1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

CONTENTS:

1.1 THE PARTICULATE NATURE OF MATTER

1.1.1 KINETIC THEORY

Solids, Liquids & Gases

Solids

- Strong forces of attraction between particles, particles are packed very closely together in a fixed and regular pattern
- Atoms vibrate in position but can't change position or move
- Solids have a fixed volume, shape and high density

Liquids

- Weaker attractive forces in liquids than in solids, particles are close together in an irregular, unfixed pattern
- Particles can move and slide past each other which is why liquids adopt the shape of the container they're in and also why they are able to flow
- Liquids have a fixed volume but not a fixed shape and have a moderate to high density

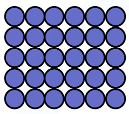
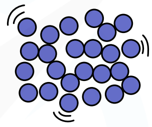
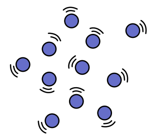
Gases

- No intermolecular forces and, since particles are in random movement, there is no defined pattern
- Particles are far apart and move quickly (around 500 m/s) in all directions, they collide with each other and with the sides of the container (this is how pressure is created inside a can of gas)
- No fixed volume, since there is a lot of space between the particles, gases can be compressed into a much smaller volume. Gases have low density

1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

1.1.1 KINETIC THEORY cont...

STATE	SOLID	LIQUID	GAS
DIAGRAM			
ARRANGEMENT OF PARTICLES	REGULAR ARRANGEMENT	RANDOMLY ARRANGEMENT	RANDOMLY ARRANGEMENT
MOVEMENT OF PARTICLES	VIBRATE ABOUT A FIXED POSITION	MOVE AROUND EACH OTHER	MOVE QUICKLY IN ALL DIRECTIONS
CLOSENESS OF PARTICLES	VERY CLOSE	CLOSE	FAR APART

EXAM TIP

Solids, liquids and gases have different physical properties.

The difference in these properties comes from **differences in how the particles are arranged** in each state.

1.1.2 STATES OF MATTER

State Changes

Melting

- Melting is when a solid changes into a liquid
- Requires heat energy which transforms into **kinetic** energy, allowing the particles to move
- Occurs at a specific temperature known as the melting point (m.p.) which is **unique** to each pure solid

Boiling

- Boiling is when a liquid changes into a gas
- Requires heat which causes bubbles of gas to form **below** the surface of a liquid, allowing for liquid particles to escape from the surface and within the liquid
- Occurs at a specific temperature known as the boiling point (b.p.) which is **unique** to each pure liquid

Freezing

- Freezing is when a liquid changes into a solid
- This is the reverse of melting and occurs at exactly the **same temperature** as melting, hence the melting point and freezing point of a pure substance are the same. Water for example freezes and melts at 0°C

1 THE PARTICULATE NATURE OF MATTER

1.1.2 STATES OF MATTER cont...

YOUR NOTES

- Requires a significant decrease in temperature (or loss of thermal energy) and occurs at a specific temperature which is **unique** for each pure substance

Evaporation

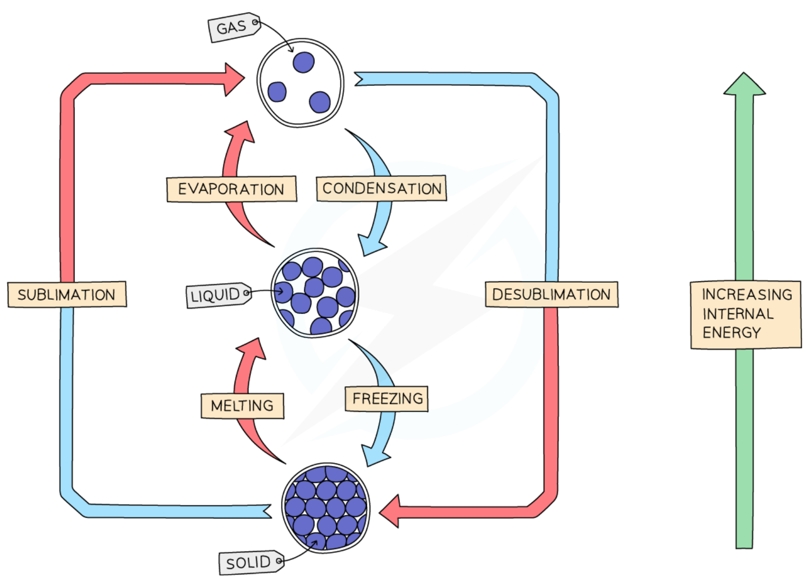
- When a liquid changes into a gas. Evaporation occurs only at the **surface** of liquids where high energy particles can escape from the liquid's surface at **low** temperatures, below the b.p. of the liquid
- The larger the surface area and the warmer the liquid/surface, the more quickly a liquid can evaporate
- For most liquids evaporation occurs readily over a range of temperatures and without the need for heating as the particles at the surface absorb heat from the surroundings. The addition of heat will accelerate the process and boiling occurs if the temperature exceeds the boiling point of the liquid

Condensation

- When a gas changes into a liquid, usually on cooling. When a gas is cooled its particles lose energy and when they bump into each other, they lack energy to bounce away again, instead grouping together to form a liquid
- No energy is required for condensation to occur and it takes place over a **range** of temperatures

Sublimation

- When a solid changes directly into a gas
- This happens to only a few solids such as iodine or solid carbon dioxide
- The reverse reaction also happens and is also called sublimation (sometimes called deposition or desublimation)
- Sublimation occurs at a specific temperature which is **unique** for a pure substance



Interconversion of solids, liquids and gases

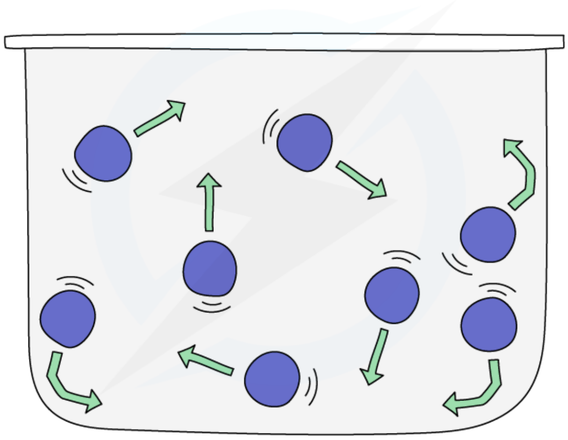
1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

1.1.2 STATES OF MATTER cont...

Gaseous Particles

- Gaseous particles are in constant and **random motion**
- An increase in temperature increases the **kinetic** energy of each particle, as the thermal energy is transformed to kinetic energy, so they move faster
- Decreasing the temperature has the opposite effect
- The pressure that a gas creates inside a closed container is produced by the gaseous particles hitting the inside walls of the container. As the temperature increases, the particles in the gas move faster, impacting the container's walls more **frequently**
- Therefore an **increase in temperature causes an increase in pressure**



Moving particles of gas colliding with each other and the container walls

EXAM TIP

The presence of impurities in a pure substance can change its melting point and boiling point (m.p. & b.p.).

Different pure substances can be identified by analysis of the value of their m.p. or b.p. since this is a physical property which is unique to each substance.

Questions on the particle theory of matter show interconversion of states with a reversible arrow: ⇌, which means that the process can go forwards and backwards.

Read the question carefully and pick the direction of the change in state that the question refers to.

1 THE PARTICULATE NATURE OF MATTER

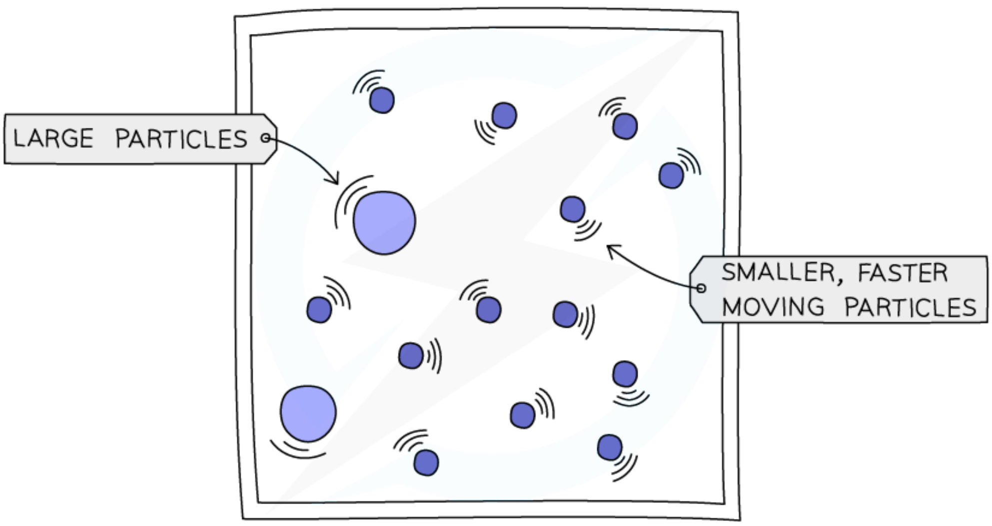
1.1.3 HEATING CURVE

YOUR NOTES

Brownian Motion & Diffusion

Brownian Motion

- Brownian motion is defined as the random movement of particles in a liquid or a gas produced by large numbers of collisions with smaller, often invisible particles
- The observation of Brownian motion proves the correctness of the kinetic particle theory



Large particles show jerky and erratic movement caused by many collisions with smaller particles

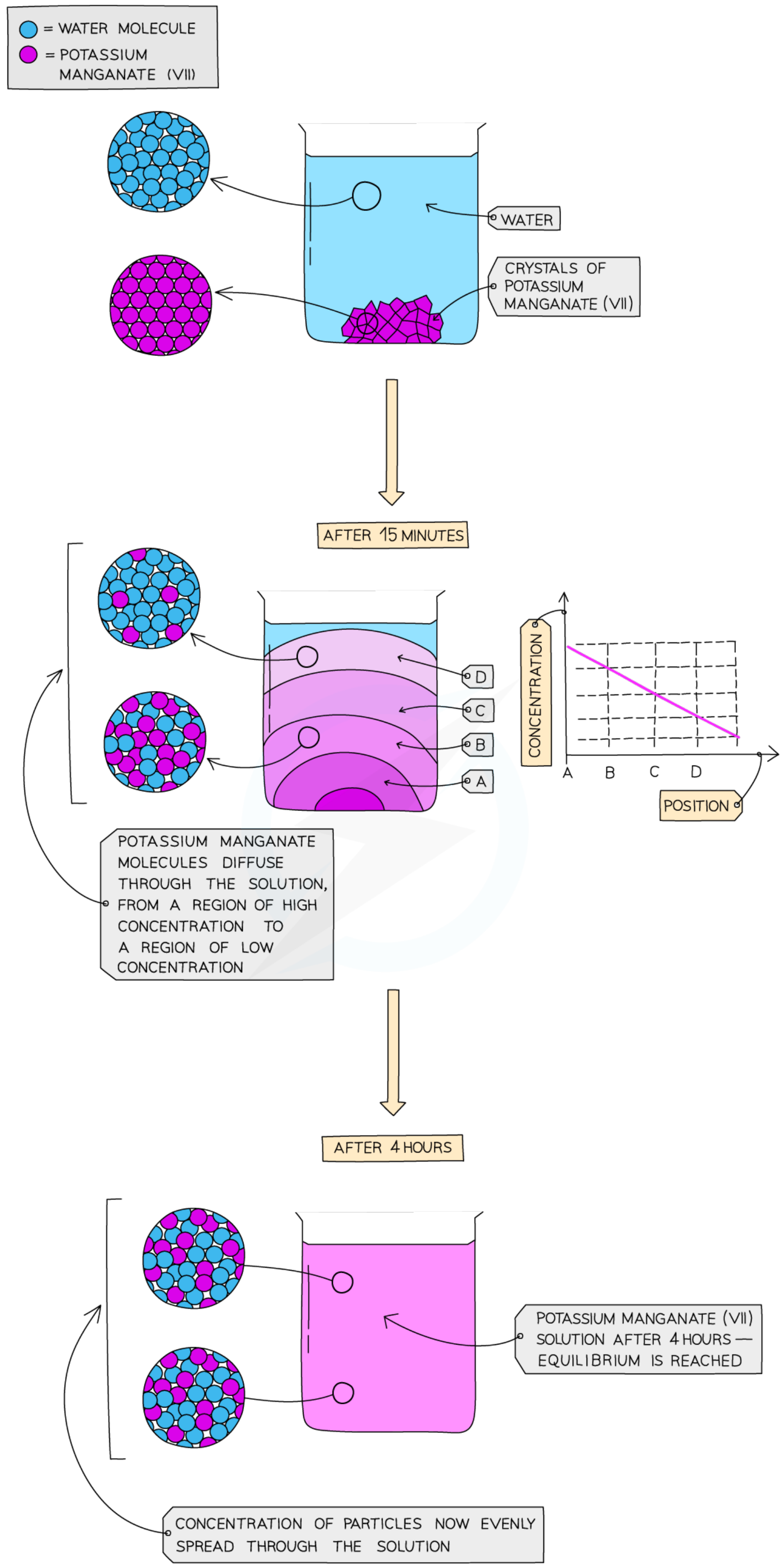
Diffusion

- This is the process by which different gases or different liquids mix and is due to the random motion of their particles
- Diffusing particles move from an area of **high concentration** to an area of **low concentration**
- Eventually the concentration of particles is **even** as they spread out to occupy all of the available space
- Diffusion happens on its own and no energy input is required although it occurs faster at higher temperatures

1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

1.1.3 HEATING CURVE cont...



Diffusion of potassium manganate (VI) in water. After a few hours the concentration of KMnO4 is the same everywhere in the solution

1 THE PARTICULATE NATURE OF MATTER

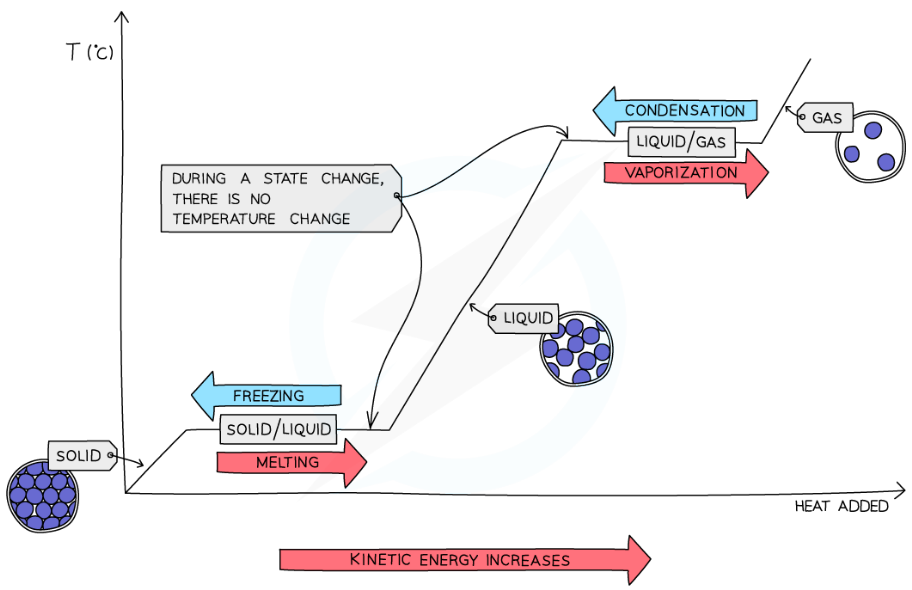
1.1.3 HEATING CURVE cont...

YOUR NOTES

EXTENDED ONLY

Changes in State & the Kinetic theory

- When substances are heated, the particles absorb thermal energy which is converted into kinetic energy. This is the basis of the kinetic theory of matter
- Heating a solid causes its particles to vibrate more and as the temperature increases, they vibrate so much that the solid expands until the structure breaks and the solid melts
- On further heating, the now liquid substance expands more and some particles at the surface gain sufficient energy to overcome the intermolecular forces and evaporate
- When the b.p. temperature is reached, all the particles gain enough energy to escape and the liquids boils
- These changes in state can be shown on a graph which is called a heating curve
- Cooling down a gas has the reverse effect and this would be called a cooling curve
- These curves are used to show how changes in temperature affect changes of state



Heating & cooling curve for water with interconversions of state

1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

1.1.3 HEATING CURVE cont...

EXAM TIP

While changing state, the temperature of the substance remains the same as the heat energy is rapidly converted into kinetic energy.

This is called latent heat and corresponds to the horizontal sections of a heating / cooling curve.

1.1.4 DIFFUSION

EXTENDED ONLY

Brownian Motion

- An example of Brownian motion is the observed jerky and erratic motion of smoke particles as they are hit by the unseen molecules in the air which can be seen under a microscope
- In 1905, physicist Albert Einstein explained that pollen grains in water were being moved by individual **water molecules**
- In all cases, larger and visible particles are caused to move by the random bombardment of smaller, invisible particles

Diffusion & Molecular Mass

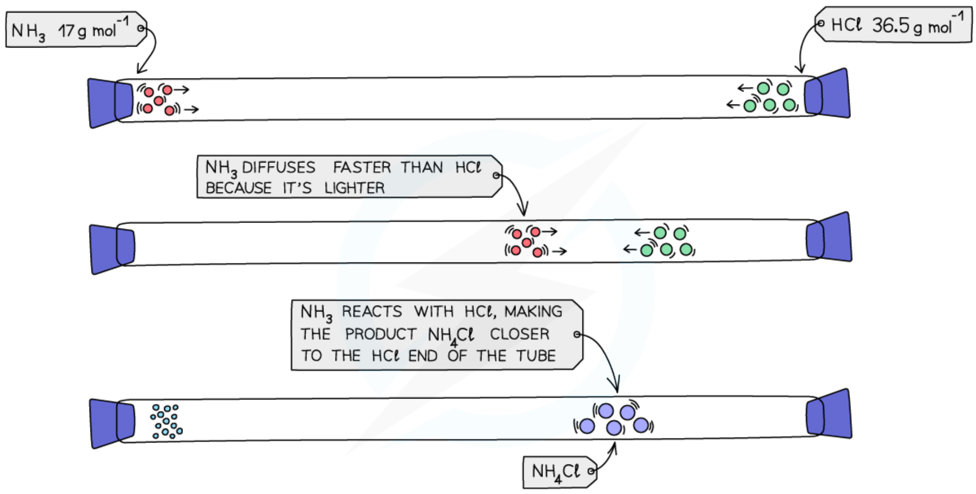
- Diffusion occurs much **faster** in gases than in liquids as gaseous particles move much quicker than liquid particles
- At the same temperature, different gases do not diffuse at the same rate
- This is due to the difference in their relative molecular masses
- Lighter gas particles can travel faster and hence further, therefore: the lower its relative mass, the faster a gas will diffuse

1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

1.1.4 DIFFUSION cont...

EXTENDED ONLY cont...



NH_3 molecules have less mass than the HCl molecule, so diffuse faster, hence the product (a white cloud of NH_4Cl) forms closer to the end where the HCl is

> NOW TRY SOME EXAM QUESTIONS

1 THE PARTICULATE NATURE OF MATTER

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A substance was analysed and was found to have a boiling point of 450 °C.

At room temperature it is a soft grey solid.

Which temperature could be the melting point of a pure sample of the substance?

A -12 °C

B 56 °C to 72 °C

C 250 °C to 275 °C

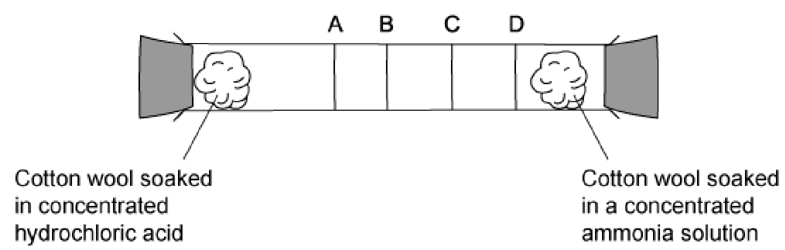
D 142 °C

QUESTION 2

Hydrogen chloride and ammonia are gases which are given off by cotton wool soaked in concentrated solutions and placed at either end of a glass tube as shown.

When the gases react together they produce ammonium chloride, a white solid.

Which line on the diagram correctly shows where the ammonium chloride is formed?



1 THE PARTICULATE NATURE OF MATTER

YOUR NOTES

EXAM QUESTIONS

QUESTION 3

Many chemical processes involve substances in either the liquid or the gaseous state.

Which of the following statements is correct?

A A specific mass of a gas has a fixed volume at room temperature

B A specific mass of a liquid has a fixed volume at room temperature

C 25 cm^3 of gas contains more particles than 25 cm^3 of liquid

D Liquid particles placed inside a sealed container have fixed positions

2 EXPERIMENTAL TECHNIQUES

YOUR NOTES

CONTENTS:

2.1 MEASUREMENT & PURITY

2.1.1 MEASUREMENT

Time, Temperature, Mass & Volume

Time

- Time can be measured using a stopwatch or stopclock which are usually accurate to one or two decimal places
- The units of time normally used are seconds or minutes although other units may be used for extremely slow reactions (e.g. rusting)
- 1 minute = 60 seconds

Temperature

- Temperature is measured using a thermometer which can normally give readings to the nearest degree. Digital thermometers are available which are more accurate
- The units of temperature are **degrees Celsius** (°C)

Mass

- Mass is measured using a digital balance which normally gives readings to two decimal places. These must be tared (set to zero) before use
- The standard unit of mass is kilograms (kg) but in chemistry grams (g) are used most often
- 1 kilogram = 1000 grams

Volume–liquids

- The volume of a liquid can be determined using several types of apparatus, depending on the level of accuracy needed
- For approximate volumes where accuracy isn't an important factor, measuring cylinders are used. These are graduated (have a scale so can be used to measure) and are available in 25 cm^3, 50 cm^3, 100 cm^3 and 250 cm^3
- Pipettes are the most accurate way of measuring a **fixed** volume of liquid, usually 10 cm^3 or 25 cm^3
- Burettes are the most accurate way of measuring a **variable** volume of liquid between 0 cm^3 and 50 cm^3 (e.g. in a titration)

2 EXPERIMENTAL TECHNIQUES

YOUR NOTES

2.1.1 MEASUREMENT cont...

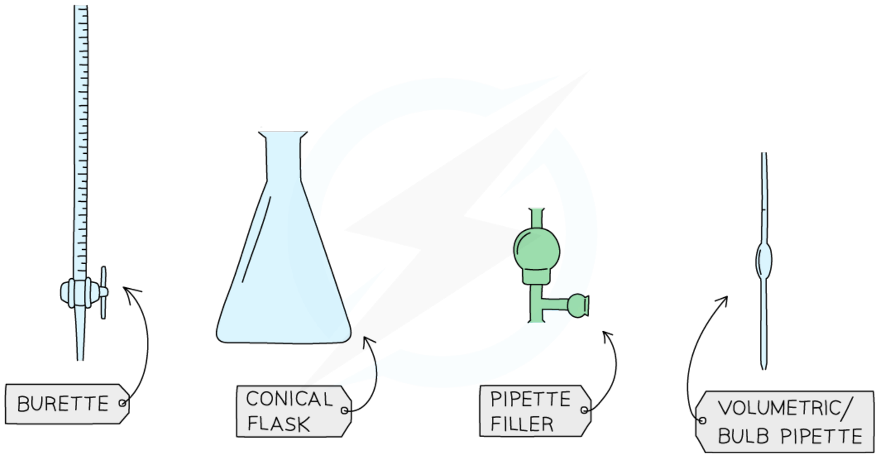


Diagram of a burette with conical flask and pipette with filler

Volume – gases

- The volume of a gas sometimes needs to be measured and is done by collecting it in a graduated measuring apparatus
- A **gas syringe** is usually the apparatus used
- A graduated cylinder inverted in water may also be used, provided the gas isn't water soluble
- If the gas happens to be heavier than air and is coloured, the cylinder can be used upright

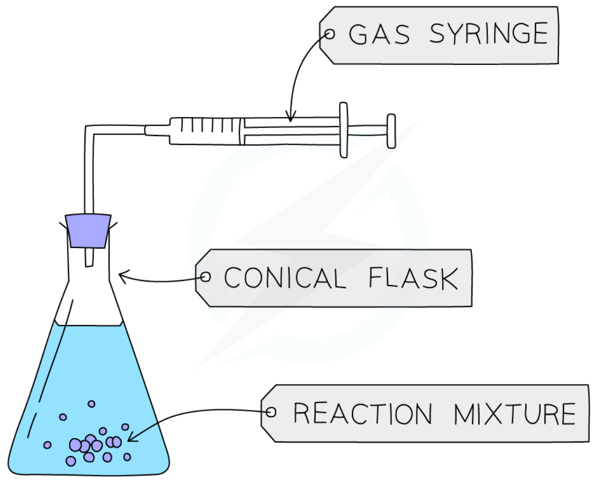


Diagram of the set-up for an experiment involving gas collection

2 EXPERIMENTAL TECHNIQUES

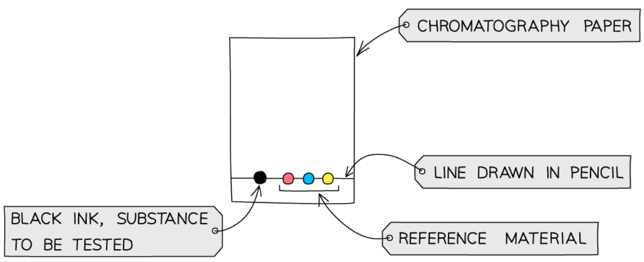
2.1.2 PURITY: CRITERIA OF PURITY

YOUR NOTES

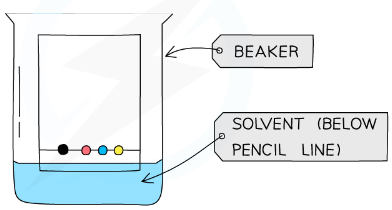
Paper Chromatography

- This technique is used to separate substances that have **different solubilities** in a given solvent (e.g. different coloured inks that have been mixed to make black ink)
- A **pencil line** is drawn on chromatography paper and spots of the sample are placed on it. Pencil is used for this as ink would run into the chromatogram along with the samples
- The paper is then lowered into the solvent container, making sure that the pencil line sits **above** the level of the solvent so the samples don´t wash into the solvent container
- The solvent travels up the paper by capillary action, taking some of the coloured substances with it
- Different substances have different solubilities so will travel at different rates, causing the substances to spread apart. Those substances with higher solubility will travel further than the others
- This will show the different components of the ink / dye

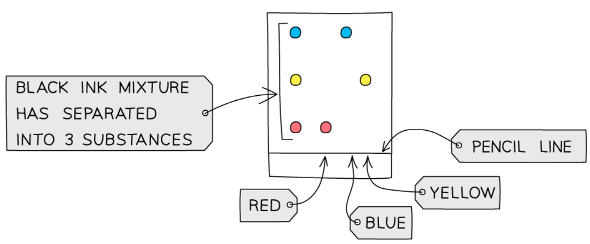
1 SET UP CHROMATOGRAPHY PAPER AS SHOWN



2 LOWER PAPER INTO A BEAKER WITH APPROPRIATE SOLVENT. WAIT FOR SOLVENT TO TRAVEL UP THE PAPER.



3 ANALYSE CHROMATAGRAM



Analysis of the composition of ink using paper chromatography

2 EXPERIMENTAL TECHNIQUES

2.1.2 PURITY: CRITERIA OF PURITY cont...

YOUR NOTES

Interpret Simple Chromatograms

- If two or more substances are the same, they will produce identical chromatograms
- If the substance is a mixture, it will separate on the paper to show all the different components as separate spots
- An impure substance will show up with more than one spot, a pure substance should only show up with one spot

Assessing Purity

- Pure substances melt and boil at specific and sharp temperatures
- Melting and boiling points data can be used to distinguish pure substances from mixtures
- An unknown pure substance can be identified by comparing its m.p and b.p and comparing to data tables
- Mixtures melt over a range of temperatures as they contain two or more substances

Importance of Purity

- A pure substance consists of **only** one substance and contains nothing else
- To have a pure substance for food and drugs is very important as impurities could be dangerous even in small amounts
- Melting and boiling point analysis is routinely used to assess the purity of food and drugs

EXAM TIP

Paper chromatography is the name given to the overall separation technique while a chromatogram is the name given to the visual output of a chromatography run, namely the piece of chromatography paper with the separated components visible after the run has finished.

The verb run is used in this technique as the samples essentially "run" up the chromatography paper.

2 EXPERIMENTAL TECHNIQUES

2.1.2 PURITY: CRITERIA OF PURITY cont...

YOUR NOTES

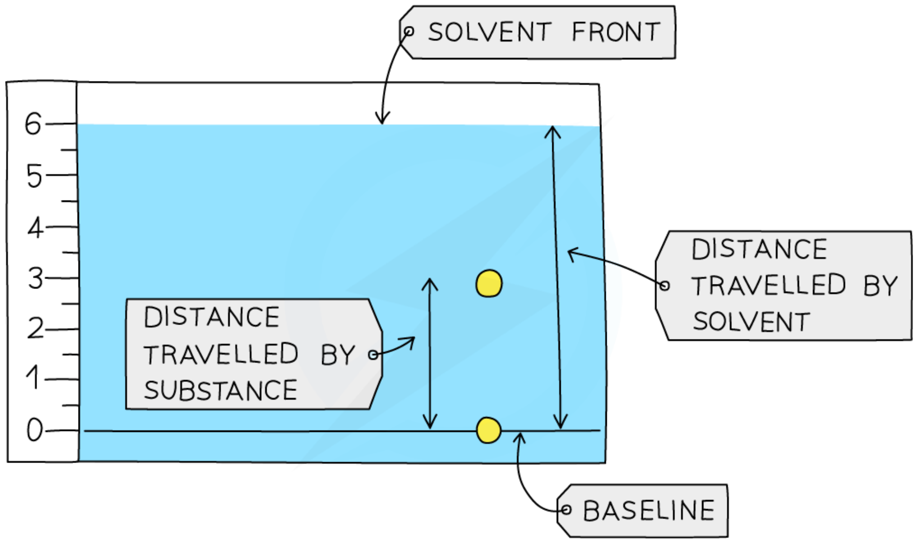
EXTENDED ONLY

Retention Factor (R_f) Values

- These values are used to identify the components of mixtures
- The R_f value of a particular compound is always the same
- Calculating the R_f value allows chemists to identify unknown substances because it can be compared with R_f values of known substances under the same conditions

Calculation

- Retention factor = distance moved by compound ÷ distance moved by solvent
- The R_f value is a ratio and therefore has no units



Using Rf values to identify components of a mixture

Locating Agents

- For chromatography to be useful the chemist needs to be able to see the components move up the paper, which is not the case for invisible samples such as proteins
- In such cases, locating agents can be used to react with the sample and produce a coloured product which is then visible
- The chromatogram is treated with the agent **after** the chromatography run has been carried out, making the sample runs visible to the naked eye

2 EXPERIMENTAL TECHNIQUES

2.1.3 PURITY: METHODS OF PURIFICATION

Methods of Purification

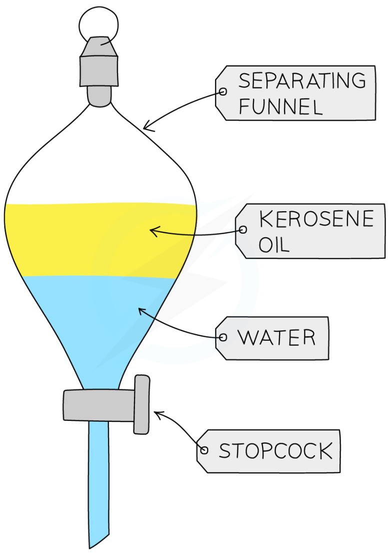
The choice of the method of separation depends on the nature of the substances being separated. All methods rely on there being a **difference** of some sort, usually in a physical property such as b.p., between the substances being separated.

Mixtures of solids

- Differences in density, magnetic properties, sublimation and solubility can be used
- For a difference in solubility, a suitable **solvent** must be chosen to ensure the desired substance only dissolves in it and not other substances or impurities

Mixtures of liquids

- You can separate immiscible liquids with a **separating** funnel or by **decanting** (pouring carefully)
- Examples include when an organic product is formed in aqueous conditions



Separating funnel being used to separate kerosene and water

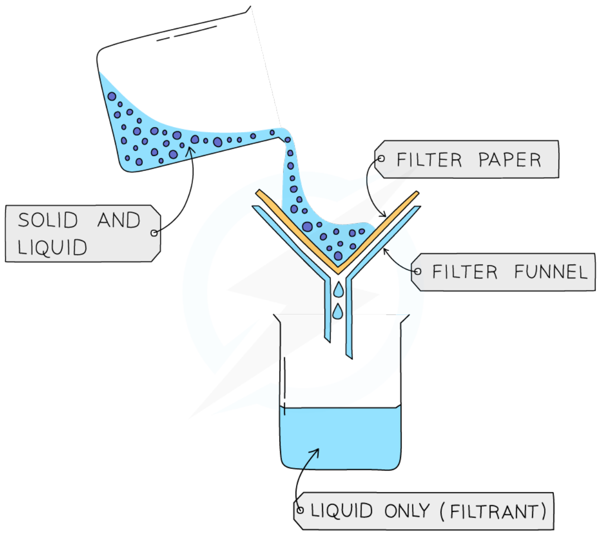
Filtration

- Used to separate an **undissolved solid** from a mixture of the solid and a liquid / solution (e.g. sand from a mixture of sand and water). **Centrifugation** can also be used for this mixture
- Filter paper is placed in a filter funnel above another beaker
- Mixture of insoluble solid and liquid is poured into the filter funnel
- Filter paper will only allow small liquid particles to pass through as the filtrate
- Solid particles are too large to pass through the filter paper so will stay behind as a residue

2 EXPERIMENTAL TECHNIQUES

2.1.3 PURITY: METHODS OF PURIFICATION cont...

YOUR NOTES



Filtration of a mixture of sand and water

Crystallisation

- Used to separate a **dissolved solid** from a solution, when the solid is much more soluble in hot solvent than in cold (e.g. copper sulphate from a solution of copper (II) sulphate in water)
- The solution is heated, allowing the solvent to evaporate to leave a saturated solution behind
- Test if the solution is saturated by dipping a clean, dry, cold glass rod into the solution. If the solution is saturated, crystals will form on the glass rod
- The saturated solution is allowed to cool slowly and solids will come out of the solution as the solubility decreases, and crystals will grow
- Crystals are collected by filtering the solution
- They are then washed with cold, distilled water to remove impurities and allowed to dry

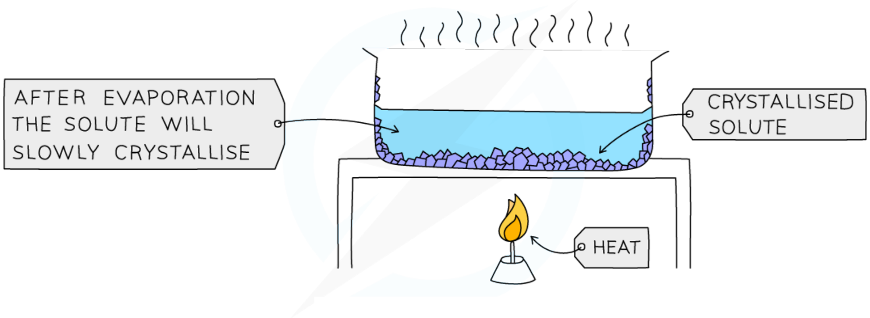


Diagram showing the process of crystallisation

2 EXPERIMENTAL TECHNIQUES

YOUR NOTES

2.1.3 PURITY: METHODS OF PURIFICATION cont...

Simple Distillation

- Used to separate a liquid and **soluble solid** from a solution (e.g. water from a solution of salt water) or a pure liquid from a mixture of liquids
- The solution is heated and pure water evaporates producing a vapour which rises through the neck of the round-bottomed flask
- The vapour passes through the condenser, where it cools and condenses, turning into pure liquid H_2O that is collected in a beaker
- After all the water is evaporated from the solution, only the solid solute will be left behind

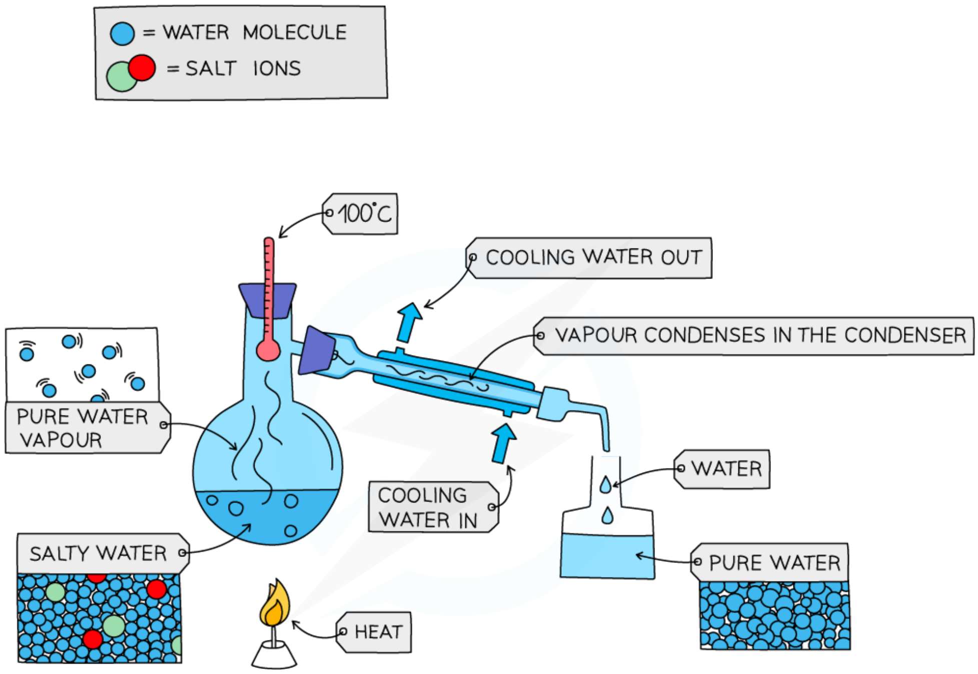


Diagram showing the simple distillation of a mixture of salt and water

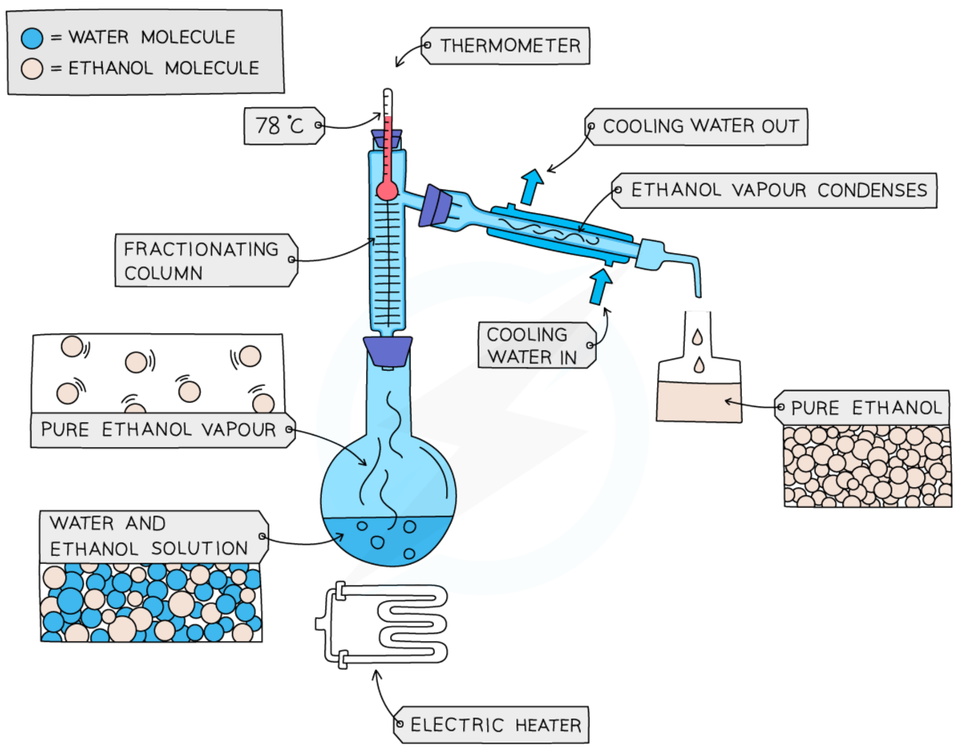
2 EXPERIMENTAL TECHNIQUES

YOUR NOTES

2.1.3 PURITY: METHODS OF PURIFICATION cont...

Fractional distillation

- Used to separate two or more liquids that are **miscible** with one another (e.g. ethanol and water from a mixture of the two)
- The solution is heated to the temperature of the substance with the lowest boiling point
- This substance will rise and evaporate first, and vapours will pass through a condenser, where they cool and condense, turning into a liquid that will be collected in a beaker
- All of the substance is evaporated and collected, leaving behind the other components(s) of the mixture
- For water and ethanol: ethanol has a boiling point of 78 °C and water of 100 °C. The mixture is heated until it reaches 78 °C, at which point the ethanol boils and distills out of the mixture and condenses into the beaker
- When the temperature starts to increase to 100 °C heating should be stopped. Water and ethanol are now separated



Fractional distillation of a mixture of ethanol and water

> NOW TRY SOME EXAM QUESTIONS

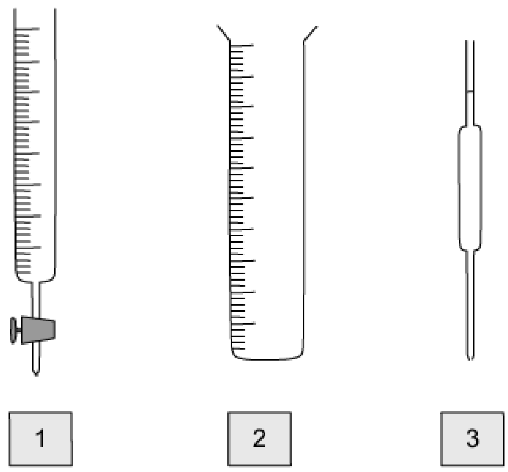
2 EXPERIMENTAL TECHNIQUES

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Measuring volumes of liquids is a fundamental aspect of experimental chemistry. The diagram shows three different pieces of apparatus used for this task.



