CHEMISTRY

PAPER 1 TOPICS

REVISION ORGANISER

Chapter 1: Atomic structure

Knowledge organiser

Development of the model of the atom

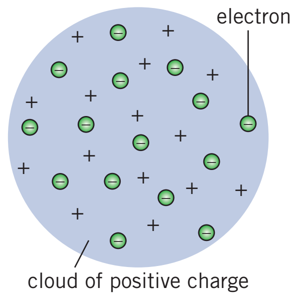
Dalton's model

John Dalton thought of the **atom** as a solid sphere that could not be divided into smaller parts. His model did not include **protons**, **neutrons**, or **electrons**.

The plum pudding model

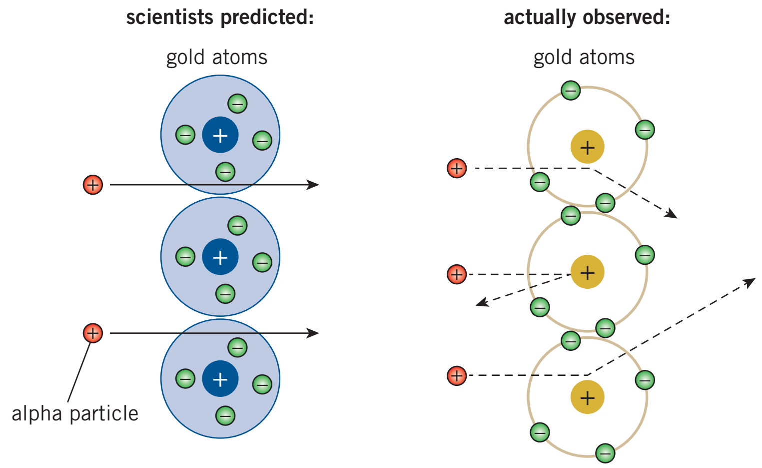
Scientists' experiments resulted in the discovery of sub-atomic charged particles. The first to be discovered were electrons – tiny, negatively charged particles.

The discovery of electrons led to the plum pudding model of the atom – a cloud of positive charge, with negative electrons embedded in it. Protons and neutrons had not yet been discovered.



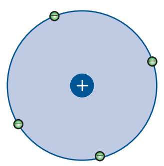
Alpha scattering experiment

1. Scientists fired small, positively charged particles (called alpha particles) at a piece of gold foil only a few atoms thick.
2. They expected the alpha particles to travel straight through the gold.
3. They were surprised that some of the alpha particles bounced back and many were deflected (alpha scattering).
4. To explain why the alpha particles were repelled the scientists suggested that the positive charge and mass of an atom must be concentrated in a small space at its centre. They called this space the **nucleus**.



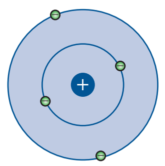
Nuclear model

Scientists replaced the plum pudding model with the nuclear model and suggested that the electrons **orbit** the nucleus, but not at set distances.



Electron shell (Bohr) model

Niels Bohr calculated that electrons must orbit the nucleus at fixed distances. These orbits are called **shells** or **energy levels**.



The proton

Further experiments provided evidence that the nucleus contained smaller particles called protons. A proton has an opposite charge to an electron.

The neutron

James Chadwick carried out experiments that gave evidence for a particle with no charge. Scientists called this the neutron and concluded that the protons and neutrons are in the nucleus, and the electrons orbit the nucleus in shells.

Relative mass

One property of protons, neutrons, and electrons is **relative mass** – their masses compared to each other. Protons and neutrons have the same mass, so are given a relative mass of 1. It takes almost 2000 electrons to equal the mass of a single proton – their relative mass is so small that we can consider it as 0.

Size

The atom has a radius of 1×10^{-10} m. Nuclei (plural of nucleus) are around 10 000 times smaller than atoms and have a radius of around 1×10^{-14} m.

Elements and compounds

Elements are substances made of one type of atom. Each atom of an element will have the same number of protons.

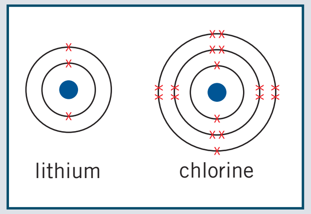
Compounds are made of different types of atoms chemically bonded together. The atoms in a compound have different numbers of protons.

Drawing atoms

Electrons in an atom are placed in fixed shells. You can put

- up to two electrons in the first shell
- eight electrons each in the second and third shells.

You must fill up a shell before moving on to the next one.



Mixtures

- A mixture consists of two or more elements or compounds that are not chemically combined together.
- The substances in a mixture can be separated using physical processes.
- These processes do not use chemical reactions.

Separating mixtures

- filtration – insoluble solids and a liquid
- crystallisation – soluble solid from a solution
- simple distillation – solvent from a solution
- fractional distillation – two liquids with similar boiling points
- paper chromatography – identify substances from a mixture in solution

Atoms and particles

	Relative charge	Relative mass	
Proton	+1	1	= atomic number
Neutron	0	1	= mass number – atomic number
Electron	–1	0 (very small)	= same as the number of protons

All atoms have equal numbers of protons and electrons, meaning they have no overall charge:

total negative charge from electrons = total positive charge from protons

Isotopes

Atoms of the same element can have a different number of neutrons, giving them a different overall mass number. Atoms of the same element with different numbers of neutrons are called **isotopes**.

The **relative atomic mass** is the average mass of all the atoms of an element:

$$\text{relative atomic mass} = \frac{(\text{abundance of isotope 1} \times \text{mass of isotope 1}) + (\text{abundance of isotope 2} \times \text{mass of isotope 2})...}{100}$$

Key terms Make sure you can write a definition for these key terms.

abundance, atom, atomic number, aqueous, compound, electron, element, energy level, isotope, neutron, nucleus, orbit, product, proton, reactant, relative atomic mass, relative charge, relative mass, shell

Chapter 2: The Periodic Table

Knowledge organiser

Development of the Periodic Table

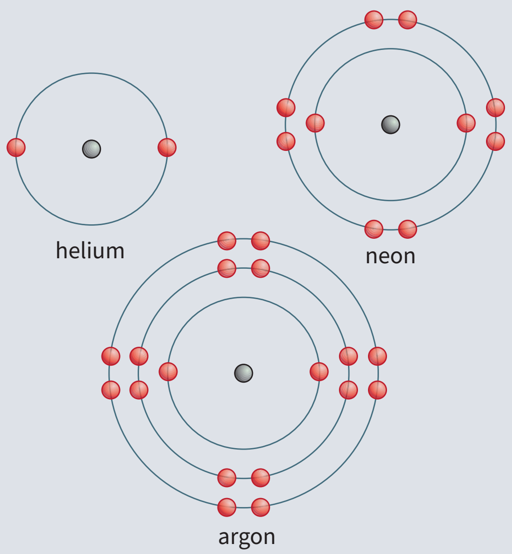
The Periodic Table has changed over time as scientists have organised it differently. Mendeleev was able to accurately predict the properties of undiscovered elements based on the gaps in the table.

	First lists of elements	Mendeleev's Periodic Table	Modern Periodic Table
How are elements ordered?	by atomic mass	normally by atomic mass but some elements were swapped around	by atomic number
Are there gaps?	no gaps	gaps left for undiscovered elements	no gaps – all elements up to a certain atomic number have been discovered
How are elements grouped?	not grouped	grouped by chemical properties	grouped by the number of electrons in the outer shells
Metals and non-metals	no clear distinction	no clear distinction	metals to the left, non-metals to the right
Problems	some elements grouped inappropriately	incomplete, with no explanation for why some elements had to be swapped to fit in the appropriate groups	—

Group 0

Elements in **Group 0** are called the **noble gases**. Noble gases have the following properties:

- full outer shells with eight electrons, so do not need to lose or gain electrons
- are very unreactive (**inert**) so exist as single atoms as they do not bond to form molecules
- boiling points that increase down the group.



