l)} + 3O_{2(g)}$

Faster shopping at the supermarket — use Electrolleys...

It might be jolly useful for your exams to learn the products of electrolysis of molten lead bromide...

Q1 A student carries out electrolysis on molten calcium chloride. What is produced at:
a) the anode? b) the cathode? [2 marks]

Q1 Video Solution

Electrolysis of Aqueous Solutions

When you electrolyse an aqueous solution, you also have to factor in the ions in the water.

It May be Easier to Discharge Ions from Water than the Solute

1) In aqueous solutions, as well as the ions from the ionic compound, there will be hydrogen ions (H^+) and hydroxide ions (OH^-) from the water: $H_2O_{(l)} \rightleftharpoons H^+_{(aq)} + OH^-_{(aq)}$
2) At the cathode, if H^+ ions and metal ions are present, hydrogen gas will be produced if the metal ions form an elemental metal that is more reactive than hydrogen (e.g. sodium ions). If the metal ions form an elemental metal that is less reactive than hydrogen (e.g. copper ions), a solid layer of the pure metal will be produced instead.
3) At the anode, if OH^- and halide ions (Cl^-, Br^-, I^-) are present, molecules of chlorine, bromine or iodine will be formed. If no halide ions are present, then the OH^- ions are discharged and oxygen will be formed.

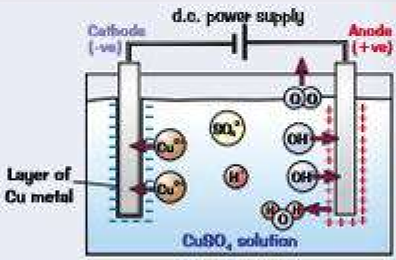
A solution of copper(II) sulfate ($CuSO_4$) contains four different ions: Cu^{2+}, SO_4^{2-}, H^+ and OH^-.

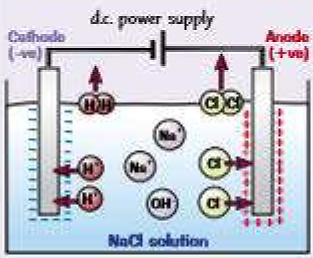
- Copper metal is less reactive than hydrogen. So at the cathode, copper metal is produced and coats the electrode.

$$Cu^{2+} + 2e^- \rightarrow Cu$$

- There aren't any halide ions present. So at the anode oxygen and water are produced. The oxygen can be seen as bubbles.

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$$





A solution of sodium chloride (NaCl) contains four different ions: Na^+, Cl^-, OH^- and H^+.

- Sodium metal is more reactive than hydrogen. So at the cathode, hydrogen gas is produced.

$$2H^+ + 2e^- \rightarrow H_2$$

- Chloride ions are present in the solution. So at the anode chlorine gas is produced.

$$2Cl^- \rightarrow Cl_2 + 2e^-$$

If you're drawing the apparatus for an electrolysis experiment, remember to include a d.c. power supply, wires and labels for the anode and the cathode. The anode is the electrode on the same side as the longer line of the d.c. power supply symbol.

PRACTICAL

You can set up an electrolysis experiment in the lab like the set-up on page 236. Once the experiment is finished you can test any gaseous products to work out what was produced.

- Chlorine bleaches damp litmus paper, turning it white.
- Hydrogen makes a "squeaky pop" with a lighted splint.
- Oxygen will relight a glowing splint.

For more on tests for gases, turn to page 155.

The Half Equations — Make Sure the Electrons Balance

Half equations show the reactions at the electrodes. The important thing to remember when you're combining half equations is that the number of electrons needs to be the same for each half equation. For the electrolysis of aqueous sodium chloride the half equations are:

Negative Electrode: $2H^+ + 2e^- \rightarrow H_2$

Positive Electrode: $2Cl^- \rightarrow Cl_2 + 2e^-$ or $2Cl^- - 2e^- \rightarrow Cl_2$

These combine to form the ionic equation: $2H^+ + 2Cl^- \rightarrow H_2 + Cl_2$

The electrons on each side of the half equations balance, so they can be cancelled out in the full ionic equation.

When a halide isn't present in the aqueous solution, the half equation for the anode is:

$$4OH^- \rightarrow O_2 + 2H_2O + 4e^- \quad \text{or} \quad 4OH^- - 4e^- \rightarrow O_2 + 2H_2O$$

I wrote a poem about my tabby — it was a cat ode...

So it's kinda confusing this electrolysis malarkey — you need to take it slow and make sure you get it.

Q1 An aqueous solution of copper bromide, $CuBr_2$, is electrolysed using inert electrodes. State what is produced at: a) the anode, b) the cathode. [2 marks]

Q1 Video Solution

Revision Questions for Topics C3 & C4

That wraps up Topic C4. Now find out how well you know Topics C3 and C4.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quizzes for Topics C3 and C4 — just scan the QR codes!

Topic C3 Quiz

Moles and Equations (p.123-127)

1) How do you calculate the relative formula mass, M_r of a substance?
2) State the value of the Avogadro constant.
3) What is the formula that relates the number of moles of a substance to its mass and M_r?
4) What does conservation of mass mean?
5) Suggest why the mass of a reaction vessel might decrease during a reaction.
6) How can you determine the number of moles of each substance that would react together from the balanced reaction equation?
7) Explain what is meant by the term 'limiting reactant'.

Concentrations of Solutions (p.128)

8) What is concentration?
9) Give the equation for working out the concentration of a solution in g/dm^3.

Acids and their Reactions (p.129-131)

Topic C4 Quiz

10) State whether the following pH values are acidic, alkaline or neutral.
    a) 9 b) 2 c) 7 d) 6
11) Give the general word equation for the reaction between an acid and a base.
12) What type of reagent could be used to show that an acid or base has been completely neutralised?
13) What is a strong acid?
14) Write a balanced equation for the reaction between hydrochloric acid and sodium carbonate.

The Reactivity Series (p. 132)

15) Is zinc more or less reactive than iron?
16) What is the general word equation for the reaction of a metal with an acid?
17) Give the balanced equation for the reaction of calcium with water.

Reduction and Oxidation (p.133-134)

18) What product forms in the oxidation of magnesium by oxygen?
19) Explain how you decide whether a metal can be extracted from its oxide by reduction with carbon.
20) In terms of electrons, give the definition of oxidation.
21) In a displacement reaction, does the metal atom get reduced or oxidised?

Electrolysis (p.135-136)

22) During electrolysis, which electrode are the positive ions attracted to?
23) Why can ionic solids not undergo electrolysis?
24) Do ions get reduced or oxidised at the anode?
25) During the manufacture of aluminium from bauxite, which electrode is aluminium formed at?
26) In what situation will hydrogen gas be given out during the electrolysis of an aqueous solution of an ionic solid?
27) If halide ions are present in an aqueous solution of an ionic solid will oxygen gas be released?

Exothermic and Endothermic Reactions

Whenever chemical reactions occur, there are changes in energy. This means that when chemicals get together, things either hot up or cool right off. I'll give you a heads up — this page is a good 'un.

Energy is Moved Around in Chemical Reactions

1) Chemicals store a certain amount of energy — and different chemicals store different amounts.
2) If the products of a reaction store more energy than the original reactants, then they must have taken in the difference in energy between the products and reactants from the surroundings during the reaction.
3) But if they store less, then the excess energy was transferred to the surroundings during the reaction.
4) The overall amount of energy doesn't change. This is because energy is conserved in reactions — it can't be created or destroyed, only moved around. This means the amount of energy in the universe always stays the same.

In an Exothermic Reaction, Heat is Given Out

1) An EXOTHERMIC reaction is one which transfers energy to the surroundings, usually by heating. This is shown by a rise in temperature.
2) The best example of an exothermic reaction is burning fuels — also called COMBUSTION. This gives out a lot of energy — it's very exothermic.
3) Neutralisation reactions (acid + alkali) are also exothermic.
4) Many oxidation reactions are exothermic. For example, adding sodium to water releases energy, so it must be exothermic — see page 108. The reaction releases energy and the sodium moves about on the surface of the water as it is oxidised.

5) Exothermic reactions have lots of everyday uses. For example:

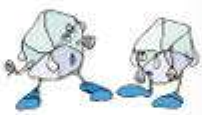
- Some hand warmers use the exothermic oxidation of iron in air (with a salt solution catalyst) to release energy.
- Self heating cans of hot chocolate and coffee also rely on exothermic reactions between chemicals in their bases.

In an Endothermic Reaction, Heat is Taken In

Physical processes can also take in or release energy. E.g. freezing is an exothermic process, melting is endothermic.

1) An ENDOTHERMIC reaction is one which takes in energy from the surroundings. This is shown by a fall in temperature.
2) Endothermic reactions are much less common than exothermic reactions, but they include:
   - The reaction between citric acid and sodium hydrogencarbonate.
   - Thermal decomposition — e.g. heating calcium carbonate causes it to decompose into calcium oxide (also called quicklime) and carbon dioxide:

Calcium carbonate — $CaCO_3$ (+ HEAT) → $CO_2 + CaO$ — Quicklime



3) Endothermic reactions also have everyday uses. For example:

Endothermic reactions are used in some sports injury packs — the chemical reaction allows the pack to become instantly cooler without having to put it in the freezer.

Right, so burning gives out heat — really...

Remember, "exo-" = exit, "-thermic" = heat, so an exothermic reaction is one that gives out heat — and endothermic means just the opposite. To make sure you really understand these terms, try this question.

Q1 A student prepares a flask containing ethanoic acid and measures its temperature as 22.5 °C. She then adds dilute potassium hydroxide solution which is 21 °C. After 2 minutes the temperature of the reaction mixture is 28.5 °C. Is the reaction exothermic or endothermic? [1 mark]

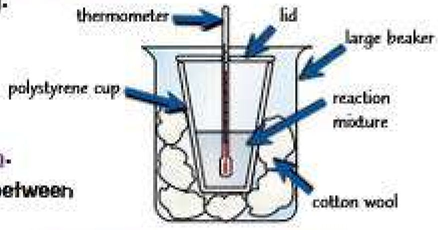
More Exothermic and Endothermic Reactions

Sometimes it's not enough to just know if a reaction is endothermic or exothermic. You may also need to know how much energy is absorbed or released — you can do experiments to find this out. Fun, fun, fun...

Energy Transfer can be Measured

PRACTICAL

1) You can measure the amount of energy released by a chemical reaction (in solution) by taking the temperature of the reagents, mixing them in a polystyrene cup and measuring the temperature of the solution at the end of the reaction. Easy.
2) The biggest problem with energy measurements is the amount of energy lost to the surroundings.
3) You can reduce it a bit by putting the polystyrene cup into a beaker of cotton wool to give more insulation, and putting a lid on the cup to reduce energy lost by evaporation.
4) This method works for neutralisation reactions or reactions between metals and acids, or carbonates and acids.



5) You can also use this method to investigate what effect different variables have on the amount of energy transferred — e.g. the mass or concentration of the reactants used.
6) Here's how you could test the effect of acid concentration on the energy released in a neutralisation reaction between hydrochloric acid (HCl) and sodium hydroxide (NaOH):

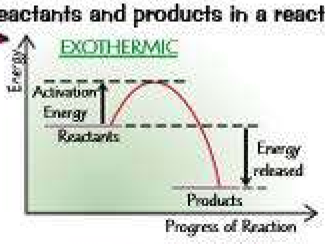
1) Put 25 cm³ of 0.25 mol/dm³ of hydrochloric acid and sodium hydroxide in separate beakers.
2) Place the beakers in a water bath set to 25 °C until they are both at the same temperature (25 °C).
3) Add the HCl followed by the NaOH to a polystyrene cup with a lid — as in the diagram above.
4) Take the temperature of the mixture every 30 seconds, and record the highest temperature.
5) Repeat steps 1-4 using 0.5 mol/dm³ and then 1 mol/dm³ of hydrochloric acid.

Reaction Profiles Show Energy Changes

Reaction profiles are sometimes called energy level diagrams.

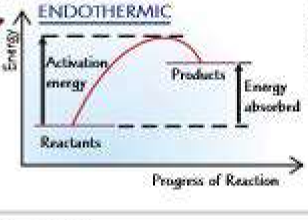
Reaction profiles are diagrams that show the relative energies of the reactants and products in a reaction, and how the energy changes over the course of the reaction.

1) This shows an exothermic reaction — the products are at a lower energy than the reactants. The difference in height represents the overall energy change in the reaction (the energy given out) per mole.
2) The initial rise in energy represents the energy needed to start the reaction. This is the activation energy (E_a).



3) The activation energy is the minimum amount of energy the reactants need to collide with each other and react. The greater the activation energy, the more energy needed to start the reaction — this has to be supplied, e.g. by heating the reaction mixture.

1) This shows an endothermic reaction because the products are at a higher energy than the reactants.
2) The difference in height represents the overall energy change during the reaction (the energy taken in) per mole.



There's more on activation energy and collision theory on pages 142-143.

Energy transfer — make sure you take it all in...

Don't get confused by these diagrams. In an exothermic reaction the particles release energy to their surroundings — even though the reaction mixture gets warmer, the particles themselves have lost energy.

Q1 Here is the equation for the combustion of methane in air: $CH_{4(g)} + 2O_{2(g)} \rightarrow CO_{2(g)} + 2H_2O_{(g)}$
Draw a reaction profile for this reaction. [3 marks]

Q1 Video Solution

Bond Energies

So you know that chemical reactions can take in or release energy — this page is about what causes these energy changes. Hint — it's all to do with making and breaking chemical bonds.

Energy Must Always be Supplied to Break Bonds

There's more on energy transfer on page 138.

1) During a chemical reaction, old bonds are broken and new bonds are formed.
2) Energy must be supplied to break existing bonds — so bond breaking is an endothermic process.
3) Energy is released when new bonds are formed — so bond formation is an exothermic process.

BOND BREAKING — ENDOTHERMIC

BOND FORMING — EXOTHERMIC

4) In exothermic reactions the energy released by forming bonds is greater than the energy used to break them. In endothermic reactions the energy used to break bonds is greater than the energy released by forming them.

Bond Energy Calculations — Need to be Practised


Bond forming

Every chemical bond has a particular bond energy associated with it. This bond energy varies slightly depending on the compound the bond occurs in. You can use these known bond energies to calculate the overall energy change for a reaction. The overall energy change is the sum of the energies needed to break bonds in the reactants minus the energy released when the new bonds are formed in the products. You need to practise a few of these, but the basic idea is really very simple...

EXAMPLE

Using the bond energies given below, calculate the energy change for the reaction between H_2 and Cl_2 forming HCl:

The bond energies you need are: H–H: +436 kJ/mol; Cl–Cl: +242 kJ/mol; H–Cl: +431 kJ/mol.

1) Find the energy required to break the original bonds:
   (1 × H–H) + (1 × Cl–Cl) = 436 kJ/mol + 242 kJ/mol = 678 kJ/mol
2) Find the energy released by forming the new bonds.
   2 × H–Cl = 2 × 431 kJ/mol = 862 kJ/mol
3) Find the overall energy change for the reaction using this equation:
   Overall energy change = energy required to break bonds – energy released by forming bonds
   = 678 kJ/mol – 862 kJ/mol = –184 kJ/mol

You can't compare the overall energy changes of reactions unless you know the numerical differences in the bond energies.

Chlorine and bromine react with hydrogen in a similar way. Br–Br bonds are weaker than Cl–Cl bonds and H–Br bonds are weaker than H–Cl bonds. So less energy is needed to break the bonds in the reaction with bromine, but less energy is released when the new bonds form. So unless you know the exact difference, you can't say which reaction releases more energy.

A student and their bed — a bond that can never be broken...

This stuff might look hard at the moment, but with a bit of practice it's dead easy and it'll win you easy marks if you understand all the theory behind it. See how you get on with this question:

Q1 Video Solution

Q1 N_2 reacts with H_2 in the following reaction: $N_2 + 3H_2 \rightarrow 2NH_3$
The bond energies for these molecules are:
N≡N: 941 kJ/mol; H–H: 436 kJ/mol; N–H: 391 kJ/mol.
Calculate the overall energy change for this reaction.

[3 marks]

Revision Questions for Topic C5

Let's see how much you can remember — flick back if you get stuck.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quiz for Topic C5 — just scan this QR code!

Topic C5 Quiz

Exothermic and Endothermic Reactions (p.138-139)

1) In an exothermic reaction is heat transferred to or from the surroundings?
2) Name two different types of reaction which are exothermic.
3) Define what is meant by an endothermic reaction.
4) Write down the equation for the thermal decomposition of calcium carbonate.
5) What is the purpose of putting the reaction container into a beaker containing cotton wool during an experiment to investigate the temperature change of an exothermic reaction?
6) Sketch an energy level diagram for an endothermic reaction.
7) What is the activation energy of a reaction?
8) Is the following statement true or false? In an endothermic reaction, the products of the reaction have more energy than the reactants.

Bond Energies (p.140)

9) For the following sentences, use either endothermic or exothermic to fill in the blanks:
   a) Bond breaking is an __________ process.
   b) Bond forming is an __________ process.
   c) In an __________ reaction, the energy released by forming bonds is greater than the energy used to break them.
10) What three steps would you use to find the overall energy change in a reaction if you were given the known bond enthalpies for the bonds present in the reactants and products?

Rates of Reaction

Rates of reaction are pretty important. In the chemical industry, the faster you make chemicals, the faster you make money (and the faster everyone gets to go home for tea).

Reactions Can Go at All Sorts of Different Rates

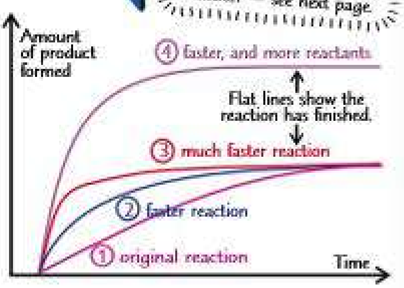
1) The rate of a chemical reaction is how fast the reactants are changed into products.
2) One of the slowest is the rusting of iron (it's not slow enough though — what about my little Mini).
3) Other slow reactions include chemical weathering — like acid rain damage to limestone buildings.
4) An example of a moderate speed reaction would be the metal magnesium reacting with an acid to produce a gentle stream of bubbles.
5) Burning is a fast reaction, but explosions are even faster and release a lot of gas. Explosive reactions are all over in a fraction of a second.

You Need to Understand Graphs for the Rate of Reaction

1) You can find the speed of a reaction by recording the amount of product formed, or the amount of reactant used up over time (see page 144).
2) The steeper the line on the graph, the faster the rate of reaction. Over time the line becomes less steep as the reactants are used up.
3) The quickest reactions have the steepest lines and become flat in the least time.
4) The plot below uses the amount of product formed over time to show how the speed of a particular reaction varies under different conditions.

For more on the conditions that affect the rate of reaction — see next page.

- Graph 1 represents the original reaction.
- Graphs 2 and 3 represent the reaction taking place quicker, but with the same initial amounts of reactants. The slopes of the graphs are steeper than for graph 1.
- Graphs 1, 2 and 3 all converge at the same level, showing that they all produce the same amount of product although they take different times to produce it.
- Graph 4 shows more product and a faster reaction. This can only happen if more reactant(s) are added at the start.



Particles Must Collide with Enough Energy in Order to React

Reaction rates are explained perfectly by collision theory. It's simple really.
The rate of a chemical reaction depends on:

1) The collision frequency of reacting particles (how often they collide). The more collisions there are the faster the reaction is. E.g. doubling the frequency of collisions doubles the rate.
2) The energy transferred during a collision. Particles have to collide with enough energy for the collision to be successful.

A successful collision is a collision that ends in the particles reacting to form products.

You might remember from page 139 that the minimum amount of energy that particles need to react is called the activation energy. Particles need this much energy to break the bonds in the reactants and start the reaction.

Factors that increase the number of collisions (so that a greater proportion of reacting particles collide) or the amount of energy particles collide with will increase the rate of the reaction (see next page for more).

Get a fast, furious reaction — tickle your teacher...

Collision theory's essential for understanding how different factors affect the rate of reaction — so make sure you understand it before moving on to the rest of Topic C6.

Q1 What is meant by the term activation energy? [1 mark]

Factors Affecting Rates of Reaction

I'd ask you to guess what this page is about, but the title pretty much says it all really. Read on...

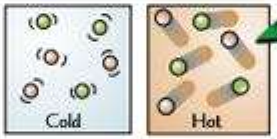
The Rate of Reaction Depends on Four Things

1) Temperature.
2) The concentration of a solution or the pressure of gas.
3) Surface area — this changes depending on the size of the lumps of a solid.
4) The presence of a catalyst.

More Collisions Increases the Rate of Reaction

All four methods of increasing the rate of a reaction can be explained in terms of increasing the number of successful collisions between the reacting particles:

Increasing the Temperature Increases the Rate

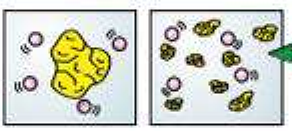


1) When the temperature is increased, the particles all move faster.
2) If they're moving faster, they're going to collide more frequently.
3) Also the faster they move the more energy they have, so more of the collisions will have enough energy to make the reaction happen.

Increasing the Concentration or Pressure Increases the Rate

1) If a solution is made more concentrated, it means there are more particles knocking about in the same volume of water (or other solvent).
2) Similarly, when the pressure of a gas is increased, it means that the same number of particles occupies a smaller space.
3) This makes collisions between the reactant particles more frequent.

Increasing the Surface Area Increases the Rate

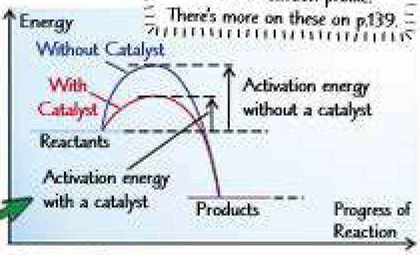


1) If one of the reactants is a solid, then breaking it up into smaller pieces will increase its surface area to volume ratio.
2) This means that for the same volume of the solid, the particles around it will have more area to work on — so there will be collisions more frequently.

Using a Catalyst Increases the Rate

1) A catalyst is a substance that speeds up a reaction, without being used up in the reaction itself. This means it's not part of the overall reaction equation.
2) Different catalysts are needed for different reactions, but they all work by decreasing the activation energy needed for the reaction to occur. They do this by providing an alternative reaction pathway with a lower activation energy.
3) Enzymes are biological catalysts — they catalyse reactions in living things.

This is a reaction profile. There's more on these on p.139.



Increase your concentration — burn through that exam paper...

Catalysts are really useful — they don't get used up so you can use them over and over again. Brilliant.

Q1 For each of the following pairs of reactions, state which one would have the fastest rate (A or B) and why:
a) A: A 2 g solid strip of magnesium with water. B: 2 g of powdered magnesium with water. [2 marks]
b) A: 2 mol/dm^3 HCl with excess ethanoic acid. B: 4 mol/dm^3 HCl with excess ethanoic acid. [2 marks]

PRACTICAL Measuring Rates of Reaction

All this talk about rates of reactions is fine and dandy, but it's no good if you can't measure it.

Here Are Three Ways to Measure the Rate of a Reaction

The rate of a reaction can be observed either by how quickly the reactants are used up or how quickly the products are formed:

$$\text{Rate of Reaction} = \frac{\text{Amount of reactant used or amount of product formed}}{\text{Time}}$$

This is the mean rate of reaction. To find the rate of a reaction at a particular time, you'll need to plot a graph and find the gradient at that time (see page 146).

When the product or reactant is a gas you usually measure the amount in cm^3. If it's a solid, then you use grams (g). Time is often measured in seconds (s). This means that the units for rate may be in cm^3/s or in g/s. You can also measure the amount of product or reactant in moles — so the units of rate could also be mol/s. Here are three different ways of measuring the rate of a reaction:

1) Precipitation and Colour Change

1) You can record the visual change in a reaction if the initial solution is transparent and the product is a precipitate which clouds the solution (it becomes opaque).
2) You can observe a mark through the solution and measure how long it takes for it to disappear — the faster the mark disappears, the quicker the reaction.
3) If the reactants are coloured and the products are colourless (or vice versa), you can time how long it takes for the solution to lose (or gain) its colour.
4) The results are very subjective — different people might not agree over the exact point when the mark 'disappears' or the solution changes colour. Also, if you use this method, you can't plot a rate of reaction graph from the results.

A posh way of saying that the cloudiness of a solution changes is to say that its 'turbidity' changes.

2) Change in Mass (Usually Gas Given Off)

1) Measuring the speed of a reaction that produces a gas can be carried out using a mass balance.
2) As the gas is released, the mass disappearing is measured on the balance.
3) The quicker the reading on the balance drops, the faster the reaction.
4) If you take measurements at regular intervals, you can plot a rate of reaction graph and find the rate quite easily (see page 146 for more).
5) This is the most accurate of the three methods described on this page because the mass balance is very accurate. But it has the disadvantage of releasing the gas straight into the room.

3) The Volume of Gas Given Off

1) This involves the use of a gas syringe to measure the volume of gas given off.
2) The more gas given off during a given time interval, the faster the reaction.
3) Gas syringes usually give volumes accurate to the nearest cm^3, so they're quite accurate. You can take measurements at regular intervals and plot a rate of reaction graph using this method too. You have to be quite careful though — if the reaction is too vigorous, you can easily blow the plunger out of the end of the syringe.

OK, have you got your stopwatch ready...*BANG!* — oh...

Make sure you've learnt the three different methods on this page, then have a go at this question:

Q1 The reaction between solid Na_2CO_3 and aqueous HCl releases CO_2 (a gas).
- a) Describe an experiment that would allow you to measure the rate of this reaction. [3 marks]
- b) Suggest units that would be appropriate for expressing the rate of this reaction. [1 mark]

Two Rates Experiments

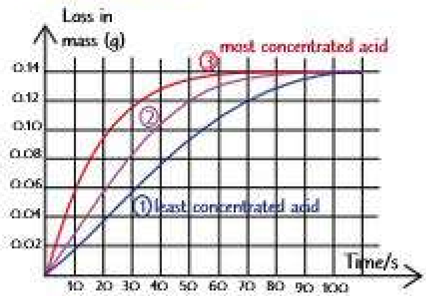
PRACTICAL

Here's a lovely page on practical investigations into the effect of concentration on the rate of a reaction. It's particularly lovely because it's got two methods that you could use. Get your safety goggles on and let's go...

Magnesium and HCl React to Produce H_2 Gas

1) Start by adding a set volume of dilute hydrochloric acid to a conical flask and carefully place on a mass balance.
2) Now add some magnesium ribbon to the acid and quickly plug the flask with cotton wool.
3) Start the stopwatch and record the mass on the balance. Take readings of the mass at regular intervals.

Putting cotton wool in the top of the flask lets the gas escape but stops the acid spitting out.



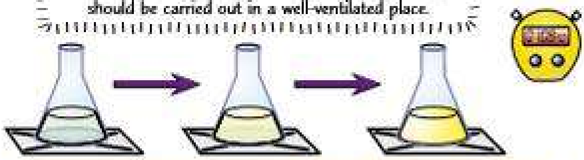
4) Plot the results in a table and work out the mass lost for each reading. Now you can plot a graph with time on the x-axis and loss of mass on the y-axis.
5) Repeat with more concentrated acid solutions. Variables such as the amount of magnesium ribbon and the volume of acid used should be kept the same each time — only change the acid's concentration. This is to make your experiment a fair test — see p.4.
6) The three graphs show that a higher concentration of acid gives a faster rate of reaction.

You could also measure the gas released using a gas syringe, as on the previous page.

Sodium Thiosulfate and HCl Produce a Cloudy Precipitate

1) These two chemicals are both clear solutions. They react together to form a yellow precipitate of sulfur.
2) Start by adding a set volume of dilute sodium thiosulfate to a conical flask.
3) Place the flask on a piece of paper with a black cross drawn on it. Add some dilute HCl to the flask and start the stopwatch.
4) Now watch the black cross disappear through the cloudy sulfur and time how long it takes to go.
5) The reaction can be repeated with solutions of either reactant at different concentrations. (Only change the concentration of one reactant at a time though). The depth of the liquid must be kept the same each time.
6) These results show the effect of increasing the concentration of HCl on the rate of reaction, when added to an excess of sodium thiosulfate.

This reaction releases sulfur dioxide, so the experiment should be carried out in a well-ventilated place.



Concentration of HCl (mol/dm³)	0.5	1	1.5	2	2.5
Time taken for mark to disappear (s)	193	184	178	171	164

7) The higher the concentration, the quicker the reaction and therefore the less time it takes for the mark to disappear.
8) One sad thing about this reaction is that it doesn't give a set of graphs. Well I think it's sad. All you get is a set of readings of how long it took till the mark disappeared for each concentration. Boring.

Although you could draw a graph of concentration against 1/time which will give you an approximate rate.

Bubbling acid, sulfurous clouds — proper witchcraft this is...

You should learn the methods involved in these experiments — but remember, other reactions can also be used to investigate the four factors that affect rate. You might see different experiments in your exams, or the same ones but measuring a different factor — so watch out.

Q1 A student carried out an experiment investigating the effect of changing the HCl concentration on the rate of reaction between HCl and Mg. State two factors that she should have kept constant. [2 marks]

Finding Reaction Rates from Graphs

You might remember a bit about how to interpret graphs on reaction rate from page 142 — well this page shows you how to use them to calculate rates.

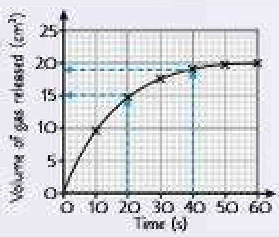
You can Calculate the Mean Reaction Rate from a Graph

1) Remember, a rate of reaction graph shows the amount of product formed or amount of reactant used up on the y-axis and time on the x-axis.
2) So to find the mean rate for the whole reaction, you just work out the overall change in the y-value and then divide this by the total time taken for the reaction.
3) You can also use the graph to find the mean rate of reaction between any two points in time:

EXAMPLE

The graph shows the volume of gas released by a reaction, measured at regular intervals. Find the mean rate of reaction between 20 s and 40 s.

Mean rate of reaction = change in y ÷ change in x
= ($19 \text{ cm}^3 - 15 \text{ cm}^3$) ÷ 20 s.
= $0.2 \text{ cm}^3/\text{s}$



If you're asked to find the mean rate of reaction for the whole reaction, remember that the reaction finishes as soon as the line on the graph goes flat.

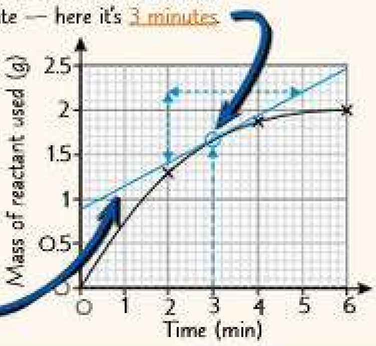
Draw a Tangent to Find the Reaction Rate at a Particular Point

If you want to find the rate of the reaction at a particular point in time, you need to find the gradient (slope) of the curve at that point. The easiest way to do this is to draw a tangent to the curve — a straight line that touches the curve at one point and doesn't cross it. You then work out the gradient of the tangent. It's simpler than it sounds, honest...

EXAMPLE

The graph below shows the mass of reactant used up measured at regular intervals during a chemical reaction. What is the rate of reaction at 3 minutes?

1) Position a ruler on the graph at the point where you want to know the rate — here it's 3 minutes.
2) Adjust the ruler until the space between the ruler and the curve is equal on both sides of the point.
3) Draw a line along the ruler to make the tangent. Extend the line right across the graph.



4) Pick two points on the line that are easy to read. Use them to calculate the gradient of the tangent in order to find the rate:

gradient = change in y ÷ change in x
= (2.2 – 1.4) ÷ (5.0 – 2.0)
= 0.8 ÷ 3.0
= 0.27

So, the rate of reaction at 3 minutes was 0.27 g/min.

Calculate your reaction to this page. Boredom? How dare you...

There's only one way to learn this stuff properly — practise. So you'd better get going with this question.

Q1 Magnesium powder was added to a conical flask containing dilute H_2SO_4.
H_2 was produced and collected in a gas syringe. The volume of gas released was recorded at 10 second intervals in the following table:

Time (s)	10	20	30	40	50	60
Volume of H_2 (cm^3)	18	28	34	38	40	41

a) Plot these results on a graph and draw a line of best fit. [3 marks]
b) Find the rate of the reaction at time = 25 s. [4 marks]

Q1 Video Solution

Reversible Reactions

Some reactions can go backwards. Honestly, that's all you need...

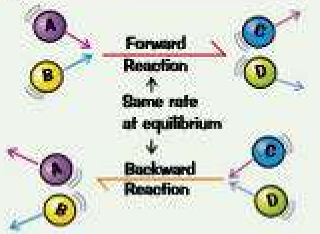
Reversible Reactions Will Reach Equilibrium

The ⇌ shows the reaction goes both ways.

This equation shows a reversible reaction — the products (C and D) can react to form the reactants (A and B) again:

A + B ⇌ C + D

1) As the reactants react, their concentrations fall — so the forward reaction will slow down (see page 143). But as more and more products are made and their concentrations rise, the backward reaction will speed up.
2) After a while the forward reaction will be going at exactly the same rate as the backward one — the system is at equilibrium.
3) At equilibrium, both reactions are still happening, but there's no overall effect (it's a dynamic equilibrium). This means the concentrations of reactants and products have reached a balance and won't change.
4) Equilibrium is only reached if the reversible reaction takes place in a 'closed system'. A closed system just means that none of the reactants or products can escape and nothing else can get in.



The Position of Equilibrium Can be on the Right or the Left

1) When a reaction's at equilibrium it doesn't mean the amounts of reactants and products are equal.
2) If the equilibrium lies to the right, the concentration of products is greater than that of the reactants.
3) If the equilibrium lies to the left, the concentration of reactants is greater than that of the products.
4) The position of equilibrium depends on the following conditions (as well as the reaction itself):
   - the temperature,
   - the pressure (this only affects equilibria involving gases),
   - the concentration of the reactants and products.

E.g. ammonium chloride ⇌ ammonia + hydrogen chloride
Heating this reaction moves the equilibrium to the right (more ammonia and hydrogen chloride) and cooling it moves it to the left (more ammonium chloride).

The next page tells you why these things affect equilibrium position.

Reversible Reactions Can Be Endothermic and Exothermic

1) In reversible reactions, if the reaction is endothermic in one direction, it will be exothermic in the other.
2) The energy transferred from the surroundings by the endothermic reaction is equal to the energy transferred to the surroundings during the exothermic reaction.
3) A good example is the thermal decomposition of hydrated copper sulfate:

See page 138 for more on endothermic and exothermic reactions.

'Anhydrous' just means 'without water', and 'hydrated' means 'with water'.

hydrated copper sulfate ⇌ anhydrous copper sulfate + water
(forward: endothermic; backward: exothermic)

If you heat blue hydrated copper(II) sulfate crystals, it drives the water off and leaves white anhydrous copper(II) sulfate powder. This is endothermic.

If you then add a couple of drops of water to the white powder you get the blue crystals back again. This is exothermic.

Dynamic equilibrium — lots of activity, but not to any great effect.*

Make sure you understand everything on this page before you move on to the next one. Trust me, it'll help.

Q1 What does it mean if a system is at equilibrium? [1 mark]

* Much like the England football team.

Le Chatelier's Principle

Reversible reactions don't like being messed around — so if you change something, the system will respond to undo the change. Sneaky.

Reversible Reactions Try to Counteract Changes...

1) Le Chatelier's Principle is the idea that if you change the conditions of a reversible reaction at equilibrium, the system will try to counteract that change.
2) It can be used to predict the effect of any changes you make to a reaction system.

...Such as Changes to the Temperature...

1) All reactions are exothermic in one direction and endothermic in the other (see previous page).
2) If you decrease the temperature, the equilibrium will move in the exothermic direction to produce more heat. This means you'll get more products for the exothermic reaction and fewer products for the endothermic reaction.
3) If you raise the temperature, the equilibrium will move in the endothermic direction to try and decrease it. You'll now get more products for the endothermic reaction and fewer products for the exothermic reaction.

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

Here the forward reaction is exothermic — a decrease in temperature moves equilibrium to the right (more NH_3).

...Pressure...

1) Changing the pressure only affects an equilibrium involving gases.
2) If you increase the pressure, the equilibrium tries to reduce it — it moves in the direction where there are fewer molecules of gas.
3) If you decrease the pressure, the equilibrium tries to increase it — it moves in the direction where there are more molecules of gas.
4) You can use the balanced symbol equation for a reaction to see which side has more molecules of gas.

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

There are 4 moles on the left (1 of N_2 and 3 of H_2) but only 2 on the right. So, if you increase the pressure, the equilibrium shifts to the right (more NH_3).

...or Concentration

1) If you change the concentration of either the reactants or the products, the system will no longer be at equilibrium.
2) So the system responds to bring itself back to equilibrium again.
3) If you increase the concentration of the reactants the system tries to decrease it by making more products.
4) If you decrease the concentration of products the system tries to increase it again by reducing the amount of reactants.

$N_2 + 3H_2 \rightleftharpoons 2NH_3$

If more N_2 or H_2 is added, the forward reaction increases to produce more NH_3.

An equilibrium is like a particularly stubborn mule...

It's good science this stuff. You do one thing, and the reaction does the other. On the face of it, that sounds like it'd be a pain, but in reality it's what gives you control of what happens in a reversible reaction. And in industry, control is what makes the whole shebang profitable. Mmmm... Money.

Q1 Video Solution

Q1 For each of the following reactions, state the effect of an increase in pressure on the amount of products at equilibrium.

a) $CO_{2(g)} + H_2O_{(l)} \rightleftharpoons H_2CO_{3(aq)}$ [1 mark]

b) $NH_4Cl_{(s)} \rightleftharpoons NH_{3(g)} + HCl_{(g)}$ [1 mark]

c) $2CO_{(g)} + O_{2(g)} \rightleftharpoons 2CO_{2(g)}$ [1 mark]

Revision Questions for Topic C6

You've almost made it — you're one page away from a nice cup of tea...

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quiz for Topic C6 — just scan this QR code!

Topic C6 Quiz

Rates of Reaction and Factors Affecting Them (p.142-143)

1) On a rate of reaction graph, what does the line getting steeper show?
2) What does a flat line on a graph of amount of products against time show?
3) What two factors relating to the collisions between particles influence the rate of a reaction?
4) What are the four factors that affect the rate of a chemical reaction?
5) Why does increasing the temperature of a reaction mixture increase the rate of a reaction?
6) Other than increasing the temperature, describe two ways of increasing the rate of reaction between a solution and a solid.
7) What is a catalyst?
8) How does a catalyst increase the rate of a reaction?

Measuring and Calculating Rates of Reaction (p.144-146)

9) State the equation that could be used to calculate the mean rate of a reaction.
10) Give three possible units for the rate of a chemical reaction.
11) How would you measure the rate of a reaction between two clear solutions, in which the product formed was a precipitate?
12) Explain why measuring a mass change during a reaction is an accurate method of measuring rate.
13) Describe how you could investigate the effect of increasing HCl concentration on the rate of reaction between HCl and Mg.
14) Describe how you could use a graph to find the mean rate of a reaction between two points in time.
15) What is a tangent?
16) How would you use a tangent to find the gradient of a curve at a particular point?

Reversible Reactions and Le Chatelier's Principle (p.147-148)

17) Which one of the following statements is true?
    a) In a reaction at equilibrium, there is the same amount of products as reactants.
    b) If the forward reaction in a reversible reaction is exothermic, then the reverse reaction is endothermic.
    c) If the equilibrium of a system lies to the right, then the concentration of products is less than the concentration of reactants.
18) What effect will decreasing the temperature have on a reversible reaction in which the forward reaction is exothermic?
19) How can you predict the effect of changing the pressure of a gaseous reaction?
20) According to Le Chatelier's Principle, what will the effect of decreasing the concentration of the products for the forward reaction have on a reversible reaction?

Hydrocarbons

Organic chemistry is about compounds that contain carbon. Hydrocarbons are the simplest organic compounds. As you're about to discover, the properties of hydrocarbons make them really useful.

Hydrocarbons Only Contain Hydrogen and Carbon Atoms

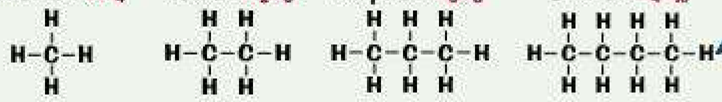
A hydrocarbon is any compound that is formed from carbon and hydrogen atoms only.
So $C_{10}H_{22}$ (decane, an alkane) is a hydrocarbon, but $CH_3COOC_3H_7$ (an ester) is not — it contains oxygen.

Alkanes Have All C–C Single Bonds

1) Alkanes are the simplest type of hydrocarbon you can get. They have the general formula C_nH_{2n+2}.
2) The alkanes are a homologous series — a group of organic compounds that react in a similar way.
3) Alkanes are saturated compounds — each carbon atom forms four single covalent bonds.
4) The first four alkanes are methane, ethane, propane and butane.

A drawing showing all the atoms and bonds in a molecule is called a displayed formula.

Methane: CH_4 Ethane: C_2H_6 Propane: C_3H_8 Butane: C_4H_{10}



Hydrocarbon Properties Change as the Chain Gets Longer

As the length of the carbon chain changes, the properties of the hydrocarbon change.

1) The shorter the carbon chain, the more runny a hydrocarbon is — that is, the less viscous (gloopy) it is.
2) Hydrocarbons with shorter carbon chains are also more volatile, i.e. they have lower boiling points.
3) Also, the shorter the carbon chain, the more flammable (easier to ignite) the hydrocarbon is.
4) The properties of hydrocarbons affect how they're used for fuels. E.g. short chain hydrocarbons with lower boiling points are used as 'bottled gases' — stored under pressure as liquids in bottles.

Complete Combustion Occurs When There's Plenty of Oxygen

1) The complete combustion of any hydrocarbon in oxygen releases lots of energy. The only waste products are carbon dioxide and water vapour.

hydrocarbon + oxygen → carbon dioxide + water (+ energy)

Oxidation can be defined as the gain of oxygen.

2) During combustion, both carbon and hydrogen from the hydrocarbon are oxidised.
3) Hydrocarbons are used as fuels due to the amount of energy released when they combust completely.
4) You need to be able to give a balanced symbol equation for the complete combustion of a simple hydrocarbon fuel when you're given its molecular formula. It's pretty easy — here's an example:

See p.99 for more on balancing equations.

EXAMPLE Write a balanced equation for the complete combustion of methane (CH_4).

1) On the left hand side, there's one carbon atom, so only one molecule of CO_2 is needed to balance this. $CH_4 + ?O_2 \rightarrow CO_2 + ?H_2O$
2) On the left hand side, there are four hydrogen atoms, so two water molecules are needed to balance them. $CH_4 + ?O_2 \rightarrow CO_2 + 2H_2O$
3) There are four oxygen atoms on the right hand side of the equation. Two oxygen molecules are needed on the left to balance them. $CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$

The name's bond — single covalent bond...

So hydrocarbons only contain two ingredients — carbon and hydrogen. Jamie Oliver would not be happy.

Q1 Write a balanced symbol equation for the complete combustion of ethane, C_2H_6. [2 marks]

Q1 Video Solution

Q2 Robyn has two alkanes, C_5H_{12} and $C_{10}H_{22}$. Compare the following properties of the alkanes:
a) viscosity b) boiling point c) flammability [3 marks]

Fractional Distillation

Crude oil can be used to make loads of useful things, such as fuels. But you can't just put crude oil in your car. First, the different hydrocarbons have to be separated. That's where fractional distillation comes in.

Crude Oil is Made Over a Long Period of Time

1) Crude oil is a fossil fuel. It's formed from the remains of plants and animals, mainly plankton, that died millions of years ago and were buried in mud. Over millions of years, with high temperature and pressure, the remains turn to crude oil, which can be drilled up from the rocks where it's found.
2) Fossil fuels like coal, oil and gas are called non-renewable fuels as they take so long to make that they're being used up much faster than they're being formed. They're finite resources (see p.161) — one day they'll run out.

Fractional Distillation can be Used to Separate Hydrocarbon Fractions

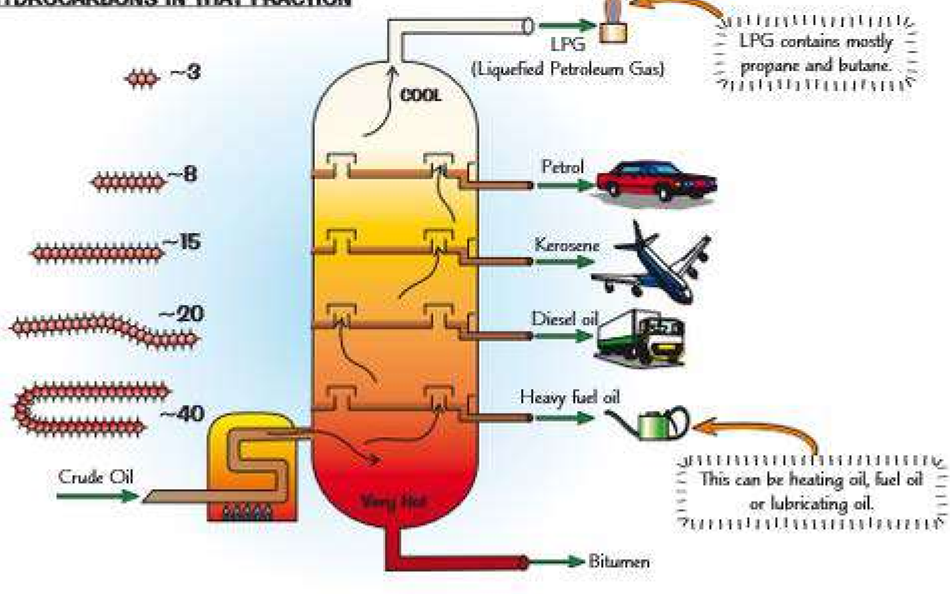
Crude oil is a mixture of lots of different hydrocarbons, most of which are alkanes. The different compounds in crude oil are separated by fractional distillation.

Hydrocarbons are molecules containing only hydrogen and carbon.

Here's how it works:

1) The oil is heated until most of it has turned into gas. The gases enter a fractionating column (and the liquid bit is drained off).
2) In the column there's a temperature gradient (it's hot at the bottom and gets cooler as you go up).
3) The longer hydrocarbons have high boiling points. They condense back into liquids and drain out of the column early on, when they're near the bottom. The shorter hydrocarbons have lower boiling points. They condense and drain out much later on, near to the top of the column where it's cooler.
4) You end up with the crude oil mixture separated out into different fractions. Each fraction contains a mixture of hydrocarbons that all contain a similar number of carbon atoms, so have similar boiling points.

APPROXIMATE NUMBER OF CARBONS IN THE HYDROCARBONS IN THAT FRACTION



How much petrol is there in crude oil? Just a fraction...

Make sure you understand how fractional distillation works — it might just save your life... OK, maybe not.

Q1 Petrol drains further up a fractionating column than diesel. Use the diagram of the fractionating column to explain why the boiling point of petrol is lower than that of diesel. [1 marks]

Q2 Describe the temperature gradient in a fractionating column used for fractional distillation. [1 mark]

Q1 Video Solution

Uses and Cracking of Crude Oil

Crude oil has fuelled modern civilisation — it would be a very different world if we hadn't discovered oil.

Crude Oil has Various Uses Important in Modern Life

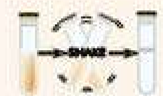
1) Oil provides the fuel for most modern transport — cars, trains, planes, the lot. Diesel oil, kerosene, heavy fuel oil and LPG (liquid petroleum gas) all come from crude oil.
2) The petrochemical industry uses some of the hydrocarbons from crude oil as a feedstock to make new compounds for use in things like polymers, solvents, lubricants, and detergents.
3) All the products you get from crude oil are examples of organic compounds (compounds containing carbon atoms). The reason you get such a large variety of products is because carbon atoms can bond together to form different groups called homologous series. These groups contain similar compounds with many properties in common. Alkanes and alkenes are both examples of homologous series.

Cracking Means Splitting Up Long–Chain Hydrocarbons

1) Short-chain hydrocarbons are flammable so make good fuels and are in high demand. However, long-chain hydrocarbons form thick gloopy liquids like tar which aren't all that useful, so...
2) ...a lot of the longer alkane molecules produced from fractional distillation are turned into smaller, more useful ones by a process called cracking.
3) Some of the products of cracking are useful as fuels, e.g. petrol for cars and paraffin for jet fuel.
4) As well as alkanes, cracking also produces another type of hydrocarbon called alkenes. Alkenes are a lot more reactive than alkanes. They're used as a starting material when making lots of other compounds and can be used to make polymers.

Bromine water can be used to test for alkenes:

1) When orange bromine water is added to an alkane, no reaction will happen and it'll stay bright orange.
2) If it's added to an alkene the bromine reacts with the alkene to make a colourless compound — so the bromine water is decolourised.

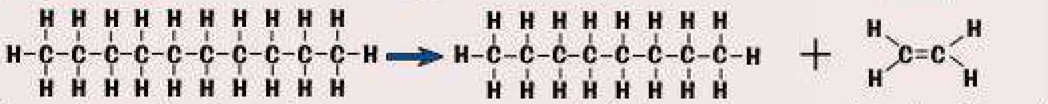


There are Different Methods of Cracking

1) Cracking is a thermal decomposition reaction — breaking molecules down by heating them.
2) The first step is to heat long-chain hydrocarbons to vaporise them (turn them into a gas).
3) Then the vapour is passed over a hot powdered aluminium oxide catalyst.
4) The long-chain molecules split apart on the surface of the specks of catalyst — this is catalytic cracking.
5) You can also crack hydrocarbons if you vaporise them, mix them with steam and then heat them to a very high temperature. This is known as steam cracking.