Which row is correct?

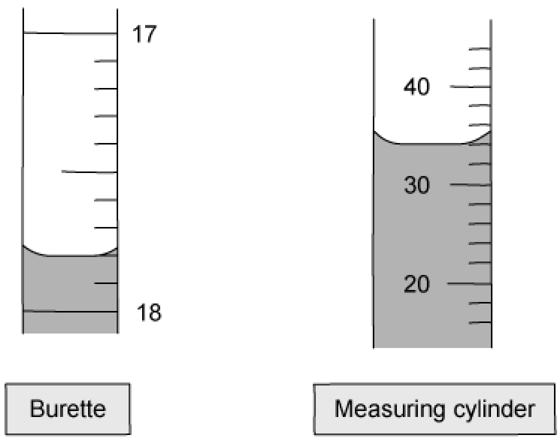
	1	2	3
A	burette	measuring cylinder	pipette
B	burette	pipette	measuring cylinder
C	pipette	measuring cylinder	burette
D	measuring cylinder	burette	pipette

EXAM QUESTIONS

YOUR NOTES

QUESTION 2

The diagram shows a burette and a measuring cylinder, both of which contain a liquid.



Which row shows the correct reading for both?

	Burette	Measuring cylinder
A	18.4	34
B	18.4	56
C	17.8	34
D	17.8	56

2 EXPERIMENTAL TECHNIQUES

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

A student wants to investigate the rate of reaction between marble chips and hydrochloric acid by measuring the volume of carbon dioxide produced with different concentrations of acid.

The equation for the reaction is as follows:

$$2\ HCl + MgCO_3 \rightarrow MgCl_2 + CO_2 + H_2O$$

Which of the following lists of equipment can she use to measure the volume of the gas produced?

A Gas syringe, cotton wool, bung, delivery tube

B Gas syringe, conical flask, bung, delivery tube

C Gas syringe, beaker, bung, balance

D Balloon, conical flask, stopper, balance

> CHECK YOUR ANSWERS AT SAVEMYEXAMS.CO.UK

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

CONTENTS:

3.1 ATOMIC STRUCTURE & BONDING

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE

Protons, Neutrons & Electrons

- Elements are made of tiny particles of matter called **atoms**
- Each atom is made of subatomic particles called **protons**, **neutrons** and **electrons**
- Their size is so tiny that we can't really compare their masses in conventional units such as kilograms or grams, so a unit called the relative atomic mass is used
- One **relative atomic mass** unit is equal to 1/12 the mass of a carbon-12 atom
- All other elements are measured relative to the mass of a carbon-12 atom and since these are ratios, the relative atomic mass has no units
- Hydrogen for example has a relative atomic mass of 1, meaning that 12 atoms of hydrogen would have exactly the same mass as 1 atom of carbon
- The relative mass and charge of the subatomic particles are shown below:

PARTICLE	RELATIVE MASS	CHARGE
PROTON	1	+1
NEUTRON	1	0 (NEUTRAL)
ELECTRON	$\frac{1}{1840}$	−1

YOUR NOTES

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

Defining Proton Number

- The **atomic number** (or **proton number**) is the number of protons in the nucleus of an atom. The symbol for this number is **Z**
- It is also the number of electrons present in an atom and determines the **position** of the element on the Periodic Table

Defining Nucleon Number

- **Nucleon number** (or **mass number**) is the total number of protons and neutrons in the nucleus of an atom. The symbol for this number is **A**
- The nucleon number **minus** the proton number gives you the number of **neutrons** of an atom
- Note that protons and neutrons can collectively be called **nucleons**
- The atomic number and mass number for every element is on the Periodic Table

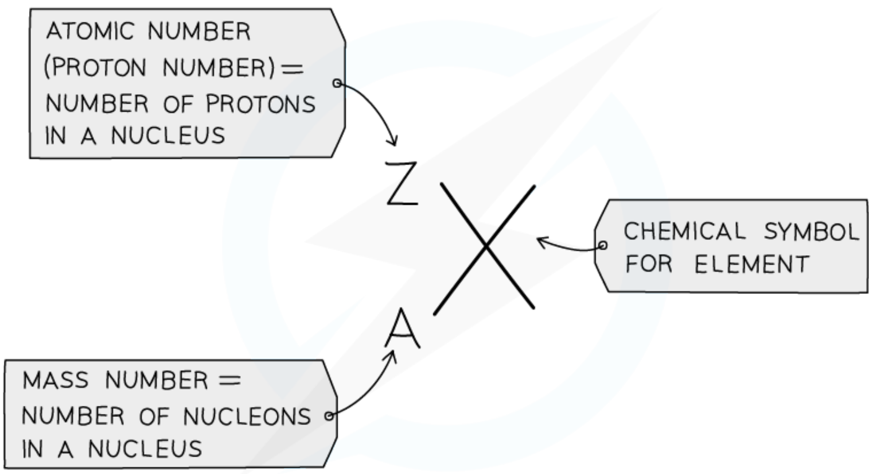


Diagram showing the notation used on the Periodic Table

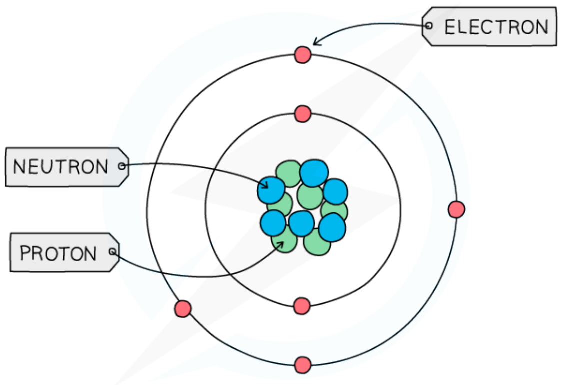
3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

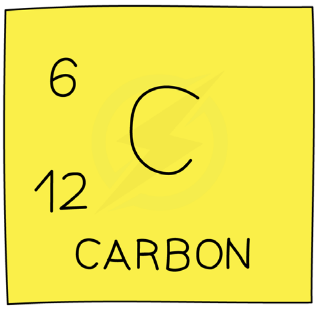
3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

Electrons (symbol e−)

- These subatomic particles move very fast around the nucleus
- They move in orbital paths called **shells**
- The mass of the electron is negligible, hence the mass of an atom is contained within the nucleus where the neutron and proton reside



The structure of the carbon atom



The symbol key for carbon as represented on the Periodic Table

EXAM TIP

Both the atomic number and the mass number are given on the Periodic Table but it can be easy to confuse them.

Think **MASS = MASSIVE**, as the mass number is **always** the bigger of the two numbers, the other smaller one is thus the atomic / proton number.

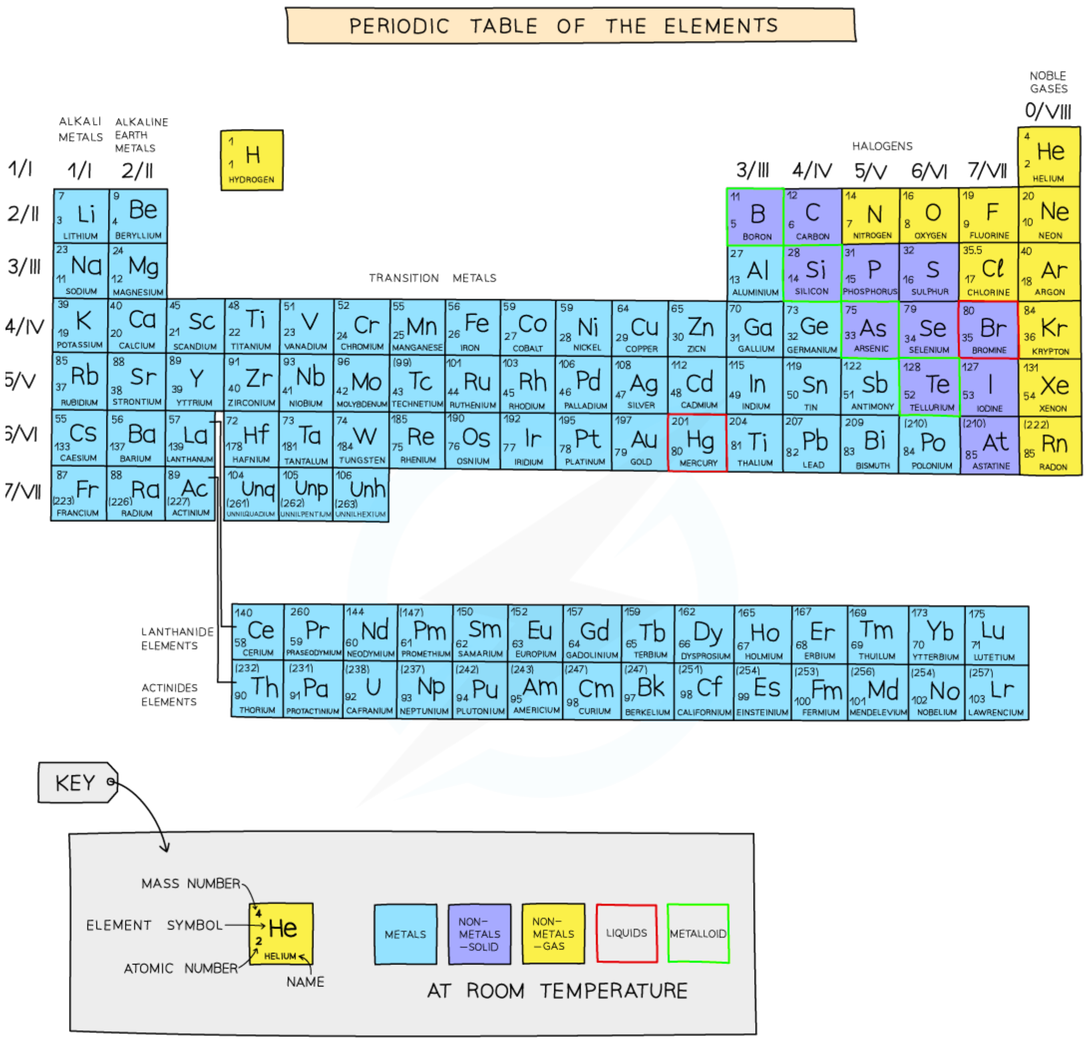
3 ATOMS, ELEMENTS & COMPOUNDS

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

YOUR NOTES

The Basis of the Periodic Table

- Elements are arranged on the Periodic table in order of **increasing atomic number** where each element has one proton **more** than the element preceding it
- Hydrogen has 1 proton, helium has 2 protons, lithium has 3 etc
- The table is arranged in vertical columns called **Groups** numbered I – VIII and in rows called **Periods**
- Elements in the same group have the same amount of electrons in their **outer shell**, which gives them **similar chemical properties**



3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

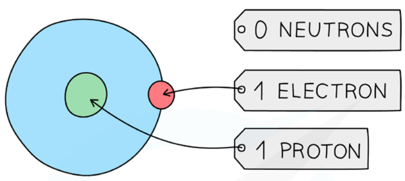
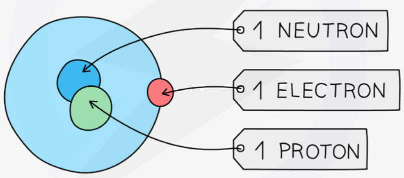
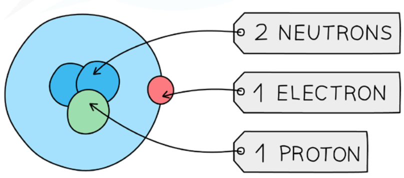
EXAM TIP

The proton number is **unique** to each element and could be considered as an element's "fingerprint".

Electrons come and go during chemical processes but the proton number doesn't change.

Defining Isotopes

- Isotopes are atoms of the **same element** that contain the same number of **protons** and electrons but a different number of **neutrons**
- The symbol for an isotope is the chemical symbol (or word) followed by a dash and then the mass number
- So C-14 is the isotope of carbon which contains 6 protons, 6 electrons and 14 – 6 = 8 neutrons

ISOTOPE	ATOMIC STRUCTURE	SYMBOL
HYDROGEN—1		$^{1}_{1}H$
HYDROGEN—2		$^{2}_{1}H$
HYDROGEN—3		$^{3}_{1}H$

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

YOUR NOTES

Types of Isotope

- Isotopes can be divided into two categories: **radioactive** and **non-radioactive**
- Radioactive isotopes (radioisotopes) are **unstable** due to the imbalance of neutrons and protons, which causes the nucleus to decay over time through **nuclear fission** and emit **radiation**. Examples of radioisotopes include tritium and carbon-14
- Decay occurs at a different rate for each isotope, but the time taken for the radioactivity of an isotope to decrease by 50% is **constant** for that particular isotope and is known as the **half-life**
- Radioactive isotopes have numerous medical and industrial uses
- Non-radioactive isotopes are stable atoms which really only differ in their mass

Uses of Radioactive Isotopes

Medical uses

- Radiation is extremely harmful and kills cells so isotopes are used to treat **cancer**. The isotope cobalt-60 is frequently used for this purpose
- **Medical tracers** as certain parts of the body absorb isotopes and others do not. In this way an isotope can be injected into the blood and its path through the body traced with a radiation-detecting camera, revealing the flow of blood through bodily systems
- Medical instruments and materials are routinely **sterilized** by exposure to radiation, which kills any bacteria present

Industrial uses

- **Radioactive dating** uses the carbon-14 isotope to date carbon-containing materials such as organic matter, rocks and other artefacts. The half-life of C-14 is 5730 years and so this technique is often used to date very old historical objects
- Similar to the medical use, radioactive tracers are deployed for detecting leaks in gas or oil pipes
- The radioactive isotope uranium-235 is used as **fuel** for controlled fission reactions in nuclear power plants

EXAM TIP

Radioactive decay is a random process which occurs inside the nucleus and is independent of temperature, pressure, pH etc.

It is a **nuclear** process and is not considered a chemical reaction.

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

YOUR NOTES

EXTENDED ONLY

Why Isotopes Share Properties

Isotopes of the same element display the **same chemical characteristics**.

This is because they have the same number of electrons in their outer shells and this is what determines an atoms chemistry.

The difference between isotopes is the neutrons which are neutral particles within the nucleus and add mass only.

Electron Build-Up & Structure

Electronic structure

- We can represent the structure of the atom in two ways: using diagrams called **electron shell diagrams** or by writing out a special notation called the **electronic configuration**

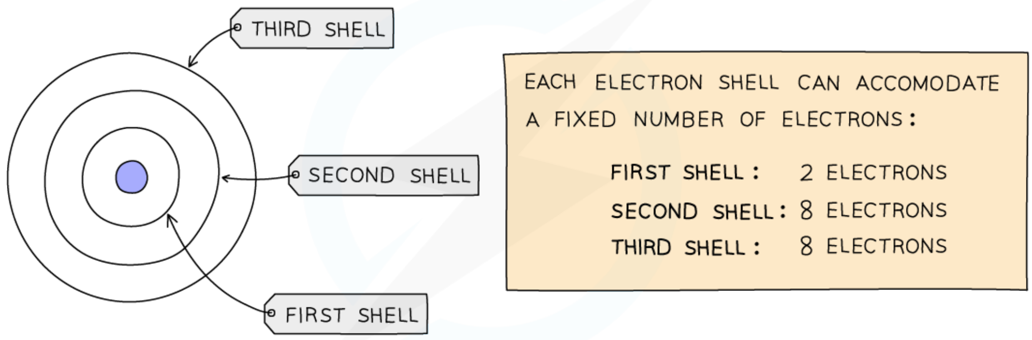
Electron shell diagrams

- Electrons orbit the nucleus in **shells** (or **energy levels**) and each shell has a different amount of energy associated with it
- The further away from the nucleus then the more energy a shell has
- Electrons occupy the shell closest to the nucleus which can hold only **2** electrons and which go in separately
- When a shell becomes full electrons then fill the next shell
- The second shell can hold **8** electrons and the third shell can hold **18** electrons and the electrons organise themselves in pairs in these shells
- The outermost shell of an atom is called the **valence** shell and an atom is much more stable if it can manage to completely fill this shell with electrons

3 ATOMS, ELEMENTS & COMPOUNDS

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

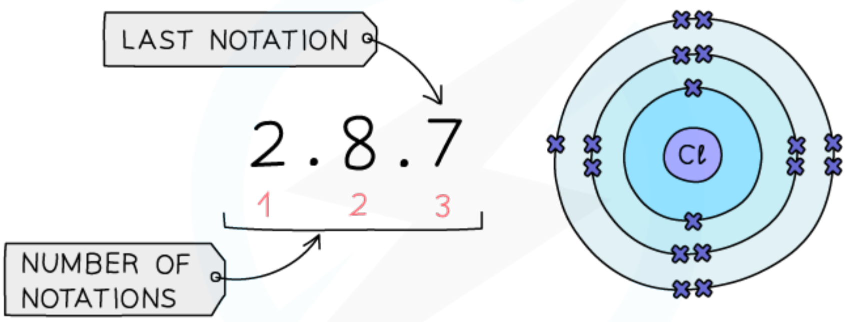
YOUR NOTES



The electron shells

Electronic configuration

- The arrangement of electrons in shells can also be explained using numbers
- There is a clear **relationship** between the outer shell electrons and how the Periodic Table is designed
- The number of notations in the electronic configuration will show the number of shells of electrons the atom has, showing the **Period** in which that element is in
- The last notation shows the number of outer electrons the atom has, showing the **Group** that element is in
- Elements in the **same Group** have the **same** number of outer **shell electrons**



The electronic configuration for chlorine

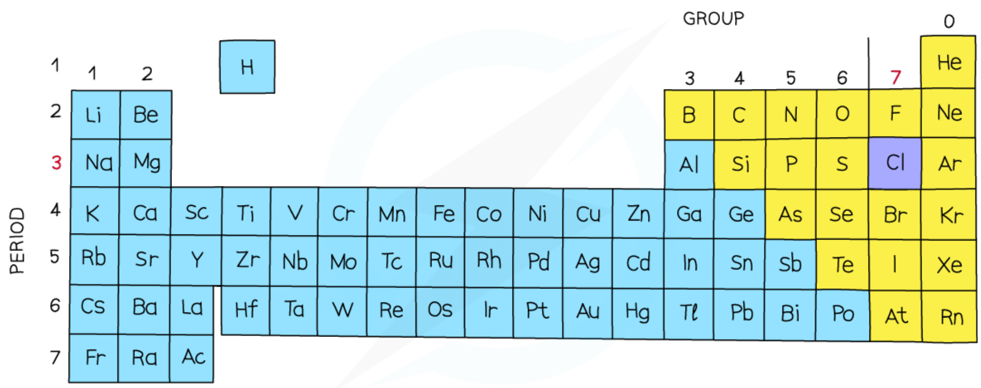
3 ATOMS, ELEMENTS & COMPOUNDS

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

YOUR NOTES

Period: The red numbers at the bottom show the number of notations, which is 3, showing that a chlorine atom has 3 shells of electrons.

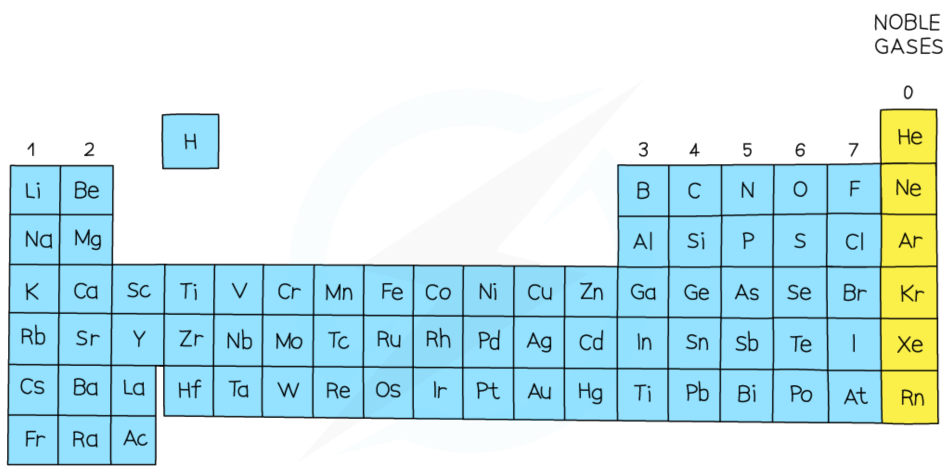
Group: The green box highlights the last notation, which is 7, showing that a chlorine atom has 7 outer electrons.



The position of chlorine on the Periodic Table

The noble gases

- The atoms of the Group 8/0 elements all have 8 electrons in their outer shells, with the exception of helium which has 2. But since helium has only 2 electrons in total and thus the first shell is full (which is the only shell), it is thus the outer shell so helium also has a full valency shell
- All of the noble gases are **unreactive** as they have full outer shells and are thus very stable
- All elements wish to fill their outer shells with electrons as this is a much more stable and desirable configuration



The noble gases are on the Periodic Table in Group 8/0

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.1.1 ATOMIC STRUCTURE & THE PERIODIC TABLE cont...

Electronic configuration of the first twenty elements:

ELEMENT	ATOMIC NUMBER	ELECTRONIC CONFIGURATION
HYDROGEN	1	1
HELIUM	2	2
LITHIUM	3	2,1
BERYLLIUM	4	2,2
BORON	5	2,3
CARBON	6	2,4
NITROGEN	7	2,5
OXYGEN	8	2,6
FLUORINE	9	2,7
NEON	10	2,8
SODIUM	11	2,8,1
MAGNESIUM	12	2,8,2
ALUMINIUM	13	2,8,3
SILICON	14	2,8,4
PHOSPHORUS	15	2,8,5
SULFUR	16	2,8,6
CHLORINE	17	2,8,7
ARGON	18	2,8,8
POTASSIUM	19	2,8,8,1
CALCIUM	20	2,8,8,2

Note: although the third shell can hold up to 18 electrons, the filling of the shells follows a more complicated pattern after potassium and calcium. For these two elements, the third shell holds 8 and the remaining electrons (for reasons of stability) occupy the fourth shell first before filling the third shell.

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.1.2 BONDING: THE STRUCTURE OF MATTER

Types of Substance & Properties

Elements, compounds & mixtures

- All substances can be classified into one of these three types

Element

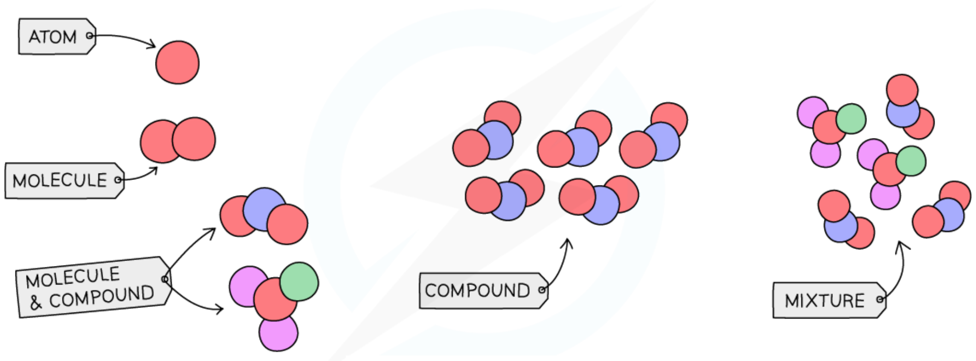
- A substance made of atoms that all contain the **same number of protons** (one type of atom) and cannot be split into anything simpler
- There is a **limited** number of elements and all elements are found on the Periodic Table
- E.g. hydrogen, carbon, nitrogen

Compound

- A pure substance made up of two or more elements **chemically combined** together
- There is an **unlimited** number of compounds
- Compounds cannot be separated into their elements by physical means
- E.g. copper (II) sulphate ($CuSO_4$), calcium carbonate (CaCO3), carbon dioxide (CO_2)

Mixture

- A combination of two or more substances (elements and/or compounds) that are **not** chemically combined
- Mixtures can be separated by **physical methods** such as filtration or evaporation
- E.g. sand and water, oil and water, sulphur powder and iron filings



Elements, compounds and mixtures

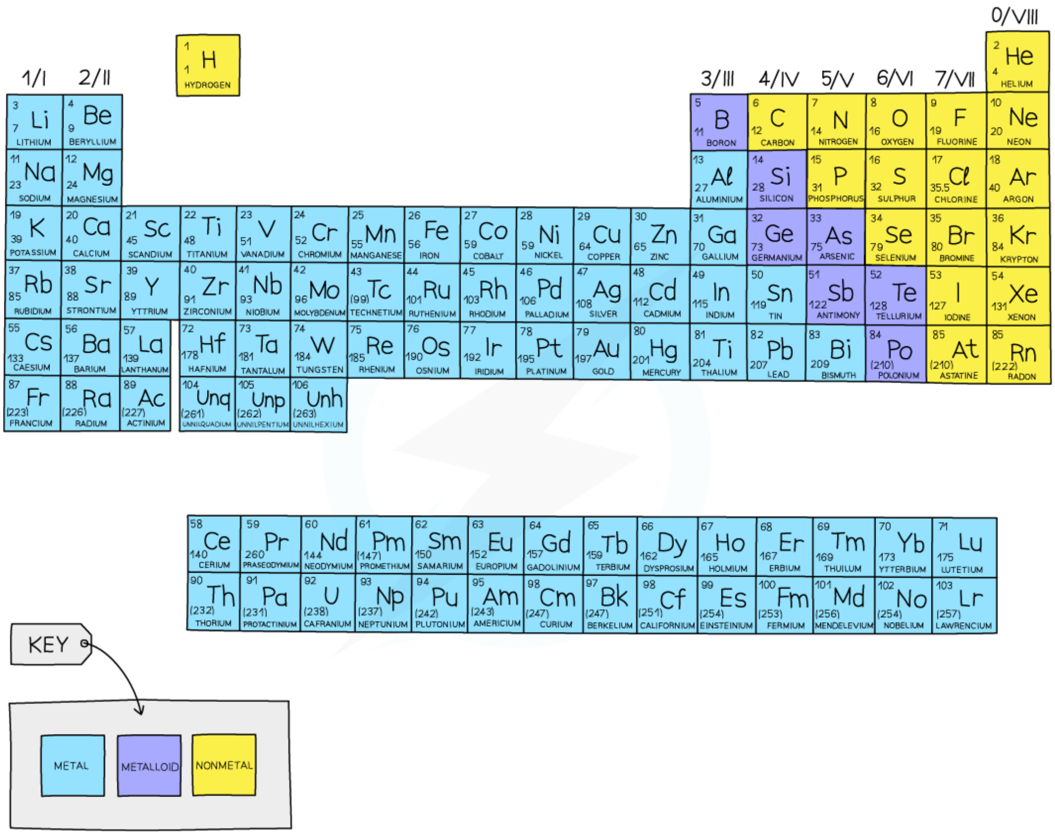
Metals & nonmetals

- The Periodic Table contains over 100 different elements
- They can be divided into two broad types: metals and nonmetals
- Most of the elements are metals and a small number of elements display properties of both types. These elements are called metalloids or semimetals.

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.1.2 BONDING: THE STRUCTURE OF MATTER



The metallic character diminishes moving left to right across the Periodic Table

Properties of metals

- Conduct **heat** and **electricity**
- Are **malleable** and **ductile** (can be hammered and pulled into different shapes)
- Tend to be **lustrous** (shiny)
- Have **high** density and usually have **high** melting points
- Form **positive** ions through electron loss
- Form **basic oxides**

Properties of nonmetals

- Do **not** conduct heat and electricity
- Are **brittle** and delicate when solid and easily break up
- Tend to be dull and nonreflective
- Have **low** density and **low** melting points (many are gases at room temperature)
- Form **negative** ions through electron gain (except for hydrogen)
- Form **acidic oxides**

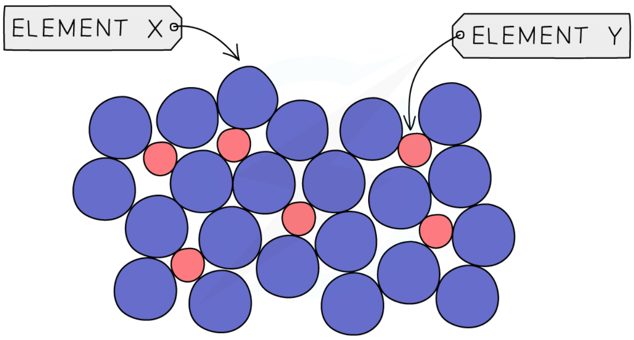
3 ATOMS, ELEMENTS & COMPOUNDS

3.1.2 BONDING: THE STRUCTURE OF MATTER

YOUR NOTES

Describing Alloys

- Alloys are **mixtures** of metals, where the metals are mixed together but are not chemically combined
- They can be made from metals mixed with nonmetals such as carbon
- Alloys often have **properties** that can be very **different** to the metals they contain, for example they can have more **strength**, **hardness** or **resistance** to **corrosion** or extreme **temperatures**
- Alloys contain atoms of **different** sizes, which **distorts** the regular arrangements of atoms
- This makes it more difficult for the layers to **slide** over each other, so they are usually much harder than the pure metal
- Brass is a common example of an alloy which contains 70% copper and 30% zinc



Particle diagram showing a mixture of elements in an alloy

> NOW TRY SOME EXAM QUESTIONS

3 ATOMS, ELEMENTS & COMPOUNDS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which option correctly describes the relative charges and masses of the subatomic particles?

	Proton	Neutron	Electron	Relative mass of proton
A	+1	0	0	0.00054
B	0	+1	+1	1
C	0	+1	-1	0.00054
D	+1	0	-1	1

QUESTION 2

The structure of four particles is described in the table.

Particle	Number of protons	Number of neutrons	Number of electrons
LI	3	X	3
LI+	3	4	2
F	Y	10	9
F-	9	10	Z

What are the correct values for X, Y and Z?

	X	Y	Z
A	4	7	9
B	3	9	9
C	4	9	10
D	3	7	10

3 ATOMS, ELEMENTS & COMPOUNDS

EXAM QUESTIONS

YOUR NOTES

? QUESTION 3

The atomic number of element Q is 9 and its mass number is 19.

In which group of the Periodic Table should element Q be placed?

A Group 0

B Group I

C Group VII

D Group II

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for more questions and revision notes

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.2 IONS & IONIC BONDS

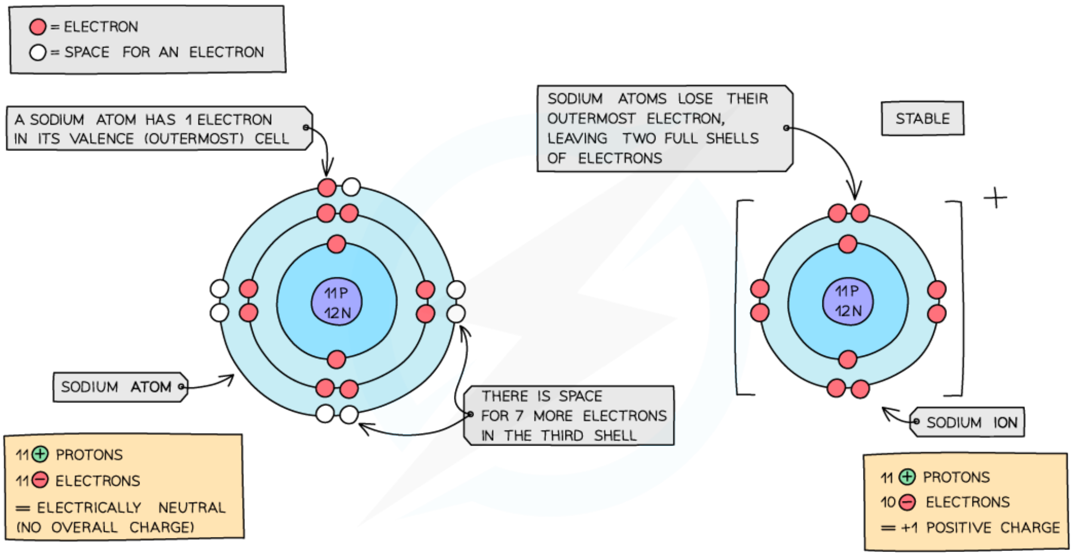
The Formation of Ions

Ions

- An ion is an **electrically charged** atom or a group of atoms formed by the **loss** or **gain** of **electrons**
- This loss or gain of electrons takes place to gain a **full outer shell** of electrons
- The electronic structure of an ion will be the same as that of a noble gas – such as helium, neon and argon

Ionisation of metals & non-metals

- **Metals:** all metals lose electrons to another atom and become positively charged ions
- **Non-metals:** all non-metals **gain** electrons from another atom to become negatively charged ions

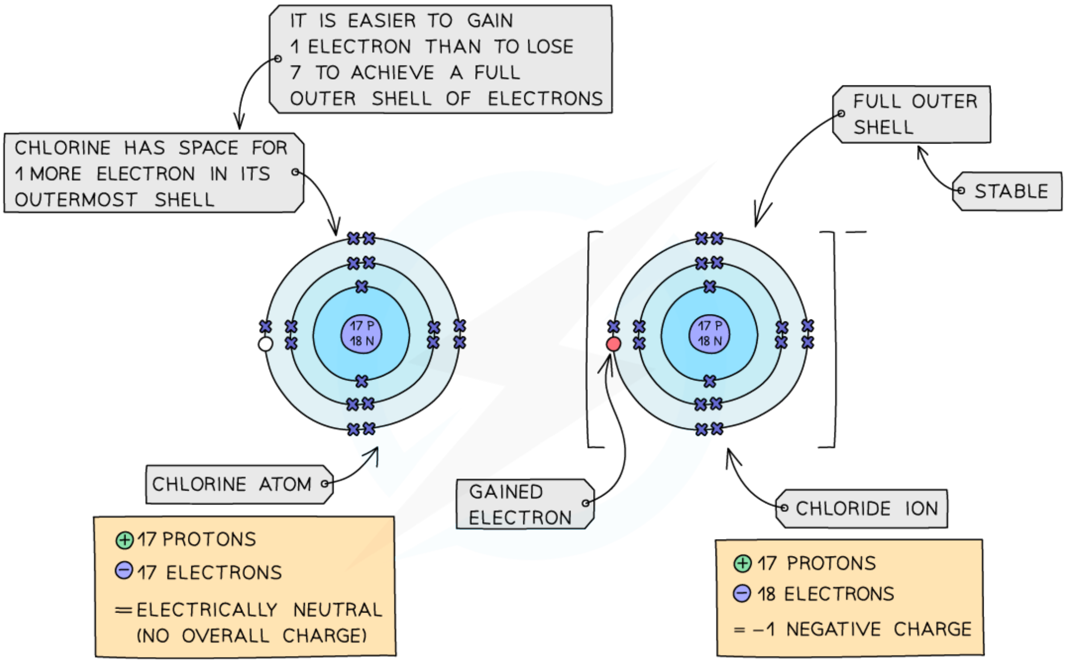


Formation of positively charged Sodium ion

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.2 IONS & IONIC BONDS cont...