Key terms Make sure you can write a definition for these key terms.

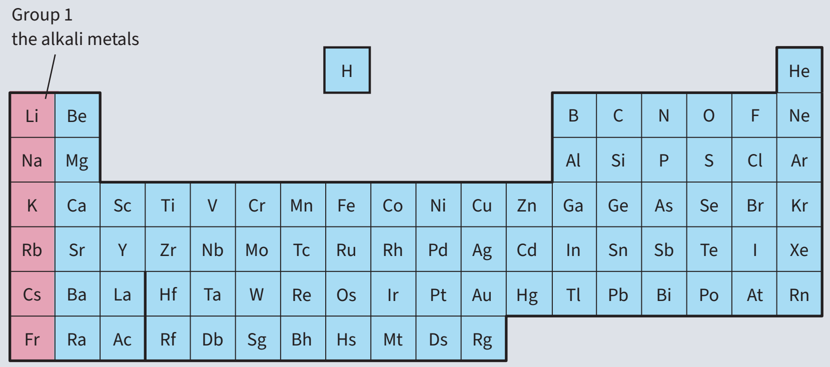
alkali metals   chemical properties   displacement   groups   halogens   inert   isotopes
noble gas   organised   Periodic Table   reactivity   undiscovered   unreactive

Group 1 elements

Group 1 elements react with oxygen, chlorine, and water, for example:

lithium + oxygen → lithium oxide
lithium + chlorine → lithium chloride
lithium + water → lithium hydroxide + hydrogen

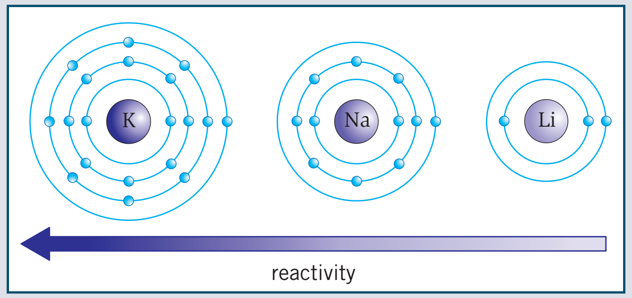
Group 1 elements are called **alkali metals** because they react with water to form an alkali (a solution of their metal hydroxide).



Group 1 properties

Group 1 elements all have one electron in their outer shell. **Reactivity** increases down Group 1 because as you move down the group:

- the atoms increase in size
- the outer electron is further away from the nucleus, and there are more shells shielding the outer electron from the nucleus
- the electrostatic attraction between the nucleus and the outer electron is weaker so it is easier to lose the one outer electron
- the melting point and boiling point decreases down Group 1.



Group 7 elements

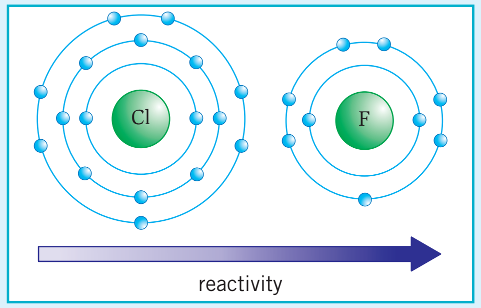
Group 7 elements are called the **halogens**. They are non-metals that exist as molecules made up of pairs of atoms.

Name	Formula	State at room temperature	Melting point and boiling point	Reactivity
fluorine	F_2	gas	increases down the group	decreases down the group
chlorine	Cl_2	gas		
bromine	Br_2	liquid		
iodine	I_2	solid		

Group 7 reactivity

Reactivity decreases down Group 7 because as you move down the group:

- the atoms increase in size
- the outer shell is further away from the nucleus, and there are more shells between the nucleus and the outer shell
- the electrostatic attraction from the nucleus to the outer shell is weaker so it is harder to gain one electron to fill the outer shell.



Group 7 displacement

More reactive Group 7 elements can take the place of less reactive ones in a compound. This is called **displacement**.
For example, fluorine displaces chlorine as it is more reactive:

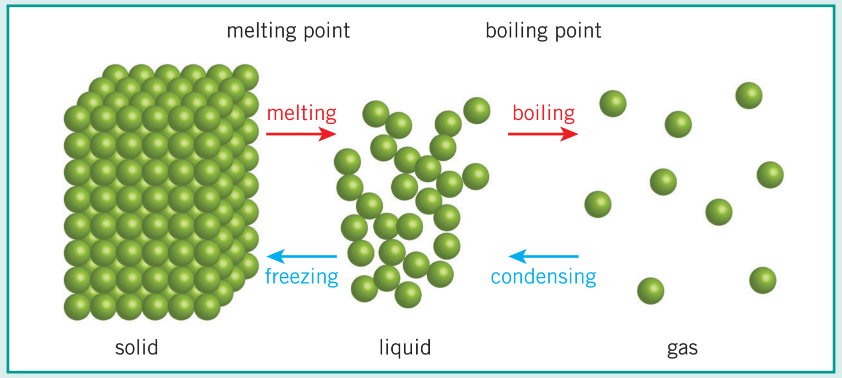
fluorine + potassium chloride → potassium fluoride + chlorine

Chapter 3: Bonding 1

Knowledge organiser

Particle model

The three states of matter can be represented in the particle model.



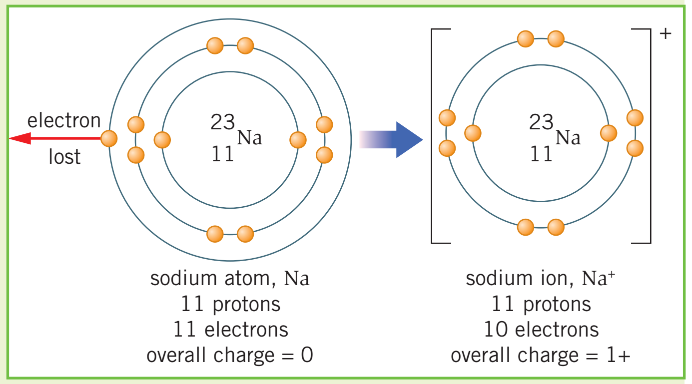
(HT only) This model assumes that:

- there are no forces between the particles
- that all particles in a substance are spherical
- that the spheres are solid.

The amount of energy needed to change the state of a substance depends on the forces between the particles. The stronger the forces between the particles, the higher the melting or boiling point of the substance.

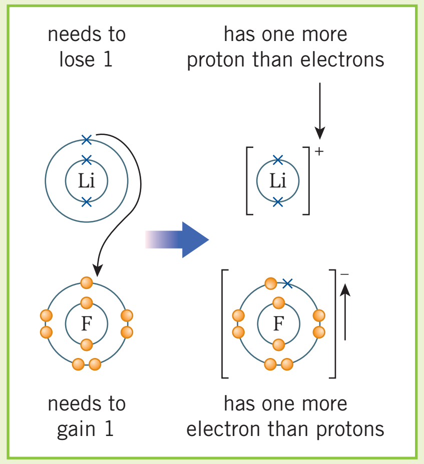
Ions

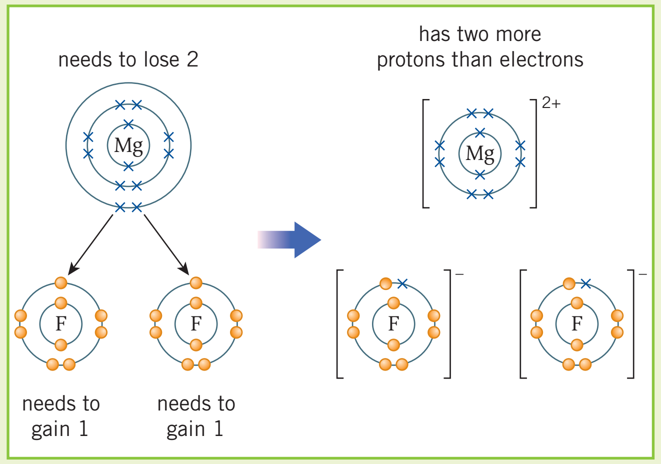
Atoms can gain or lose electrons to give them a full outer shell. The number of protons is then different from the number of electrons. The resulting particle has a charge and is called an **ion**.