You need to be able to balance chemical equations for cracking. For example:

Long-chain hydrocarbon molecule → Shorter alkane molecule + alkene



E.g. decane (ten C atoms) → octane (eight C atoms) + ethene (two C atoms)

(too much of this in crude oil) (useful for petrol) (for making plastics)

This page is tough — better get cracking...

We use lots of oil — we're dependent on it for loads of things. So we could be in a proper pickle when it runs out. Just like you could be in a pickle if you don't revise this page. See what I did there? Ahaha...

Q1 Pentane, C_5H_{12}, can be cracked into ethene and one other hydrocarbon. Give the balanced symbol equation for the cracking reaction. [1 mark]

Q1 Video Solution

Purity and Formulations

In an ideal world, every compound a chemist made would be 100% pure. Unfortunately, in the real world it doesn't always work out like that — but luckily, there are ways to find out how pure a substance is.

Purity is Defined Differently in Chemistry to Everyday

1) Usually when you refer to a substance as being pure you mean that nothing has been added to it, so it's in its natural state. For example: pure milk or beeswax.
2) In chemistry, a pure substance is something that only contains one compound or element throughout — not mixed with anything else.

The Boiling or Melting Point Tells You How Pure a Substance Is

1) A chemically pure substance will melt or boil at a specific temperature.
2) You can test the purity of a sample by measuring its melting or boiling point and comparing it with the melting or boiling point of the pure substance (which you can find from a data book).
3) The closer your measured value is to the actual melting or boiling point, the purer your sample is.
4) Impurities in your sample will lower the melting point and increase the melting range of your substance.
5) Impurities in your sample will also increase the boiling point and may result in your sample boiling at a range of temperatures.

Formulations are Mixtures with Exact Amounts of Components

1) Formulations are useful mixtures with a precise purpose that are made by following a 'formula' (a recipe). Each component in a formulation is present in a measured quantity, and contributes to the properties of the formulation so that it meets its required function.

Take a look at p.100 for more on mixtures.

For example, paints are formulations composed of:
- Pigment — gives the paint colour, for example titanium oxide is used as a pigment in white paints.
- Solvent — used to dissolve the other components and alter the viscosity.
- Binder (resin) — forms a film that holds the pigment in place after it's been painted on.
- Additives — added to further change the physical and chemical properties of the paint.

Depending on the purpose of the paint, the chemicals used and their amounts will be changed so the paint produced is right for the job.

2) Formulations are really important in the pharmaceutical industry. For example, by altering the formulation of a pill, chemists can make sure it delivers the drug to the correct part of the body at the right concentration, that it's consumable and has a long enough shelf life.
3) In everyday life, formulations can be found in cleaning products, fuels, cosmetics, fertilisers, metal alloys and even food and drink.
4) When you buy a product, you might find that it has information about its composition on the packaging. For example, the ratio or percentage of each component. This tells you the product's a formulation. It also lets you choose a formulation with the right composition for your particular use.

Cake and tea are key to the revision success formula...

Knowing how pure a product is can be vital in industries such as pharmaceuticals and the food industry. Luckily for us, chemists have lots of different ways to make sure they're making exactly what they want.

Q1 The melting point of a sample of aspirin made by a student is measured as being between 128-132 °C. The melting point and boiling point of pure aspirin are 136 °C and 140 °C respectively.

a) Give two reasons why the melting point measured shows that the sample is not pure. [2 marks]

b) Suggest a value for the boiling point of the sample. [1 mark]

Paper Chromatography

You met chromatography on page 100. Now it's time to see how it works. Careful — things might get crazy...

Chromatography uses Two Phases

Chromatography is an analytical method used to separate the substances in a mixture. You can then use it to identify the substances. There are different types of chromatography, but they all have two 'phases':

- A mobile phase — where the molecules can move. This is always a liquid or a gas.
- A stationary phase — where the molecules can't move. This can be a solid or a really thick liquid.

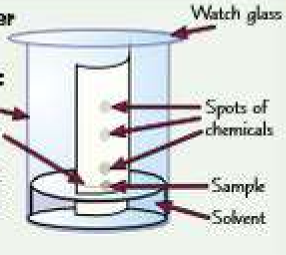
1) During a chromatography experiment, the substances in the sample constantly move between the mobile and the stationary phases — an equilibrium is formed between the two phases.
2) The mobile phase moves through the stationary phase, and anything dissolved in the mobile phase moves with it. How quickly a chemical moves depends on how it's 'distributed' between the two phases — whether it spends more time in the mobile phase or the stationary phase.
3) The chemicals that spend more time in the mobile phase than the stationary phase will move further.
4) The components in a mixture will normally separate through the stationary phase, so long as all the components spend different amounts of time in the mobile phase. The number of spots may change in different solvents as the distribution of the chemical will change depending on the solvent. A pure substance will only ever form one spot in any solvent as there is only one substance in the sample.

During paper chromatography the stationary phase is the chromatography paper (often filter paper) and the mobile phase is the solvent (e.g ethanol or water). The amount of time the molecules spend in each phase depends on two things:

- How soluble they are in the solvent.
- How attracted they are to the paper.

Molecules with a higher solubility in the solvent, and which are less attracted to the paper, will spend more time in the mobile phase — and they'll be carried further up the paper.

The method for carrying out paper chromatography is on p.100.



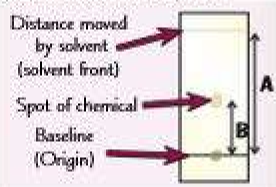
You can Calculate the R_f Value for Each Chemical

PRACTICAL

1) The result of chromatography analysis is called a chromatogram.
2) An R_f value is the ratio between the distance travelled by the dissolved substance (the solute) and the distance travelled by the solvent. The further through the stationary phase a substance moves, the larger the R_f value. You can calculate R_f values using the formula:

$$R_f = \frac{\text{distance travelled by substance (B)}}{\text{distance travelled by solvent (A)}}$$

This is the distance from the baseline to the centre of the spot.



3) Chromatography is often carried out to see if a certain substance is present in a mixture. To do this, you run a pure sample of that substance (a reference) alongside the unknown mixture. If the R_f values of the reference and one of the spots in the mixture match, the substance may be present (although you haven't yet proved they're the same).
4) The R_f value is dependent on the solvent — if you change the solvent the R_f value for a substance will change. You can test both the mixture and the reference in a number of different solvents. If the R_f value of the reference compound matches the R_f value of one of the spots in the mixture in all the solvents, then it's likely the reference compound is present in the mixture. If the spots in the mixture and the spot in the reference only have the same R_f value in some of the solvents, then the reference compound isn't present in the mixture.

Chromatography revision — a phase you have to get through...

You can't see the chemicals moving between the two phases, but it does happen. You just have to trust me.

Q1 A spot on a chromatogram moved 6.3 cm from the baseline. The solvent front moved 8.4 cm. Calculate the R_f value. [1 mark]

Q1 Video Solution

Tests for Gases

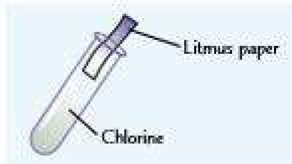
PRACTICAL

Ahh... tests, glorious tests. Luckily, these aren't the kind of tests you have to revise for, but you should probably revise these tests for your exam — it's swings and roundabouts really...

There are Tests for 4 Common Gases

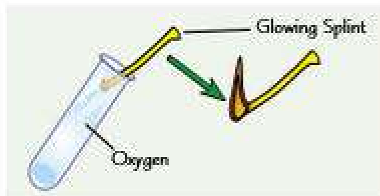
1) Chlorine

Chlorine bleaches damp litmus paper, turning it white. (It may turn red for a moment first though — that's because a solution of chlorine is acidic.)



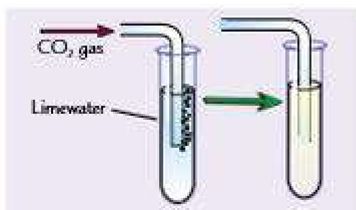
2) Oxygen

If you put a glowing splint inside a test tube containing oxygen, the oxygen will relight the glowing splint.



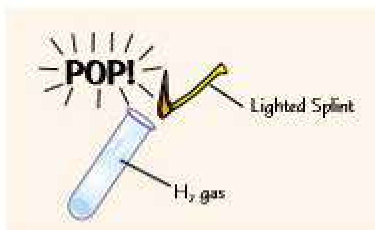
3) Carbon Dioxide

Bubbling carbon dioxide through (or shaking carbon dioxide with) an aqueous solution of calcium hydroxide (known as limewater) causes the solution to turn cloudy.



4) Hydrogen

If you hold a lit splint at the open end of a test tube containing hydrogen, you'll get a "squeaky pop". (The noise comes from the hydrogen burning quickly with the oxygen in the air to form H_2O.)



Hopefully this page won't be too testing for you...

Tests for gases are brilliant. You might think it's because you get to do a nice experiment to do in class, but I like them because you get to write 'squeaky pop' as a real scientific observation.

Q1 Hadia collects the gas given off during a reaction and bubbles it through limewater. The limewater goes cloudy. Identify the gas produced. [1 mark]

Revision Questions for Topics C7 & C8

Well, that's it for Topics C7 and C8 — I think they were my favourite so far.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quizzes for Topics C7 and C8 — just scan the QR codes!

Hydrocarbons (p.150)

1) What two elements do hydrocarbons contain?
2) What is the general formula for alkanes?
3) Draw the displayed formula of butane.
4) What two waste products form from the complete combustion of hydrocarbons?

Crude Oil (p.151-152)

5) How is crude oil formed?
6) Where are the shortest carbon chains found in the fractional distillation column?
7) Give three products that can be made from crude oil.
8) Why is cracking used?
9) Give a product of cracking that is used for making plastics.
10) What is used to test for alkenes?

Purity, Formulations and Paper Chromatography (p.153-154)

11) What is a formulation?
12) What are the two phases called in chromatography?
13) In paper chromatography, how many spots will a pure substance form on the paper?
14) Give the formula for working out the R_f value of a substance.
15) Would you expect the R_f value of a substance to change if you changed the solvent used in the chromatography experiment?

Tests for Gases (p.155)

16) What colour does litmus paper turn in the presence of chlorine?
17) How can you test if a gas in a test tube is oxygen?

The Evolution of the Atmosphere

Theories for how the Earth's atmosphere evolved have changed a lot over the years — it's hard to gather evidence from such a long time period and from so long ago (4.6 billion years). Here's one idea we've got:

Phase 1 — Volcanoes Gave Out Gases

1) The first billion years of Earth's history were pretty explosive — the surface was covered in volcanoes that erupted and released lots of gases. We think this was how the early atmosphere was formed.
2) The early atmosphere was probably mostly carbon dioxide, with virtually no oxygen. This is quite like the atmospheres of Mars and Venus today.
3) Volcanic activity also released nitrogen, which built up in the atmosphere over time, as well as water vapour and small amounts of methane and ammonia.

Phase 2 — Oceans, Algae and Green Plants Absorbed Carbon Dioxide

1) When the water vapour in the atmosphere condensed, it formed the oceans.
2) Lots of carbon dioxide was removed from the early atmosphere as it dissolved in the oceans. This dissolved carbon dioxide then went through a series of reactions to form carbonate precipitates that formed sediments on the seabed.
3) Green plants and algae evolved and absorbed some of the carbon dioxide so that they could carry out photosynthesis (see below). Later, marine animals evolved. Their shells and skeletons contained carbonates from the oceans.
4) Some of the carbon these organisms took in from the atmosphere and oceans became locked up in rocks and fossil fuels after the organisms died.

- When plants, plankton and marine animals die, they fall to the seabed and get buried by layers of sediment. Over millions of years, they become compressed and form sedimentary rocks, oil and gas — trapping the carbon within them and helping to keep carbon dioxide levels in the atmosphere reduced.
- Things like coal, crude oil and natural gas that are made by this process are called 'fossil fuels'.
- Crude oil and natural gas are formed from deposits of plankton. These fossil fuels form reservoirs under the seabed when they get trapped in rocks.
- Coal is a sedimentary rock made from thick plant deposits.
- Limestone is also a sedimentary rock. It's mostly made of calcium carbonate deposits from the shells and skeletons of marine organisms.

Phase 3 — Green Plants and Algae Produced Oxygen

1) As well as absorbing the carbon dioxide in the atmosphere, green plants and algae produced oxygen by photosynthesis — this is when plants use light to convert carbon dioxide and water into sugars:

$$\text{carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$
$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

2) Algae evolved first — about 2.7 billion years ago. Then over the next billion years or so, green plants also evolved.
3) As oxygen levels built up in the atmosphere over time, more complex life (like animals) could evolve.
4) Eventually, about 200 million years ago, the atmosphere reached a composition similar to what it is today: approximately 80% nitrogen, 20% oxygen and small amounts of other gases (each only makes up less than 1% of the atmosphere), mainly carbon dioxide, noble gases and water vapour.

The atmosphere's evolving — shut the window will you...

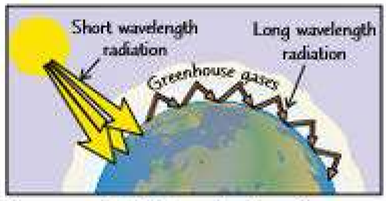
We've learnt about the atmosphere from Antarctic ice cores. Each year, a layer of ice forms with bubbles of air trapped in it. The deeper the ice, the older the air, so examining air in different layers shows us how it's changed.

Q1 Describe how sedimentary rocks are formed. [2 marks]

Greenhouse Gases and Climate Change

Greenhouse gases are important but can also cause problems — it's all about keeping a delicate balance.

Carbon Dioxide is a Greenhouse Gas



1) Greenhouse gases like carbon dioxide, methane and water vapour act like an insulating layer in the Earth's atmosphere — this, amongst other factors, allows the Earth to be warm enough to support life.
2) All particles absorb certain frequencies of radiation. Greenhouse gases don't absorb the incoming short wavelength radiation from the sun — but they do absorb the long wavelength radiation that gets reflected back off the Earth. Then they re-radiate it in all directions — including back towards the Earth. The longwave radiation is thermal radiation, so it results in warming of the surface of the Earth. This is the greenhouse effect.
3) Some forms of human activity affect the amount of greenhouse gases in the atmosphere. E.g:

- Deforestation: fewer trees means less CO_2 is removed from the atmosphere via photosynthesis.
- Burning fossil fuels: carbon that was 'locked up' in these fuels is released as CO_2.
- Agriculture: more farm animals produce more methane through their digestive processes.
- Creating waste: more landfill sites and more waste from agriculture means more CO_2 and methane released by decomposition of waste.

Increasing Carbon Dioxide is Linked to Climate Change

1) The Earth's temperature varies naturally, but recently the average temperature of the Earth's surface has been increasing. Most scientists agree that the extra carbon dioxide from human activity is causing this increase and that this will lead to climate change.
2) Evidence for this has been peer-reviewed (see page 1) — so you know that the information out there is reliable.
3) Unfortunately, it's hard to fully understand the Earth's climate — this is because it's so complex, and there are so many variables, that it's very hard to make a model that isn't oversimplified.
4) This has led to speculation, particularly in the media — where stories may be biased or only some of the information given.

See page 2 for more on science in the media.

Climate Change Could Have Dangerous Consequences

The Earth's climate is complex, but it's still important to make predictions about the consequences of climate change so that policy-makers can make decisions now. For example:

1) An increase in global temperature could lead to polar ice caps melting — causing a rise in sea levels, increased flooding in coastal areas and coastal erosion.
2) Changes in rainfall patterns (the amount, timing and distribution) may cause some regions to get too much or too little water. This, along with changes in temperature, may affect the ability of certain regions to produce food.
3) The frequency and severity of storms may also increase.
4) Changes in temperature and the amount of water available in a habitat may affect wild species, leading to differences in their distribution.

Problems, problems — there's always summat goin' wrong...

Everyone's talking about climate change these days — it's pretty scary stuff, so make sure you get it.

Q1 Describe the greenhouse effect and how it affects global temperature. [4 marks]

Q1 Video Solution

Carbon Footprints

It's generally accepted that greenhouse gas emissions from human activities is causing climate change. Knowing what leads to a lot of emissions of carbon dioxide could be useful for stopping it happening.

Carbon Footprints are Tricky to Measure

1) Carbon footprints are basically a measure of the amount of carbon dioxide and other greenhouse gases released over the full life cycle of something. That can be a service (e.g. the school bus), an event (e.g. the Olympics), a product (e.g. a toastie maker) — almost anything.
2) Measuring the total carbon footprint of something can be really hard, though — or even impossible.
3) That's because there are so many different factors to consider — for example, you would have to count the emissions released as a result of sourcing all the parts of your toastie maker and in making it, not to mention the emissions produced when you actually use it and finally dispose of it. Eugh, complicated...
4) Still, a rough calculation can give a good idea of what the worst emitters are — so that people can avoid them in the future.

There are Ways of Reducing Carbon Footprints

You can't always measure a carbon footprint exactly, but there are always methods to try and reduce it. Anything that reduces the amount of greenhouse gases (e.g. carbon dioxide or methane) given out by a process will also reduce its carbon footprint. Here are some things that can be done:

- Renewable energy sources or nuclear energy could be used instead of fossil fuels.
- Using more efficient processes could conserve energy and cut waste. Lots of waste decomposes to release methane, so this will reduce methane emissions.
- Governments could tax companies or individuals based on the amount of greenhouse gases they emit — e.g. taxing cars based on the amount of carbon dioxide they emit over a set distance could mean that people choose to buy ones that are more fuel-efficient and so less polluting.
- Governments can also put a cap on emissions of all greenhouse gases that companies make — then sell licences for emissions up to that cap.
- There's also technology that captures the CO_2 produced by burning fossil fuels before it's released into the atmosphere — it can then be stored deep underground in cracks in the rock such as old oil wells.

But Making Reductions is Still Difficult

1) It's easy enough saying that we should cut emissions, but actually doing it — that's a different story.
2) For a start, there's still a lot of work to be done on alternative technologies that result in lower CO_2 emissions.
3) A lot of governments are also worried that making these changes will impact on the economic growth of communities — which could be bad for people's well-being. This is particularly important for countries that are still developing.
4) Because not everyone is on board, it's hard to make international agreements to reduce emissions. Most countries don't want to sacrifice their economic development if they think that others won't do the same.
5) It's not just governments, though — individuals in developed countries need to make changes to their lifestyles. But it might be hard to get people to make changes if they don't want to and if there isn't enough education provided about why the changes are necessary and how to make them.

Who has the biggest carbon footprint then? Clowns of course...

Carbon footprints are a game of 'fortunately/unfortunately'. Unfortunately, carbon emissions can lead to global warming. Fortunately, there are steps we can take to cut our carbon dioxide emissions. Unfortunately, not everyone's on board. Fortunately, as time goes on, people are doing more to reduce their emissions. And so on...

Q1 State two things governments can do to try to reduce the greenhouse gas emissions of businesses. [2 marks]

Air Pollution

Increasing carbon dioxide is causing climate change. But CO_2 isn't the only gas released when fossil fuels burn — you also get other nasties like oxides of nitrogen, sulfur dioxide and carbon monoxide.

Combustion of Fossil Fuels Releases Gases and Particles

Hydrocarbons are compounds that only contain hydrogen and carbon (see page 150).

1) Fossil fuels, such as crude oil and coal, contain hydrocarbons. During combustion, the carbon and hydrogen in these compounds are oxidised so that carbon dioxide and water vapour are released into the atmosphere.
2) When there's plenty of oxygen, all the fuel burns — this is called complete combustion.
3) If there's not enough oxygen, some of the fuel doesn't burn — this is called incomplete combustion. Under these conditions, solid particles (called particulates) of soot (carbon) and unburnt fuel are released and carbon monoxide can be produced as well as carbon dioxide.
4) Particulates in the air can cause all sorts of problems:
   - If particulates are inhaled, they can get stuck in the lungs and cause damage. This can then lead to respiratory problems.
   - They're also bad for the environment — they themselves, or the clouds they help to produce, reflect sunlight back into space. This means that less light reaches the Earth — causing global dimming.

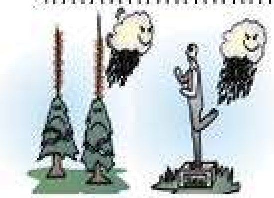
There's more about complete combustion on p.150.

5) It's not just particulates from incomplete combustion that cause problems. Carbon monoxide is pretty nasty too.
   - Carbon monoxide (CO) is really dangerous because it can stop your blood from doing its proper job of carrying oxygen around the body.
   - It does this by binding to the haemoglobin in your blood that normally carries O_2 — so less oxygen is able to be transported round your body.
   - A lack of oxygen in the blood can lead to fainting, a coma or even death.
   - Carbon monoxide doesn't have any colour or smell, so it's very hard to detect. This makes it even more dangerous.

Sulfur Dioxide and Oxides of Nitrogen Can be Released

1) Sulfur dioxide (SO_2) is released during the combustion of fossil fuels, such as coal, that contain sulfur impurities — the sulfur in the fuel becomes oxidised.
2) Nitrogen oxides are created from a reaction between the nitrogen and oxygen in the air, caused by the heat of the burning. (This can happen in the internal combustion engines of cars.)
3) When these gases mix with clouds they form dilute sulfuric acid or dilute nitric acid. This then falls as acid rain.
4) Acid rain kills plants and damages buildings and statues. It also makes metal corrode. It's shocking.
5) Not only that, but sulfur dioxide and nitrogen oxides can also be bad for human health — they cause respiratory problems if they're breathed in.

SO_2 gas reacts with water to form sulfuric acid. You can test for sulfur impurities in a fuel by bubbling the gases from combustion through a solution containing universal indicator — if the fuel contains sulfur, the gases will contain SO_2 which will form sulfuric acid and turn the universal indicator red.



Revision and pollution — the two bugbears of modern life...

Eeee.... cars and fossil fuels — they're nowt but trouble. But at least this topic is kind of interesting, what with its relevance to everyday life and all. Just think... you could see this kind of stuff on TV.

Q1 Name three potential pollutants that could be released as a result of incomplete combustion of hydrocarbons, that wouldn't be released as a result of complete combustion. [3 marks]

Finite and Renewable Resources

There are lots of different resources that humans use to provide energy for things like heating or travelling, as well as for building materials and food. Some of these resources get replaced, some don't.

Natural Resources Come From the Earth, Sea and Air

1) Natural resources form without human input. They include anything that comes from the earth, sea or air. For example, cotton for clothing or oil for fuel.
2) Some of these natural products can be replaced by synthetic products or improved upon by man-made processes. For example, rubber is a natural product that can be extracted from the sap of a tree, however man-made polymers have now been made which can replace rubber in uses such as tyres.
3) Agriculture provides conditions where natural resources can be enhanced for our needs. E.g. the development of fertilisers have meant we can produce a high yield of crops.

Some Natural Resources will Run Out

1) Renewable resources reform at a similar rate to, or faster than, we use them.
2) For example, timber is a renewable resource as trees can be planted following a harvest and only take a few years to regrow. Other examples of renewable resources include fresh water and food.
3) Finite (non-renewable) resources, aren't formed quickly enough to be considered replaceable.
4) Finite resources include fossil fuels and nuclear fuels such as uranium and plutonium. Minerals and metals found in ores in the earth are also non-renewable materials.
5) After they've been extracted, many finite resources undergo man-made processes to provide fuels and materials necessary for modern life. For example, fractional distillation (see p.151) is used to produce usable products such as petrol from crude oil and metal ores are reduced to produce a pure metal (see p.133).

Tables, Charts and Graphs can Give You an Insight Into Different Resources

You may be asked to interpret information about resources in the exam.

EXAMPLE

The table below shows information for two resources, coal and timber. Identify which resource is which.

	Energy Density (MJ/m³)	Time it takes to form
Resource 1	7600-11400	10 years
Resource 2	23000-26000	10^6 years

The time it takes for Resource 1 to reform is 10^5 times shorter than Resource 2 suggesting it is a renewable resource. Resource 1 is also a far less energetic fuel than Resource 2, so is more likely to be timber than coal.

Resource 1 is timber and Resource 2 is coal.

10^6 is a shorthand way of showing 1 000 000. This is because $10^6 = 10 \times 10 \times 10 \times 10 \times 10 \times 10 = 1000000$.

Extracting Finite Resources has Risks

1) Many modern materials are made from raw, finite resources, for example most plastics, metals and building materials.
2) People have to balance the social, economic and environmental effects of extracting finite resources.
3) For example, mining metal ores is good because useful products can be made. It also provides local people with jobs and brings money into the area. However, mining ores is bad for the environment as it uses loads of energy, scars the landscape, produces lots of waste and destroys habitats.

This book is a renewable resource — a gift that keeps on giving...

Unfortunately we can't just run around using every resource we get our hands on — we have to consider the impacts of our actions. If you ever start a major mining project think... What would David Attenborough do?

Q1 Using examples, state the difference between a finite and renewable resource. [2 marks]

Reuse and Recycling

Many materials used in the modern world are limited. Once they're finished with, it's usually far better to recycle them than to use new finite resources which will eventually run out.

Chemistry is Improving Sustainability

1) Sustainable development is an approach to development that takes account of the needs of present society while not damaging the lives of future generations.
2) As you saw on the last page, not all resources are renewable so it's unsustainable to keep using them.
3) As well as using resources, extracting resources can be unsustainable due to the amount of energy used and waste produced. Processing the resources into useful materials, such as glass or bricks, can be unsustainable too, as the processes often use energy that's made from finite resources.
4) One way of reducing the use of finite resources is for people to use less. This doesn't just reduce the use of that resource but also anything needed to produce it.
5) We can't stop using finite resources altogether, but chemists can develop and adapt processes that use lower amounts of finite resources and reduce damage to the environment. For example, chemists have developed catalysts that reduce the amount of energy required for certain industrial processes.

Copper-Rich Ores are in Short Supply

1) Copper is a finite resource. One way to improve its sustainability is by extracting it from low-grade ores (ores without much copper in). Scientists are looking into new ways of doing this:
   - Bioleaching — bacteria are used to convert copper compounds in the ore into soluble copper compounds, separating out the copper from the ore in the process. The leachate (the solution produced by the process) contains copper ions, which can be extracted, e.g. by electrolysis (see p.135) or displacement (see p.134) with a more reactive metal, e.g. scrap iron.
   - Phytomining — this involves growing plants in soil that contains copper. The plants can't use or get rid of the copper so it gradually builds up in the leaves. The plants can be harvested, dried and burned in a furnace. The ash contains soluble copper compounds from which copper can be extracted by electrolysis or displacement using scrap iron.

   These methods can be used to extract other metals too.
2) Traditional methods of copper mining are pretty damaging to the environment. These new methods of extraction have a much smaller impact, but the disadvantage is that they're slow.

Recycling Metals is Important

Recycling is a way to reduce our need for copper rich ores.

1) Mining and extracting metals takes lots of energy, most of which comes from burning fossil fuels.
2) Recycling metals often uses much less energy than is needed to mine and extract new metal, conserves the finite amount of each metal in the earth and cuts down on the amount of waste getting sent to landfill.
3) Metals are usually recycled by melting them and then casting them into the shape of the new product.
4) Depending on what the metal will be used for after recycling, the amount of separation required for recyclable metals can change. For example, waste steel and iron can be kept together as they can both be added to iron in a blast furnace to reduce the amount of iron ore required.

A blast furnace is used to extract iron from its ore at a high temperature using carbon.

Glass can Also be Recycled

Glass recycling can help sustainability by reducing the amount of energy needed to make new glass products, and also the amount of waste created when used glass is thrown away.

1) Glass bottles can often be reused without reshaping.
2) Other forms of glass can't be reused so they're recycled instead. Usually the glass is separated by colour and chemical composition before being recycled.
3) The glass is crushed and then melted to be reshaped for use in glass products such as bottles or jars. It might also be used for a different purpose such as insulating glass wool for wall insulation in homes.

CGP Jokes — 85% recycled since 1996...

Recycling is really handy — as well as saving limited finite materials it also saves energy.

Q1 Give three positive effects of recycling metals. [3 marks]

Life Cycle Assessments

If a company wants to manufacture a new product, they carry out a life cycle assessment (LCA).

Life Cycle Assessments Show Total Environmental Costs

A life cycle assessment (LCA) looks at every stage of a product's life to assess the impact it would have on the environment.

1 Getting the Raw Materials:

1) Extracting raw materials needed for a product can damage the local environment, e.g. mining metals. Extraction can also result in pollution due to the amount of energy needed.
2) Raw materials often need to be processed to extract the desired materials and this often needs large amounts of energy. E.g. extracting metals from ores or fractional distillation of crude oil.

2 Manufacture and Packaging:

1) Manufacturing products and their packaging can use a lot of energy resources and can also cause a lot of pollution, e.g. harmful fumes such as carbon monoxide or hydrogen chloride.
2) You also need to think about any waste products and how to dispose of them. The chemical reactions used to make compounds from their raw materials can produce waste products. Some waste can be turned into other useful chemicals, reducing the amount that ends up polluting the environment.

3 Using the Product:

1) The use of a product can damage the environment. For example, burning fuels releases greenhouse gases and other harmful substances. Fertilisers can leach into streams and rivers causing damage to ecosystems.
2) How long a product is used for or how many uses it gets is also a factor — products that need lots of energy to produce but are used for ages mean less waste in the long run.

4 Product Disposal:

1) Products are often disposed of in landfill sites. This takes up space and pollutes land and water, e.g. if paint washes off a product and gets into rivers.
2) Energy is used to transport waste to landfill, which causes pollutants to be released into the atmosphere.
3) Products might be incinerated (burnt), which causes air pollution.

You Can Compare Life Cycle Assessments for Plastic and Paper Bags

Life Cycle Assessment Stage	Plastic Bag	Paper Bag
Raw Materials	Crude oil	Timber
Manufacturing and Packaging	The compounds needed to make the plastic are extracted from crude oil by fractional distillation, followed by cracking and then polymerisation. Waste is reduced as the other fractions of crude oil have other uses.	Pulped timber is processed using lots of energy. Lots of waste is made.
Using the Product	Can be reused. Can be used for other things as well as shopping, for example bin liners.	Usually only used once.
Product Disposal	Recyclable but not biodegradable and will take up space in landfill and pollute land.	Biodegradable, non-toxic and can be recycled.

Life cycle assessments have shown that even though plastic bags aren't biodegradable, they take less energy to make and have a longer lifespan than paper bags, so may be less harmful to the environment.

There are Problems with Life Cycle Assessments

1) The use of energy, some natural resources and the amount of certain types of waste produced by a product over it's lifetime can be easily quantified. But the effect of some pollutants is harder to give a numerical value to. E.g. it's difficult to apply a value to the negative visual effects of plastic bags in the environment compared to paper ones.
2) So, producing an LCA is not an objective method as it takes into account the values of the person carrying out the assessment. This means LCAs can be biased.
3) Selective LCAs, which only show some of the impacts of a product on the environment can also be biased as they can be written to deliberately support the claims of a company, in order to give them positive advertising.

Need exercise? Go life-cycling then...

In the exam you may be asked to evaluate the use of different materials for a particular product, using an LCA.

Q1 What are the four stages that need to be considered to conduct a life cycle assessment? [4 marks]

Potable Water

We all need safe drinking water. The way that water's made safe depends on local conditions.

Potable Water is Water You Can Drink

1) Potable water is water that's been treated or is naturally safe for humans to drink — it's essential for life.
2) Chemists wouldn't call it pure, though. Pure water only contains H_2O molecules whereas potable water can contain lots of other dissolved substances.
3) The important thing is that the levels of dissolved salts aren't too high, that it has a pH between 6.5 and 8.5 and also that there aren't any nasties (like bacteria or other microbes) swimming around in it.

The Way that Potable Water is Produced Depends on Where You Are

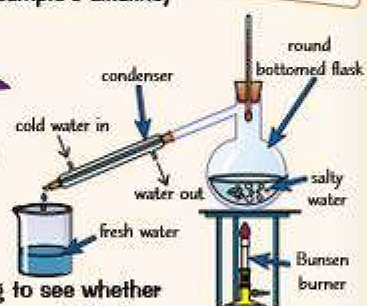
1) Rainwater is a type of fresh water. Fresh water is water that doesn't have much dissolved in it.
2) When it rains, water can either collect as surface water (in lakes, rivers and reservoirs) or as groundwater (in rocks called aquifers that trap water underground).
3) In the UK, the source of fresh water used depends on location. Surface water tends to dry up first, so in warm areas, e.g. the south-east, most of the domestic water supply comes from groundwater.
4) Even though it only has low levels of dissolved substances, water from these fresh water sources still needs to be treated to make it safe before it can be used. This process includes:
   - Filtration — a wire mesh screens out large twigs etc, and then gravel and sand beds filter out any other solid bits.
   - Sterilisation — the water is sterilised to kill any harmful bacteria or microbes. This can be done by bubbling chlorine gas through it or by using ozone or ultraviolet light.

5) In some very dry countries, e.g. Kuwait, there's not enough surface or groundwater and instead seawater must be treated by desalination to provide potable water.
6) Distillation can be used to desalinate seawater.
7) You can test and purify a sample of water in the lab using distillation:

Chemicals can also be added to the water supply, such as fluoride (which is good for teeth). This is controversial, because people aren't given any choice over whether they consume them or not.

PRACTICAL

- First, test the pH of the water using a pH meter. If the pH is too high or too low, you'll need to neutralise it. You do this by adding some acid (if the sample's alkaline) or some alkali (if the sample's acidic) until the pH is 7.
- Set up the equipment as shown in the diagram on the right.
- As the water in the flask heats up, it'll evaporate (become a gas) and will enter the condenser as steam.
- The drop in temperature inside the condenser, due to the cold water around it, will cause the steam to condense back into liquid water.
- Collect the water running out of the condenser in a beaker.
- Retest the pH of the water with a pH meter to check it's neutral.
- You can tell whether there were salts in your initial sample by looking to see whether there are any crystals in the round bottomed flask once the water's been distilled.



8) Seawater can also be treated by processes that use membranes — like reverse osmosis. The salty water is passed through a membrane that only allows water molecules to pass through. Ions and larger molecules are trapped by the membrane so separated from the water.
9) Both distillation and reverse osmosis need loads of energy, so they're really expensive and not practical for producing large quantities of fresh water.

Potable water — nothing to do with gardening...

Distilling salty water could be useful if you ever end up stranded on a desert island. Oh, and for your exams.

Q1 Describe the steps used to treat fresh water to make it potable. [2 marks]

Q1 Video Solution

Waste Water Treatment

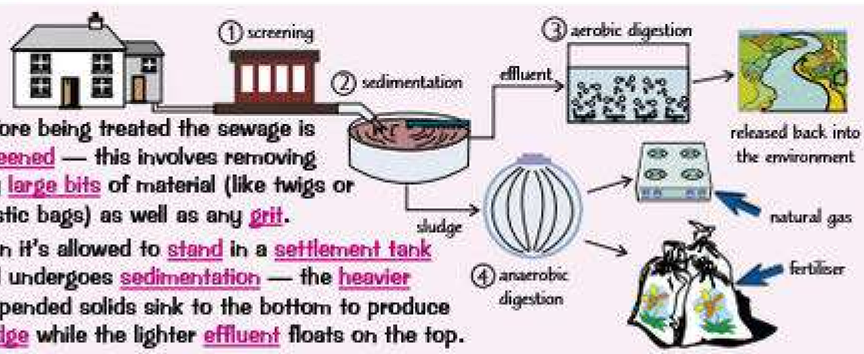
It might not be pretty, but dealing with our waste is really important to ensure that we don't pollute the natural environment — it also means that we can access nice clean water. Super.

Waste Water Comes from Lots of Different Sources

1) We use water for lots of things at home — like having a bath, going to the toilet, doing the washing-up, etc. When you flush this water down the drain, it goes into the sewers and towards sewage treatment plants.
2) Agricultural systems also produce a lot of waste water including nutrient run-off from fields and slurry from animal farms.
3) Sewage from domestic or agricultural sources has to be treated to remove any organic matter and harmful microbes before it can be put back into freshwater sources like rivers or lakes. Otherwise it would make them very polluted and would pose health risks.
4) Industrial processes also produce a lot of waste water that has to be collected and treated.
5) As well as organic matter, industrial waste water can also contain harmful chemicals — so it has to undergo additional stages of treatment before it is safe to release it into the environment.

Sewage Treatment Happens in Several Stages

Some of the processes involved in treating waste water at sewage treatment plants include:



1) Before being treated the sewage is screened — this involves removing any large bits of material (like twigs or plastic bags) as well as any grit.
2) Then it's allowed to stand in a settlement tank and undergoes sedimentation — the heavier suspended solids sink to the bottom to produce sludge while the lighter effluent floats on the top.
3) The effluent in the settlement tank is removed and treated by biological aerobic digestion. This is when air is pumped through the water to encourage aerobic bacteria to break down any organic matter — including other microbes in the water.
4) The sludge from the bottom of the settlement tank is also removed and transferred into large tanks. Here it gets broken down by bacteria in a process called anaerobic digestion.
5) Anaerobic digestion breaks down the organic matter in the sludge, releasing methane gas in the process. The methane gas can be used as an energy source and the remaining digested waste can be used as a fertiliser.
6) For waste water containing toxic substances, additional stages of treatment may involve adding chemicals (e.g. to precipitate metals), UV radiation or using membranes.

Aerobic just means with oxygen, whereas anaerobic means without oxygen.

Sewage treatment requires more processes than treating fresh water but uses less energy than the desalination of salt water, so could be used as an alternative in areas where there's not much fresh water. For example, Singapore is treating waste water and recycling it back into drinking supplies. However, people don't like the idea of drinking water that used to be sewage.

Is it just me, or does this page stink? Phew...

Modern sewage systems have done wonders to make life much less... well... smelly.

Q1 Name and describe the first two stages of waste water treatment at a sewage treatment plant. [2 marks]

Q1 Video Solution

Revision Questions for Topics C9 & C10

That's all for Topics C9 and C10, so here are some questions to try.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quizzes for Topics C9 and C10 — just scan the QR codes!

Topic C9 Quiz

The Evolution of the Atmosphere (p.157)

1) How do scientists think the atmosphere was formed during the first billion years or so of Earth's history?
2) Name five gases that scientists think were present in the early atmosphere.
3) Describe how the levels of carbon dioxide in the atmosphere were reduced.
4) Write the balanced chemical equation for photosynthesis.
5) State the approximate composition of the atmosphere today.

Pollution and Climate Change (p.158-160)

6) Name three greenhouse gases.
7) Explain how the greenhouse effect works to keep the Earth warm.
8) State three ways in which human activity is leading to an increase in carbon dioxide in the atmosphere.
9) What is a carbon footprint?
10) Explain why reducing carbon dioxide emissions can be a difficult issue.
11) Describe how the following air pollutants are produced:
    a) particulates, b) carbon monoxide, c) sulfur dioxide, d) nitrogen oxides.
12) Why is carbon monoxide dangerous?
13) Explain how acid rain forms.
14) State two problems caused by acid rain.

Topic C10 Quiz

Chemistry and Sustainability (p.161-163)

15) Give two examples of renewable resources.
16) Suggest one way in which chemistry is improving sustainability.
17) State two methods that can be used to extract copper from low grade ores.
18) Other than recycling, how can glass bottles be used in a sustainable way?
19) What do life cycle assessments (LCAs) do?
20) Give one problem of life cycle assessments.

Potable Water and Waste Water Treatment (p.164-165)

21) What is potable water?
22) Suggest a source of fresh water.
23) Describe how you could distil seawater in the lab.
24) What other method could you use for making sea water potable?
25) Name three different sources of waste water.
26) Why is it important to treat waste water before releasing it into the environment?
27) What type of waste water could contain harmful chemicals?
28) What two products can be obtained by the anaerobic digestion of sewage sludge?

Energy Stores and Systems

Energy is never used up. Instead it's just transferred between different energy stores and different objects...

Energy is Transferred Between Stores

When energy is transferred to an object, the energy is stored in one of the object's energy stores.

The energy stores you need to know are:

1) Thermal energy stores
2) Kinetic energy stores
3) Gravitational potential energy stores
4) Elastic potential energy stores
5) Chemical energy stores
6) Magnetic energy stores
7) Electrostatic energy stores
8) Nuclear energy stores

Energy is transferred mechanically (by a force doing work), electrically (work done by moving charges), by heating or by radiation (e.g. light, p.220, or sound).

You may also see thermal energy stores called internal energy stores.

When a System Changes, Energy is Transferred

1) A system is just a fancy word for a single object (e.g. the air in a piston) or a group of objects (e.g. two colliding vehicles) that you're interested in.
2) When a system changes, energy is transferred. It can be transferred into or away from the system, between different objects in the system or between different types of energy stores.
3) Closed systems are systems where neither matter nor energy can enter or leave. The net change in the total energy of a closed system is always zero.

Energy can be Transferred by Heating...

1) Take the example of boiling water in a kettle — you can think of the water as the system. Energy is transferred to the water (from the kettle's heating element) by heating, into the water's thermal energy store (causing the temperature of the water to rise).
2) You could also think of the kettle's heating element and the water together as a two-object system. Energy is transferred electrically to the thermal energy store of the kettle's heating element, which transfers energy by heating to the water's thermal energy store.

...or by Doing Work

1) Work done is just another way of saying energy transferred — they're the same thing.
2) Work can be done when current flows (work is done against resistance in a circuit, see p.179) or by a force moving an object (there's more on this on page 203).

The initial force exerted by a person to throw a ball upwards does work. It causes an energy transfer from the chemical energy store of the person's arm to the kinetic energy store of the ball and arm.

A ball dropped from a height is accelerated by gravity. The gravitational force does work. It causes energy to be transferred from the ball's gravitational potential energy store to its kinetic energy store.

The friction between a car's brakes and its wheels does work as it slows down. It causes an energy transfer from the wheels' kinetic energy stores to the thermal energy store of the surroundings.

In a collision between a car and a stationary object, the normal contact force between the car and the object does work. It causes energy to be transferred from the car's kinetic energy store to other energy stores, e.g. the elastic potential and thermal energy stores of the object and the car body. Some energy might also be transferred away by sound waves.

All this work, I can feel my energy stores being drained...

Energy stores pop up everywhere in physics, the pesky scoundrels — make sure you understand them.

Q1 Describe the energy transfers that occur when the wind causes a windmill to spin. [3 marks]

Q1 Video Solution

Kinetic and Potential Energy Stores

Now you've got your head around energy stores, it's time to see how you can calculate the amount of energy in three of the most common ones — kinetic, gravitational potential and elastic potential energy stores.

Movement Means Energy in an Object's Kinetic Energy Store

1) Anything that is moving has energy in its kinetic energy store. Energy is transferred to this store when an object speeds up and is transferred away from this store when an object slows down.
2) The energy in the kinetic energy store depends on the object's mass and speed. The greater its mass and the faster it's going, the more energy there will be in its kinetic energy store.
3) There's a slightly tricky formula for it, so you have to concentrate a little bit harder for this one.

$$E_k = \frac{1}{2}mv^2$$

Kinetic energy (J), Mass (kg), (Speed)^2 (m/s)^2

$\frac{1}{2}mv^2$ means $\frac{1}{2} \times m \times v^2$.

EXAMPLE

A car of mass 2500 kg is travelling at 20 m/s. Calculate the energy in its kinetic energy store.

$E_k = \frac{1}{2} \times 2500 \times 20^2 = 500\ 000$ J

Raised Objects Store Energy in Gravitational Potential Energy Stores

1) Lifting an object in a gravitational field requires work. This causes a transfer of energy to the gravitational potential energy (g.p.e.) store of the raised object. The higher the object is lifted, the more energy is transferred to this store.
2) The amount of energy in a g.p.e. store depends on the object's mass, its height and the strength of the gravitational field the object is in (p.202).
3) You can use this equation to find the change in energy in an object's gravitational potential energy store for a change in height, h.

$$E_p = mgh$$

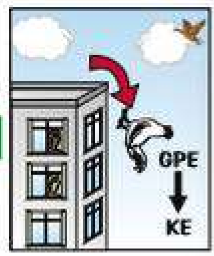
g.p.e (J), Mass (kg), Gravitational field strength (N/kg), Height (m)

Falling Objects Also Transfer Energy

1) When something falls, energy from its gravitational potential energy store is transferred to its kinetic energy store.
2) For a falling object when there's no air resistance:

Energy lost from the g.p.e. store = Energy gained in the kinetic energy store

3) In real life, air resistance (p.210) acts against all falling objects — it causes some energy to be transferred to other energy stores, e.g. the thermal energy stores of the object and surroundings.



Stretching can Transfer Energy to Elastic Potential Energy Stores

Stretching or squashing an object can transfer energy to its elastic potential energy store. So long as the limit of proportionality has not been exceeded (p.205) energy in the elastic potential energy store of a stretched spring can be found using:

$$E_e = \frac{1}{2}ke^2$$

Elastic potential energy (J), Spring constant (N/m), (Extension)^2 (m)^2

Make the most of your potential — jump on your bed...

Wow, that's a lot of energy equations. Make sure you know how to use them, and remember that the energy in an object's kinetic energy store only changes if it's changing its speed. Now have a crack at this question...

Q1 A 2.0 kg object is dropped from a height of 10 m. Calculate the speed of the object after it has fallen 5.0 m, assuming there is no air resistance. Give your answer to 2 significant figures. g = 9.8 N/kg. [5 marks]

Q1 Video Solution

Specific Heat Capacity

Specific heat capacity is really just a sciencey way of saying how hard it is to heat something up...

Different Materials Have Different Specific Heat Capacities

1) More energy needs to be transferred to the thermal energy store of some materials to increase their temperature than others. E.g. you need 4200 J to warm 1 kg of water by 1 °C, but only 139 J to warm 1 kg of mercury by 1 °C.
2) Materials that need to gain lots of energy in their thermal energy stores to warm up also transfer loads of energy when they cool down again. They can 'store' a lot of energy.
3) Specific heat capacity is the amount of energy needed to raise the temperature of 1 kg of a substance by 1 °C.
4) Here's the equation that links energy transferred to specific heat capacity: (the Δ's just mean "change in").

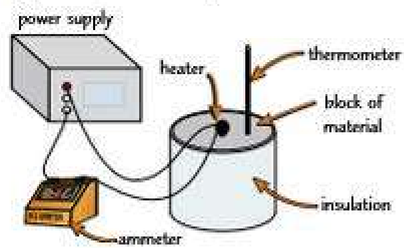
$$\Delta E = mc\Delta\theta$$

Change in thermal energy (J); Mass (kg); Specific heat capacity (J/kg°C); Temperature change (°C)

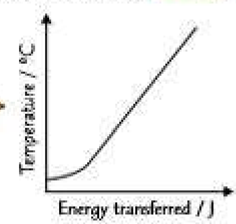
You Can Investigate Specific Heat Capacities

PRACTICAL

1) To investigate a solid material (e.g. copper), you'll need a block of the material with two holes in it (for the heater and thermometer to go into, see below).
2) Measure the mass of the block, then wrap it in an insulating layer (e.g. a thick layer of newspaper) to reduce the energy transferred from the block to the surroundings. Insert the thermometer and heater as shown on the right.



3) Measure the initial temperature of the block and set the potential difference, V, of the power supply to be 10 V. Turn on the power supply and start a stop watch.
4) When you turn on the power, the current in the circuit (i.e. the moving charges) does work on the heater, transferring energy electrically from the power supply to the heater's thermal energy store. This energy is then transferred to the material's thermal energy store by heating, causing the material's temperature to increase.
5) As the block heats up, take readings of the temperature and current, I, every minute for 10 minutes. You should find that the current through the circuit doesn't change as the block heats up.
6) When you've collected enough readings (10 should do it), turn off the power supply. Using your measurement of the current, and the potential difference of the power supply, you can calculate the power supplied to the heater, using $P = VI$ (p.188). You can use this to calculate how much energy, E, has been transferred to the heater at the time of each temperature reading using the formula $E = Pt$, where t is the time in seconds since the experiment began.
7) If you assume all the energy supplied to the heater has been transferred to the block, you can plot a graph of energy transferred to the thermal energy store of the block against temperature. It should look something like this: (you may or may not get the curved bit at the beginning, don't worry about it).



8) Find the gradient of the straight part of the graph. This is $\Delta\theta \div \Delta E$. You know from the equation above that $\Delta E = mc\Delta\theta$. So the specific heat capacity of the material of the block is: 1 ÷ (gradient × the mass of the block).
9) You can repeat this experiment with different materials to see how their specific heat capacities compare.

You can also investigate the specific heat capacity of liquids — just place the heater and thermometer in an insulated beaker filled with a known mass of the liquid.

I've eaten five sausages — I have a high specific meat capacity...

The specific heat capacity equation looks tricky, but like all equations, it's easy to use when you know how.

Q1 Find the final temperature of 5 kg of water, at an initial temperature of 5 °C, after 50 kJ of energy has been transferred to it. The specific heat capacity of water is 4200 J/kg°C. [3 marks]

Q1 Video Solution

Conservation of Energy and Power

Repeat after me: energy is NEVER destroyed. Make sure you learn that fact, it's really important.

You Need to Know the Conservation of Energy Principle

1) The conservation of energy principle is that energy is always conserved:

Energy can be transferred usefully, stored or dissipated, but can never be created or destroyed.

2) When energy is transferred between stores, not all of the energy is transferred usefully into the store that you want it to go to. Some energy is always dissipated when an energy transfer takes place.
3) Dissipated energy is sometimes called 'wasted energy' because the energy is being stored in a way that is not useful (usually energy has been transferred into thermal energy stores).

A mobile phone is a system. When you use the phone, energy is usefully transferred from the chemical energy store of the battery in the phone. But some of this energy is dissipated in this transfer to the thermal energy store of the phone (you may have noticed your phone feels warm if you've been using it for a while).

4) You also need to be able to describe energy transfers for closed systems:

A cold spoon is dropped into an insulated flask of hot soup, which is then sealed. You can assume that the flask is a perfect thermal insulator so the spoon and the soup form a closed system. Energy is transferred from the thermal energy store of the soup to the useless thermal energy store of the spoon (causing the soup to cool down slightly). Energy transfers have occurred within the system, but no energy has left the system — so the net change in energy is zero, p.167.