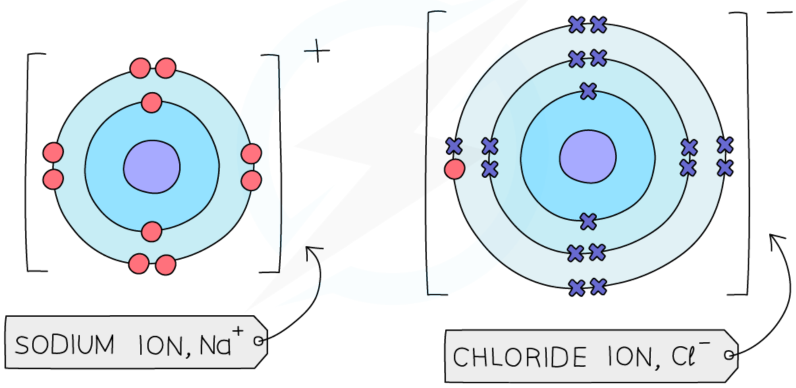


Formation of negatively charged Chloride ion

Electrostatic attraction

- The positive and negative charges are held together by the strong **electrostatic forces of attraction** between **opposite** charges
- This is what holds ionic compounds together

IONIC BONDING IN SODIUM CHLORIDE



Electrostatic forces between the positive Na ion & negative Cl ion

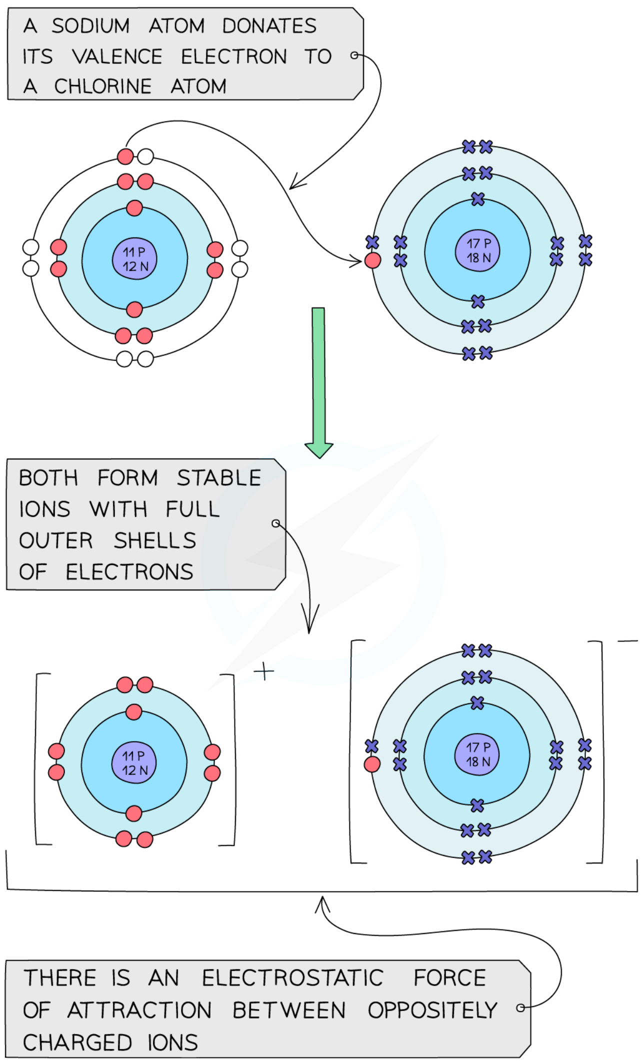
3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.2 IONS & IONIC BONDS cont...

The Formation of Ionic Bonds, Groups I to VII

Example: Sodium Chloride, NaCl



Explanation

- Sodium is a group 1 metal so will lose one outer electron to another atom to gain a full outer shell of electrons
- A positive ion with the charge +1 is formed
- Chlorine is a group 7 non-metal so will need to gain an electron to have a full outer shell of electrons
- One electron will be transferred from the outer shell of the Sodium atom to the outer shell of the Chlorine atom
- Chlorine atom will gain an electron to form a negative ion with charge -1

Formula of Ionic Compound: NaCl

3 ATOMS, ELEMENTS & COMPOUNDS

3.2 IONS & IONIC BONDS cont...

YOUR NOTES

EXTENDED ONLY

Ionic Bonds between Metallic & Non-Metallic Elements

Example: Magnesium Oxide, MgO

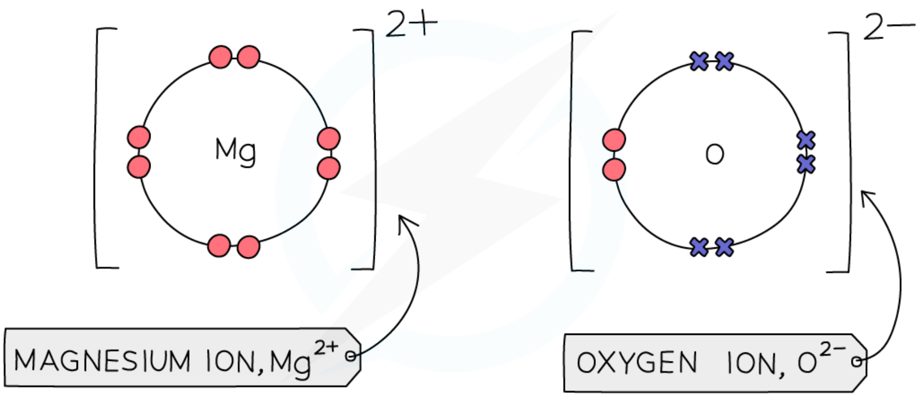


Diagram Showing the Dot-and-Cross Diagram of Magnesium Oxide

Explanation

- Magnesium is a group 2 metal so will lose two outer electrons to another atom to have a full outer shell of electrons
- A positive ion with the charge +2 is formed
- Oxygen is a group 6 non-metal so will need to gain two electrons to have a full outer shell of electrons
- Two electrons will be transferred from the outer shell of the Magnesium atom to the outer shell of the Oxygen atom
- Oxygen atom will gain two electrons to form a negative ion with charge -2

Formula of Ionic Compound: MgO

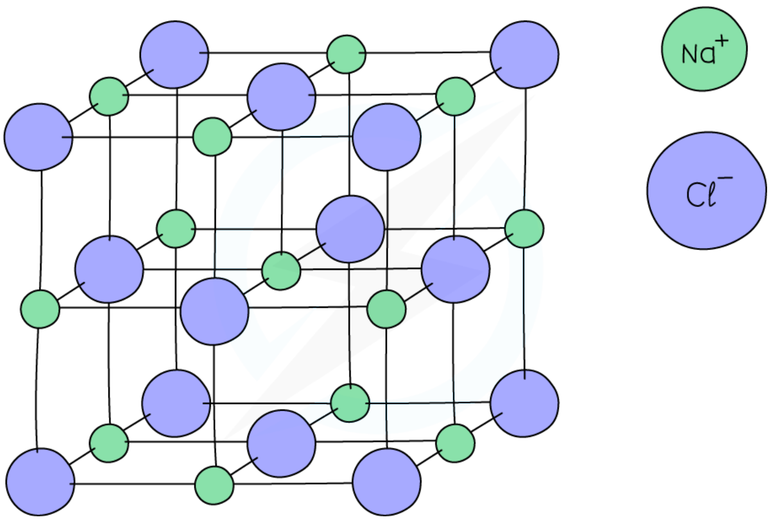
3.2 IONS & IONIC BONDS cont...

YOUR NOTES

EXTENDED ONLY cont...

The Lattice Structure of Ionic Compounds

- Lattice structure refers to the arrangement of the atoms of a substance in 3D space
- In these structures the atoms are arranged in an **ordered** and **repeating** fashion
- The lattices formed by ionic compounds consist of a **regular arrangement** of **alternating** positive and negative ions



The lattice structure of NaCl

> NOW TRY SOME EXAM QUESTIONS

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

EXAM QUESTIONS

QUESTION 1

What change occurs to an atom when it forms a negative ion?

A It loses electrons.

B It gains protons.

C It gains electrons.

D It loses protons.

QUESTION 2

Which element does not form a stable ion with the same electronic configuration as neon?

A Magnesium

B Fluorine

C Sodium

D Chlorine

QUESTION 3

Calcium reacts with fluorine to form calcium fluoride.
Which statement describes what happens to calcium atoms in this reaction?

A Calcium ions lose electrons to form positive charges. .

B ms gain 3 electrons to form positive ions.

C Calcium ions gain 2 electrons to form positive ions.

D Calcium atoms lose 2 electrons to form positive ions.

> CHECK YOUR ANSWERS AT SAVEMYEXAMS.CO.UK

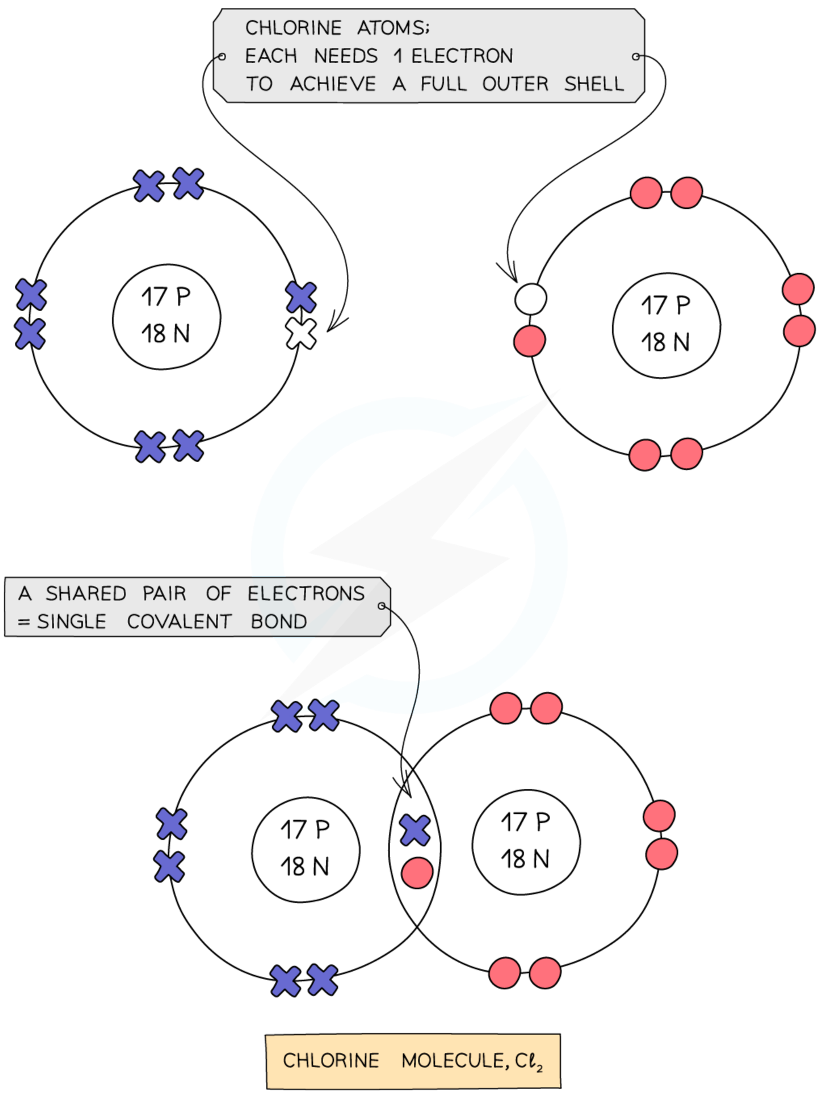
3.3 MOLECULES & COVALENT BONDS

YOUR NOTES

Single Covalent Bonds

Covalent compounds

- Covalent compounds are formed when electrons are **shared** between atoms
- Only **non-metal elements** participate in covalent bonding
- As in ionic bonding, each atom gains a **full outer shell** of electrons
- When two or more atoms are chemically bonded together, we describe them as 'molecules'



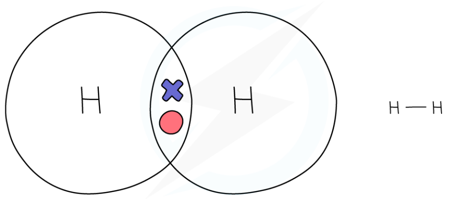
Covalent bonding in non–metals

3 ATOMS, ELEMENTS & COMPOUNDS

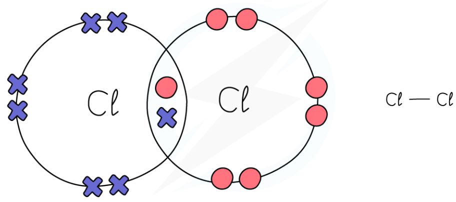
3.3 MOLECULES & COVALENT BONDS cont...

YOUR NOTES

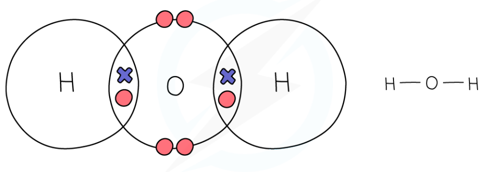
Hydrogen:



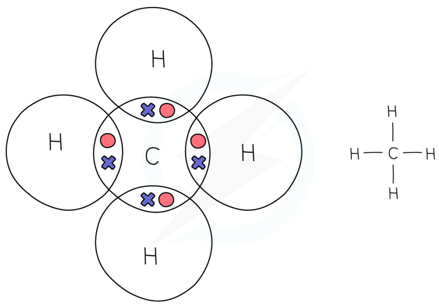
Chlorine:



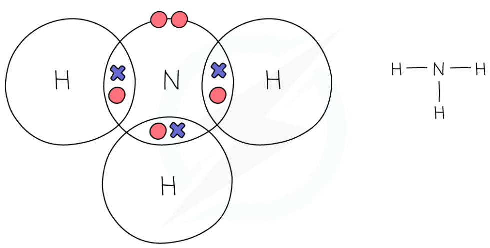
H_2O:



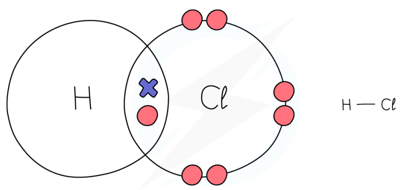
CH_4 (methane):



NH_3 (ammonia):



HCl:



Ionic & Covalent Compounds

Ionic compounds:

- Have **high melting** and **boiling** points so ionic compounds are usually **solid** at room temperature
- **Not volatile** so they don't evaporate easily
- Usually **water soluble** as both ionic compounds and water are **polar** (see **polarity** in Glossary)
- Conduct electricity in **molten** state or in **solution** as they have ions that can move and carry charge

3 ATOMS, ELEMENTS & COMPOUNDS

3.3 MOLECULES & COVALENT BONDS cont...

YOUR NOTES

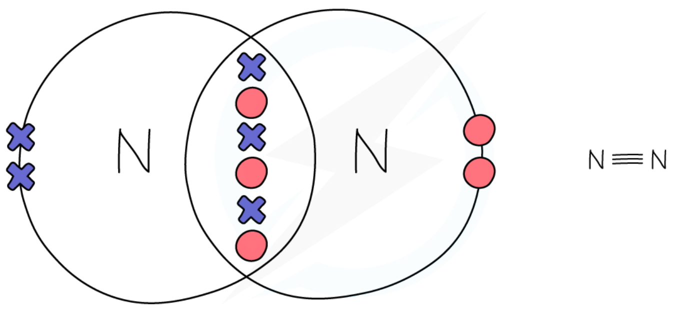
Covalent compounds:

- Have **low melting** and **boiling** points so covalent compounds are usually **liquids** or **gases** at room temperature
- **Usually volatile** which is why many covalent organic compounds have distinct aromas
- Usually not water soluble as covalent compounds tend to be **nonpolar** but can dissolve in **organic solvents**
- Cannot conduct electricity as all electrons are involved in bonding so there are no free electrons or ions to carry the charge

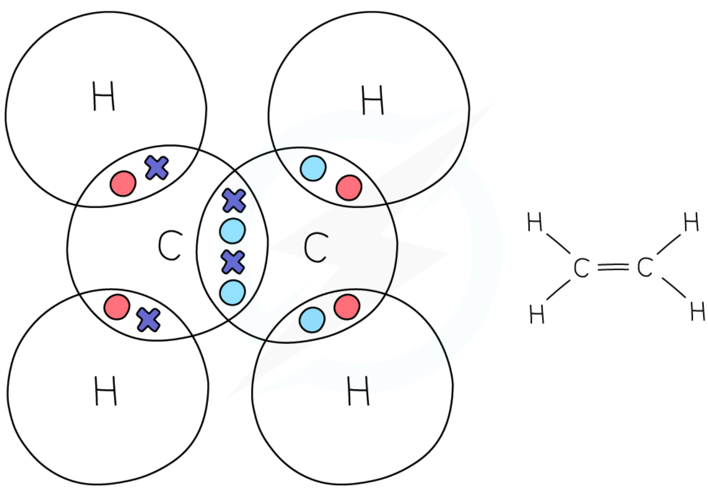
EXTENDED ONLY

Electron Arrangement in Complex Covalent Molecules

Nitrogen:



C_2H_4 (ethene):



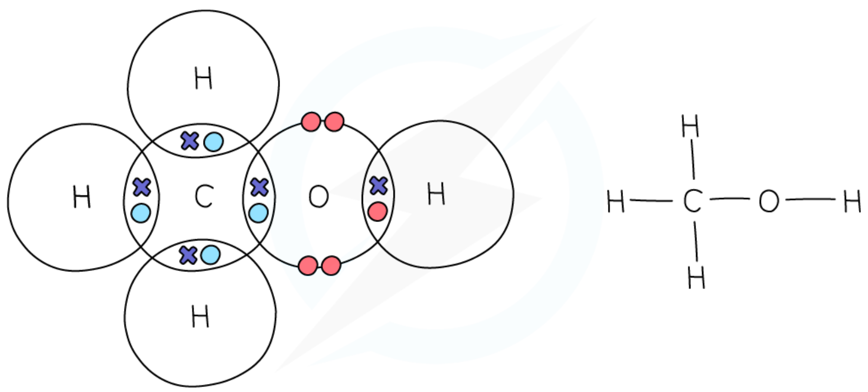
3 ATOMS, ELEMENTS & COMPOUNDS

3.3 MOLECULES & COVALENT BONDS cont...

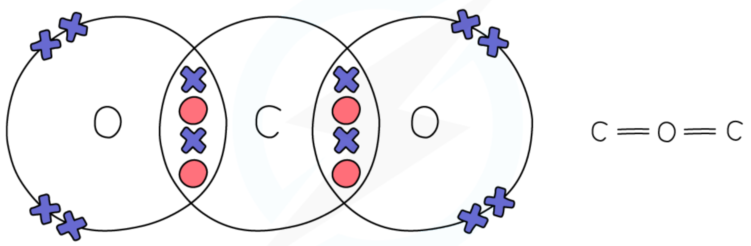
YOUR NOTES

EXTENDED ONLY cont...

CH_3OH (methanol):



CO_2:



Melting & Boiling Points of Ionic & Covalent Compounds

- Ionic compounds have **high** melting and boiling points
- This is because the ions in the lattice structure are attracted to each other by **strong electrostatic forces** which hold them firmly in place
- **Large** amounts of energy are needed to overcome these forces so the m.p. and b.p. are high
- Covalent substances have very strong covalent bonds **between** the atoms, but much **weaker intermolecular forces** holding the molecules together
- When one of these substances melts or boils, it is these weak **intermolecular forces** that break, not the strong covalent bonds
- So less energy is needed to break the molecules apart so they have **lower** m.p. and b.p than ionic compounds

> NOW TRY SOME EXAM QUESTIONS

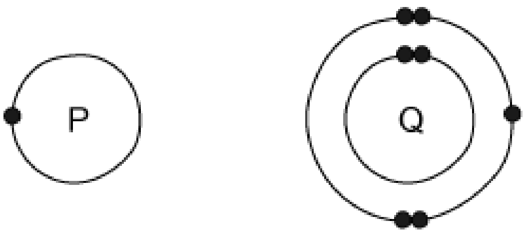
3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

EXAM QUESTIONS

QUESTION 1

Atoms P and Q have electronic structures as shown in the diagram. They react together to form a covalent compound.



What is the formula of the compound?

A P_2Q_3

B P_3Q

C P_3Q_2

D PQ_4

QUESTION 2

The atom of element Z has 6 electrons in its outer shell. How would this element react?

A It shares two electrons with four from another atom to form two covalent bonds

B It shares four electrons with four from another atom to form four covalent bonds

C It shares four electrons with two from another atom to form two covalent bonds

D It shares two electrons with two from another atom to form two covalent bonds

YOUR NOTES

EXAM QUESTIONS

QUESTION 3

Which of the following compounds are formed by covalent bonding?

1 Potassium fluoride

2 Propane

3 Carbon dioxide

4 Lithium bromide

A 2 and 3 **B** 2 and 4 **C** 1, 2 and 3 **D** 1 and 4

3 ATOMS, ELEMENTS & COMPOUNDS

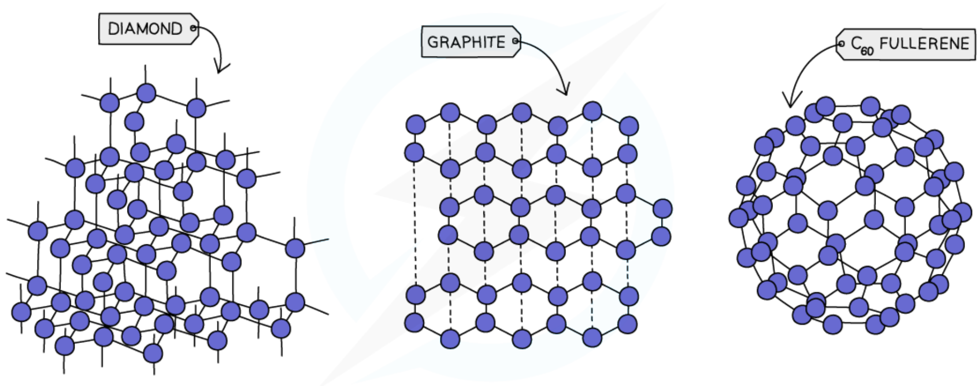
3.4 MACROMOLECULES & METALLIC BONDING

3.4.1 MACROMOLECULES

YOUR NOTES

Giant Covalent Structures

- Diamond and graphite are **allotropes** of carbon which have **giant covalent structures**
- These classes of substance contain a lot of non-metal atoms, each joined to adjacent atoms by covalent bonds forming a giant lattice structure
- Giant covalent structures have **high** melting and boiling points as they have many strong covalent bonds that need to be broken down
- Large amounts of heat energy are needed to overcome these forces and break down bonds



Diamond, graphite & fullerene are examples of Giant Covalent Structures

Uses of Giant Covalent Structures

Diamond

- Each carbon atom bonds with four other carbons, forming a **tetrahedron**
- All the covalent bonds are identical and strong with no weak **intermolecular forces**
- Diamond thus:
  - Does not conduct electricity
  - Has a very high melting point
  - Is extremely hard and dense (3.51 g/cm^3)
- Diamond is used in **jewellery** and as **cutting tools**
- The cutting edges of discs used to cut bricks and concrete are tipped with diamonds
- Heavy-duty drill bits and tooling equipment are also diamond tipped

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.4.1 MACROMOLECULES cont...

Graphite

- Each carbon atom is bonded to **three** others forming **layers** of hexagonal shaped forms, leaving one free electron per carbon atom
- These free electrons exist **in between** the layers and are free to move and carry charge, hence graphite can conduct electricity
- The covalent bonds within the layers are very strong but the layers are connected to each other by weak **intermolecular forces** only, hence the layers can **slide** over each other making graphite **slippery** and **smooth**
    - Graphite thus
    - Conducts electricity
    - Has a very high melting point
- Is soft and slippery, less dense than diamond (2.25 g/cm^3)
- Graphite is used in **pencils** and as an industrial **lubricant**, in engines and in locks
- It is also used to make non-reactive **electrodes** for **electrolysis**.

EXTENDED ONLY

The Structure of Silicon(IV) Oxide (Silicon Dioxide)

- SiO_2 is a macromolecular compound which occurs naturally as **sand** and **quartz**
- Each oxygen atom forms covalent bonds with **2** silicon atoms and each silicon atom in turn forms covalent bonds with **4** oxygen atoms
- A tetrahedron is formed with one silicon atom and four oxygen atoms, similar as in diamond

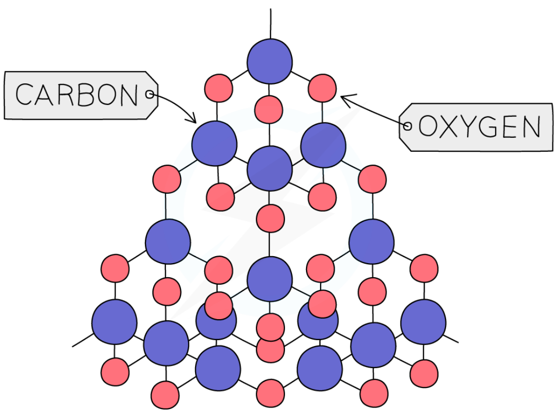


Diagram showing the structure of SiO2 with the silicon atoms in dark grey and the oxygen atoms in red

3 ATOMS, ELEMENTS & COMPOUNDS

YOUR NOTES

3.4.1 MACROMOLECULES cont...

EXTENDED ONLY cont...

Diamond & Silicon(IV) Properties

- SiO_2 has lots of very strong covalent bonds and no intermolecular forces so it has similar properties as diamond
- It is very **hard**, has a very **high** boiling point, is insoluble in water and does not conduct electricity
- SiO_2 is cheap since it is available naturally and is used to make sandpaper and to line the inside of furnaces.

3.4.2 METALLIC BONDING

EXTENDED ONLY

Electrical Conductivity & Malleability of Metals

- Metal atoms are held together strongly by metallic bonding
- Within the metal lattice, the atoms lose their valence electrons and become positively charged
- The valence electrons no longer belong to any metal atom and are said to be **delocalised**
- They move freely between the positive metal ions like a sea of electrons
- Metallic bonds are strong and are a result of the attraction between the positive metal ions and the negatively charged delocalised electrons

3 ATOMS, ELEMENTS & COMPOUNDS

3.4.2 METALLIC BONDING cont...

YOUR NOTES

EXTENDED ONLY cont...

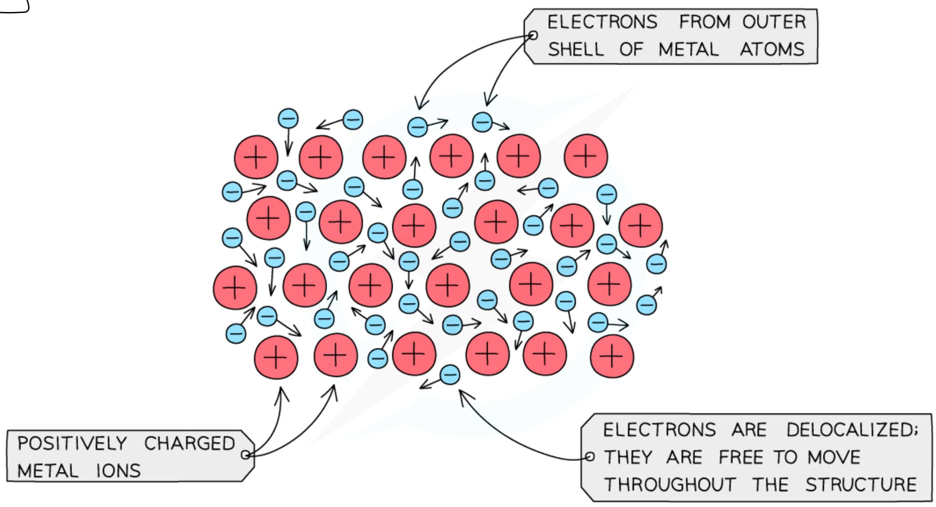


Diagram showing Metallic Lattice structure with delocalised electrons

The link between metallic bonding and the properties of metals:

- Metals have **high** melting and boiling points:
    - There are many **strong metallic bonds** in giant metallic structures
    - A lot of heat energy is needed to overcome forces and break these bonds
- Metals **conduct** electricity:
    - There are **free electrons** available to move and carry charge
    - Electrons entering one end of the metal cause a delocalised electron to displace itself from the other end
    - Hence electrons can flow so electricity is conducted
- Metals are **malleable** and **ductile**:
    - Layers of positive ions can **slide** over one another and take up different positions
    - Metallic bonding is not disrupted as the valence electrons do not belong to any particular metal atom so the delocalised electrons will move with them
    - Metallic bonds are thus not broken and as a result metals are strong but **flexible**
    - They can be hammered and bent into different shapes without breaking

> NOW TRY SOME EXAM QUESTIONS

YOUR NOTES

EXAM QUESTIONS

QUESTION 1

Which of the following statements about graphite and diamond are incorrect?

1 They are allotropes of carbon.

2 They both conduct electricity.

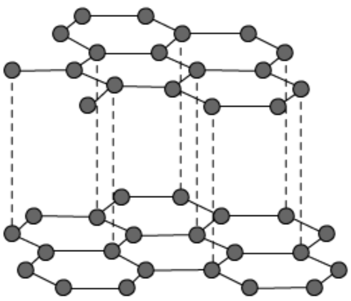
3 They form different numbers of bonds within their structures.

4 They have different uses.

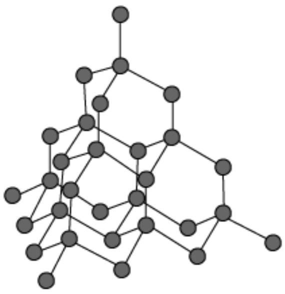
A 2 and 3 **B** 2 only **C** 1, 3 and 4 **D** 2 and 4

QUESTION 2

The structures of two solids X and Y are shown below.



X



Y

	X	Y
A	industrial lubricating	glass cutters
B	industrial lubricating	industrial lubricating
C	glass cutters	industrial lubricating
D	glass cutters	glass cutters

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Which statement correctly describes the structure of macromolecules?

A Giant molecular crystal which is held together by weak intermolecular forces.

B Giant molecular crystal which is held together by strong ionic bonds.

C Giant molecular crystal which is held together by weak metallic bonds.

D Giant molecular crystal which is held together by strong covalent bonds.

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4 STOICHIOMETRY

YOUR NOTES

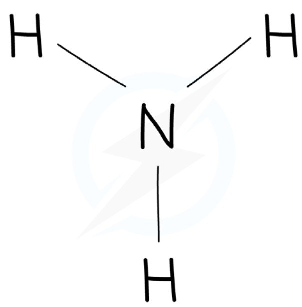
CONTENTS:

4.1 STOICHIOMETRY

Symbols & Formulae of Elements & Compounds

Element symbols

- Each element is represented by its own unique symbol as seen on the Periodic Table e.g. H is hydrogen
- Where a symbol contains two letters, the first one is always in capital letters and the other is small e.g. sodium is Na, not NA
- Atoms combine together in fixed ratios that will give them full outer shells of electrons
- The chemical formula is what tells you the ratio of atoms
- E.g. H_2O is a compound containing 2 hydrogen atoms which combine with 1 oxygen atom
- The chemical formula can be deduced from the relative number of atoms present
- E.g. if a molecule contains 3 atoms of hydrogen and 1 atom of nitrogen then the formula would be NH_3
- Diagrams or models can also be used to represent the chemical formula



The ammonia molecule consists of a central nitrogen atom bonded to 3 hydrogen atoms

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

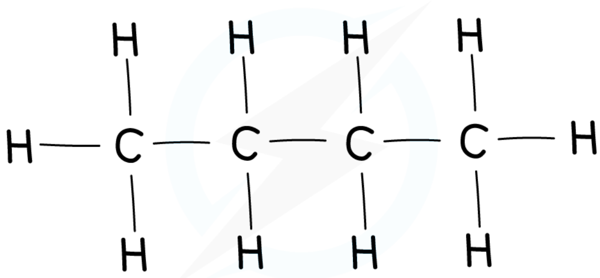
YOUR NOTES

Chemical formulae

- The **structural** formula tells you the way in which the atoms in a particular molecule are bonded. This can be done by either a **diagram** (displayed formula) or **written** (simplified structural formula)
- The **empirical** formula tells you the simplest whole number ratio of atoms in a compound
- The **molecular** formula tells you the actual number of atoms of each element in one molecule of the compound or element e.g. H_2 has 2 hydrogen atoms, HCl has 1 hydrogen atom and 1 chlorine atom

Example: Butane

- **Structural formula (displayed)**



- **Structural formula (simplified)**

$$CH_3CH_2CH_2CH_3$$

- **Molecular formula**

$$C_4H_{10}$$

- **Empirical formula**

$$C_2H_5$$

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

YOUR NOTES

Deducing formulae by combining power

- The concept of **valency** is used to deduce the formulae of compounds
- Valency or combing power tells you how many bonds an atom can make with another atom
- E.g. carbon is in Group IV so a single carbon atom can make 4 single bonds or 2 double bonds

The following valencies apply to elements in each group:

GROUP	VALENCY
I	1
II	2
III	3
IV	4
V	3
VI	2
VII	1
VIII	0

- We can use the combining power of each atom to work out a formula
- Example: what is the formula of aluminium sulfide?

Write out the symbols of each element and write their combining powers underneath:

Al S

3 2

- The formula is then calculated by cross multiplying each atom with the number opposite, hence the formula for aluminium sulfide is Al_2S_3

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

EXTENDED ONLY

Deducing Formulae of Ionic Compounds

- The formulae of these compounds can be calculated if you know the charge on the ions
- Below are some common ions and their charges:

ION	FORMULA AND CHARGE
IRON(II)	Fe^{2+}
COPPER(II)	Cu^{2+}
CHROMIUM(III)	Cr^{3+}
AMMONIUM	NH^{4+}
HYDROXIDE	OH^-
NITRATE	NO_3^-
SULFATE	SO_4^{2-}
CARBONATE	CO_3^{2-}
HYDROGEN CARBONATE	HCO_3^-

- For ionic compounds you have to balance the charge of each part by multiplying each ion until the sum of the charges = 0
- Example: what is the formula of aluminium sulfate?
    - Write out the formulae of each ion, including their charges.
    - Al^{3}+ SO_4^{2}-
- Balance the charges by multiplying them out: Al^{3}+ x **2** = +6 and SO_4^{2}- x **3** = -6; so +6 – 6 = 0
- So the formula is $Al_2(SO_4)_3$

YOUR NOTES

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

YOUR NOTES

Writing Word Equations & Balanced Equations

Word equations

- These show the reactants and products of a chemical reaction using their full chemical names
- The arrow (which is spoken as "goes to" or "produces") implies the conversion of reactants into products
- Reaction conditions or the name of a catalyst can be written above the arrow

Names of compounds

For compounds consisting of 2 atoms:

- If one is a **metal** and the other a **nonmetal**, then the name of the metal atom comes first and the ending of the second atom is replaced by adding –**ide**
  - E.g. NaCl which contains sodium and chlorine thus becomes sodium chlor**ide**
- If both atoms are **nonmetals** and one of those is **hydrogen**, then hydrogen comes first
  - E.g. hydrogen and chlorine combined is called hydrogen chlor**ide**
- For other combinations of nonmetals as a general rule, the element that has a lower Group number comes first in the name
  - E.g. carbon and oxygen combine to form CO_2 which is carbon dioxide since carbon is in Group 4 and oxygen in Group 6

For compounds that contain certain groups of atoms:

- There are **common** groups of atoms which occur regularly in chemistry
- Examples include the carbonate ion(CO_3^{2-}), sulfate ion (SO_4^{2-}), hydroxide ion (OH^-) and the nitrate ion (NO_3^-)
- When these ions form a compound with a metal atom, the name of the **metal** comes **first**
  - E.g. KOH is potassium hydroxide, $CaCO_3$ is calcium carbonate

Writing & balancing chemical equations

- These use the chemical symbols of each reactant and product
- When balancing equations, there needs to be the **same number of atoms** of each element on either side of the equation
- The following nonmetals must be written as molecules: H_2, N_2, O_2, F_2, Cl_2, Br_2 and I_2
- Work across the equation from left to right, checking one element after another
- If there is a group of atoms, for example a nitrate group (NO_3^-) that has not changed from one side to the other, then count the whole group as one entity rather than counting the individual atoms. For example:
  - $NaOH + HCl \rightarrow NaCl + H_2O$
  - There are equal numbers of each atom on either side of the reaction arrow so the equation is balanced

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

EXTENDED ONLY

Equations with State Symbols & Deducing Balanced Equations

Using state symbols:

State symbols are written after formulae in chemical equations to show which physical state each substance is in:

SOLID	LIQUID	GAS	AQUEOUS
(s)	(l)	(g)	(aq)

Example 1:

Aluminium (s) + Copper (II) Oxide (s) → Aluminium Oxide (s) + Copper (s)

Unbalanced symbol equation:

$$Al + CuO \rightarrow Al_2O_3 + Cu$$

ALUMINIUM: There is 1 aluminium atom on the left and 2 on the right so if you end up with 2, you must start with 2. To achieve this, it must be 2Al

$$2Al + CuO \rightarrow Al_2O_3 + Cu$$

OXYGEN: There is 1 oxygen atom on the left and 3 on the right so if you end up with 3, you must start with 3. To achieve this, it must be 3CuO.

$$2Al + 3CuO \rightarrow Al_2O_3 + Cu$$

COPPER: There is 3 copper atoms on the left and 1 on the right. The only way of achieving 3 on the right is to have 3Cu

$$2Al + 3CuO \rightarrow Al_2O_3 + 3Cu$$

Example 2:

Magnesium Oxide (s) + Nitric Acid (aq) → Magnesium Nitrate (aq) + Water (l)

Unbalanced symbol equation:

$$MgO + HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$$

MAGNESIUM: There is 1 magnesium atom on the left and 1 on the right so there are equal numbers of magnesium atoms on both sides so these are kept the same

$$MgO + HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$$

YOUR NOTES

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

YOUR NOTES

EXTENDED ONLY cont...