Ionic bonding

When metal atoms react with non-metal atoms they **transfer** electrons to the non-metal atom.

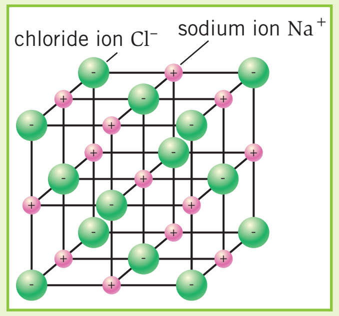




Metal atoms lose electrons to become positive ions. Non-metal atoms gain electrons to become negative ions.

Giant ionic lattice

When metal atoms transfer electrons to non-metal atoms you end up with positive and negative ions. These are attracted to each other by the strong **electrostatic force of attraction**. This is called ionic bonding.



The electrostatic force of attraction works in all directions, so many billions of ions can be bonded together in a 3D structure.

Conductivity

Solid ionic substances do not conduct electricity because the ions are fixed in position and not free to carry charge.

When melted or dissolved in water, ionic substances do conduct electricity because the ions are free to move and carry charge.

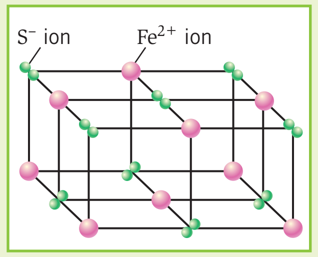
Melting points

Ionic substances have high melting points because the electrostatic force of attraction between oppositely charged ions is strong and so requires lots of energy to break.

Formulae

The formula of an ionic substance can be worked out

1. from its bonding diagram: for every one magnesium ion there are two fluoride ions – so the formula for magnesium fluoride is MgF_2
2. from a lattice diagram: there are nine Fe^{2+} ions and 18 S^- ions – simplifying this ratio gives a formula of FeS_2



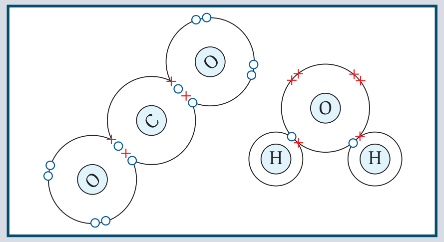
Covalent bonding

Atoms can share or transfer electrons to form strong chemical bonds.

A **covalent bond** is when electrons are *shared* between **non-metal** atoms.

The number of electrons shared depends on how many extra electrons an atom needs to make a full outer shell.

If you include electrons that are shared between atoms, each atom has a full outer shell. **Single bond** = each atom shares one pair of electrons. **Double bond** = each atom shares two pairs of electrons.



Covalent structures

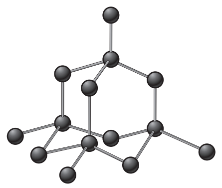
There are three main types of covalent structure:

Structure and bonding

Giant covalent

Many billions of atoms, each one with a strong covalent bond to a number of others.

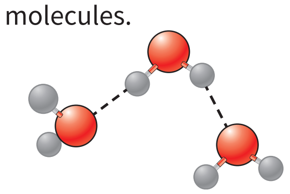
An example of a giant covalent structure is diamond.



Small molecules

Each molecule contains only a few atoms with strong covalent bonds between these atoms. Different molecules are held together by weak **intermolecular forces**.

For example, water is made of small molecules.



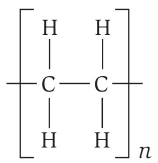
Large molecules

Many repeating units joined by covalent bonds to form a chain.

The small section is bonded to many identical sections to the left and right. The '*n*' represents a large number.

Separate chains are held together by intermolecular forces that are stronger than in small molecules.

Polymers are examples of long molecules.



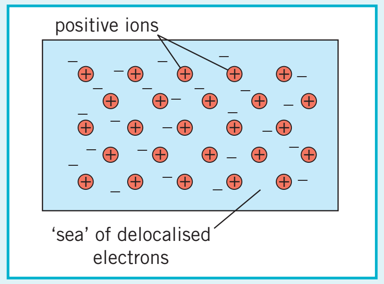
Metals: structure and properties

The atoms that make up metals form layers. The electrons in the outer shells of the atoms are **delocalised** – this means they are free to move through the whole structure.

The positive metal ions are then attracted to these delocalised electrons by the electrostatic force of attraction.

Some important properties of metals are:

- pure metals are **malleable** because the layers can slide over each other
- they are good **conductors** of electricity and of thermal energy because delocalised electrons are free to move through the whole structure
- they have high melting and boiling points because the electrostatic force of attraction between metal ions and delocalised electrons is strong so lots of energy is needed to break it.



Chapter 3: Bonding 2

Knowledge organiser

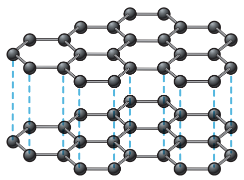
Properties	High melting and boiling points because the strong covalent bonds between the atoms must be broken to melt or boil the substances. This requires a lot of energy. Solid at room temperature.	Low melting and boiling points because only the intermolecular forces need to be overcome to melt or boil the substances, not the bonds between the atoms. This does not require a lot of energy as the intermolecular forces are weak. Normally gaseous or liquid at room temperature.	Melting and boiling points are low compared to giant covalent substances but higher than for small molecules. Large molecules have stronger intermolecular forces than small molecules, which require more energy to overcome. Normally solid at room temperature.

Most covalent structures do not conduct electricity because they do not have **delocalised electrons** or ions that are free to move to carry charge.

Graphite

Graphite is a giant covalent structure, but is different to other giant covalent substances.

Structure



Made only of carbon – each carbon atom bonds to three others, and forms hexagonal rings in layers. Each carbon atom has one spare electron, which is delocalised and therefore free to move around the structure.

Hardness

The layers can slide over each other because they are not covalently bonded. Graphite is therefore softer than diamond, even though both are made only of carbon, as each atom in diamond has four strong covalent bonds.

Conductivity

The delocalised electrons are free to move through graphite, so can carry charges and allow an electrical current to flow. Graphite is therefore a conductor of electricity.

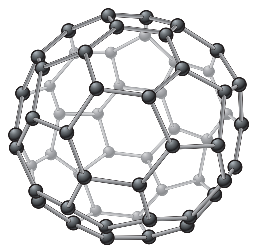
Graphene

Graphene consists of only a single layer of graphite. Its strong covalent bonds make it a strong material that can also conduct electricity. It could be used in composites and high-tech electronics.

Fullerenes

- hollow cages of carbon atoms bonded together in one molecule
- can be arranged as a sphere or a tube (called a **nanotube**)
- molecules held together by weak intermolecular forces, so can slide over each other
- conduct electricity

Spheres

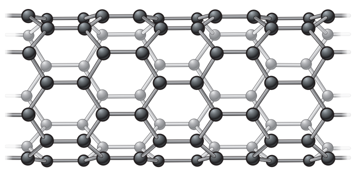


Buckminsterfullerene was the first fullerene to be discovered, and has 60 carbon atoms.

Other fullerenes exist with different numbers of carbon atoms arranged in rings that form hollow shapes.

Fullerenes like this can be used as lubricants and in drug delivery.