Power is the 'Rate of Doing Work' — i.e. How Much per Second

1) Power is the rate of energy transfer, or the rate of doing work.
2) Power is measured in watts. One watt = 1 joule of energy transferred per second.
3) You can calculate power using these equations:

$$P = \frac{E}{t}$$

Power (W), Energy transferred (J), Time (s)

$$P = \frac{W}{t}$$

Power (W), Work done (J), Time (s)

4) A powerful machine is not necessarily one which can exert a strong force (although it usually ends up that way). A powerful machine is one which transfers a lot of energy in a short space of time.

Take two cars that are identical in every way apart from the power of their engines. Both cars race the same distance along a straight race track to a finish line. The car with the more powerful engine will reach the finish line faster than the other car — i.e. it will transfer the same amount of energy but over less time.

EXAMPLE

It takes 8000 J of work to lift a stunt performer to the top of a building. Motor A can lift the stunt performer to the correct height in 50 s. Motor B would take 300 s to lift the performer to the same height. Which motor is most powerful? Calculate the power of this motor.

1) Both motors transfer the same amount of energy, but motor A would do it quicker than motor B. So, motor A is the more powerful motor.
2) Plug the time taken and work done for motor A into the equation $P = W \div t$ and find the power.
$P = W \div t = 8000 \div 50 = 160$ W

Energy can't be created or destroyed — only talked about a lot...

Remember, when energy is wasted it's not destroyed — it still exists, it just isn't stored usefully anymore.

Q1 A motor transfers 4.8 kJ of energy in 2 minutes. Calculate its power output. [3 marks]

Q1 Video Solution

Reducing Unwanted Energy Transfers

There are a few ways you can reduce the amount of energy scampering off to a completely useless store — lubrication and thermal insulation are the ones you need to know about. Read on...

Lubrication Reduces Frictional Forces

1) Whenever something moves, there's usually at least one frictional force acting against it (p.210). This causes some energy in the system to be dissipated (p.170), e.g. air resistance can transfer energy from a falling object's kinetic energy store to its thermal energy store.
2) For objects that are being rubbed together, lubricants can be used to reduce the friction between the objects' surfaces when they move. Lubricants are usually liquids (like oil), so they can flow easily between objects and coat them.

Streamlining reduces air resistance too, see p.210.

Heating Can Occur by Conduction and Convection

1) When an object is heated, energy is transferred to the kinetic energy stores of its particles.
2) This causes the particles to vibrate more and to collide with each other. During these collisions, energy is transferred between the particles' kinetic energy stores. This is conduction.
3) Thermal conductivity is a measure of how quickly energy is transferred through a material in this way. Materials with a high thermal conductivity transfer energy between their particles at a faster rate.
4) If the particles are free to move (e.g. in a gas or a liquid) the particles moving faster means that the space between individual particles increases. This causes the density (p.192) of the region being heated to decrease.
5) Because liquids and gases can flow, the warmer and less dense region will rise above denser, cooler regions. So energetic particles move away from hotter to cooler regions — this is convection.

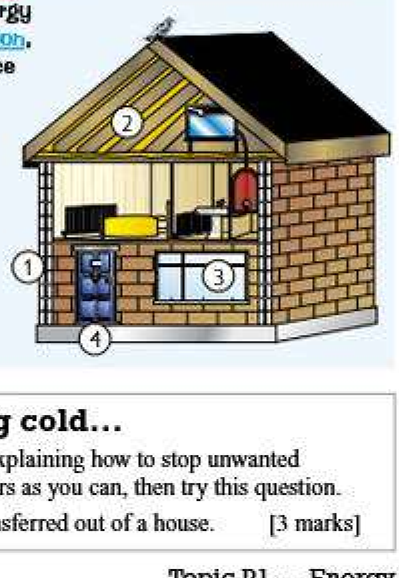
Insulation Reduces the Rate of Energy Transfer by Heating

The last thing you want when you've made your house nice and toasty is for that energy to escape outside. There are a few things you can do to prevent energy losses through heating:

- Have thick walls that are made from a material with a low thermal conductivity. The thicker the walls and the lower their thermal conductivity, the slower the rate of energy transfer will be (so the building will cool more slowly).
- Use thermal insulation. Here are some examples:

Reducing the difference between the temperature inside and outside the house will also reduce the rate of energy transfer.

1) Some houses have cavity walls, made up of an inner and an outer wall with an air gap in the middle. The air gap reduces the amount of energy transferred by conduction through the walls. Cavity wall insulation, where the cavity wall air gap is filled with a foam, can also reduce energy transfer by convection in the wall cavity.
2) Loft insulation can reduce convection currents (a cycle where air particles are constantly being heated, rising, cooling and then sinking) being created in lofts.
3) Double-glazed windows work in the same way as cavity walls — they have an air gap between two sheets of glass to prevent energy transfer by conduction through the windows.
4) Draught excluders around doors and windows reduce energy transfers by convection.



Bundle your brew in newspaper to stop it going cold...

Understanding conduction and convection is really useful, especially when explaining how to stop unwanted transfers. Have a go at naming as many methods for reducing energy transfers as you can, then try this question.

Q1 Explain how cavity wall insulation reduces the amount of energy transferred out of a house. [3 marks]

Efficiency

More! More! Tell me more about energy transfers please! Oh go on then, since you insist...

Most Energy Transfers Involve Some Waste Energy

1) Useful devices are only useful because they can transfer energy from one store to another.
2) As you'll probably have gathered by now, some of the input energy is usually wasted by being transferred to a useless energy store — usually a thermal energy store.
3) The less energy that is 'wasted' in this energy store, the more efficient the device is said to be.
4) You can improve the efficiency of energy transfers by insulating objects, lubricating them or making them more streamlined (see pages 171 and 210).
5) The efficiency for any energy transfer can be worked out using this equation:

$$\text{Efficiency} = \frac{\text{Useful output energy transfer}}{\text{Total input energy transfer}}$$

You can give efficiency as a decimal or you can multiply your answer by 100 to get a percentage, i.e. 0.75 or 75%.

6) You might not know the energy inputs and outputs of a device, but you can still calculate its efficiency as long as you know the power input and output:

$$\text{Efficiency} = \frac{\text{Useful power output}}{\text{Total power input}}$$

EXAMPLE

A blender is 70% efficient. It has a total input power of 600 W. Calculate the useful output power.

1) Change the efficiency from a percentage to a decimal. — efficiency = 70% = 0.7
2) Rearrange the equation for useful power output. — useful power output = efficiency × total power input
3) Stick in the numbers you're given. — = 0.7 × 600 = 420 W

Useful Energy Output Isn't Usually Equal to Total Energy Input

1) For any given example you can talk about the types of energy being input and output, but remember: NO device is 100% efficient and the wasted energy is usually transferred to useless thermal energy stores.
2) Electric heaters are the exception to this. They're usually 100% efficient because all the energy in the electrostatic energy store is transferred to "useful" thermal energy stores.
3) Ultimately, all energy ends up transferred to thermal energy stores. For example, if you use an electric drill, its energy transfers to lots of different energy stores, but quickly ends up all in thermal energy stores.

Don't waste your energy — turn the TV off while you revise...

Make sure you can use and rearrange the equations for efficiency, then have a go at these questions.

Q1 A motor in a remote-controlled car transfers 300 J of energy into the car's energy stores. 225 J are transferred to the car's kinetic energy stores. Calculate the efficiency of the motor. [2 marks]

Q2 A machine has a useful power output of 900 W and a total power input of 1200 W. In a given time, 72 kJ of energy is transferred to the machine. Calculate the amount of energy usefully transferred by the machine in this time. [4 marks]

Q2 Video Solution

Energy Resources and Their Uses

Energy resources, both renewable and non-renewable, are mostly used to generate electricity.
There's loads more on how over the next few pages, but two other major uses are transport and heating.

Non-Renewable Energy Resources Will Run Out One Day

Non-renewable energy resources are fossil fuels and nuclear fuel (uranium and plutonium). Fossil fuels are natural resources that form underground over millions of years. They are typically burnt to provide energy. The three main fossil fuels are:

1) Coal
2) Oil
3) (Natural) Gas

- These will all 'run out' one day.
- They all do damage to the environment.
- But they provide most of our energy.

Renewable Energy Resources Will Never Run Out

Renewable energy resources are:

1) The Sun (Solar)
2) Wind
3) Water waves
4) Hydro-electricity
5) Bio-fuel
6) Tides
7) Geothermal

- These will never run out — the energy can be 'renewed' as it is used.
- Most of them do damage the environment, but in less nasty ways than non-renewables.
- The trouble is they don't provide much energy and some of them are unreliable because they depend on the weather.

Energy Resources can be Used for Transport...

Transport is one of the most obvious places where fuel is used. Here are a few transportation methods that use either renewable or non-renewable energy resources:

Electricity can also be used to power vehicles, (e.g. trains and some cars). It can be generated using renewable or non-renewable energy resources (p174-176).

NON-RENEWABLE ENERGY RESOURCES

- Petrol and diesel powered vehicles (including most cars) use fuel created from oil.
- Coal is used in some old-fashioned steam trains to boil water to produce steam.

RENEWABLE ENERGY RESOURCES

Vehicles that run on pure bio-fuels (p.176) or a mix of a bio-fuel and petrol or diesel (only the bio-fuel bit is renewable, though).

...And for Heating

Energy resources are also needed for heating things like your home.

NON-RENEWABLE ENERGY RESOURCES

- Natural gas is the most widely used fuel for heating homes in the UK. The gas is used to heat water, which is then pumped into radiators throughout the home.
- Coal is commonly burnt in fireplaces.
- Electric heaters (sometimes called storage heaters) which use electricity generated from non-renewable energy resources.

RENEWABLE ENERGY RESOURCES

- A geothermal (or ground source) heat pump uses geothermal energy resources (p.174) to heat buildings.
- Solar water heaters work by using the sun to heat water which is then pumped into radiators in the building.
- Burning bio-fuel or using electricity generated from renewable resources can also be used for heating.

I'm pretty sure natural gas is renewable — I make enough of it...

You need to know the difference between the two different types of energy resource, so get cracking.

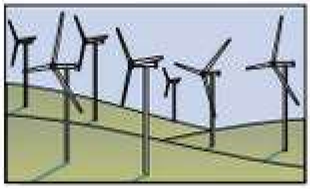
Q1 Write down whether each of the following are renewable or non-renewable energy resources.
a) Tidal power b) Natural gas c) Nuclear power d) Bio-fuel [4 marks]

Wind, Solar and Geothermal

Renewable energy resources, like wind, solar and geothermal resources, will not run out. They don't generate as much electricity as non-renewables though — if they did we'd all be using solar-powered toasters by now.

Wind Power — Lots of Little Wind Turbines

1) This involves putting lots of wind turbines up in exposed places like on moors or round coasts.
2) Each turbine has a generator inside it — the rotating blades turn the generator and produce electricity.
3) There's no pollution (except for a little bit when they're manufactured).
4) But they do spoil the view. You need about 1500 wind turbines to replace one coal-fired power station and 1500 of them cover a lot of ground — which would have a big effect on the scenery.
5) And they can be very noisy, which can be annoying for people living nearby.
6) There's also the problem of the turbines stopping when the wind stops or if the wind is too strong, and it's impossible to increase supply when there's extra demand. On average, wind turbines produce electricity 70-85% of the time.
7) The initial costs are quite high, but there are no fuel costs and minimal running costs.
8) There's no permanent damage to the landscape — if you remove the turbines, you remove the noise and the view returns to normal.



Solar Cells — Expensive but No Environmental Damage

(well, there may be a bit caused by making the cells)

1) Solar cells generate electric currents directly from sunlight. Solar cells are often the best source of energy to charge batteries in calculators and watches which don't use much electricity.
2) Solar power is often used in remote places where there's not much choice (e.g. the Australian outback) and to power electric road signs and satellites.
3) There's no pollution. (Although they do use quite a lot of energy to manufacture in the first place.)
4) In sunny countries solar power is a very reliable source of energy — but only in the daytime. Solar power can still be cost-effective even in cloudy countries like Britain though.
5) Like wind, you can't increase the power output when there is extra demand (p.189).
6) Initial costs are high but after that the energy is free and running costs almost nil.
7) Solar cells are usually used to generate electricity on a relatively small scale.

Time to recharge.

Geothermal Power — Energy in Underground Thermal Energy Stores

1) This is possible in volcanic areas or where hot rocks lie quite near to the surface. The source of much of the energy is the slow decay of various radioactive elements, including uranium, deep inside the Earth.
2) This is actually brilliant free energy that's reliable and does very little damage to the environment.
3) Geothermal power can be used to generate electricity, or to heat buildings directly.
4) The main drawbacks with geothermal power are that there aren't very many suitable locations for power plants, and that the cost of building a power plant is often high compared to the amount of energy it produces.

People love the idea of wind power — just not in their back yard...

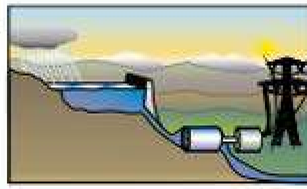
There are pros and cons to all energy resources. Make sure you know them for solar, wind and geothermal.

Q1 Explain why geothermal power is more reliable than wind power. [2 marks]

Hydro-electricity, Waves and Tides

Good ol' water. Not only can we drink it, we can also use it to generate electricity. It's easy to get confused between wave and tidal power as they both involve the seaside — but don't. They are completely different.

Hydro-electric Power Uses Falling Water

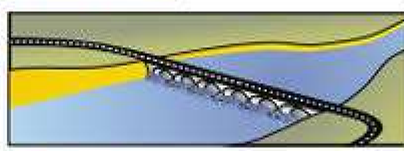


1) Hydro-electric power usually requires the flooding of a valley by building a big dam. Water is allowed out through turbines. There is no pollution (as such).
2) But there is a big impact on the environment due to the flooding of the valley (rotting vegetation releases methane and CO_2) and possible loss of habitat for some species (sometimes the loss of whole villages). The reservoirs can also look very unsightly when they dry up. Putting hydroelectric power stations in remote valleys tends to reduce their impact on humans.
3) A big advantage is it can provide an immediate response to an increased demand for electricity.
4) There's no problem with reliability except in times of drought — but remember this is Great Britain we're talking about.
5) Initial costs are high, but there are no fuel costs and minimal running costs.
6) It can be a useful way to generate electricity on a small scale in remote areas.

Wave Power — Lots of Little Wave-Powered Turbines

1) You need lots of small wave-powered turbines located around the coast. Like with wind power (p.174) the moving turbines are connected to a generator.
2) There is no pollution. The main problems are disturbing the seabed and the habitats of marine animals, spoiling the view and being a hazard to boats.
3) They are fairly unreliable, since waves tend to die out when the wind drops.
4) Initial costs are high, but there are no fuel costs and minimal running costs. Wave power is never likely to provide energy on a large scale, but it can be very useful on small islands.

Tidal Barrages — Using the Sun and Moon's Gravity



1) Tides are used in lots of ways to generate electricity. The most common method is building a tidal barrage.
2) Tidal barrages are big dams built across river estuaries, with turbines in them. As the tide comes in it fills up the estuary. The water is then allowed out through turbines at a controlled speed.
3) Tides are produced by the gravitational pull of the Sun and Moon.
4) There is no pollution. The main problems are preventing free access by boats, spoiling the view and altering the habitat of the wildlife, e.g. wading birds, sea creatures and beasties who live in the sand.
5) Tides are pretty reliable in the sense that they happen twice a day without fail, and always near to the predicted height. The only drawback is that the height of the tide is variable so lower (neap) tides will provide significantly less energy than the bigger 'spring' tides. They also don't work when the water level is the same either side of the barrage — this happens four times a day because of the tides.
6) Initial costs are moderately high, but there are no fuel costs and minimal running costs. Even though it can only be used in some of the most suitable estuaries tidal power has the potential for generating a significant amount of energy.

The hydro-electric power you're supplying — it's electrifying...

Learn the differences between all of these water-based resources before having a go at this question.

Q1 Give one negative environmental impact of wave power. [1 mark]

Bio-fuels and Non-renewables

And the energy resources just keep on coming. It's over soon, I promise. Just a few more to go.

Bio-fuels are Made from Plants and Waste

1) Bio-fuels are renewable energy resources created from either plant products or animal dung. They can be solid, liquid or gas and can be burnt to produce electricity or run cars in the same way as fossil fuels.
2) They are supposedly carbon neutral, although there is some debate about this as it's only really true if you keep growing plants at the rate that you're burning things.
3) Bio-fuels are fairly reliable, as crops take a relatively short time to grow and different crops can be grown all year round. However, they cannot respond to immediate energy demands. To combat this, bio-fuels are continuously produced and stored for when they are needed.
4) The cost to refine bio-fuels is very high and some worry that growing crops specifically for bio-fuels will mean there isn't enough space or water to meet the demands for crops that are grown for food.
5) In some regions, large areas of forest have been cleared to make room to grow bio-fuels, resulting in lots of species losing their natural habitats. The decay and burning of this vegetation also increases CO_2 and methane emissions.

Non-Renewables are Reliable...

1) Fossil fuels and nuclear energy are reliable. There's enough fossil and nuclear fuels to meet current demand, and they are extracted from the Earth at a fast enough rate that power plants always have fuel in stock. This means that the power plants can respond quickly to changes in demand (p.189).
2) However, these fuels are slowly running out. If no new resources are found, some fossil fuel stocks may run out within a hundred years.
3) While the set-up costs of power plants can be quite high compared to some other energy resources, the running costs aren't that expensive. Combined with fairly low fuel extraction costs, using fossil fuels is a cost effective way to produce energy (which is why it's so popular).

...But Create Environmental Problems

1) Coal, oil and gas release CO_2 into the atmosphere when they're burned. All this CO_2 adds to the greenhouse effect, and contributes to global warming.
2) Burning coal and oil also releases sulfur dioxide, which causes acid rain — which can be harmful to trees and soils and can have far-reaching effects in ecosystems.
3) Acid rain can be reduced by taking the sulfur out before the fuel is burned, or cleaning up the emissions.
4) Coal mining makes a mess of the landscape, especially "open-cast mining". As with many energy resources, the view can be spoilt by fossil fuel power plants.
5) Oil spillages cause serious environmental problems, affecting mammals and birds that live in and around the sea. We try to avoid them, but they'll always happen.
6) Nuclear power is clean but the nuclear waste is very dangerous and difficult to dispose of.
7) Nuclear fuel (e.g. uranium) is relatively cheap but the overall cost of nuclear power is high due to the cost of the power plant and final decommissioning.
8) Nuclear power always carries the risk of a major catastrophe like the Fukushima disaster in Japan.

Radiation can be very dangerous to humans — see p.199 for more.

Bio-fuels are great — but don't burn your biology notes just yet...

Make sure you can talk about the reliability and any environmental issues of using bio-fuels or non-renewables.

Q1 Give two benefits of power plants that use fossil fuels. [2 marks]

Q2 Describe the environmental impact of using oil as an energy resource for generating electricity. [3 marks]

Trends in Energy Resource Use

Over time, the types of energy resources we use change. There are lots of reasons for this — breakthroughs in technology, understanding more about how they affect the environment or changes in cost are just a few.

Currently we Still Depend on Fossil Fuels

See p.189 for more about the supply and demand of electricity.

1) Over the 20th century, the electricity use of the UK hugely increased as the population grew and people began to use electricity for more and more things.
2) Since the beginning of the 21st century, electricity use in the UK has been decreasing (slowly), as we get better at making appliances more efficient (p.172) and become more careful with energy use in our homes.
3) Some of our electricity is produced using fossil fuels and from nuclear power.
4) Generating electricity isn't the only reason we burn fossil fuels — oil (diesel and petrol) is used to fuel cars, and gas is used to heat homes and cook food.
5) However, we are trying to increase our use of renewable energy resources. This move towards renewable energy resources has been triggered by many things...

People Want to use More Renewable Energy Resources

1) We now know that burning fossil fuels is very damaging to the environment (p.176). This makes many people want to use more renewable energy resources that affect the environment less.
2) People and governments are also becoming increasingly aware that non-renewables will run out one day. Many people think it's better to learn to get by without non-renewables before this happens.
3) Pressure from other countries and the public has meant that governments have begun to introduce targets for using renewable resources. This in turn puts pressure on energy providers to build new power plants that use renewable resources to make sure they do not lose business and money.
4) Car companies have also been affected by this change in attitude towards the environment. Electric cars and hybrids (cars powered by two fuels, e.g. petrol and electricity) are already on the market and their popularity is increasing.

The Use of Renewables is Limited by Reliability, Money and Politics

1) There's a lot of scientific evidence supporting renewables, but although scientists can give advice, they don't have the power to make people, companies or governments change their behaviour (see p.2).
2) Building new renewable power plants costs money, so some energy providers are reluctant to do this, especially when fossil fuels are so cost effective. The cost of switching to renewable power will have to be paid, either by customers in their bills, or through government and taxes. Some people don't want to or can't afford to pay, and there are arguments about whether it's ethical to make them.
3) Even if new power plants are built, there are arguments over where to put them. E.g. many people don't want to live next to a wind farm, causing protests. There are arguments over whether it's ethical to make people put up with wind farms built next to them when they may not agree with the reasons for their use.
4) Some energy resources like wind power are not as reliable as traditional fossil fuels, whilst others cannot increase their power output on demand. This would mean either having to use a combination of different power plants (which would be expensive) or researching ways to improve reliability.
5) Research on improving the reliability and cost of renewables takes time and money — it may be years before improvements are made even with funding. Until then, we need dependable, non-renewable power.
6) Making personal changes can also be quite expensive. Hybrid cars are generally more expensive than equivalent petrol cars and things like solar panels for your home are still quite pricey. The cost of these things is slowly going down, but they are still not an option for many people.

Going green is on-trend this season...

So with more people wanting to help the environment, others not wanting to be inconvenienced and greener alternatives being expensive to set up, the energy resources we use are changing. Just not particularly quickly.

Q1 Give two reasons why we currently do not use more renewable energy resources in the UK. [2 marks]

Revision Questions for Topic P1

Well, that wraps up Topic P1 — time to test how much you really know.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quiz for Topic P1 — just scan this QR code!

Topic P1 Quiz

Energy Stores and Systems (p.167-168)

1) Write down four energy stores.
2) Describe the energy transfers that occur as a ball falls to the ground.
3) Give the equation for finding the energy in an object's kinetic energy store.
4) If energy is transferred to an object's kinetic energy store, what happens to its speed?
5) Give the equation for finding the energy in an object's gravitational potential energy store.
6) What kind of energy store is energy transferred to when you compress a spring?

Specific Heat Capacity (p.169)

7) What is the definition of the specific heat capacity of a material?
8) Give the equation that relates energy transferred and specific heat capacity.
9) Describe an experiment to find the specific heat capacity of a material.

Conservation of Energy and Power (p.170)

10) State the conservation of energy principle.
11) Define power and give two equations to calculate power.
12) What are the units of power?

Reducing Unwanted Energy Transfers and Improving Efficiency (p.171-172)

13) How can you reduce unwanted energy transfers in a machine with moving, touching components?
14) True or false? A high thermal conductivity means there is a high rate of energy transfer.
15) Give four ways to prevent unwanted energy transfers in a home.
16) True or false? Thicker walls make a house cool down quicker.
17) What is the efficiency of an energy transfer? Give the equation that relates efficiency to power.

Energy Resources and Trends in their Use (p.173-177)

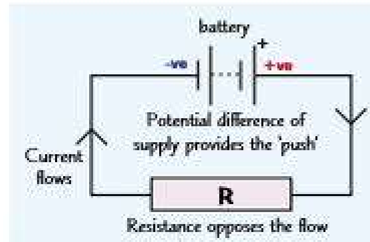
18) Name four renewable energy resources and four non-renewable energy resources.
19) What is the difference between renewable and non-renewable energy resources?
20) Give an example of how a renewable energy resource is used in everyday life.
21) Explain why solar power is considered to be a fairly reliable energy resource.
22) True or false? Tidal barrages are useful for storing energy to be used during times of high demand.
23) Give two ways in which the environment can be damaged when using fossil fuels.
24) Give one environmental benefit of using nuclear power.
25) Explain why the UK plans to use more renewable energy resources in the future.

Current and Circuit Symbols

It's pretty bad news if the word current makes you think of delicious cakes instead of physics. Learn what it means, as well as some handy symbols to show items like batteries and switches in a circuit.

Current is the Flow of Electrical Charge

1) Electric current is a flow of electrical charge. Electrical charge will only flow round a complete (closed) circuit if there is a potential difference, so a current can only flow if there's a source of potential difference. The unit of current is the 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.183).
3) Potential difference (or voltage) is the driving force that pushes the charge round. Its unit is the volt, V.
4) Resistance is anything that slows the flow down. Unit: ohm, Ω.
5) The current flowing through a component depends on the potential difference across it and the resistance of the component (p.180).



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

Total Charge Through a Circuit Depends on Current and Time

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

$$Q = It$$

Charge flow (coulombs, C) — Q; Current (A) — I; Time (s) — t

More charge passes around the circuit when a larger current flows.

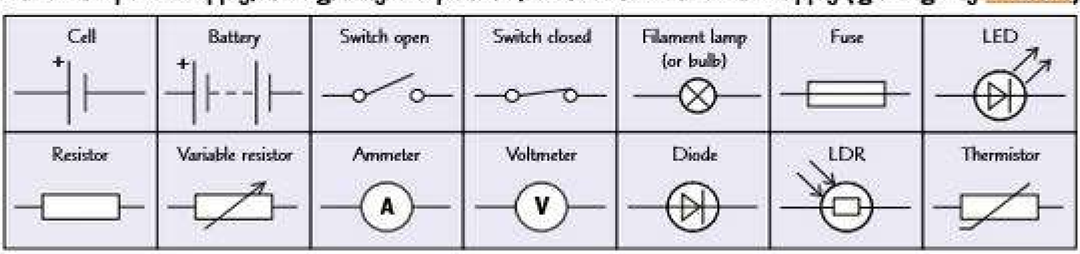
EXAMPLE

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).



I think it's about time you took charge...

Practise drawing all of the circuit symbols above, even if you've seen some of them before. It's no good if you get asked to draw a circuit diagram and you can't tell a resistor from a fuse.

Q1 A laptop charger passes a current of 8 A through a laptop battery. Calculate, in minutes, how long the charger needs to be connected to the battery for 28 800 C of charge to be transferred. [4 marks]

Q2 A student creates a simple circuit containing a battery, a switch and a bulb. He connects them all in a single, closed loop. Draw the circuit diagram for this circuit. [3 marks]

Q1 Video Solution

Resistance and $V = IR$

Ooh experiments, you've gotta love 'em. Here's a simple experiment for investigating resistance.

There's a Formula Linking Potential Difference and Current

The formula linking pd and current is very useful (and pretty common):

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

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

EXAMPLE

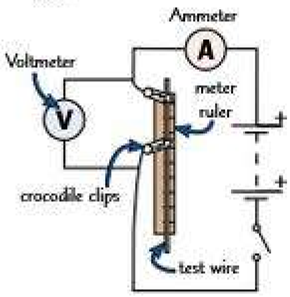
A 4.0 Ω resistor in a circuit has a potential difference of 6.0 V across it. What is the current through the resistor?

Rearrange $V = IR$ to give $I = V \div R$, then substitute in the values you have. $I = 6.0 \div 4.0 = 1.5$ A

You Can Investigate the Factors Affecting Resistance

PRACTICAL

The resistance of a circuit can depend on a number of factors, like whether components are in series or parallel, p.185, 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.

See p.183-184 for more on series and parallel circuits.

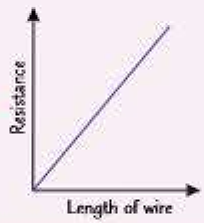
The Voltmeter

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.184) — NOT around any other bit of the circuit, e.g. the battery.

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

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.5).

The wire may heat up during the experiment, which will affect its resistance (p.181). Leave the switch open for a bit between readings to let the circuit cool down.



Measure gymnastics — use a vaultmeter...

You could also investigate the effect of diameter or material on the resistance of a wire. What fun.

Q1 An appliance is connected to a 230 V source. Calculate the resistance of the appliance if a current of 5.0 A is flowing through it. [3 marks]

Q1 Video Solution

Resistance and *I-V* Characteristics

There are three different graphs to learn on this page — you have to know how you get them too.

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 $V = IR$, previous page.)
2) The resistance of some resistors and components DOES change, e.g. a diode or a filament lamp.
3) When an electrical charge flows through a filament lamp, it transfers some energy to the thermal energy store of the filament (p.167), 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.

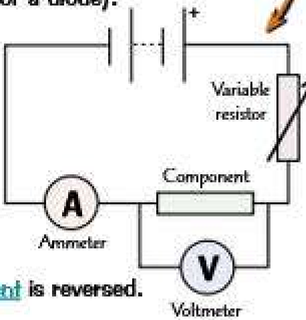
Three Very Important *I-V* Characteristics

PRACTICAL

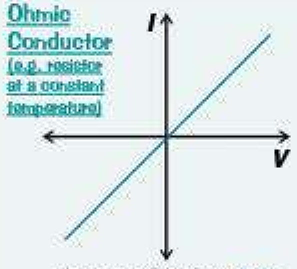
This type of circuit uses direct current (dc) (p.186) and is a series circuit (p.183).

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. Linear components have an *I-V* characteristic that's a straight line (e.g. a fixed resistor). Non-linear components have a curved *I-V* characteristic (e.g. a filament lamp or a diode).

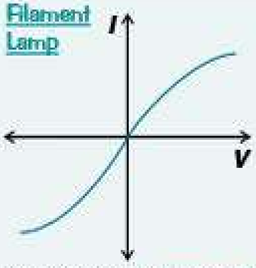
You can do this experiment to find a component's *I-V* characteristic:



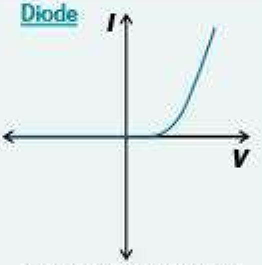
1) Set up the test circuit shown on the right.
2) Begin to vary the variable resistor. This alters the current flowing through the circuit and the potential difference across the component.
3) Take several pairs of readings from the ammeter and voltmeter to see how the potential difference across the 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 battery, so the direction of the current is reversed.
5) Plot a graph of current against voltage for the component.
6) The *I-V* characteristics you get for an ohmic conductor, filament lamp and diode should look like this:



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



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.



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 $R = V/I$.

In the end you'll have to learn this — resistance is futile...

Draw out those graphs until you're sketching them in your sleep — it's essential that you know them.

Q1 Explain the shape of the filament lamp *I-V* characteristic above, for the quadrant where *I* and *V* are positive. [3 marks]

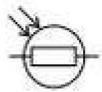
Q1 Video Solution

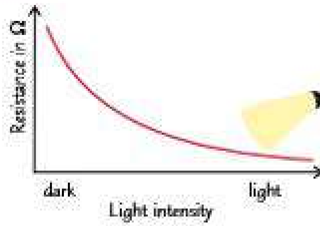
Circuit Devices

The fun doesn't stop with filament bulbs. As well as temperature, resistance can depend on things like light intensity, which is how LDRs work. They're really useful for circuits that sense changes in light levels.

LDR is Short for Light Dependent Resistor

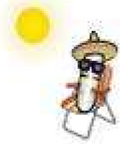
1) An LDR is a resistor that is dependent on the intensity of light. Simple really.
2) In bright light, the resistance falls.
3) In darkness, the resistance is highest.
4) They have lots of applications including automatic night lights, outdoor lighting and burglar detectors.

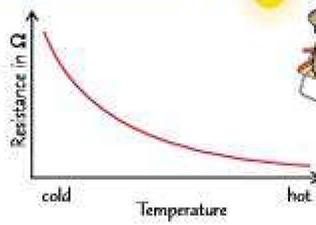




The Resistance of a Thermistor Depends on Temperature

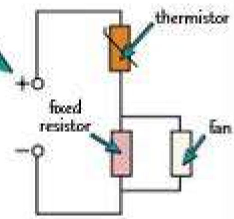
1) A thermistor is a temperature dependent resistor.
2) In hot conditions, the resistance drops.
3) In cool conditions, the resistance goes up.
4) Thermistors make useful temperature detectors, e.g. car engine temperature sensors and electronic thermostats.



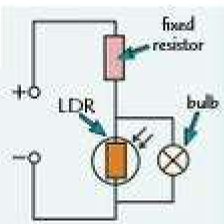


You Can Use LDRs and Thermistors in Sensing Circuits

1) Sensing circuits can be used to turn on or increase the power to components depending on the conditions that they are in.
2) The circuit on the right is a sensing circuit used to operate a fan in a room.
3) The fixed resistor and the fan will always have the same potential difference across them (because they're connected in parallel — see p.184).
4) The pd 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 pd it takes.
5) As the room gets hotter, the resistance of the thermistor decreases and it takes a smaller share of the pd from the power supply. So the pd across the fixed resistor and the fan rises, making the fan go faster.



You can also connect the component across the variable resistor instead. For example, if you connect a bulb in parallel to an LDR, the pd across both the LDR and the bulb will be high when it's dark and the LDR's resistance is high. The greater the pd across a component, the more energy it gets. So a bulb connected across an LDR would get brighter as the room got darker.



LDRs — Light Dependent Rabbits...

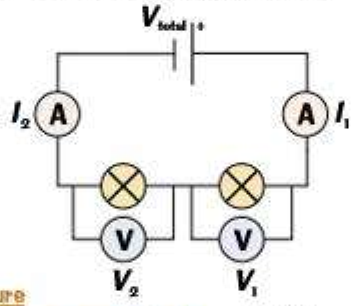
More odd circuit symbols, but at least we're getting into how different components are used in daily life — the next time your heating turns on automatically, you can be smug in your knowledge of thermistors.

Q1 Describe one everyday use for the following components:
a) a LDR b) a thermistor [2 marks]

Series Circuits

There's a difference between connecting components in series and parallel. Make sure you learn it, and know the rules about what happens to current, pd and resistance in each case — read on for more series fun.

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 circuit on p.181 and the sensor circuits on p.182).

Potential Difference is Shared

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

$$V_{total} = V_1 + V_2 + \ldots$$

Current is the Same Everywhere

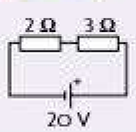
1) In series circuits the same current flows through all components, i.e.: $I_1 = I_2 = \ldots$
2) The size of the current is determined by the total pd of the cells and the total resistance of the circuit: i.e. $I = V \div R$.

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 pd.
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 below, calculate the current passing through the circuit.



1) First find the total resistance by adding together the resistance of the two resistors. $R_{total} = 2 + 3 = 5\ \Omega$
2) Then rearrange $V = IR$ and substitute in the values you have. $I = V \div R$
$= 20 \div 5$
$= 4$ A

Cell Potential Differences Add Up

1) There is a bigger pd when more cells are in series, if they're all connected the same way.
2) For example when two cells with a potential difference of 1.5 V are connected in series they supply 3 V between them.

Series circuits — they're no laughing matter...

Get those rules straightened out in your head, then have a quick go at this question to test what you know.

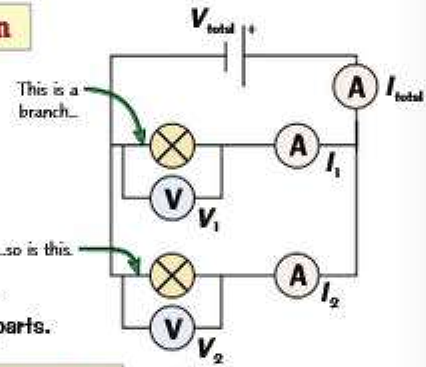
Q1 A battery is connected in series with a 4 Ω resistor, a 5 Ω resistor and a 6 Ω resistor. A current of 0.6 A flows through the circuit. Calculate the potential difference of the battery. [3 marks]

Q1 Video Solution

Parallel Circuits

Parallel circuits are much more sensible than series circuits and so they're much more common in real life. All the electrics in your house will be wired in parallel circuits.

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 potential difference is the same across all components:

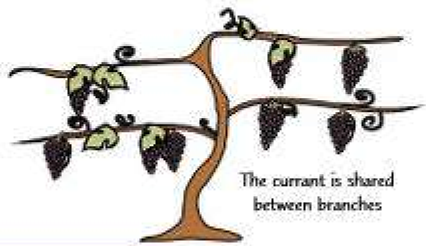
$$V_1 = V_2 = ...$$

2) This means that identical bulbs connected in parallel will all be at the same brightness.

Current is Shared Between Branches

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

1) In parallel circuits the total current flowing around the circuit is equal to the total of all the currents through the separate components.
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.
3) If two identical components are connected in parallel then the same current will flow through each component.



The currant is shared between branches

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 pd 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.

A current shared (between identical components) — is a current halved...

Parallel circuits are trickier, but they're much more useful than series circuits, so get learning them.

Q1 A circuit contains three resistors, each connected in parallel with a cell. Explain what happens to the total current and resistance in the circuit when one resistor is removed. [4 marks]

Q1 Video Solution

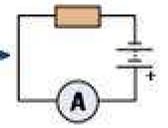
Q2 Draw a circuit diagram for two filament lamps connected in parallel to a battery. Both of the lamps can be switched on and off without affecting each other. [3 marks]

Investigating Resistance

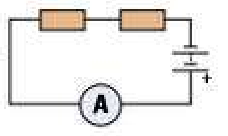
PRACTICAL

You saw on page 180 how the length of the wire 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...

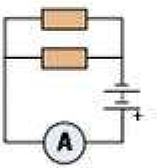


1) First, you'll need to find at least four identical resistors.
2) Then build the circuit shown on the right using one of the resistors. Make a note of the potential difference of the battery (V).
3) Measure the current through the circuit using the ammeter. Use this to calculate the resistance of the 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).



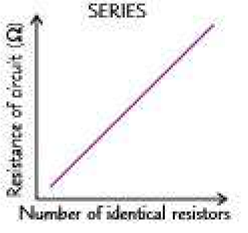
...or in Parallel

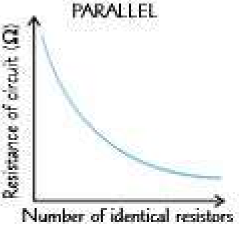
1) Using the same equipment as before (so the experiment is a fair test), build the same initial circuit.
2) Measure the total current through the circuit and calculate the resistance of the circuit using $R = V \div I$ (again, V is the potential difference of the battery).
3) Next, add another resistor, 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 right.
5) These results agree with what you learnt about resistance in series and parallel circuits on pages 183 and 184.





I can't resist a good practical...

Nothing too hard on this page, which makes a nice change from all of those rules about circuits. Make sure you're completely happy building circuits from diagrams, before moving on to the fun world of mains electricity... wooo...

Q1 Draw a diagram of a single circuit that could be used to investigate the effect of adding resistors in parallel. Your circuit should include switches. [1 mark]

Electricity in the Home

There are two types of electricity supply — alternating and direct currents. Read on for more about both...

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 voltages 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 voltage.

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:

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

2) NEUTRAL WIRE — blue. The neutral wire completes the circuit — when the appliance is operating normally, current flows through the live and neutral wires. It is around 0 V.

3) EARTH WIRE — green and yellow. It 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.

The Live Wire Can Give You an Electric Shock

1) Your body (just like the earth) is at 0 V. This means that if you touch the live wire, a large potential difference is produced across your body and a current flows through you.
2) This causes a large electric shock which could injure or even kill you.
3) 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's 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.
4) 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.

Why are earth wires green and yellow — when mud is brown..?

Electricity is very useful, but it can also be very dangerous. Make sure you know the risks.

Q1 State the potential difference of: a) the live wire b) the neutral wire c) the earth wire. [3 marks]

Power of Electrical Appliances

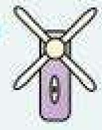
Energy is transferred between stores electrically (like you saw on page 167) by electrical appliances.

Energy is Transferred from Cells and Other Sources

1) You know from page 167 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.203.)
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.172.

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:

This equation should be familiar from page 170.

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

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

   Remember that the time must be in seconds.
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.

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.170).

Transfer this page to your useful knowledge store...

Get that equation for power hard-wired into your brain and then become a powerful physicist by practising it:

Q1 An appliance transfers 6000 J of energy in 30 seconds. Calculate its power. [2 marks]

Q2 Calculate the difference in the amount of energy transferred by a 250 W TV and a 375 W TV when they are both used for two hours. [4 marks]

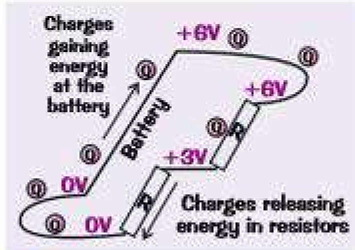
Q2 Video Solution

More on Power

And we're not done yet. There are even more power equations for you to get your head around, how fun.

Potential Difference is Energy Transferred per Charge Passed

1) When an electrical charge goes through a change in potential difference, then 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 real simple:



$$E = QV$$

Energy transferred (J), 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) $\quad P = VI$

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 180 into $P = VI$, which gives you:

$$P = I^2R$$

Resistance (Ω)

You have the power — now use your potential...

I'm afraid the best way to learn all of this is to just practise using those equations again and again. Sorry.

Q1 Calculate the energy transferred from a 200 V source as 10 000 C of charge passes. [2 marks]

Q2 An appliance is connected to a 12 V source. A current of 4.0 A flows through it. Calculate the power of the appliance. [2 marks]

Q3 An appliance has a power of 2300 W and has a current of 10.0 A flowing through it. Calculate the resistance of the appliance. [3 marks]

Q3 Video Solution

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 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

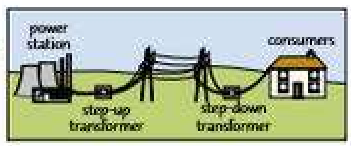
1) Throughout the day, electricity usage (the demand) changes. Power stations have to produce enough electricity for everyone to have it when they need it.
2) They can predict when the most electricity will be used though. Demand increases when people get up in the morning, come home from school or work 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.

The National Grid Uses a High Pd and a Low Current

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

1) To transmit the huge amount of power needed, you need either a high potential difference or a high current (as $P = VI$, from the previous page).
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.
3) It's much cheaper to boost the pd up really high (400 000 V) and keep the current as low as possible.
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 for efficient transmission we use transformers (and big pylons with huge insulators).
2) Transformers all have two coils, a primary coil and a secondary coil, joined with an iron core.
3) Potential difference is increased using a step-up transformer. They have more turns on the secondary coil than the primary coil. As the pd is increased by the transformer, the current is decreased.
4) The pd is then reduced again at the local consumer end using a step-down transformer (the current is therefore increased by this transformer). They have more turns on the primary coil than the secondary.
5) The power of a primary coil is given by power = pd × current. Transformers are nearly 100% efficient, so the power in primary coil = power in secondary coil. This means that:

pd across primary coil (V) × current in primary coil (A) = pd across secondary coil (V) × current in secondary coil (A)

$$V_p I_p = V_s I_s$$

Transformers — NOT robots in disguise...

Transformers can be a little tricky, but what's important here is that you understand how they're used in the national grid to reduce energy losses during transmission. Have a go at this question to test what you've learnt.

Q1 Explain why the national grid is efficient at transferring energy. Refer to the potential difference and current during transmission. [4 marks]

Revision Questions for Topic P2

And that's it for Topic P2. Let's see how much has stuck in your head.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quiz for Topic P2 — just scan this QR code!

Topic P2 Quiz

Circuit Basics (p.179-182)

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 diagram symbols for a resistor, a voltmeter, an LED and a diode.
4) What is the equation that links potential difference, current and resistance?
5) Explain how you would investigate how the length of a wire affects its resistance.
6) Name one linear component and one non-linear component.
7) Draw the *I-V* characteristic for an ohmic conductor, a filament lamp and a diode.
8) True or false? The resistance of an LDR increases with light intensity.
9) What happens to the resistance of a thermistor as it gets hotter?

Series and Parallel Circuits (p.183-185)

10) True or false? Potential difference is shared between components in a series circuit.
11) How does the current through each component vary in a series circuit?
12) True or false? Current is shared between the branches of a parallel circuit.
13) A resistor is in series with a cell. A second resistor is added in parallel to the first. How does the overall resistance of the circuit change?
14) Describe an experiment to investigate how adding resistors in series and parallel affects the total resistance of the circuit.

Electricity in the Home (p.186)

15) True or false? Mains supply electricity is an alternating current.
16) What is the potential difference and the frequency of the UK mains supply?
17) Name and give the colours of the three wires in a three-core cable. Why are they colour coded?
18) Explain why touching a live wire is dangerous.

Power and the National Grid (p.187-189)

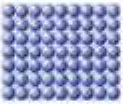
19) Describe the energy transfers that occur for a battery-powered fan.
20) What is the power rating of an appliance?
21) State three equations that can be used to calculate electrical power.
22) What is the national grid?
23) Explain why electricity is transferred by the national grid at a high pd but low current.
24) What are the functions of step-up and step-down transformers?

The Particle Model and Motion in Gases

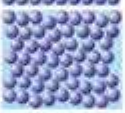
The particle model of matter says that everything is made up of lots of tiny particles. It's dead useful.

All Matter is Made up of Particles

In particle theory, you can think of the particles that make up matter as tiny balls. You can explain the ways that matter behaves in terms of how these tiny balls move, and the forces between them. The three states of matter are solid (e.g. ice), liquid (e.g. water) and gas (e.g. water vapour). The particles of a substance in each state are the same — only the arrangement and energy of the particles are different.



SOLIDS — strong forces of attraction hold the particles close together in a fixed, regular arrangement. The particles don't have much energy so they can only vibrate about their fixed positions.



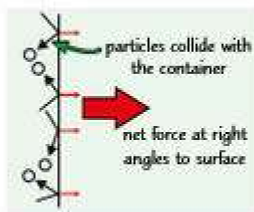
LIQUIDS — there are weaker forces of attraction between the particles. The particles are close together, but can move past each other, and form irregular arrangements. They have more energy than the particles in a solid — they move in random directions at low speeds.

GASES — there are almost no forces of attraction between the particles. The particles have more energy than in liquids and solids — they're free to move, and are constantly moving with random directions and speeds.

The gas particles move at a range of speeds.

Colliding Gas Particles Create Pressure

1) Particles in gases (and liquids to a certain extent, but you don't need to worry about them) are free to move around. As they move, they bang into each other and whatever else happens to get in the way (like the sides of the container they're being kept in).
2) When they collide with something, they exert a force on it.
3) Pressure is the force exerted per unit area.
4) So in a sealed container, the outward gas pressure is the total force exerted by all of the particles in the gas on a unit area of the container walls.



Increasing the Temperature of a Gas Can Increase its Pressure

1) If you increase the temperature of a gas, you transfer energy into the kinetic energy stores of its particles (there's more about this on p.193).
2) The temperature of a gas is related to the average energy in the kinetic energy stores of the particles in the gas. The higher the temperature, the higher the average energy.
3) So as you increase the temperature of a gas, the average speed of its particles increases. This is because the energy in the particles' kinetic energy stores is $\frac{1}{2}mv^2$ — p.168.
4) This means that, for a gas at a constant volume, increasing its temperature increases its pressure.

- As the particles are travelling quicker, it means that they hit the sides of the container more often in a given amount of time.
- Each particle also has a larger momentum (p.216) which means that they exert a larger force when they collide with the container.

These factors both increase the total force exerted on a unit area, and so increase the pressure.

Don't let the pressure of exams get to you...

Get your head around the ideas behind the particle model before you tackle the rest of the topic.

Q1 Explain why decreasing the temperature of a fixed volume of gas decreases its pressure. [3 marks]

Density of Materials

The density of an object tells you how many of its particles have been squished into a given space.

The Particle Model can also Explain Density

Density is a measure of the 'compactness' of a substance. It relates the mass of a substance to how much space it takes up (i.e. it's a substance's mass per unit volume).

The units of density are kg/m^3 (the mass is in kg and the volume is in m^3).

You might also see density given in g/cm^3. ($1\ g/cm^3 = 1000\ kg/m^3$)

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

The symbol for density is a Greek letter rho (ρ) — it looks like a p but it isn't.

This number is given in standard form — a way of writing very large or small numbers quickly: $6.3 \times 10^{-4} = 0.00063$

EXAMPLE

A gold bar has a mass of 12 kg and a volume of 6.3×10^{-4} m³. Calculate the density of the gold bar. Give your answer to two significant figures.

1) First, plug the numbers you've been given into the equation for density.
   Density = mass ÷ volume
   $= 12 \div (6.3 \times 10^{-4}) = 19047.6...$
2) Then round your answer to two significant figures.
   Density = 19 000 kg/m³ (to 2 s.f.)
3) Check your units match what's given in the question.

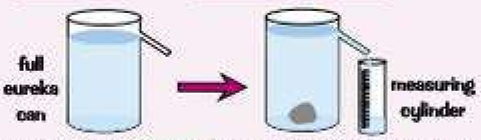
1) The density of an object depends on what it's made of and how its particles are arranged.
2) A dense material has its particles packed tightly together. The particles in a less dense material are more spread out — if you compressed the material, its particles would move closer together, and it would become more dense. (You wouldn't be changing its mass, but you would be decreasing its volume.)
3) This means that density varies between different states of matter (see previous page). Solids are generally denser than liquids, and gases are usually less dense than liquids.

You Need to be Able to Measure Density in Different Ways

PRACTICAL

To find the density of a solid object

1) Use a balance to measure its mass (see p.232).
2) If it's a regular solid, start by measuring its length, width and height with an appropriate piece of equipment (e.g. a ruler). Then calculate its volume using the relevant formula for that shape.
3) For an irregular solid, you can find its volume by submerging it in a eureka can filled with water. The water displaced by the object will be transferred to the measuring cylinder:



4) Record the volume of water in the measuring cylinder. This is the volume of the object.
5) Plug the object's mass and volume into the formula above to find its density.