OXYGEN: There is 1 oxygen atom on the left and 1 on the right so there is an equal number of oxygen atoms on both sides. It is therefore kept the same (remember that you are counting the nitrate group as separate group, so do not count the oxygen atoms in this group)

$$MgO + HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$$

HYDROGEN: There is 1 hydrogen atom on the left and 2 on the right. Therefore you must change HNO_3 to $2HNO_3$

$$MgO + 2HNO_3 \rightarrow Mg(NO_3)_2 + H_2O$$

Balancing ionic equations

- In aqueous solutions ionic compounds **dissociate** into their ions, meaning they separate into the component atoms or ions that formed them
- E.g. hydrochloric acid and potassium hydroxide dissociate as follows:

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

$$KOH \rightarrow K^+ + OH^-$$

- It is important that you can recognise common ionic compounds and their constituent ions
- These include:
    - Acids such as HCl and H_2SO_4
    - Group I and Group II hydroxides e.g. sodium hydroxide
    - Soluble salts e.g. potassium sulfate, sodium chloride
- Follow the example below to write **ionic equations**

Example: Write the ionic equation for the reaction of aqueous chlorine and aqueous potassium iodide.

- **Step 1:** Write out the full balanced the equation:

$$2KI(aq) + Cl_2(aq) \rightarrow 2KCl(aq) + I_2(aq)$$

- **Step 2:** Identify the ionic substances and write down the ions separately:

$$2K^+(aq) + 2I^-(aq) + Cl_2(aq) \rightarrow 2K^+(aq) + 2Cl^-(aq) + I_2(aq)$$

- **Step 3:** Rewrite the equation eliminating the ions which appear on both sides of the equation (spectator ions) which in this case are the K+ ions:

$$2I^-(aq) + Cl_2(aq) \rightarrow 2Cl^-(aq) + I_2(aq)$$

YOUR NOTES

4.1 STOICHIOMETRY cont...

EXAM TIP

When balancing equations you cannot change any of the formulae, only the amounts of each atom or molecule.

This is done by changing the numbers that go in front of each chemical species.

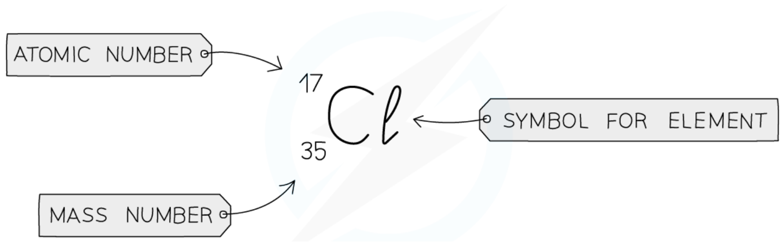
You need to be able to identify the products which are not ions in ionic equations.

These are usually molecules such as water or bromine but they may also be precipitated solids.

Relative Atomic Mass & Relative Molecular Mass

Relative Atomic mass

- The symbol for the relative atomic mass is Ar
- This is calculated from the mass number and relative abundances of all the isotopes of a particular element



Symbol, mass number and atomic number of chlorine

Equation:

$$A_r = \frac{\text{\% of isotope a} \times \text{mass of isotope a}) + (\text{\% of isotope b} \times \text{mass of isotope b})}{100}$$

- The top line of the equation can be extended to include the number of different isotopes of a particular element present

4 STOICHIOMETRY

4.1 STOICHIOMETRY cont...

YOUR NOTES

Example for Isotopes:

The Table shows information about the Isotopes in a sample of Rubidium

ISOTOPE	NUMBER OF PROTONS	NUMBER OF NEUTRONS	PERCENTAGE OF ISOTOPE IN SAMPLE
1	37	48	72
2	37	50	28

Use information from the table to calculate the relative atomic mass of this sample of Rubidium.

Give your answer to one decimal place:

$$(72 \times 85) + (28 \times 87) / 100 = 85.6$$

Relative formula (molecular) mass

- The symbol for the relative molecular mass is Mr and it refers to the total mass of the molecule
- To calculate the Mr of a substance, you have to add up the Relative Atomic Masses of all the atoms present in the formula

Example:

SUBSTANCE	ATOMS PRESENT	M_r
HYDROGEN (H_2)	$2 \times H$	$(2 \times 1) = 2$
WATER (H_2O)	$(2 \times H) + (1 \times O)$	$(2 \times 1) + 16 = 18$
POTASSIUM CARBONATE (K_2CO_3)	$(2 \times K) + (1 \times C) + (3 \times O)$	$(2 \times 39) + 12 + (3 \times 16) = 138$
CALCIUM HYDROXIDE ($Ca(OH)_2$)	$(1 \times Ca) + (2 \times O) + (2 \times H)$	$40 + (2 \times 16) + (2 \times 1) = 74$
AMMONIUM SULFATE ($(NH_4)_2SO_4$)	$(2 \times N) + (8 \times H) + (1 \times S) + (4 \times O)$	$(2 \times 14) + (8 \times 1) + 32 + (4 \times 16) = 132$

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A molecule contains carbon, hydrogen and oxygen. For every carbon atom there are twice as many hydrogen atoms but the same number of oxygen atoms.

What is the formula of the molecule?

A C2H6O

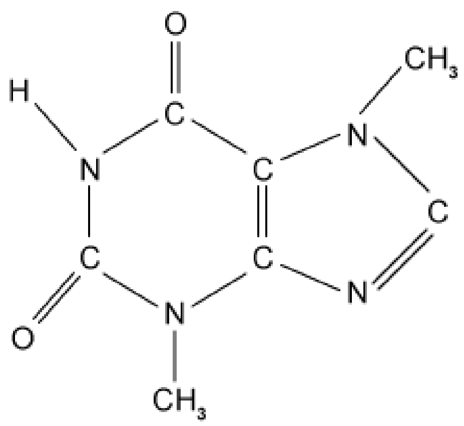
B C2H4O2

C C4H8O2

D C2H2O2

QUESTION 2

Theobromine is a stimulant found in chocolate and in tea leaves and is closely related to caffeine, the stimulant found in coffee.



Theobromine

What is the formula of theobromine?

A C6H5N4O2 **B** C7H8N4O2 **C** C7H8N3O2 **D** C7H7N4O2

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Hydrogen reacts with elements from Group VII to produce compounds called hydrogen halides. An example is when a molecule of hydrogen reacts with a molecule of fluorine to produce hydrogen fluoride.

What is the correct equation for the reaction?

A 2 H + 2 F → 2 HF

B H2 + F2 → H2F2

C 2 H + 2 F → H2F2

D H2 + F2 → 2 HF

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4 STOICHIOMETRY

4.2 THE MOLE CONCEPT

YOUR NOTES

EXTENDED ONLY

The Mole & Avogadro's Constant

The Mole

- This is the mass of substance containing the same number of fundamental units as there are atoms in exactly 12.000 g of ^{12}C
- The mole is the unit representing the amount of atoms, ions, or molecules
- One mole is the amount of a substance that contains **6.02 x 10^{23}** particles (Atoms, Molecules or Formulae) of a substance (6.02 x 10^{23} is known as the **Avogadro Number**)

Examples

- 1 mole of Sodium (Na) contains 6.02 x 10^{23} **Atoms** of Sodium
- 1 mole of Hydrogen (H2) contains 6.02 x 10^{23} **Molecules** of Hydrogen
- 1 mole of Sodium Chloride (NaCl) contains 6.02 x 10^{23} **Formula units** of Sodium Chloride

Linking the mole & the atomic mass

- One mole of any element is equal to the relative atomic mass of that element in grams
- For example one mole of carbon, that is if you had 6.02 x 10^{23} atoms of carbon in your hand, it would have a mass of 12g
- So one mole of helium atoms would have a mass of 4g, lithium 7g etc
- For a compound we add up the relative atomic masses
- So one mole of water would have a mass of 2 x 1 + 16 = 18g
- Hydrogen which has an atomic mass of 1 is therefore equal to 1/12 mass of a ^{12}C atom
- So one carbon atom has the same mass as 12 hydrogen atoms

The Mole & the Volume of Gases

Molar volume

- This is the volume that one mole of any gas (be it molecular such as CO_2 or monoatomic such as helium) will occupy
- Its value is 24dm^3 or 24,000 cm^3 at room temperature and pressure (r.t.p.)

Calculations Involving Gases

General Equation:

Amount of gas (mol) = (Volume of gas (dm^3) ÷ 24

or

Amount of gas (mol) = Volume of gas (cm^3) ÷ 24000

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

1. Calculating the volume of gas that a particular amount of moles occupies.

Equation:

Volume of Gas (dm^3) = Amount of Gas (mol) x 24

or

Volume of Gas (cm^3) = Amount of Gas (mol) x 24000

Example:

NAME OF GAS	AMOUNT OF GAS	VOLUME OF GAS
HYDROGEN	3 mol	(3 x 24) = 72 dm^3
CARBON DIOXIDE	0.25 mol	(0.25 x 24) = 6 dm^3
OXYGEN	5.4 mol	(5.4 x 24,000) = 129,600 cm^3
AMMONIA	0.02 mol	(0.02 x 24) = 0.48 dm^3

2. Calculating the moles in a particular volume of gas.

Equation:

Volume of Gas (dm^3) = Amount of Gas (mol) ÷ 24

or

Volume of Gas (cm^3) = Amount of Gas (mol) ÷ 24000

Example:

NAME OF GAS	VOLUME OF GAS	MOLES OF GAS
METHANE	225.6 dm^3	(225.6 : 24) = 9.4 mol
CARBON MONOXIDE	7.2 dm^3	(7.2 : 24) = 0.3 mol
SULFUR DIOXIDE	960 dm^3	(960 : 24) = 40 mol
OXYGEN	1200 cm^3	(1200 : 24000) = 0.05 mol

4 STOICHIOMETRY

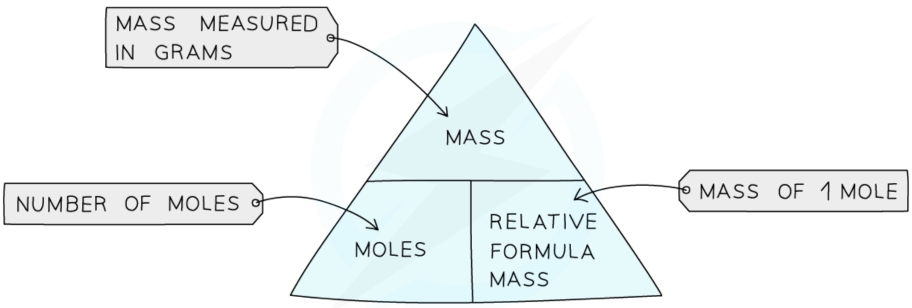
4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY

Calculating Reacting Masses, Solutions & Concentrations of Solutions in g/dm^3 & mol/dm^3

Calculating percentage composition, moles, mass & relative formula mass



Formula triangle for moles, mass and formula mass

1. Calculating moles

Equation:

Amount in Moles = Mass of Substance in grams ÷ M_r (or A_r)

Example:

SUBSTANCE	MASS	MR	AMOUNT
NaOH	80 g	40	(80 ÷ 40) = 2 moles
$CaCO_3$	25 g	100	(25 ÷ 100) = 0.25 moles
H_2SO_4	4.9 g	98	(4.9 ÷ 98) = 0.05 moles
H_2O	108 g	18	(108 ÷ 18) = 6 moles
$CuSO_4.5H_2O$	75 g	250	(75 ÷ 250) = 0.3 moles

2. Calculating mass

Equation:

Mass of Substance (grams) = Moles x M_r (or A_r)

4 STOICHIOMETRY

YOUR NOTES

4.2 THE MOLE CONCEPT cont...

EXTENDED ONLY cont...

Example:

SUBSTANCE	AMOUNT	MR	MASS
H_2O	0.5 moles	18	(0.5 x 18) = 9 g
NaCl	3 moles	58.5	(3 x 58.5) = 175.5 g
K_2CO_3	0.2 moles	138	(0.2 x 138) = 27.6 g
$(NH_4)2SO_4$	2.5 moles	132	(2.5 x 132) = 330 g
$MgSO_4.7H_2O$	0.25 moles	246	(0.25 x 246) = 61.5 g

3. Calculating Relative Formula Mass

Equation:

M_r (or A_r) = Mass of Substance in Grams ÷ Moles

Example:

10 moles of Carbon Dioxide has a Mass of 440 g. What is the Relative Formula Mass of Carbon Dioxide?

Relative Formula Mass = Mass ÷ Number of Moles

Relative Formula Mass = 440 ÷ 10 = 44

Relative Formula Mass of Carbon Dioxide = 44

4. Calculating Percentage Composition

- The percentage composition is found by calculating the percentage by mass of each particular element in a compound

Example:

Calculate the percentage of oxygen in CO_2

Step 1: Calculate the molar mass of the compound

Molar mass CO_2 = (2 x 16) + 12 = 44

Step 2: Add the atomic masses of the element required as in the question (oxygen)

16 + 16 = 32

Step 3: Calculate the percentage

% of oxygen in CO_2 = 32/44 x 100 = 72.7%

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

Calculations of solutions: moles, concentration & volume

General Equation:

$$\text{Concentration (mol / dm}^3\text{)} = \frac{\text{Amount of substance (mol)}}{\text{Volume of solution (dm}^3\text{)}}$$

This general equation is rearranged for the term as is asked in the question

Calculating Moles

Equation:

$$\text{Amount of Substance (mol)} = \text{Concentration} \times \text{Volume of Solution (dm}^3\text{)}$$

Example:

Calculate the Moles of Solute Dissolved in 2 dm^3 of a 0.1 mol / dm^3 Solution

Concentration of Solution : 0.1 mol / dm^3

Volume of Solution : 2 dm^3

Moles of Solute = 0.1 x 2 = 0.1 mol (the dm3 above and below the line cancel out)

Amount of Solute = 0.2 mol

Calculating Concentration

Equation:

$$\text{Concentration (mol / dm}^3\text{)} = \frac{\text{Amount of substance (mol)}}{\text{Volume of solution (dm}^3\text{)}}$$

Example:

25.0 cm^3 of 0.050 mol / dm^3 sodium carbonate was completely neutralised by 20.00 cm^3 of dilute hydrochloric acid. Calculate the concentration, in mol / dm^3 of the hydrochloric acid.

Step 1: Calculate the amount, in moles, of sodium carbonate reacted by rearranging the equation for amount of substance (mol) and dividing by 1000 to convert cm^3 to dm^3
Amount of Na_2CO_3 = (25.0 x 0.050) ÷ 1000 = 0.00125 mol

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

Step 2: Calculate the amount, in moles, of hydrochloric acid reacted

$Na_2CO_3 + 2HCl \rightarrow 2NaCl + H_2O + CO_2$

1 mol of Na_2CO_3 reacts with 2 mol of HCl, so the Molar Ratio is 1 : 2

Therefore 0.00125 moles of Na_2CO_3 react with 0.00250 moles of HCl

Step 3: Calculate the concentration, in mol / dm^3 of the Hydrochloric Acid

1 dm^3 = 1000 cm^3

Volume of HCl = 20 ÷ 1000 = 0.0200 dm^3

Concentration HCl (mol / dm^3) = 0.00250 ÷ 0.0200 = 0.125

Concentration of Hydrochloric Acid = 0.125 mol / dm^3

Calculating Volume

Equation:

$$\text{Volume (dm}^3\text{)} = \frac{\text{Amount of substance (mol)}}{\text{Concentration (mol / dm}^3\text{)}}$$

Example:

Calculate the volume of hydrochloric acid of concentration 1.0 mol / dm^3 that is required to react completely with 2.5g of calcium carbonate.

Step 1: Calculate the amount, in moles, of calcium carbonate that reacts

M_r of $CaCO_3$ is 100

Amount of $CaCO_3$ = (2.5 ÷ 100) = 0.025 mol

Step 2: Calculate the moles of hydrochloric acid required

$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$

1 mol of $CaCO_3$ requires 2 mol of HCl

So 0.025 mol of $CaCO_3$ Requires 0.05 mol of HCl

Step 3: Calculate the volume of HCl Required

Volume = (Amount of Substance(mol) ÷ Concentration (mol / dm^3)

= 0.05 ÷ 1.0

= 0.05 dm^3 (the moles cancel out above and below the line)

Volume of Hydrochloric Acid = 0.05 dm^3

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

The limiting reactant & reacting masses

Limiting reactant

- The limiting reactant is the reactant which is not present in excess in a reaction
- It is always the first reactant to be used up which then causes the reaction to stop
- In order to determine which reactant is the limiting reagent in a reaction, we have to consider the ratios of each reactant in the balanced equation

Example:

9.2g of sodium is reacted with 8.0g of sulfur to produce sodium sulfide, Na2S. Which reactant is in excess and which is the limiting reactant?

Step 1: Calculate the moles of each reactant

Moles = Mass ÷ Ar

Moles Na = 9.2/23 = 0.40

Moles S = 8.0/32 = 0.25

Step 2: Write the balanced equation and determine the molar ratio

$2Na + S \rightarrow Na_2S$ so the molar ratios is 2 : 1

Step 3: Compare the moles. So to react completely 0.40 moles of Na require 0.20 moles of S and since there are 0.25 moles of S, then S is in excess. Na is therefore the limiting reactant

Calculating reacting masses

- Chemical equations can be used to calculate the moles or masses of reactants and products
- Use information from the question to find the amount in moles of the substances being considered
- Identify the ratio between the substances using the balanced chemical equation
- Apply mole calculations to find answer

Example 1:

Calculate the Mass of Magnesium Oxide that can be made by completely burning 6 g of Magnesium in Oxygen

Magnesium (s) + Oxygen (g) → Magnesium Oxide (s)

Symbol Equation:

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

Relative Formula Mass: Magnesium : 24 Magnesium Oxide : 40

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

Step 1: Calculate the moles of Magnesium Used in reaction
Moles = Mass ÷ Mr   Moles = 6 ÷ 24 = 0.25

Step 2: Find the Ratio of Magnesium to Magnesium Oxide using the balanced Chemical Equation

	MAGNESIUM	MAGNESIUM OXIDE
MOL	2	2
RATIO	1	1
MOL	0.25	0.25
MOLES OF MAGNESIUM OXIDE	= 0.25	

Step 3: Find the Mass of Magnesium Oxide
Moles of Magnesium Oxide = 0.25
Mass = Moles x Mr   Mass = 0.25 x 40 = 10 g
Mass of Magnesium Oxide Produced = 10 g

Example 2:

Calculate the Mass, in Tonnes, of Aluminium that can be Produced from 51 Tonnes of Aluminium Oxide

Aluminium Oxide (s) → Aluminium (s) + Oxygen (g)

Symbol Equation:

$$2Al_2O_3 \rightarrow 4Al + 3O_2$$

A_r and M_r: Aluminium : 27   Oxygen : 16   Aluminium Oxide : 102

1 Tonne = 10^6 g

Step 1: Calculate the moles of Aluminium Oxide Used
Mass of Aluminium Oxide in Grams = 51 x 10^6 = 51,000,000 g
Moles = Mass ÷ A_r Moles = 51,000,000 ÷ 102 = 500,000

Step 2: Find the Ratio of Aluminium Oxide to Aluminium using the balanced Chemical Equation

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

	ALUMINIUM OXIDE	ALUMINIUM
MOL	1	2
RATIO	1	2
MOL	500,000	1,000,000
MOLES OF ALUMINIUM = 1,000,000		

Step 3: Find the Mass of Aluminium

Moles of Aluminium = 1,000,000

Mass in grams = Moles x A_r Mass = 1,000,000 x 27 = 27,000,000

Mass in Tonnes = 27,000,000 ÷ 106 = 27 Tonnes

Mass of Aluminium Produced = 27 Tonnes

Using the Mole to Determine Empirical & Molecular Formulae

Empirical Formula: Gives the **simplest whole number ratio** of atoms of each element in the compound

- Calculated from knowledge of the ratio of masses of each element in the compound

Example:

A compound that contains 10 g of Hydrogen and 80 g of Oxygen has an Empirical Formula of H_2O. This can be shown by the following calculations:

Amount of Hydrogen Atoms = Mass in grams ÷ A_r of Hydrogen = (10 ÷ 1) = **10 moles**

Amount of Oxygen Atoms = Mass in grams ÷ A_r of Oxygen = (80 ÷ 16) = **5 moles**

The Ratio of Moles of Hydrogen Atoms to Moles of Oxygen Atoms:

	HYDROGEN	OXYGEN
MOLES	10	5
RATIO	2	1

Since equal numbers of Moles of Atoms contain the same number of atoms, the Ratio of Hydrogen Atoms to Oxygen Atoms is 2:1

Hence the **Empirical Formula** is H_2O

4 STOICHIOMETRY

YOUR NOTES

4.2 THE MOLE CONCEPT cont...

EXTENDED ONLY cont...

Molecular Formula: Gives the exact numbers of atoms of each element present in the formula of the compound

- Divide the relative formula mass of the molecular formula by the relative formula mass of the Empirical Formula
- Multiply the number of each element present in the Empirical Formula by this number to find the Molecular Formula

Relationship between Empirical & Molecular Formula:

NAME OF COMPOUND	EMPIRICAL FORMULA	MOLECULAR FORMULA
METHANE	CH_4	CH_4
ETHANE	CH_3	C_2H_6
ETHENE	CH_2	C_2H_4
BENZENE	CH	C_6H_6

Example:

The Empirical Formula of X is C4H10S1 and the Relative Formula Mass of X is 180. What is the Molecular Formula of X?

Relative Formula Mass: Carbon : 12 Hydrogen : 1 Sulfur : 32

Step 1: Calculate Relative Formula Mass of Empirical Formula
(C x 4) + (H x 10) + (S x 1) = (12 x 4) + (1 x 10) + (32 x 1) = 90

Step 2: Divide Relative Formula Mass of X by Relative Formula Mass of Empirical Formula
180 / 90 = 2

Step 3: Multiply Each Number of Elements by 2
$(C_4 \times 2) + (H_{10} \times 2) + (S_{1 \times 2}) = (C8) + (H_{20}) + (S_2)$

Molecular Formula of X = $C_8H_{20}S_2$

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY

Calculating Percentage Yield & Percentage Purity of the Product

Percentage yield

- This is the calculation of the percentage yield obtained from the theoretical yield
- In practice, you never get 100% yield in a chemical process for several reasons
- These include some reactants being left behind in the equipment, the reaction may be reversible or product may also be lost during separation stages

Equation:

Percentage Yield = (Yield Obtained ÷ Theoretical Yield) x 100

Example:

In an experiment to displace copper from copper sulfate, 6.5 g of Zinc was added to an excess of copper (II) sulfate solution. The copper was filtered off, washed and dried. The mass of copper obtained was 4.8 g. Calculate the percentage yield of copper.

Equation Of Reaction:

$$Zn\,(s) + CuSO_4\,(aq) \rightarrow ZnSO_4\,(aq) + Cu\,(s)$$

Step 1: Calculate the Amount, in Moles of Zinc Reacted
Moles of Zinc = 6.5 ÷ 65 = 0.10 moles

Step 2: Calculate the Maximum Amount of Copper that could be formed from the Molar ratio
Maximum Moles of Copper = 0.10 moles (Molar ratio is 1:1)

Step 3: Calculate the Maximum Mass of Copper that could be formed
Maximum Mass of Copper = (0.10 x 64) = 6.4 g

Step 4: Calculate the Percentage of Yield of Copper
Percentage Yield = (4.8 ÷ 6.4) x 100 = 75%

Percentage Yield of Copper = 75%

4 STOICHIOMETRY

4.2 THE MOLE CONCEPT cont...

YOUR NOTES

EXTENDED ONLY cont...

Percentage purity

Often the product you are trying to fabricate may become contaminated with unwanted substances such as unreacted reactants, catalysts etc.

Equation:

Percentage Purity =
(Mass of pure substance ÷ Mass of impure substance) x 100

Example:

In an experiment 7.0g of impure calcium carbonate were heated to a very high temperature and 2.5g of carbon dioxide were formed. Calculate the percentage purity of the calcium carbonate.

Equation Of Reaction:

$CaCO_3 (s) \rightarrow CaO(s) + CO_2 (g)$

Step 1: Calculate the relative formula masses
1 mole $CaCO_3$ → 1 mole CO_2
40+12+(3×16) 12+(2×16)
100 → 44

Step 2: Calculate the theoretical mass of calcium carbonate used if pure
From 2.5g CO_2 we would expect 2.5/44 x 100 = 5.68g

Step 3: Calculate the percentage purity
(Mass of pure substance / mass of impure substance) x 100
= 5.68/7.0 x 100
= 81.1%

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which row correctly describes the mole and the value of Avogadro's constant?

	one mole of a substanc is equal to	one mole of a substance contains
A	the substances relative atomic or molecular mass in grams	6.02×10^{23} atoms, molecules or formula units
B	the substances atomic number in grams	12.02×10^{23} atoms, molecules or formula units
C	the substances relative atomic or molecular mass in grams	6.02×10^{22} atoms, molecules or formula units
D	the substances atomic number in grams	12.02×10^{23} atoms, molecules or formula units

QUESTION 1

The complete combustion of methane produces carbon dioxide and steam.

$$CH_4(g) + 2\ O_2(g) \rightarrow 2\ H_2O(g) + CO_2(g)$$

Which statements are about the reaction correct?

1 The empirical formula of methane is CH4

2 The number of atoms in 1 mole of methane is 4 x Avogadro's constant

3 1 mole of methane produces 72 dm3 of gaseous products at r.t.p

4 1 mole of methane occupies a volume of 12 dm3 at r.t.p

A 1, 2 and 3 **B** 1 and 2 **C** 1 and 3 **D** 2 and 4

4 STOICHIOMETRY

EXAM QUESTIONS

YOUR NOTES

QUESTION X

Calcium carbide and water react to produce ethyne and calcium hydroxide.

$$CaC_2(s) + 2\,H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(s)$$

What is the volume of C2H2 produced when 45 g of water reacts completely with calcium carbide?

A 72 dm^3

B 30 dm^3

C 24 dm^3

D 6 dm^3

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5 ELECTRICITY & CHEMISTRY

CONTENTS:

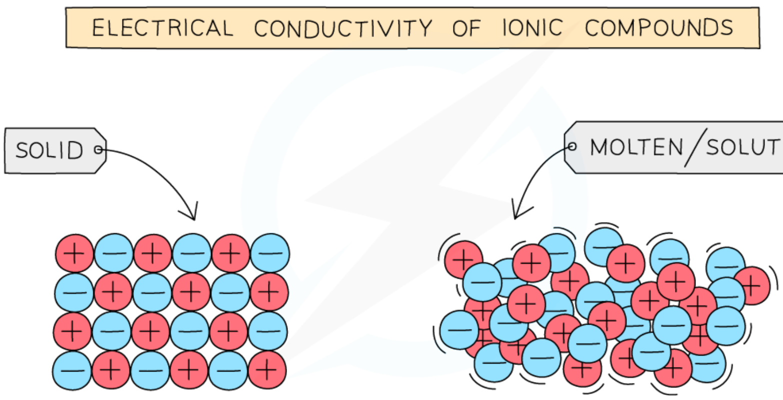
YOUR NOTES

5.1 ELECTROCHEMISTRY

5.1.1 ELECTROLYSIS

Electrolysis

- When an electric current is passed through a molten ionic compound the compound decomposes or breaks down
- The process also occurs for aqueous solutions of ionic compounds
- Covalent compounds cannot conduct electricity hence they do not undergo electrolysis
- Ionic compounds in the solid state cannot conduct electricity either since they have no free ions that can move and carry the charge



Particles in ionic compounds are in fixed position in the solid state but can move around when molten or in solution

EXAM TIP

Use the PANIC mnemonic to remember which electrode is the positive and which is the negative:

Positive (is) Anode Negative Is Cathode.

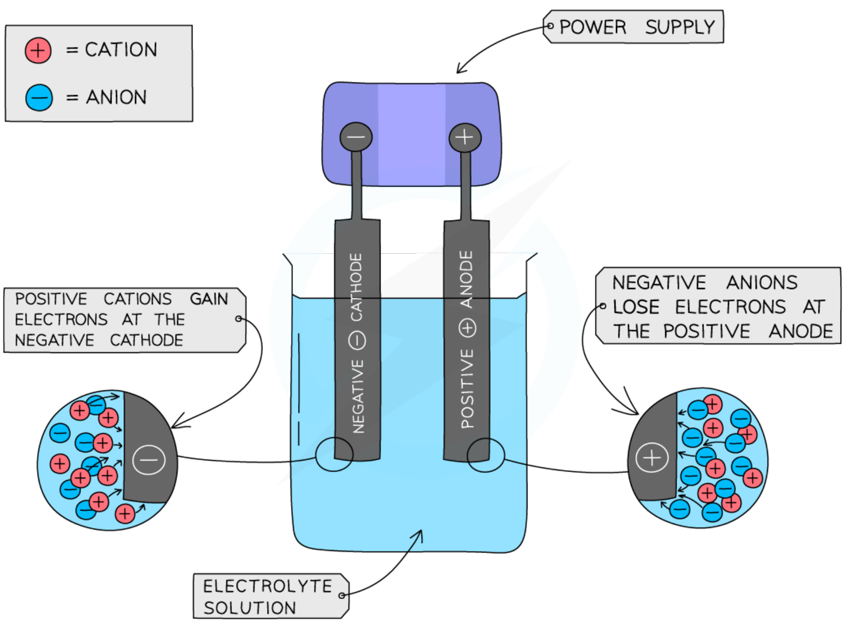
5 ELECTRICITY & CHEMISTRY

YOUR NOTES

5.1.1 ELECTROLYSIS cont...

Key Terms

- **Electrode** is a rod of metal or graphite through which an electric current flows into or out of an electrolyte
- **Electrolyte** is the ionic compound in molten or dissolved solution that conducts the electricity
- **Anode** is the positive electrode of an electrolysis cell
- **Anion** is a negatively charged ion which is attracted to the anode
- **Cathode** is the negative electrode of an electrolysis cell
- **Cation** is a positively charged ion which is attracted to the cathode



The basic set-up of an electrolysis cell

EXAM TIP

Cations are attracted to the cathode and anions are attracted to the anode.

Electron flow in electrochemistry occurs in alphabetical order as electrons flow from the Anode to the Cathode.