Nanotubes

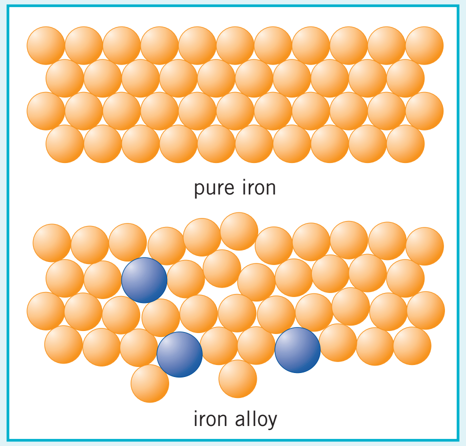


The carbon atoms in nanotubes are arranged in cylindrical tubes.
Their high **tensile strength** (they are difficult to break when pulled) makes them useful in electronics.

Alloys

Pure metals are often too soft to use as they are. Adding atoms of a different element can make the resulting mixture harder because the new atoms will be a different size to the pure metal's atoms. This will disturb the regular arrangement of the layers, preventing them from sliding over each other.

The harder mixture is called an **alloy**.



Measuring particles

We use different units and scales to measure the size of particles.

Particle	Particulate matter	Size	Standard form	Full form
grain of sand	N/A	0.1 mm	1×10^{-4} m	0.0001 m
coarse particles (e.g., dust)	PM_{10}	10 μm	1×10^{-5} m	0.00001 m
fine particles	$PM_{2.5}$	100 nm	1×10^{-7} m	0.0000001 m
nanoparticles	$< PM_{2.5}$	1 to 100 nm	1×10^{-9} to 1×10^{-7} m	0.000000001 m to 0.0000001 m

PM stands for **particulate matter** and is another way of measuring very small particles.

Uses of nanoparticles

Nanoparticles often have very different properties to bulk materials of the same substance, caused by their high surface area-to-volume-ratio.

Nanoparticles have many uses and are an important area of research. They are used in healthcare, electronics, cosmetics, and as catalysts.

However, nanoparticles have the potential to be hazardous to health and to ecosystems, so it is important that they are researched further.

Key terms Make sure you can write a definition for these key terms.

conductivity, conductor, delocalised electron, electrostatic force of attraction, ion, lattice, layer, malleable, nanoparticle, particulate matter, surface area to volume ratio, transfer

Chapter 4: Calculations

Knowledge organiser

Formula mass

Every substance has a **formula mass**, M_r.

formula mass M_r = sum (relative atomic mass of all the atoms in the formula)

Avogadro's constant (HT only)

One mole of a substance contains 6.02×10^{23} atoms, ions, or molecules. This is **Avogadro's constant**.

One mole of a substance has the same mass as the M_r of the substance. For example, the M_r (H_2O) = 18, so 18 g of water molecules contains 6.02×10^{23} molecules, and is called one mole of water.

You can write this as: $\text{moles} = \dfrac{\text{mass}}{M_r}$

Theoretical yield

The **theoretical yield** of a chemical reaction is the mass of a product that you expect to be produced.

Even though no atoms are gained or lost during a chemical reaction, it is not always possible to obtain the theoretical yield because

- some of the product can be lost when it is separated from the reaction mixture
- there can be unexpected side reactions between reactants that produce different products
- the reaction may be reversible.

Percentage yield

The **yield** is the amount of product that you actually get in a chemical reaction.

Percentage yield is the actual yield as a proportion of the theoretical yield:

$$\text{percentage yield} = \frac{\text{actual yield}}{\text{theoretical yield}} \times 100$$

Atom economy

The **atom economy** of a reaction tells you the proportion of atoms that you started with that are part of *useful* products.

High atom economies are more sustainable, as they mean fewer atoms are being wasted in products that are not useful.

The percentage atom economy is calculated by:

$$\text{atom economy} = \frac{M_r \text{ of useful product}}{M_r \text{ of all products}} \times 100$$

Key terms

Make sure you can write a definition for these key terms.

atom economy, burette, concordant, end point, excess reactant, formula mass, limiting reactant, percentage yield, pipette, room temperature and pressure, theoretical yield, titration, titre, useful, yield

Using balanced equations (HT only)

In a balanced symbol equation the sum of the M_r of the reactants equals the sum of the M_r of the products.

If you are asked what mass of a product will be formed from a given mass of a specific reactant, you can use the steps below to calculate the result.

1. balance the symbol equation
2. calculate moles of the substance with a known mass using $\text{moles} = \dfrac{\text{mass}}{M_r}$
3. using the balanced symbol equation, work out the number of moles of the unknown substance
4. calculate the mass of the unknown substance using mass = moles × M_r

If you are asked to balance an equation, you can use the steps below to work out the answer.

1. work out M_r of all the substances
2. calculate the number of moles of each substance in the reaction using $\text{moles} = \dfrac{\text{mass}}{M_r}$
3. convert to a whole number ratio
4. balance the symbol equation

Excess and limiting reactants (HT only)

In a chemical reaction between two or more reactants, often one of the reactants will run out before the others. You then have some of the other reactants left over. The reactant that is left over is in **excess**. The reactant that runs out is the **limiting reactant**.

To work out which reactants are in excess and which is the limiting reactant, you need to:

1. write the balanced symbol equation for the reaction
2. pick one of the reactants and its quantity as given in the question
3. use the ratio of the reactants in the balanced equation to see how much of the other reactant you need
4. compare this value to the quantity given in the question
5. determine which reactant is in excess and which is limiting.

Concentration

Concentration is the amount of solute in a volume of solvent.

The unit of concentration is g/dm³. Concentration can be calculated using:

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

Sometimes volume is measured in cm³:

$$\text{volume (dm}^3) = \frac{\text{volume (cm}^3)}{1000}$$

- lots of solute in little solution = high concentration
- little solute in lots of solution = low concentration

Concentration in mol/dm³

Concentration can also be measured in mol/dm³.

$$\text{concentration of solution (mol/dm}^3) = \frac{\text{number of moles of solute}}{\text{volume of solution (dm}^3)}$$

You can use this formula and mass = moles × M_r to calculate the mass of solute dissolved in a solution.

- The greater the mass of solute in solution, the greater the number of moles of solute, and therefore the greater the concentration.
- If the same number moles of solute is dissolved in a smaller volume of solution, the concentration will be greater.

mol is a the unit of moles

Moles of gases (HT only)

At any given temperature and pressure, the same number of moles of a gas will occupy the same volume.

At room temperature (25 °C) and pressure (1 atm), one mole of *any* gas will occupy 24 dm³.

To calculate the number of moles of a gas:

$$\text{moles of a gas} = \frac{\text{volume (dm}^3)}{24\text{ dm}^3}$$

or

$$\text{moles of a gas} = \frac{\text{volume (cm}^3)}{24\,000\text{ cm}^3}$$

Calculating concentration

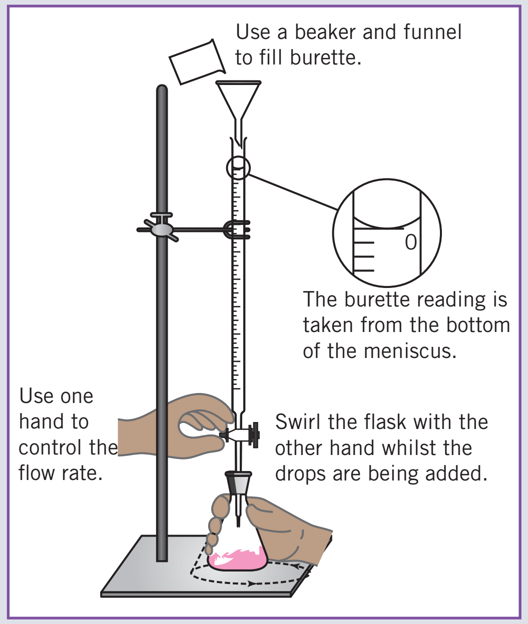
To calculate the concentration of the unknown solution (the solution in the conical flask):

1. Write a balanced symbol equation for the reaction.
2. Calculate the moles used from the known solution using:
   $\text{moles} = \text{concentration (mol/dm}^3) \times \text{volume (dm}^3)$
3. Use the ratio from the balanced symbol equation to deduce the number of moles present in the unknown solution.
4. Calculate the concentration of the unknown solution using:
   $\text{concentration (mol/dm}^3) = \dfrac{\text{moles}}{\text{volume (dm}^3)}$

Titration

Titration is an experimental technique to work out the concentration of an unknown solution in the reaction between an acid and an alkali.