To find the density of a liquid

1) Place a measuring cylinder on a balance and zero the balance.
2) Pour 10 ml of the liquid into the measuring cylinder (see p.232) and record the liquid's mass.
3) Pour another 10 ml into the measuring cylinder, repeating the process until the cylinder is full and recording the total volume and mass each time.
4) For each measurement, use the formula to find the density. (Remember that 1 ml = 1 cm³.)
5) Finally, take an average of your calculated densities. This will give you a value for the density of the liquid.

The volume of a cube is equal to length × width × height. Make sure you know the formulas for basic shapes.

Who can measure volume — the eureka can can, oh the eureka can can...

Remember — density is all about how tightly packed the particles in a substance are. Nice and simple.

Q1 A 0.019 kg gemstone is placed into a full eureka can, causing 7.0 cm³ of water to be pushed out the spout into a measuring cylinder. Calculate the density of the gemstone in g/cm³. [3 marks]

Q1 Video Solution

Internal Energy and Changes of State

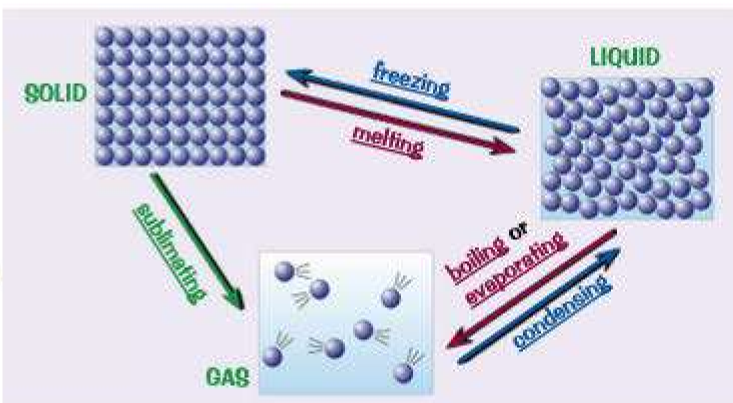
This page is all about heating things. Take a look at your specific heat capacity notes (p.169) before you start — you need to understand it and be able to use $\Delta E = mc\Delta\theta$ for this topic too I'm afraid.

Internal Energy is the Total Energy Stored by Particles in a System

1) The particles in a system vibrate or move around — they have energy in their kinetic energy stores.
2) They also have energy in their potential energy stores due to their positions.
3) The energy stored in a system is stored by its particles (atoms and molecules). The internal energy of a system is the total energy that its particles have in their kinetic and potential energy stores.
4) Heating the system transfers energy to its particles (they gain energy in their kinetic stores and move faster), increasing the internal energy.
5) This leads to a change in temperature or a change in state. If the temperature changes, the size of the change depends on the mass of the substance, what it's made of (its specific heat capacity) and the energy input. Make sure you remember all of the stuff on specific heat capacity from p.169, particularly how to use the formula.
6) A change in state occurs if the substance is heated enough — the particles will have enough energy in their kinetic energy stores to break the bonds holding them together.

A Change of State Conserves Mass

1) When you heat a liquid, it boils (or evaporates) and becomes a gas. When you heat a solid, it melts and becomes a liquid. These are both changes of state.
2) The state can also change due to cooling. The particles lose energy and form bonds.
3) The changes of state are:



4) A change of state is a physical change (rather than a chemical change). This means you don't end up with a new substance — it's the same substance as you started with, just in a different form.
5) If you reverse a change of state (e.g. freeze a substance that has been melted), the substance will return to its original form and get back its original properties.
6) The number of particles doesn't change — they're just arranged differently. This means mass is conserved — none of it is lost when the substance changes state.

Breaking Bonds — Blofeld never quite manages it...

I'll say it one more time — have a look back over your specific heat capacity notes. They'll really help you understand all this stuff on temperature changes and internal energy. Now don't say I didn't warn you...

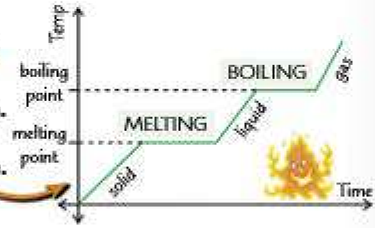
Q1 During an experiment, a solid is heated until it melts into a liquid. Explain how heating the solid causes this change of state. [3 marks]

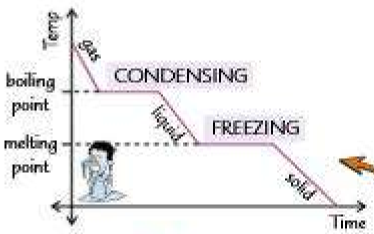
Specific Latent Heat

If you heat up a pan of water on the stove, the water never gets any hotter than 100 °C. You can carry on heating it up, but the temperature won't rise. How come, you say? It's all to do with latent heat...

A Change of State Requires Energy

1) When a substance is melting or boiling, you're still putting in energy and so increasing the internal energy, but the energy's used for breaking bonds between particles rather than raising the temperature. There are flat spots on the heating graph where energy is being transferred by heating but not being used to change the temperature.





2) When a substance is condensing or freezing, bonds are forming between particles, which releases energy. This means the internal energy decreases, but the temperature doesn't go down until all the substance has turned to liquid (condensing) or a solid (freezing). The flat parts of the graph show this energy transfer.

3) The energy needed to change the state of a substance is called latent heat.

Specific Latent Heat is the Energy Needed to Change the State of a 1 kg Mass

1) The specific latent heat (SLH) of a substance is the amount of energy needed to change 1 kg of it from one state to another without changing its temperature.
2) For cooling, specific latent heat is the energy released by a change in state.
3) Specific latent heat is different for different materials, and for changing between different states.
4) The specific latent heat for changing between a solid and a liquid (melting or freezing) is called the specific latent heat of fusion. The specific latent heat for changing between a liquid and a gas (evaporating, boiling or condensing) is called the specific latent heat of vaporisation.

There's a Formula for Specific Latent Heat

Don't get confused with specific heat capacity (p.169), which relates to a temperature rise of 1 °C. Specific latent heat is about changes of state where there's no temperature change.

You can work out the energy needed (or released) when a substance of mass m changes state using this formula:

Energy (E) = Mass (m) × Specific Latent Heat (L) or: $E = mL$

Energy is given in joules (J), mass is in kg and SLH is in J/kg.

If you're finding mass or SLH, you'll need to rearrange. Here's the formula triangle.

EXAMPLE

The specific latent heat of vaporisation for water (boiling) is 2 260 000 J/kg. How much energy is needed to completely boil 1.50 kg of water at 100 °C?

1) Just plug the numbers into the formula.
2) The units are joules because it's energy.

$E = mL$
$= 1.50 \times 2\,260\,000$
$= 3\,390\,000$ J

My specific latent heat of revision* is 500 J/kg...

When it comes to the specific latent heat of vaporisation and fusion, the formula's the same, but the process is different. Make sure you understand which process you're actually looking at.

Q1 The SLH of fusion for a particular substance is 120 000 J/kg. How much energy is needed to melt 250 g of the substance when it is already at its melting temperature? [2 marks]

Q1 Video Solution

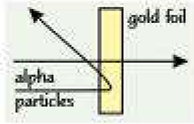
*the amount of energy required to turn 1 kg of revision notes into a top grade

Developing the Model of the Atom

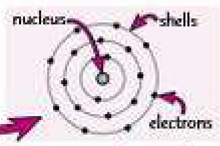
All this started with a Greek fella called Democritus in the 5th Century BC. He thought that all matter, whatever it was, was made up of identical lumps called "atomos". And that's as far as it got until the 1800s...

Rutherford Replaced the Plum Pudding Model with the Nuclear Model...

1) In 1804 John Dalton agreed with Democritus that matter was made up of tiny spheres ("atoms") that couldn't be broken up, but he reckoned that each element was made up of a different type of "atom".
2) Nearly 100 years later, J J Thomson discovered particles called electrons that could be removed from atoms. So Dalton's theory wasn't quite right. Thomson suggested atoms were spheres of positive charge with tiny negative electrons stuck in them like fruit in a plum pudding — the plum pudding model.
3) However, in 1909, scientists in Rutherford's lab tried firing a beam of alpha particles (see p.196) at thin gold foil — this was the alpha scattering experiment. From the plum pudding model, they expected the particles to pass straight through the gold sheet, or only be slightly deflected. But although most of the particles did go straight through the sheet, some were deflected more than expected, and a few were deflected back the way they had come — something the plum pudding model couldn't explain.
4) Because a few alpha particles were deflected back, the scientists realised that most of the mass of the atom must be concentrated at the centre in a tiny nucleus. This nucleus must also have a positive charge, since it repelled the positive alpha particles.
5) They also realised that because nearly all the alpha particles passed straight through, most of an atom is just empty space. This was the first nuclear model of the atom.

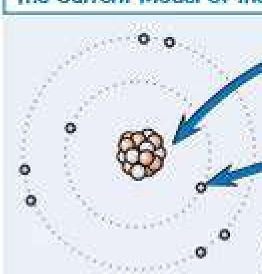


...Which Developed into the Current Model of the Atom



1) The nuclear model that resulted from the alpha particle scattering experiment was a positively charged nucleus surrounded by a cloud of negative electrons.
2) Niels Bohr said that electrons orbiting the nucleus do so at certain distances called energy levels. His theoretical calculations agreed with experimental data.
3) Evidence from further experiments changed the model to have a nucleus made up of a group of particles (protons) which all had the same positive charge that added up to the overall charge of the nucleus.
4) About 20 years after the idea of a nucleus was accepted, in 1932, James Chadwick proved the existence of the neutron, which explained the imbalance between the atomic and mass numbers (page 196).

The Current Model of the Atom



The nucleus is tiny but it makes up most of the mass of the atom. It contains protons (which are positively charged — they have a +1 relative charge) and neutrons (which are neutral, with a relative charge of 0) — which gives it an overall positive charge. Its radius is about 10 000 times smaller than the radius of the atom.

The rest of the atom is mostly empty space. Negative electrons (relative charge –1) whizz round the outside of the nucleus really fast. They give the atom its overall size — the radius of an atom is about 1×10^{-10} m.

The number of protons = the number of electrons, as protons and electrons have an equal but opposite charge and atoms have no overall charge.

Electrons in energy levels can move within (or sometimes leave) the atom. If they gain energy by absorbing EM radiation (p.220) they move to a higher energy level, further from the nucleus. If they release EM radiation, they move to a lower energy level that is closer to the nucleus. If one or more outer electrons leaves the atom, the atom becomes a positively charged ion.

We're currently pretty happy with this model, but there's no saying it won't change. Just like for the plum pudding, new experiments sometimes mean we have to change or completely get rid of current models.

These models don't have anything on my miniature trains...

This is science in action folks — as new evidence came along, the model of the atom was changed and updated.

Q1 a) Describe the current model of the atom. [4 marks]
b) State the radius of an atom and describe how this compares to the size of its nucleus. [2 marks]

Isotopes and Nuclear Radiation

Isotopes and ionisation. They sound similar, but they're totally different, so read this page carefully.

Isotopes are Different Forms of the Same Element

Every oxygen atom has 8 protons.

Mass number — $^{16}_{8}O$ — Element symbol (oxygen)
Atomic number

All atoms can be shown with this notation.

1) All atoms of each element have a set number of protons (so each nucleus has a given positive charge). The number of protons in an atom is its atomic number.
2) The mass number of an atom (the mass of the nucleus) is the number of protons + the number of neutrons in its nucleus.
3) Isotopes of an element are atoms with the same number of protons (the same atomic number, and so the same charge on the nucleus) but a different number of neutrons (a different mass number). E.g. $^{18}_{8}O$ is an isotope of oxygen.
4) All elements have different isotopes, but there are usually only one or two stable ones.
5) The other unstable isotopes tend to decay into other elements and give out radiation as they try to become more stable (they try to balance the number of protons and neutrons in their nucleus or get rid of any excess energy). This process is called radioactive decay.

6) Radioactive substances spit out one or more types of ionising radiation from their nucleus — the ones you need to know are alpha, beta and gamma radiation.
7) They can also release neutrons (n) when they decay to rebalance the number of protons and neutrons.
8) Ionising radiation is radiation that knocks electrons off atoms, creating positive ions. The ionising power of a radiation source is how easily it can do this.

Alpha Particles are Helium Nuclei

1) Alpha radiation is when an alpha particle (α) is emitted from the nucleus. An α-particle is two neutrons and two protons (like a helium nucleus).
2) They don't penetrate very far into materials and are stopped quickly — they can only travel a few cm in air and are absorbed by a sheet of paper.
3) Because of their size they are strongly ionising.

Alpha radiation is used in smoke detectors — it ionises air particles, causing a current to flow. If there is smoke in the air, it binds to the ions — meaning the current stops and the alarm sounds.

Beta Particles are High-Speed Electrons

1) A beta particle (β) is simply a fast-moving electron released by the nucleus. Beta particles have virtually no mass and a charge of –1.
2) They are moderately ionising. They penetrate moderately far into materials before colliding and have a range in air of a few metres. They are absorbed by a sheet of aluminium (around 5 mm).
3) For every beta particle emitted, a neutron in the nucleus has turned into a proton (page 197).

Beta emitters are used to test the thickness of sheets of metal, as the particles are not immediately absorbed by the material like alpha radiation would be and do not penetrate as far as gamma rays.

Gamma Rays are EM Waves with a Short Wavelength

1) Gamma rays (γ) are waves of electromagnetic radiation (p.220) released by the nucleus.
2) They penetrate far into materials without being stopped and will travel a long distance through air.
3) This means they are weakly ionising because they tend to pass through rather than collide with atoms. Eventually they hit something and do damage.
4) They can be absorbed by thick sheets of lead or metres of concrete.

Uses of gamma rays are on p.224.

Ionising radiation — good for getting creases out of clothes...

Knowing different kinds of radiation and what can absorb them often bags you a few easy marks in an exam.

Q1 In order to sterilise medical equipment, radiation is directed at the equipment while it is sealed in packaging. Explain whether alpha radiation would be suitable for this use. [2 marks]

Q1 Video Solution

Nuclear Equations

Nuclear equations show radioactive decay and once you get the hang of them they're dead easy. Get going.

Mass and Atomic Numbers Have to Balance

1) Nuclear equations are a way of showing radioactive decay by using element symbols (p.196).
2) They're written in the form: atom before decay → atom after decay + radiation emitted.
3) There is one golden rule to remember: the total mass and atomic numbers must be equal on both sides.

Alpha Decay Decreases the Charge and Mass of the Nucleus $^{4}_{2}He$

1) Remember, alpha particles are made up of two protons and two neutrons. So when an atom emits an alpha particle, its atomic number reduces by 2 and its mass number reduces by 4.
2) A proton is positively charged and a neutron is neutral, so the charge of the nucleus decreases.
3) In nuclear equations, an alpha particle can be written as a helium nucleus: $^{4}_{2}He$.

The nuclear equation for this decay would be:

$$^{238}_{92}U \rightarrow ^{234}_{90}Th + ^{4}_{2}He$$

$238 \rightarrow 234 + 4$
$92 \rightarrow 90 + 2$

Gamma rays are sometimes also released when a nucleus decays by alpha or beta decay.

Beta Decay Increases the Charge of the Nucleus $^{0}_{-1}e$

1) When beta decay occurs, a neutron in the nucleus turns into a proton and releases a fast-moving electron (the beta particle).
2) The number of protons in the nucleus has increased by 1. This increases the positive charge of the nucleus (the atomic number).
3) Because the nucleus has lost a neutron and gained a proton during beta decay, the mass of the nucleus doesn't change (protons and neutrons have the same mass).
4) A beta particle is written as $^{0}_{-1}e$ in nuclear equations.

The nuclear equation for this decay would be: $^{14}_{6}C \rightarrow ^{14}_{7}N + ^{0}_{-1}e$

$14 \rightarrow 14 + 0$
$6 \rightarrow 7 - 1$

In both alpha and beta emissions, a new element will be formed, as the number of protons (atomic number) changes.

Gamma Rays Don't Change the Charge or Mass of the Nucleus

1) Gamma rays are a way of getting rid of excess energy from a nucleus.
2) This means that there is no change to the atomic mass or atomic number of the atom.

Keep balanced during revision and practise nuclear equations...

Nuclear equations are simple, but that doesn't mean you shouldn't practise them. Give these questions a go.

Q1 What type of radiation is given off in this decay? $^{8}_{3}Li \rightarrow ^{8}_{4}Be$ + radiation. [1 mark]

Q2 Write the nuclear equation for $^{219}_{86}Rn$ decaying to polonium (Po) by emitting an alpha particle. [3 marks]

Q2 Video Solution

Half-life

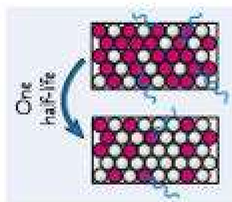
How quickly unstable nuclei decay is measured using activity and half-life — two very important terms.

Radioactivity is a Totally Random Process

1) Radioactive substances give out radiation from the nuclei of their atoms — no matter what.
2) This radiation can be measured with a Geiger-Muller tube and counter, which records the count-rate — the number of radiation counts reaching it per second.
3) Radioactive decay is entirely random. So you can't predict exactly which nucleus in a sample will decay next, or when any one of them will decay.
4) But you can find out the time it takes for the amount of radiation emitted by a source to halve, this is known as the half-life. It can be used to make predictions about radioactive sources, even though their decays are random.
5) Half-life can be used to find the rate at which a source decays — its ACTIVITY. Activity is measured in becquerels, Bq (where 1 Bq is 1 decay per second).

The Radioactivity of a Source Decreases Over Time

1) Each time a radioactive nucleus decays to become a stable nucleus, the activity as a whole will decrease. (Older sources emit less radiation.)
2) For some isotopes it takes just a few hours before nearly all the unstable nuclei have decayed, whilst others last for millions of years.
3) The problem with trying to measure this is that the activity never reaches zero, which is why we have to use the idea of half-life to measure how quickly the activity drops off.



The half-life is the time taken for the number of radioactive nuclei in an isotope to halve.

4) Half-life can also be described as the time taken for the activity (and so count-rate) to fall to half of its initial value.

EXAMPLE

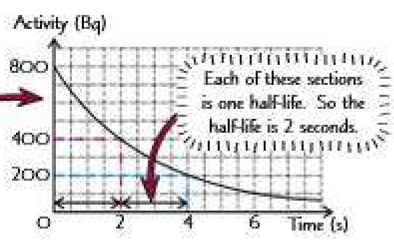
The initial activity of a sample is 640 Bq. Calculate the final activity as a percentage of the initial activity after two half-lives.

1) Find the activity after each half-life. — 1 half-life: 640 ÷ 2 = 320
   2 half-lives: 320 ÷ 2 = 160
2) Now divide the final activity by the initial activity, then multiply by 100 to make it a percentage. — (160 ÷ 640) × 100 = 0.25 × 100 = 25%

Always double check what the question is asking for — it may want a fraction, ratio or a percentage.

You Can Measure Half-Life Using a Graph

1) If you plot a graph of activity against time, it will always be shaped like the one to the right.
2) The half-life is found from the graph by finding the time interval on the bottom axis corresponding to a halving of the activity on the vertical axis. Easy.



The half-life of a box of chocolates is about five minutes...

Half-life — the time for the number of radioactive nuclei, the activity or the count-rate to halve. Simple.

Q1 The initial count-rate of a sample is 40 cps. Show that the ratio of its final count rate to its initial count rate is 1:8 after three half-lives. [3 marks]

Q1 Video Solution

Irradiation and Contamination

Time to find out how to reduce the risks associated with working with radioactive sources.

There are Risks to Using Radiation

Ionising radiation can enter living cells and ionise atoms within them. This can damage the cells (which can cause things like cancer) or kill them off completely. That's why it's important that you know the precautions to take when working with any sources of radiation.

Exposure to Radiation is called Irradiation

1) Objects near a radioactive source are irradiated by it. This simply means they're exposed to it.
2) Irradiating something does not make it radioactive (and won't turn you into a superhero).
3) Keeping sources in lead-lined boxes and standing behind barriers when using sources are common ways of reducing the effects of irradiation.
4) In some industries, the source may be in a different room and remote-controlled arms are used to handle it.

Contamination is Radioactive Particles Getting onto Objects

1) If unwanted radioactive atoms get onto or into an object, the object is said to be contaminated. E.g. if you touch a radioactive source without wearing gloves, your hands would be contaminated.
2) These contaminating atoms might then decay, releasing radiation which could cause you harm.
3) Contamination is especially dangerous because radioactive particles could get inside your body.
4) Gloves and tongs should be used when handling sources, to avoid particles getting stuck to your skin or under your nails.
5) Some industrial workers wear protective suits to stop them breathing in particles.

The Seriousness of Irradiation and Contamination Depends on the Source

Contamination or irradiation can cause different amounts of harm, based on the radiation type.

1) Outside the body, beta and gamma sources are the most dangerous.
2) This is because beta and gamma can penetrate the body and get to the delicate organs.
3) Alpha is less dangerous because it can't penetrate the skin and is easily blocked by a small air gap (p.196).
4) High levels of irradiation from all sources are dangerous, but especially from ones that emit beta and gamma.
5) Inside the body, alpha sources are the most dangerous, because they do all their damage in a very localised area. So contamination, rather than irradiation, is the major concern when working with alpha sources.
6) Beta sources are less damaging inside the body, as radiation is absorbed over a wider area, and some passes out of the body altogether. Gamma sources are the least dangerous inside the body, as they mostly pass straight out — they have the lowest ionising power, p.196.

The more we understand how different types of radiation affect our bodies, the better we can protect ourselves when using them. This is why it's so important that research about this is published. The data is peer-reviewed (see p.1) and can quickly become accepted, leading to many improvements in our use of radioactive sources.

Top tip number 364 — if something is radioactive, don't lick it...

Make sure you can describe how to prevent irradiation and contamination, and why it's so important that you do.

Q1 State one way of preventing irradiation. [1 mark]

Q2 For a gamma source, is contamination or irradiation a larger concern? [1 mark]

Revision Questions for Topics P3 & P4

At last, Topics P3 and P4 done and dusted. Time to see what you've absorbed.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quizzes for Topics P3 and P4 — just scan the QR codes!

The Particle Model, Motion in Gases and Density (p.191-192)

Topic P3 Quiz

1) What are the three states of matter?
2) For each state of matter, describe the arrangement of the particles.
3) Explain how a gas in a sealed container exerts a pressure on the walls of the container.
4) What is the formula for density? What are the units of density?
5) True or false? Solids are usually denser than gases.
6) Describe how you could find the volume of an irregular solid object.

Internal Energy and Changes of State (p.193-194)

7) What is internal energy?
8) What happens to the particles in a substance when that substance is heated?
9) Name the five changes of state.
10) True or false? Mass stays the same when a substance changes state.
11) Sketch a graph of temperature against time for a gas being cooled. Your graph should show the points that the gas turns into a liquid and that the liquid turns into a solid.
12) Define specific latent heat. Give a formula for specific latent heat.

The Atomic Model (p.195)

Topic P4 Quiz

13) True or false? People used to believe that atoms were tiny spheres that couldn't be broken apart.
14) Describe Rutherford and Marsden's experiment which disproved the plum pudding model.
15) What happens to an electron in an atom if it releases EM radiation?
16) Who provided evidence to suggest the existence of the neutron?
17) True or false? Electrons make up most of the mass of an atom.
18) What is the overall charge of an atom?
19) What happens to an atom if it loses one or more of its electrons?

Nuclear Decay and Half-life (p.196-198)

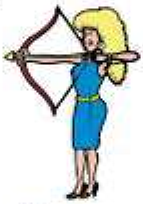
20) Which number defines what element an atom is: the atomic number or the mass number?
21) What is the atomic number of an atom? What is the mass number of an atom?
22) What is an isotope? Are they usually stable?
23) For the three types of ionising radiation, give: a) their ionising power, b) their range in air.
24) Draw the symbols for both alpha and beta radiation in nuclear equations.
25) What is the activity of a source? How does activity relate to count-rate?
26) Define half-life and describe how to find a source's half-life, given a graph of its activity over time.

Dangers of Radiation (p.199)

27) Define irradiation and contamination.
28) Give two examples of how to protect against: a) contamination, b) irradiation.
29) Compare the hazards of being irradiated and contaminated by:
    a) an alpha source, b) a gamma source.

Contact and Non-Contact Forces

When you're talking about the forces acting on an object, it's not enough to just talk about the size of each force. You need to know their direction too — force is a vector, with a size and a direction.



Vectors Have Magnitude and Direction

1) Force is a vector quantity — vector quantities have a magnitude and a direction.
2) Lots of physical quantities are vector quantities:

   Vector quantities: force, velocity, displacement, acceleration, momentum, etc.

3) Some physical quantities only have magnitude and no direction. These are called scalar quantities:

   Scalar quantities: speed, distance, mass, temperature, time, etc.

4) Vectors are usually represented by an arrow — the length of the arrow shows the magnitude, and the direction of the arrow shows the direction of the quantity.

Velocity is a vector, but speed is a scalar quantity.
Both bikes are travelling at the same speed, v (the length of each arrow is the same).
They have different velocities because they are travelling in different directions.

Forces Can be Contact or Non-Contact

1) A force is a push or a pull on an object that is caused by it interacting with something.
2) All forces are either contact or non-contact forces.
3) When two objects have to be touching for a force to act, that force is called a contact force.

   E.g. friction, air resistance, tension in ropes, normal contact force, etc.

4) If the objects do not need to be touching for the force to act, the force is a non-contact force.

   E.g. magnetic force, gravitational force, electrostatic force, etc.

5) When two objects interact, there is a force produced on both objects.
   An interaction pair is a pair of forces that are equal and opposite and act on two interacting objects.
   (This is basically Newton's Third Law — see p.212.)

The Sun and the Earth are attracted to each other by the gravitational force. This is a non-contact force. An equal but opposite force of attraction is felt by both the Sun and the Earth.

A chair exerts a force on the ground, whilst the ground pushes back at the chair with the same force (the normal contact force). Equal but opposite forces are felt by both the chair and the ground.

My life's feeling pretty scalar — I've no idea where I'm headed...

This all seems pretty basic, but it's vital you understand it if you want to make it through the rest of this topic.

Q1 A tennis ball is dropped from a height. Name one contact force and one non-contact force that act on the ball as it falls. [2 marks]

Q2 Name two examples of: a) a scalar quantity b) a vector quantity [4 marks]

Weight, Mass and Gravity

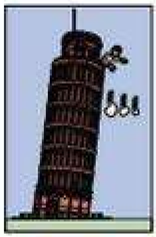
Now for something a bit more attractive — the force of gravity. Enjoy...

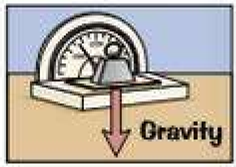
Gravitational Force is the Force of Attraction Between Masses

Gravity attracts all masses, but you only notice it when one of the masses is really really big, e.g. a planet. Anything near a planet or star is attracted to it very strongly.

This has two important effects:

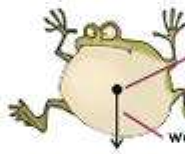
1) On the surface of a planet, it makes all things fall towards the ground.
2) It gives everything a weight.





Weight and Mass are Not the Same

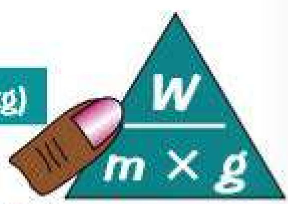
1) Mass is just the amount of 'stuff' in an object. For any given object this will have the same value anywhere in the universe.
2) Weight is the force acting on an object due to gravity (the pull of the gravitational force on the object). Close to Earth, this force is caused by the gravitational field around the Earth.
3) Gravitational field strength varies with location. It's stronger the closer you are to the mass causing the field, and stronger for larger masses.
4) The weight of an object depends on the strength of the gravitational field at the location of the object. This means that the weight of an object changes with its location.
5) For example, an object has the same mass whether it's on Earth or on the Moon — but its weight will be different. A 1 kg mass will weigh less on the Moon (about 1.6 N) than it does on Earth (about 9.8 N), simply because the gravitational field strength on the surface of the Moon is less.
6) Weight is a force measured in newtons. You can think of the force as acting from a single point on the object, called its centre of mass (a point at which you assume the whole mass is concentrated). For a uniform object (one that's the same density, p.192, throughout and is a regular shape), this will be at the centre of the object.
7) Weight is measured using a calibrated spring balance (or newtonmeter).
8) Mass is not a force. It's measured in kilograms with a mass balance (an old-fashioned pair of balancing scales).



Mass and Weight are Directly Proportional

1) You can calculate the weight of an object if you know its mass (m) and the strength of the gravitational field that it is in (g):

Weight (N) = Mass (kg) × Gravitational Field Strength (N/kg)



2) For Earth, $g \simeq 9.8$ N/kg and for the Moon it's around 1.6 N/kg. Don't worry, you'll always be given a value of g to use in the exam.
3) Increasing the mass of an object increases its weight. If you double the mass, the weight doubles too, so you can say that weight and mass are directly proportional.
4) You can write this, using the direct proportionality symbol, as $W \propto m$.

I don't think you understand the gravity of this situation...

Remember, weight is a force due to gravity that acts from an object's centre of mass. It changes depending on the strength of the gravitational field the object is in (and is directly proportional to the object's mass).

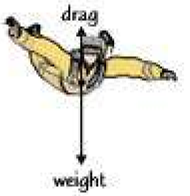
Q1 Calculate the weight in newtons of a 5 kg mass:
a) on Earth ($g \simeq 9.8$ N/kg) b) on the Moon ($g \simeq 1.6$ N/kg) [4 marks]

Q1 Video Solution

Resultant Forces and Work Done

I'm sure you're no stranger to doing work, but in physics it's all to do with overall forces and energy.

Free Body Diagrams Show All the Forces Acting on an Object



1) You need to be able to describe all the forces acting on an isolated object or a system (p.167) — i.e. every force acting on the object or system but none of the forces the object or system exerts on the rest of the world.
2) For example, a skydiver's weight acts on him pulling him towards the ground and drag (air resistance) also acts on him, in the opposite direction to his motion.
3) This can be shown using a free body diagram like the one on the right.
4) The sizes of the arrows show the relative magnitudes of the forces and the directions show the directions of the forces acting on the object.

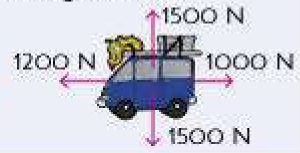
A Resultant Force is the Overall Force on a Point or Object

1) In most real situations there are at least two forces acting on an object along any direction.
2) If you have a number of forces acting at a single point, you can replace them with a single force (so long as the single force has the same effect as all the original forces together).
3) This single force is called the resultant force. (There's a downward resultant force acting on the skydiver above.)
4) If the forces all act along the same line (they're all parallel), the overall effect is found by adding those going in the same direction and subtracting any going in the opposite direction.

EXAMPLE For the free body force diagram given, calculate the resultant force acting on the van.

1) Consider the horizontal and vertical directions separately.
2) State the size and direction of the resultant force.

Vertical: 1500 – 1500 = 0 N
Horizontal: 1200 – 1000 N = 200 N
The resultant force is 200 N to the left.



If A Resultant Force Moves An Object, Work is Done

When a force moves an object through a distance, ENERGY IS TRANSFERRED and WORK IS DONE on the object.

1) To make something move (or keep it moving if there are frictional forces), a force must be applied.
2) The thing applying the force needs a source of energy (like fuel or food).
3) The force does 'work' to move the object and energy is transferred from one store to another (p.167).
4) Whether energy is transferred 'usefully' (e.g. lifting a load) or is 'wasted' (p.170) you can still say that 'work is done'. Just like Batman and Bruce Wayne, 'work done' and 'energy transferred' are the same.

When you push something along a rough surface (like a carpet) you are doing work against frictional forces. Energy is being transferred to the kinetic energy store of the object because it starts moving, but some is also being transferred to thermal energy stores due to the friction. This causes the overall temperature of the object to increase. (Like rubbing your hands together to warm them up.)

5) You can find out how much work has been done using:
6) One joule of work is done when a force of one newton causes an object to move a distance of one metre. You need to be able to convert joules to newton metres: 1 J = 1 Nm.

$$W = Fs$$

Work done (J); Force (N); Distance (moved along the line of action of the force) (m)

Consolidate all your forces into one easy-to-manage force...

Free body diagrams make most force questions easier, so start by sketching one. Then get to work.

Q1 A force of 20 N pushes an object 20 cm. Calculate the work done on the object. [3 marks]

Q1 Video Solution

Calculating Forces

Scale drawings are useful things — they can help you resolve forces or work out the resultant force.

Use Scale Drawings to Find Resultant Forces

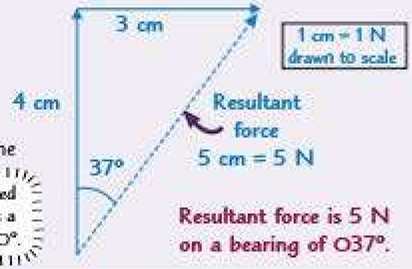
1) Draw all the forces acting on an object, to scale, 'tip-to-tail'.
2) Then draw a straight line from the start of the first force to the end of the last force — this is the resultant force.
3) Measure the length of the resultant force on the diagram to find the magnitude and the angle to find the direction of the force.

EXAMPLE

A man is on an electric bicycle that has a driving force of 4 N north. However, the wind produces a force of 3 N east. Find the magnitude and direction of the resultant force.

1) Start by drawing a scale drawing of the forces acting.
2) Make sure you choose a sensible scale (e.g. 1 cm = 1 N).
3) Draw the resultant from the tail of the first arrow to the tip of the last arrow.
4) Measure the length of the resultant with a ruler and use the scale to find the force in N.
5) Use a protractor to measure the direction as a bearing.

A bearing is an angle measured clockwise from north, given as a 3 digit number, e.g. 10° = 010°.



Resultant force is 5 N on a bearing of 037°.

An Object is in Equilibrium if the Forces on it are Balanced

1) If all of the forces acting on an object combine to give a resultant force of zero, the object is in equilibrium.
2) On a scale diagram, this means that the tip of the last force you draw should end where the tail of the first force you drew begins. E.g. for three forces, the scale diagram will form a triangle.
3) You might be given forces acting on an object and told to find a missing force, given that the object is in equilibrium. To do this, draw out the forces you do know (to scale and tip-to-tail), join the end of the last force to the start of the first force. This line is the missing force so you can measure its size and direction.

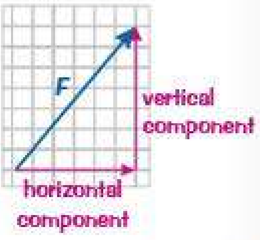
Make sure you draw the last force in the right direction. It's in the opposite direction to how you'd draw a resultant force.

Tip-to-tail the forces join up...

...so the resultant force is zero.

You Can Split a Force into Components

1) Not all forces act horizontally or vertically — some act at awkward angles.
2) To make these easier to deal with, they can be split into two components at right angles to each other (usually horizontal and vertical).
3) Acting together, these components have the same effect as the single force.
4) You can resolve a force (split it into components) by drawing it on a scale grid. Draw the force to scale, and then add the horizontal and vertical components along the grid lines. Then you can just measure them.



Don't blow things out of proportion — it's only scale drawings...

Keep those pencils sharp and those scale drawings accurate — or you'll end up with the wrong answer.

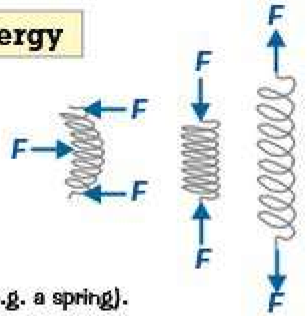
Q1 An object in equilibrium is being acted on by three forces. The first force is 0.50 N acting south and the second force is 0.30 N acting on a bearing of 045°. Find the magnitude and bearing of the third force. [3 marks]

Q1 Video Solution

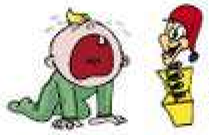
Forces and Elasticity

You can use forces to stretch things too. The fun never ends...

Stretching, Compressing or Bending Transfers Energy



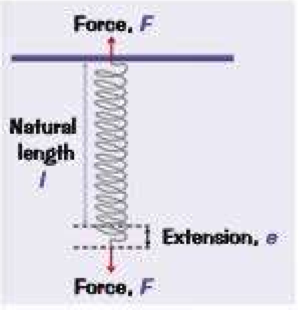
1) When you apply a force to an object you may cause it to stretch, compress or bend.
2) To do this, you need more than one force acting on the object (otherwise the object would simply move in the direction of the applied force, instead of changing shape).
3) An object has been elastically deformed if it can go back to its original shape and length after the force has been removed.
4) Objects that can be elastically deformed are called elastic objects (e.g. a spring).
5) An object has been inelastically deformed if it doesn't return to its original shape and length after the force has been removed.
6) Work is done when a force stretches or compresses an object and causes energy to be transferred to the elastic potential energy store of the object. If it is elastically deformed, ALL this energy is transferred to the object's elastic potential energy store (see p.168).



Elastic objects — useful for passing exams and scaring small children

Extension is Directly Proportional to Force...

If a spring is supported at the top and then a weight is attached to the bottom, it stretches.



1) The extension of a stretched spring (or other elastic object) is directly proportional to the load or force applied — so $F \propto e$.
2) This is the equation:

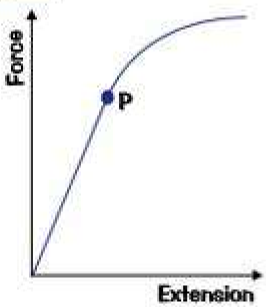
$$F = ke$$

Force (N) — F; Spring constant (N/m) — k; Extension (m) — e

3) The spring constant depends on the material that you are stretching — a stiffer spring has a greater spring constant.
4) The equation also works for compression (where e is just the difference between the natural and compressed lengths — the compression).

...but this Stops Working when the Force is Great Enough

There's a limit to the amount of force you can apply to an object for the extension to keep on increasing proportionally.



1) The graph shows force against extension for an elastic object.
2) There is a maximum force above which the graph curves, showing that extension is no longer proportional to force. This is known as the limit of proportionality and is shown on the graph at the point marked P.
3) You might see graphs with these axes the other way around — extension-force graphs. The graph still starts has a straight part, but starts to curve upwards once you go past the limit of proportionality, instead of downwards.

I could make a joke, but I don't want to stretch myself...

That equation is pretty simple, but that doesn't mean you can skip over it. Have a go at the question below.

Q1 A spring is fixed at one end and a force of 1 N is applied to the other end, causing it to stretch. The spring extends by 2 cm. Calculate the spring constant of the spring. [4 marks]

Q1 Video Solution

Investigating Springs

You can do an easy experiment to see exactly how adding masses to a spring causes it to stretch.

You Can Investigate the Link Between Force and Extension

PRACTICAL

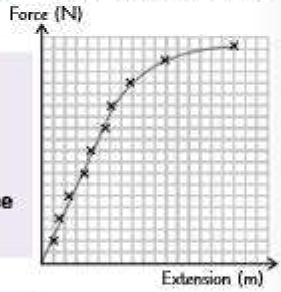
Set up the apparatus as shown in the diagram. Make sure you have plenty of extra masses, then measure the mass of each (with a mass balance) and calculate its weight (the force applied) using $W = mg$ (p.202).

You could do a quick pilot experiment first to check your masses are a good size:

- Using an identical spring to the one you'll be testing, load it with masses one at a time up to a total of five. Measure the extension each time you add another mass.
- Work out the increase in the extension of the spring for each of your masses. If any of them cause a bigger increase than the previous masses, you've gone past the spring's limit of proportionality. If this happens, you'll need to use smaller masses, or else you won't get enough measurements for your graph.

1) Measure the natural length of the spring (when no load is applied) with a millimetre ruler clamped to the stand. Make sure you take the reading at eye level and add a marker (e.g. a thin strip of tape) to the bottom of the spring to make the reading more accurate.
2) Add a mass to the spring and allow it to come to rest. Record the mass and measure the new length of the spring. The extension is the change in length.
3) Repeat this process until you have enough measurements (no fewer than 6).
4) Plot a force-extension graph of your results. It will only start to curve if you exceed the limit of proportionality, but don't worry if yours doesn't (as long as you've got the straight line bit).

To check whether the deformation is elastic or inelastic, you can remove each mass temporarily and check the spring goes back to the previous extension.



- When the line of best fit is a straight line it means there is a linear relationship between force and extension (they're directly proportional, see previous page). $F = ke$, so the gradient of the straight line is equal to k, the spring constant.
- When the line begins to bend, the relationship is now non-linear between force and extension — the spring stretches more for each unit increase in force.

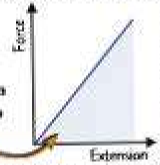
You Can Work Out Energy Stored for Linear Relationships

1) As long as a spring is not stretched past its limit of proportionality, the work done in stretching (or compressing) a spring can be found using:

$$E_e = \frac{1}{2}ke^2$$

Elastic potential energy (J); Spring constant (N/m); Extension (m)

The energy in the elastic potential energy store of a stretched spring is equal to the area under a force-extension graph up to that point.



2) For elastic deformation, this formula can be used to calculate the energy stored in a spring's elastic potential energy store. It's also the energy transferred to the spring as it's deformed (or transferred by the spring as it returns to its original shape).

Time to spring into action and learn all this...

Remember, you can only use the gradient to find the spring constant if the graph is linear (a straight line).

Q1 A spring with a spring constant of 40 N/m extends elastically by 2.5 cm. Calculate the amount of energy stored in its elastic potential energy store. [3 marks]

Q1 Video Solution

Distance, Displacement, Speed and Velocity

Time for a quick recap on distance and speed. You should race through this page. On your marks...

Distance is Scalar, Displacement is a Vector

1) Distance is just how far an object has moved. It's a scalar quantity (p.201) so it doesn't involve direction.
2) Displacement is a vector quantity. It measures the distance and direction in a straight line from an object's starting point to its finishing point — e.g. the plane flew 5 metres north. The direction could be relative to a point, e.g. towards the school, or a bearing (a three-digit angle from north, e.g. 035°).
3) If you walk 5 m north, then 5 m south, your displacement is 0 m but the distance travelled is 10 m.

Speed and Velocity are Both How Fast You're Going

1) Speed and velocity both measure how fast you're going, but speed is a scalar and velocity is a vector:

> **Speed** is just how fast you're going (e.g. 30 mph or 20 m/s) with no regard to the direction.
> **Velocity** is speed in a given direction, e.g. 30 mph north or 20 m/s, 060°.

2) This means you can have objects travelling at a constant speed with a changing velocity. This happens when the object is changing direction whilst staying at the same speed. An object moving in a circle at a constant speed has a constantly changing velocity, as the direction is always changing (e.g. a car going around a roundabout).
3) If you want to measure the speed of an object that's moving with a constant speed, you should time how long it takes the object to travel a certain distance, e.g. using a ruler and a stopwatch. You can then calculate the object's speed from your measurements using this formula:

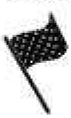
$$s = vt$$

distance travelled (m) = speed (m/s) × time (s)

4) Objects rarely travel at a constant speed. E.g. when you walk, run or travel in a car, your speed is always changing. For these cases, the formula above gives the average (mean) speed during that time.

You Need to Know Some Typical Everyday Speeds

1) Whilst every person, train, car etc. is different, there is usually a typical speed that each object travels at. Remember these typical speeds for everyday objects:



A person walking — 1.5 m/s	A car — 25 m/s
A person running — 3 m/s	A train — 30 m/s
A person cycling — 6 m/s	A plane — 250 m/s

2) Lots of different things can affect the speed something travels at. For example, the speed at which a person can walk, run or cycle depends on their fitness, their age, the distance travelled and the terrain (what kind of land they're moving over, e.g. roads, fields) as well as many other factors.
3) It's not only the speed of objects that varies. The speed of sound (330 m/s in air) changes depending on what the sound waves are travelling through, and the speed of wind is affected by many factors.
4) Wind speed can be affected by things like temperature, atmospheric pressure and if there are any large buildings or structures nearby (e.g. forests reduce the speed of the air travelling through them).

Ah, speed equals distance over time — that old chestnut...

Remember those typical speeds of objects — you might need to use them to make estimates.

Q1 A sprinter runs 200 m in 25 s. Calculate his speed. [3 marks]

Q1 Video Solution

Q2 Marie walks her dog after school. She takes a route of 1500 m that starts at and returns to her house. State: a) the distance she travels b) her displacement [2 marks]

Acceleration

Uniform acceleration sounds fancy, but it's just speeding up (or slowing down) at a constant rate.

Acceleration is How Quickly You're Speeding Up

1) Acceleration is definitely not the same as velocity or speed.
2) Acceleration is the change in velocity in a certain amount of time.
3) You can find the average acceleration of an object using:

$$a = \frac{\Delta v}{t}$$

Acceleration (m/s²) — a; Change in velocity (m/s) — Δv; Time (s) — t

4) Deceleration is just negative acceleration (if something slows down, the change in velocity is negative).

EXAMPLE

A cat accelerates at 2.5 m/s² from 2.0 m/s to 6.0 m/s. Find the time it takes to do this.

$t = \Delta v \div a$
$= (6.0 - 2.0) \div 2.5 = 1.6$ s

You Need to be Able to Estimate Accelerations

You might have to estimate the acceleration (or deceleration) of an object. To do this, you need the typical speeds from the previous page:

EXAMPLE

A car is travelling along a road, when it collides with a tree and comes to a stop. Estimate the deceleration of the car.

1) First, give a sensible speed for the car to be travelling at. — The typical speed of a car is ~25 m/s.
2) Next, estimate how long it would take the car to stop. — The car comes to a stop in ~1 s.
3) Put these numbers into the acceleration equation. — $a = \Delta v \div t$ $= (-25) \div 1$ $= -25$ m/s²
4) The question asked for the deceleration, so you can lose the minus sign (which shows the car is slowing down): — So the deceleration is ~25 m/s²

The ~ symbol just means it's an approximate value (or answer).

Uniform Acceleration Means a Constant Acceleration

1) Constant acceleration is sometimes called uniform acceleration.
2) Acceleration due to gravity (g) is uniform for objects in free fall. It's roughly equal to 9.8 m/s² near the Earth's surface and has the same value as gravitational field strength (p.202).
3) You can use this equation for uniform acceleration:

$$v^2 - u^2 = 2as$$

Final velocity (m/s) — v; Initial velocity (m/s) — u; Acceleration (m/s²) — a; Distance (m) — s

Initial velocity is just the starting velocity of the object.

EXAMPLE

A van travelling at 23 m/s starts decelerating uniformly at 2.0 m/s² as it heads towards a built-up area 112 m away. What will its speed be when it reaches the built-up area?

1) First, rearrange the equation so v^2 is on one side. — $v^2 = u^2 + 2as$
2) Now put the numbers in — remember a is negative because it's a deceleration. — $v^2 = 23^2 + (2 \times -2.0 \times 112)$ $= 81$
3) Finally, square root the whole thing. — $v = \sqrt{81} = 9$ m/s

Uniform problems — get a clip-on tie or use the equation above...

You might not be told what equation to use in the exam, so make sure you can spot when to use the equation for uniform acceleration. Make a list of the information you're given to help you see what to do.

Q1 A ball is dropped from a height, h, above the ground. The speed of the ball just before it hits the ground is 7 m/s. Calculate the height the ball is dropped from. (acceleration due to gravity ≈ 9.8 m/s²) [3 marks]

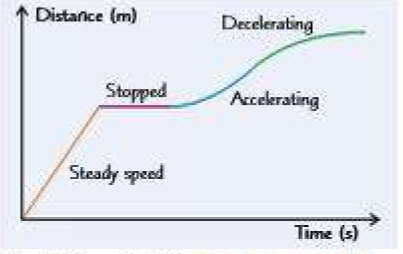
Q1 Video Solution

Distance-Time and Velocity-Time Graphs

You need to be able to draw and interpret distance and velocity-time graphs.

You Can Show Journeys on Distance-Time Graphs

If an object moves in a straight line, its distance travelled can be plotted on a distance-time graph.

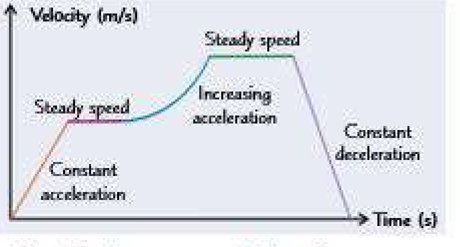


1) Gradient = speed. (The steeper the graph, the faster it's going.) This is because: speed = distance ÷ time = (change in vertical axis) ÷ (change in horizontal axis).
2) Flat sections are where it's stationary — it's stopped.
3) Straight uphill sections mean it is travelling at a steady speed.
4) Curves represent acceleration or deceleration (p.208)
5) A steepening curve means it's speeding up (increasing gradient).
6) A levelling off curve means it's slowing down.
7) If the object is changing speed (accelerating) you can find its speed at a point by finding the gradient of the tangent to the curve at that point, p.146.

You Can Also Show them on a Velocity-Time Graph

How an object's velocity changes as it travels can be plotted on a velocity-time graph.

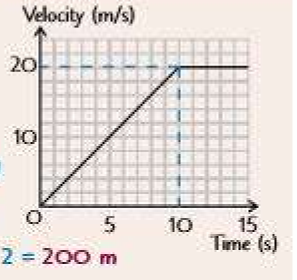
1) Gradient = acceleration, since acceleration is change in velocity ÷ time.
2) Flat sections represent travelling at a steady speed.
3) The steeper the graph, the greater the acceleration or deceleration.
4) Uphill sections (/) are acceleration.
5) Downhill sections (\) are deceleration.
6) A curve means changing acceleration.
   If the graph is curved, you can use a tangent to the curve at a point to find the acceleration at that point.



7) The area under any section of the graph (or all of it) is equal to the distance travelled in that time interval.
8) If the section under the graph is irregular, it's easier to find the area by counting the squares under the line and multiplying the number by the value of one square.