5 ELECTRICITY & CHEMISTRY

5.1.1 ELECTROLYSIS cont...

YOUR NOTES

Electrolysis of Molten Compounds e.g: Lead (II) Bromide:

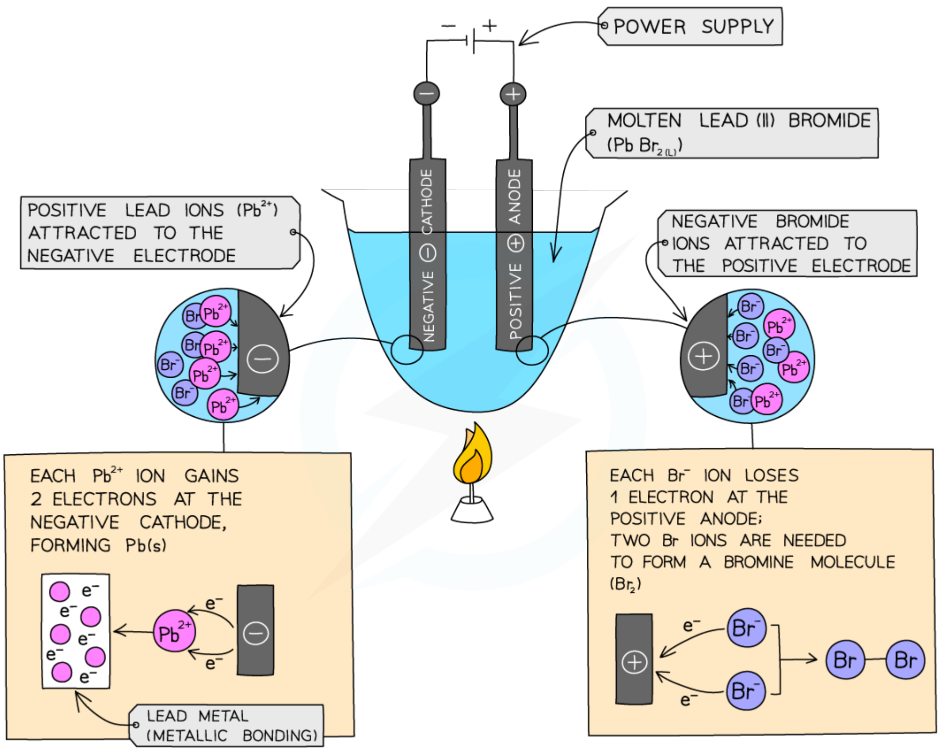


Diagram Showing the Electrolysis of Lead (II) Bromide

Method:

- Add Lead (II) Bromide into a beaker and heat so it will turn molten, allowing ions to be free to move and conduct an electric charge
- Add two graphite rods as the electrodes and connect this to a power pack or battery
- Turn on power pack or battery and allow electrolysis to take place
- Negative bromide ions move to the positive electrode (anode) and lose two electrons to form bromine molecules. There is bubbling at the anode as brown bromine gas is given off
- Positive lead ions move to the negative electrode (cathode) and gain electrons to form a grey lead metal which deposits on the surface of the electrode

Reaction at Electrodes:

SOLUTION	PRODUCT AT POSITIVE ELECTRODE	PRODUCT AT NEGATIVE ELECTRODE
LEAD (II) BROMIDE ($PbBr_2$)	BROMINE – Br_2 $2Br^- - 2e^- \rightarrow Br_2$	Lead – Pb $Pb^{2+} + 2e^- \rightarrow Pb$

5.1.1 ELECTROLYSIS cont...

YOUR NOTES

Electrolysis of Aqueous Solutions

Rules

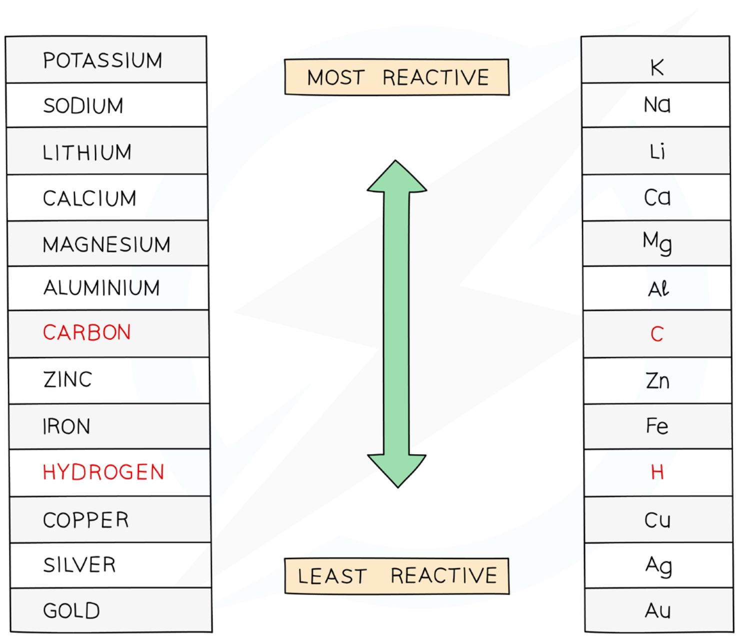
- Aqueous solutions will always have water (H_2O)
- H^+ and OH^- ions from the water are involved as well

Positive Electrode (anode)

- OH^- ions and non-metal ions attracted to positive electrode
- Either OH^- or non-metal ions will lose electrons and oxygen gas or gas of non-metal in question is released E.g. Chlorine, Bromine, Nitrogen
- The product formed depends on which ion loses electrons more **readily**, with the more reactive ion remaining in solution. A reactivity series of anions is shown below:
  - **More reactive** $SO_4^{2-} \rightarrow NO_3^- \rightarrow OH^- \rightarrow Cl^- \rightarrow Br^- \rightarrow I^-$ Less reactive

Negative Electrode (cathode)

- H^+ and metal ions attracted to the negative electrode but only one will gain electrons
- Either hydrogen or metal will be produced
- If the metal is **above hydrogen** in reactivity series, then hydrogen will be produced and bubbling will be seen at the cathode



The reactivity series of metals including hydrogen and carbon

5 ELECTRICITY & CHEMISTRY

YOUR NOTES

5.1.1 ELECTROLYSIS cont...

Concentrated & dilute solutions

- Concentrated and dilute solutions of the **same** compound give **different** products
- For anions, the more concentrated ion will tend to get discharged over a more dilute ion

Electrolysis of binary molten compound

- For a **binary** molten compound of a metal and a nonmetal, the cathode product will always be the metal
- The product formed at the anode will always be the non-metal

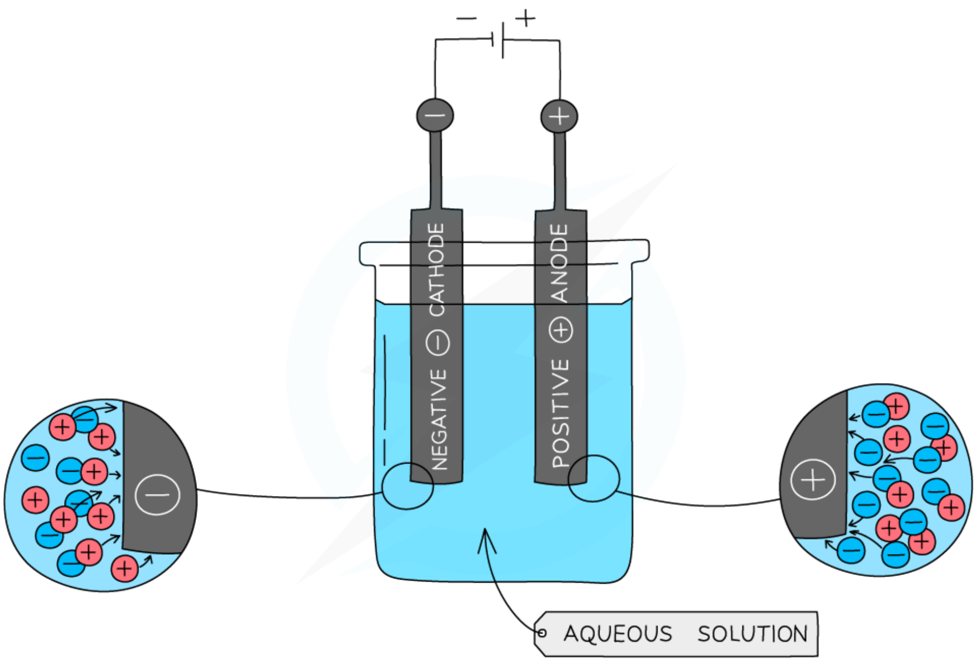


Diagram Showing the Electrolysis of Aqueous Solutions

Method:

- Add aqueous solution into a beaker
- Add two Graphite rods as the electrodes and connect this to a power pack or battery
- Turn on power pack or battery and allow electrolysis to take place

YOUR NOTES

5.1.1 ELECTROLYSIS cont...

Reaction at Electrodes:

(IONS PRESENT) AQUEOUS SOLUTION	ANODE REACTION	CATHODE REACTION
CONCENTRATED SODIUM CHLORIDE (NaCl) IONS FROM NaCl: Na^+ Cl^- IONS FROM H_2O: H^+ OH^-	$2Cl^- \rightarrow Cl2 + 2e-$ CHLORINE GAS RELEASED.	$2H^+ + 2e^- \rightarrow H_2$ HYDROGEN GAS RELEASED.
DILUTE SODIUM CHLORIDE (NaCl) IONS FROM NaCl: Na+ Cl− IONS FROM H_2O: H+ OH−	$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ OXYGEN PRODUCED.	$2H^+ + 2e^- \rightarrow H_2$ HYDROGEN GAS RELEASED.
CONCENTRATED AQUEOUS COPPER (II) SULFATE ($CuSO_4$) IONS FROM $CuSO_4$: Cu^{2+} SO_4^{2-} IONS FROM H_2O: H^+ OH^-	$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ OXYGEN GAS RELEASED.	$Cu2^+ + 2e^- \rightarrow Cu$ COPPER IS **LOWER** THAN HYDROGEN IN THE REACTIVITY SERIES SO COPPER IS PREFERENTIALLY DISCHARGED AS A METAL.
CONCENTRATED AQUEOUS HYDROCHLORIC ACID (HCl) IONS FROM HCl: H^+ Cl^- IONS FROM H_2O: H^+ OH^-	$2Cl^- \rightarrow Cl2 + 2e^-$ CHLORINE GAS RELEASED.	$2H^+ + 2e^- \rightarrow H_2$ HYDROGEN GAS RELEASED.
DILUTE HYDROCHLORIC ACID (HCl) IONS FROM HCl: H^+ Cl^- IONS FROM H_2O: H^+ OH^-	$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ OXYGEN PRODUCED.	$2H^+ + 2e^- \rightarrow H_2$ HYDROGEN GAS RELEASED.
DILUTE SULFURIC ACID (H_2SO_4) IONS FROM H_2SO_4: H^+ SO_4^{2-} IONS FROM H_2O: H^+ OH^-	$4OH^- \rightarrow O_2 + 2H_2O + 4e^-$ OXYGEN GAS RELEASED. OH^- MORE READILY GIVES UP ELECTRONS THAN SO_4^{2-}.	$2H^+ + 2e^- \rightarrow H_2$ HYDROGEN GAS RELEASED.

Determining what Gas is Produced

- If the gas produced at the **cathode** burns with a 'pop' when a sample is lit with a lighted splint then the gas is **hydrogen**
- If the gas produced at the **anode** relights a glowing splint dipped into a sample of the gas then the gas is **oxygen**
- The halogen gases all produce their own colours (bromine is **red-brown**, chlorine is **yellow-green** and fluorine is **pale yellow**)

5 ELECTRICITY & CHEMISTRY

5.1.1 ELECTROLYSIS cont...

YOUR NOTES

EXTENDED ONLY

Products of Electrolysis & Charge Transfer

Copper refining

- The electrolysis of $CuSO_4$ using graphite rods produces oxygen and copper
- By changing the electrodes from graphite to pure and impure copper, the products can be changed at each electrode
- Electrolysis can be used to purify metals by separating them from their impurities
- In the set-up, the **impure** metal is always the **anode**, in this case the impure copper
- The cathode is a thin sheet of **pure**
- The electrolyte used is an aqueous solution of a **soluble** salt of the pure metal at the anode, e.g: $CuSO_4$
- Copper atoms at the anode lose electrons, go into solution as ions and are attracted to the cathode where they gain electrons and form now purified copper atoms
- The anode thus becomes thinner due to loss of atoms and the impurities fall to the bottom of the cell as sludge
- The cathode gradually becomes **thicker**

Electrolysis of halide solutions

- We have seen that cations that are lower down on the reactivity series tend to be discharged in preference to more reactive cations
- The same occurs for anions which can be arranged in order of ease of discharge:
    - **More reactive** $SO_4^{2-} \rightarrow NO_3^- \rightarrow OH^- \rightarrow Cl^- \rightarrow Br^- \rightarrow I^-$ **Less reactive**
- E.g: in a concentrated aqueous solution of barium chloride, the Cl– ions are discharged more readily than the OH^- ions, so chlorine gas is produced at the anode
- If the solution is dilute however only the OH^- ion is discharged and so oxygen would be formed

Transfer of charge

- During electrolysis the electrons move from the power supply towards the cathode
- Positive ions within the electrolyte move towards the **negatively** charged electrode which is the **cathode**
- Here they **accept** electrons from the cathode and either a metal or hydrogen gas is produced

5 ELECTRICITY & CHEMISTRY

5.1.1 ELECTROLYSIS cont...

YOUR NOTES

EXTENDED ONLY cont...

- Negative ions within the electrolyte move towards the **positively** charged electrode which is the anode
- If the anode is **inert** (such as graphite or platinum), the ions **lose** electrons to the anode and form a nonmetal or oxygen gas
- If the anode is a **reactive** metal, then the metal atoms of the anode lose electrons and go into solution as ions, thinning the anode

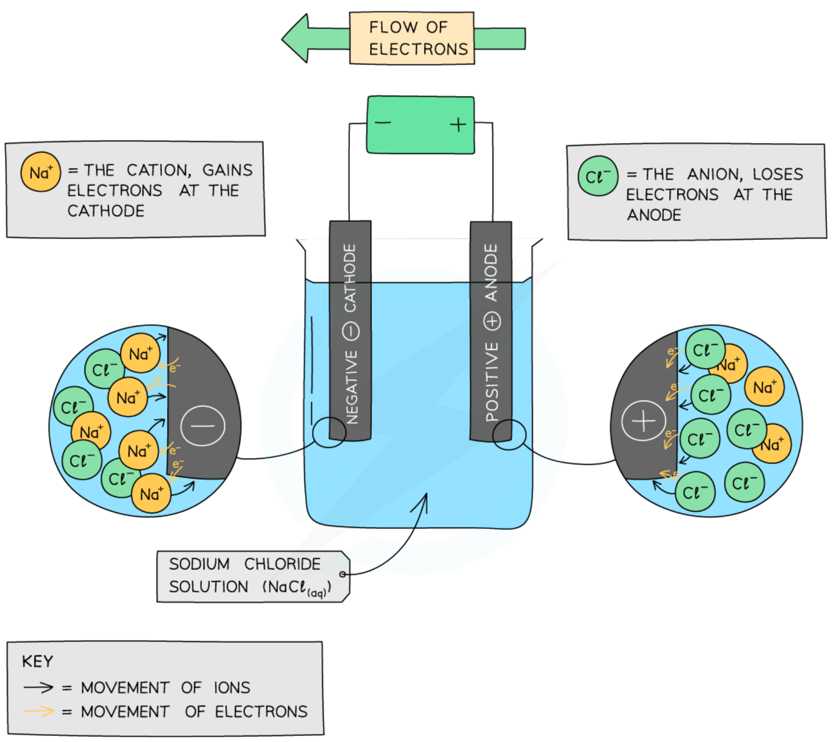


Diagram showing the direction of movement of electrons and ions in the electrolysis of NaCl

EXAM TIP

When a metal conducts it is the **electrons** that are moving through the metal.

When a salt solution conducts it is the **ions** in the solution that move towards the electrodes carrying the electrons.

5.1.1 ELECTROLYSIS cont...

YOUR NOTES

EXTENDED ONLY

Ionic Half–Equations & Electrical Energy

Ionic Half–equations at the Cathode

- Reduction occurs at the cathode as the positive ions gain electrons.

SOLUTION	HALF–EQUATION AT THE CATHODE
Lead (II) Bromide ($PbBr_2$)	$Pb2^+ + 2e^- \longrightarrow Pb$
Sodium Chloride (NaCl)	$2H^+ + 2e^- \longrightarrow H_2$
Dilute Sulfuric Acid (H_2SO_4)	$2H^+ + 2e^- \longrightarrow H_2$
Copper (II) Sulfate ($CuSO_4$)	$Cu^{2+} + 2e^- \longrightarrow Cu$
Hydrochloric Acid (HCl)	$2H^+ + 2e^- \longrightarrow H_2$

Electrochemical cells

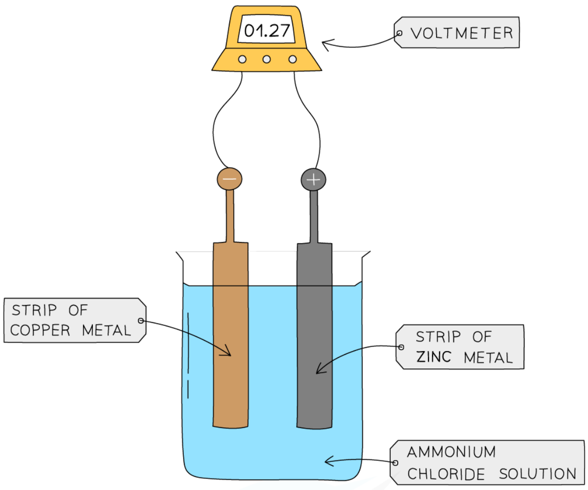
- An electrochemical cell is a source of electrical **energy**
- The simplest design consists of two electrodes made from metals of **different reactivity** immersed in an electrolyte and connected to an external circuit
- A common example is zinc and copper
- Zinc is the more reactive metal and forms ions more easily, releasing electrons as its atoms form ions
- The electrons give the more reactive electrode a negative charge and they then flow around the circuit to the copper electrode
- The difference in the ability of the electrodes to release electrons causes a voltage to be produced
- The greater the difference in the metal's reactivity then the greater the voltage

5 ELECTRICITY & CHEMISTRY

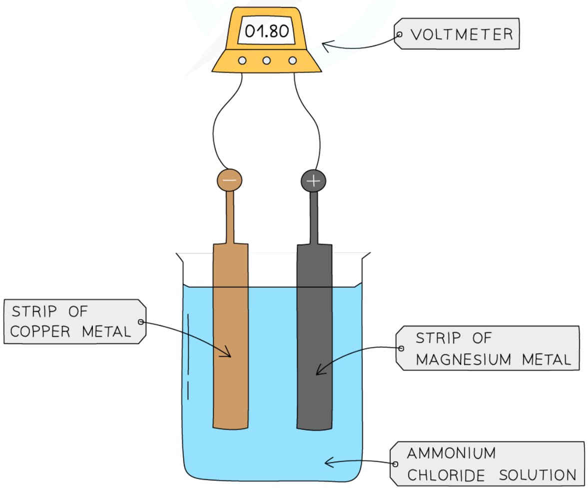
5.1.1 ELECTROLYSIS cont...

YOUR NOTES

EXTENDED ONLY cont...



THE GREATER THE DIFFERENCE IN REACTIVITY, THE HIGHER THE VOLTAGE



Electrochemical cell made with copper and magnesium. These metals are further apart on the reactivity series than copper and zinc and would hence produce a greater voltage

EXAM TIP

During electrolysis oxidation of the non metal ions always occurs at the anode and reduction of the metal or hydrogen ions occurs at the cathode.

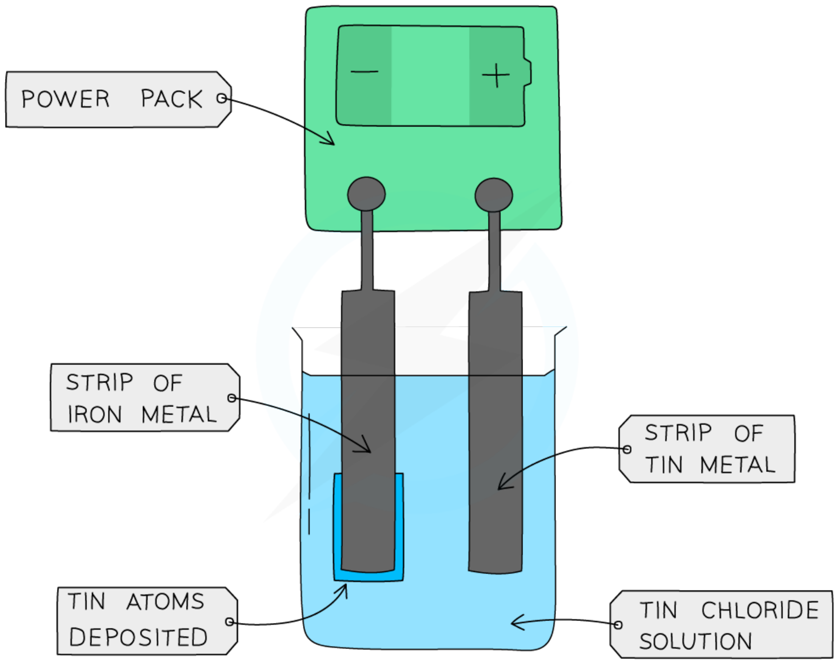
5 ELECTRICITY & CHEMISTRY

YOUR NOTES

5.1.2 ELECTROPLATING

Electroplating

- This is a process where the surface of one metal is **coated** with a layer of a different metal
- The metal being used to coat is a less reactive metal than the one it is covering
- The **anode** is made from the **pure** metal used to coat
- The cathode is the **object** to be electroplated
- The electrolyte is an aqueous solution of a soluble salt of the pure metal at the anode



A piece of iron being electroplated with tin.
The electrolyte is tin(II) chloride, a water soluble salt of tin

Uses of Electroplating

- Electroplating is done to make metals more **resistant** to corrosion or damage, e.g: chromium and nickel plating
- It is also done to improve the appearance of metals, e.g: silver plating cutlery

5 ELECTRICITY & CHEMISTRY

5.1.2 ELECTROPLATING cont...

YOUR NOTES

Conductors & Insulators

Conductors

- Conductors of electricity allow electrical charge to pass through them easily
- Conductors can be:
    - Solids such as **metals** or **graphite**
    - Liquids such as **molten** lead bromide or molten metals
    - Solutions such as sodium chloride solution
- Copper is used extensively in electrical wiring as it is an excellent conductor and is **malleable** and easy to work with
- Aluminium is used in overhead cables which are reinforced with a steel core
- The steel core provides extra strength and prevents the cable from breaking under its own weight
- Although not as good a conductor as copper, it is **less dense** and **cheaper** than copper

Insulators

- Insulators resist the flow of electricity and do not conduct
- Most insulators are solids of **plastic**, **rubber** or **ceramic**
- Plastics are used as insulators and are placed around electrical wiring and for some tool and machine handles
- Ceramics are used in very high voltage lines where contact between the power line and the metal of the pylon would be dangerous

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which statement about electrolysis is correct?

A Electrons move through the electrolyte from the cathode to the anode.

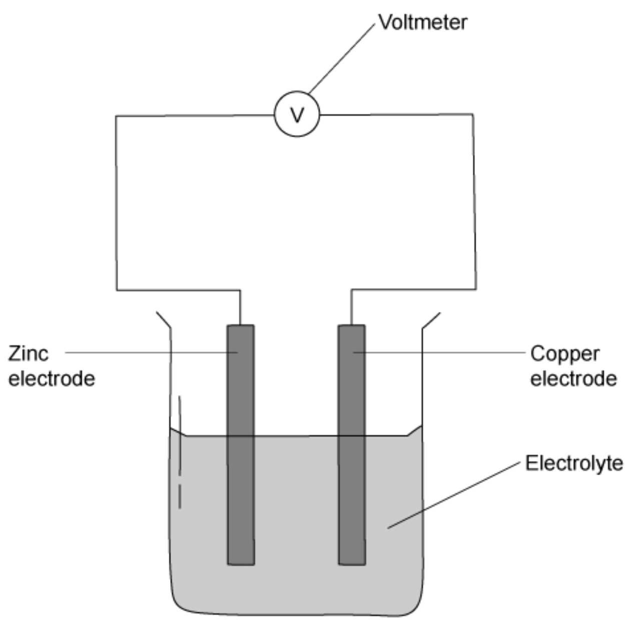
B Electrons move towards the cathode in the external circuit.

C Negative ions move towards the anode in the external circuit.

D Positive ions move through the electrolyte towards the anode during electrolysis.

QUESTION 2

The diagram shows a simple cell.



Which statement about the process occurring when the cell is in operation is correct?

A Cu^{2+} ions are formed in solution.

B Electrons travel through the solution.

C The reaction $Zn \rightarrow Zn^{2+} + 2e^{-}$ occurs.

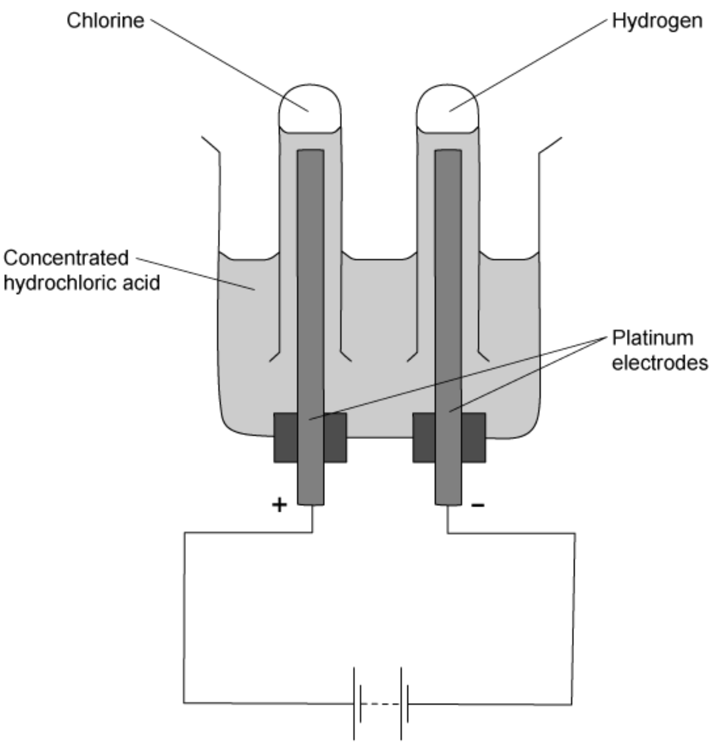
D The zinc electrode increases in mass

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

The electrolysis of concentrated hydrochloric acid is shown.



Which statement describes what happens to the electrons during the electrolysis?

A They are added to chloride ions.

B They are added to hydrogen ions.

C They move through the circuit from positive to negative.

D They move through the solution from negative to positive.

5 ELECTRICITY & CHEMISTRY

5.2 INDUSTRIAL APPLICATIONS

YOUR NOTES

EXTENDED ONLY

Manufacture of Aluminium, Chlorine, Hydrogen & Sodium Hydroxide

Extraction of aluminium

- The Earth's Crust contains metals and metal compounds such as Gold, Iron Oxide and Aluminium Oxide, but when found in the Earth, these are often mixed with other substances
- To be useful, the metals have to be extracted from their ore through processes such as electrolysis, using a blast furnace or by reacting with more reactive material
- Metals which lie above carbon have to be extracted by electrolysis as they are too reactive

Reactivity Series and Extraction of Metals

METAL	METHOD OF EXTRACTION
MOST REACTIVE	
POTASSIUM	EXTRACTED BY ELECTROLYSIS OF MOLTEN CHLORIDE OR MOLTEN OXIDE LARGE AMOUNTS OF ELECTRICITY REQUIRED, SO AN EXPENSIVE PROCESS
SODIUM	
LITHIUM	
CALCIUM	
MAGNESIUM	
ALUMINIUM	
CARBON	
ZINC	EXTRACTED BY HEATING WITH A REDUCING AGENT SUCH AS CARBON OR CARBON MONOXIDE IN A BLAST FURNACE CHEAP PROCESS AS CARBON IS CHEAP AND CAN BE SOURCE OF HEAT AS WELL
IRON	
HYDROGEN	
COPPER	
SILVER	FOUND AS PURE ELEMENTS
GOLD	
LEAST REACTIVE	

5 ELECTRICITY & CHEMISTRY

5.2 INDUSTRIAL APPLICATIONS cont...

YOUR NOTES

Extraction of aluminium

- Extraction of Aluminium by electrolysis, IGCSE & GCSE Chemistry revision notes
- Diagram Showing the Extraction of Aluminium by Electrolysis

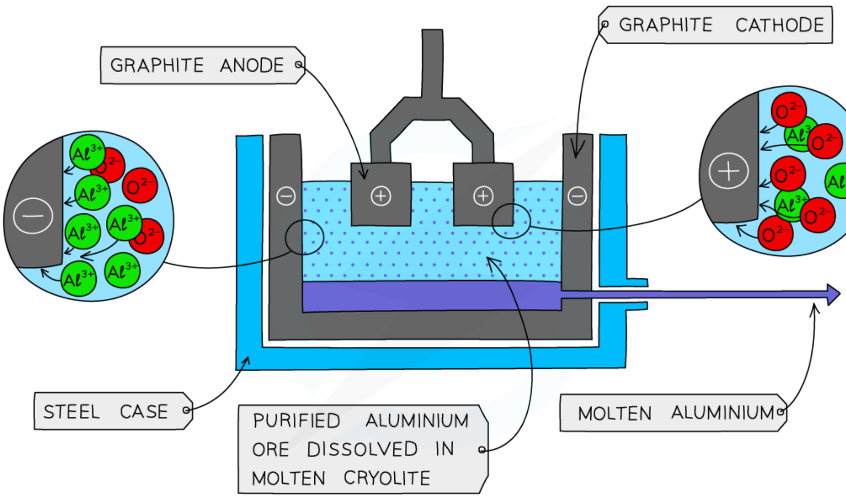


Diagram Showing the Extraction of Aluminium by Electrolysis

Raw Materials:

- Aluminium Ore (Bauxite)

Explanation:

- The Bauxite is first purified to produce Aluminium Oxide Al_2O_3
- Aluminium Oxide has a very high melting point so it is first dissolved in molten **Cryolite**, producing an electrolyte, which:
  - has a lower melting point
  - is a better conductor of electricity than molten aluminium oxide
  - reduces expense considerably
- The electrolyte is a solution of aluminium oxide in molten cryolite at a temperature of about 1000 °C
- The molten aluminium is siphoned off from time to time and fresh aluminium oxide is added to the cell
- The cell operates at 5-6 volts and with a current of 100,000 amps
- The heat generated by the huge current keeps the electrolyte molten
- A lot of electricity is required for this process of extraction, this is a major expense

5 ELECTRICITY & CHEMISTRY

YOUR NOTES

5.2 INDUSTRIAL APPLICATIONS cont...

Reaction at the Negative Electrode:

- The Aluminium melts and collects at the bottom of the cell and is then tapped off:

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

Reaction at the Positive Electrode:

$$2O_2^- - 4e^- \rightarrow O_2$$

Some of the Oxygen Produced at the positive electrode then reacts with the Graphite (Carbon) electrode to produce Carbon Dioxide Gas:

$$C\ (s) + O_2\ (g) \rightarrow CO_2\ (g)$$

*This causes the carbon anodes to burn away, so they must be replaced regularly.

Manufacture of chlorine, hydrogen and sodium hydroxide

- **Brine** is a concentrated solution of aqueous sodium chloride
- When electrolysed it produces chlorine, hydrogen and sodium hydroxide
- The electrolyte is concentrated sodium chloride which contains the following ions: H^+, Cl^- and OH^-
- The H^+ ions are discharged at the **cathode** as hydrogen gas
- The Cl^- ions are discharged at the **anode** as chlorine gas
- The Na^+ and OH^- ions remain behind and form the NaOH solution

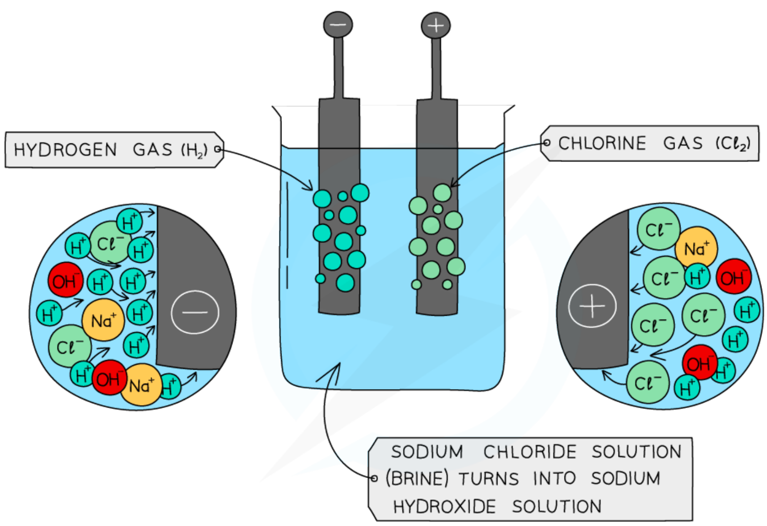


Diagram showing the products of the electrolysis of brine

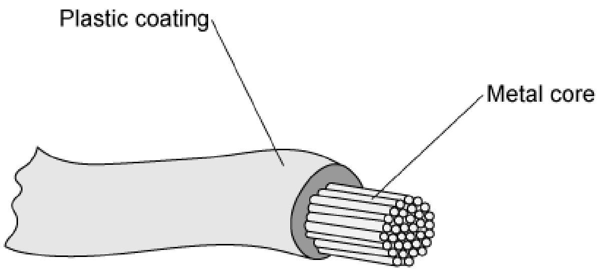
> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

The diagram shows an electrical cable.



Which statement about the substances used is correct?

A The coating is plastic because it conducts electricity well.

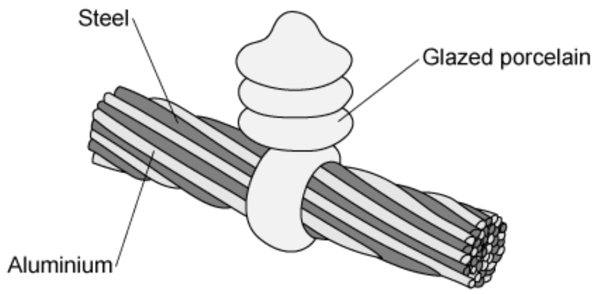
B The core is copper because it conducts electricity well.

C The core is copper because it is cheap and strong.

D The core is iron because it is cheap and strong.

QUESTION 2

The diagram shows a section of an overhead power cable.



Which statement explains why a particular substance is used?

A Aluminium has a low density and is a good conductor of electricity.

B Porcelain is a good conductor of electricity.

C Steel can rust in damp air.

D Steel is more dense than aluminium.

5 ELECTRICITY & CHEMISTRY

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Electrical cables are made from either ……**1**……, because it is a very good conductor of electricity, or from ……**2**……, because it has a low density. Overhead cables have a ……**3**…… core in order to give the cable strength.

Which words correctly complete gaps 1, 2 and 3?

	1	2	3
A	aluminium	copper	magnesium
B	copper	aluminium	magnesium
C	copper	aluminium	steel
D	magnesium	copper	steel

6 CHEMICAL ENERGETICS

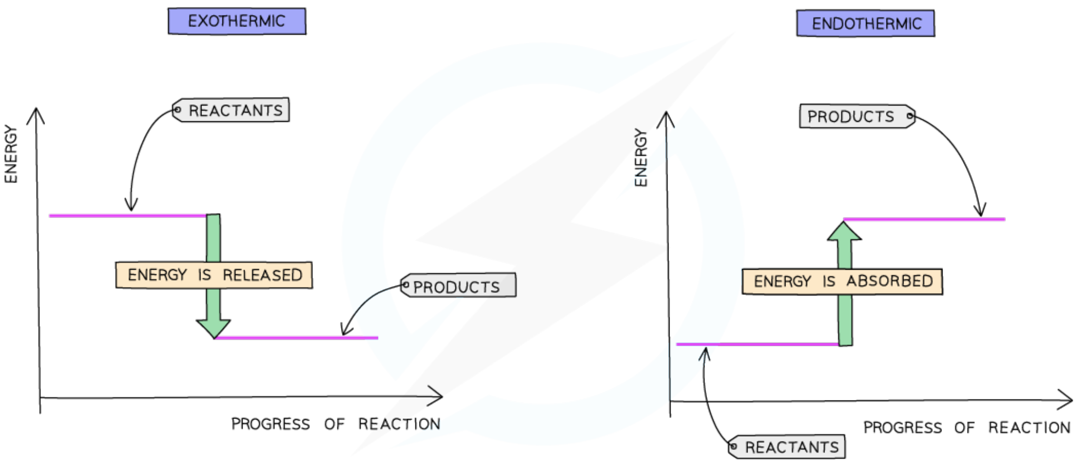
YOUR NOTES

CONTENTS:

6.1 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION

Exothermic & Endothermic Reactions



EXAM TIP

To help you remember whether a chemical system is exothermic or endothermic, in **EX**othermic reactions heat **Ex**its the system and in **EN**dothermic reactions heat **EN**ters the system.

Exothermic reactions always give off heat and they feel hot, whereas endothermic reactions take heat in and they feel cold.

6 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION cont...

YOUR NOTES

EXTENDED ONLY

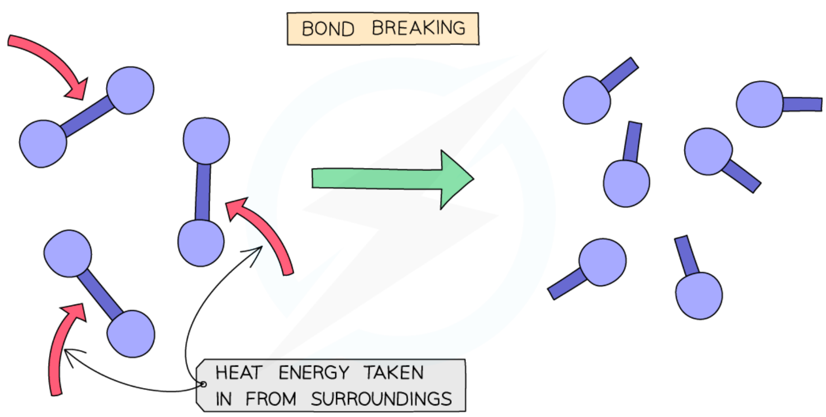
Bond Breaking & Bond Forming

Endothermic & Exothermic reactions

- Whether a reaction is endothermic or exothermic depends on the difference between the energy needed to **break** bonds and the energy released when the new bonds are **formed**

Endothermic

- If more energy is absorbed than is released, this reaction is **endothermic**
- More energy is required to break the bonds than that gained from making the new bonds
- The change in energy is positive since the products have more energy than the reactants
- The symbol ΔH (delta H) is used to show the change in heat energy. H is the symbol for **enthalpy**, which is a measure of the total **heat of reaction** of a chemical reaction
- Therefore an endothermic reaction has a **positive** ΔH



Breaking chemical bonds requires energy which is taken in from the surroundings in the form of heat

Exothermic

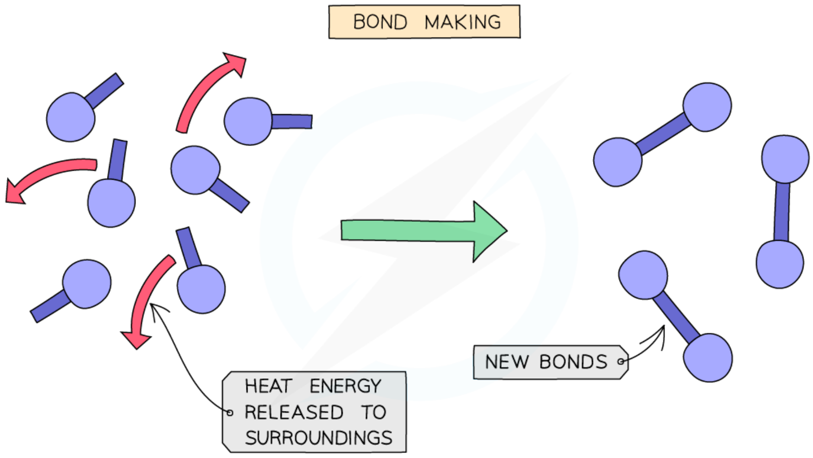
- If more energy is released than is absorbed, then the reaction is **exothermic**
- More energy is released when new bonds are formed than energy required to break the bonds in the reactants
- The change in energy is negative since the products have less energy than the reactants
- Therefore an exothermic reaction has a **negative** ΔH value

6 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...



Making new chemical bonds releases energy which radiates outwards from the reaction to the surroundings in the form of heat

Energy level diagrams

- These are graphical representations of the heat changes in chemical reactions (see above)
- The enthalpy of the reactants and products is displayed on the y-axis
- The reaction pathway is shown on the x-axis
- Arrows on the diagrams indicate whether the reaction is exothermic (**downwards** pointing) or endothermic (**upwards** pointing)

Enthalpy change during an exothermic reaction explanation:

- During an exothermic reaction, energy is given out
- This means that the energy of the products will be lower than the energy of the reactants, so the change in enthalpy (ΔH) is negative
- This is represented on the energy-level diagram above with a downwards arrow as the energy of the products is lower than the reactants

Enthalpy change during an endothermic reaction explanation:

- During an endothermic reaction, energy is absorbed
- This means that the energy of the products will be higher than the energy of the reactants, so the change in enthalpy (ΔH) is positive
- This is represented on the energy-level diagram above with an upwards arrow as the energy of the products is higher than the reactants

6 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION cont...

EXTENDED ONLY

Calculating the Energy of a Reaction

Energy of reaction calculations

- Each chemical bond has a specific **bond energy** associated with it.
- This is the amount of energy required to **break** the bond or the amount of energy given out when the bond is **formed**.
- This energy can be used to calculate how much heat would be released or absorbed in a reaction.
- To do this it is necessary to know the bonds present in both the reactants and products.

Method

- Add together all the bond energies for all the bonds in the reactants – this is the 'energy in'.
- Add together the bond energies for all the bonds in the products – this is the 'energy out'.
- Calculate the energy change: Energy change = energy in – energy out

Equation

Energy change = Energy needed in – Energy given out

Example: An exothermic reaction

Hydrogen and chlorine react to form hydrogen chloride gas:

$$H_2 + Cl_2 \rightarrow 2HCl$$

The table below shows the bond energies relevant to this reaction:

BOND	BOND ENERGY (kJ / mole)
H – H	436
Cl – Cl	243
H – Cl	432

6 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

Energy In = 436 + 243 = 679 KJ / Mole

Energy Out = 2 x 432 = 864 KJ / Mole

Energy Change = 679 – 864 = -185 KJ / Mole

*The energy change is negative, showing that energy is released to the surroundings so it is an exothermic reaction.