1. Use a pipette to extract a known volume of the solution with an unknown concentration. A pipette measures a fixed volume only.
2. Add the solution of unknown concentration to a conical flask and put the conical flask on a white tile.
3. Add a few drops of a suitable indicator to the conical flask.
4. Add the other solution with a known concentration to the burette.
5. Carry out a rough titration to find out approximately what volume of solution in the burette needs to be added to the solution in the conical flask. Add the solution from the burette to the solution in the conical flask 1 cm³ at a time until the end point is reached.
6. The end point is when the indicator just changes colour.
7. Record the volume of the end point as your rough value.
8. Now repeat steps 1–7, but as you approach the end point add the solution from the burette drop-by-drop. Swirl the conical flask in between drops.
9. Record the volume of the end point.



Chapter 5: Chemical changes 1

Knowledge organiser

Reactions of metals

The **reactivity** of a metal is how chemically reactive it is. When added to water, some metals react very vigorously – these metals have *high* reactivity. Other metals will barely react with water or acid, or won't react at all – these metals have *low* reactivity.

Reactivity series

The reactivity series places metals in order of their reactivity.

Sometimes, for example in the table below, hydrogen and carbon are included in the series, even though they are non-metals.

<table>
<tr><th rowspan="2">Reaction with water</th><th rowspan="2">Reaction with acid</th><th colspan="2">Reactivity series</th><th rowspan="2">Extraction method</th></tr>
<tr><th>Metal</th><th>Reactivity</th></tr>
<tr><td rowspan="4">fizzes, gives off hydrogen gas</td><td rowspan="3">explodes</td><td>potassium</td><td rowspan="11">high reactivity
Decreasing reactivity
low reactivity</td><td rowspan="6">electrolysis</td></tr>
<tr><td>sodium</td></tr>
<tr><td>lithium</td></tr>
<tr><td rowspan="3">fizzes, gives off hydrogen gas</td><td>calcium</td></tr>
<tr><td rowspan="2">reacts very slowly</td><td>magnesium</td></tr>
<tr><td>aluminium
(carbon)
zinc</td></tr>
<tr><td rowspan="5">no reaction</td><td rowspan="2">reacts slowly with warm acid</td><td>iron</td><td rowspan="3">reduction with carbon</td></tr>
<tr><td>tin</td></tr>
<tr><td rowspan="3">no reaction</td><td>lead
(hydrogen)
copper</td></tr>
<tr><td>silver</td><td rowspan="2">mined from the Earth's crust</td></tr>
<tr><td>gold</td></tr>
</table>

Metal extraction

Some metals, like gold, are so unreactive that they are found as pure metals in the Earth's crust and can be mined.

Most metals exist as compounds in rock and have to be extracted from the rock. If there is enough metal compound in the rock to be worth extracting it is called an **ore**.

Metals that are less reactive than carbon can be extracted by reduction with carbon. For example:

iron oxide + carbon → iron + carbon dioxide

Metals that are more reactive than carbon can be extracted using a process called **electrolysis**.

Reduction and oxidation

If a substance gains oxygen in a reaction, it has been **oxidised**.

If a substance loses oxygen in a reaction, it has been **reduced**.

For example:

iron + oxygen → iron oxide

iron has been oxidised

iron oxide + carbon → iron + carbon dioxide

iron oxide has been reduced

Salts

When acids react with metals or metal compounds, they form salts. A salt is a compound where the hydrogen from an acid has been replaced by a metal. For example nitric acid, HNO_3, reacts with sodium to form $NaNO_3$. The H in nitric acid is replaced with Na.

The table shows how to name salts.

Acid	hydrochloric acid	sulfuric acid	nitric acid
Formula	HCl	H_2SO_4	HNO_3
Ions formed in solution	H^+ and Cl^-	$2H^+$ and SO_4^{2-}	H^+ and NO_3^-
Type of salt formed	metal chloride	metal sulfate	metal nitrate
Sodium salt example	sodium chloride, $NaCl$	sodium sulfate, Na_2SO_4	sodium nitrate, $NaNO_3$

Displacement reactions

In a **displacement** reaction a *more* reactive element takes the place of a *less* reactive element in a compound.

For example:

copper sulfate + iron → iron sulfate + copper

$$CuSO_4(aq) + Fe(s) \rightarrow FeSO_4(aq) + Cu(s)$$

Iron is more reactive than copper, so iron displaces the copper in copper sulfate.

Reactivity and ions

A metal's reactivity depends on how readily it forms an **ion** by losing electrons.

In the displacement reaction of copper sulfate and iron, iron forms an ion more easily than copper.

At the end of the reaction you are left with iron ions, not copper ions.

Ionic equations (HT only)

When an ionic compound is dissolved in a solution, we can write the compound as its separate ions. For example, $CuSO_4(aq)$ can be written as $Cu^{2+}(aq)$ and $SO_4^{2-}(aq)$.

The displacement reaction of copper sulfate and iron can be written as:

$$Fe(s) + Cu^{2+}(aq) + SO_4^{2-}(aq) \rightarrow Fe^{2+}(aq) + SO_4^{2-}(aq) + Cu(s)$$

The SO_4^{2-} is unchanged in the reaction – it is a **spectator ion**. Spectator ions are removed from the equation to give an **ionic equation**:

$$Fe(s) + Cu^{2+}(aq) \rightarrow Fe^{2+}(aq) + Cu(s)$$

Metals, covalent substances, and solid ionic substances do not split into ions in the ionic equation.

Steps for writing an ionic equation (HT only)

1. check symbol equation is balanced
2. identify all aqueous ionic compounds
3. write those compounds out as ions
4. remove spectator ions.

Half equations (HT only)

In the displacement reaction, an iron atom loses two electrons to form a iron ion:

$$Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$$

A copper ion gains two electrons to form a copper atom:

$$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$$

These two equations are called **half equations** – they each show half of the ionic equation.

Reduction and oxidation: electrons (HT only)

Oxidation and reduction (**redox** reactions) can be defined in terms of oxygen, but can also be defined as the loss or gain of electrons.

Oxidation is the *loss* of electrons, and reduction is the *gain* of electrons.

In the example displacement reaction:

- iron atoms have been oxidised
- copper ions have been reduced.

Acids and alkalis

Acids are compounds that, when dissolved in water, release H^+ ions. There are three main acids: sulfuric acid H_2SO_4, nitric acid HNO_3, and hydrochloric acid HCl.

Alkalis are compounds that, when dissolved in water, release OH^- ions.

The **pH** scale is a measure of acidity and alkalinity. It runs from 1 to 14.

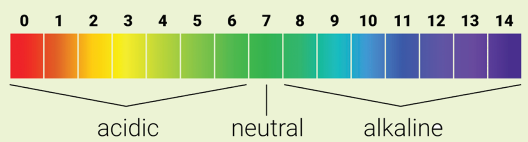
- Aqueous solutions with pH < 7 are acidic.
- Aqueous solutions with pH > 7 are alkaline.
- Aqueous solutions with pH = 7 are neutral.

Indicators

Indicators can show if something is an acid or an alkali.

- **Universal indicator** can also tell us the approximate pH of a solution.
- Electronic pH probes can give us the exact pH of a solution.