EXAMPLE

The velocity-time graph of a car's journey is plotted.
a) Calculate the acceleration of the car over the first 10 s.
b) How far does the car travel in the first 15 s of the journey?



a) This is just the gradient of the line. $a = \Delta v \div t = 20 \div 10 = 2\ m/s^2$

b) Split the area into a triangle and a rectangle, then add together their areas. Area = (½ × 10 × 20) + (5 × 20) = 200 m

Or find the value of one square, count the total number of squares under the line, and then multiply these two values together.
1 square = 2 m/s × 1 s = 2 m
Area = 100 squares = 100 × 2 = 200 m

Understanding motion graphs — it can be a real uphill struggle...

Make sure you know the difference between distance-time and velocity-time graphs, and how to interpret them.

Q1 Sketch the distance-time graph for an object that accelerates before travelling at a steady speed. [2 marks]

Q2 A stationary car starts accelerating increasingly for 10 s until it reaches a speed of 20 m/s. It travels at this speed for 20 s until the driver sees a hazard and brakes. He decelerates uniformly, coming to a stop 4 s after braking. Draw the velocity-time graph for this journey. [3 marks]

Q2 Video Solution

Terminal Velocity

Ever wondered why it's so hard to run into a hurricane whilst wearing a sandwich board? It's all to do with the air around you causing drag. Read on to find out more about drag and how it affects terminal velocity...

Friction is Always There to Slow Things Down

1) If an object has no force propelling it along it will always slow down and stop because of friction (unless you're in space where there's nothing to rub against).
2) Friction always acts in the opposite direction to movement.
3) To travel at a steady speed, the driving force needs to balance the frictional forces (see next page).
4) You get friction between two surfaces in contact, or when an object passes through a fluid (drag).
5) You can reduce friction between surfaces by using a lubricant (p.171).

Drag Increases as Speed Increases

1) Drag is the resistance you get in a fluid (a gas or a liquid). Air resistance is a type of drag.
2) The most important factor by far in reducing drag is keeping the shape of the object streamlined.
3) This is where the object is designed to allow fluid to flow easily across it, reducing drag. Parachutes work in the opposite way — they want as much drag as they can get.
4) Frictional forces from fluids always increase with speed. A car has much more friction to work against when travelling at 70 mph compared to 30 mph. So at 70 mph the engine has to work much harder just to maintain a steady speed.

Air flows easily over a streamlined car.

Objects Falling Through Fluids Reach a Terminal Velocity

1) When a falling object first sets off, the force of gravity is much more than the frictional force slowing it down, so it accelerates.
2) As the speed increases the friction builds up.
3) This gradually reduces the acceleration until eventually the frictional force is equal to the accelerating force (so the resultant force is zero).
4) It will have reached its maximum speed or terminal velocity and will fall at a steady speed.

Falling with style

Terminal Velocity Depends on Shape and Area

1) Typically, the less streamlined an object is, the lower its terminal velocity.
2) So objects with large surface areas tend to have lower terminal velocities.
3) For example, if you dropped a marble and a beach ball off a tall building, the marble's terminal velocity would be higher than the terminal velocity of the beach ball.
4) This is because there is more air resistance acting on the beach ball, at any given speed.
5) So the beach ball spends less time accelerating (and so doesn't speed up as much) before the air resistance is large enough to equal the accelerating force.

Learning about air resistance — it can be a real drag...

Frictional forces are pretty much everywhere and they crop up again and again in physics, so make sure you are comfortable talking about them. Then move on to explaining how drag affects an object's terminal velocity.

Q1 Explain why a ball falling from the top of a tall building reaches terminal velocity. [3 marks]

Newton's First and Second Laws

In the 1660s, a chap called Isaac Newton worked out his dead useful Laws of Motion. Here are the first two.

A Force is Needed to Change Motion

This may seem simple, but it's important. Newton's First Law says that a resultant force (p.203) is needed to make something start moving, speed up or slow down:

> If the resultant force on a stationary object is zero, the object will remain stationary. If the resultant force on a moving object is zero, it'll just carry on moving at the same velocity (same speed and direction).

So, when a train or car or bus or anything else is moving at a constant velocity, the resistive and driving forces on it must all be balanced. The velocity will only change if there's a non-zero resultant force acting on the object.

1) A non-zero resultant force will always produce acceleration (or deceleration) in the direction of the force.
2) This "acceleration" can take five different forms: starting, stopping, speeding up, slowing down and changing direction.
3) On a free body diagram, the arrows will be unequal.

Acceleration is Proportional to the Resultant Force

1) The larger the resultant force acting on an object, the more the object accelerates — the force and the acceleration are directly proportional. You can write this as $F \propto a$.
2) Acceleration is also inversely proportional to the mass of the object — so an object with a larger mass will accelerate less than one with a smaller mass (for a fixed resultant force).
3) There's an incredibly useful formula that describes Newton's Second Law:

$$F = ma$$

Resultant force (N) — F; Acceleration (m/s²) — a; Mass (kg) — m

EXAMPLE

A van of mass of 2080 kg has an engine that provides a driving force of 5200 N. At 70 mph the drag force acting on the van is 5148 N. Find its acceleration at 70 mph.

1) Work out the resultant force on the van. (Drawing a free body diagram may help.)
   Resultant force = 5200 – 5148 = 52 N
2) Rearrange $F = ma$ and stick in the values you know.
   $a = F \div m$
   $= 52 \div 2080 = 0.025$ m/s²

You can use Newton's Second Law to get an idea of the forces involved in everyday transport. Large forces are needed to produce large accelerations:

EXAMPLE

Estimate the resultant force on a car as it accelerates from rest to a typical speed.

1) Estimate the acceleration of the car, using typical speeds from page 207. (The ~ means approximately.)
   A typical speed of a car is ~25 m/s. It takes ~10 s to reach this.
   So $a = \Delta v \div t = 25 \div 10 = 2.5$ m/s²
2) Estimate the mass of the car.
   Mass of a car is ~1000 kg.
3) Put these numbers into Newton's 2nd Law.
   So using $F = ma = 1000 \times 2.5 = 2500$ N
   So the resultant force is ~2500 N.

Accelerate your learning — force yourself to revise...

Short and sweet, just how I like my equations. Sadly you can't get away with just learning those symbols — make sure you've got your head around both of those laws, before moving on to Newton's third and final law.

Q1 Find the force needed for an 80 kg man on a 10 kg bike to accelerate at 0.25 m/s². [2 marks]

Q1 Video Solution

Inertia and Newton's Third Law

Inertia and Newton's Third Law can seem simple on the surface, but they can quickly get confusing. Make sure you really understand what's going on with it — especially if an object is in equilibrium.

Inertia is the Tendency for Motion to Remain Unchanged

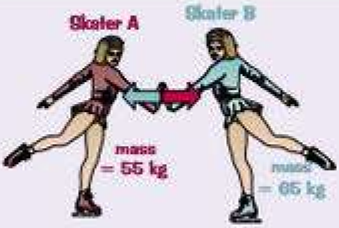
1) Until acted upon by a resultant force, objects at rest stay at rest and objects moving at a steady speed will stay moving at that speed (Newton's First Law). This tendency to continue in the same state of motion is called inertia.
2) An object's inertial mass measures how difficult it is to change the velocity of an object.
3) Inertial mass can be found using Newton's Second Law of $F = ma$ (previous page). Rearranging this gives $m = F \div a$, so inertial mass is just the ratio of force over acceleration.

Newton's Third Law Involves Equal and Opposite Forces

Newton's Third Law says:

> When two objects interact, the forces they exert on each other are equal and opposite.

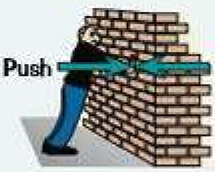
1) If you push something, say a shopping trolley, the trolley will push back against you, just as hard.
2) And as soon as you stop pushing, so does the trolley. Kinda clever really.
3) So far so good. The slightly tricky thing to get your head round is this — if the forces are always equal, how does anything ever go anywhere? The important thing to remember is that the two forces are acting on different objects.



When skater A pushes on skater B (the 'action' force), she feels an equal and opposite force from skater B's hand (the 'normal contact' force). Both skaters feel the same sized force, in opposite directions, and so accelerate away from each other.

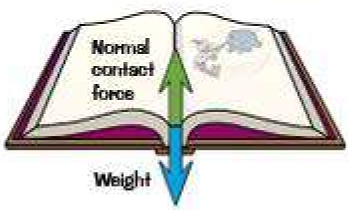
Skater A will be accelerated more than skater B, though, because she has a smaller mass — remember $a = F \div m$.

An example of Newton's Third Law in an equilibrium situation is a man pushing against a wall. As the man pushes the wall, there is a normal contact force acting back on him. These two forces are the same size. As the man applies a force and pushes the wall, the wall 'pushes back' on him with an equal force.



It can be easy to get confused with Newton's Third Law when an object is in equilibrium. A book resting on the ground is in equilibrium. The weight of the book is equal to the normal contact force.

But this is NOT Newton's Third Law because the two forces are different types, and both acting on the book.



Newton's fourth law — revision must be done with tea...

Newton's 3rd law can trip people up, so make sure you understand exactly what the forces are acting on and how that results in movement (or lack of it). Then have a crack at this question to practise what you know.

Q1 A car moves at a constant velocity along a road, so that it is in equilibrium. Give an example of a pair of forces that demonstrate Newton's Third Law in this situation. [1 mark]

Q1 Video Solution

Investigating Motion

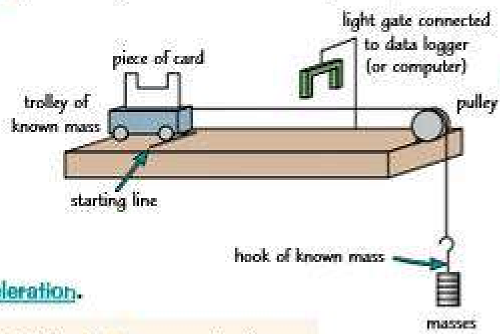
Sure, you can learn the different laws of motion, but doing an experiment for yourself can really help you to understand what's going on. Read on for some snazzy ways to test how mass and force affect motion.

You can Investigate how Mass and Force Affect Acceleration

PRACTICAL

It's time for an experiment that tests Newton's 2nd law, $F = ma$ (p.211).

1) Set up the apparatus shown below. Set up the trolley so it holds a piece of card with a gap in the middle that will interrupt the signal on the light gate twice. If you measure the length of each bit of card that will pass through the light gate and input this into the software, the light gate can measure the velocity for each bit of card. It can use this to work out the acceleration of the trolley.
2) Connect the trolley to a piece of string that goes over a pulley and is connected on the other side to a hook (that you know the mass of and can add more masses to).
3) The weight of the hook and any masses attached to it will provide the accelerating force, equal to the mass of the hook (m) × acceleration due to gravity (g).
4) The weight of the hook and masses accelerates both the trolley and the masses, so you are investigating the acceleration of the system (the trolley and the masses together).
5) Mark a starting line on the table the trolley is on, so that the trolley always travels the same distance to the light gate.
6) Place the trolley on the starting line, holding the hook so the string is taut (not loose and touching the table), and release it.
7) Record the acceleration measured by the light gate as the trolley passes through it. This is the acceleration of the whole system.
8) Repeat this twice more to get an average acceleration.



1) To investigate the effect of mass, add masses to the trolley one at a time to increase the mass of the system. Don't add masses to the hook, or you'll change the force. Record the average acceleration for each mass.
2) To investigate the effect of force, you need to keep the total mass of the system the same, but change the mass on the hook. To do this, start with all the masses loaded onto the trolley, and transfer the masses to the hook one at a time, to increase the accelerating force (the weight of the hanging masses). The mass of the system stays the same as you're only transferring the masses from one part of the system (the trolley) to another (the hook). Record the average acceleration for each force.

The friction between the trolley and the bench might affect your acceleration measurements. You could use an air track to reduce this friction (a track which hovers a trolley on jets of air).

Newton's Second Law Can Explain the Results

1) Newton's Second Law can be written as $F = ma$. Here, F = weight of the hanging masses, m = mass of the whole system and a = acceleration of the system.
2) By adding masses to the trolley, the mass of the whole system increases, but the force applied to the system stays the same. This should lead to a decrease in the acceleration of the trolley, as $a = F \div m$.
3) By transferring masses to the hook, you are increasing the accelerating force without changing the mass of the whole system. So increasing the force should lead to an increase in the acceleration of the trolley.

My acceleration increases with nearby cake...

Know the ins and outs of that experiment — you could be asked about any part of it or to describe the whole thing.

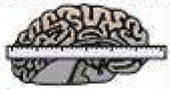
Q1 Explain how a light gate can be used to measure the acceleration of a trolley. [3 marks]

Stopping Distances

Knowing what affects stopping distances is especially useful for everyday life, as well as the exam.

Many Factors Affect Your Total Stopping Distance

1) In an emergency (e.g. a hazard ahead in the road), a driver may perform an emergency stop. This is where maximum force is applied by the brakes in order to stop the car in the shortest possible distance. The longer it takes to perform an emergency stop, the higher the risk of crashing into whatever's in front.
2) The distance it takes to stop a car in an emergency (its stopping distance) is found by:



Stopping Distance = Thinking Distance + Braking Distance

Where the THINKING DISTANCE is how far the car travels during the driver's reaction time (the time between the driver seeing a hazard and applying the brakes). And the BRAKING DISTANCE is the distance taken to stop under the braking force (once the brakes are applied). Typical car braking distances are: 14 m at 30 mph, 55 m at 60 mph and 75 m at 70 mph.

Thinking distance is affected by:
- Your SPEED — the faster you're going the further you'll travel during the time you take to react.
- Your REACTION TIME — the longer your reaction time (see p.215), the longer your thinking distance.

Braking distance is affected by:
- Your SPEED — for a given braking force, the faster a vehicle travels, the longer it takes to stop.
- The WEATHER or ROAD SURFACE — if it is wet or icy, or there are leaves or oil on the road, there is less grip (and so less friction) between a vehicle's tyres and the road, which can cause tyres to skid.
- The CONDITION of your TYRES — if the tyres of a vehicle are bald (they don't have any tread left) then they cannot get rid of water in wet conditions. This leads to them skidding on top of the water.
- How good your BRAKES are — if brakes are worn or faulty, they won't be able to apply as much force as well-maintained brakes, which could be dangerous when you need to brake hard.

3) You need to be able to describe the factors affecting stopping distance and how this affects safety — especially in an emergency. E.g. icy conditions increase the chance of skidding (and so increase the stopping distance) so driving too close to other cars in icy conditions is unsafe. The longer your stopping distance, the more space you need to leave in front in order to stop safely.
4) Speed limits are really important because speed affects the stopping distance so much.

Braking Relies on Friction Between the Brakes and Wheels

1) When the brake pedal is pushed, this causes brake pads to be pressed onto the wheels. This contact causes friction, which causes work to be done. The work done between the brakes and the wheels transfers energy from the kinetic energy stores of the wheels to the thermal energy stores of the brakes. The brakes increase in temperature.
2) The faster a vehicle is going, the more energy it has in its kinetic stores, so the more work needs to be done to stop it. This means that a greater braking force is needed to make it stop within a certain distance.
3) A larger braking force means a larger deceleration. Very large decelerations can be dangerous because they may cause brakes to overheat (so they don't work as well) or could cause the vehicle to skid.
4) You can estimate the forces involved in accelerations of vehicles using typical values:

EXAMPLE

A car travelling at a typical speed makes an emergency stop to avoid hitting a hazard 25 m ahead. Estimate the braking force needed to produce this deceleration.

1) Assume the deceleration is uniform, and rearrange $v^2 - u^2 = 2as$ to find the deceleration.
   $v = \sim 25$ m/s $m = \sim 1000$ kg
   $a = (v^2 - u^2) \div 2s = (0^2 - 25^2) \div (2 \times 25) = -12.5$
2) Then use $F = ma$, with $m = \sim 1000$ kg.
   $F = 1000 \times 12.5 = 12\,500$ N, so F is $\sim 12\,500$ N

Stop right there — and learn this page...

Make sure you can calculate stopping distances and explain the factors that affect the braking distance.

Q1 Give one factor that affects braking distance. [1 mark]

Reaction Times

Go long! You need fast reaction times to avoid getting hit in the face when playing catch.

Reaction Times Vary From Person to Person

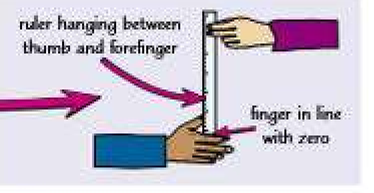
Everyone's reaction time is different, but a typical reaction time is between 0.2 and 0.9 s. This can be affected by tiredness, drugs or alcohol. Distractions can also affect your ability to react.

You can Measure Reaction Times with the Ruler Drop Test

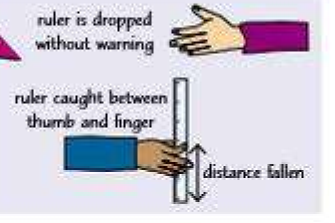
You can do simple experiments to investigate your reaction time, but as reaction times are so short, you haven't got a chance of measuring one with a stopwatch.

One way of measuring reaction times is to use a computer-based test (e.g. clicking a mouse when the screen changes colour).

Another is the ruler drop test:



1) Sit with your arm resting on the edge of a table (this should stop you moving your arm up or down during the test). Get someone else to hold a ruler so it hangs between your thumb and forefinger, lined up with zero. You may need a third person to be at eye level with the ruler to check it's lined up.
2) Without giving any warning, the person holding the ruler should drop it. Close your thumb and finger to try to catch the ruler as quickly as possible.



3) The measurement on the ruler at the point where it is caught is how far the ruler dropped in the time it takes you to react.
4) The longer the distance, the longer the reaction time.
5) You can calculate how long the ruler falls for (the reaction time) because acceleration due to gravity is constant (roughly 9.8 m/s²).

> E.g. say you catch the ruler at 20 cm. From p.208 you know: $v^2 - u^2 = 2as$.
>
> $u = 0$, $a = 9.8$ m/s² and $s = 0.2$ m, so: $v = \sqrt{2 \times 9.8 \times 0.2 + 0} = 1.97...$ m/s
>
> v is equal to the change in velocity of the ruler.
>
> You also know: $a = \Delta v \div t$ so $t = \Delta v \div a = 1.97... \div 9.8 = 0.202...$ s $= 0.2$ s (to 1 s.f.).
>
> This gives your reaction time.

6) It's pretty hard to do this experiment accurately, so you should do a lot of repeats and calculate an average reaction time. The results will be better if the ruler falls straight down — you might want to add a blob of modelling clay to the bottom to stop it from waving about.
7) Make sure it's a fair test — use the same ruler for each repeat, and have the same person dropping it.
8) You could try to investigate some factors affecting reaction time, e.g. you could introduce distractions by having some music playing or by having someone talk to you while the test takes place (see the previous page for more on the factors affecting reaction time).
9) Remember to still do lots of repeats and calculate the mean reaction time with distractions, which you can compare to the mean reaction time without distractions.

Test a friend's reaction time by throwing this book at them...

Not really. Instead re-read this page and make sure you can describe the experiment. Much more fun.

Q1 Video Solution

Q1 Mark's reaction time is tested using the ruler drop test. He is tested in the early afternoon and at night. In the afternoon, he catches the ruler after it has fallen a distance of 16.2 cm. At night, he catches the ruler after it has fallen 18.5 cm.

a) Calculate Mark's reaction time in the afternoon. Give your answer to 2 significant figures. [5 marks]

b) Explain why Mark's thinking distance might be longer when driving in the evening. [2 marks]

Momentum

A large rugby player running very fast has much more momentum than a skinny one out for a Sunday afternoon stroll. It's something that all moving objects have, so you better get your head around it.

Momentum = Mass × Velocity

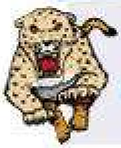
Momentum is mainly about how much 'oomph' an object has. It's a property that all moving objects have.

1) The greater the mass of an object, or the greater its velocity, the more momentum the object has.
2) Momentum is a vector quantity — it has size and direction.
3) You can work out the momentum of an object using:

$$p = mv$$

momentum (kg m/s) = mass (kg) × velocity (m/s)

EXAMPLE



A 50 kg cheetah is running at 60 m/s. Calculate its momentum.

$p = mv = 50 \times 60$
$= 3000$ kg m/s

EXAMPLE

A boy has a mass of 30 kg and a momentum of 75 kg m/s. Calculate his velocity.

$v = p \div m = 75 \div 30 = 2.5$ m/s

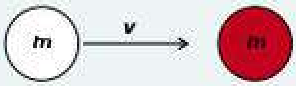
Momentum Before = Momentum After

In a closed system, the total momentum before an event (e.g. a collision) is the same as after the event. This is called conservation of momentum.

A closed system is just a fancy way of saying that no external forces act.

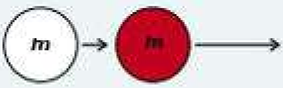
In snooker, balls of the same size and mass collide with each other. Each collision is an event where the momentum of each ball changes, but the overall momentum stays the same (momentum is conserved).

Before:



The red ball is stationary, so it has zero momentum. The white ball is moving with a velocity v, so has a momentum of $p = mv$.

After:

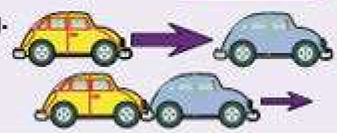


The white ball hits the red ball, causing it to move. The red ball now has momentum. The white ball continues moving, but at a much smaller velocity (and so a much smaller momentum).

The combined momentum of the red and white ball is equal to the original momentum of the white ball, mv.

A moving car hits into the back of a parked car. The crash causes the two cars to lock together, and they continue moving in the direction that the original moving car was travelling, but at a lower velocity.

Before: The momentum was equal to mass of moving car × its velocity.
After: The mass of the moving object has increased, but its momentum is equal to the momentum before the collision. So an increase in mass causes a decrease in velocity.



If the momentum before an event is zero, then the momentum after will also be zero. E.g. in an explosion, the momentum before is zero. After the explosion, the pieces fly off in different directions, so that the total momentum cancels out to zero.

Learn this stuff — it'll only take a moment... um...

Conservation of momentum is incredibly handy — make sure you get your head down and practise it.

Q1 Calculate the momentum of a 60 kg woman running at 3 m/s. [2 marks]

Q1 Video Solution

Q2 Describe how momentum is conserved by a gun recoiling (moving backwards) as it shoots a bullet. [4 marks]

Revision Questions for Topic P5

Well, that's Topic P5 all done. See how you've done with this summary.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quiz for Topic P5 — just scan this QR code!

Topic P5 Quiz

Forces and Work Done (p.201-204)

1) Explain the difference between scalar and vector quantities.
2) True or false? Time is a vector quantity.
3) What is the difference between contact and non-contact forces?
4) Explain the difference between mass and weight.
5) What is the formula for calculating the weight of an object?
6) What is a free body diagram?
7) What is a resultant force?
8) Give the formula for calculating the work done by a force, and explain what each symbol means.
9) How many joules of work does 1 Nm equal?
10) Describe the forces acting on an object in equilibrium.

Stretching (p.205-206)

11) What is the difference between an elastic and an inelastic deformation?
12) Give the equation that relates force, extension and the spring constant of an object.
13) What is the limit of proportionality?
14) Describe an experiment you could do to investigate the relationship between force and extension.
15) How do you find the following from a linear force-extension graph? a) spring constant, b) work done
16) Give the equation used to find the energy in an elastic object's elastic potential energy store.

Motion (p.207-213)

17) What is the difference between displacement and distance?
18) Define acceleration in terms of velocity and time.
19) What does the term 'uniform acceleration' mean?
20) What does the gradient represent for a) a distance-time graph? b) a velocity-time graph?
21) What is terminal velocity? What causes it?
22) State Newton's three laws of motion.
23) What is inertia?

Car Safety and Momentum (p.214-216)

24) What is the stopping distance of a vehicle? How can it be calculated?
25) State four things that can affect the braking distance of a vehicle.
26) Give two things that affect a person's reaction time.
27) What is an average reaction time?
28) Briefly describe an experiment you could do to compare people's reaction times.
29) State the formula used to calculate an object's momentum.

Transverse and Longitudinal Waves

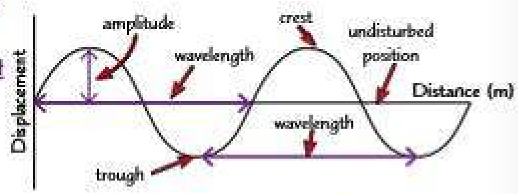
Waves transfer energy from one place to another without transferring any matter (stuff).

Waves Transfer Energy in the Direction they are Travelling

When waves travel through a medium, the particles of the medium oscillate and transfer energy between each other (see p.167). BUT overall, the particles stay in the same place — only energy is transferred.

For example, if you drop a twig into a calm pool of water, ripples form on the water's surface. The ripples don't carry the water (or the twig) away with them though. Similarly, if you strum a guitar string and create sound waves, the sound waves don't carry the air away from the guitar and create a vacuum.

1) The amplitude of a wave is the maximum displacement of a point on the wave from its undisturbed position.
2) The wavelength is the distance between the same point on two adjacent waves (e.g. between the trough of one wave and the trough of the wave next to it).
3) Frequency is the number of complete waves passing a certain point per second. Frequency is measured in hertz (Hz). 1 Hz is 1 wave per second.
4) From the frequency, you can find the period of a wave using: This is the amount of time it takes for a full cycle of the wave.
5) All waves are either transverse or longitudinal (see below).



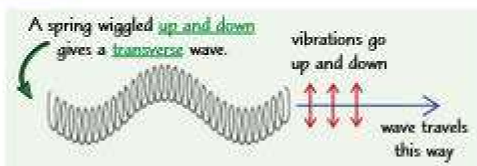
$$T = \frac{1}{f}$$

Period (s) — Frequency (Hz)

Transverse Waves Have Sideways Vibrations

In transverse waves, the oscillations (vibrations) are perpendicular (at 90°) to the direction of energy transfer. Most waves are transverse, including:

1) All electromagnetic waves, e.g. light (p.220).
2) Ripples and waves in water (see p.219).
3) A wave on a string.



Water waves, shock waves and waves in springs and ropes are all examples of mechanical waves.

Longitudinal Waves Have Parallel Vibrations

In longitudinal waves, the oscillations are parallel to the direction of energy transfer. An example is sound waves in air.

Wave Speed = Frequency × Wavelength

The wave speed is the speed at which energy is being transferred (or the speed the wave is moving at). The wave equation applies to all waves:

$$v = f\lambda$$

Wave speed (m/s) — Frequency (Hz) — Wavelength (m)

EXAMPLE

A radio wave has a frequency of 12.0×10^6 Hz. Find its wavelength. (The speed of radio waves in air is 3.0×10^8 m/s.)

$\lambda = v \div f$
$= (3.0 \times 10^8) \div (12.0 \times 10^6) = 25$ m

So, that's the wave basics...

Make sure this is all clear in your head, otherwise the rest of the topic will just be a wavey blur of nonsense.

Q1 A wave has a speed of 0.15 m/s and a wavelength of 7.5 cm. Calculate its frequency. [4 marks]

Q1 Video Solution

Experiments With Waves

Time to experiment. Make sure you can choose suitable equipment to measure the speed of different waves.

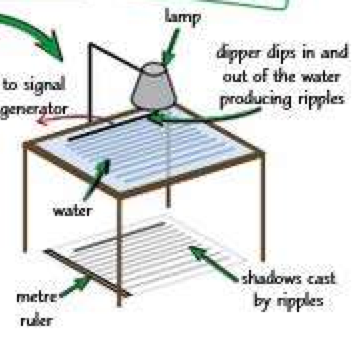
Use an Oscilloscope to Measure the Speed of Sound

By attaching a signal generator to a speaker you can generate sounds with a specific frequency. You can use two microphones and an oscilloscope to find the wavelength of the sound waves generated.

1) Set up the oscilloscope so the detected waves at each microphone are shown as separate waves.
2) Start with both microphones next to the speaker, then slowly move one away until the two waves are aligned on the display, but have moved exactly one wavelength apart.
3) Measure the distance between the microphones to find one wavelength (λ).
4) You can then use the formula $v = f\lambda$ (p.218) to find the speed (v) of the sound waves passing through the air — the frequency (f) is whatever you set the signal generator to (around 1 kHz is sensible).
5) The speed of sound in air is around 330 m/s, so check your results roughly agree with this.

Measure the Speed of Water Ripples Using a Ripple Tank

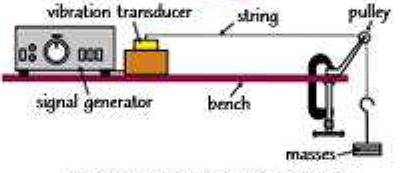
PRACTICAL



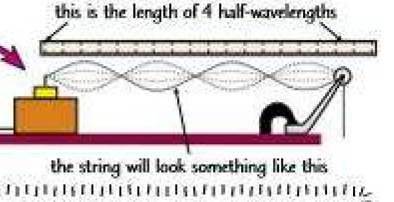
1) Using a signal generator attached to the dipper of a ripple tank you can create water waves at a set frequency (f).
2) Dim the lights in the lab and turn on the lamp. You should see the wave crests as shadows on the screen below the tank.
3) The distance between each shadow line is equal to one wavelength. Measure the distance between shadow lines that are 10 wavelengths apart, then divide this distance by 10 to find the average wavelength.
4) This is a good method for measuring the wavelength of moving waves (p.233) or small wavelengths.
5) Use $v = f\lambda$ to calculate the wave speed of the waves.
6) This set-up is suitable for investigating waves, because it allows you to measure the wavelength without disturbing the waves.

You can Use the Wave Equation for Waves on Strings

PRACTICAL



1) Set up the equipment shown on the right, then turn on the signal generator and vibration transducer. The string will start to vibrate.
2) Adjust the frequency of the signal generator until there's a clear wave on the string. The frequency you need will depend on the length of string between the pulley and the transducer, and the masses you've used.
3) You need to measure the wavelength of these waves. The best way to do this accurately is to measure the lengths of, say four or five half-wavelengths (as many as you can) in one go, then divide to get the mean half-wavelength (p.6). You can then double this mean to get a full wavelength.
4) The frequency of the wave is whatever the signal generator is set to.
5) You can find the speed of the wave using $v = f\lambda$.



This set-up is suitable for investigating waves on a string because it's easy to see and measure the wavelength (and frequency).

Surf's up, it's time to, like, totally measure some gnarly waves...

Sound waves, ripples, and waves on strings are used as model waves because they're easy to work with.

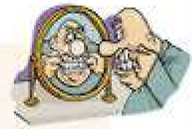
Q1 Describe a suitable experiment to measure the wavelength of a water wave. [3 marks]

Wave Behaviour and Electromagnetic Waves

The differences between types of electromagnetic (EM) waves make them useful to us in different ways.

All Waves Can be Absorbed, Transmitted or Reflected

When a wave meets a boundary between two materials, three things can happen:



1) The wave is ABSORBED by the second material — the wave transfers energy to the material's energy stores. Often, the energy is transferred to a thermal energy store, which leads to heating (this is how a microwave works, see page 223).
2) The wave is TRANSMITTED through the second material — the wave carries on travelling through the new material. This often leads to refraction (see p.221). This can be used in communications (p.222) as well as in the lenses of glasses and cameras.
3) The wave is REFLECTED — this is where the incoming ray is neither absorbed or transmitted, but instead is 'sent back' away from the second material. This is how echoes are created.

What actually happens depends on the wavelength of the wave and the properties of the materials involved.

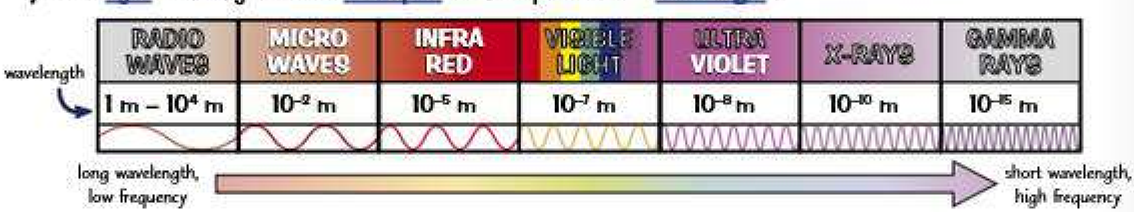
There's a Continuous Spectrum of EM Waves

1) Electromagnetic (EM) waves are transverse waves (p.218).
2) They transfer energy from a source to an absorber.

A camp fire transfers energy to its surroundings by emitting infrared radiation. These infrared waves are absorbed by objects and transfer energy to the object's thermal energy store, causing the object to warm up.

Radio waves transfer energy to the kinetic energy stores of electrons in radio receivers, which generates an electric current (see page 222).

3) All EM waves travel at the same speed through air or a vacuum (space). Electromagnetic waves aren't vibrations of particles, they're vibrations of electric and magnetic fields (p.227). This means they can travel through a vacuum.
4) They travel at different speeds in different materials (which can lead to refraction).
5) EM waves vary in wavelength from around 10^{-15} m to more than 10^{4} m.
6) We group them based on their wavelength and frequency — there are seven basic types, but the different groups merge to form a continuous spectrum.
7) Our eyes can only detect a small part of this spectrum — visible light.



8) There is such a large range of frequencies because EM waves are generated by a variety of changes in atoms and their nuclei (p.195). E.g. changes in the nucleus of an atom creates gamma rays (p.196).
9) This also explains why atoms can absorb a range of frequencies — each one causes a different change.
10) Because of their different properties, different EM waves are used for different purposes.

Learn about the EM spectrum and wave goodbye to exam woe...

Nothing too difficult here, just a lot of facts to remember. Here's a handy mnemonic for the order of EM waves: 'Rock Music Is Very Useful for eXperiments with Goats'.

Q1 State the type of electromagnetic wave that has the lowest frequency. [1 mark]

Q2 Name the section of the electromagnetic spectrum that humans can see. [1 mark]

Refraction

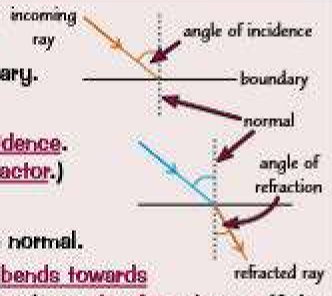
Go and grab a glass of water a put a straw in it. The straw looks like it's bending — is it wizardry or refraction? Answer: refraction (unless you know something I don't).

Refraction — Waves Changing Direction at a Boundary

1) When a wave crosses a boundary between two materials it changes speed.
2) If the wave is travelling along the normal it will change speed, but it's NOT refracted.
3) If the wave hits the boundary at an angle it changes direction — it's refracted.
4) The wave bends towards the normal if it slows down. It bends away from the normal if it speeds up.
5) How much it's refracted by depends on how much the wave speeds up or slows down, which usually depends on the density of the two materials (usually the higher the density of a material, the slower a wave travels through it).
6) The optical density of a material is a measure of how quickly light can travel through it — the higher the optical density, the slower light waves travels through it.
7) The wavelength of a wave changes when it is refracted, but the frequency stays the same.

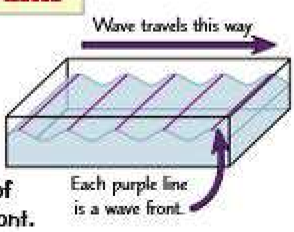
Ray Diagrams Show the Path of a Wave

Rays are straight lines that are perpendicular to wave fronts. They show the direction a wave is travelling in. You can construct a ray diagram for a refracted light ray.

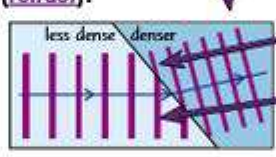


1) First, start by drawing the boundary between your two materials and the normal. The normal is an imaginary line that's perpendicular (at right angles) to the point where the incoming wave hits the boundary.
2) Draw an incident ray that meets the normal at the boundary.
3) The angle between the incident ray and the normal is the angle of incidence. (If you're given this angle, make sure to draw it carefully with a protractor.)
4) Now draw the refracted ray on the other side of the boundary.
5) The angle of refraction is the angle between the refracted ray and the normal.
6) If the second material is optically denser than first, the refracted ray bends towards the normal (like on the right) and the angle of refraction is smaller than the angle of incidence. If the second material is less optically dense, the angle of refraction is larger than the angle of incidence.

You can also Explain Refraction using Wave Front Diagrams



1) A wave front is a line showing all of the points on a wave that are in the same position as each other after a given number of wavelengths.
2) When a wave crosses a boundary at an angle, only part of a wave front crosses the boundary at first. If it's travelling into a denser material, that part travels slower than the rest of the wave front.
3) So by the time the whole wave front crosses the boundary, the faster part of the wave front will have travelled further than the slower part of the wave front.
4) This difference in distance travelled (caused by the difference in speed) by the wave front causes the wave to bend (refract).



Lights, camera, refraction...

Refraction is a common behaviour of waves, so make sure you really understand it before moving on.

Q1 Draw a ray diagram for light entering a less optically dense medium, 40° to the normal. [3 marks]

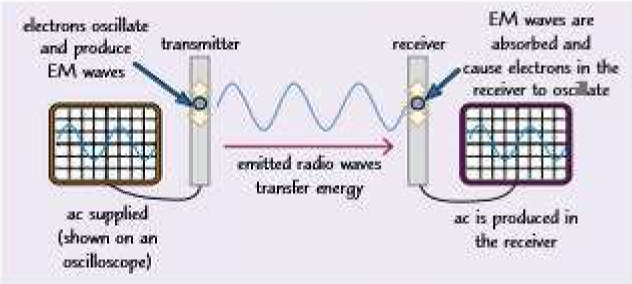
Q1 Video Solution

Radio Waves

EM waves are used for all sorts of stuff — and radio waves are definitely the most entertaining. They transfer energy to your car radio and your TV — what would you do without them?

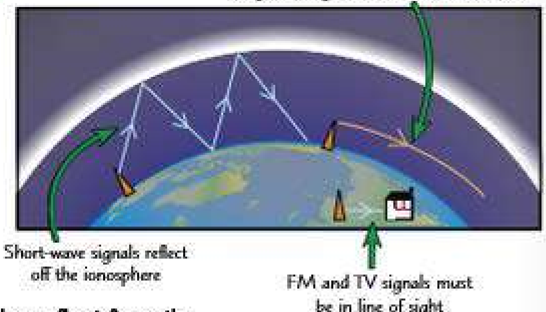
Radio Waves are Made by Oscillating Charges

1) EM waves are made up of oscillating electric and magnetic fields.
2) Alternating currents (ac) (p.186) are made up of oscillating charges. As the charges oscillate, they produce oscillating electric and magnetic fields, i.e. electromagnetic waves.
3) The frequency of the waves produced will be equal to the frequency of the alternating current.
4) You can produce radio waves using an alternating current in an electrical circuit. The object in which charges (electrons) oscillate to create the radio waves is called a transmitter.
5) When transmitted radio waves reach a receiver, the radio waves are absorbed.
6) The energy carried by the waves is transferred to the electrons in the material of the receiver.
7) This energy causes the electrons to oscillate and, if the receiver is part of a complete electrical circuit, it generates an alternating current.
8) This current has the same frequency as the radio wave that generated it.



Radio Waves are Used Mainly for Communication

1) Radio waves are EM radiation with wavelengths longer than about 10 cm.
2) Long-wave radio (wavelengths of 1 – 10 km) can be transmitted from London, say, and received halfway round the world. That's because long wavelengths diffract (bend) around the curved surface of the Earth. Long-wave radio wavelengths can also diffract around hills, into tunnels and all sorts.
3) This makes it possible for radio signals to be received even if the receiver isn't in line of the sight of the transmitter.
4) Short-wave radio signals (wavelengths of about 10 m – 100 m) can, like long-wave, be received at long distances from the transmitter. That's because they are reflected (see p.220) from the ionosphere — an electrically charged layer in the Earth's upper atmosphere.
5) Bluetooth® uses short-wave radio waves to send data over short distances between devices without wires (e.g. wireless headsets so you can use your phone while driving a car).
6) Medium-wave signals (well, the shorter ones) can also reflect from the ionosphere, depending on atmospheric conditions and the time of day.
7) The radio waves used for TV and FM radio transmissions have very short wavelengths. To get reception, you must be in direct sight of the transmitter — the signal doesn't bend or travel far through buildings.



Size matters — and my wave's longer than yours...

Producing radio waves — who knew it was so tricky? It's worth it though — they're just so darn useful.

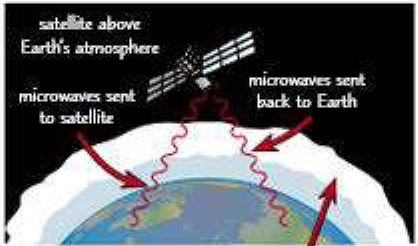
Q1 State one use of radio waves. [1 mark]

Q2 Describe how radio waves can be produced. [1 mark]

EM Waves and Their Uses

Radio waves aren't the only waves used for communication — other EM waves come in pretty handy too. The most important thing is to think about how the properties of a wave relate to its uses.

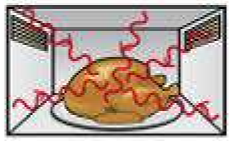
Microwaves are Used by Satellites



1) Communication to and from satellites (including satellite TV signals and satellite phones) uses microwaves. It's best to use microwaves which can pass easily through the Earth's watery atmosphere.
2) For satellite TV, the signal from a transmitter is transmitted into space...
3) ... where it's picked up by the satellite receiver dish orbiting thousands of kilometres above the Earth. The satellite transmits the signal back to Earth in a different direction...
4) ... where it's received by a satellite dish on the ground. There is a slight time delay between the signal being sent and received because of the long distance the signal has to travel.

Microwave Ovens Also Use Microwaves

1) In microwave ovens, the microwaves are absorbed by water molecules in food.
2) The microwaves penetrate up to a few centimetres into the food before being absorbed and transferring the energy they are carrying to the water molecules in the food, causing the water to heat up.
3) The water molecules then transfer this energy to the rest of the molecules in the food by heating — which quickly cooks the food.



Infrared Radiation Can be Used to Increase or Monitor Temperature

1) Infrared (IR) radiation is given out by all objects — and the hotter the object, the more IR radiation it gives out.
2) Infrared cameras can be used to detect infrared radiation and monitor temperature. The camera detects the IR radiation and turns it into an electrical signal, which is displayed on a screen as a picture. The hotter an object is, the brighter it appears. E.g. energy transfer from a house's thermal energy store can be detected using infrared cameras.

Different colours represent different amounts of IR radiation being detected. Here, the redder the colour, the more infrared radiation is being detected.

3) Absorbing IR radiation causes objects to get hotter. Food can be cooked using IR radiation — the temperature of the food increases when it absorbs IR radiation, e.g. from a toaster's heating element.
4) Electric heaters heat a room in the same way. Electric heaters contain a long piece of wire that heats up when a current flows through it. This wire then emits lots of infrared radiation (and a little visible light — the wire glows). The emitted IR radiation is absorbed by objects and the air in the room — energy is transferred by the IR waves to the thermal energy stores of the objects, causing their temperature to increase.

Revision time — adjust depending on brain wattage...

The next time you're feeling hungry and zap some food in the microwave, think of it as doing revision.

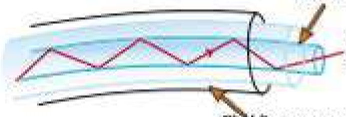
Q1 Explain why signals between satellites are transmitted as microwaves. [1 mark]

More Uses of EM Waves

Haven't had enough uses of EM waves? Good, because here are just a few more uses of those incredibly handy waves — complete with the all-important reasons for why they have been used. Get learning.

Fibre Optic Cables Use Visible Light to Transmit Data

1) Optical fibres are thin glass or plastic fibres that can carry data (e.g. from telephones or computers) over long distances as pulses of visible light.
2) They work because of reflection (p.220). The light rays are bounced back and forth until they reach the end of the fibre.
3) Visible light is used in optical fibres because it is easy to refract light enough so that it remains in a narrow fibre.
4) Light is also not easily absorbed or scattered as it travels along a fibre.



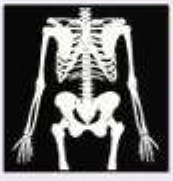
Ultraviolet Radiation Gives You a Suntan

1) Fluorescence is a property of certain chemicals, where ultra-violet (UV) radiation is absorbed and then visible light is emitted. That's why fluorescent colours look so bright — they actually emit light.
2) Fluorescent lights generate UV radiation, which is absorbed and re-emitted as visible light by a layer of a compound called phosphor on the inside of the bulb. They're energy-efficient (p.172) so they're good to use when light is needed for long periods (like in your classroom).
3) Security pens can be used to mark property with your name (e.g. laptops). Under UV light the ink will glow (fluoresce), but it's invisible otherwise. This can help the police identify your property if it's stolen.
4) Ultraviolet radiation (UV) is produced by the Sun, and exposure to it is what gives people a suntan.
5) When it's not sunny, some people go to tanning salons where UV lamps are used to give them an artificial suntan. However, overexposure to UV radiation can be dangerous (fluorescent lights emit very little UV — they're totally safe).

There's more on the dangers of UV on p.226.

X-rays and Gamma Rays are Used in Medicine

1) Radiographers in hospitals take X-ray 'photographs' of people to see if they have any broken bones.
2) X-rays pass easily through flesh but not so easily through denser material like bones or metal. So it's the amount of radiation that's absorbed (or not absorbed) that gives you an X-ray image.
3) Radiographers use X-rays and gamma rays to treat people with cancer (radiotherapy). This is because high doses of these rays kill all living cells — so they are carefully directed towards cancer cells, to avoid killing too many normal, healthy cells.



The brighter bits are where fewer X-rays get through. This is a negative image. The plate starts off all white.

There's more on gamma rays on p.196.

4) Gamma radiation can also be used as a medical tracer — this is where a gamma-emitting source is injected into the patient, and its progress is followed around the body. Gamma radiation is well suited to this because it can pass out through the body to be detected.
5) Both X-rays and gamma rays can be harmful to people (p.226), so radiographers wear lead aprons and stand behind a lead screen or leave the room to keep their exposure to them to a minimum.

Don't lie to an X-ray — they can see right through you...

I hate to say it, but go back to page 222 and read all of the uses for EM waves again to really learn them.

Q1 State two uses of X-rays. [2 marks]

Q2 Explain why plastic optical fibres use pulses of visible light to transmit data. [2 marks]

Investigating Infrared Radiation

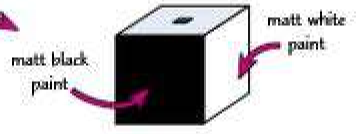
You saw on p.223 that all objects emit infrared radiation, but now it's time to see how the surface of the object affects how much it emits. I know, you can hardly contain your excitement. Neither can I.

You Can Investigate Emission With a Leslie Cube

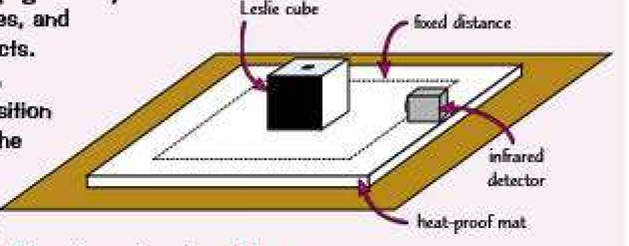
PRACTICAL

The amount of infrared radiation emitted from an object is not just dependent on its temperature. It's also dependent on the material of its surface.

A Leslie cube is a hollow, watertight, metal cube made of e.g. aluminium, whose four vertical faces have different surfaces (for example, matt black paint, matt white paint, shiny metal and dull metal). You can use them to investigate IR emission by different surfaces:



1) Place an empty Leslie cube on a heat-proof mat.
2) Boil water in a kettle and fill the Leslie cube with boiling water.
3) Wait a while for the cube to warm up, then hold a thermometer against each of the four vertical faces of the cube. You should find that all four faces are the same temperature.
4) Hold an infrared detector a set distance (e.g. 10 cm) away from one of the cube's vertical faces, and record the amount of IR radiation it detects.
5) Repeat this measurement for each of the cube's vertical faces. Make sure you position the detector at the same distance from the cube each time.
6) You should find that you detect more infrared radiation from the black surface than the white one, and more from the matt surfaces than the shiny ones.
7) As always, you should do the experiment more than once, to make sure your results are repeatable (p.4).
8) It's important to be careful when you're doing this experiment. Don't try to move the cube when it's full of boiling water — you might burn your hands. And be careful if you're carrying a full kettle — your mate won't thank you if you spill boiling water into their bag (or down their back).

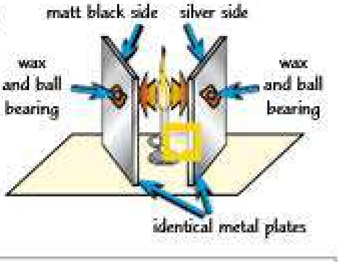


You Can Investigate Absorption with the Melting Wax Trick

PRACTICAL

The amount of infrared radiation absorbed by different materials also depends on the material. You can do an experiment to show this, using a bunsen burner and some candle wax.

1) Set up the equipment as shown on the right. Two ball bearings are each stuck to one side of a metal plate with solid pieces of candle wax. The other sides of these plates are then faced towards the flame.
2) The sides of the plates that are facing towards the flame each have a different surface colour — one is matt black and the other is silver.
3) The ball bearing on the black plate will fall first as the black surface absorbs more infrared radiation — transferring more energy to the thermal energy store of the wax. This means the wax on the black plate melts before the wax on the silver plate.



Feelin' hot hot hot...

When doing the experiment with the Leslie cube, you could also place your hand near each surface of the cube (but no touching, it'll be super hot) — you'll be able to feel which surface is emitting more infrared radiation.

Q1 A student makes two identical cups of tea in two mugs. The two mugs are the same, apart from their colour — one mug is black and the other is white. Explain which cup of tea will initially cool at a faster rate. [3 marks]

Dangers of Electromagnetic Waves

Okay, so you know how useful electromagnetic radiation can be — well, it can also be pretty dangerous.