Example: An Endothermic reaction

Hydrogen Bromide decomposes to form Hydrogen and Bromine:

$$2 \times (H - Br) \rightarrow H - H + Br - Br$$

The table below shows the bond energies relevant to this reaction:

BOND	BOND ENERGY (kJ / mole)
H – Br	366
H – H	436
Br – Br	193

Energy In = 2 x 366 = 732 KJ / Mole

Energy Out = 436 + 193 = 629 KJ / Mole

Energy Change = 732 - 629 = +103 KJ / Mole

*The energy change is positive, showing that energy is taken in from the surroundings so is an endothermic reaction

6 CHEMICAL ENERGETICS

6.1.1 ENERGETICS OF A REACTION cont...

YOUR NOTES

EXAM TIP

For bond enthalpy questions, it is helpful to write down a displayed formula equation for the reaction before identifying the type and number of bonds, to avoid making mistakes.

The reaction thus becomes: H-H + Cl-Cl → H-Cl + H-Cl

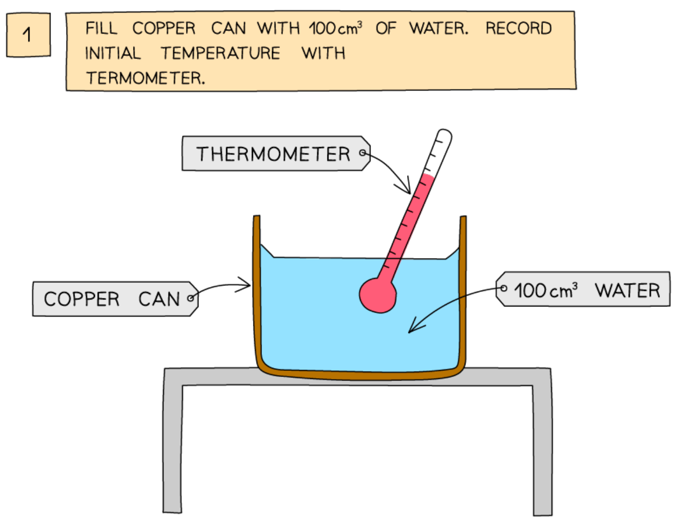
6.1.2 ENERGY TRANSFER

Fuel, Combustion, Hydrogen

Energy from Fuels

- A fuel is a substance which releases energy when burned
- When the fuel is a **hydrocarbon** then water and carbon dioxide are produced in combustion reactions
- Propane for example undergoes combustion according to the following equation:
  - $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ $\Delta H = -2219$ kJ/mol
- The efficiency of a fuel refers to how much energy is released per unit amount
- We can measure the efficiency of fuels by **calorimetry**
- A known mass of the fuel is combusted and used to heat up a known mass of water to calculate its **heat of combustion**
- Different fuels heat the water by different amounts and they can be analysed and compared in this way

Calorimetry experiment

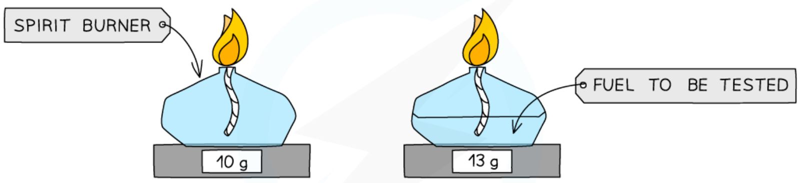


6 CHEMICAL ENERGETICS

YOUR NOTES

6.1.2 ENERGY TRANSFER cont...

2 MEASURE AND RECORD THE MASS OF AN EMPTY SPIRIT BURNER. ADD FUEL AND RECORD MASS



3 LIGHT THE WICK. HEAT WATER (STIRRING CONSTANTLY) FOR SET TIME/UNTIL FUEL IS COMPLETELY BURNT.

RECORD TEMPERATURE OF WATER.

MEASURE MASS OF BURNER + ANY REMAINING FUEL. SUBTRACT TO FIND MASS OF FUEL BURNT.

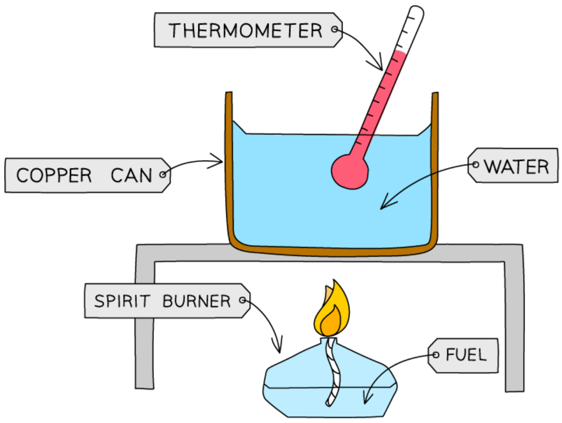


Diagram showing the calorimetry experiment for combustion

Method:

- Using a measuring cylinder, put 100 cm^3 of water into a copper can
- Measure and record the initial temperature of the water
- Fill the spirit burner with test substance and measure and record its mass
- Place the burner under the copper can and light the wick
- Stir the water constantly with the thermometer and continue heating until the spirit burner burns out
- Measure and record the highest temperature of the water

6.1.2 ENERGY TRANSFER cont...

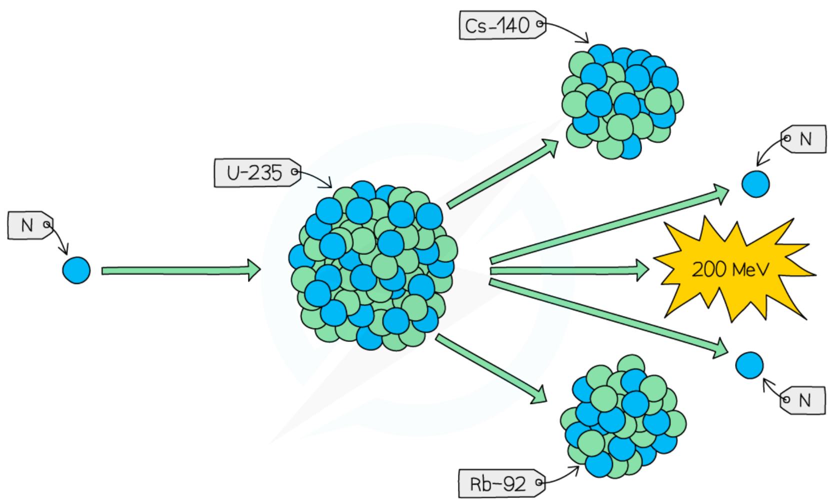
YOUR NOTES

Hydrogen as a fuel

- Hydrogen is used in rocket engines and in fuel cells to power some cars
- Hydrogen has a series of advantages and disadvantages regarding its use as a fuel
- **Advantages**:
  - It releases **more energy** per kilogram than any other fuel (except for nuclear fuels)
  - It does **not pollute** as it only produces water on combustion, no other product is formed
- **Disadvantages**:
  - **Expensive** to produce and requires energy for the production process
  - **Difficult** and **dangerous** to store and move around (usually stored as liquid hydrogen in highly pressurised containers)

Radioactive Isotopes as Fuels

- Uranium-235 undergoes **decay** and gives off heat energy which nuclear power stations harness
- The heat it produces is used to heat water to steam, which in turn is used to power turbines to generate electricity
- Nuclear fuel energy is clean as it does not produce **pollutants** such as CO_2 or oxides of nitrogen or sulfur
- But nuclear power plants are **expensive** to build and maintain as well as being potentially dangerous in the event of an accident as **radioactive** materials may be released



The nuclear fission of a large nucleus of uranium – 235 into smaller daughter nuclei

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A student adds a small amount of ammonium chloride to a beaker of water.
The temperature of the water decreases from 21 oC to 17 oC.

Which type of reaction has occurred and why?

	type of reaction	reason
A	exothermic	heat is released
B	exothermic	heat is absorbed
C	endothermic	heat is released
D	endothermic	heat is absorbed

QUESTION 2

Which of the following processes is endothermic?

A Reacting sodium with water.

B The use of petrol in an engine.

C Distilling crude oil.

D Burning fossil fuels.

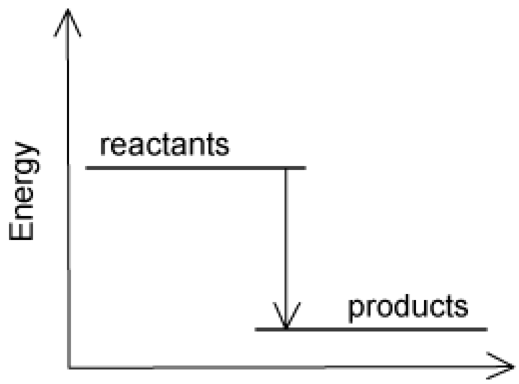
6 CHEMICAL ENERGETICS

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

The energy level diagram below shows the relative energies of the reactants and products in a reaction.



Which row correctly describes the type of reaction and corresponding energy change?

	type of reaction	energy change
A	endothermic	heat is released
B	endothermic	heat is absorbed
C	exothermic	heat is released
D	exothermic	heat is absorbed

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7 CHEMICAL REACTIONS

YOUR NOTES

CONTENTS:

7.1 PHYSICAL & CHEMICAL CHANGES

7.1.1 PHYSICAL & CHEMICAL CHANGES

Physical & Chemical Change

Physical change

- Physical changes (such as **melting** or **evaporating**) do not produce any new chemical substances
- These changes are often **easy to reverse** and mixtures produced are usually relatively easy to separate

Chemical change

- In chemical reactions, **new chemical** products are formed that have very different **properties** to the reactants
- Most chemical reactions are impossible to **reverse**
- Energy changes also accompany chemical changes and energy can be given out (**exothermic**) or taken in (**endothermic**)
- The majority of chemical reactions are exothermic with only a small number being endothermic

7.1.2 RATE (SPEED) OF REACTION

YOUR NOTES

Rates of Reaction Factors

Effect of Concentration

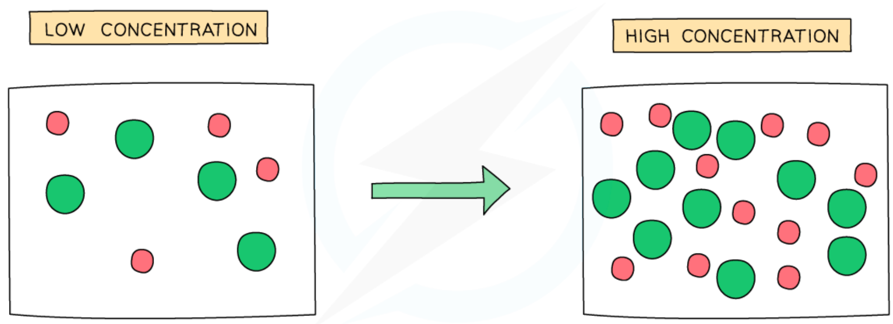


Diagram showing increase in concentration of solution

Explanation:

- **Increase in the concentration of a solution, the rate of reaction will increase**
- This is because there will be more reactant particles in a given volume, allowing more frequent and successful collisions per second, increasing the rate of reaction

Effect of Surface Area

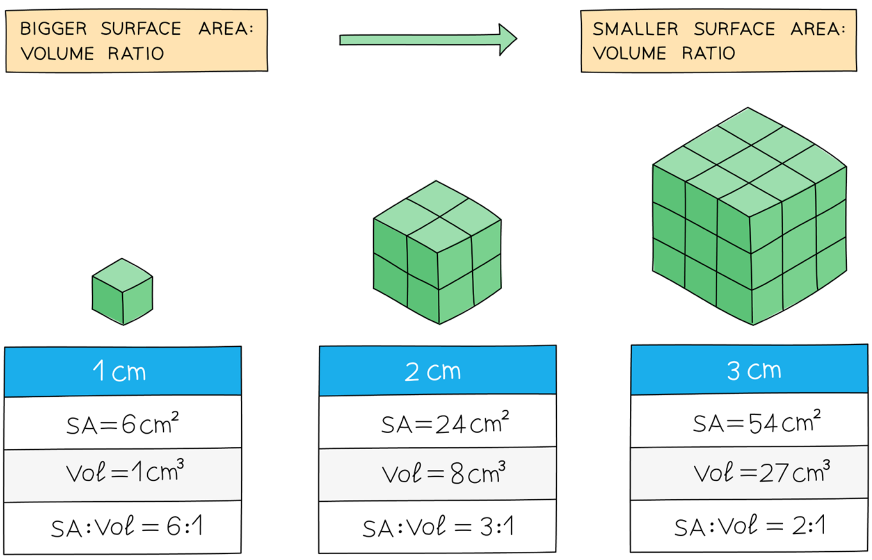


Diagram showing surface area to volume ratio of various sized cubes

Explanation:

- **Increase in the surface area of the solid, the rate of reaction will increase**
- This is because more surface area particles will be exposed to the other reactant so there will be more frequent and successful collisions per second, increasing the rate of reaction

7 CHEMICAL REACTIONS

YOUR NOTES

7.1.2 RATE (SPEED) OF REACTION cont...

Effect of Temperature

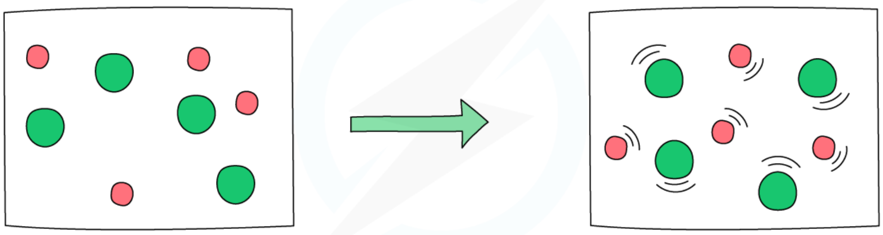
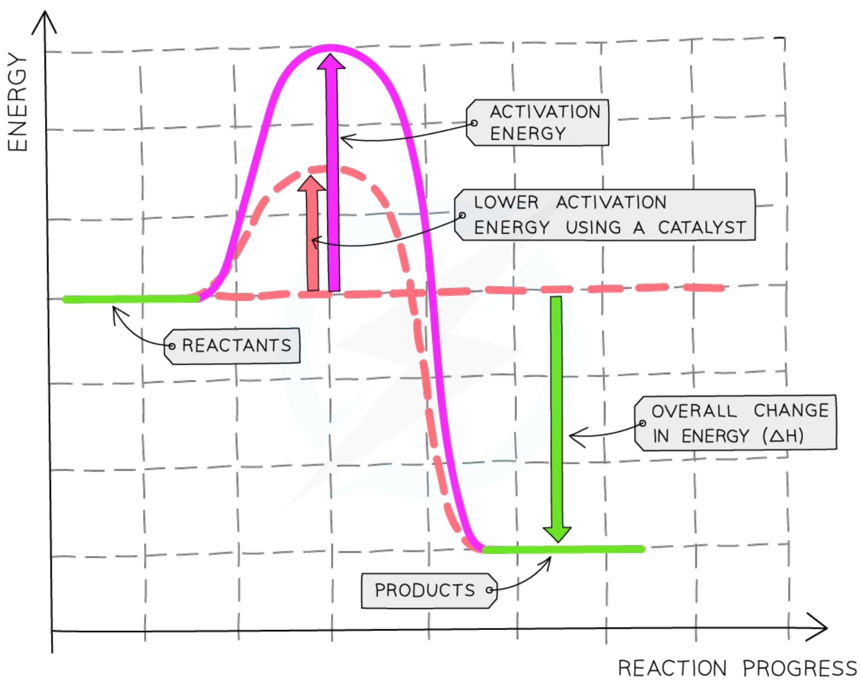


Diagram showing the effect of temperature on particles Explanation:

- **Increase in the temperature, the rate of reaction will increase**
- This is because the particles will have more kinetic energy than the required **activation energy**, therefore there will be more frequent and successful collisions per second, increasing the rate of reaction

Effect of Using a Catalyst



Graph showing the effect of the use of a catalyst on the rate of reaction

Explanation:

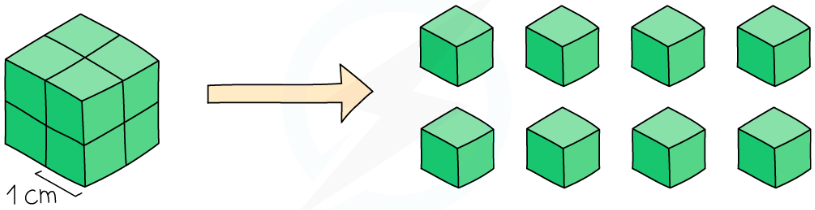
- Catalysts reduce the activation energy as they create alternative pathways requiring lower activation energy, allowing more successful and frequent collisions
- **This shows that when a catalyst is used, the rate of reaction will increase**

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

Explosive Combustion

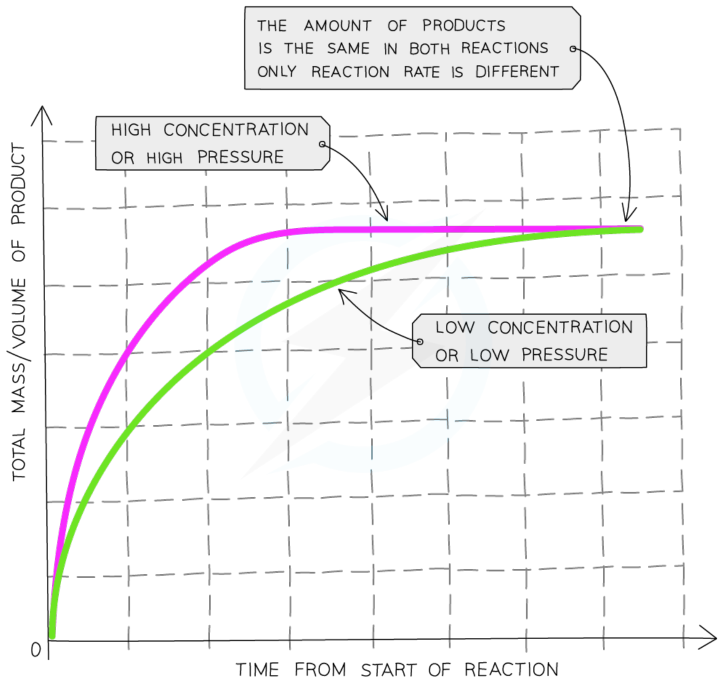
- Explosive combustion occurs when there are many **fine particles** in the air
- Many industrial processes such as metal working, coal mining or flour milling produce very fine and tiny particles
- These particles have a very large **surface area** and are **combustible** in air
- Even a small spark may cause them to ignite and since the surface area is so large, the rate of reaction can be incredibly **fast**, hence they are explosive
- Methane gas mixed with air in coal mines can also form an explosive mixture



A single 2 cm length cube has a surface area of 2 x 2 x 6 = 24cm^2. Cutting it into 8 x 1cm cubes means it now has a surface area of 1 x 1 x 6 x 8 = 48cm^2

Interpreting Data

Concentration



Graph showing the effect of the concentration of a solution on the rate of reaction

7 CHEMICAL REACTIONS

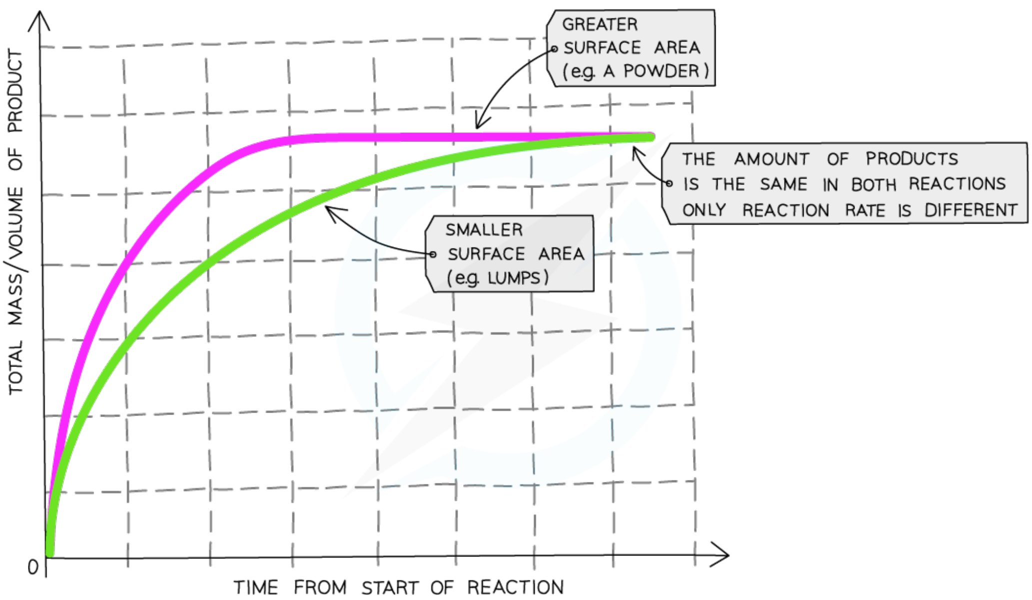
YOUR NOTES

7.1.2 RATE (SPEED) OF REACTION cont…

Explanation:

- Compared to a reaction with a reactant at a low concentration, the graph line for the same reaction but at a higher concentration has a steeper gradient at the start and becomes horizontal sooner
- **This shows that with increased concentration of a solution, the rate of reaction will increase**

Particle Size



Graph showing the effect of the surface area of a solid on the rate of reaction

Explanation:

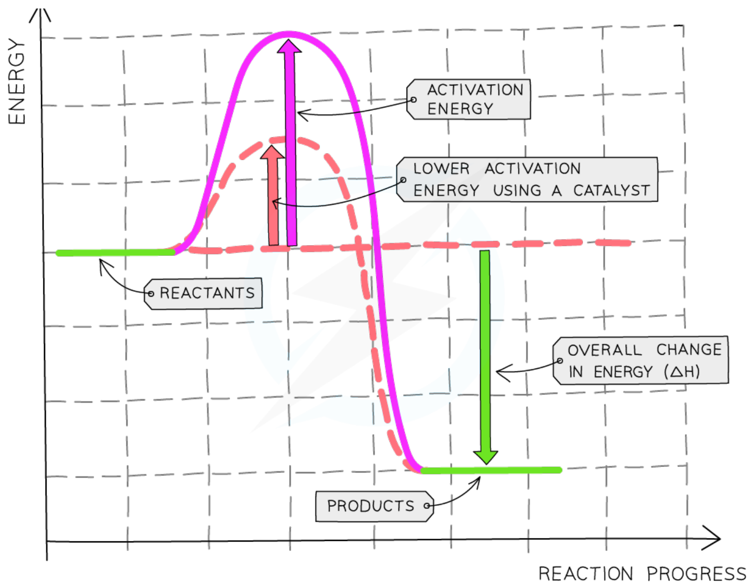
- Compared to a reaction with lumps of reactant, the graph line for the same reaction but with powdered reactant has a steeper gradient at the start and becomes horizontal sooner
- **This shows that with increased surface area of the solid, the rate of reaction will increase**

7 CHEMICAL REACTIONS

YOUR NOTES

7.1.2 RATE (SPEED) OF REACTION cont...

Catalyst

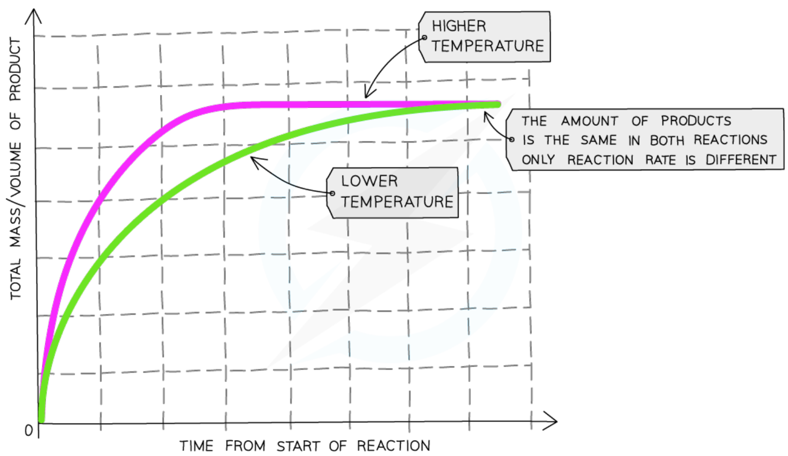


Graph showing the effect of the use of a catalyst on the rate of reaction

Explanation:

- The diagram shows that when a catalyst is used, the activation energy is reduced as it creates an alternative pathway requiring lower activation energy, allowing more successful and frequent collisions
- **This shows that when a catalyst is used, the rate of reaction will increase**

Temperature



Graph showing the effect of temperature on the rate of reaction

Explanation:

- Compared to a reaction at a low temperature, the graph line for the same reaction but at a higher temperature has a steeper gradient at the start and becomes horizontal sooner
- **This shows that with increased temperature, the rate of reaction will increase**

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

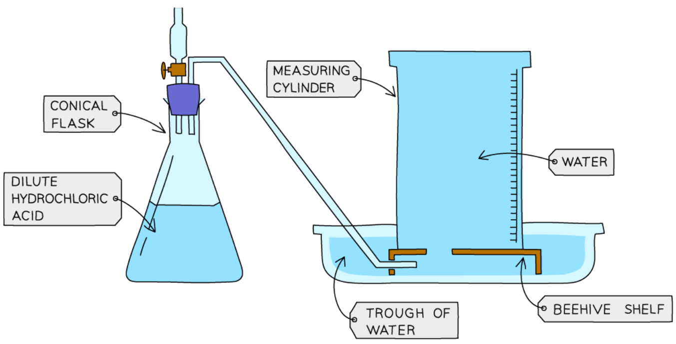
YOUR NOTES

EXTENDED ONLY

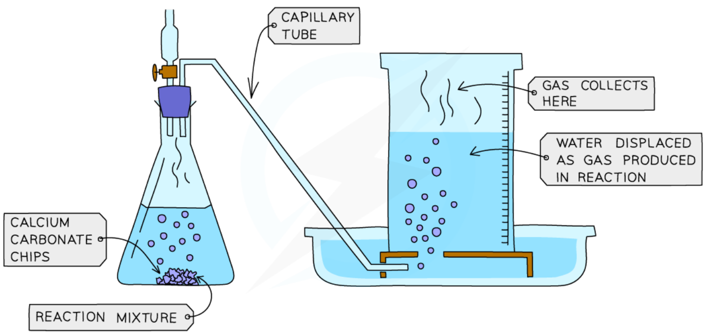
Investigating the Rate of a Reaction

Effect of Surface Area of a Solid on the Rate of Reaction:

1 SET UP EQUIPMENT AS SHOWN



2 ADD CALCIUM CARBONATE CHIPS TO ACID, AFTER A FIXED TIME RECORD THE VOLUME OF WATER DISPLACED



2 REPEAT, USING DIFFERENT FORMS OF CALCIUM CARBONATE

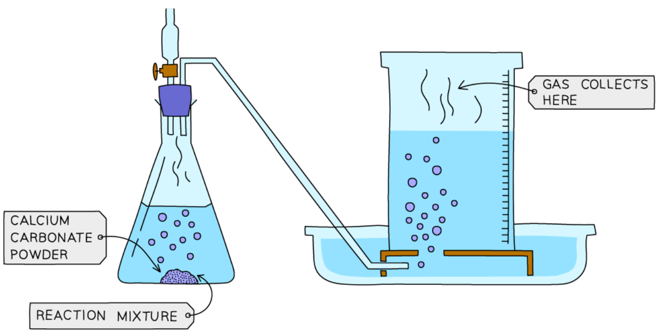


Diagram showing the process of downwards displacement to investigate the effect of the surface area of a solid on the rate of reaction

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

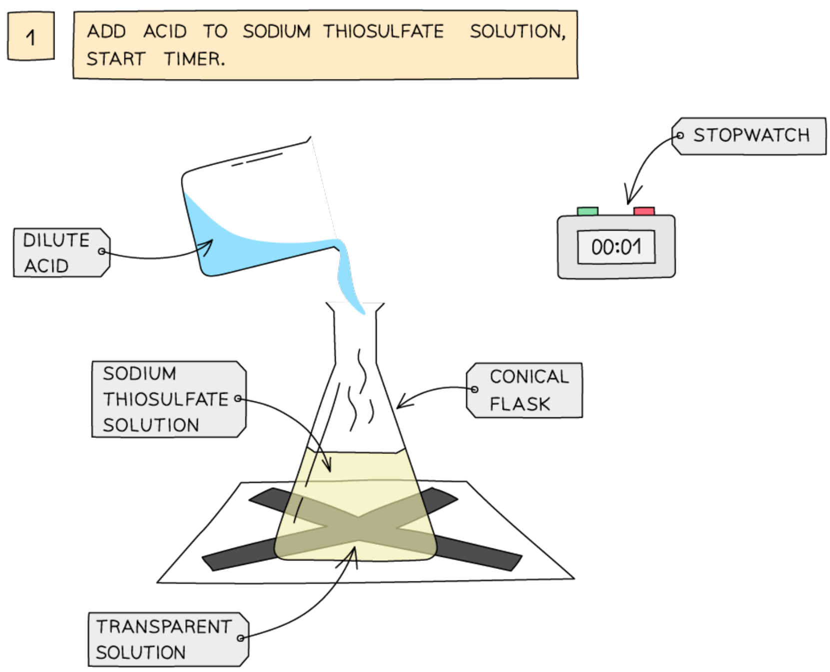
Method:

- Add dilute hydrochloric acid into a conical flask
- Use a capillary tube to connect this flask to a measuring cylinder upside down in a bucket of water (downwards displacement)
- Add calcium carbonate chips into the conical flask and close the bung
- Measure the volume of gas produced in a fixed time using the measuring cylinder
- Repeat with different sizes of calcium carbonate chips (solid, crushed and powdered)

Result:

- Smaller sizes of chips causes an increase in the surface area of the solid, so the rate of reaction will increase
- This is because more surface area of the particles will be exposed to the other reactant so there will be more frequent and successful collisions, increasing the rate of reaction

Effect of Concentration of a Solution on the Rate of Reaction:



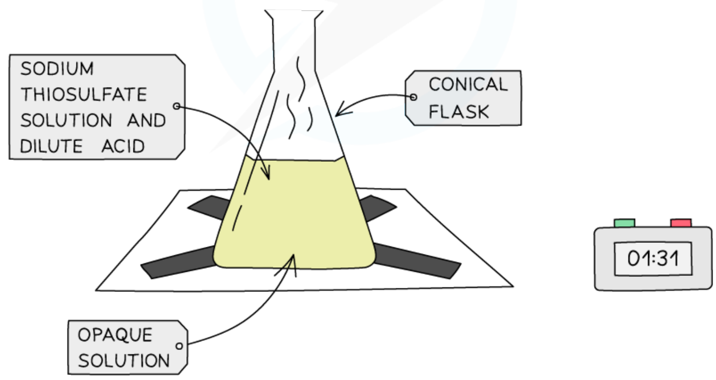
7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

2 STOP TIMER WHEN 'X' IS NO LONGER VISIBLE. RECORD TIME.



3 REPEAT STEPS 1–2 WITH DIFFERENT CONCENTRATIONS OF SODIUM THIOSULFATE (MADE BY MIXING DIFFERENT VOLUMES OF WATER AND SODIUM THIOSULFATE)

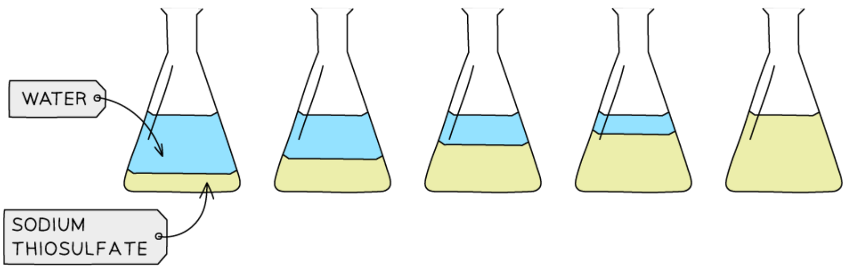


Diagram showing the apparatus needed to investigate the effect of concentration on the rate of reaction

Method:

- Measure 50 cm^3 of Sodium Thiosulfate solution into a flask
- Measure 5 cm^3 of dilute Hydrochloric acid into a measuring cylinder
- Draw a cross on a piece of paper and put it underneath the flask
- Add the acid into the flask and immediately start the stopwatch
- Look down at the cross from above and stop the stopwatch when the cross can no longer be seen
- Repeat using different concentrations of Sodium Thiosulfate solution (mix different volumes of sodium thiosulfate solution with water to dilute it)

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

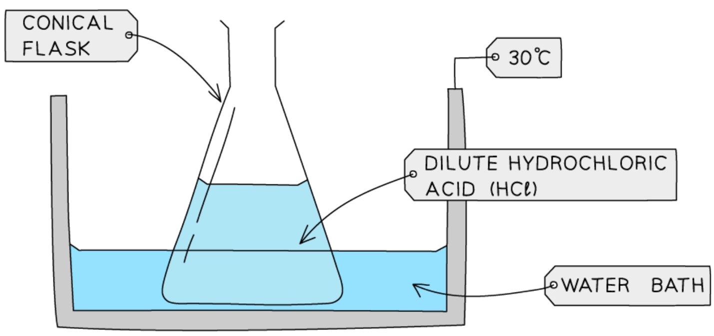
EXTENDED ONLY cont...

Result:

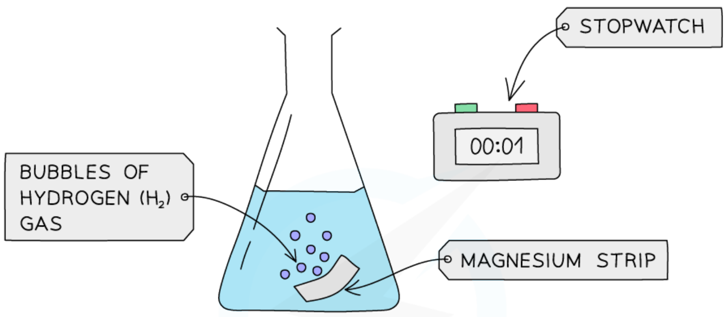
- With an increase in the concentration of a solution, the rate of reaction will increase
- This is because there will be more reactant particles in a given volume, allowing more frequent and successful collisions, increasing the rate of reaction

Effect of Temperature on the Rate of Reaction:

1 HEAT DILUTE HYDROCHLORIC ACID TO A DESIRED TEMPERATURE



2 ADD A STRIP OF MAGNESIUM TO THE DILUTE HCl AND START A STOPWATCH

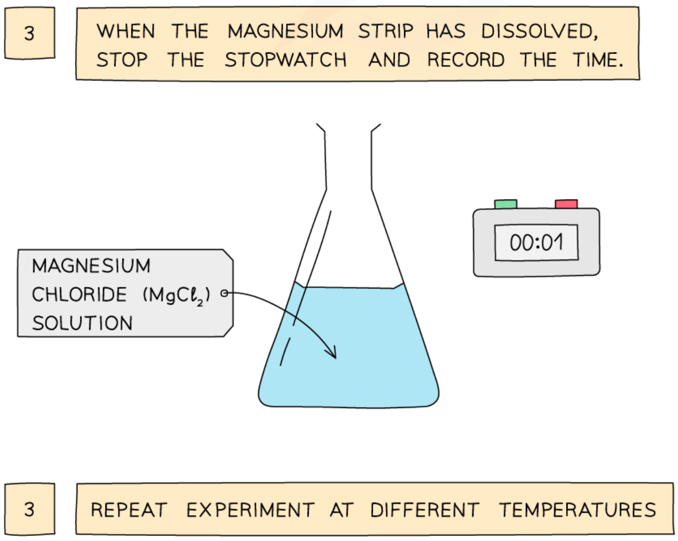


7 CHEMICAL REACTIONS

YOUR NOTES

7.1.2 RATE (SPEED) OF REACTION cont...

EXTENDED ONLY cont...