The pH scale



Chapter 5: Chemical changes 2

Knowledge organiser

Reactions of acids

Reactions of acids with metals

Acids react with some metals to form salts and hydrogen gas.

magnesium + hydrochloric acid → sodium chloride + hydrogen

Neutralisation reactions

Reactions of acids with metal hydroxides

Acids react with metal hydroxides to form salts and water.

hydrochloric acid + sodium hydroxide → sodium chloride + water

The ionic equation for this reaction is always:

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(l)$$

Reactions of acids with metal oxides

Acids react with metal oxides to form salts and water.

hydrochloric acid + sodium oxide → sodium chloride + water

Reactions of acids with metal carbonates

Acids react with metal carbonates to form a salt, water, and carbon dioxide.

hydrochloric acid + sodium carbonate → sodium chloride + water + carbon dioxide

Alkalis and bases

Bases neutralise acids to form water in **neutralisation** reactions. Some metal hydroxides dissolve in water to form alkaline solutions, called alkalis.

Some metal oxides and metal hydroxide do not dissolve in water. They are **bases**, but are not alkalis.

Strong and weak acids

Sulfuric acid, nitric acid, and hydrochloric acid, are all **strong acids**. This means that, when dissolved in water, every molecule splits up into ions – they are completely ionised:

- $H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$
- $HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$
- $HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$

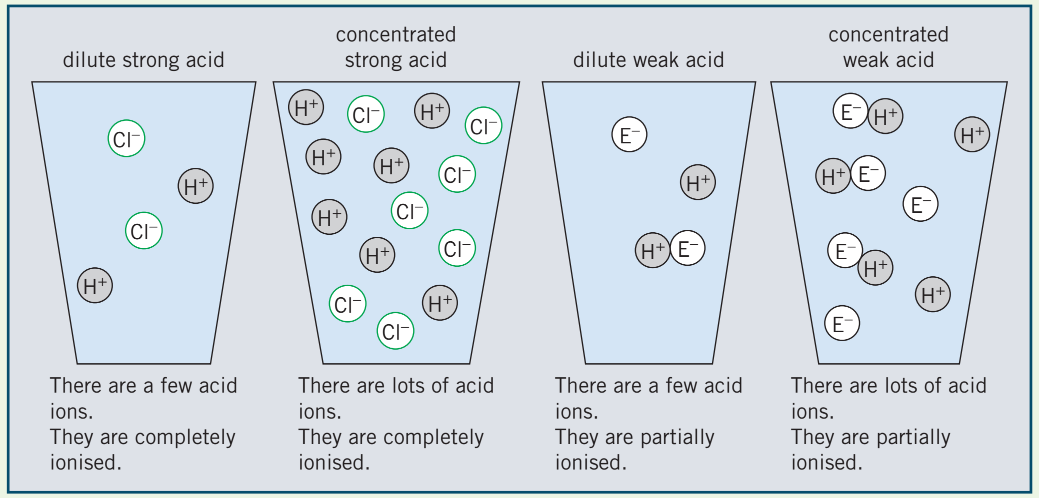
Ethanoic acid, citric acid, and carbonic acid are **weak acids**. This means that only a percentage of their molecules split up into ions when dissolved in water – they are partially ionised.

For a given concentration, the *stronger* the acid, the *lower* the pH.

Concentrated and dilute acids

Concentration tells us how much of a substance there is dissolved in water:

- more concentrated acids have lots of acid in a small volume of water
- less concentrated acids (dilute acids) have little acid in a large volume of water.



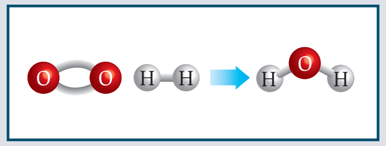
Balancing symbol equations

When writing symbol equations you need to ensure that the number of each atom on each side is equal.

$H_2 + O_2 \rightarrow H_2O$

unbalanced

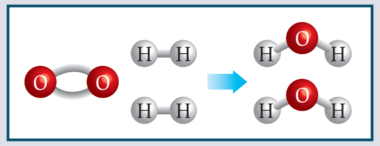
there are 2 hydrogen atoms on each side, but 2 oxygen atoms in the reactants and 1 in the product



$2H_2 + O_2 \rightarrow 2H_2O$

balanced

there are 4 hydrogen atoms on each side, and 2 oxygen atoms on each side



State symbols

A balanced symbol equation should also include state symbols.

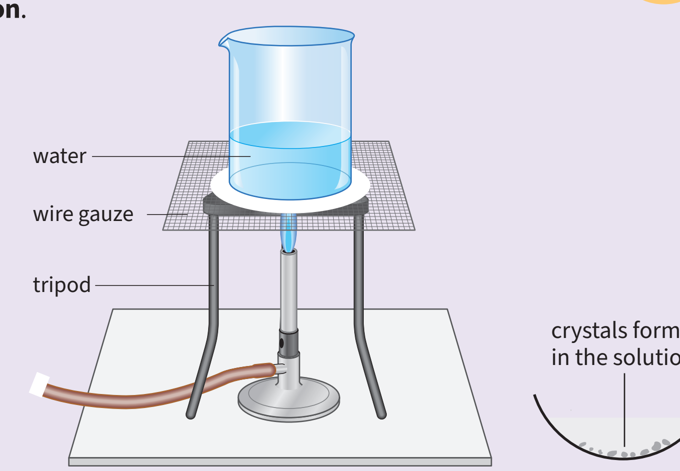
State	Symbol
solid	(s)
liquid	(l)
gas	(g)
aqueous or dissolved in water	(aq)

Crystallisation

You can produce a solid salt from an insoluble base by **crystallisation**.

The experimental method is:

1. Choose the correct acid and base to produce the salt.
2. Put some of the dilute acid into a flask. Heat gently with a Bunsen burner.
3. Add a small amount of the base and stir.
4. Keep adding the base until no more reacts – the base is now in excess.
5. Filter to remove the unreacted base.
6. Add the remaining solution to an evaporating dish.
7. Use a water bath or electric heater to evaporate the water. The salt crystals will be left behind.



Key terms

Make sure you can write a definition for these key terms.

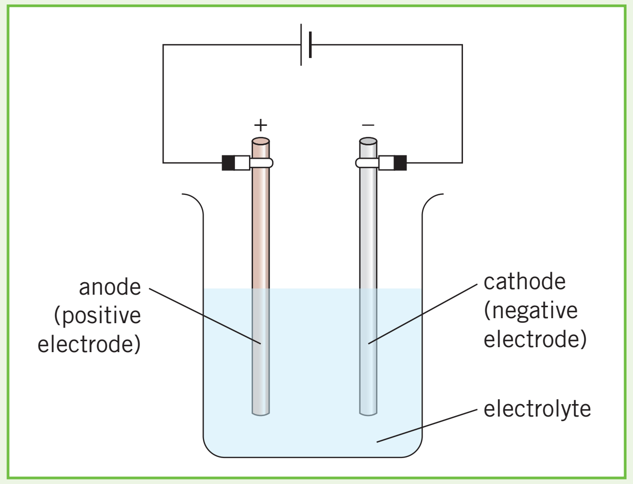
displacement *electrolysis* *extraction* *half equation* *ion* *ionic equation* *metal* *ore* *oxidation* *reactivity* *reactivity series* *redox* *reduction* *spectator ion* *state symbols*

Chapter 6: Electrolysis

Knowledge organiser

Electrolysis

In the process of **electrolysis**, an electric current is passed through an **electrolyte**. An electrolyte is a liquid or solution that contains ions and so can conduct electricity. This causes the ions to move to the **electrodes**, where they form pure elements.



Electrolysis of molten compounds

Solid ionic compounds do not conduct electricity as the ions cannot move. To undergo electrolysis they must be molten or dissolved, so the ions are free to move.

When an ionic compound is molten:

- The positive metal ions are *attracted* to the **cathode**, where they will *gain* electrons to form the pure metal
- The negative non-metal ions are *attracted* to the **anode**, where they will *lose* electrons and become the pure non-metal.

For example, molten sodium chloride, NaCl, can undergo electrolysis to form sodium at the cathode and chlorine at the anode.