Some EM Radiation Can be Harmful to People

1) When EM radiation enters living tissue — like you — it's often harmless, but sometimes it creates havoc. The effects of each type of radiation are based on how much energy the wave transfers.
2) Low frequency waves, like radio waves, don't transfer much energy and so mostly pass through soft tissue without being absorbed.
3) High frequency waves like UV, X-rays and gamma rays all transfer lots of energy and so can cause lots of damage.
4) UV radiation damages surface cells, which can lead to sunburn and cause skin to age prematurely. Some more serious effects are blindness and an increased risk of skin cancer.
5) X-rays and gamma rays are types of ionising radiation. (They carry enough energy to knock electrons off of atoms.) This can cause gene mutation or cell destruction, and cancer.

You Can Measure Risk Using the Radiation Dose in Sieverts

1) Whilst UV radiation, X-rays and gamma rays can all be harmful, they are also very useful (see pages 222-224). Before any of these types of EM radiation are used, people look at whether the benefits outweigh the health risks.
2) For example, the risk of a person involved in a car accident developing cancer from having an X-ray photograph taken is much smaller than the potential health risk of not finding and treating their injuries.
3) Radiation dose (measured in sieverts) is a measure of the risk of harm from the body being exposed to radiation.
4) This is not a measure of the total amount of radiation that has been absorbed.
5) The risk depends on the total amount of radiation absorbed and how harmful the type of radiation is.
6) A sievert is pretty big, so you'll often see doses in millisieverts (mSv), where 1000 mSv = 1 Sv.

Radiation doses can be calculated for all types of radiation, not just UV, X-rays and gamma rays.

Risk can be Different for Different Parts of the Body

A CT scan uses X-rays and a computer to build up a picture of the inside of a patient's body. The table shows the radiation dose received by two different parts of a patient's body when having CT scans.

	Radiation dose (mSv)
Head	2.0
Chest	8.0

If a patient has a CT scan on their chest, they are four times more likely to suffer damage to their genes (and their added risk of harm is four times higher) than if they had a head scan.

This is not an excuse to stay in bed all day...

It's impossible to avoid all forms of harmful radiation, so it's all about balancing risks and reducing your exposure.

Q1 Give two effects of a person being exposed to too much UV radiation. [2 marks]

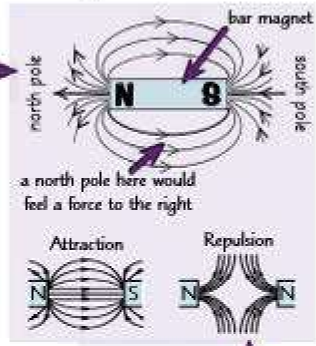
Q2 A patient's pelvis is being examined. It can either be examined with a single X-ray photograph or with a CT scan. An X-ray of the pelvis has a radiation dose of 0.7 mSv. A CT scan of the pelvis has a radiation dose of 7 mSv. How much larger is the added risk of harm if the patient has a CT scan? [1 mark]

Permanent and Induced Magnets

I think magnetism is an attractive subject, but don't get repelled by the exam — revise.

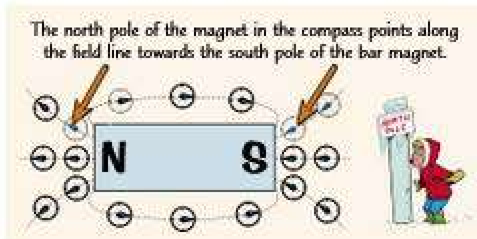
Magnets Produce Magnetic Fields

1) All magnets have two poles — north (or north seeking) and south (or south seeking).
2) All magnets produce a magnetic field — a region where other magnets or magnetic materials (e.g. iron, steel, nickel and cobalt) experience a non-contact force (p.201).
3) You can show a magnetic field by drawing magnetic field lines.
4) The lines always go from north to south and they show which way a force would act on a north pole if it was put at that point in the field.
5) The closer together the lines are, the stronger the magnetic field. The further away from a magnet you get, the weaker the field is.
6) The magnetic field is strongest at the poles of a magnet. This means that the magnetic forces are also strongest at the poles.
7) The force between a magnet and a magnetic material is always attractive, no matter the pole.
8) If two poles of a magnet are put near each other, they will each exert a force on each other. This force can be attractive or repulsive. Two poles that are the same (these are called like poles) will repel each other. Two unlike poles will attract each other.



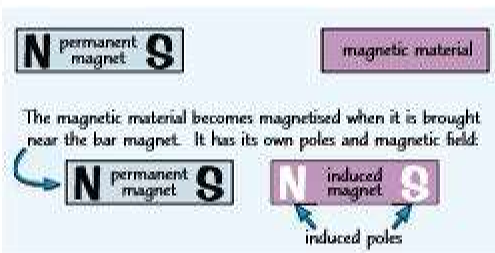
Compasses Show the Directions of Magnetic Fields

1) Inside a compass is a tiny bar magnet. The north pole of this magnet is attracted to the south pole of any other magnet it is near. So the compass points in the direction of the magnetic field it is in.
2) You can move a compass around a magnet and trace its position on some paper to build up a picture of what the magnetic field looks like.
3) When they're not near a magnet, compasses always point north. This is because the Earth generates its own magnetic field, which shows the inside (core) of the Earth must be magnetic.



Magnets Can be Permanent or Induced

1) There are two types of magnet — permanent magnets and induced magnets.
2) Permanent magnets produce their own magnetic field.
3) Induced magnets are magnetic materials that turn into a magnet when they're put into a magnetic field.
4) The force between permanent and induced magnets is always attractive (see magnetic materials above).
5) When you take away the magnetic field, induced magnets quickly lose their magnetism (or most of it) and stop producing a magnetic field.



Magnets are like farmers — surrounded by fields...

Magnetism is one of those things that takes a while to make much sense. Learn these basics — you'll need them.

Q1 Draw the magnetic field lines for a bar magnet. Label the areas where the field is strongest. [2 marks]

Q2 Give two differences between permanent and induced magnets. [2 marks]

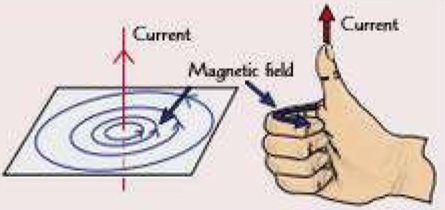
Electromagnetism

On this page you'll see that a magnetic field is also found around a wire that has a current passing through it. The strength of this field can be increased by wrapping the wire into a long coil called a solenoid. Fun.

A Moving Charge Creates a Magnetic Field

1) When a current flows through a wire, a magnetic field is created around the wire.
2) The field is made up of concentric circles perpendicular to the wire, with the wire in the centre.
3) You can see this by placing a compass near a wire that is carrying a current. As you move the compass, it will trace the direction of the magnetic field.
4) Changing the direction of the current changes the direction of the magnetic field — use the right-hand thumb rule to work out which way it goes.

The Right-Hand Thumb Rule
Using your right hand, point your thumb in the direction of current and curl your fingers. The direction of your fingers is the direction of the field.



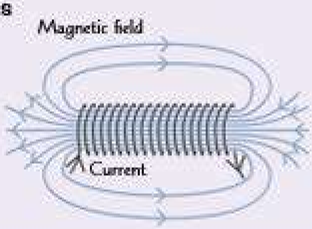
Don't get this confused with the left-hand rule that's over on page 230.

5) The strength of the magnetic field produced changes with the current and the distance from the wire. The larger the current through the wire, or the closer to the wire you are, the stronger the field is.

A Solenoid is a Coil of Wire

1) You can increase the strength of the magnetic field that a wire produces by wrapping the wire into a coil called a solenoid.
2) This happens because the field lines around each loop of wire line up with each other.
3) This results in lots of field lines pointing in the same direction that are very close to each other. As you saw on the last page, the closer together field lines are, the stronger the field is.

- The magnetic field inside a solenoid is strong and uniform (it has the same strength and direction at every point in that region).
- Outside the coil, the magnetic field is just like the one round a bar magnet.
- This means that the ends of a solenoid act like the north pole and south pole of a bar magnet. You can work out which end of the solenoid is the north pole and which is the south pole using the right-hand rule shown above.



4) You can increase the field strength of the solenoid even more by putting a block of iron in the centre of the coil. This iron core becomes an induced magnet whenever current is flowing.
5) If you stop the current, the magnetic field disappears. A solenoid with an iron core (a magnet whose magnetic field can be turned on and off with an electric current) is called an ELECTROMAGNET.

Strong, in uniform and a magnetic personality — I'm a catch...

Electromagnets are used in many everyday things from alarms to trains, so you'd better learn how they work.

Q1 Draw the magnetic field for a current-carrying wire. [2 marks]

Q2 a) Draw the magnetic field for a current-carrying solenoid. [2 marks]
b) State one way that you can increase the field strength of a solenoid. [1 mark]

Q1 Video Solution

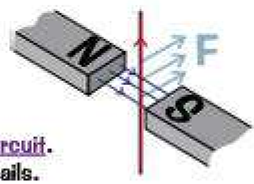
The Motor Effect

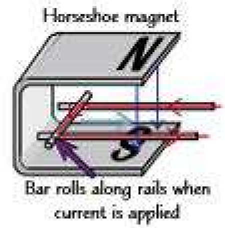
The motor effect can happen when you put a current-carrying wire in a magnetic field. It's really useful in stuff like... well... electric motors. If you want to know exactly what it is, you'll have to keep reading.

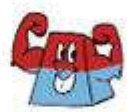
A Current in a Magnetic Field Experiences a Force

When a current-carrying wire (or any other conductor) is put between magnetic poles, the magnetic field around the wire interacts with the magnetic field it has been placed in. This causes the magnet and the conductor to exert a force on each other. This is called the motor effect and can cause the wire to move.

1) To experience the full force, the wire has to be at 90° to the magnetic field. If the wire runs parallel to the magnetic field, it won't experience any force at all. At angles in between, it'll feel some force.
2) The force always acts at right angles to the magnetic field of the magnets and the direction of the current in the wire.
3) A good way of showing the direction of the force is to apply a current to a set of rails inside a horseshoe magnet (shown opposite). A bar is placed on the rails, which completes the circuit. This generates a force that rolls the bar along the rails.
4) The magnitude (strength) of the force increases with the strength of the magnetic field.
5) The force also increases with the amount of current passing through the conductor.







You Can Find the Size of the Force Using $F = BIl$

The force acting on a conductor in a magnetic field depends on three things:

1) The magnetic flux density — how many field (flux) lines there are in a region. This shows the strength of the magnetic field (p.227).
2) The size of the current through the conductor.
3) The length of the conductor that's in the magnetic field.

When the current is at 90° to the magnetic field it is in, the force acting on it can be found using the equation on the right.

$$F = BIl$$

Force (N), Magnetic flux density (T, tesla), Current (A), Length (m)

EXAMPLE

An iron bar of length 0.20 m is connected in a circuit so a current of 15 A flows through it. If an external magnetic field of 0.18 T is placed at right angles to the direction of the current in the bar, calculate the force acting on the iron bar due to the presence of the magnetic field.

Force on the bar = magnetic flux density × current × bar length = 0.18 × 15 × 0.20 = 0.54 N

A current-carrying conductor — a ticket inspector eating sultanas...

You need to be comfortable rearranging and using that equation for force, so have a quick practise.

Q1 A 35 cm long piece of wire is at 90° to an external magnetic field. The wire experiences a force of 9.8 N when a current of 5.0 A is flowing through it. Calculate the magnetic flux density of the field. [4 marks]

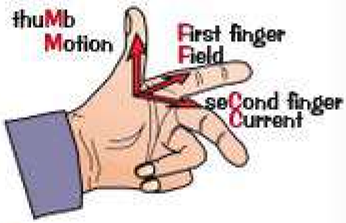
Electric Motors

And now it's time to learn a silly hand gesture... and apply the stuff you read about on the last page... (sorry).

You Can Find the Direction of the Force Using the Left-hand Rule

You learnt on the previous page that a force is exerted on any current-carrying conductor in a magnetic field.
You can find the direction of this force with Fleming's left-hand rule.

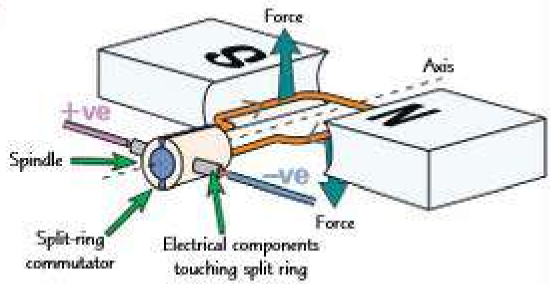
1) Using your left hand, point your First finger in the direction of the magnetic Field.
2) Point your seCond finger in the direction of the Current.
3) Your thuMb will then point in the direction of the force (Motion).



Fleming's left-hand rule shows that if either the current or the magnetic field is reversed, then the direction of the force will also be reversed.
This can be used for all sorts of things — like motors, shown below.

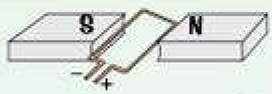
A Current-Carrying Coil of Wire Rotates in a Magnetic Field

1) The diagram on the right shows a basic dc motor. Forces act on the two side arms of a coil of wire that's carrying a current.
2) These forces are just the usual forces which act on any current in a magnetic field (p.229).
3) Because the coil is on a spindle and the forces act one up and one down, it rotates.
4) The split-ring commutator is a clever way of swapping the contacts every half turn to keep the motor rotating in the same direction.



5) The direction of the motor can be reversed either by swapping the polarity of the dc supply (reversing the current) or swapping the magnetic poles over (reversing the field).
6) The speed of the motor can be increased by increasing the current, adding more turns to the coil or increasing the magnetic flux density.
7) You can use Fleming's left-hand rule to work out which way the coil will turn.

EXAMPLE Is the coil turning clockwise or anticlockwise?



1) Draw in current arrows (from positive to negative, p.179).
2) Use Fleming's left-hand rule on one branch (here, I've picked the right-hand branch).
3) Point your first finger in the direction of the magnetic field (remember, this is north to south).
4) Point your second finger in the direction of the current.
5) Draw in the direction of motion (the direction your thumb is pointing in).

The coil is turning anticlockwise.

Left-hand rule for the motor effect — drive on the left...

Use the left-hand rule in the exam. You might look a bit silly, but it makes getting the marks much easier.

Q1 A section of a current-carrying wire is in a magnetic field, as shown in the diagram. The wire is at 90° to the magnetic field. Find the direction of the force acting on the wire. [1 mark]

Q1 Video Solution

Revision Questions for Topics P6 & P7

That's Topics P6 and P7 done — phew. Time to see how much you remember.

- Try these questions and tick off each one when you get it right.
- When you're completely happy with a sub-topic, tick it off.

For even more practice, try the Retrieval Quizzes for Topics P6 and P7 — just scan the QR codes!

Topic P6 Quiz

Wave Properties (p.218-219)

1) What is the amplitude, wavelength, frequency and period of a wave?
2) Describe the difference between transverse and longitudinal waves and give an example of each kind.
3) Write down the equation that links wave speed, frequency and wavelength.
4) Describe an experiment you could do to measure:
   a) the speed of sound in air. b) the speed of waves on a string.

Electromagnetic Waves and Refraction (p.220-221)

5) Explain the terms absorption, transmission and reflection in terms of waves.
6) True or false? All electromagnetic waves are transverse.
7) Give an example of electromagnetic waves transferring energy from a source to an absorber.
8) Explain refraction and draw a ray diagram for a light ray entering a less optically dense material.
9) Draw a wave front diagram showing a wave entering a denser material.

Uses and Dangers of Electromagnetic Waves (p.222-226)

10) What kind of current is used to generate radio waves in an antenna?
11) Explain why microwaves are used for satellite communication and mobile phone signals.
12) Give an everyday use of infrared radiation.
13) What type of radiation is used to transmit a signal in an optical fibre?
14) What does the term 'ionising radiation' mean?
15) What does radiation dose in sieverts measure?
16) What is a Leslie cube? How could you use one to investigate IR emission by different surfaces?
17) True or false? The amount of infrared radiation absorbed by an object depends on the material of the object.

Magnetism and Basic Electromagnetism (p.227-228)

Topic P7 Quiz

18) What is a magnetic field? In what direction do magnetic field lines point?
19) True or false? The force between two unlike poles is attractive.
20) Describe the behaviour of a compass that is far away from a magnet.
21) True or false? The force between a magnet and a magnetic material is always repulsive.
22) Describe the magnetic field around a current-carrying wire.
23) Why does adding more turns to a solenoid increase the strength of its magnetic field?
24) What is an electromagnet?

The Motor Effect (p.229-230)

25) Explain why a current-carrying conductor in a magnetic field experiences a force.
26) Name two ways you could increase the force on a current-carrying wire in a magnetic field.
27) What is Fleming's left-hand rule?
28) Explain how a basic dc motor works.

Measuring Techniques

Safety specs out and lab coats on, it's time to find out about the skills you'll need in experiments. Finally time to look like a real scientist... hurrah! But you also need to know about this stuff in your exams... boooo...

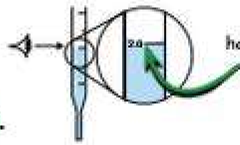
Mass Should Be Measured Using a Balance

1) To measure mass, start by putting the container you're measuring the substance into on the balance.
2) Set the balance to exactly zero and then start adding your substance.
3) It's no good carefully measuring out your substance if it's not all transferred to your reaction vessel — the amount in the reaction vessel won't be the same as your measurement. Here are a couple of methods you can use to make sure that none gets left in your weighing container...

- If you're dissolving a mass of a solid in a solvent to make a solution, you could wash any remaining solid into the new container using the solvent. This way you know that all the solid you weighed has been transferred.
- You could set the balance to zero before you put your weighing container on the balance. Then reweigh the weighing container after you've transferred the substance. Use the difference in mass to work out exactly how much substance you've transferred.

Different Ways to Measure Liquids

There are a few methods you might use to measure the volume of a liquid. Whichever method you use, always read the volume from the bottom of the meniscus (the curved upper surface of the liquid) when it's at eye level.



Pipettes are long, narrow tubes that are used to suck up an accurate volume of liquid and transfer it to another container. A pipette filler attached to the end of the pipette is used so that you can safely control the amount of liquid you're drawing up. Pipettes are often calibrated to allow for the fact that the last drop of liquid stays in the pipette when the liquid is ejected. This reduces transfer errors.

Measuring cylinders are the most common way to measure out a liquid. They come in all different sizes. Make sure you choose one that's the right size for the measurement you want to make. It's no good using a huge 1000 cm³ cylinder to measure out 2 cm³ of a liquid — the graduations will be too big, and you'll end up with massive errors. It'd be much better to use one that measures up to 10 cm³.

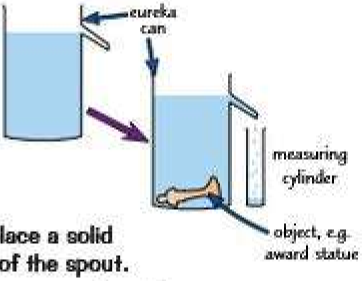
If you only want a couple of drops of liquid, and don't need it to be accurately measured, you can use a dropping pipette to transfer it. For example, this is how you'd add a couple of drops of indicator into a mixture.

Gas Syringes Measure Gas Volumes

1) Gases can be measured with a gas syringe. They should be measured at room temperature and pressure as the volume of a gas changes with temperature and pressure. You should also use a gas syringe that's the right size for the measurement you're making. Before you use the syringe, you should make sure it's completely sealed and that the plunger moves smoothly.
2) Alternatively, you can use an upturned measuring cylinder filled with water. The gas will displace the water so you can read the volume off the scale — see page 237.
3) Other methods to measure the amount of gas include counting the bubbles produced or measuring the length of a gas bubble drawn along a tube (see p.52). These methods are less accurate, but will give you relative amounts of gas to compare results.
4) When you're measuring a gas, you need to make sure that the equipment is set up so that none of the gas can escape, otherwise your results won't be accurate.

Measuring Techniques

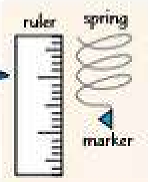
Eureka Cans Measure the Volumes of Solids



1) Eureka cans are used in combination with measuring cylinders to find the volumes of irregular solids (p.192).
2) They're essentially a beaker with a spout. To use them, fill them with water so the water level is above the spout.
3) Let the water drain from the spout, leaving the water level just below the start of the spout (so all the water displaced by an object goes into the measuring cylinder and gives you the correct volume).
4) Place a measuring cylinder below the end of the spout. When you place a solid in the beaker, it causes the water level to rise and water to flow out of the spout.
5) Make sure you wait until the spout has stopped dripping before you measure the volume of the water in the measuring cylinder. And eureka! You know the object's volume.

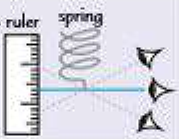
Measure Most Lengths with a Ruler

1) In most cases a bog-standard centimetre ruler can be used to measure length. It depends on what you're measuring though — metre rulers are handy for large distances, while micrometers are used for measuring tiny things like the diameter of a wire.
2) The ruler should always be parallel to what you want to measure.
3) If you're dealing with something where it's tricky to measure just one accurately (e.g. water ripples, p.219), you can measure the length of ten of them and then divide to find the length of one.
4) If you're taking multiple measurements of the same object (e.g. to measure changes in length) then make sure you always measure from the same point on the object. It can help to draw or stick small markers onto the object to line up your ruler against.



5) Make sure the ruler and the object are always at eye level when you take a reading. This stops parallax affecting your results.

Parallax is where a measurement appears to change based on where you're looking from. The blue line is the measurement taken when the spring is at eye level. It shows the correct length of the spring.



Use a Protractor to Find Angles

1) First align the vertex (point) of the angle with the mark in the centre of the protractor.
2) Line up the base line of the protractor with one line that forms the angle and then measure the angle of the other line using the scale on the protractor.
3) If the lines creating the angle are very thick, align the protractor and measure the angle from the centre of the lines. Using a sharp pencil to trace light rays or draw diagrams helps to reduce errors when measuring angles.
4) If the lines are too short to measure easily, you may have to extend them. Again, make sure you use a sharp pencil to do this.

Measure Temperature Accurately

You can use a thermometer to measure the temperature of a substance:

1) Make sure the bulb of your thermometer is completely submerged in any mixture you're measuring.
2) If you're taking an initial reading, you should wait for the temperature to stabilise first.
3) Read your measurement off the scale on a thermometer at eye level to make sure it's correct.

Measuring Techniques

You May Have to Measure the Time Taken for a Change

1) You should use a stopwatch to time experiments. These measure to the nearest 0.1 s, so are sensitive.
2) Always make sure you start and stop the stopwatch at exactly the right time. Or alternatively, set an alarm on the stopwatch so you know exactly when to stop an experiment or take a reading.
3) You might be able to use a light gate instead (p.239). This will reduce the errors in your experiment.

Measure pH to Find Out How Acidic or Alkaline a Solution Is

You need to be able to decide the best method for measuring pH, depending on what your experiment is.

1) Indicators are dyes that change colour depending on whether they're in an acid or an alkali. You use them by adding a couple of drops of the indicator to the solution you're interested in.
2) Universal indicator is a mixture of indicators that changes colour gradually as pH changes. It doesn't show a sudden colour change. It's useful for estimating the pH of a solution based on its colour.
3) Indicators can be soaked into paper and strips of this paper can be used for testing pH. If you use a dropping pipette to spot a small amount of a solution onto some indicator paper, it will change colour depending on the pH of the solution.
4) Indicator paper is useful when you don't want to change the colour of all of the substance, or if the substance is already coloured so might obscure the colour of the indicator. You can also hold a piece of damp indicator paper in a gas sample to test its pH.
5) pH probes are attached to pH meters which have a digital display that gives a numerical value for the pH of a solution. They're used to give an accurate value of pH.

Litmus paper turns red in acidic conditions and blue in basic conditions. Universal indicator paper can be used to estimate the pH based on its colour.

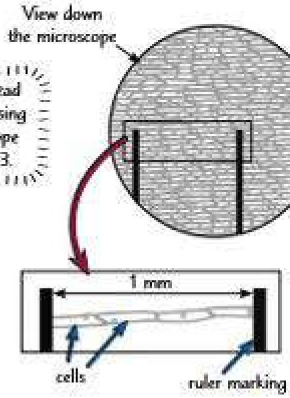
You Can Measure the Size of a Single Cell

When viewing cells under a microscope, you might need to work out their size.

To work out the size of a single cell:

1) Place a clear, plastic ruler on top of your microscope slide. Clip the ruler and slide onto the stage.
2) Select the objective lens that gives an overall magnification of x 100.
3) Adjust the focus to get a clear image of the cells.
4) Move the ruler so that the cells are lined up along 1 mm. Then count the number of cells along this 1 mm sample.
5) 1 mm = 1000 μm. So to calculate the length of a single cell in μm, you just need to divide 1000 μm by the number of cells in the sample. E.g. if you counted 4 cells in 1 mm, the length of a single cell would be: 1000 ÷ 4 = 250 μm

You can read all about using a microscope on page 13.



Use the Cell Size to Work out the Length of a Scale Bar

1) If you draw a diagram of a cell you've observed under a microscope, you might want to include a scale bar.
2) Once you know the size of one cell, you can use it to calculate how long your scale bar should be.
3) To draw a 500 μm scale bar, just use this formula:

$$\text{scale bar length } (\mu m) = \frac{\text{drawn length of cell } (\mu m) \times 500}{\text{actual length of cell } (\mu m)}$$

Experimentus apparatus...

Wizardry won't help you here, unfortunately. Most of this'll be pretty familiar to you by now, but make sure you know these techniques inside out so they're second nature when it comes to any practicals.

Safety and Ethics

Before you start any experiment, you need to know what safety precautions you should be taking. And they depend on your method, your equipment, and the chemicals you're using.

Make Sure You're Working Safely in the Lab

1) Make sure that you're wearing sensible clothing when you're in the lab (e.g. open shoes won't protect your feet from spillages). When you're doing an experiment, you should wear a lab coat to protect your skin and clothing. Depending on the experiment, you may need to also wear safety goggles and gloves.
2) You also need to be aware of general safety in the lab, e.g. keep anything flammable away from lit Bunsen burners, don't directly touch any hot equipment, handle glassware carefully so it doesn't break, etc.
3) You should follow any instructions that your teacher gives you carefully. But here are some basic principles for dealing with chemicals and equipment...

Be Careful When You're Using Chemicals...

1) The chemicals you're using may be hazardous — for example, they might be flammable (catch fire easily), or they might irritate or burn your skin if it comes into contact with them.
2) Make sure you're working in an area that's well ventilated and if you're doing an experiment that might produce nasty gases (such as chlorine), you should carry out the experiment in a fume hood so that the gas can't escape out into the room you're working in.
3) Never directly touch any chemicals (even if you're wearing gloves). Use a spatula to transfer solids between containers. Carefully pour liquids between containers, using a funnel to avoid spillages.
4) Be careful when you're mixing chemicals, as a reaction might occur. If you're diluting a liquid, add the concentrated substance to the water (not the other way around) or the mixture could get very hot.

...and Equipment

1) Stop masses and equipment falling by using clamp stands. Make sure masses are of a sensible weight so they don't break the equipment they're used with, and use pulleys of a sensible length. That way, any hanging masses won't hit the floor during the experiment.
2) When heating materials, make sure to let them cool before moving them, or wear insulated gloves while handling them. If you're using an immersion heater to heat liquids, you should always let it dry out in air, just in case any liquid has leaked inside the heater.
3) If you're using a laser, there are a few safety rules you must follow. Always wear laser safety goggles and never look directly into the laser or shine it towards another person. Make sure you turn the laser off if it's not needed to avoid any accidents.
4) When working with electronics, make sure you use a low enough voltage and current to prevent wires overheating (and potentially melting) and avoid damage to components, like blowing a filament bulb.

You Need to Think About Ethical Issues In Your Experiments

1) Any organisms involved in your investigations need to be treated safely and ethically.
2) Animals need to be treated humanely — they should be handled carefully and any wild animals captured for studying (e.g. during an investigation of the distribution of an organism) should be returned to their original habitat.
3) Any animals kept in the lab should also be cared for in a humane way, e.g. they should not be kept in overcrowded conditions.
4) If you are carrying out an experiment involving other students (e.g. investigating the effect of caffeine on reaction time), they should not be forced to participate against their will or feel pressured to take part.

Safety first...

I know — lab safety isn't the most exciting topic. But it's mega important. Not only will it stop you from blowing your eyebrows off, it'll help you pick up more marks in the exam. And that IS worth getting excited about...

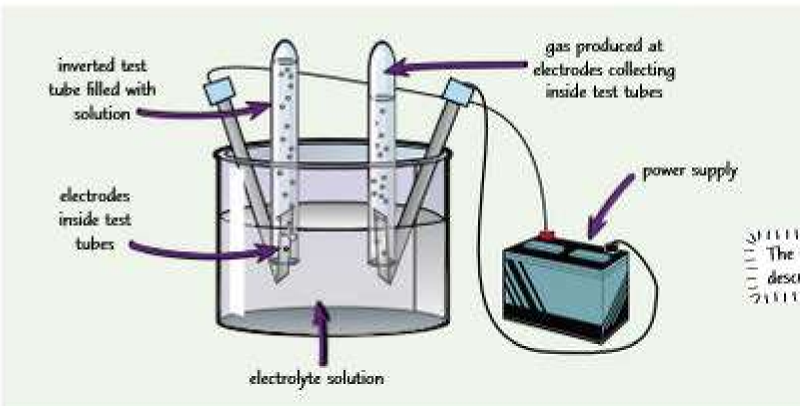
Setting Up Experiments

Setting up the equipment for an experiment correctly is important. These pages cover some of the experimental set-ups that you could be asked about in your exams. So you'd better get on and learn them.

You May Have to Identify the Products of Electrolysis

There's more about electrolysis on p.135-136.

1) When you electrolyse an aqueous solution, the products of electrolysis will depend on how reactive the ions in the solution are compared to the H^+ and OH^- ions that come from water.
2) At the cathode you'll either get a pure metal coating the electrode or bubbles of hydrogen gas.
3) At the anode, you'll get bubbles of oxygen gas unless a halide ion is present, when you'll get the halogen.
4) You may have to predict and identify what's been made in an electrolysis experiment. To do this, you need to be able to set up the equipment correctly so that you can collect any gas that's produced. The easiest way to collect the gas is in a test tube.
5) Here's how to set up the equipment...



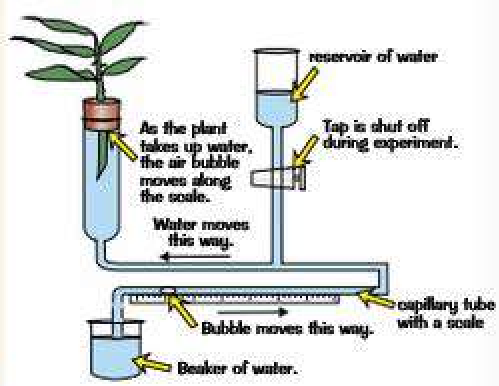
The tests for gases are described on page 155.

Potometers Should Be Set Up Underwater

A potometer is a special piece of apparatus used to measure the water uptake by a plant. Here's how to set one up:

If there are air bubbles in the apparatus or the plant's xylem it will affect your results.

1) Cut a shoot underwater to prevent air from entering the xylem. Cut it at a slant to increase the surface area available for water uptake.
2) Assemble the potometer in water and insert the shoot under water, so no air can enter.
3) Remove the apparatus from the water but keep the end of the capillary tube submerged in a beaker of water.
4) Check that the apparatus is watertight and airtight.
5) Dry the leaves, allow time for the shoot to acclimatise and then shut the tap.
6) Remove the end of the capillary tube from the beaker of water until one air bubble has formed, then put the end of the tube back into the water.
7) A potometer can be used to estimate the transpiration rate of a plant. There's more about this on page 41.

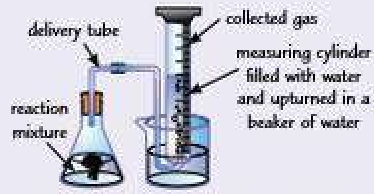


Setting Up Experiments

To Collect Gases, the System Needs to be Sealed

1) There are times when you might want to collect the gas produced by a reaction. For example, to investigate the rate of reaction.
2) The most accurate way to measure the volume of a gas that's been produced is to collect it in a gas syringe (see page 232).
3) You could also collect it by displacing water from a measuring cylinder. Here's how you do it...

- Fill a measuring cylinder with water, and carefully place it upside down in a container of water. Record the initial level of the water in the measuring cylinder.
- Position a delivery tube coming from the reaction vessel so that it's inside the measuring cylinder, pointing upwards. Any gas that's produced will pass through the delivery tube and into the measuring cylinder. As the gas enters the measuring cylinder, the water is pushed out.
- Record the level of water in the measuring cylinder and use this value, along with your initial value, to calculate the volume of gas produced.



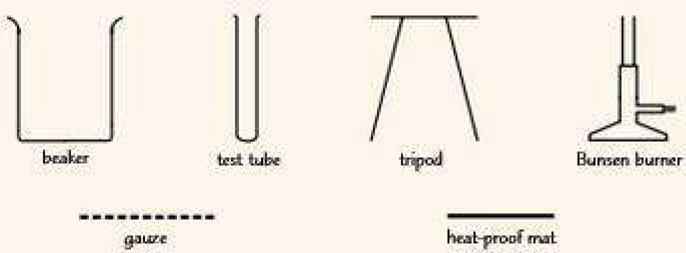
If the delivery tube is underneath the measuring cylinder rather than inside it then some of the gas might escape out into the air.

4) This method is less accurate than using a gas syringe to measure the volume of gas produced. This is because some gases can dissolve in water, so less gas ends up in the measuring cylinder than is actually produced.
5) If you just want to collect a sample to test (and don't need to measure a volume), you can collect it over water, as above, using a test tube. Once the test tube is full of gas, you can stopper it and store the gas for later.

Remember — when you're measuring a gas, your equipment has to be sealed or some gas could escape and your results wouldn't be accurate.

Make Sure You Can Draw Diagrams of Your Equipment

1) When you're writing out a method for your experiment, it's always a good idea to draw a labelled diagram showing how your apparatus will be set up.
2) The easiest way to do this is to use a scientific drawing, where each piece of apparatus is drawn as if you're looking at its cross-section.
3) For example:



The pieces of glassware are drawn without tops so they aren't sealed. If you want to draw a closed system, remember to draw a bung in the top.

Science exams — they're a set-up...

It may seem like science exams are a devious ploy by the creatures of darkness to set you up for misery and heartache... and maybe they are. But whether they are or not, you need to know each of the experimental set-ups on these pages. It'll be worth it in the end, when you ace the exam and smite the evil ones with your top grades...

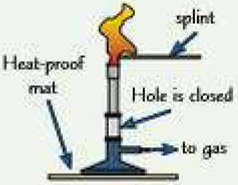
Heating Substances

Heating a reaction isn't as simple as wrapping it up in a lumpy wool jumper and a stripy scarf. There's more than one way to do it, and you need to be able to decide on the best, and the safest, method.

Bunsen Burners Have a Naked Flame

Bunsen burners are good for heating things quickly. You can easily adjust how strongly they're heating. But you need to be careful not to use them if you're heating flammable compounds as the flame means the substance would be at risk of catching fire.

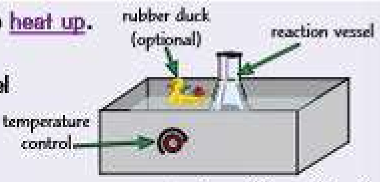
Here's how to use a Bunsen burner...



- Connect the Bunsen burner to a gas tap, and check that the hole is closed. Place it on a heat-proof mat.
- Light a splint and hold it over the Bunsen burner. Now, turn on the gas. The Bunsen burner should light with a yellow flame.
- The more open the hole is, the more strongly the Bunsen burner will heat your substance. Open the hole to the amount you want. As you open the hole more, the flame should turn more blue.
- The hottest part of the flame is just above the blue cone, so you should heat things here.
- If your Bunsen burner is alight but not heating anything, make sure you close the hole so that the flame becomes yellow and clearly visible.
- If you're heating something so that the container (e.g. a test tube) is in the flame, you should hold the vessel at the top, furthest away from the substance (and so the flame) using a pair of tongs.
- If you're heating something over the flame (e.g. an evaporating dish), you should put a tripod and gauze over the Bunsen burner before you light it, and place the vessel on this.

The Temperature of Water Baths & Electric Heaters Can Be Set

1) A water bath is a container filled with water that can be heated to a specific temperature. A simple water bath can be made by heating a beaker of water over a Bunsen burner and monitoring the temperature with a thermometer. However, it is difficult to keep the temperature of the water constant.
2) An electric water bath will monitor and adjust the temperature for you. Here's how you use one:
   - Set the temperature on the water bath, and allow the water to heat up.
   - Place the vessel containing your substance in the water bath using a pair of tongs. The level of the water outside the vessel should be just above the level of the substance inside the vessel. The substance will then be warmed to the same temperature as the water.



   As the substance in the vessel is surrounded by water, the heating is very even. Water boils at 100 °C though, so you can't use a water bath to heat something to a higher temperature than this — the water won't get hot enough.

Handle any glassware you've heated with tongs until you're sure it's cooled down.

3) Electric heaters are often made up of a metal plate that can be heated to a certain temperature. The vessel containing the substance you want to heat is placed on top of the hot plate. You can heat substances to higher temperatures than you can in a water bath but, as the vessel is only heated from below, you'll usually have to stir the substance inside to make sure it's heated evenly.

A bath and an electric heater — how I spend my January nights...

You know, I used to have a science teacher who'd play power ballads when the Bunsen burners were alight and sway at the front of the class like she was at a gig. You think I made that up, but it's true.

Working with Electronics

Electrical devices are used in a bunch of experiments, so make sure you know how to use them.

You Have to Interpret Circuit Diagrams

Before you get cracking on an experiment involving any kind of electrical devices, you have to plan and build your circuit using a circuit diagram. Make sure you know all of the circuit symbols on page 179 so you're not stumped before you've even started.

There Are a Couple of Ways to Measure Potential Difference and Current

Voltmeters Measure Potential Difference

1) If you're using an analogue voltmeter, choose the voltmeter with the most appropriate unit (e.g. V or mV). If you're using a digital voltmeter, you'll most likely be able to switch between them.
2) Connect the voltmeter in parallel (p.184) across the component you want to test. The wires that come with a voltmeter are usually red (positive) and black (negative). These go into the red and black coloured ports on the voltmeter. Funnily enough.
3) Then simply read the potential difference from the scale (or from the screen if it's digital).

Ammeters Measure Current

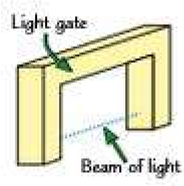
1) Just like with voltmeters, choose the ammeter with the most appropriate unit.
2) Connect the ammeter in series (p.183) with the component you want to test, making sure they're both on the same branch. Again, they usually have red and black ports to show you where to connect your wires.
3) Read off the current shown on the scale or by the screen.

Turn your circuit off between readings to prevent wires overheating and affecting your results (p.181).

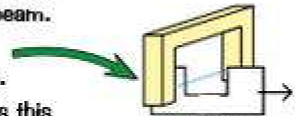
Multimeters Measure Both

1) Instead of having a separate ammeter and voltmeter, many circuits use multimeters. These are devices that measure a range of properties — usually potential difference, current and resistance.
2) If you want to find potential difference, make sure the red wire is plugged into the port that has a 'V' (for volts).
3) To find the current, use the port labelled 'A' or 'mA' (for amps).
4) The dial on the multimeter should then be turned to the relevant section, e.g. to 'A' to measure current in amps. The screen will display the value you're measuring.

Light Gates Measure Speed and Acceleration



1) A light gate sends a beam of light from one side of the gate to a detector on the other side. When something passes through the gate, the beam of light is interrupted. The light gate then measures how long the beam was undetected.
2) To find the speed of an object, connect the light gate to a computer. Measure the length of the object and input this using the software. It will then automatically calculate the speed of the object as it passes through the beam.
3) To measure acceleration, use an object that interrupts the signal twice in a short period of time, e.g. a piece of card with a gap cut into the middle.
4) The light gate measures the speed for each section of the object and uses this to calculate its acceleration. This can then be read from the computer screen.



Have a look at page 213 for an example of a light gate being used.

A light gate is better than a heavy one...

After finishing this page, you should be able to take on any electrical experiment that they throw at you... ouch.

Sampling

I love samples... especially when I'm a bit peckish in the supermarket and they're handing out free cheese. Unfortunately, this page isn't about those samples. It's a lot more useful than that...

Sampling Should be Random

1) When you're investigating a population, it's generally not possible to study every single organism in the population. This means that you need to take samples of the population you're interested in.
2) The sample data will be used to draw conclusions about the whole population, so it's important that it accurately represents the whole population.
3) To make sure a sample represents the population, it should be random.

If a sample doesn't represent the population as a whole, it's said to be biased.

Organisms Should Be Sampled At Random Sites in an Area

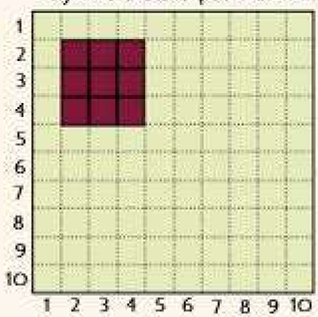
1) If you're interested in the distribution of an organism in an area, or its population size, you can take population samples in the area you're interested in using quadrats or transects (see pages 87-88).
2) If you only take samples from one part of the area, your results will be biased — they may not give an accurate representation of the whole area.
3) To make sure that your sampling isn't biased, you need to use a method of choosing sampling sites in which every site has an equal chance of being chosen. For example:

If you're looking at plant species in a field...

1) Divide the field into a grid.
2) Label the grid along the bottom and up the side with numbers.
3) Use a random number generator (on a computer or calculator) to select coordinates, e.g. (2,6).
4) Take your samples at these coordinates.

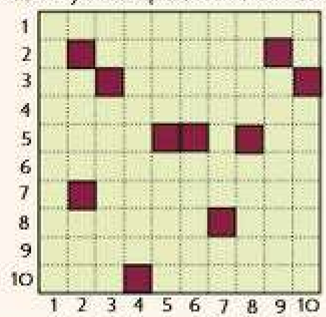
Non-random sampling

Only looks at a small part of the field.



Random sampling

Randomly selects squares from all over the field.



Health Data Should be Taken from Randomly Selected People

1) As mentioned above, it's not practical (or even possible) to study an entire human population.
2) You need to use random sampling to choose members of the population you're interested in. For example:

A health professional is investigating how many people diagnosed with Type 2 diabetes in a particular country also have heart disease:

1) All the people who have been diagnosed with Type 2 diabetes in the country of interest are identified by hospital records. In total, there are 270 196 people.
2) These people are assigned a number between 1 and 270 196.
3) A random number generator is used to choose the sample group (e.g. it selects the individuals #72 063, #11 822, #193 123, etc.)
4) The proportion of people in the sample that have heart disease can be used to estimate the total number of people with Type 2 diabetes that also have heart disease.

'Eeny, meeny, miny, moe' just doesn't cut it any more...

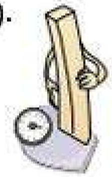
Sampling is an important part of an investigation. It needs to be done randomly, or the data won't be worth much.

Comparing Results

Being able to compare your results is really important. Here are some ways you might do it. I spoil you.

Percentage Change Allows you to Compare Results

1) When investigating the change in a variable, you may want to compare results that didn't have the same initial value. For example, you may want to compare the change in mass of potato cylinders left in different concentrations of sugar solution that had different initial masses (see page 18).
2) One way to do this is to calculate the percentage change. You work it out like this:



$$\text{percentage (\%) change} = \frac{\text{final value} - \text{original value}}{\text{original value}} \times 100$$

EXAMPLE

A student is investigating the effect of the concentration of sugar solution on potato cells. She records the mass of potato cylinders before and after placing them in sugar solutions of different concentrations. The table on the right shows some of her results. Which potato cylinder had the largest percentage change?

Potato cylinder	Concentration (mol/dm^3)	Mass at start (g)	Mass at end (g)
1	0.0	7.5	8.7
2	1.0	8.0	6.8

1) Stick each set of results into the equation:

$$\% \text{ change} = \frac{\text{final value} - \text{original value}}{\text{original value}} \times 100$$

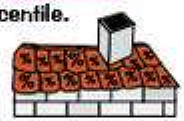
1. $\frac{8.7 - 7.5}{7.5} \times 100 = 16\%$ — The mass at the start is the original value. The mass at the end is the final value.

2. $\frac{6.8 - 8.0}{8.0} \times 100 = -15\%$ — Here, the mass has decreased so the percentage change is negative.

2) Compare the results. 16% is greater than 15%, so the potato cylinder in the 0.0 mol/dm^3 sugar solution had the largest percentage change.

Percentiles Tell you Where in Your Data Set a Data Point Lies

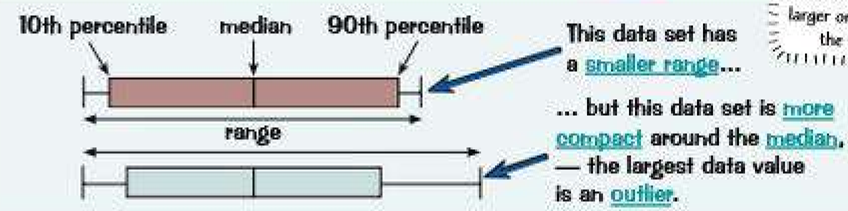
1) Percentiles are useful if you want to compare the value of one data point to the rest of your data.
2) To find a percentile, you rank your data from smallest to largest, then divide it into one hundred equal chunks. Each chunk is one percentile.
3) This means that each percentile represents one percent of the data, and so the value of a percentile tells you what percentage of the data has a value lower than the data points in that percentile.



E.g. Mike the Meerkat is in the 90th percentile for height in his gang. This means that 90% of the gang are shorter than Mike.

4) Percentiles can be used to give a more realistic idea of the spread of data than the range (see p.6) — by finding the range between the 10th and 90th percentiles in a data set (the middle 80% of the data), you can look at the spread of the data while ignoring any outlying results.

An outlier is a value that's much larger or smaller than the rest of the values in a data set.



The median is the middle value (see p.6). It's also the 50th percentile.

Percentage change in how much I love maths after this page — 0%

Aaaand that's the end of Practical Skills, folks. Go forth, and science like you've never scienced before...

Answers

p.11 — Cells

Q1 Any two from: e.g. prokaryotic cells are smaller than eukaryotic cells *[1 mark]*. / Prokaryotic cells don't have mitochondria but eukaryotic cells do *[1 mark]*. / Prokaryotic cells don't have a true nucleus but eukaryotic cells do *[1 mark]*. / Prokaryotic cells have circular DNA but eukaryotic cells don't *[1 mark]*.

p.12 — Microscopy

Q1 real size = image size ÷ magnification
= 2.4 mm ÷ 40
= 0.06 mm *[1 mark]*
0.06 × 1000 = 60 μm *[1 mark]*

p.13 — More on Microscopy

Q1 To highlight objects within the sample by adding colour to them *[1 mark]*.

p.14 — Cell Differentiation and Specialisation

Q1 E.g. they have few subcellular structures. / They're joined end to end. / They're long. *[1 mark]*

Q2 The cell has a hair-like shape, which gives it a large surface area *[1 mark]* to absorb water and minerals from the soil *[1 mark]*.

p.15 — Chromosomes and Mitosis

Q1 a) 11 ÷ (62 + 11) = 0.150...
0.150... × 100 = 15% *[1 mark]*

b) E.g. she could see the X-shaped chromosomes in the middle of the cells. / She could see the arms of the chromosomes being pulled apart *[1 mark]*.

p.16 — Stem Cells

Q1 Copies of the plant can be made by taking stem cells from the meristem of the plant *[1 mark]* and growing them into new, genetically identical plants (clones) *[1 mark]*.

p.17 — Diffusion

Q1 a) The ink will diffuse / spread out through the water *[1 mark]*. This is because the ink particles will move from where is a higher concentration of them (the drop of ink) to where there is a lower concentration of them (the surrounding water) *[1 mark]*.

b) The ink particles will diffuse / spread out faster *[1 mark]*.

p.18 — Osmosis

Q1 Water will move out of the piece of potato by osmosis *[1 mark]*, so its mass will decrease *[1 mark]*.

p.19 — Active Transport

Q1 Active transport allows nutrients such as glucose to move from a lower concentration in the gut to a higher concentration in the blood (against the concentration gradient) *[1 mark]*.

p.20 — Exchange Surfaces

Q1 Surface area:
(2 × 2) × 2 = 8
(2 × 1) × 4 = 8
8 + 8 = 16 μm² *[1 mark]*
Volume:
2 × 2 × 1 = 4 μm³ *[1 mark]*
So the surface area to volume ratio is 16 : 4, or 4 : 1 *[1 mark]*.

p.21 — Exchanging Substances

Q1 E.g. they have a large surface area. / They have a moist lining for dissolving gases. / They have very thin walls. / They have a good blood supply. *[1 mark]*

Q2 The damage to the villi is likely to reduce the surface area for absorption *[1 mark]*. Therefore, less iron can be absorbed from the digested food in the small intestine into the blood *[1 mark]*.

p.22 — More on Exchanging Substances

Q1 Any two from: e.g. it is made up of gill filaments which give a large surface area. / each gill filament is covered in lamellae, which further increases the surface area. / The lamellae have a thin surface layer of cells. / The lamellae have lots of capillaries. / A large concentration gradient is maintained between the water and the blood. *[2 marks]*

p.24 — Cell Organisation

Q1 That it is made up of different tissues *[1 mark]* that work together to perform a particular function *[1 mark]*.

p.25 — Enzymes

Q1 If the pH is too high or too low, it can interfere with the bonds holding the enzyme together. This changes the shape of the active site *[1 mark]* and denatures the enzyme *[1 mark]*.

p.26 — Investigating Enzymatic Reactions

Q1 2 minutes = 2 × 60 = 120 seconds
36 ÷ 120 = 0.3 cm³/s *[1 mark]*

p.27 — Enzymes and Digestion

Q1 Bile is alkaline, so it neutralises the stomach acid and makes conditions in the small intestine alkaline *[1 mark]*. The enzymes of the small intestine work best in these alkaline conditions *[1 mark]*. It also emulsifies fats/breaks down fats into tiny droplets *[1 mark]*. This gives a bigger surface area of fat for the enzyme lipase to work on, making digestion faster *[1 mark]*.

p.28 — More on Enzymes and Digestion

Q1 Stomach *[1 mark]*, pancreas *[1 mark]* and small intestine *[1 mark]*.

p.29 — Food Tests

Q1 iodine solution *[1 mark]*

p.30 — The Lungs

Q1 495 ÷ 12
= 41 breaths per minute. *[1 mark]*

p.31 — Circulatory System — The Heart

Q1 The right ventricle *[1 mark]*.