TEMP (°C)	TIME TO DISSOLVES (S)
10	
20	
30	
40	

Diagram showing the apparatus needed to investigate the effect of temperature on the rate of reaction

Method:

- Dilute Hydrochloric acid is heated to a set temperature using a water bath
- Add the dilute Hydrochloric acid into a conical flask
- Add a strip of Magnesium and start the stopwatch
- Stop the time when the Magnesium fully dissolves
- Repeat at different temperatures and compare results

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

Result:

- With an increase in the temperature, the rate of reaction will increase
- This is because the particles will have more kinetic energy than the required activation energy, therefore more frequent and successful collisions will occur, increasing the rate of reaction

Effect of a Catalyst on the Rate of Reaction:

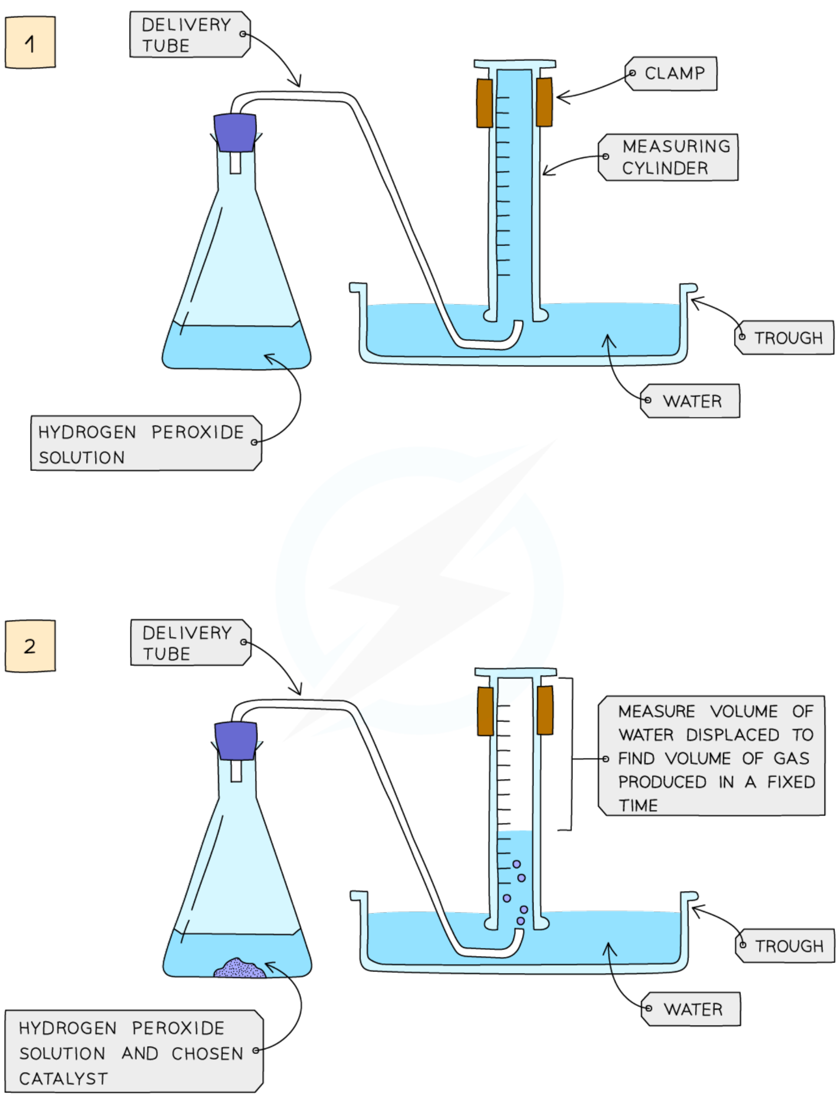


Diagram showing the apparatus needed to investigate the effect of a catalyst on the rate of reaction

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

Method:

- Add Hydrogen Peroxide into a conical flask
- Use a capillary tube to connect this flask to a measuring cylinder upside down in a bucket of water (downwards displacement)
- Add the catalyst Manganese(IV) Oxide into the conical flask and close the bung
- Measure the volume of gas produced in a fixed time using the measuring cylinder
- Repeat experiment without the catalyst of Manganese(IV) Oxide and compare results

Result:

- Using a catalyst will increase the rate of reaction
- The catalyst will provide an alternative pathway requiring lower activation energy so more colliding particles will have the necessary activation energy to react
- This will allow more frequent and successful collisions, increasing the rate of reaction

EXTENDED ONLY

Temperature & Concentration

Temperature

- Particles need to have at least a **minimum amount of energy** to react when they collide
- This is called the **activation energy**
- At low temperatures only a small number of particles will have enough activation energy so the reaction will be slow
- At higher temperatures the particles have **more** kinetic energy so they move faster and with more energy
- The collisions are thus more energetic and there is a greater number of particles with sufficient energy to react, so the rate of reaction increases

7 CHEMICAL REACTIONS

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXTENDED ONLY cont...

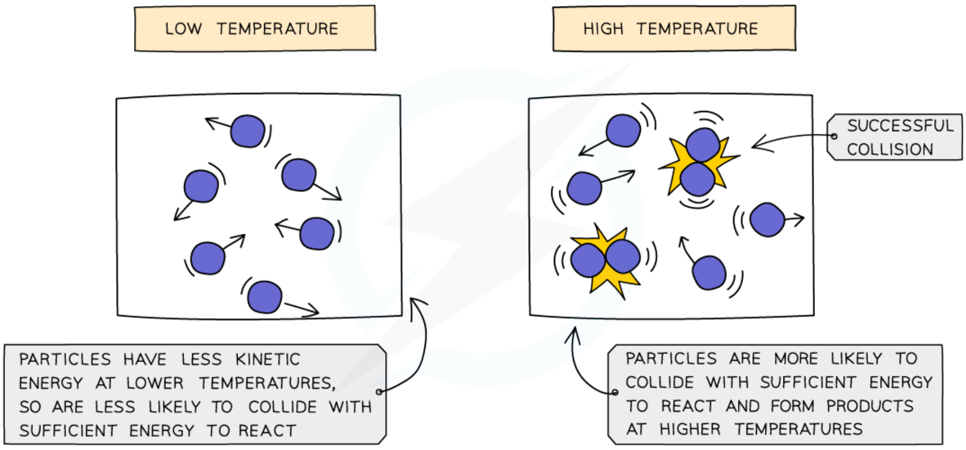


Diagram showing the increased kinetic energy that particles have at higher temperatures

Concentration

- Increasing the concentration means there are more particles per cm3, so there is less space between the particles
- Since there are more particles then it follows that there are more collisions, hence the rate of reaction increases

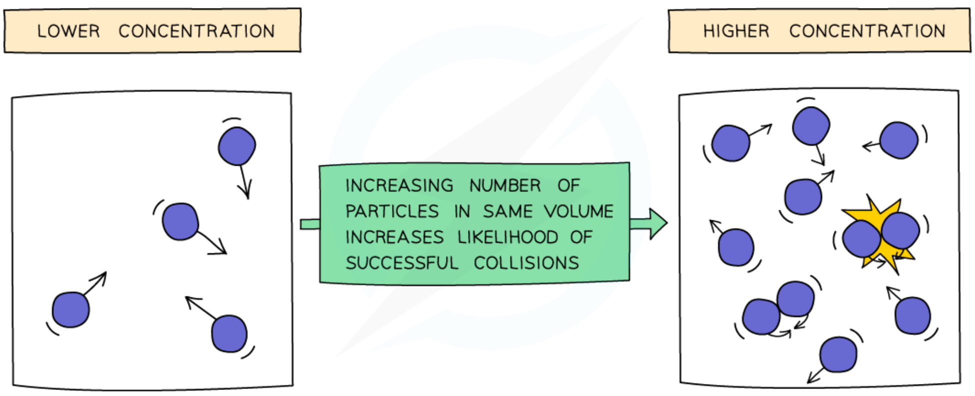


Diagram showing the decreases in space between particles at higher concentrations

7.1.2 RATE (SPEED) OF REACTION cont...

YOUR NOTES

EXAM TIP

When answering questions on the effect of concentration on the rate of reaction, you should mention that there are more particles per unit volume (usually cm^3) and this causes an increase in the rate of collisions.

EXTENDED ONLY

Photochemistry

Photochemical reactions

- These reactions occur only when light is present
- The greater the intensity of ultraviolet light then the greater the rate of reaction
- E.g. the substitution of hydrogen atoms in methane by chlorine:

$$CH_4 + Cl_2 \rightarrow CH_3Cl + HCl$$

Silver salts in photography

- Black and white photography film surfaces contain crystals of silver bromide
- When exposed to light they decompose to silver:

$$2AgBr \rightarrow 2Ag + Br_2$$

- AgBr is colourless at low concentrations but the Ag appears grey-black
- Parts of the film appear black, grey or white depending on the exposure:
    - Stronger light = black or dark grey
    - Weaker light = light grey
    - Not exposed = white

Photosynthesis

- This is the process in which plants produce food for reproduction and growth
- The equation is:

$$6CO_2 + 6H_2O \rightarrow C6H_{12}O6 + 6O_2$$

- The process requires sunlight and chlorophyll
- Chlorophyll is the green pigment in plants which absorbs sunlight and acts as the catalyst for photosynthesis

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which of the following processes represents a physical change?

A Acid base neutralisation

B Metal displacement reactions

C Boiling ethanol

D Combustion of magnesium

QUESTION 2

Physical and chemical changes are different processes. Which of the following row correctly identifies characteristics of each one?

	chemical change	physical change
A	no new substance formed	change of state
B	no new substance formed	involves electron transfer
C	new substance formed	involves electron transfer
D	new substance formed	change of state

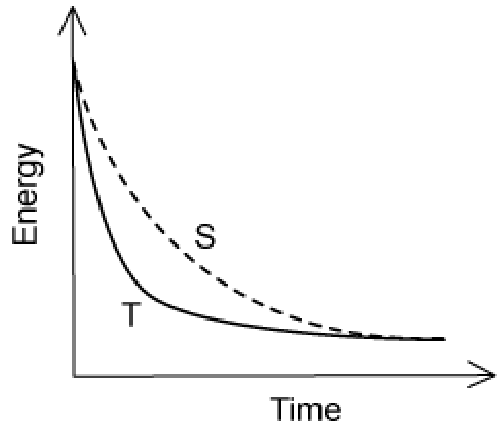
7 CHEMICAL REACTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

A student was investigating the rate of reaction between a solid base and a solution of sulfuric acid. Two experiments were performed, S and T, in which the mass of the reaction flask was recorded as shown in the graph.



Which of the following changes could explain the difference in results between S and T?

A The sulfuric acid is less concentrated in T

B The sulfuric acid is more concentrated in T

C A higher temperature is used in S

D Larger sized particles are used in T

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YOUR NOTES

7.2 REVERSIBLE REACTIONS

Reversible Reactions

Reversible reactions

- Some reactions go to **completion**, where the reactants are used up to form the product molecules and the reaction stops when all of the reactants are used up
- In **reversible reactions**, the product molecules can themselves react with each other or decompose and form the reactant molecules again
- It is said that the reaction can occur in **both** directions: the forward reaction (which forms the products) and the reverse direction (which forms the reactants)

Chemical equations for reversible reactions

- When writing chemical equations for reversible reactions, two arrows are used to indicate the forward and reverse reactions
- Each one is drawn with just half an arrowhead – the top one points to the right, and the bottom one points to the left

Example

- The reaction for the **Haber Process** which is the production of ammonia from hydrogen and nitrogen:

$$N_2 + 3H_2 \rightarrow 2NH_3$$

Hydrated & anhydrous salts

- **Hydrated** salts are salts that contain **water** of crystallisation which affects their molecular shape and colour
- Water of crystallisation is the water that is stoichiometrically included in the structure of some salts during the crystallisation process
- A common example is copper(II) sulfate which crystallises forming the salt copper(II) sulfate pentahydrate, $CuSO_4.5H_20$
- Water of crystallisation is indicated with a dot written in between the salt molecule and the surrounding water molecules
- **Anhydrous** salts are those that have lost their water of crystallisation, usually by heating, in which the salt becomes **dehydrated**

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

Dehydration of Hydrated Copper (II) Sulfate:

Hydrated Copper (II) Sulfate ⇌ Anhydrous Copper (II) Sulfate + Water

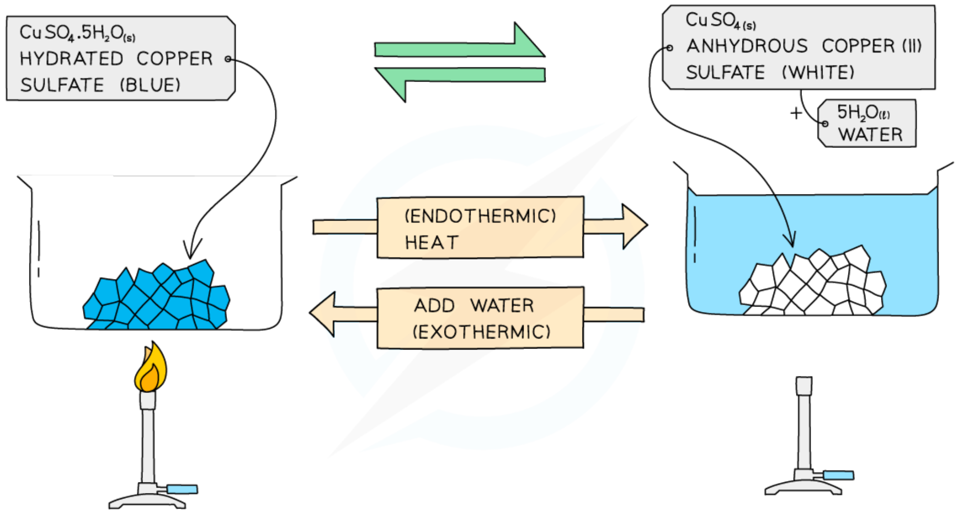


Diagram showing the dehydration of Hydrated Copper (II) Sulfate

Explanation:

When anhydrous copper (II) sulfate crystals are added to water they turn blue and heat is given off (exothermic); this reaction is reversible.

When Copper (II) Sulfate crystals are heated in a test tube, the blue crystals turn into a white powder and a clear, colourless liquid (water) collects at the top of the test tube.

The form of Copper (II) Sulfate in the crystals is known as Hydrated Copper (II) Sulfate because it contains water of crystallisation.

When Hydrated Copper (II) Sulfate is heated, it loses its water of crystallisation and turns into anhydrous Copper (II) Sulfate:

$$CuSO_4.5H_2O\ (s) \rightleftharpoons CuSO_4\ (s) + 5H_2O\ (l)$$

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

Dehydration of Hydrated Cobalt (II) Chloride:

Hydrated Cobalt (II) Chloridee ⇌ Anhydrous Cobalt (II) Chloride + Water

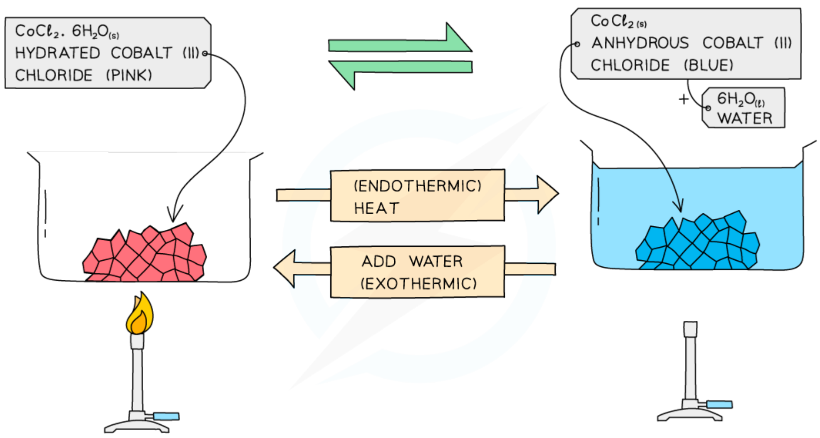


Diagram showing the dehydration of Hydrated Cobalt (II) Chloride

Hydration of Cobalt(II) Chloride

- When anhydrous **blue** cobalt(II) chloride crystals are added to water they turn **pink** and the reaction is **reversible**
- When the cobalt(II) chloride crystals are heated in a test tube, the **pink** crystals turn back to the **blue** colour again as the water of crystallisation is lost
- The form of cobalt(II) chloride in the crystals that are pink is known as hydrated cobalt (II) chloride because it contains water of crystallisation
- When hydrated cobalt(II) chloride is heated, it loses its water of crystallisation and turns into anhydrous cobalt(II) chloride:

$$CoCl_2.6H_2O\ (s) \rightleftharpoons CoCl_2\ (s) + 6H_2O\ (l)$$

EXAM TIP

Both the hydration of CoCl2 and $CuSO_4$ are chemical tests which are commonly used to detect the presence of water.

You should remember the equations and colour changes:

- $CoCl_2 + 6H_2O \rightleftharpoons CoCl_2.6H_2O$ **Blue to pink**
- $CuSO_4 + 5H_2O \rightleftharpoons CuSO_4.5H_2O$ **White to blue**

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXTENDED ONLY

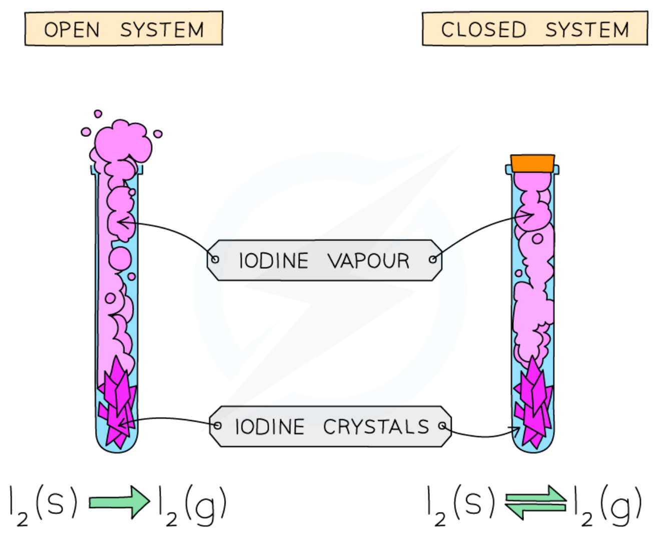
The Concept of Equilibrium

Reversible reactions and equilibrium

- We have already seen that a reversible reaction is one that occurs in **both** directions
- When during the course of reaction, the rate of the forward reaction equals the rate of the reverse reaction, then the overall reaction is said to be in a state of **equilibrium**

Characteristics of a reaction at equilibrium

- It is **dynamic** i.e: the molecules on the left and right of the equation are **changing** into each other by chemical reactions constantly and at the same rate
- The concentration of reactants and products remains **constant** (given there is no other change to the system such as temperature and pressure)
- It only occurs in a **closed system** so that none of the participating chemical species are able to leave the reaction vessel



Equilibrium can only be reached in a closed vessel which prevents reactants or products from escaping system

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXTENDED ONLY cont...

The reaction between H_2 & N_2 in the Haber process

- When only nitrogen and hydrogen are present at the beginning of the reaction, the rate of the forward reaction is at its highest, since the concentrations of hydrogen and nitrogen are at their highest
- As the reaction proceeds, the concentrations of hydrogen and nitrogen gradually decrease, so the rate of the forward reaction will decrease
- However, the concentration of ammonia is gradually increasing and so the rate of the backward reaction will increase (ammonia will decompose to reform hydrogen and nitrogen)
- Since the two reactions are interlinked and none of the gas can escape, the rate of the forward reaction and the rate of the backward reaction will eventually become equal and equilibrium is reached:

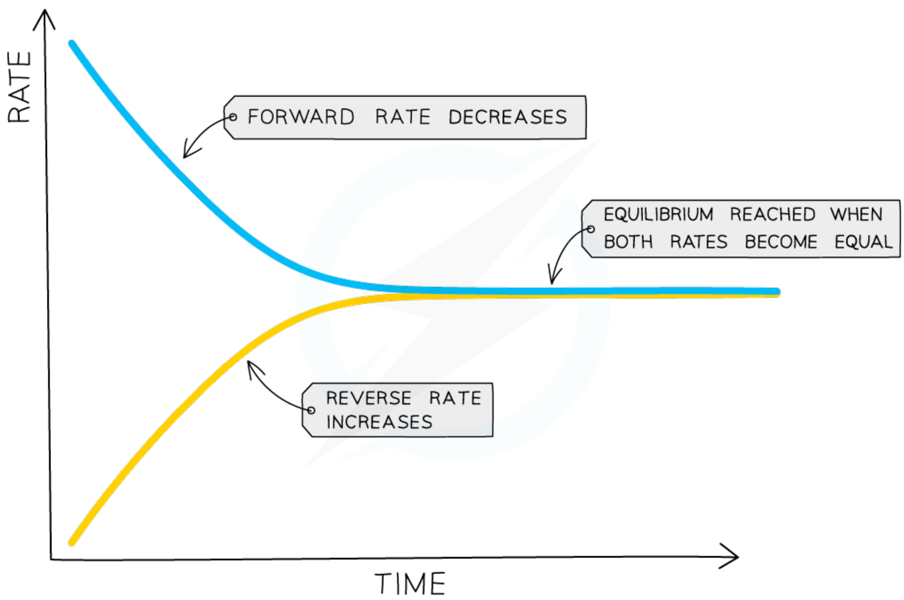


Diagram showing when the rates of forward and backward reactions become equal

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXTENDED ONLY cont...

The position of equilibrium

- **Equilibrium position** refers to the relationship between the concentration of reactants and products at the equilibrium state
- When the position of equilibrium shifts to the **left**, it means the concentration of **reactant** increases
- When the position of equilibrium shifts to **right**, this means the concentration of **product** increases

Effect of catalyst on equilibrium position

- The presence of a catalyst does **not** affect the position of equilibrium but it does increase the rate at which equilibrium is reached
- This is because the catalyst increases the rate of **both** the forward and backward reactions by the same amount (by providing an alternative pathway requiring lower activation energy)
- As a result, the **concentration** of reactants and products is nevertheless the same at equilibrium as it would be without the catalyst

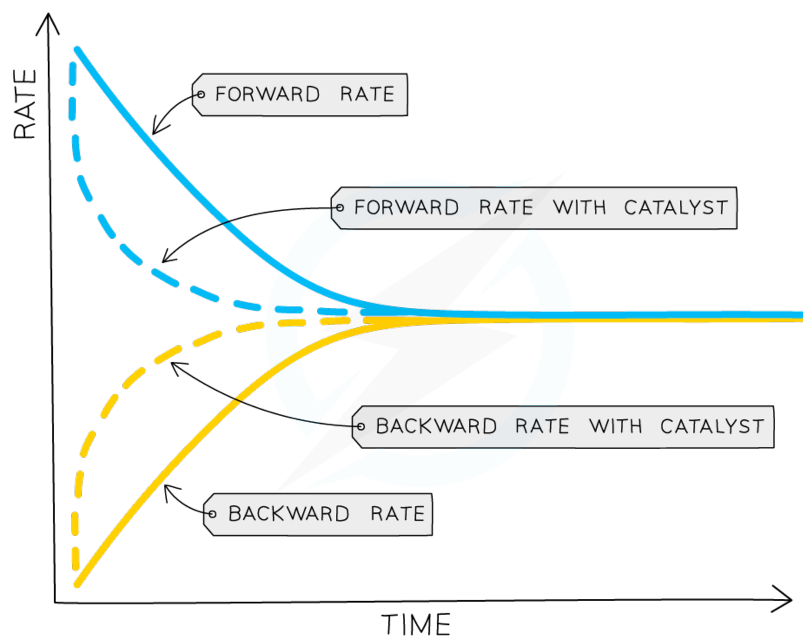


Diagram showing the effect of catalyst on equilibrium position

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXTENDED ONLY

Le Chatelier's Principle

- Le Chatelier's principle states that when a change is made to the conditions of a system at equilibrium, the system automatically moves to oppose the change
- The principle is used to predict changes to the position of equilibrium when there are changes in temperature, pressure or concentration

Effects of temperature

CHANGE	HOW THE EQUILIBRIUM SHIFTS
INCREASE IN TEMPERATURE	EQUILIBRIUM MOVES IN THE **ENDOTHERMIC** DIRECTION TO REVERSE THE CHANGE
DECREASE IN TEMPERATURE	EQUILIBRIUM MOVES IN THE **EXOTHERMIC** DIRECTION TO REVERSE THE CHANGE

Example:

- Iodine Monochloride reacts reversibly with Chlorine to form Iodine Trichloride

$$ICl + Cl_2 \rightleftharpoons ICl_3$$

Dark Brown Yellow

When the equilibrium mixture is heated, it becomes dark brown in colour. Explain whether the backward reaction is exothermic or endothermic:

- Equilibrium has shifted to the left as the colour dark brown means that more of ICl is produced
- Increasing temperature moves the equilibrium in the endothermic direction
- **So the backward reaction is endothermic**

Effects of pressure:

CHANGE	HOW THE EQUILIBRIUM SHIFTS
INCREASE IN PRESSURE	EQUILIBRIUM SHIFTS IN THE DIRECTION THAT PRODUCES THE **SMALLER** NUMBER OF MOLECULES OF GAS TO DECREASE THE PRESSURE AGAIN
DECREASE IN PRESSURE	EQUILIBRIUM SHIFTS IN THE DIRECTION THAT PRODUCES THE **LARGER** NUMBER OF MOLECULES OF GAS TO INCREASE THE PRESSURE AGAIN

7 CHEMICAL REACTIONS

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXTENDED ONLY

Example:

Nitrogen Dioxide can form Dinitrogen Tetroxide, a colourless gas

$$2NO_2 \rightleftharpoons N2O_4$$

Brown Gas — Colourless Gas

Predict the effect of an increase in pressure on the position of equilibrium:

- Number of molecules of gas on the left = 2
- Number of molecules of gas on the right = 1
- An increase in pressure will cause equilibrium to shift in the direction that produces the smaller number of molecules of gas
- **So equilibrium shifts to the right**

Effects of concentration:

CHANGE	HOW THE EQUILIBRIUM SHIFTS
INCREASE IN CONCENTRATION	EQUILIBRIUM SHIFTS TO THE **RIGHT** TO REDUCE THE EFFECT OF INCREASE IN THE CONCENTRATION OF A REACTANT
DECREASE IN CONCENTRATION	EQUILIBRIUM SHIFTS TO THE **LEFT** TO REDUCE THE EFFECT OF A DECREASE IN REACTANT (OR AN INCREASE IN THE CONCENTRATION OF PRODUCT)

Example:

Iodine Monochloride reacts reversibly with Chlorine to form Iodine Trichloride.

$$ICl + Cl_2 \rightleftharpoons ICl_3$$

Dark Brown — Yellow

Predict the effect of an increase in concentration on the position of equilibrium:

- An increase in the concentration of ICl or Cl_2 causes the equilibrium to shift to the **right** so more of the **yellow** product is formed
- A decrease in the concentration of ICl or Cl_2 causes the equilibrium to shift to the **left** so more of the **dark brown** reactant is formed

7.2 REVERSIBLE REACTIONS cont...

YOUR NOTES

EXAM TIP

When the conditions at equilibrium are changed, the system always responds by doing the **opposite**.

For example if the concentration is increased the system tries to reduce it by changing the direction of the reaction or if the temperature is increased, the system will try to reduce the temperature by absorbing the extra heat.

> NOW TRY SOME EXAM QUESTIONS

7 CHEMICAL REACTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Water and a white solid are produced when blue copper(II) sulfate is heated. On the addition of water to the white solid, heat is released and the white solid turns blue.

Which row correctly describes the reaction and the blue copper(II) sulfate?

	type of reaction	blue copper(II) sulfate
A	non-reversible	anhydrous
B	reversible	anhydrous
C	non-reversible	hydrated
D	reversible	hydrated

QUESTION 2

Steam and a blue solid are produced when pink cobalt(II) chloride crystals are heated. With the addition of water to the blue solid, heat is released and the blue solid turns pink.

Which row correctly describes the reaction and the pink cobalt(II) chloride crystals?

	type of reaction	pink cobalt(II) chloride
A	non-reversible	hydrated
B	reversible	hydrated
C	non-reversible	anhydrous
D	reversible	anhydrous

7 CHEMICAL REACTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Which of the following reactions cannot be reversed?

A Melting ice

B Thermal decomposition of hydrated cobalt(II) chloride

C Combustion of propane

D Hydration of anhydrous copper(II) sulfate

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7 CHEMICAL REACTIONS

YOUR NOTES

7.3 REDOX

Oxidation and Reduction

Oxidation and reduction

- Oxidation and reduction take **place together** at the **same time** in the **same reaction**
- These are called **redox** reactions
- There are **three** definitions of **oxidation**. It is a reaction in which:
    - **oxygen** is **added** to an element or a compound
    - an element, ion or compound **loses electrons**
    - the oxidation state of an element is **increased**
- There are **three** definitions of **reduction**. It is a reaction in which:
    - **oxygen** is **removed** from an element or a compound
    - an element, ion or compound **gains electrons**
    - the **oxidation state** of an element is **decreased**

Oxidation state

- The oxidation state (also called oxidation number) is a number assigned to an atom or ion in a compound which indicates the **degree of oxidation** (or reduction)
- The oxidation state helps you to keep track of the movement of electrons in a redox process
- It is written as a +/- sign followed by a number
- E.g: O^{2-} means that it is an atom of oxygen that has an oxidation state of -2. It is not written as O^{2-} as this refers to the ion and its charge

Assigning the oxidation number

- Oxidation number refers to a **single** atom or **ion**
- The oxidation number of a **compound** is **0** and of an **element** (for example Br in Br_2) is also **0**
- The oxidation number of oxygen in a compound is always **-2** (except in peroxide R-O-O-R, where it is **-1**)
- For example in FeO, oxygen is -2 then Fe must have an oxidation number of **+2** as the overall oxidation number for the **compound** must be **0**

Ionic Equations

- **Ionic equations** are used to show only the particles that actually take part in a reaction
- These equations show only the ions that change their status during a chemical process, i.e: their bonding or physical state changes
- The other ions present are not involved and are called **spectator ions**

7 CHEMICAL REACTIONS

7.3 REDOX cont...

YOUR NOTES

Writing ionic equations

- For the neutralisation reaction between hydrochloric acid and sodium hydroxide:

$$HCl(aq) + NaOH(aq) \rightarrow NaCl(aq) + H_2O(l)$$

- If we write out all of the ions present in the equation and include the state symbols, we get:

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

- The **spectator** ions are thus Na^+ and Cl^-. Removing these from the previous equation leaves the overall net ionic equation:

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

- This ionic equation is the **same for all acid-base neutralisation**

Example redox equation: oxygen loss/gain

Zinc oxide + carbon → zinc + carbon monoxide

$$ZnO + C \rightarrow Zn + CO$$

- In this reaction the zinc oxide has been reduced since it has **lost** oxygen. The carbon atom has been oxidised since it has gained oxygen

Example redox equation: electron loss/gain and oxidation state

Zinc + copper sulphate → zinc sulphate + copper

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$$

- Writing this as an ionic equation:

$$Zn(s) + Cu^2 + (aq) + SO4^2 - (aq) \rightarrow Zn^2 + (aq) + SO_4{}^2 - (aq) + Cu(s)$$

- By analysing the ionic equation, it becomes clear that zinc has become oxidised as its oxidation state has **increased** and it has **lost** electrons:

$$Zn(s) \rightarrow Zn^2+(aq)$$

- Copper has been reduced as its oxidation state has **decreased** and it has **gained** electrons:

$$Cu^2 + (aq) \rightarrow Cu(s)$$

EXAM TIP

Use the mnemonic **OIL-RIG** to remember oxidation and reduction in terms of the movement of electrons:

Oxidation **I**s **L**oss – **R**eduction **I**s **G**ain.

7 CHEMICAL REACTIONS

7.3 REDOX cont...

YOUR NOTES

EXTENDED ONLY

Redox Reactions

Oxidising agent

- A substance that oxidises another substance, in so doing becoming itself reduced
- Common examples include hydrogen peroxide, fluorine and chlorine

Reducing agent

- A substance that reduces another substance, in so doing becoming itself oxidised
- Common examples include carbon and hydrogen
- The process of reduction is very important in the chemical industry as a means of extracting metals from their ores

Example:

$$CuO + H_2 \rightarrow Cu + H_2O$$

- In the above reaction, hydrogen is reducing the CuO and is itself oxidised, so the reducing agent is therefore hydrogen
- The CuO is reduced to Cu and has oxidised the hydrogen, so the oxidising agent is therefore copper oxide

Identifying redox reactions

- Redox reactions can be identified by the changes in the oxidation states when a reactant goes to a product

Example:

Chlorine + potassium iodide → potassium chloride + iodine

$$Cl_2 + 2KI \rightarrow 2KCl + I_2$$

Chlorine has become reduced as its oxidation state has decreased from 0 to -1 on changing from the chlorine molecule to chloride ions:

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

- Iodine has been oxidised as its oxidation state has increased from -1 to 0 on changing from iodide ions to the iodine molecule:

$$2I^-(aq) \rightarrow I_2(s)$$

7 CHEMICAL REACTIONS

7.3 REDOX cont...

YOUR NOTES

EXTENDED ONLY cont...

Identifying redox reactions by colour changes

- The tests for redox reactions involve the observation of a colour change in the solution being analysed
- Two common examples are acidified potassium manganate(VII), and potassium iodide
- Potassium manganate (VII), $KMnO_4$, is an oxidising agent which is often used to test for the presence of reducing agents
- When acidified potassium manganate (VII) is added to a reducing agent its colour changes from pink-purple to colourless
- Potassium iodide, KI, is a reducing agent which is often used to test for the presence of oxidising agents
- When added to an acidified solution of an oxidising agent such as aqueous chlorine or hydrogen peroxide, the solution turns a brown colour due to the formation of iodine

> NOW TRY SOME EXAM QUESTIONS

7 CHEMICAL REACTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which row correctly describes oxidation in terms of oxygen, electrons and oxidation state?

	oxygen is	electrons are	oxidation state is
A	added	added	increased
B	added	lost	increased
C	lost	added	decreased
D	lost	lost	decreased

QUESTION 2

Which row correctly describes the process of reduction in terms of oxygen, electrons and oxidation state?

	oxygen is	electrons are	oxidation state is
A	lost	added	unchanged
B	added	lost	increased
C	lost	added	decreased
D	added	lost	increased

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Three reactions are shown below.

$$NO + O_3 \rightarrow NO_2 + O_2$$

$$2C + O_2 \rightarrow 2CO$$

$$2MgO + O_2 \rightarrow 2MgO_2$$

Which row correctly describes the process each reactant molecule undergoes?

	NO	O_3	MgO
A	oxidised	reduced	oxidised
B	oxidised	oxidised	reduced
C	reduced	oxidised	oxidised
D	reduced	reduced	oxidised

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8 ACIDS, BASES & SALTS

YOUR NOTES

CONTENTS:

8.1 ACIDS, BASES & OXIDES

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES

Properties of Acids

Properties of acids

- Acids have pH values of below 7, have a sour taste and are corrosive
- In acidic conditions, blue litmus paper turns **red** and methyl orange **indicator** turns **red**
- Acids are substances that can neutralise a base, forming a salt and water
- When acids react, they will lose electrons to form positively charged **hydrogen ions** (H^+)
- The presence of H+ ions is what makes a solution acidic

Example: Hydrochloric Acid

$$HCl\ (aq) \rightarrow H^+\ (aq) + Cl^-\ (aq)$$

Typical reactions of acids

Acids and metals

- Only metals **above hydrogen** in the reactivity series will react with dilute acids
- When acids react with metals they form a salt and hydrogen gas:

$$\text{Acid} + \text{Metal} \rightarrow \text{Salt} + \text{Hydrogen}$$

Examples of Reaction Between Acids and Metals:

ACID	NAME OF PRODUCTS	EQUATION FOR REACTION
HYDROCHLORIC ACID	METAL CHLORIDE AND HYDROGEN	$M + 2HCl \rightarrow MCl_2 + H_2$
SULFURIC ACID	METAL SULFATE AND HYDROGEN	$M + H2SO_4 \rightarrow MSO_4 + H_2$

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

YOUR NOTES

Acids with Bases (Alkalis)

- Metal **oxides** and metal **hydroxides** can act as **bases**
- When they react with acid, a **neutralisation** reaction occurs
- Acids and bases will react together in a neutralisation reaction and produce a **salt** and **water**:

Acid + Base → Salt + Water

Examples of Reaction Between Acids and Bases:

ACID	NAME OF PRODUCTS	EQUATION FOR REACTION
HYDROCHLORIC ACID	METAL CHLORIDE AND WATER	$MOH + HCl \longrightarrow MCl + H_2O$
SULFURIC ACID	METAL SULFATE AND WATER	$MO + H_2SO_4 \longrightarrow MSO_4 + H_2O$
NITRIC ACID	METAL NITRATE AND WATER	$M(OH)_2 + 2HNO_3 \longrightarrow M(NO_3)_2 + 2H_2O$

Acids with Metal Carbonates

- Acids will react with metal carbonates to form the corresponding metal salt, carbon dioxide and water:

Acid + Metal Carbonate → Salt + Carbon Dioxide + Water

Examples of Reaction Between Acids and Bases:

ACID	NAME OF PRODUCTS	EQUATION FOR REACTION
HYDROCHLORIC ACID	METAL CHLORIDE, CARBON DIOXIDE AND WATER	$MCO_3 + 2HCl \longrightarrow MCl_2 + CO_2 + H_2O$
SULFURIC ACID	METAL SULFATE, CARBON DIOXIDE AND WATER	$MCO_3 + H_2SO_4 \longrightarrow MSO_4 + CO_2 + H_2O$
NITRIC ACID	METAL NITRATE, CARBON DIOXIDE AND WATER	$MCO_3 + 2HNO_3 \longrightarrow M(NO_3)_2 + CO_2 + H_2O$

YOUR NOTES

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

Properties of Bases

Properties of bases

- Bases have pH values of above 7
- A base which is water soluble is referred to as an **alkali**
- In basic (alkaline) conditions red litmus paper turns **blue** and methyl orange indicator turns **yellow**
- Bases are substances which can neutralise an acid, forming a salt and water
- Bases are usually **oxides** or **hydroxides** of metals
- When alkalis react, they gain electrons to form negative hydroxide ions (OH–)
- The presence of the OH– ions is what makes the aqueous solution an alkali

Example: Sodium Hydroxide

$$NaOH\ (s) \rightarrow Na^+\ (aq) + OH^-\ (aq)$$

Typical reactions of bases

Bases and acids

- When they react with an acid, a neutralisation reaction occurs
- Acids and bases react together in a neutralisation reaction and produce a salt and water:

$$\text{Acid} + \text{Base} \rightarrow \text{Salt} + \text{Water}$$

Examples of Reaction Between Bases and Acids:

ACID	NAME OF PRODUCTS	EQUATION FOR REACTION
HYDROCHLORIC ACID	METAL CHLORIDE AND WATER	$MOH + HCl \longrightarrow MCl + H_2O$
SULFURIC ACID	METAL SULFATE AND WATER	$MO + H_2SO_4 \longrightarrow MSO_4 + H_2O$
NITRIC ACID	METAL NITRATE AND WATER	$M(OH)_2 + 2HNO_3 \longrightarrow M(NO_3)_2 + 2H_2O$

Alkalis and ammonium salts

- Ammonium salts undergo **decomposition** when warmed with an alkali
- Even though ammonia is itself a weak base, it is very **volatile** and can easily by displaced from the salt by another alkali
- A salt, water and ammonia are produced

Example:

$$NH_4Cl + NaOH \rightarrow NaCl + H_2O + NH_3$$

YOUR NOTES

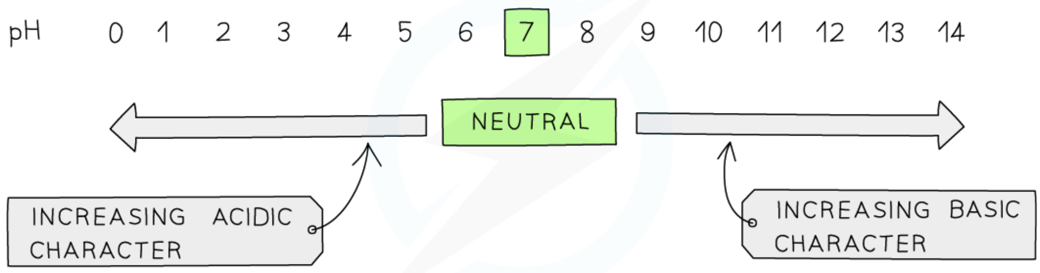
8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

- This reaction is used as a chemical test to confirm the presence of the ammonium ion (NH_4^+)
- Alkali is added to the substance with gentle warming followed by the test for ammonia gas using damp red litmus paper
- The litmus paper will turn from **red** to **blue** if ammonia is present.