Half equations (HT only)

sodium chloride ⟶ sodium + chlorine

$2NaCl(l) \rightarrow 2Na(s) + Cl_2(g)$

- at the cathode:

$2Na^+(l) + 2e^- \rightarrow 2Na(s)$

- at the anode:

$2Cl^-(l) \rightarrow Cl_2(g) + 2e^-$

Electrolysis of aqueous solutions

Solid ionic compounds can also undergo electrolysis when dissolved in water.

- It requires less energy to dissolve ionic compounds in water than it does to melt them.
- However, in the electrolysis of solutions, the pure elements are not always produced. This is because the water can also undergo ionisation:

$$H_2O(l) \rightarrow H^+(aq) + OH^-(aq)$$

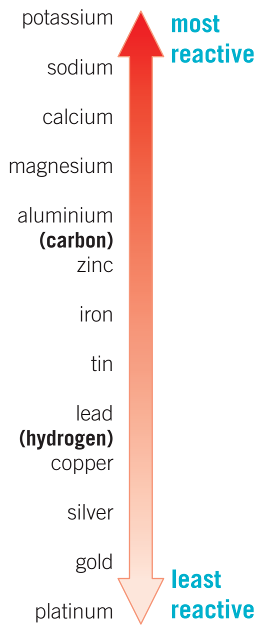
Products at the anode

In In the electrolysis of a solution, if the non-metal contains oxygen then oxygen gas is formed at the anode:

- The $OH^-(aq)$ ions formed from the ionisation of water are attracted to the anode.
- The $OH^-(aq)$ ions lose electrons to the anode and form oxygen gas.
- $4OH^-(aq) \rightarrow O_2(g) + 2H_2O(l) + 4e^-$

If the non-metal ion is a halogen, then the halogen gas is formed at the anode.

- $2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-$



Products at the cathode

In the electrolysis of a solution, if the metal is *more* **reactive** than hydrogen then hydrogen gas is formed at the cathode:

- The $H^+(aq)$ ions from the ionisation of water are attracted to the cathode and react with it.
- The $H^+(aq)$ ions gain electrons from the cathode and form hydrogen gas.
- $2H^+(aq) + 2e^- \rightarrow H_2(g)$
- The metal ions remain in solution.

Electrolysis of aluminium oxide

Electrolysis can be used to extract metals from their ionic compounds.

Electrolysis is used if the metal is more reactive than carbon.

Aluminium is extracted from aluminium oxide by electrolysis.

1. The aluminium oxide is mixed with a substance called **cryolite**, which lowers the melting point.
2. The mixture is then heated until it is molten.
3. The resulting molten mixture undergoes electrolysis.

aluminium oxide ⟶ *aluminium* + *oxygen*

$2Al_2O_3(l) \rightarrow 4Al(l) + 3O_2(g)$

cathode: pure aluminium is formed

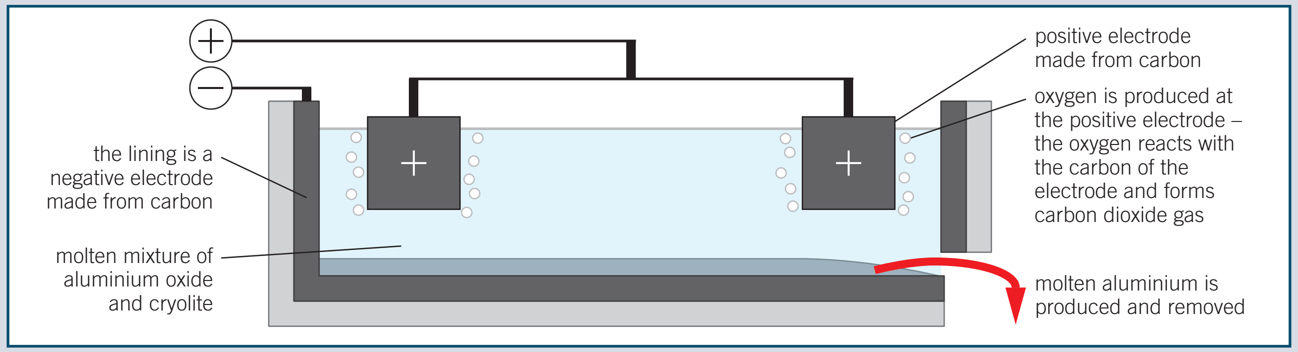
$Al^{3+}(l) + 3e^- \rightarrow Al(l)$

anode: oxygen is formed

$2O^{2-}(l) \rightarrow O_2(g) + 4e^-$

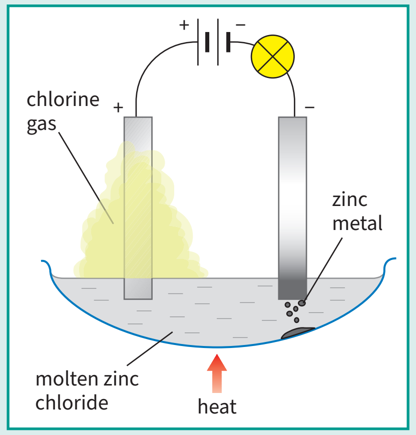
In the electrolysis of aluminium, the anode is made of graphite.

The graphite reacts with the oxygen to form carbon dioxide and so slowly wears away. It therefore needs to be replaced frequently.



Electrolysis of zinc chloride

Molten zinc chloride is broken down by electrolysis. This means zinc metal is collected at the cathode and a pale green chlorine gas is collected at the anode. Free ions from the molten zinc chloride are able to move around and carry electric currents, hence why the bulb lights up.



Key terms Make sure you can write a definition for these key terms.

anode *cathode* *cryolite* *electrode* *electrolysis* *electrolyte* *reactivity*

Chapter 7: Energy changes

Knowledge organiser

Energy changes

During a chemical reaction, energy transfers occur.

Energy can be transferred:

- to the surroundings – **exothermic**
- from the surroundings – **endothermic**

This energy transfer can cause a temperature change.

Energy is always conserved in chemical reactions. This means that there is the same amount of energy in the Universe at the start of a chemical reaction as at the end of the chemical reaction.

The surroundings

When chemists say energy is transferred from or to "the *surroundings*" they mean "everything that isn't the reaction".

For example, imagine you have a reaction mixture in a test tube. If you measure the temperature in the test tube using a thermometer, the thermometer is then part of the surroundings.

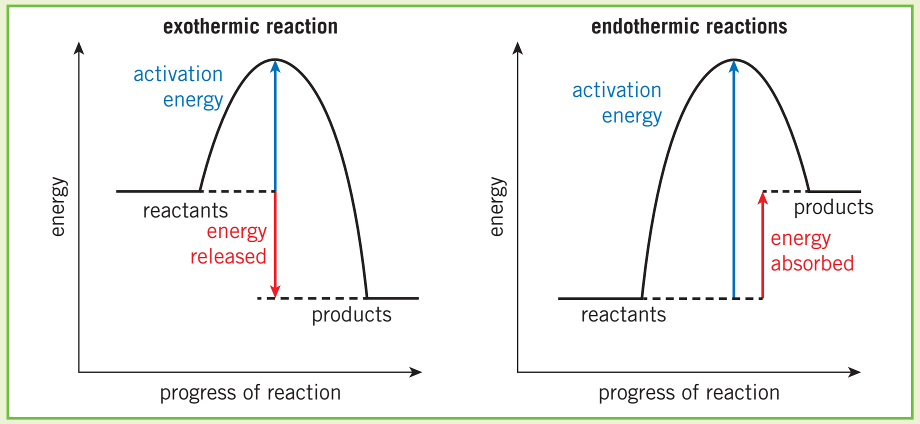
- If the thermometer records an increase in temperature, the reaction in the test tube is exothermic.
- If the thermometer records a decrease in temperature, the reaction in the test tube is endothermic.