Q2 They supply oxygenated blood to the heart itself *[1 mark]*.

p.32 — Circulatory System — Blood Vessels

Q1 2.175 l × 1000 = 2175 ml *[1 mark]*
2175 ÷ 8.7 = 250 ml/min *[1 mark]*

p.33 — Circulatory System — Blood

Q1 They help the blood to clot at a wound *[1 mark]*.

Q2 To carry oxygen from the lungs to all the cells in the body *[1 mark]*.

p.34 — Cardiovascular Disease

Q1 a) Stents can be inserted into the coronary arteries to keep them open *[1 mark]*. This ensures that the supply of oxygenated blood to the heart isn't interrupted *[1 mark]*.

b) Any two from: e.g. there is a risk of complications such as a heart attack during the operation. / There's a risk of infection from surgery. / There's a risk of the patient developing a blood clot/thrombosis near the stent *[2 marks]*.

p.35 — More on Cardiovascular Disease

Q1 a) The heart valves might not be able to open fully, meaning that less blood can flow through them *[1 mark]*. They can also become leaky, meaning that blood is able to flow in both directions *[1 mark]*.

b) By replacing the valve with a biological or mechanical valve *[1 mark]*.

Q2 Any one from: e.g. surgery to fit an artificial heart can lead to bleeding and infection. / Parts of the artificial heart could wear out. / The electric motor could fail. / Blood doesn't flow through the heart as smoothly, which could cause clots and lead to strokes. / The patient has to take blood thinning drugs to prevent blood clots, which could cause problems with bleeding if they're hurt in an accident *[1 mark]*.

p.36 — Health and Disease

Q1 The state of physical and mental wellbeing *[1 mark]*.

Q2 It can be spread from person to person *[1 mark]*.

p.37 — Risk Factors for Non-Communicable Diseases

Q1 The presence of certain substances in the body. / The presence of certain substances in the environment *[1 mark]*.

p.38 — Cancer

Q1 Body cells dividing out of control *[1 mark]*.

Q2 Any three from: e.g. smoking / obesity / UV exposure / viral infection *[1 mark for each correct answer, up to 3 marks]*.

p.39 — Plant Cell Organisation

Q1 Meristem tissue is found at the growing tips of roots and shoots *[1 mark]* and is able to differentiate into lots of different types of plant cell *[1 mark]*.

p.40 — Transpiration and Translocation

Q1 Xylem is made up of dead cells joined together end to end *[1 mark]* with no end walls between them and a hole down the middle *[1 mark]*. It is strengthened by lignin *[1 mark]*.

p.41 — Transpiration and Stomata

Q1 Aloe vera, because the transpiration rate will be higher in the hot, dry area *[1 mark]*, so the aloe vera will have fewer stomata to help conserve water *[1 mark]*.

p.43 — Communicable Disease

Q1 Viruses replicate themselves by using the machinery of the cell they live in to produce many copies of themselves *[1 mark]*. The cell will usually then burst, releasing all the new viruses *[1 mark]*.

p.44 — Viral, Fungal and Protist Diseases

Q1 a red skin rash *[1 mark]*

Q2 Using a fungicide *[1 mark]* and by stripping the plants of the affected leaves and destroying them *[1 mark]*.

p.45 — Bacterial Diseases and Preventing Disease

Q1 Strains of the bacteria becoming resistant to antibiotics/penicillin *[1 mark]*.

Q2 To prevent the contamination of food by disease-causing pathogens *[1 mark]*.

p.46 — Fighting Disease

Q1 It is when white blood cells engulf foreign cells and digest them *[1 mark]*.

Q2 They secrete mucus to trap pathogens *[1 mark]*. They have cilia *[1 mark]*, which waft the mucus up to the back of the throat where it can be swallowed *[1 mark]*.

p.47 — Fighting Disease — Vaccination

Q1 Basia's white blood cells recognise the antigens on the flu virus and rapidly produce antibodies, which kill the pathogen *[1 mark]*. Cassian's white blood cells don't recognise the antigens, so it takes a while for them to produce antibodies and he becomes ill in the meantime *[1 mark]*.

p.48 — Fighting Disease — Drugs

Q1 bacteria *[1 mark]*

p.49 — Developing Drugs

Q1 Whether the drug works and produces the effect you're looking for *[1 mark]*.

Q2 To make sure that the drug doesn't have any harmful side effects when the body is working normally *[1 mark]*.

Q3 To help to prevent false claims about the results *[1 mark]*.

p.50 — Photosynthesis and Limiting Factors

Q1 Glucose *[1 mark]* and oxygen *[1 mark]*.

Q2 Light intensity *[1 mark]*, volume of CO_2 *[1 mark]* and amount of chlorophyll *[1 mark]*.

p.53 — The Rate of Photosynthesis

Q1 E.g. light intensity *[1 mark]*, CO_2 *[1 mark]*.

Q2 $\text{light intensity} \propto \frac{1}{\text{distance}^2}$

$1 \div 15^2 = 0.00444...$ a.u. *[1 mark]*

$1 \div 5^2 = 0.04$ a.u. *[1 mark]*

$0.04 \div 0.00444... = 9$ *[1 mark]*

p.54 — Respiration and Metabolism

Q1 Any two from: e.g. to build up larger molecules from smaller ones. / To contract muscles. / To keep body temperature steady. *[1 mark for each]*

Q2 The sum of all of the reactions that happen in a cell or the body *[1 mark]*.

p.55 — Aerobic and Anaerobic Respiration

Q1 Glucose *[1 mark]* and oxygen *[1 mark]*.

Q2 fermentation *[1 mark]*

p.56 — Exercise

Q1 Running *[1 mark]*. It raises the pulse rate the most, so it is the most vigorous type of exercise *[1 mark]*. The more vigorous the exercise, the more anaerobic respiration will be taking place in the muscles *[1 mark]*. Anaerobic respiration produces lactic acid, so running will lead to the greatest build up of lactic acid in the blood *[1 mark]*.

p.58 — Homeostasis

Q1 To maintain the right conditions for cells to function properly and for enzyme action *[1 mark]*.

Q2 receptor (cell) *[1 mark]*

p.59 — The Nervous System

Q1 Muscles *[1 mark]*, glands *[1 mark]*.

p.60 — Synapses and Reflexes

Q1 A rapid, automatic response to a stimulus that doesn't involve the conscious part of the brain *[1 mark]*.

Q2 a) muscle *[1 mark]*

b) The heat stimulus is detected by receptors in the hand *[1 mark]*, which send impulses along a sensory neurone to the CNS *[1 mark]*. The impulses are transferred to a relay neurone *[1 mark]*. They are then transferred to a motor neurone and travel along it to the effector/muscle *[1 mark]*.

p.61 — Investigating Reaction Time

Q1 a) 242 + 256 + 253 + 249 + 235 = 1235 *[1 mark]*

1235 ÷ 5 = 247 ms *[1 mark]*

b) Any two from: e.g. the hand each person used to click the mouse / the computer equipment/ programme used / the amount of energy drink they consumed / the type of energy drink used / the time between consuming the energy drink and taking the test *[2 marks]*.

p.62 — The Endocrine System

Q1 Because it produces many hormones that act on other glands to regulate body conditions *[1 mark]*.

p.63 — Controlling Blood Glucose

Q1 Curve 1, because the secretion rate is high when the blood glucose level is low / the secretion rate decreases as the blood glucose level rises *[1 mark]*. Glucagon increases the blood glucose level, so it is secreted when the blood glucose level becomes too low *[1 mark]*.

p.64 — Puberty and the Menstrual Cycle

Q1 FSH/follicle-stimulating hormone *[1 mark]*

Q2 testes *[1 mark]*

p.65 — Controlling Fertility

Q1 The pill/oral contraceptives *[1 mark]*. The contraceptive patch *[1 mark]*.

p.66 — More on Controlling Fertility

Q1 They stimulate several eggs to mature *[1 mark]*.

Q2 E.g. it doesn't always work. / It can be expensive. / Too many eggs can be stimulated, resulting in unexpected multiple pregnancies. *[1 mark]*

p.67 — Adrenaline and Thyroxine

Q1 thyroid gland *[1 mark]*

Q2 When the high level of thyroxine is detected, the secretion of TSH from the pituitary gland is inhibited *[1 mark]*. This reduces the amount of thyroxine released from the thyroid gland *[1 mark]*, so the level in the blood falls back towards normal *[1 mark]*.

p.68 — DNA

Q1 A small section of DNA found on a chromosome *[1 mark]* that codes for a particular sequence of amino acids *[1 mark]* that are put together to make a specific protein *[1 mark]*.

Q2 The entire set of genetic material in an organism *[1 mark]*.

p.69 — Reproduction

Q1 mitosis *[1 mark]*

Q2 Because there are two parents, the offspring contain a mixture of their parents' genes *[1 mark]*. This mixture of genetic information produces variation *[1 mark]*.

p.70 — Meiosis

Q1 23 *[1 mark]*

p.71 — X and Y Chromosomes

Q1 XX *[1 mark]*

p.72 — Genetic Diagrams

Q1 Your genotype is the combination of alleles you have *[1 mark]*. Your phenotype is the characteristics you have *[1 mark]*.

p.73 — More Genetic Diagrams

Q1

	R	r
r	Rr	rr
r	Rr	rr

round peas : wrinkly peas

1 : 1

[1 mark for correct gametes, 1 mark for correct offspring genotypes and 1 mark for correct ratio.]

p.74 — Inherited Disorders

Q1 Because the allele which causes cystic fibrosis is recessive *[1 mark]*, so you have to have two recessive alleles to have the disorder *[1 mark]*. Heterozygous people have one dominant and one recessive allele *[1 mark]*.

p.75 — Variation

Q1 Differences between members of the same species *[1 mark]* that have been caused by the environment/conditions something lives in *[1 mark]*.

p.76 — Evolution

Q1 There was a variety of tongue lengths in the moth population *[1 mark]*. Moths with longer tongues got more food/nectar and were more likely to survive *[1 mark]*. These moths were more likely to reproduce and pass on the genes responsible for their long tongues *[1 mark]*. So, over time, longer tongues became more common in the moth population *[1 mark]*.

p.77 — Selective Breeding

Q1 Select rabbits with floppy ears *[1 mark]* and breed them together to produce offspring *[1 mark]*. Select offspring with floppy ears and breed them together *[1 mark]*. Repeat this over many generations until all of the offspring have floppy ears *[1 mark]*.

Q2 Selective breeding reduces the gene pool *[1 mark]*. This causes an increased chance of organisms inheriting harmful genetic defects *[1 mark]*. There is also an increased chance that a population could be wiped out by a new disease *[1 mark]*.

p.78 — Genetic Engineering

Q1 Benefit — E.g. the characteristics chosen for GM crops can mean that they have an increased yield. / GM crops can be engineered to contain certain nutrients, which some people in developing nations may lack from their diets *[1 mark]*. Concern — E.g. some people are not convinced that GM crops are safe and are concerned that we might not fully understand the effects of eating them on human health. / Some people say that growing GM crops will affect the number of wild flowers and insects that live in and around the crops. / There is concern that the transplanted genes could get out into the natural environment, which could lead to the creation of 'superweeds' *[1 mark]*.

p.79 — Fossils

Q1 The microbes that cause decay can't survive in low oxygen conditions *[1 mark]*, so the dead organisms are preserved rather than decayed *[1 mark]*.

p.80 — Antibiotic-Resistant Bacteria

Q1 Any one from: e.g. when the illness is only minor. / When the infection is being caused by a virus *[1 mark]*.

Q2 Taking the complete course makes sure that all the bacteria are destroyed *[1 mark]*. This means that there are none left to mutate and develop into antibiotic-resistant strains *[1 mark]*.

p.81 — Classification

Q1 B and C *[1 mark]*

p.83 — Competition

Q1 Any three from: light / space / water / mineral ions *[1 mark for each correct answer, up to 3 marks]*.

Q2 E.g. the frog population might increase as there might be more water spiders available for them to eat *[1 mark]* because there will be fewer sticklebacks to eat the water spiders / less competition for food *[1 mark]*. / The frog population might decrease as they are more likely to be eaten by pike *[1 mark]* because there will be fewer sticklebacks for the pikes to eat *[1 mark]*.

p.84 — Abiotic and Biotic Factors

Q1 Any four from: moisture level / light intensity / temperature / carbon dioxide level / wind intensity / wind direction / soil pH / mineral content of soil *[1 mark for each correct answer, up to 4 marks]*.

Q2 Any two from: availability of food / competition for resources / new pathogens *[1 mark for each correct answer, up to 2 marks]*.

p.85 — Adaptations

Q1 a) A behavioural adaptation *[1 mark]*.

b) E.g. it has flippers *[1 mark]* so it can swim for food *[1 mark]*. / A thick layer of fat *[1 mark]* so it retains heat *[1 mark]*. / A low surface area to volume ratio *[1 mark]* so it retains heat *[1 mark]*.

p.86 — Food Chains

Q1 a) grass *[1 mark]*

b) three *[1 mark]*

c) grasshopper *[1 mark]*

d) The population of grasshoppers could increase *[1 mark]* as there's nothing to eat them *[1 mark]*. The population of snakes could decrease *[1 mark]* as there's nothing for them to eat *[1 mark]*.

p.87 — Using Quadrats

Q1 $0.75 \times 4 = 3$ buttercups per m^2 *[1 mark]*.
$3 \times 1200 = 3600$ buttercups in total *[1 mark]*.

p.88 — Using Transects

Q1 A line used to help find out how organisms are distributed across an area *[1 mark]*.

Q2 They could mark out a line across the field, from one corner to the other *[1 mark]*. Then they could count all of the dandelions that touch the line *[1 mark]*.

Q3 You could estimate the percentage of the quadrat covered by the organisms *[1 mark]*.

p.89 — The Water Cycle

Q1 a) By evaporation / transpiration *[1 mark]*.

b) By providing them with fresh water *[1 mark]*.

p.90 — The Carbon Cycle

Q1 Microorganisms/detritus feeders break them down/digest them *[1 mark]*.

Q2 By green plants and algae in photosynthesis *[1 mark]*.

p.91 — Biodiversity and Waste Management

Q1 The variety of different species of organisms on Earth, or within an ecosystem *[1 mark]*.

p.92 — Global Warming

Q1 Global warming causes higher temperatures, which cause ice to melt and seawater to expand *[1 mark]*. This causes the sea level to rise *[1 mark]*, which could lead to flooding of low-lying land and therefore the loss of habitats *[1 mark]*.

p.93 — Deforestation and Land Use

Q1 Trees 'lock up' some of the carbon that they absorb during photosynthesis, so if lots of trees are removed, less carbon will be locked up from the atmosphere *[1 mark]*. If the land is cleared by burning the trees, this means that lots of carbon dioxide is released *[1 mark]*. Microorganisms feeding on leftover dead wood release carbon dioxide as a waste product of respiration *[1 mark]*.

p.94 — Maintaining Ecosystems and Biodiversity

Q1 Hedgerows and field margins can be reintroduced around single-crop fields *[1 mark]*. These provide a habitat for organisms that would otherwise be unable to live in the area *[1 mark]*.

Q2 Breeding programmes breed endangered animals in captivity to make sure the species survives if they die out in the wild *[1 mark]*. Individuals can sometimes be released into the wild to boost or re-establish a population *[1 mark]*.

p.96 — Atoms

Q1 protons = atomic number = 31 *[1 mark]*
electrons = protons = 31 *[1 mark]*
neutrons = mass number – atomic number
= 70 – 31 = 39 *[1 mark]*

p.97 — Elements

Q1 E.g. it's the number of protons in an atom that determines what type of atom it is, so if all the atoms have the same number of protons then the substance is an element *[1 mark]*.

Q2 Relative atomic mass =

$$\frac{(92.2 \times 28) + (4.7 \times 29) + (3.1 \times 30)}{92.2 + 4.7 + 3.1}$$ *[1 mark]*

$$= \frac{2581.6 + 136.3 + 93}{100} = \frac{2810.9}{100}$$

= 28.109 = 28.1 *[1 mark]*

p.98 — Compounds

Q1 (2 × Na) + (1 × C) + (3 × O) = 6 *[1 mark]*

Q2 Aluminium — 2 atoms, sulfur — 3 atoms and oxygen — 12 atoms *[1 mark]*.

p.99 — Chemical Equations

Q1 $2Fe + 3Cl_2 \rightarrow 2FeCl_3$ *[1 mark]*

Q2 a) water → hydrogen + oxygen *[1 mark]*

b) $2H_2O \rightarrow 2H_2 + O_2$
[1 mark for correct reactants and products, 1 mark for correctly balancing]

p.100 — Mixtures and Chromatography

Q1 The pen ink might dissolve in the solvent and rise up the filter paper *[1 mark]*.

p.101 — More Separation Techniques

Q1 Pour the copper sulfate solution into an evaporating dish and slowly heat the solution until crystals start to form or some of the solvent has evaporated *[1 mark]*. Leave the dish to cool until crystals form *[1 mark]*. Filter *[1 mark]* and then dry the crystals using a desiccator/drying oven *[1 mark]*.

p.102 — Distillation

Q1 Ethanol *[1 mark]*. Ethanol has the second lowest boiling point and will be collected once all the methanol has been distilled off and the temperature increased *[1 mark]*.

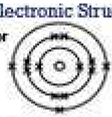
p.103 — The History of the Atom

Q1 In the plum pudding model, the atom is a ball of positive charge with electrons spread throughout it *[1 mark]*.

Q2 If the plum pudding model was correct you would expect most of the alpha particles to have passed through the foil or only to have been deflected slightly *[1 mark]*. The actual deflections of the particles suggests that atoms contain a small nucleus where the positive charge is concentrated *[1 mark]*.

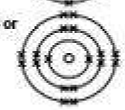
p.104 — Electronic Structure

Q1 2,8,3 or



[1 mark]

Q2 2,8,8 or



[1 mark]

p.105 — Development of the Periodic Table

Q1 By atomic weight *[1 mark]*.

Q2 E.g. he left gaps in order to keep elements with similar properties in the same group *[1 mark]*. He switched the order of elements based on their properties, even if their atomic weights were no longer in order. *[1 mark]*.

p.106 — The Modern Periodic Table

Q1 2 *[1 mark]*

Q2 Both chlorine and bromine are in Group 7 and so have the same number of electrons in their outer shell *[1 mark]*.

Q3 E.g. potassium forms 1+ ions as it's in the same group as sodium so will react in a similar way *[1 mark]*.

p.107 — Metals and Non-Metals

Q1 non-metal *[1 mark]*

Q2 Any three from: e.g. metals tend to be strong / good conductors of heat / good at conducting electricity / malleable / high melting/boiling temperatures *[1 mark for each, up to a maximum of 3 marks]*.

Q3 Positive ions *[1 mark]*. Metals can be towards the left of the periodic table, where they don't have many electrons in their outer shell *[1 mark]*, or they can be towards the bottom of the periodic table where the outer electrons are a long way from the nucleus so feel a weak attraction *[1 mark]*. This means that not much energy is needed to remove the outer electrons and form a positive ion *[1 mark]*.

p.108 — Group 1 Elements

Q1 lithium + water → lithium hydroxide + hydrogen *[1 mark]*

Q2 As you go further down the group the outer electron is further away from the nucleus *[1 mark]*. This means the attraction between the nucleus and the electron decreases so is more easily removed resulting in an increase in reactivity *[1 mark]*.

p.109 — Group 7 Elements

Q1 $Br_2 + 2NaI \rightarrow 2NaBr + I_2$ *[1 mark]*

Q2 Halogens react by gaining electrons to make a full outer-shell *[1 mark]*. As you go further down the group the outer electrons are further away so there is less attraction between them and the nucleus *[1 mark]*. This means electrons are harder to gain so they become less reactive *[1 mark]*.

p.110 — Group 0 Elements

Q1 Xenon has a higher boiling point than neon *[1 mark]*.

Q2 Argon has a full outer-shell *[1 mark]* so is electronically stable and does not readily lose or gain electrons *[1 mark]*.

p.112 — Formation of Ions

Q1 Noble gas electronic structures have a full shell of outer electrons *[1 mark]*, which is a very stable structure *[1 mark]*.

Q2 a) 1– *[1 mark]*

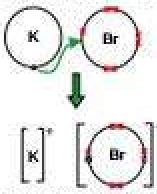
b) 2+ *[1 mark]*

c) 1+ *[1 mark]*

p.113 — Ionic Bonding

Q1 Each sodium atom loses an electron to form an Na^+ ion *[1 mark]*. Each chlorine atom gains an electron to form a Cl^- ion *[1 mark]*. The oppositely charged ions are attracted to each other by electrostatic attraction *[1 mark]*.

Q2



[1 mark for arrow showing electron transferred from potassium to bromine, 1 mark for correct outer shell electron configurations (with or without inner shells), 1 mark for correct charges]

p.114 — Ionic Compounds

Q1 a) It will have a high melting point *[1 mark]* because a lot of energy is needed to break the strong attraction between the ions/the strong ionic bonds *[1 mark]*.

b) When melted, the ions are free to move, so they can carry an electric charge *[1 mark]*.

c) The compound contains magnesium and sulfide ions. Magnesium is in Group 2 so forms 2+ ions *[1 mark]*, and sulfur is in Group 6 so forms 2– ions *[1 mark]*. The charges balance with one of each ion, so the empirical formula is MgS *[1 mark]*.

p.115 — Covalent Bonding

Q1

[1 mark for 3 shared pairs of electrons, 1 mark for correct number of electrons in outer shell of each atom (with our without inner shells on nitrogen)]

p.116 — Simple Molecular Substances

Q1 The intermolecular forces between molecules of O_2 are weak and don't need much energy to break *[1 mark]*.

Q2 N_2 molecules aren't charged/There aren't any free electrons or ions *[1 mark]*.

p.117 — Polymers and Giant Covalent Structures

Q1 $(C_2H_3Cl)_n$ *[1 mark]*

Q2 To melt diamond you have to break the covalent bonds between atoms which are very strong *[1 mark]* but to melt poly(ethene) you only have to break the weaker intermolecular forces which needs less energy *[1 mark]*. So diamond has a higher melting point *[1 mark]*.

p.118 — Allotropes of Carbon

Q1 Any three from: e.g. lubricants / catalysts / drug delivery / to strengthen materials ***[1 mark for each, up to a maximum of 3 marks]***

p.119 — Metallic Bonding

Q1 Copper is a good electrical conductor *[1 mark]* as it contains delocalised electrons which are able to carry an electrical charge through the whole structure *[1 mark]*.

Q2 Pure copper would be too soft to use for a door hinge, but alloys are harder than pure metals, so are suitable *[1 mark]*.

p.120 — States of Matter

Q1 The gaseous state *[1 mark]*.

p.121 — Changing State

Q1 a) solid *[1 mark]*

b) liquid *[1 mark]*

c) liquid *[1 mark]*

d) gas *[1 mark]*

p.123 — Relative Formula Mass

Q1 a) A_r of H = 1 and A_r of O = 16
M_r of H_2O = (2 × 1) + 16 = 18 *[1 mark]*

b) A_r of Li = 7, A_r of O = 16 and A_r of H = 1
So M_r of LiOH = 7 + 16 + 1 = 24 *[1 mark]*

c) A_r of H = 1, A_r of S = 32 and A_r of O = 16
M_r of H_2SO_4 = (2 × 1) + 32 + (4 × 16) = 98 *[1 mark]*

Q2 A_r of K = 39, A_r of O = 16 and A_r of H = 1
M_r of KOH = 39 + 16 + 1 = 56 *[1 mark]*
$\frac{39}{56}$ × 100 = 70% *[1 mark]*

p.124 — The Mole

Q1 M_r of H_2O = 16 + (2 × 1) = 18 *[1 mark]*
number of moles = mass ÷ M_r
number of moles = 90 g ÷ 18 = 5 moles *[1 mark]*

Q2 M_r of KBr = 39 + 80 = 119 *[1 mark]*
mass = number of moles × M_r
mass = 0.20 × 119 = 24 g *[1 mark]*

p.125 — Conservation of Mass

Q1 Total mass on the left hand side
= $M_r(H_2SO_4)$ + 2 × M_r(NaOH)
M_r of H_2SO_4 = (2 × 1) + 32 + (4 × 16) = 98
2 × M_r of NaOH = 2 × (23 + 16 + 1) = 80
So total mass on the left hand side
= 98 + 80 = 178
[2 marks for 178, 1 mark for either 98 or 80]
Total mass on right hand side
= $M_r(Na_2SO_4)$ + 2 × $M_r(H_2O)$
M_r of Na_2SO_4 = (2 × 23) + 32 + (4 × 16) = 142
2 × M_r of H_2O = 2 × [(2 × 1) + 16] = 36
142 + 36 = 178
[2 marks for 178, 1 mark for either 142 or 36]
The total M_r on the left-hand side is equal to the total M_r on the right-hand side, so mass is conserved *[1 mark]*.

p.126 — The Mole and Equations

Q1 a) N_2: $\frac{84}{28}$ = 3.0 mol *[1 mark]*
H_2: $\frac{18}{2}$ = 9 mol *[1 mark]*
NH_3: $\frac{102}{17}$ = 6.0 mol *[1 mark]*

b) Divide by the smallest number of moles (3.0):
N_2: $\frac{3.0}{3.0}$ = 1 H_2: $\frac{9}{3.0}$ = 3 NH_3: $\frac{6.0}{3.0}$ = 2.0 *[1 mark]*
The balanced symbol equation is:
$N_2 + 3H_2 \rightarrow 2NH_3$ *[1 mark]*

p.127 — Limiting Reactants

Q1 M_r(KBr) = 119, M_r(KCl) = 74.5 *[1 mark]*
No. of moles of KBr = 23.8 ÷ 119 = 0.200 mol *[1 mark]*
From the reaction equation, 2 moles of KBr react to form 2 moles of KCl. So 0.200 moles of KBr reacts to form 0.200 moles of KCl *[1 mark]*.
Mass KCl = 74.5 × 0.200 = 14.9 g *[1 mark]*

p.128 — Concentrations of Solutions

Q1 volume = 15 ÷ 1000 = 0.015 dm^3 *[1 mark]*
concentration = mass ÷ volume = 0.6 ÷ 0.015 = 40 g/dm^3 *[1 mark]*

p.129 — Acids and Bases

Q1 red/orange *[1 mark]*

Q2 alkaline *[1 mark]*

p.130 — Strong Acids and Weak Acids

Q1 Any one of, e.g. sulfuric acid / nitric acid / hydrochloric acid *[1 mark]*.

Q2 Change in pH = 3 – 6 = –3
Change in concentration of H^+ = $10^{-(-3)}$ = 10^3 = 1000
So, the concentration of H^+ is 1000 times greater at pH = 3 than at pH = 6 *[1 mark]*.

p.131 — Reactions of Acids

Q1 calcium carbonate + hydrochloric acid → calcium chloride + carbon dioxide + water
[1 mark for calcium chloride, 1 mark for carbon dioxide and water]
$CaCO_3 + 2HCl \rightarrow CaCl_2 + CO_2 + H_2O$
[1 mark for the correctly balanced equation]

p.132 — The Reactivity Series

Q1 $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$
[1 mark for correct reactants and products, 1 mark for balancing, 1 mark for state symbols]

p.133 — Separating Metals From Metal Oxides

Q1 $2PbO + C \rightarrow 2Pb + CO_2$
[1 mark for the correct products, 1 mark for the correctly balanced equation]

Q2 Carbon is less reactive than calcium and therefore will not reduce calcium oxide / Calcium is more reactive than carbon, so calcium oxide won't be reduced by carbon *[1 mark]*.

p.134 — Redox Reactions

Q1 a) $Zn_{(s)} + Fe^{2+}_{(aq)} \rightarrow Zn^{2+}_{(aq)} + Fe_{(s)}$ *[1 mark]*

b) $Zn_{(s)}$ is being oxidised *[1 mark]*.
$Fe^{2+}_{(aq)}$ is being reduced *[1 mark]*.

p.135 — Electrolysis

Q1 a) chlorine gas/Cl_2 *[1 mark]*

b) calcium atoms/Ca *[1 mark]*

p.136 — Electrolysis of Aqueous Solutions

Q1 a) bromine gas/Br_2 *[1 mark]*

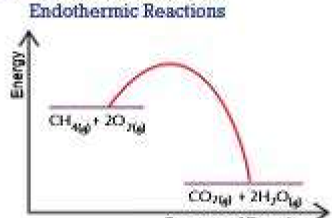
b) copper atoms/Cu *[1 mark]*

p.138 — Exothermic and Endothermic Reactions

Q1 exothermic *[1 mark]*

p.139 — More Exothermic and Endothermic Reactions

Q1



[1 mark for correct axes, 1 mark for correct energy levels of reactants and products, 1 mark for correct shape of curve linking the reactants to the products]

p.140 — Bond Energies

Q1 Energy required to break original bonds:
(1 × N≡N) + (3 × H–H)
= 941 kJ/mol + 1308 kJ/mol = 2249 kJ/mol *[1 mark]*
Energy released by forming new bonds:
(6 × N–H)
= 2346 kJ/mol *[1 mark]*
Overall energy change:
= 2249 kJ/mol – 2346 kJ/mol = –97 kJ/mol *[1 mark]*

p.142 — Rates of Reaction

Q1 The activation energy for a reaction is the minimum amount of energy that particles need to react *[1 mark]*.

p.143 — Factors Affecting Rates of Reaction

Q1 a) B *[1 mark]*, because the powder has a higher surface area to volume ratio than the solid strip *[1 mark]*.

b) B *[1 mark]*, because the 4 mol/dm^3 HCl solution is more concentrated than the 2 mol/dm^3 solution *[1 mark]*.

p.144 — Measuring Rates of Reaction

Q1 a) Add Na_2CO_3 to a flask containing HCl *[1 mark]* and take readings of the mass of the flask at regular intervals *[1 mark]* using a mass balance *[1 mark]*. / Add Na_2CO_3 to a flask containing HCl *[1 mark]* and take regular readings of the volume of gas released *[1 mark]* using a gas syringe *[1 mark]*. ***Maximum of 3 marks available.***

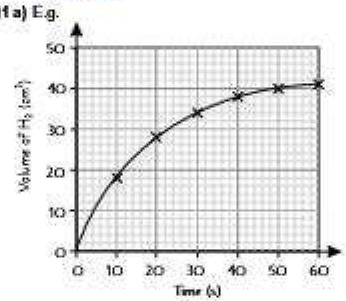
b) E.g. cm^3/s *[1 mark]*

p.145 — Two Rates Experiments

Q1 E.g. volume of HCl added *[1 mark]*, mass of magnesium used *[1 mark]*.

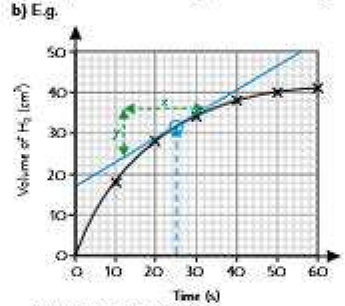
p.146 — Finding Reaction Rates from Graphs

Q1 a) E.g.



[1 mark for correctly marking on all 6 points, 1 mark for choosing a sensible scale for the axes, 1 mark for drawing a line of best fit]

b) E.g.



change in y = 36 – 24 = 12,
change in x = 32 – 12 = 20,
rate = change in y ÷ change in x
= 12 ÷ 20 = 0.6 cm^3/s
[1 mark for drawing a tangent at 25 s, 1 mark for correctly calculating a change in y from the tangent, 1 mark for correctly calculating a change in x from the tangent and 1 mark for a rate between 0.5 cm^3/s and 0.7 cm^3/s]

p.147 — Reversible Reactions

Q1 A system is at equilibrium when both the forward and reverse reactions are happening at the same rate *[1 mark]*.

p.148 — Le Chatelier's Principle

Q1 a) More $H_2CO_{3(aq)}$ would be produced *[1 mark]*.

b) Less $NH_{3(g)}$ and $HCl_{(g)}$ would be produced *[1 mark]*.

c) More $CO_{2(g)}$ would be produced *[1 mark]*.

p.150 — Hydrocarbons

Q1 $C_2H_6 + 3\frac{1}{2}O_2 \rightarrow 2CO_2 + 3H_2O$ or
$2C_2H_6 + 7O_2 \rightarrow 4CO_2 + 6H_2O$
[1 mark for correct reactants and products, 1 mark for correctly balancing]

Q2 a) $C_{10}H_{22}$ is more viscous than C_5H_{12} *[1 mark]*.

b) $C_{10}H_{22}$ has a higher boiling point than C_5H_{12} *[1 mark]*.

c) $C_{10}H_{22}$ is less flammable than C_5H_{12} *[1 mark]*.

p.151 — Fractional Distillation

Q1 The diagram shows that hydrocarbons in petrol have a shorter chain length than the hydrocarbons in diesel, so petrol has a lower boiling point than diesel *[1 mark]*.

Q2 It's hot at the bottom and cooler at the top *[1 mark]*.

p.152 — Uses and Cracking of Crude Oil

Q1 $C_6H_{14} \rightarrow C_4H_8 + C_2H_6$ *[1 mark]*

p.153 — Purity and Formulations

Q1 a) The sample melts over a range of temperatures *[1 mark]*. The melting point is lower than that of pure aspirin *[1 mark]*.

b) Any range or single value within the range: 141-200 °C *[1 mark]*

p.154 — Paper Chromatography

Q1 $R_f = \frac{6.3}{8.4} = 0.75$ *[1 mark]*.

p.155 — Tests for Gases

Q1 carbon dioxide *[1 mark]*

p.157 — The Evolution of the Atmosphere

Q1 Sedimentary rocks are formed when organic matter such as plant deposits or the shells and skeletons dead of marine animals fall to the seabed *[1 mark]*. These become buried and compressed by sediments over millions of years forming rocks *[1 mark]*.

p.158 — Greenhouse Gases and Climate Change

Q1 The sun gives out short wavelength radiation *[1 mark]* which is reflected back by the Earth as long wavelength/thermal radiation *[1 mark]*. The thermal radiation is absorbed by greenhouse gases in the atmosphere *[1 mark]*. Greenhouse gases give out the thermal radiation in all directions including back towards the Earth, causing the temperature to rise *[1 mark]*.

p.159 — Carbon Footprints

Q1 E.g. governments can put a cap on the amount of greenhouse gases that a business can emit and issue licences for set amounts of emissions up to this point *[1 mark]*. They can also impose taxes on companies according to the amount of greenhouse gases that they emit to encourage them to cut down on emissions *[1 mark]*.

p.160 — Air Pollution

Q1 E.g. particulates (soot) *[1 mark]*, unburnt fuels *[1 mark]* and carbon monoxide *[1 mark]*.

p.161 — Finite and Renewable Resources

Q1 A finite resource, such as e.g. crude oil, will take a long time to replenish *[1 mark]*. On the other hand, a renewable resource, such as e.g. timber, can be replaced within a relatively short time scale *[1 mark]*.

p.162 — Reuse and Recycling

Q1 E.g. saves energy needed to extract metals from the earth / conserves limited supplies of metals from the earth / cuts down on the amount of waste going to landfill *[1 mark for each]*.

p.163 — Life Cycle Assessments

Q1 Choice of material / manufacturing and packaging / using the product / product disposal *[1 mark for each]*.

p.164 — Potable Water

Q1 E.g. the water is filtered using a wire mesh, and then using filter beds *[1 mark]*. The filtered water is then sterilised using chlorine / ozone / ultraviolet light *[1 mark]*.

p.165 — Waste Water Treatment

Q1 Screening — sewage is screened to remove any large bits of material and grit *[1 mark]*. Sedimentation — heavier solids sink to the bottom to form sludge, while the lighter effluent floats on the top *[1 mark]*.

p.167 — Energy Stores and Systems

Q1 Energy is transferred mechanically *[1 mark]* from the kinetic energy store of the wind *[1 mark]* to the kinetic energy store of the windmill *[1 mark]*.

p.168 — Kinetic and Potential Energy Stores

Q1 The change in height is 5.0 m. So the energy transferred from the gravitational potential energy store is:
$E_p = mgh = 2.0 \times 9.8 \times 5.0 = 98$ J *[1 mark]*
This is transferred to the kinetic energy store of the object, so $E_k = 98$ J *[1 mark]*
$E_k = \frac{1}{2}mv^2$ so $v^2 = 2E_k \div m$ *[1 mark]*
$= (2 \times 98) \div 2.0$ *[1 mark]*
$= 98$ m²/s²
$v = \sqrt{98} = 9.899...$
$= 9.9$ m/s (to 2 s.f.) *[1 mark]*

p.169 — Specific Heat Capacity

Q1 $\Delta E = mc\Delta\theta$ so $\Delta\theta = \Delta E \div (m \times c)$ *[1 mark]*
$= 50\,000 \div (5 \times 4200) = 2.380...$ °C *[1 mark]*
So the new temperature
$= 5 + 2.380... = 7.380...$
$= 7$ °C (to 1 s.f.) *[1 mark]*

p.170 — Conservation of Energy and Power

Q1 $P = E \div t$
$t = 2 \times 60 = 120$ s *[1 mark]*
$P = 4800 \div 120$ *[1 mark]* $= 40$ W *[1 mark]*

p.171 — Reducing Unwanted Energy Transfers

Q1 Cavity wall insulation reduces energy transfer by convection *[1 mark]*. It also reduces energy transfer by conduction *[1 mark]* because the insulating foam has a low thermal conductivity and so has a low rate of energy transfer from thermal energy stores *[1 mark]*.

p.172 — Efficiency

Q1 efficiency = useful output energy transfer ÷ total input energy transfer
= 225 ÷ 300 *[1 mark]* = 0.75 *[1 mark]*

Q2 efficiency = useful power output ÷ total power input
= 900 ÷ 1200 = 0.75 *[1 mark]*
useful output energy transfer
= efficiency × total input energy transfer *[1 mark]*
= 0.75 × 72 000 *[1 mark]* = 54 000 J *[1 mark]*

p.173 — Energy Resources and Their Uses

Q1 a) renewable *[1 mark]*

b) non-renewable *[1 mark]*

c) non-renewable *[1 mark]*

d) renewable *[1 mark]*

p.174 — Wind, Solar and Geothermal

Q1 E.g. wind power can be unreliable as sometimes there's no wind or the turbines have to be stopped because the wind is too strong, so they don't provide a constant supply of energy *[1 mark]*. Geothermal power plants can run continuously as they transfer energy from the thermal energy store of the ground *[1 mark]*.

p.175 — Hydro-electricity, Waves and Tides

Q1 E.g. they disturb the seabed / they disturb the habitats of marine animals *[1 mark]*

p.176 — Bio-fuels and Non-renewables

Q1 Any two from: e.g. they're reliable / they're comparatively cheap to run / they can respond quickly to changes in demand *[2 marks]*

Q2 E.g. burning oil releases carbon dioxide, which contributes to global warming *[1 mark]*. It also produces sulfur dioxide which causes acid rain, which is harmful to trees and animals and can have far-reaching effects in ecosystems *[1 mark]*. Oil spills also occur when transporting oil, which can harm/kill animals that live in and around the sea *[1 mark]*.

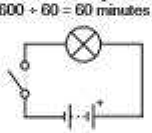
p.177 — Trends in Energy Resource Use

Q1 Any two from: e.g. building new power plants is expensive / people don't want to live near new power plants / renewable energy resources are less reliable than non-renewable energy resources / hybrid cars are more expensive than equivalent petrol cars *[2 marks]*.

p.179 — Current and Circuit Symbols

Q1 $Q = It$ so $t = Q \div I$ *[1 mark]*
$= 28\,800 \div 8$ *[1 mark]*
$= 3600$ s *[1 mark]*
$t = 3600 \div 60 = 60$ minutes *[1 mark]*

Q2 E.g.



[1 mark for each correct symbol connected in a single loop, otherwise, award 2 marks for correct symbols in an incorrect loop]

p.180 — Resistance and $V = IR$

Q1 $V = IR$ so $R = V \div I$ *[1 mark]*
$= 230 \div 5.0$ *[1 mark]*
$= 46\ \Omega$ *[1 mark]*

p.181 — Resistance and *I-V* Characteristics

Q1 As the current through the lamp increases, the temperature of its filament increases *[1 mark]* causing its resistance to increase *[1 mark]*. A larger resistance means less current can flow per unit potential difference, and so the graph gets shallower *[1 mark]*.

p.182 — Circuit Devices

Q1 a) E.g. automatic night lights — a light automatically turns on when it gets dark *[1 mark]*.

b) E.g. thermostats — the heating automatically turns on/off at a certain temperature *[1 mark]*.

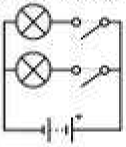
p.183 — Series Circuits

Q1 $R_{total} = 4 + 5 + 6 = 15\ \Omega$ ***[1 mark]***
$V = I \times R = 0.6 \times 15$ ***[1 mark]*** $= 9$ V ***[1 mark]***

p.184 — Parallel Circuits

Q1 The total current through the circuit decreases ***[1 mark]*** as there are fewer paths for the current to take ***[1 mark]***. The total resistance of the circuit increases ***[1 mark]*** as, using $V = IR$, a decrease in the total current means an increase in the total resistance ***[1 mark]***.

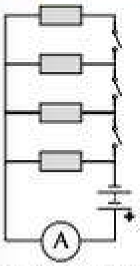
Q2 E.g.



[1 mark for the correct circuit symbols, 1 mark for two bulbs connected in parallel, 1 mark for both switches being on the same branches as the lamps]

p.185 — Investigating Resistance

Q1



[1 mark for a circuit with several resistors connected in parallel and switches allowing one resistor to be added at a time.]

p.186 — Electricity in the Home

Q1 a) 230 V ***[1 mark]***
b) 0 V ***[1 mark]***
c) 0 V ***[1 mark]***

p.187 — Power of Electrical Appliances

Q1 $P = E \div t = 6000 \div 30$ ***[1 mark]***
$= 200$ W ***[1 mark]***

Q2 $E = P \times t$ ***[1 mark]***
$= 250 \times (2 \times 60 \times 60)$
$= 1\,800\,000$ J ***[1 mark]***
$E = 375 \times (2 \times 60 \times 60) = 2\,700\,000$ J ***[1 mark]***
So change in energy is
$2\,700\,000 - 1\,800\,000 = 900\,000$ J ***[1 mark]***

p.188 — More on Power

Q1 $E = Q \times V = 10\,000 \times 200$ ***[1 mark]***
$= 2\,000\,000$ J ***[1 mark]***

Q2 $P = V \times I = 12 \times 4.0$ ***[1 mark]*** $= 48$ W ***[1 mark]***

Q3 $R = P \div I^2$ ***[1 mark]*** $= 2300 \div 10.0^2$ ***[1 mark]***
$= 23\ \Omega$ ***[1 mark]***

p.189 — The National Grid

Q1 The national grid distributes electricity at a high p.d. and a low current ***[1 marks]***. A high p.d. means that it can distribute lots of power per second (as power = p.d. × current) ***[1 mark]***. Using a low current reduces energy losses ***[1 mark]*** which makes the national grid efficient at transferring energy ***[1 mark]***.

p.191 — The Particle Model and Motion in Gases

Q1 Decreasing the temperature of the gas means that the gas particles have less energy in their kinetic energy stores ***[1 mark]***. They collide with the container less often ***[1 mark]*** and exert a smaller force when they do collide, meaning that the gas pressure is lower ***[1 mark]***.

p.192 — Density of Materials

Q1 Gemstone's mass = 0.019 kg = 0.019 × 1000
= 19 g ***[1 mark]***
Gemstone's volume = volume of water pushed out of eureka can = 7.0 cm³
$\rho = m \div V$
$= 19 \div 7.0$ ***[1 mark]***
$= 2.714...$
$= 2.7$ g/cm³ (to 2 s.f.) ***[1 mark]***

p.193 — Internal Energy and Changes of State

Q1 Heating the solid transfers energy to the kinetic energy stores of the particles (increasing the internal energy) ***[1 mark]***. When the particles have enough energy in their kinetic energy stores, they can break the bonds holding them together ***[1 mark]***. The solid changes state and becomes liquid ***[1 mark]***.

p.194 — Specific Latent Heat

Q1 $E = m \times L = 0.25 \times 120\,000$ ***[1 mark]***
$= 30\,000$ J ***[1 mark]***

p.195 — Developing the Model of the Atom

Q1 a) The centre of an atom is a tiny, positively charged nucleus ***[1 mark]***. This is made up of protons and neutrons and is the source of most of the atom's mass ***[1 mark]***. Most of the atom is empty space ***[1 mark]***. Electrons orbit the nucleus at set energy levels ***[1 mark]***.
b) The radius of an atom is around 1×10^{-10} m ***[1 mark]***. The radius of a nucleus is 10 000 times smaller than this ***[1 mark]***.

p.196 — Isotopes and Nuclear Radiation

Q1 E.g. Alpha would not be suitable because it is stopped by a few cm of air or a sheet of paper ***[1 mark]***. It would not be able to pass through the packaging to sterilise the equipment ***[1 mark]***.

p.197 — Nuclear Equations

Q1 Beta particles ***[1 mark]***

Q2 $^{219}_{86}\text{Rn} \rightarrow {}^{215}_{84}\text{Po} + {}^{4}_{2}\text{He}$
[1 mark for correct layout, 1 mark for correct symbol for an alpha particle, 1 mark for total atomic and mass numbers being equal on both sides]

p.198 — Half-life

Q1 After one half-life the count-rate will be
40 ÷ 2 = 20 cps ***[1 mark]***
After a second: 20 ÷ 2 = 10 cps
After a third: 10 ÷ 2 = 5 cps ***[1 mark]***
So the ratio is 5:40 = 1:8 ***[1 mark]***

p.199 — Irradiation and Contamination

Q1 E.g. keeping sources in lead-lined boxes / standing behind shielding ***[1 mark]***

Q2 Irradiation ***[1 mark]***

p.201 — Contact and Non-Contact Forces

Q1 Contact force: air resistance ***[1 mark]***
Non-contact force: gravitational force ***[1 mark]***

Q2 a) Any two from: e.g. speed / distance / mass / temperature ***[2 marks]***
b) Any two from: e.g. displacement / momentum / force / acceleration / velocity ***[2 marks]***

p.202 — Weight, Mass and Gravity

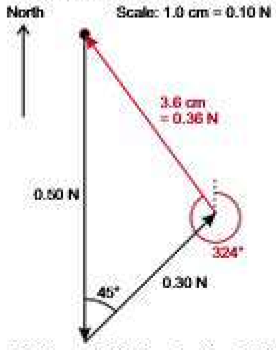
Q1 a) $W = mg = 5 \times 9.8$ ***[1 mark]*** $= 49$ N ***[1 mark]***
b) $W = 5 \times 1.6$ ***[1 mark]*** $= 8$ N ***[1 mark]***

p.203 — Resultant Forces and Work Done

Q1 20 cm = 0.2 m ***[1 mark]***
$W = Fs = 20 \times 0.2$ ***[1 mark]*** $= 4$ J ***[1 mark]***

p.204 — Calculating Forces

Q1 Draw the given forces to scale and tip-to-tail. The third force is found by joining the end of the second force to the start of the first force. E.g.



Third force = 0.36 N on a bearing of 324°.
[1 mark for a correct scale drawing with a sensible scale, 1 mark for a magnitude between 0.35 and 0.37 N, 1 mark for a bearing between 323 and 325°]

p.205 — Forces and Elasticity

Q1 2 cm = 0.02 m ***[1 mark]***
$F = ke$ so $k = F \div e$ ***[1 mark]***
$= 1 \div 0.02$ ***[1 mark]***
$= 50$ N/m ***[1 mark]***

p.206 — Investigating Springs

Q1 2.5 cm = 0.025 m ***[1 mark]***
$E_e = \frac{1}{2}ke^2 = \frac{1}{2} \times 40 \times (0.025)^2$ ***[1 mark]***
$= 0.0125$ J ***[1 mark]***

p.207 — Distance, Displacement, Speed and Velocity

Q1 $s = vt$ so $v = s \div t$ ***[1 mark]***
$= 200 \div 25$ ***[1 mark]*** $= 8$ m/s ***[1 mark]***

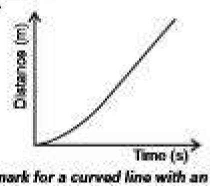
Q2 a) Distance travelled = 1500 m ***[1 mark]***
b) Marie's journey ends at the same position as it started, so the displacement is 0 m ***[1 mark]***.

p.208 — Acceleration

Q1 $u = 0$ m/s, $v = 7$ m/s, $a = g = 9.8$ m/s²,
$s = (v^2 - u^2) \div 2a$ ***[1 mark]***
$= (49 - 0) \div (2 \times 9.8)$ ***[1 mark]***
$= 2.5$ m ***[1 mark]***

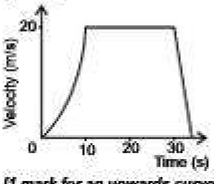
p.209 — Distance-Time and Velocity-Time Graphs

Q1 E.g.