Reaction	Energy transfer	Temperature change	Example	Everyday use	Bonds
exothermic	to the surroundings	temperature of the surroundings increases	• **oxidation** • **combustion** • **neutralisation**	• self-heating cans • hand warmers	more energy released when making bonds than required to break bonds
endothermic	from the surroundings	temperature of the surroundings decreases	• **thermal decomposition** • citric acid and sodium hydrogen carbonate	• sports injury packs	less energy released when making bonds than required to break bonds

Reaction profiles

A **reaction profile** shows whether a reaction is exothermic or endothermic.

The **activation energy** is the minimum amount of energy that particles must have to react when they collide.



Bonds (HT only)

Atoms are held together by strong chemical bonds. In a reaction, those bonds are broken and new ones are made between different atoms.

- Breaking a bond requires energy so is endothermic.
- Making a bond releases energy so is exothermic.

Breaking bonds

If a lot of energy is released when making the bonds and only a little energy is required to break them, then overall energy is released and the reaction as a whole is exothermic.

Making bonds

If a little energy is released when making the bonds and a lot is required to break them, then overall energy is taken in and the reaction as a whole is endothermic.

Bond calculations

Different bonds require different amounts of energy to be broken (their **bond energies**). To work out the overall energy change of a reaction, you need to:

1. work out how much energy is required to break all the bonds in the reactants
2. work out how much energy is released when making all the bonds in the products.

overall energy transferred = energy required to break bonds – energy required to make bonds

- A positive number means an endothermic reaction.
- A negative number means an exothermic number.

Chemical cells

In a metal displacement reaction, one metal is oxidised – it loses electrons. These electrons are transferred to another metal, which gains the electrons and so is reduced.

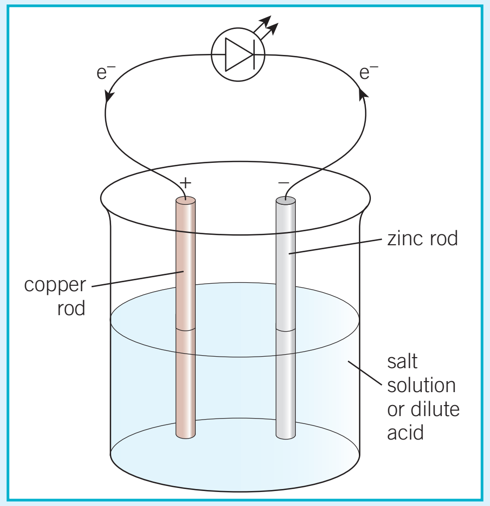
By using a **chemical cell** to conduct this reaction, the electron's movement generates a current.

In the cell shown, the zinc atoms from the electrode lose electrons, turn into ions, and move into the solution.

The electrons travel through the circuit to the copper electrode, causing the LED to light up.

Once at the copper electrode, a metal ion *from the solution* will pick the electrons up and become a metal atom.

The greater the difference in reactivity between the two metals in the cell, the greater the potential difference produced.



Batteries

A **battery** is formed of two or more cells connected in series.

- Some batteries are **rechargeable**. An external electric current is applied, which reverses the reaction.
- Some batteries, like alkaline batteries, are not rechargeable because the reaction is not reversible. Once the reactants are used up, the chemical reaction stops and no more potential differences are released.

Hydrogen fuel cells

Fuel cells use a fuel and oxygen from the air to generate a potential difference.

Hydrogen fuel cells generate electricity from hydrogen and oxygen. The overall reaction is:

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$$

The hydrogen is oxidised to produce water.

There are different types of hydrogen fuel cell. In alkaline fuel cells, the half equations are below:

- $2H_2(g) + 4OH^-(aq) \rightarrow 4H_2O(l) + 4e^-$
- $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

Advantages

- the only waste is water
- do not need to be electrically recharged

Disadvantages

- hydrogen is highly flammable and difficult to store
- hydrogen is often produced from non-renewable resources

Key terms

Make sure you can write a definition for these key terms.

activation energy, battery, bond energy, chemical cell, combustion, endothermic, exothermic, fuel cell, neutralisation, oxidation, reaction profile, rechargeable, thermal decomposition

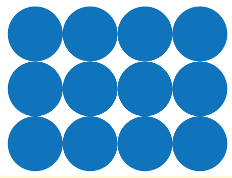
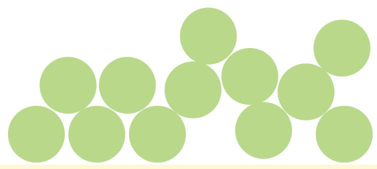
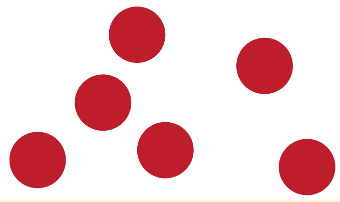
C1 Chapter 1: Particles and their behaviour

Knowledge organiser

changes of state

particles gain energy from the surroundings → particles vibrate faster → particles lose their place in the pattern (melting)

particles gain more energy from the surroundings → particles move faster → particles pull completely away from each other (boiling / evaporation)

state of matter	solid	liquid	gas
how do the particles move?	particles do not move around, but vibrate on the spot	particles are touching but can slide over each other	particles are spread out far away from each other
arrangement of particles			
can it be compressed?	no, because there is no space between the particles	no, because the particles are touching their neighbours	yes, because there is space between the particles
can it flow?	no, because the particles can't move around	yes, because the particles can slide over each other and move around	yes, because the particles can move around

freezing: particles lose more energy to the surroundings → particles move even slower → particles take a fixed place in a pattern

condensation: particles lose energy to the surroundings → particles move slower → particles come close together

changes of state

Sublimation

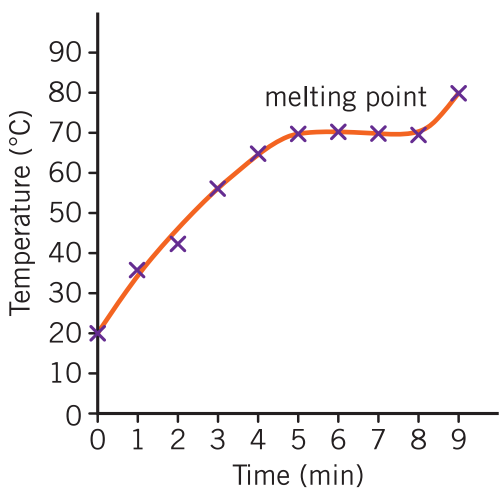
Some substances do not exist as liquids, but instead directly change state from solid to gas in a process called sublimation.

Melting and boiling points

Melting point — the temperature at which a **substance** melts

Boiling point — the temperature at which a substance boils

If you heat a **solid** and plot a graph of temperature against time the melting point will appear as a flat line if the substance is **pure** (has only one type of particle).



Diffusion

Particles move about randomly in liquids and gases and spread out through **mixtures**. This process is called diffusion. How quickly diffusion happens depends upon three variables:

Variable	Effect on diffusion
temperature	diffusion is faster at higher temperatures *because* particles move faster when hotter
particle size	diffusion is slower with larger, heavier particles
state of matter	diffusion is: • fast in gases • slow in liquids • doesn't happen in solids

Gas pressure

Density

Density tells us how heavy something is for its size. You can calculate density using the formula: density = mass / volume

Mass is the amount of 'stuff' an object is made of, measured in grams or kilograms.

Volume is the amount of space an object takes up, measured in cm^3.

Density of a substance depends on:

- the mass of the particles
- how closely together the particles are arranged.

A substance is most dense as a solid, as the particles are closely packed together, and least dense as a gas, as the particles are spread far apart.

Particle model and properties

The properties of a substance depend on:

1. the shape and size of its particles
2. the arrangement of its particles
3. how its particles move
4. how strong the forces between its particles are.

Key words

Make sure you can write a definition for these key terms.

boiling, boiling point, change of state, condensation, diffusion, evaporation, freezing, gas, liquid, melting, mixture, particle, solid, state of matter, sublimation, substance