[1 mark for a curved line with an increasing positive gradient, 1 mark for the line becoming a straight line with a positive gradient]

Q2



[1 mark for an upwards curved acceleration line to 20m/s, 1 mark for a straight line representing steady speed, 1 mark for a straight line representing deceleration]

p.210 — Terminal Velocity

Q1 As the ball falls, it accelerates towards earth due to the force of gravity ***[1 mark]***. Air resistance means that eventually the resultant force on the ball is zero ***[1 mark]***. The object cannot go any faster — this is its terminal velocity ***[1 mark]***.

p.211 — Newton's First and Second Laws

Q1 $F = ma = (80 + 10) \times 0.25$ ***[1 mark]***
$= 22.5$ N ***[1 mark]***

p.212 — Inertia and Newton's Third Law

Q1 Any one from: e.g the gravitational force of the Earth attracts the car and the gravitational force of the car attracts the Earth ***[1 mark]*** / the car exerts a normal contact force down against the ground and the normal contact force from the ground pushes up against the car ***[1 mark]*** / the car (tyres) pushes the road backwards and the road pushes the car (tyres) forwards ***[1 mark]***.

p.213 — Investigating Motion

Q1 A piece of card with a gap in the middle is attached to the trolley, so that two bits of card stick up and interrupt the light gate beam as it moves ***[1 mark]***. The length of each bit of card is input into the light gate software, and the light gate measures the velocity of each bit of card as the trolley moves ***[1 mark]***. It can use the two velocity values to find the acceleration ***[1 mark]***.

p.214 — Stopping Distances

Q1 Any one from: e.g. speed / road surface / condition of tyres / condition of brakes ***[1 mark]***

p.215 — Reaction Times

Q1 a) $v^2 - u^2 = 2as$
$v^2 = 2 \times 9.8 \times 0.162 + 0$ ***[1 mark]*** $= 3.1752$ m^2/s^2
$v = \sqrt{3.1752} = 1.781...$ m/s ***[1 mark]***
$a = \Delta v \div t$ so
$t = \Delta v \div a$ ***[1 mark]***
$= 1.781... \div 9.8$ ***[1 mark]*** $= 0.181...$ s
$= 0.18$ s (to 2 s.f.) ***[1 mark]***

b) His reaction time is longer in the evening ***[1 mark]*** so whilst driving, he may take longer to react to a hazard, meaning his thinking distance would be longer ***[1 mark]***.

p.216 — Momentum

Q1 $p = mv = 60 \times 3$ ***[1 mark]*** $= 180$ kg m/s ***[1 mark]***

Q2 Before the gun fires the bullet, the total momentum is zero (neither the gun nor the bullet are moving) ***[1 mark]***. When the bullet leaves the gun, it has momentum in one direction ***[1 mark]***. The gun moves backwards so it has momentum in the opposite direction ***[1 mark]***. This means that the total momentum after the bullet has been fired is zero. Momentum has been conserved ***[1 mark]***.

p.218 — Transverse and Longitudinal Waves

Q1 $7.5 \div 100 = 0.075$ m ***[1 mark]***
wave speed = frequency × wavelength, so
frequency = wave speed ÷ wavelength ***[1 mark]***
$= 0.15 \div 0.075$ ***[1 mark]***
$= 2$ Hz ***[1 mark]***

p.219 — Experiments With Waves

Q1 E.g. attach a signal generator to a dipper and place it in a ripple tank filled with water to create some waves ***[1 mark]***. Place a screen underneath the ripple tank, then turn on a lamp above the ripple tank and dim the other lights in the room ***[1 mark]***. Measure the distance between shadow lines that are 10 wavelengths apart on the screen beneath the tank, then divide this number by 10 — this is equal to the wavelength of the ripples ***[1 mark]***.

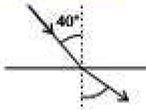
p.220 — Wave Behaviour and Electromagnetic Waves

Q1 Radio waves ***[1 mark]***

Q2 Visible light spectrum ***[1 mark]***

p.221 — Refraction

Q1



[1 mark for a correct diagram showing rays and the normal, 1 mark for an angle of incidence of 40°, 1 mark for an angle of refraction greater than 40°]

p.222 — Radio Waves

Q1 E.g. hands-free Bluetooth® headsets to use in the car ***[1 mark]***.

Q2 Radio waves can be produced by alternating currents / oscillations of charged particles in electrical circuits ***[1 mark]***.

p.223 — EM Waves and Their Uses

Q1 They can pass easily through the Earth's watery atmosphere without being absorbed ***[1 mark]***.

p.224 — More Uses of EM Waves

Q1 E.g. X-ray photographs ***[1 mark]***
treating cancer (radiotherapy) ***[1 mark]***

Q2 Visible light is easy to refract to the angles that are needed to trap the light ray inside the optical fibre ***[1 mark]***. Visible light is also not easily absorbed or scattered in a fibre ***[1 mark]***.

p.225 — Investigating Infrared Radiation

Q1 The black mug will initially cool at a faster rate ***[1 mark]***. This is because a black surface emits more infrared radiation than a white one ***[1 mark]***, so more energy is transferred away from the thermal energy store of the tea ***[1 mark]***.

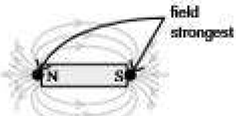
p.226 — Dangers of Electromagnetic Waves

Q1 Any two from: e.g. UV radiation damages surface cells / cause sunburn / cause premature ageing of the skin / cause blindness / increase the risk of skin cancer.
[2 marks — 1 mark for each correct effect]

Q2 7 mSv ÷ 0.7 mSv = 10
So the added risk of harm from a CT scan is ten times higher than from an X-ray ***[1 mark]***.

p.227 — Permanent and Induced Magnets

Q1



[1 mark for a correct diagram, 1 mark for an indication of the field being strongest at the poles]

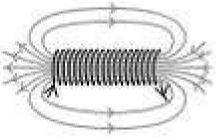
Q2 E.g. Permanent magnets produce their own magnetic fields but induced magnets become magnets when they're in a magnetic field ***[1 mark]***. The force between an induced magnet and a permanent magnet is always attractive, but between two permanent magnets it can be attractive or repulsive ***[1 mark]***.

p.228 — Electromagnetism

Q1 E.g. for current out of the page:

[1 mark for concentric circles getting further apart, 1 mark for arrows on field lines with correct direction]

Q2 a)



[1 mark for uniform field inside coil, 1 mark for field similar to a bar magnet outside of coil]

b) E.g. put a block of iron in the centre of the solenoid ***[1 mark]***.

p.229 — The Motor Effect

Q1 35 cm = 0.35 m ***[1 mark]***
Rearrange $F = B \times I \times l$
for the magnetic flux density, B:
$B = F \div (I \times l)$ ***[1 mark]***
$= 9.8 \div (5.0 \times 0.35)$ ***[1 mark]***
$= 5.6$ T ***[1 mark]***

p.230 — Electric Motors

Q1 Into the page ***[1 mark]***.

Glossary

Abiotic factor	A non-living factor of the environment.
Acceleration	A change in velocity in a certain amount of time.
Accurate result	A result that is very close to the true answer.
Acid	A substance with a pH of less than 7 that forms H^+ ions in water.
Activation energy	The minimum amount of energy that reactant particles must have when they collide in order to react.
Active transport	The movement of particles against a concentration gradient (i.e. from an area of lower concentration to an area of higher concentration) using energy transferred during respiration.
Activity (radioactive)	The number of nuclei of a sample that decay per second.
Adaptation	A feature or characteristic that helps an organism to survive in its natural environment.
Aerobic respiration	Respiration taking place in the presence of oxygen.
Air resistance	The frictional force caused by air on a moving object.
Alkali	A substance with a pH of more than 7 that forms OH^- ions in solution.
Alkali metal	An element in Group 1 of the periodic table. E.g. sodium, potassium etc.
Alkane	A saturated hydrocarbon with the general formula C_nH_{2n+2}. E.g. methane, ethane etc.
Alkene	An unsaturated hydrocarbon that contains a carbon-carbon double bond and has the general formula C_nH_{2n}. E.g. ethene, propene etc.
Allele	An alternative version of a gene.
Alloy	A metal that is a mixture of two or more metals, or a mixture involving metals and non-metals.
Alpha decay	A type of radioactive decay in which an alpha particle is given out from a decaying nucleus.
Alpha particle	A positively-charged particle made up of two protons and two neutrons (a helium nucleus).
Alpha particle scattering experiment	An experiment in which alpha particles were fired at gold foil to see if they were deflected. It led to the plum pudding model being abandoned in favour of the nuclear model of the atom.
Alternating current (ac)	Current that is constantly changing direction.
Alveolus	A tiny air sac in the lungs, where gas exchange occurs.
Amino acid	A small molecule that is a building block of proteins.
Ammeter	A component used to measure the current through a component. It is always connected in series with the component.
Amplitude	The maximum displacement of a point on a wave from its undisturbed position.
Anaerobic respiration	Respiration taking place in the absence of oxygen.
Angle of incidence	The angle the incoming ray makes with the normal at a boundary.
Angle of refraction	The angle a refracted ray makes with the normal when a wave refracts at a boundary.
Anion	A particle with a negative charge, formed when one or more electrons are gained.
Anomalous result	A result that doesn't seem to fit with the rest of the data.
Antibiotic	A drug used to kill or prevent the growth of bacteria.
Antibiotic resistance	When bacteria aren't killed by an antibiotic.
Antibody	A protein produced by white blood cells in response to the presence of an antigen.
Antigen	A molecule on the surface of a cell or a pathogen. Foreign antigens trigger white blood cells to produce antibodies.

Antitoxin	A protein produced by white blood cells that counteracts toxins made by invading bacteria.
Artery	A blood vessel that carries blood away from the heart.
Asexual reproduction	Where organisms reproduce by mitosis to produce genetically identical offspring.
Atmosphere	The layer of air that surrounds a planet.
Atom	A neutral particle made up of protons and neutrons in the nucleus, with electrons surrounding the nucleus.
Atomic number	The number of protons in the nucleus of an atom. It's also known as proton number.
Avogadro constant	The number of particles in one mole of a substance, which is 6.02×10^{23}.
Base	A substance that reacts with acids in neutralisation reactions.
Behavioural adaptation	A way in which an organism behaves that helps it to survive in its environment.
Beta decay	A type of radioactive decay in which a beta particle is given out from a decaying nucleus.
Beta particle	A high-speed electron emitted in beta decay.
Bias	Unfairness in the way data is presented, possibly because the presenter is trying to make a particular point (sometimes without knowing they're doing it).
Binomial system	The system used in classification for naming organisms using a two-part Latin name.
Bio-fuel	A renewable energy resource made from plant products or animal dung.
Biodiversity	The variety of different species of organisms on Earth, or within an ecosystem.
Bioleaching	The process by which a metal is separated from its ore using bacteria.
Biotic factor	A living factor of the environment.
Bond energy	The amount of energy required to break a bond (or the amount of energy released when a bond is made).
Braking distance	The braking distance is the distance a vehicle travels after the brakes are applied until it comes to a complete stop, as a result of the braking force.
Calibrate	Measure something with a known quantity to see if the instrument being used to measure that quantity gives the correct value.
Capillary	A type of blood vessel involved in the exchange of materials at tissues.
Carbohydrase	A type of digestive enzyme that catalyses the breakdown of a carbohydrate into sugars.
Carbon footprint	A measure of the amounts of greenhouse gases released by a product, a service or an event.
Cardiovascular disease	Disease of the heart or blood vessels.
Catalyst	A substance that increases the speed of a reaction, without being changed or used up.
Categoric data	Data that comes in distinct categories, e.g. blood type (A+, B–, etc.), metals (copper, zinc, etc.).
Cation	A particle with a positive charge, formed when one or more electrons are lost.
Cell membrane	A membrane surrounding a cell, which holds it together and controls what goes in and out.
Cell wall	A structure surrounding some cell types, which gives strength and support.
Cellulose	A molecule which strengthens cell walls in plants and algae.
Central Nervous System (CNS)	The brain and spinal cord. It's where reflexes and actions are coordinated.
Chemical bond	The attraction of two atoms for each other, caused by the sharing or transfer of electrons.
Chlorophyll	A green substance found in chloroplasts which absorbs light for photosynthesis.
Chloroplast	A structure found in plant cells and algae. It is the site of photosynthesis.

Chromatogram	The pattern of spots formed as a result of separating a mixture using chromatography.
Chromatography	An analytical method used to separate the substances in a mixture based on how the components interact with a mobile phase and a stationary phase.
Chromosome	A long molecule of DNA found in the nucleus. Each chromosome carries many genes.
Climate change	A change in the Earth's climate. E.g. global warming, changing rainfall patterns etc.
Clinical trial	A set of drug tests on human volunteers.
Clone	An organism that is genetically identical to another organism.
Closed system	A system where neither matter nor energy can enter or leave. The net change in total energy in a closed system is always zero.
Collision theory	The theory that in order for a reaction to occur, particles must collide with sufficient energy.
Combustion	An exothermic reaction between a fuel and oxygen.
Communicable disease	A disease that can spread between individuals.
Community	The populations of different species living in a habitat.
Compound	A substance made up of atoms of at least two different elements, chemically joined together.
Concentration	The amount of a substance in a certain volume of solution, given in units of 'units of amount of substance'/'units of volume'.
Conduction	A method of energy transfer by heating where vibrating particles transfer energy through a material by colliding with neighbouring particles and transferring energy between their kinetic energy stores.
Conservation of energy principle	Energy can be transferred usefully from one energy store to another, stored or dissipated — but it can never be created or destroyed.
Conservation of momentum	In a closed system, the total momentum before an event is the same as the total momentum after the event.
Contamination (radioactive)	The presence of unwanted radioactive atoms on or inside an object.
Continuous data	Numerical data that can have any value within a range (e.g. length, volume or temperature).
Contraceptive	A method of preventing pregnancy, which can be hormonal or non-hormonal.
Control experiment	An experiment that's kept under the same conditions as the rest of the investigation, but where the independent variable isn't altered.
Control variable	A variable in an experiment that is kept the same.
Convection	A method of energy transfer by heating in liquids and gases in which energetic particles move away from hotter regions to cooler regions.
Conversion factor	A number which you must multiply or divide a unit by to convert it to a different unit.
Coordination centre	An organ (e.g. the brain, spinal cord or pancreas) that processes information from receptors and organises a response from the effectors.
Coronary artery	A blood vessel which supplies blood to the heart muscle.
Coronary heart disease	A disease in which the coronary arteries are narrowed by the build up of fatty deposits.
Correlation	A relationship between two variables.
Covalent bond	A chemical bond formed when atoms share a pair of electrons.
Covalent substance	A substance where the atoms are held together by covalent bonds.
Cracking	The process that is used to break long-chain hydrocarbons down into shorter, more useful hydrocarbons. Two types of cracking are catalytic cracking and steam cracking.

Crystallisation	The formation of solid crystals as water evaporates from a solution. For example, salt solutions undergo crystallisation to form solid salt crystals.
Current	The flow of electric charge. The size of the current is the rate of flow of charge. Measured in amperes (A).
Cystic fibrosis	An inherited disorder of the cell membranes caused by a recessive allele.
Cytoplasm	A gel-like substance in a cell where most of the chemical reactions take place.
Deforestation	The cutting down of forests (large areas of trees).
Delocalised electron	An electron that isn't associated with a particular atom or bond and is free to move within a structure.
Density	A substance's mass per unit volume.
Dependent variable	The variable in an experiment that is measured.
Diabetes	A condition that affects the body's ability to control its blood glucose level.
Differentiation	The process by which a cell becomes specialised for its job.
Diffusion	The spreading out of particles from an area of higher concentration to an area of lower concentration.
Diode	A circuit component that only allows current to flow through it in one direction. It has a very high resistance in the other direction.
Direct current (dc)	Current that always flows in the same direction.
Discrete data	Numerical data that can only take a certain value, with no in-between value (e.g. number of people).
Displacement	The straight-line distance and direction from an object's starting position to its finishing position.
Displacement reaction	A reaction where a more reactive element replaces a less reactive element in a compound.
Displayed formula	A chemical formula that shows the atoms in a covalent compound and all the bonds between them.
Distance-time graph	A graph showing how the distance travelled by an object changes over a period of time.
Distillation	A way of separating out a liquid from a mixture. You heat the mixture until the bit you want evaporates, then cool the vapour to turn it back into a liquid.
Distribution	Where organisms are found in a particular area.
DNA	Deoxyribonucleic acid. The molecule in cells that stores genetic information.
Dominant allele	The allele for the characteristic that's shown by an organism if two different alleles are present for that characteristic.
Double-blind trial	A clinical trial where neither the doctors nor the patients know who has received the drug and who has received the placebo until all the results have been gathered.
Drag	The frictional force caused by any fluid (a liquid or gas) on a moving object.
Earth wire	The green and yellow wire in an electrical cable that only carries current when there's a fault. It stops exposed metal parts of an appliance from becoming live.
Ecosystem	The interaction of a community of living organisms with the abiotic parts of their environment.
Effector	Either a muscle or gland which responds to nervous impulses.
Efficacy	Whether something, e.g. a drug, works or not.
Efficiency	The proportion of input energy transfer which is usefully transferred. Also the proportion of input power which is usefully output.
Elastic deformation	An object undergoing elastic deformation will return to its original shape and length once any forces being applied to it are removed.
Elastic object	An object which can be elastically deformed.

Elastic potential energy store	Anything that has been stretched or compressed, e.g. a spring, has energy in its elastic potential energy store.
Electrode	An electrical conductor which is submerged in the electrolyte during electrolysis.
Electrolysis	The process of breaking down a substance using electricity.
Electrolyte	A liquid or solution used in electrolysis to conduct electricity between the two electrodes.
Electromagnet	A solenoid with an iron core.
Electromagnetic (EM) spectrum	A continuous spectrum of all the possible wavelengths of electromagnetic waves.
Electron	A subatomic particle with a relative charge of –1.
Electron shell	A region of an atom that contains electrons. It's also known as an energy level.
Electronic structure	The number of electrons in an atom (or ion) of an element and how they are arranged.
Electrostatic force	A force of attraction between opposite charges.
Element	A substance that is made up only of atoms with the same number of protons.
Empirical formula	A chemical formula showing the simplest possible whole number ratio of atoms in a compound.
Endothermic reaction	A reaction which takes in energy from the surroundings.
Energy level	A region of an atom that contains electrons. It's also known as an electron shell.
Energy store	A means by which an object stores energy. There are different types of energy store: thermal (or internal), kinetic, gravitational potential, elastic potential, chemical, magnetic, electrostatic and nuclear.
Enzyme	A protein that acts as a biological catalyst.
Equilibrium (physics)	A state in which all the forces acting on an object are balanced, so the resultant force is zero.
Equilibrium (reversible reactions)	The point at which the rates of the forward and backward reactions in a reversible reaction are the same, and so the amounts of reactants and products in the reaction container don't change.
Eukaryotic cell	A complex cell, such as a plant or animal cell.
Evolution	The changing of the inherited characteristics of a population over time.
Excretion	The removal of waste products from the body.
Exothermic reaction	A reaction which transfers energy to the surroundings.
Extinction	When no living individuals of a species remain.
Extremophile	An organism that's adapted to live in extreme conditions.
Fair test	A controlled experiment where the only thing that changes is the independent variable.
Family tree	A diagram that shows how a characteristic is inherited in a group of related people.
Feedstock	A raw material used to produce other substances through industrial processes.
Fermentation	The process of anaerobic respiration in yeast cells.
Fertilisation	The fusion of male and female gametes during sexual reproduction.
Fertility	The ability to conceive a child.
Filtration	A physical method used to separate an insoluble solid from a liquid.
Finite resource	A resource that isn't replaced at a quick enough rate to be considered replaceable.
Flammability	How easy it is to ignite a substance.
Fleming's left-hand rule	The rule used to work out the direction of the force produced by the motor effect. Your first finger points in the direction of the magnetic field, your second finger points in the direction of the current and your thumb points in the direction of the force (or motion).

Fluid	A substance that can flow — either a liquid or a gas.
Food security	Having enough food to feed the population.
Force	A push or a pull on an object caused by it interacting with something.
Formulation	A useful mixture with a precise purpose made by following a formula.
Fossil	The remains of an organism from many years ago, which is found in rock.
Fossil fuel	The fossil fuels are coal, oil and natural gas. They're non-renewable energy resources that we burn to generate electricity.
Fossil record	The history of life on Earth preserved as fossils.
Fraction	A group of hydrocarbons that condense together when crude oil is separated using fractional distillation. E.g. petrol, naphtha, kerosene etc.
Fractional distillation	A process that can be used to separate substances in a mixture according to their boiling points.
Free body diagram	A diagram that shows all the forces acting on an isolated object, the direction in which the forces are acting and their (relative) magnitudes.
Frequency	The number of complete waves passing a certain point per second. Measured in hertz, Hz.
Friction	A force that opposes an object's motion. It acts in the opposite direction to motion.
Functional adaptation	Something that goes on inside an organism's body that helps it to survive in its environment.
Gamete	A sex cell, e.g. an egg cell or a sperm cell in animals.
Gamma decay	A type of radioactive decay in which a gamma ray is given out from a decaying nucleus.
Gamma ray	A high-frequency, short-wavelength electromagnetic wave.
Geiger-Müller tube	A particle detector that is used with a counter to measure count rate.
Gene	A short section of DNA, found on a chromosome, which contains the instructions needed to make a protein (and so controls the development of a characteristic).
General formula	A formula that can be used to find the molecular formula of any member of a homologous series.
Genetic engineering	The process of cutting out a useful gene from one organism's genome and inserting it into another organism's cell(s).
Genetically modified (GM) crop	A crop which has had its genes modified through genetic engineering.
Genome	All of the genetic material in an organism.
Genotype	What alleles you have, e.g. Tt.
Geothermal power	A renewable energy resource where energy is transferred from the thermal energy stores of hot rocks underground and is used to generate electricity or to heat buildings.
Giant covalent structure	A large molecule made up of a very large number of atoms held together by covalent bonds (also known as a macromolecule).
Gland	An organ that hormones are produced and secreted from.
Global dimming	The decrease in the amount of sunlight reaching the Earth's surface due to an increase in the amount of particulates in the atmosphere.
Global warming	The increase in the average temperature of the Earth.
Glucagon	A hormone produced and secreted by the pancreas when blood glucose level is too low.
Glycogen	A molecule that acts as a store of glucose in liver and muscle cells.
Gradient	The slope of a line graph. It shows how quickly the variable on the y-axis changes with the variable on the x-axis.
Gravitational potential energy (g.p.e.) store	Anything that has mass and is in a gravitational field has energy in its gravitational potential energy store.

Greenhouse effect	When greenhouse gases in the atmosphere absorb long wavelength radiation and re-radiate it in all directions, including back towards Earth, helping to keep the Earth warm.
Greenhouse gas	A gas that can absorb long wavelength radiation.
Group	A column in the periodic table.
Guard cell	A type of cell found on either side of a stoma. A pair of these cells control the stoma's size.
Habitat	The place where an organism lives.
Haemoglobin	A red pigment found in red blood cells that carries oxygen.
Half equation	An equation which shows how electrons are transferred when a substance is reduced or oxidised. E.g. at an electrode during electrolysis.
Half-life	The time it takes for the number of nuclei of a radioactive isotope in a sample to halve. OR The time it takes for the count rate (or activity) of a radioactive sample to fall to half its initial level.
Hazard	Something that has the potential to cause harm (e.g. fire, electricity, etc.).
Heterozygous	Where an organism has two alleles for a particular gene that are different.
Homeostasis	The regulation of conditions inside your body (and cells) to maintain a stable internal environment, in response to changes in both internal and external conditions.
Homologous series	A group of chemicals that react in a similar way because they have the same functional group. E.g. the alcohols or the carboxylic acids.
Homozygous	Where an organism has two alleles for a particular gene that are the same.
Hormone	A chemical messenger which travels in the blood to activate target cells.
Hydrocarbon	A compound that is made from only hydrogen and carbon.
Hypothesis	A possible explanation for a scientific observation.
I-V characteristic	A graph of current against potential difference for a component.
In excess	A reactant that is not used up during a reaction.
Inbreeding	When closely related animals or plants are bred together.
Incomplete combustion	When a fuel burns but there isn't enough oxygen for it to burn completely. Products can include carbon monoxide and carbon particulates. Also known as partial combustion.
Independent variable	The variable in an experiment that is changed.
Indicator	A substance that changes colour above or below a certain pH.
Induced magnet	A magnetic material that turns into a magnet when it is placed inside another magnetic field.
Inelastic deformation	An object undergoing inelastic deformation will not return to its original shape and length once the forces being applied to it are removed.
Inertia	The tendency of an object to remain stationary or continue travelling at a constant velocity.
Inertial mass	The ratio between the resultant force acting on an accelerating object and its acceleration.
Infrared (IR) radiation	A type of electromagnetic wave that is given out by all objects. It can also be absorbed by objects which makes the object hotter.
Inherited disorder	A disorder caused by a faulty allele, which can be passed on to an individual's offspring.
Insoluble	A substance is insoluble if it does not dissolve in a particular solvent.
Insulin	A hormone produced and secreted by the pancreas when blood glucose level is too high.
Interdependence	Where, in a community, each species depends on other species for things such as food, shelter, pollination and seed dispersal.
Intermolecular force	A force of attraction that exists between molecules.
Internal energy	The total energy that a system's particles have in their kinetic and potential energy stores.

Ion	A charged particle formed when one or more electrons are lost or gained from an atom or molecule.
Ionic bond	A strong attraction between oppositely charged ions.
Ionic compound	A compound that contains positive and negative ions held together in a regular arrangement (a lattice) by electrostatic forces of attraction.
Ionic equation	An equation that shows only the particles that react and the products they form.
Ionic lattice	A closely-packed regular arrangement of particles held together by electrostatic forces of attraction.
Ionising radiation	Radiation that has enough energy to knock electrons off atoms.
Irradiation	Exposure to radiation.
Isotope	A different form of the same element, which has atoms with the same number of protons (atomic number), but a different number of neutrons (and so different mass number).
IVF	*In vitro* fertilisation. The artificial fertilisation of eggs in the lab.
Joules	The standard unit of energy.
Kinetic energy store	Anything that's moving has energy in its kinetic energy store.
Lattice	A closely-packed regular arrangement of particles.
Le Chatelier's principle	The idea that if the conditions of a reaction are changed when a reversible reaction is at equilibrium, the system will try to counteract the change.
Life cycle assessment	An assessment of the environmental impact of a product over the course of its life.
Light-dependent resistor (LDR)	A resistor whose resistance is dependent on light intensity. The resistance decreases as light intensity increases.
Limit of proportionality	The point beyond which the force applied to an elastic object is no longer directly proportional to the extension of the object.
Limiting factor	A factor which prevents a reaction from going any faster.
Limiting reactant	A reactant that gets completely used up in a reaction, so limits the amount of product that's formed.
Linear graph	A straight line graph.
Lipase	A type of digestive enzyme that catalyses the breakdown of lipids into fatty acids and glycerol.
Litmus	A single indicator that's blue in alkalis and red in acids.
Live wire	The brown wire in an electrical cable that carries an alternating potential difference from the mains.
Longitudinal wave	A wave in which the oscillations are parallel to the direction of energy transfer.
Lubricant	A substance (usually a liquid) that can flow easily between two objects. Used to reduce friction between surfaces.
Macromolecule	A large molecule made up of a very large number of atoms held together by covalent bonds (also known as a giant covalent structure).
Magnetic field	A region where magnetic materials (like iron and steel) and current-carrying wires experience a force.
Magnetic flux density	The number of magnetic field lines per unit area. Its symbol is B and it is measured in tesla, T.
Magnetic material	A material (such as iron, steel, cobalt or nickel) which can become an induced magnet while it's inside another magnetic field.
Mass number	The number of neutrons and protons in the nucleus of an atom.
Mean (average)	A measure of average found by adding up all the data and dividing by the number of values there are.

Median (average)	A measure of average found by selecting the middle value from a data set arranged in ascending order.
Medical tracer	A radioactive isotope that can be injected into or swallowed by people. Their progress around the body can be followed using an external detector and can diagnose medical conditions.
Meiosis	A type of cell division where a cell divides twice to produce four genetically different gametes. It occurs in the reproductive organs.
Menstrual cycle	A monthly sequence of events during which the body prepares the lining of the uterus (womb) in case it receives a fertilised egg, and releases an egg from an ovary. The uterus lining then breaks down if the egg has not been fertilised.
Meristem tissue	Tissue found at the growing tips of plant shoots and roots that is able to differentiate.
Metabolism	All the chemical reactions that happen in a cell or the body.
Metal ore	Rocks that are found naturally in the Earth's crust containing enough metal to make the metal profitable to extract.
Metal	An element that can form positive ions when it reacts.
Metallic bond	The attraction between metal ions and delocalised electrons in a metal.
Microwave	A type of electromagnetic wave that can be used for cooking and satellite communications.
Mitochondria	Structures in a cell which are the site of most of the reactions for aerobic respiration.
Mitosis	A type of cell division where a cell reproduces itself by splitting to form two identical offspring.
Mixture	A substance made from two or more elements or compounds that aren't chemically bonded to each other.
Mobile phase	In chromatography, the mobile phase is a gas or liquid where the molecules are able to move.
Mode (average)	A measure of average found by selecting the most frequent value from a data set.
Model	Something used to describe or display how an object or system behaves in reality.
Mole	A unit of amount of substance — the mass of one mole of a substance is equal to the value of the relative formula mass of that substance in grams, and contains 6.02×10^{23} particles of the substance.
Molecular formula	A chemical formula showing the actual number of atoms of each element in a compound.
Molecule	A particle made up of at least two atoms held together by covalent bonds.
Momentum	A property of a moving object that is the product of its mass and velocity.
Motor effect	When a current-carrying wire in a magnetic field experiences a force.
Motor neurone	A nerve cell that carries electrical impulses from the CNS to effectors.
MRSA	A strain of antibiotic-resistant bacteria. (Meticillin-resistant *Staphylococcus aureus*.)
Mutation	A random change in an organism's DNA.
National grid	The network of transformers and cables that distributes electrical power from power stations to consumers.
Natural resource	A resource formed without human input.
Natural selection	The process by which species evolve.
Negative feedback	A mechanism that restores a level back to optimum in a system.
Nervous system	The organ system in animals that allows them to respond to changes in their environment.
Neurone	A nerve cell. Neurones transmit information around the body, including to and from the CNS.
Neutral substance	A substance with a pH of 7.
Neutral wire	The blue wire in an electrical cable that current in an appliance normally flows through. It is around 0 V.

Neutralisation reaction	The reaction between acids and bases that leads to the formation of neutral products — usually a salt and water.
Neutron	A subatomic particle with a relative charge of 0.
Newton's First Law	An object will remain at rest or travelling at a constant velocity unless it is acted on by a resultant force.
Newton's Second Law	The acceleration of an object is directly proportional to the resultant force acting on it, and inversely proportional to its mass.
Newton's Third Law	When two objects interact, they exert equal and opposite forces on each other.
Non-communicable disease	A disease that cannot spread between individuals.
Non-contact force	A force that can act between objects that are not touching.
Non-metal	An element that doesn't form positive ions when it reacts with the exception of hydrogen.
Non-renewable energy resource	An energy resource that is non-renewable cannot be made at the same rate as it's being used, so it will run out one day.
Normal (at a boundary)	A line that's perpendicular (at 90°) to a surface at the point of incidence (where a wave hits the surface).
Nuclear model	A model of the atom that says that the atom has a small, central positively-charged nucleus with negatively-charged electrons moving around the nucleus, and that most of the atom is empty space. The nucleus is made up of protons and neutrons.
Nucleus (atom)	The centre of an atom, containing protons and neutrons.
Nucleus (of a cell)	A structure found in animal and plant cells which contains the genetic material.
Obesity	A condition where a person has an excessive amount of body fat, to the point where it poses a risk to their health.
Ohmic conductor	A conductor with resistance that is constant at a constant temperature. It has a linear *I-V* characteristic.
Optimum dose	The dose of a drug that is most effective and has few side effects.
Optimum level (in the body)	A level of something (e.g. water, ions or glucose) that enables the body to work at its best.
Organ	A group of different tissues that work together to perform a certain function.
Organ system	A group of organs working together to perform a particular function.
Organic compound	A chemical compound that contains carbon atoms.
Osmosis	The movement of water molecules across a partially permeable membrane from a region of higher water concentration to a region of lower water concentration.
Oxidation	A reaction where electrons are lost or oxygen is gained by a species.
Oxygen debt	The amount of extra oxygen your body needs after exercise to react with the build up of lactic acid and remove it from cells.
Paper chromatography	An analytical technique that can be used to separate and analyse coloured substances.
Parallel circuit	A circuit in which every component is connected separately to the positive and negative ends of the battery.
Partially permeable membrane	A membrane with tiny holes in it, which lets some molecules through it but not others.
Pathogen	A microorganism that causes disease, e.g. a bacterium, virus, protist or fungus.
Peer-review	The process in which other scientists check the results and explanations of an investigation before they are published.
Period (chemistry)	A row in the periodic table.
Period (of a wave)	The time taken for one full cycle of a wave to be completed.

Periodic table	A table of all the known elements, arranged in order of atomic number so that elements with similar chemical properties are in groups.
Permanent magnet	A magnetic material that always has its own magnetic field around it.
Permanent vacuole	A structure in plant cells that contains cell sap.
pH scale	A scale from 0 to 14 that is used to measure how acidic or alkaline a solution is.
Phagocytosis	The process by which white blood cells engulf foreign cells and digest them.
Phenotype	The characteristics you have, e.g. brown eyes.
Phloem	A type of plant tissue which transports dissolved sugars around the plant.
Photosynthesis	The process by which plants use energy to convert carbon dioxide and water into glucose and oxygen.
Physical change	A change where you don't end up with a new substance — it's the same substance as before, just in a different form. (A change of state is a physical change.)
Phytomining	The process by which a metal is extracted from soil by using plants.
Placebo	A substance that is like a drug being tested, but which doesn't do anything.
Plasma	The liquid component of blood, which carries blood cells and other substances around the body.
Platelet	A small fragment of a cell found in the blood, which helps blood to clot at a wound.
Plum pudding model	A disproved theory of the atom as a ball of positive charge with electrons inside it.
Polydactyly	An inherited disorder, caused by a dominant allele, where a person has extra fingers or toes.
Polymer	A long chain molecule that is formed by joining lots of smaller molecules (monomers) together.
Potable water	Water that is safe for drinking.
Potential difference	The driving force that pushes electric charge around a circuit, measured in volts (V). Also known as pd or voltage.
Power	The rate of transferring energy (or doing work). Normally measured in watts (W).
Precipitate	A solid that is formed in a solution during a chemical reaction.
Precise result	When all the data is close to the mean.
Predator	An animal that hunts and kills other animals for food.
Prediction	A statement based on a hypothesis that can be tested.
Pressure	The force per unit area exerted on a surface.
Prey	An animal that is hunted and killed by another animal for food.
Primary consumer	An organism in a food chain that feeds on a producer.
Producer	An organism at the start of a food chain that makes its own food using energy from the Sun.
Product	A substance that is formed in a chemical reaction.
Prokaryotic cell	A small, simple cell, e.g. a bacterium.
Protease	A type of digestive enzyme that catalyses the breakdown of proteins into amino acids.
Protein	A large biological molecule made up of long chains of amino acids.
Protist	A type of pathogen. Protists are often transferred to other organisms by a vector.
Proton	A subatomic particle with a relative charge of +1.
Punnett square	A type of genetic diagram.
Pure substance	A substance that only contains one compound or element throughout.
Quadrat	A square frame enclosing a known area. It is used to study the distribution of organisms.

Radiation dose	A measure of the risk of harm to your body due to exposure to radiation.
Radio wave	A type of electromagnetic wave mainly used for radio and TV signals.
Radioactive decay	The random process of a radioactive substance giving out radiation from the nuclei of its atoms.
Radioactive substance	A substance that spontaneously gives out radiation from the nuclei of its atoms.
Radiotherapy	A treatment of cancer that uses ionising radiation (such as gamma rays and X-rays) to kill cancer cells.
Random error	A difference in the results of an experiment caused by unpredictable events, e.g. human error in measuring.
Range	The difference between the smallest and largest values in a set of data.
Rate of reaction	How fast the reactants in a reaction are changed into products.
Ray	A straight line showing the path along which a wave moves.
Reactant	A substance that reacts in a chemical reaction.
Reaction profile	A graph that shows how the energy in a reaction changes as the reaction progresses (also known as an energy level diagram).
Reaction time	The time taken for a person to react after an event (e.g. seeing a hazard).
Reactivity series	A list of elements arranged in order of their reactivity. The most reactive elements are at the top and the least reactive at the bottom.
Receptor	A group of cells that are sensitive to a stimulus (e.g. receptor cells in the eye detect light).
Recessive allele	An allele whose characteristic only appears in an organism if there are two copies present.
Redox reaction	A reaction where one substance is reduced and another is oxidised.
Reduction	A reaction where electrons are gained or oxygen is lost.
Reflection	When a wave bounces back as it meets a boundary between two materials.
Reflex	A fast, automatic response to a stimulus.
Refraction	When a wave changes direction as it passes across the boundary between two materials at an angle to the normal.
Relative atomic mass (A_r)	The average mass of the atoms of an element measured relative to the mass of one atom of carbon-12. The relative atomic mass of an element is the same as its mass number in the periodic table.
Relative formula mass (M_r)	All the relative atomic masses (A_r) of the atoms in a compound added together.
Relay neurone	A nerve cell that carries electrical impulses from sensory neurones to motor neurones.
Reliable result	A result that is repeatable and reproducible.
Renewable energy resource	An energy resource that is renewable is one that is being, or can be, made at the same rate (or faster) than it's being used, and so will never run out.
Repeating unit	The shortest repeating section of a polymer.
Reproducible result	A result that will come out the same if someone different does the experiment, or a slightly different method or piece of equipment is used.
Resistance	Anything in a circuit that reduces the flow of current. Measured in ohms, Ω.
Resolution	The smallest change a measuring instrument can detect.
Respiration	The process of breaking down glucose to transfer energy, which occurs in every cell.
Resultant force	A single force that can replace all the forces acting on an object to give the same effect as the original forces acting altogether.
Reversible reaction	A reaction where the products of the reaction can themselves react to produce the original reactants.

R_f value	In chromatography, the ratio between the distance travelled by a dissolved substance and the distance travelled by a solvent.
Ribosome	A structure in a cell, where proteins are made.
Right-hand thumb rule	The rule to work out the direction of the magnetic field around a current-carrying wire. Your thumb points in the direction of the current, and your fingers curl in the direction of the magnetic field.
Risk	The chance that a hazard will cause harm.
Risk factor	Something that is linked to an increased likelihood that a person will develop a certain disease.
S.I. unit	A standard unit of measurement, recognised by scientists all over the world.
Scalar	A quantity that has magnitude but no direction.
Scaling prefix	A word or symbol which goes before a unit to indicate a multiplying factor (e.g. 1 km = 1000 m).
Secondary consumer	An organism in a food chain that eats a primary consumer.
Selective breeding (artificial selection)	When humans artificially select the plants or animals that are going to breed, so that the genes for particular characteristics remain in the population.
Sensory neurone	A nerve cell that carries electrical impulses from a receptor in a sense organ to the CNS.
Series circuit	A circuit in which every component is connected in a line, end to end.
Sex chromosome (humans)	One of the 23rd pair of chromosomes, X or Y. Together they determine whether an individual is male or female.
Sexual reproduction	Where two gametes combine at fertilisation to produce a genetically different new individual.
Significant figure	The first significant figure of a number is the first non-zero digit. The second, third and fourth significant figures follow on immediately after it.
Simple distillation	A way of separating a liquid out from a mixture if there are large differences in the boiling points of the substances.
Simple molecule	A molecule made up of only a few atoms held together by covalent bonds.
Solar cell	A device that generates electricity directly from the Sun's radiation.
Solenoid	A coil of wire often used in the construction of electromagnets.
Solute	A substance dissolved in a solvent to make a solution.
Solution	A mixture made up of one substance (the solute) dissolved in another (the solvent).
Solvent	A liquid in which another substance (a solute) can be dissolved.
Solvent front	The point the solvent has reached up the filter paper during paper chromatography.
Species	A group of similar organisms that can reproduce to give fertile offspring.
Specific heat capacity	The amount of energy (in joules) needed to raise the temperature of 1 kg of a material by 1 °C.
Specific latent heat (SLH)	The amount of energy needed to change 1 kg of a substance from one state to another without changing its temperature. (For cooling, it is the energy released by a change in state.)
Specific latent heat of fusion	The specific latent heat for changing between a solid and a liquid (melting or freezing).
Specific latent heat of vaporisation	The specific latent heat for changing between a liquid and a gas (evaporating, boiling or condensing).
Split-ring commutator	A ring with gaps in it that swaps the electrical contacts of a device every half-turn.
Stable community	A community where all the species and environmental factors are in balance, so that the population sizes are roughly constant.
Standard form	A number written in the form $A \times 10^n$, where A is a number between 1 and 10.
State of matter	The form which a substance can take — e.g. solid, liquid or gas.

State symbol	The letter, or letters, in brackets that are placed after a substance in an equation to show what physical state it's in. E.g. gaseous carbon dioxide is shown as $CO_{2(g)}$.
Statins	A group of medicinal drugs that are used to decrease the risk of heart and circulatory disease.
Stationary phase	In chromatography, the stationary phase is a solid or really thick liquid where molecules are unable to move.
Stem cell	An undifferentiated cell which has the ability to become one of many different types of cell, or to produce more stem cells.
Stent	A wire mesh tube that's inserted inside an artery to help keep it open.
Stimulus	A change in the environment.
Stoma	A tiny hole in the surface of a leaf.
Stopping distance	The distance covered by a vehicle in the time between the driver spotting a hazard and the vehicle coming to a complete stop. It's the sum of the thinking distance and the braking distance.
Strong acid	An acid which fully ionises in an aqueous solution.
Structural adaptation	A feature of an organism's body structure that helps it to survive in its environment.
Sustainable development	An approach to development that takes into the account the needs of present society while not damaging the lives of those in the future.
Synapse	The connection between two neurones.
System	The object, or group of objects, that you're considering.
Systematic error	An error that is consistently made throughout an experiment.
Tangent	A straight line that touches a curve at a particular point without crossing it.
Terminal velocity	The maximum velocity a falling object can reach without any added driving forces. It's the velocity at which the resistive forces (drag) acting on the object match the force due to gravity (weight).
Tertiary consumer	An organism in a food chain that eats a secondary consumer.
Theory	A hypothesis which has been accepted by the scientific community because there is good evidence to back it up.
Thermal conductivity	A measure of how quickly an object transfers energy by heating through conduction.
Thermal decomposition	A reaction where one substance chemically changes into at least two new substances when it's heated.
Thermal insulator	A material with a low thermal conductivity.
Thermistor	A resistor whose resistance is dependent on the temperature. The resistance decreases as temperature increases.
Thinking distance	The distance a vehicle travels during the driver's reaction time (before the brakes have been applied).
Three-core cable	An electrical cable containing a live wire, a neutral wire and an earth wire.
Tissue	A group of similar cells that work together to carry out a particular function.
Toxicity	How harmful something is, e.g. a drug.
Toxin	A poison. Toxins are often produced by bacteria.
Transect	A line which can be used to study the distribution of organisms across an area.
Transformer	A device which can change the potential difference of an ac supply.
Translocation	The movement of dissolved sugars around a plant.
Transpiration stream	The movement of water from a plant's roots, through the xylem and out of the leaves.
Transverse wave	A wave in which the oscillations are perpendicular (at 90°) to the direction of energy transfer.

Tumour	A growth of abnormal cells.
Ultraviolet (UV) radiation	A type of electromagnetic wave, the main source of which is sunlight.
Uncertainty	The amount by which a given result may differ from the true value.
Universal indicator	A wide range indicator that changes colour depending on the pH of the solution that it's in.
Urea	A waste product produced from the breakdown of amino acids in the liver.
Vaccination	The injection of dead or inactive microorganisms, in order to produce an immune response that will help to protect you against a particular pathogen in the future.
Valid result	A result that is repeatable, reproducible and answers the original question.
Valve	A structure within the heart or a vein which prevents blood flowing in the wrong direction.
Variation	The differences that exist between individuals.
Vector (in disease)	An organism that transfers a disease from one animal or plant to another, which doesn't get the disease itself.
Vector (in genetic engineering)	Something used to transfer DNA into a cell, e.g. a virus or a bacterial plasmid.
Vector (physics)	A quantity which has both magnitude (size) and a direction.
Vein	A blood vessel that carries blood to the heart.
Velocity	The speed and direction of an object.
Velocity-time graph	A graph showing how the velocity of an object changes over a period of time.
Virus	A tiny pathogen that can only replicate within host body cells.
Viscosity	How runny or gloopy a substance is.
Visible light	The part of the electromagnetic spectrum that we can see with our eyes.
Voltmeter	A component used to measure the potential difference across a component. Always connected in parallel with the component.
Wave	An oscillation that transfers energy without transferring any matter.
Wavelength	The length of a full cycle of a wave, e.g. from a crest to the next crest.
Weak acid	An acid which partially ionises in an aqueous solution.
Weight	The force acting on an object due to gravity.
White blood cell	A blood cell that is part of the immune system, defending the body against disease.
Work done	The energy transferred when a force moves an object through a distance, or by a moving charge.
X-ray	A high-frequency, short-wavelength electromagnetic wave. It is mainly used in medical imaging and treatment.
Xylem	A type of plant tissue which transports water and mineral ions around the plant.
Zero error	A type of systematic error caused by using a piece of equipment that isn't zeroed properly.

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The Periodic Table

Relative atomic mass →

Atomic (proton) number →

Periods	Group 1	Group 2											Group 3	Group 4	Group 5	Group 6	Group 7	Group 0
1								1 H Hydrogen 1										4 He Helium 2
2	7 Li Lithium 3	9 Be Beryllium 4											11 B Boron 5	12 C Carbon 6	14 N Nitrogen 7	16 O Oxygen 8	19 F Fluorine 9	20 Ne Neon 10
3	23 Na Sodium 11	24 Mg Magnesium 12											27 Al Aluminium 13	28 Si Silicon 14	31 P Phosphorus 15	32 S Sulfur 16	35.5 Cl Chlorine 17	40 Ar Argon 18
4	39 K Potassium 19	40 Ca Calcium 20	45 Sc Scandium 21	48 Ti Titanium 22	51 V Vanadium 23	52 Cr Chromium 24	55 Mn Manganese 25	56 Fe Iron 26	59 Co Cobalt 27	59 Ni Nickel 28	63.5 Cu Copper 29	65 Zn Zinc 30	70 Ga Gallium 31	73 Ge Germanium 32	75 As Arsenic 33	79 Se Selenium 34	80 Br Bromine 35	84 Kr Krypton 36
5	85 Rb Rubidium 37	88 Sr Strontium 38	89 Y Yttrium 39	91 Zr Zirconium 40	93 Nb Niobium 41	96 Mo Molybdenum 42	[98] Tc Technetium 43	101 Ru Ruthenium 44	103 Rh Rhodium 45	106 Pd Palladium 46	108 Ag Silver 47	112 Cd Cadmium 48	115 In Indium 49	119 Sn Tin 50	122 Sb Antimony 51	128 Te Tellurium 52	127 I Iodine 53	131 Xe Xenon 54
6	133 Cs Caesium 55	137 Ba Barium 56	139 La Lanthanum 57	178 Hf Hafnium 72	181 Ta Tantalum 73	184 W Tungsten 74	186 Re Rhenium 75	190 Os Osmium 76	192 Ir Iridium 77	195 Pt Platinum 78	197 Au Gold 79	201 Hg Mercury 80	204 Tl Thallium 81	207 Pb Lead 82	209 Bi Bismuth 83	[209] Po Polonium 84	[210] At Astatine 85	[222] Rn Radon 86
7	[223] Fr Francium 87	[226] Ra Radium 88	[227] Ac Actinium 89	[261] Rf Rutherfordium 104	[262] Db Dubnium 105	[266] Sg Seaborgium 106	[264] Bh Bohrium 107	[277] Hs Hassium 108	[268] Mt Meitnerium 109	[271] Ds Darmstadtium 110	[272] Rg Roentgenium 111	[285] Cn Copernicium 112	[286] Nh Nihonium 113	[289] Fl Flerovium 114	[289] Mc Moscovium 115	[293] Lv Livermorium 116	[294] Ts Tennessine 117	[294] Og Oganesson 118

The Lanthanides (atomic numbers 58-71) and the Actinides (atomic numbers 90-103) are not shown in this table.

Formula Triangles

Formula Triangles

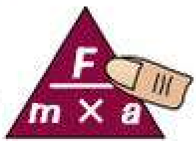
It's pretty important to learn how to put any formula into a triangle. There are two easy rules:

1) If the formula is "$A = B \times C$" then A goes on the top and $B \times C$ goes on the bottom.
2) If the formula is "$A = B \div C$" then B must go on the top (because that's the only way it'll give "B divided by something") — and so pretty obviously A and C must go on the bottom.

Three Examples:

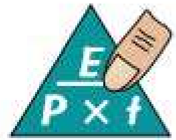
$F = ma$

turns into:



$P = E \div f$

turns into:



How to use them: Cover up the thing you want to find and write down what's left showing.

EXAMPLE: To find m from the first one, cover up m and you get $\frac{F}{a}$ left showing, so "$m = \frac{F}{a}$".

Using Formulas — the Three Rules:

1) Find a formula which contains the thing you want to find together with the other things which you've got values for. Convert that formula into a formula triangle.
2) Think very carefully about all the units, then stick the numbers in.
3) Work out the answer and check that it is sensible.

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