Neutrality & Relative Acidity & Alkalinity

The pH scale

- The pH scale is a numerical scale which is used to show how **acidic** or **alkaline** a solution is
- It goes from 1 – 14 (extremely acidic substances can have values of below 1)
- All acids have pH values of **below** 7, all alkalis have pH values of **above** 7
- The **lower** the pH then the more acidic the solution is
- The **higher** the pH then the more alkaline the solution is
- A solution of pH 7 is described as being **neutral** e.g. water



The pH scale showing acidity, neutrality and alkalinity

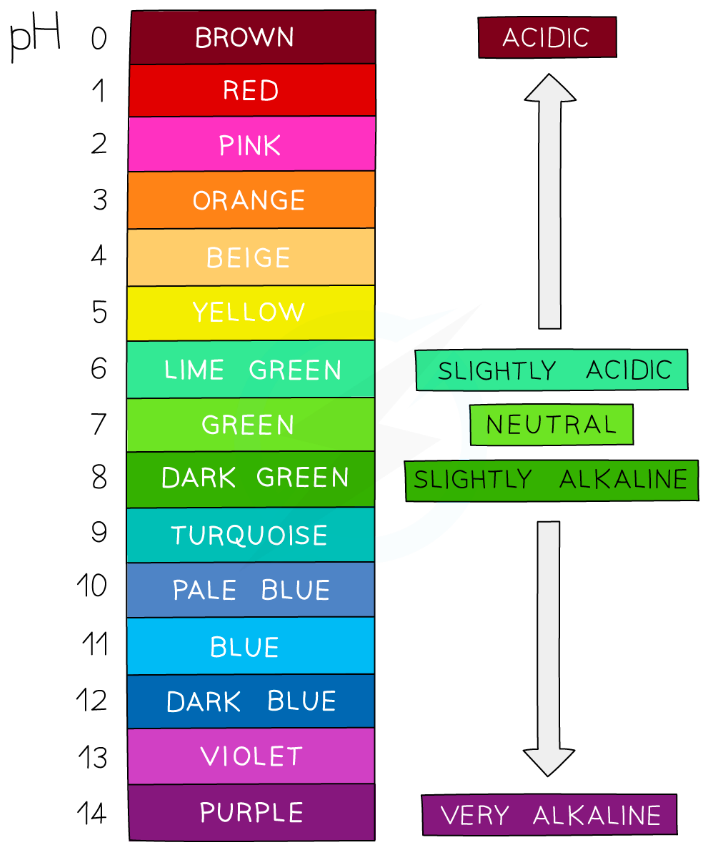
Universal indicator

- Universal indicator is a mixture of different **indicators** which is used to measure the pH
- A drop is added to the solution and the colour is matched with a colour chart which indicates the pH which matches specific colours.

8 ACIDS, BASES & SALTS

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

YOUR NOTES



The pH scale with the Universal Indicator colours which can be used to determine the pH of a solution

The importance of pH and soil acidity

- Soil pH is analysed to indicate the **acidity** or **alkalinity** of soil
- Most plants favour a pH value of between **5.5** and **8**
- Changes in soil which cause a pH to be outside this range adversely affect plant processes resulting in reduced **growth** and **crop yield**
- Soils may become acid from **acid rain**, overuse of **fertilisers** which contain ammonium salts or by the excessive breakdown of organic matter by bacteria
- Crushed or powdered limestone (calcium carbonate) or lime (calcium oxide) or slaked lime (calcium hydroxide) is added to neutralise the excess acidity in the soil
- The addition process must be carefully monitored though, as if added in excess, further damage could be done if the pH goes too high

8 ACIDS, BASES & SALTS

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

YOUR NOTES

EXTENDED ONLY

Proton Transfer & Weak & Strong Acids & Bases

Proton transfer in acids and bases (Alkalis)

Proton transfer

- The earlier definition of an acid and a base can be extended
- In terms of proton transfer, we can further define each substance in how they interact with protons

Acids

- Acids are **proton donors** as they ionize in solution producing protons, H^+ ions
- These H^+ ions make the aqueous solution acidic

Bases (Alkalis)

- Bases (alkalis) are **proton acceptors** as they ionize in solution producing OH^- ions which can accept protons
- These OH^- ions make the aqueous solution alkaline

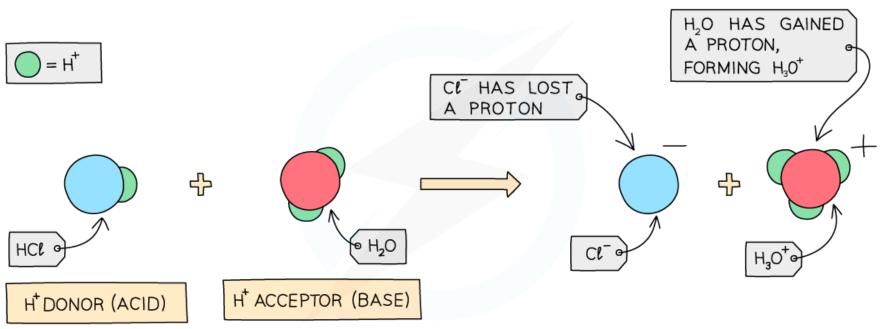


Diagram Showing the Role of Acids and Bases in the Transfer of Protons

Strong acids and bases

- Acids and alkalis can be either **strong** or **weak**, depending on how many ions they produce when dissolved in water
- Strong acids and bases **ionize completely** in water, producing solutions of **very low pH** for an acid or **very high** pH for a base
- Strong acids include HCl and H_2SO_4 and strong bases include the Group I hydroxides

8 ACIDS, BASES & SALTS

8.1.1 THE CHARACTERISTIC PROPERTIES OF ACIDS & BASES cont...

YOUR NOTES

EXTENDED ONLY

Proton Transfer & Weak & Strong Acids & Bases

- Weak acids and bases
- Weak acids and bases **partially** ionize in water and produce pH values which are closer to the **middle** of the pH scale
- Weak acids include organic acids such as ethanoic acid, CH_3COOH and weak bases include aqueous ammonia
- For both weak acids and bases, there is usually an equilibrium set-up between the molecules and their ions once they have been added to water
- Example of a weak acid: propanoic acid

$$CH_3CH_2COOH \rightleftharpoons H^+ + CH_3CH_2COO^-$$

- Example for a weak base: aqueous ammonia

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

- In both cases the equilibrium lies to the **left**, indicating a high concentration of intact acid / base molecules, with a low concentration of ions in solution

Effect of concentration on strong and weak acids and alkalis

- A concentrated solution of either an acid or a base is one that contains a **high number** of acid or base **molecules** per dm^3 of solution
- It does not necessarily mean that the acid or base is strong though, as it may be made from a weak acid or base which does not dissociate
- For example a dilute solution of HCl will be more acidic than a concentrated solution of ethanoic acid, since most of the HCl molecules **dissociate** but very few of the CH_3COOH do.

EXAM TIP

In acid-base chemistry, the terms **strong** and **weak** refer to the ability to dissociate and produce H^+/OH^- ions.

If referring to concentration when answering a question, then the words concentrated or **dilute** should be used.

8.1.2 TYPES OF OXIDES

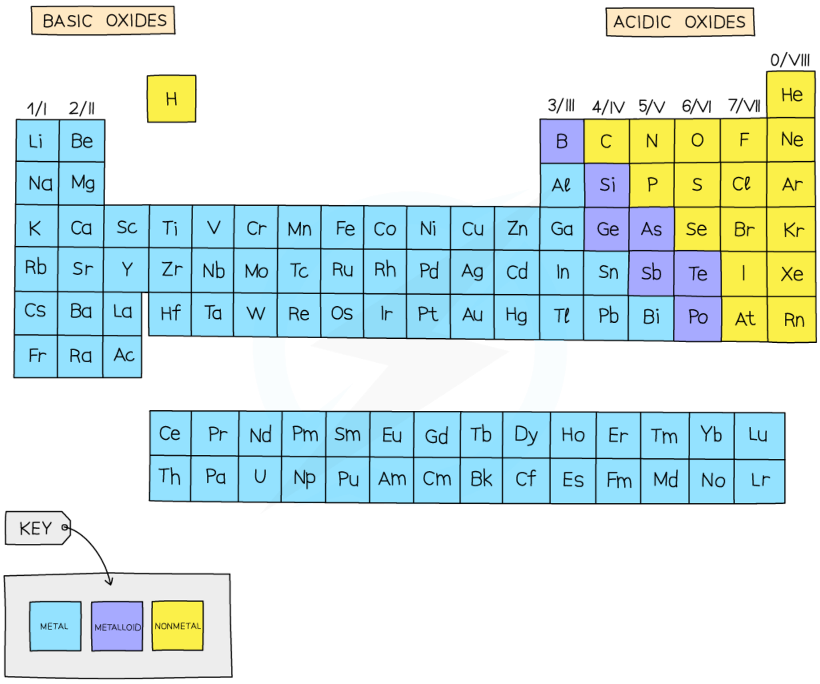
YOUR NOTES

Classifying Oxides

Types of oxide

Acid and basic oxides

- Acidic and basic oxides have different properties and values of pH
- The difference in their pH stems from whether they are bonded to a **metal** or a **nonmetal** element
- The metallic character of the element influences the acidic or alkaline behaviour of the molecule



Metals form basic oxides and hydroxides while nonmetals form acidic oxides

Acidic oxides

- Acidic oxides are formed when a **nonmetal** element combines with oxygen
- They react with bases to form a salt and water
- When dissolved in water they produce an **acidic** solution with a **low** pH
- Common examples include SO_2 and SiO_2

Basic oxides

- Basic oxides are formed when a **metal** element combines with oxygen
- They react with acids to form a salt and water
- When dissolved in water they produce a **basic** solution with a **high** pH
- Common examples include NaOH, KOH and $Ca(OH)_2$

8 ACIDS, BASES & SALTS

8.1.2 TYPES OF OXIDES cont...

YOUR NOTES

EXTENDED ONLY

Neutral & Amphoteric Oxides

Neutral oxides

- Some oxides do not react with either acids or bases and thus are said to be **neutral**
- Examples include N_2O, NO and CO

Amphoteric oxides

- Amphoteric oxides are a curious group of oxides that can behave as **both acidic** and **basic**, depending on whether the other reactant is an acid or a base
- In both cases a salt and water is formed
- Two most common amphoteric oxides are **zinc** oxide and **aluminum** oxide
- The **hydroxides** of both of these elements also behave amphoterically
- Example of aluminium oxide behaving as a base:

$$Al_2O_3 + 6HCl \rightarrow 2AlCl_3 + 3H_2O$$

- Example for an aluminium oxide behaving as an acid:

$$Al_2O_3 + 2NaOH \rightarrow 2NaAlO_2 + H_2O$$

> NOW TRY SOME EXAM QUESTIONS

8 ACIDS, BASES & SALTS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A student is provided with an unmarked beaker containing a colourless solution and asked to identify it. The student decides to perform a series of reactions with the solution and record the observations.

Which of these observations is not indicative of an acid?

A The solution causes blue litmus to turn red.

B On heating and the addition of copper oxide, the solution turns blue.

C On the addition of ammonium carbonate, a colourless, pungent gas is released.

D On the addition of a piece of magnesium, effervescence was produced and the magnesium piece ‘disappeared’ after a few minutes.

QUESTION 2

Which of the following statements is not correct?

A Ammonia is released when a base reacts with an ammonium salt.

B Neutralisation occurs when an acid and an alkali react together.

C Carbon dioxide is released when an acid and a carbonate react together.

D The higher the pH of a solution, the higher its acidity.

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Which of the following properties is not indicative of a base?

A Carbon dioxide is released when it reacts with a carbonate.

B A salt is formed on reaction with an acid.

C Ammonia is released on reaction with an ammonium salt.

D Universal indicator paper turns blue when placed in an alkaline solution.

8 ACIDS, BASES & SALTS

YOUR NOTES

8.2 SALTS & CHEMICAL ANALYSIS

8.2.1 PREPARATION OF SALTS

Preparation, Separation & Purification of Salts

Salts

- A salt is a compound that is formed when the **hydrogen atom** in an acid is replaced by a **metal**
- For example if we replace the H in HCl with a potassium atom, then the salt potassium chloride is formed, KCl
- Salts are an important branch of chemistry due to the varied and important uses of this class of compounds
- These uses include fertilisers, batteries, cleaning products, healthcare products and fungicides

Naming salts

- The name of a salt has two parts
- The first part comes from the **metal**, **metal** oxide or **metal** carbonate used in the reaction
- The second part comes from the **acid**
- The name of the salt can be determined by looking at the reactants
- For example hydrochloric acid always produces salts that end in chloride and contain the **chloride** ion, Cl^-
- Other examples:
  - **Sodium** hydroxide reacts with hydro**chloric** acid to produce sodium chloride
  - **Zinc** oxide reacts with **sulf**uric acid to produce **zinc sulfate**

Preparing salts

- Some salts can be extracted by mining but others need to be prepared in the laboratory
- There are two key ideas to consider when preparing salts:
  - Is the salt being formed **soluble** or **insoluble** in water?
  - Is there **water of crystallisation** present in the salt crystals?

8 ACIDS, BASES & SALTS

8.2.1 PREPARATION OF SALTS cont...

YOUR NOTES

Solubility of the common salts

SALTS	SOLUBLE	INSOLUBLE
SODIUM, POTASSIUM AND AMMONIUM	ALL	NONE
NITRATES	ALL	NONE
ETHANOATES	ALL	NONE
CHLORIDES	MOST ARE SOLUBLE	SILVER AND LEAD (II)
SULFATES	MOST ARE SOLUBLE	BARIUM, CALCIUM AND LEAD (II)
CARBONATES	CARBONATES OF SODIUM, POTASSIUM AND AMMONIUM	MOST ARE INSOLUBLE
HYDROXIDES	HYDROXIDES OF SODIUM, POTASSIUM AND CALCIUM (CALCIUM HYDROXIDE IS SLIGHTLY SOLUBLE)	MOST ARE INSOLUBLE

8 ACIDS, BASES & SALTS

8.2.1 PREPARATION OF SALTS cont...

YOUR NOTES

Preparing soluble salts

Method A: adding acid to a solid metal, base or carbonate

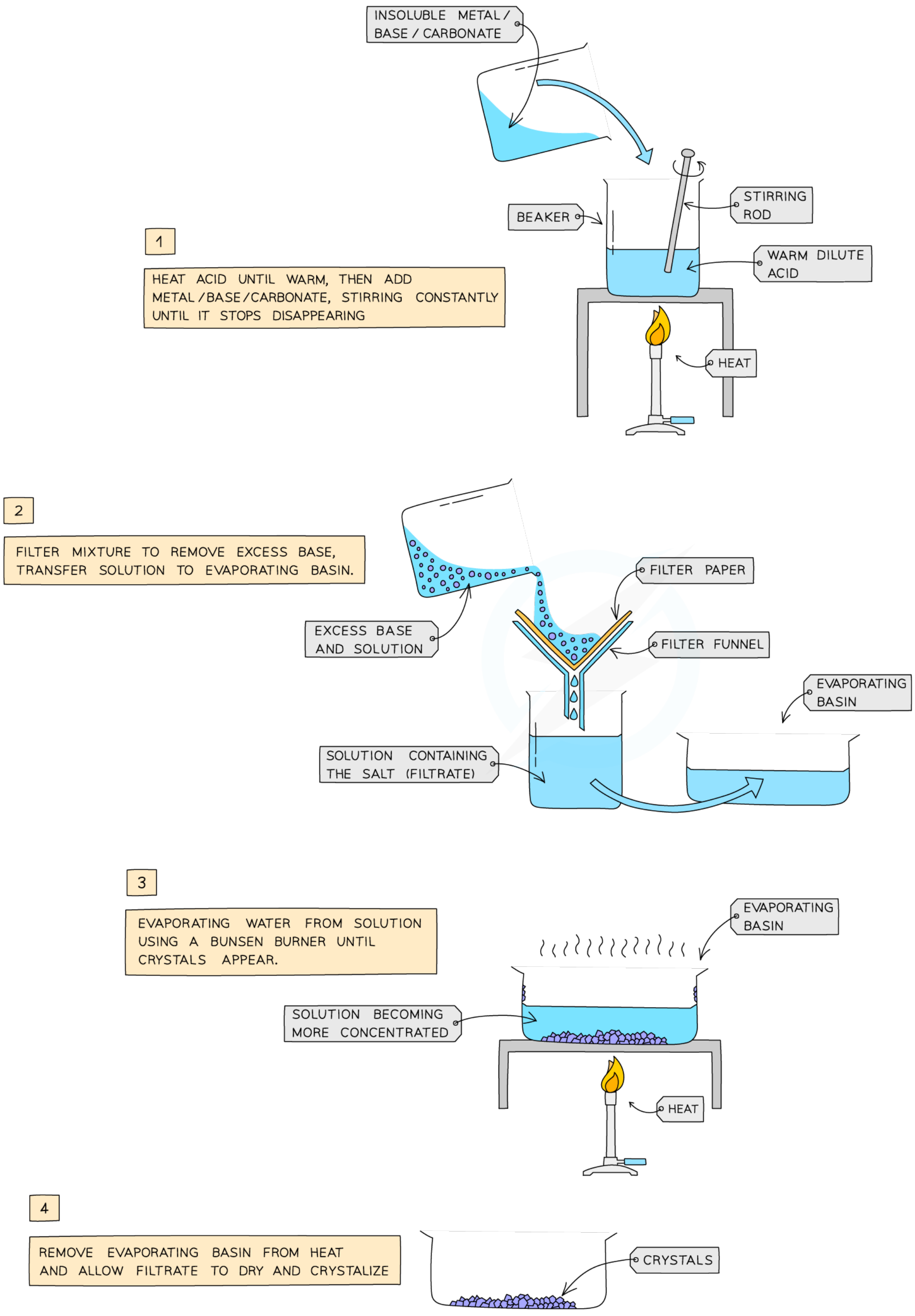


Diagram showing the preparation of soluble salts

YOUR NOTES

8.2.1 PREPARATION OF SALTS cont...

Method:

- Add dilute acid into a beaker and heat using a bunsen burner flame
- Add the insoluble metal, base or carbonate, a little at a time, to the warm dilute acid and stir until the base is in excess (i.e. until the base stops disappearing and a suspension of the base forms in the acid)
- Filter the mixture into an evaporating basin to remove the excess base
- Heat the solution to evaporate water and to make the solution saturated
- Check the solution is saturated by dipping a cold, glass rod into the solution and seeing if crystals form on the end
- Leave the filtrate in a warm place to dry and crystallize
- Decant excess solution and allow crystals to dry

Preparation of Pure, Hydrated Copper (II) Sulfate Crystals using Method A

Acid = Dilute Sulfuric Acid **Insoluble Base** = Copper (II) Oxide

Method:

- Add dilute sulfuric acid into a beaker and heat using a bunsen burner flame
- Add copper (II) oxide (insoluble base), a little at a time to the warm dilute sulfuric acid and stir until the copper (II) oxide is in excess (stops disappearing)
- Filter the mixture into an evaporating basin to remove the excess copper (II) oxide
- Leave the filtrate in a warm place to dry and crystallize
- Decant excess solution
- Blot crystals dry

Equation Of Reaction:

Copper (II) Oxide + Dilute Sulfuric Acid → Copper (II) Sulphate + Water

$CuO\ (s)$ $H_2SO_4\ (aq)$ $CuSO_4\ (s)$ $H_2O\ (l)$

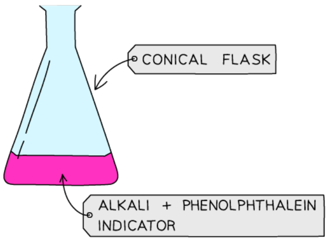
8 ACIDS, BASES & SALTS

8.2.1 PREPARATION OF SALTS cont...

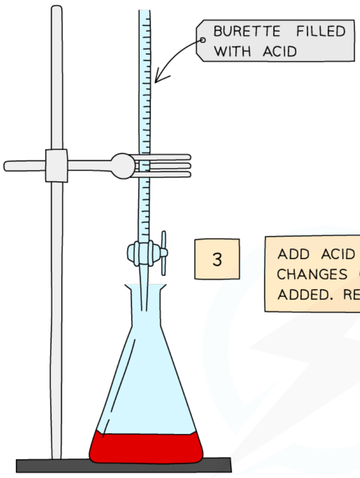
YOUR NOTES

Method B: reacting a dilute acid & alkali

1 ADD ALKALI + INDICATOR TO CONICAL FLASK USING A PIPETTE

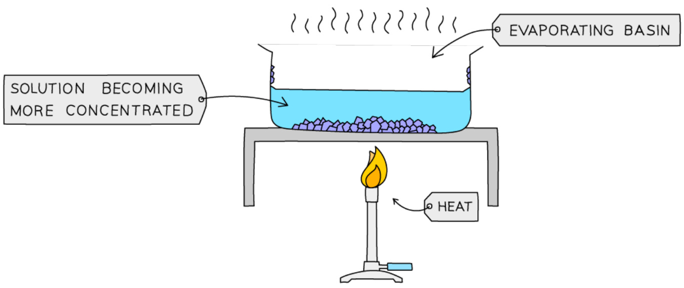


2 ADD ACID TO BURETTE, NOTING THE STARTING VOLUME



3 ADD ACID TO ALKALI SLOWLY UNTIL INDICATOR CHANGES COLOUR. CALCULATE VOLUME OF ACID ADDED. REPEAT STEPS 1–3 WITHOUT INDICATOR

4 TRANSFER SOLUTION TO AN EVAPORATING BASIN, HEAT TO PARTIALLY EVAPORATE WATER.



5 REMOVE EVAPORATING BASIN FROM HEAT AND ALLOW FILTRATE TO DRY AND CRYSTALIZE

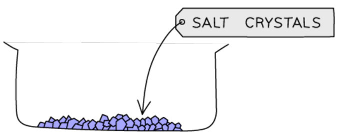


Diagram showing the apparatus needed to prepare a salt by titration

YOUR NOTES

8.2.1 PREPARATION OF SALTS cont...

Method:

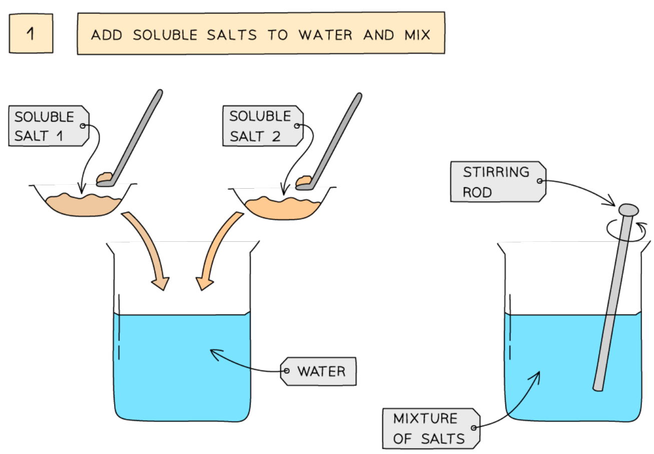
- Use a pipette to measure the alkali into a conical flask and add a few drops of indicator (phenolphthalein or methyl orange)
- Add the acid into the burette and note the starting volume
- Add the acid very slowly from the burette to the conical flask until the indicator changes to appropriate colour
- Note and record the final volume of acid in burette and calculate the volume of acid added (starting volume of acid – final volume of acid)
- Add this same volume of acid into the same volume of alkali without the indicator
- Heat to partially evaporate, leaving a saturated solution
- Leave to crystallise decant excess solution and allow crystals to dry

EXTENDED ONLY

Preparing Insoluble Salts

- Insoluble salts can be prepared using a **precipitation reaction**
- The solid salt obtained is the precipitate, thus in order to successfully use this method the solid salt being formed must be insoluble in water

Using Two Soluble Reactants

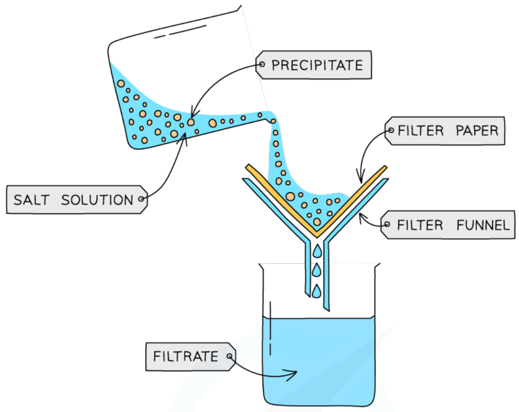


8 ACIDS, BASES & SALTS

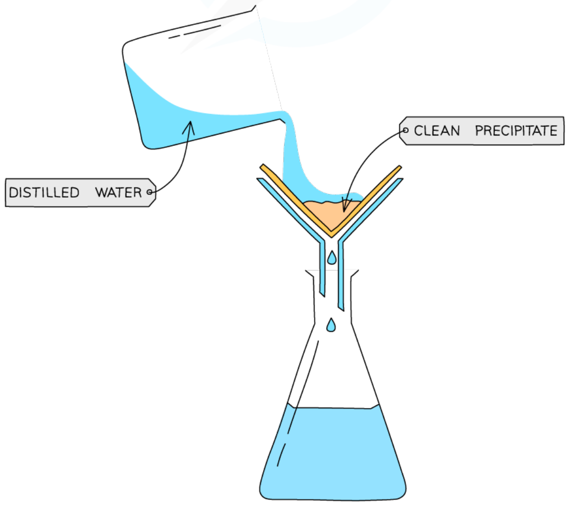
8.2.1 PREPARATION OF SALTS cont...

YOUR NOTES

EXTENDED ONLY



3 WASH THE PRECIPITATE WITH DISTILLED WATER TO REMOVE TRACES OF SOLUTION



4 DRY THE PRECIPITATE (INSOLUBLE SALT) IN AN OVEN

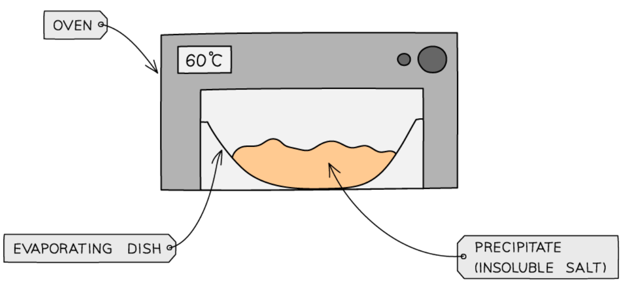


Diagram showing the use of titration to prepare a salt

8.2.1 PREPARATION OF SALTS cont...

YOUR NOTES

EXTENDED ONLY cont...

Method:

- Dissolve soluble salts in water and mix together using a stirring rod in a beaker
- Filter to remove precipitate from mixture
- Wash filtrate with water to remove traces of other solutions
- Leave in an oven to dry

Preparation Of Pure, Dry Lead (II) Sulfate Crystals using a precipitation reaction

- **Soluble Salt 1** = Lead (II) Nitrate **Soluble Salt 2** = Potassium Sulfate

Method:

- Dissolve Lead (II) Nitrate and Potassium Sulfate in water and mix together using a stirring rod in a beaker
- Filter to remove precipitate from mixture
- Wash filtrate with water to remove traces of potassium nitrate solution
- Leave in an oven to dry

Equation of Reaction:

Lead (II) Nitrate + Potassium Sulfate → Lead (II) Sulfate + Potassium Nitrate

$Pb(NO_3)_2$ (s) K_2SO_4 (s) $PbSO_4$ (s) $2KNO_3$ (s)

Selecting a Method of Preparation

- When deciding the method of preparation, if is important to first know whether the salt being produced is soluble or insoluble
- If it is **soluble** than it can be prepared using either method (A or B) for preparing a soluble salt
- If it is **insoluble** then it must be prepared using by **precipitation**

YOUR NOTES

8.2.2 IDENTIFICATION OF IONS & GASES

Identification of Cations

Test for aqueous cations

- Metal cations in aqueous solution can be identified by the **colour** of the precipitate they form on addition of sodium hydroxide and ammonia
- If only a small amount of NaOH is used then normally the **metal hydroxide** precipitates
- In **excess** NaOH some of the precipitates may dissolve
- A few drops of NaOH is added at first and any colour changes or precipitates formed are noted
- Then the NaOH is added in excess and the reaction is observed again
- The steps are repeated for the test using ammonia solution

EXAM TIP

The ammonia or sodium hydroxide solution must be added very slowly.

If it is added too quickly, and the precipitate is soluble in excess, then you run the risk of missing the formation of the initial precipitate, which dissolves as quickly as it it forms if excess solution is added.

Analysing results

- The table below contains the results for each of the cations included in the syllabus
- If a precipitate is formed from either NaOH or aqueous ammonia then the hydroxide is insoluble in water
- Zinc for example reacts as such:

$$ZnCl_2(aq) + 2NaOH(aq) \rightarrow Zn(OH)_2 + H_2O(l)$$

- Ca^{2+} ions can be distinguished from Zn^{2+} and Al^{3+} as CaOH calcium hydroxide precipitate **does not dissolve** in excess NaOH but both zinc hydroxide and aluminium hydroxide do
- Zn^{2+} ions can be distinguished from Al^{3+} ions as ZnOH **dissolves** in excess aqueous ammonia but $Al(OH)_3$ **does not**
- Most transition metals produce hydroxides with distinctive colours

8 ACIDS, BASES & SALTS

8.2.2 IDENTIFICATION OF IONS & GASES cont...

METAL CATION	EFFECT OF ADDING NaOH	EFFECT OF ADDING AMMONIA SOLUTION
ALUMINIUM (Al^{3+})	WHITE PRECIPITATE, DISSOLVES IN EXCESS NaOH TO FORM A COLOURLESS SOLUTION	WHITE PRECIPITATE, INSOLUBLE IN EXCESS AMMONIA, WHITE PRECIPITATE REMAINS
AMMONIUM (NH^{4+})	AMMONIA PRODUCED IF WARMED	–
CALCIUM (Ca^{2+})	WHITE PRECIPITATE, INSOLUBLE SO REMAINS IN EXCESS NaOH	VERY FAINTLY VISIBLE WHITE PRECIPITATE
CHROMIUM (III) (Cr^{3+})	GREEN PRECIPITATE WHICH FORMS A GREEN SOLUTION IN EXCESS	GREY–GREEN PRECIPITATE, INSOLUBLE IN EXCESS
COPPER (II) (Cu^{2})	LIGHT BLUE PRECIPITATE, INSOLUBLE IN EXCESS	LIGHT BLUE PRECIPITATE, SOLUBLE IN EXCESS TO FORM DARK BLUE COLOUR
IRON (II) (Fe^{2+})	GREEN PRECIPITATE, INSOLUBLE IN EXCESS	GREEN PRECIPITATE, INSOLUBLE IN EXCESS
IRON (III) (Fe^{3+})	RED–BROWN PRECIPITATE, INSOLUBLE IN EXCESS	RED–BROWN PRECIPITATE, INSOLUBLE IN EXCESS
ZINC (Zn^{2+})	WHITE PRECIPITATE, DISSOLVES IN EXCESS TO FORM COLOURLESS SOLUTION	WHITE PRECIPITATE, DISSOLVES IN EXCESS TO FORM COLOURLESS SOLUTION

EXAM TIP

Be sure to distinguish between the term “**colourless**” and “**clear**”.

A solution that loses its colour has become colourless.

A clear solution is one that you can see through such as water.

Solutions can be clear **and** have colour e.g. dilute copper sulphate.

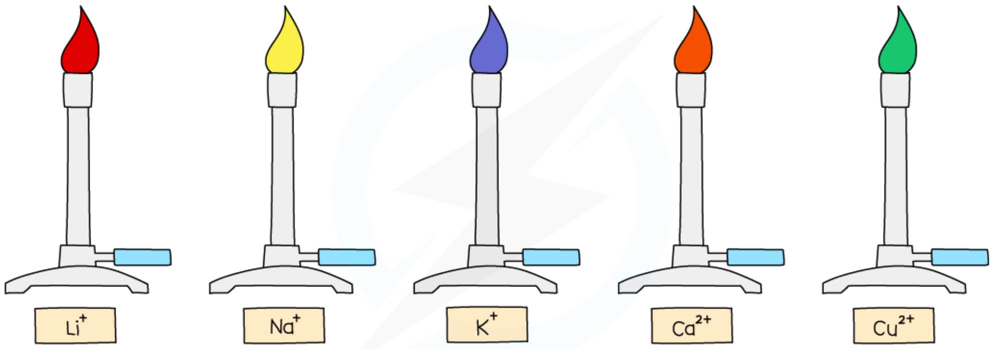
YOUR NOTES

8 ACIDS, BASES & SALTS

8.2.2 IDENTIFICATION OF IONS & GASES cont...

Tests for cations

- The **flame test**
- is used to identify the metal cations by the colour of the flame they produce
- A small sample of the compound is placed on an **unreactive** metal wire such as nichrome or platinum
- The colour of the flame is observed and used to identify the metal



The different coloured flames produced by metal cations during flame tests

CATION	COLOUR OF FLAME
Li^+	RED
Na^+	YELLOW
K^+	LILAC
Ca^{2+}	ORANGE–RED
Cu^{2+}	BLUE–GREEN

8 ACIDS, BASES & SALTS

YOUR NOTES

8.2.2 IDENTIFICATION OF IONS & GASES cont...

Identification of Aqueous Anions

ANION	TEST	RESULT
CARBONATE (CO_3^{2-})	ADD DILUTE ACID AND TEST THE GAS RELEASED	EFFERVESCENCE, GAS PRODUCED IS CO_2 WHICH TURNS LIMEWATER MILKY
CHLORIDE (Cl^-)	ACIDIFY WITH DILUTE NITRIC ACID AND ADD AQUEOUS SILVER NITRATE	WHITE PRECIPITATE FORMED
BROMIDE (Br^-)	ACIDIFY WITH DILUTE NITRIC ACID AND ADD AQUEOUS SILVER NITRATE	CREAM PRECIPITATE FORMED
IODIDE (I^-)	ACIDIFY WITH DILUTE NITRIC ACID AND ADD AQUEOUS SILVER NITRATE	YELLOW PRECIPITATE FORMED
NITRATE (NO_3^{2-})	ADD AQUEOUS NaOH AND ALUMINIUM FOIL, WARM GENTLY AND TEST THE GAS RELEASED	GAS GIVEN OFF IS AMMONIA, HAS A PUNGENT SMELL AND TURNS MOIST RED LITMUS PAPER BLUE
SULFATE (SO_4^{2-})	ACIDIFY WITH DILUTE NITRIC ACID AND ADD AQUEOUS BARIUM NITRATE	WHITE PRECIPITATE FORMED
SULFITE (SO32−)	ADD DILUTE ACID, WARM GENTLY AND TEST THE GAS RELEASED	GAS DECOLOURISES PURPLE ACIDIFIED AQUEOUS POTASSIUM MANGANATE(VII) SOLUTION

EXAM TIP

When it comes to qualitative inorganic analysis, always remember that there will be:

- a test for the metal **cation** part of the molecule
- and another test for the **anion** part.

8 ACIDS, BASES & SALTS

8.2.2 IDENTIFICATION OF IONS & GASES cont...

YOUR NOTES

Identification of Gases

Tests for gases

- Several tests for anions and cations produce **gases** which then need to be tested
- The table below indicates the tests for the gases included in the syllabus

GAS	APPEARANCE OF TEST	TEST	RESULT
AMMONIA (NH_3)	COLOURLESS, PUNGENT SMELL	DAMP RED LITMUS PAPER	TURNS BLUE
CARBON DIOXIDE (CO_2)	COLOURLESS AND ODOURLESS	BUBBLE THROUGH LIMEWATER	LIMEWATER TURNS MILKY/ CLOUDY
CHLORINE (Cl_2)	PALE GREEN, CHOKING SMELL	DAMP BLUE LITMUS PAPER	TURNS RED
HYDROGEN (H_2)	COLOURLESS AND ODOURLESS	HOLD A LIGHTED SPLINT IN MOUTH OF TEST TUBE	BURNS WITH A "SQUEAKY POP" SOUND
OXYGEN (O_2)	COLOURLESS AND ODOURLESS	HOLD A GLOWING SPLINT	SPLINT RELIGHTS
SULFUR DIOXIDE (SO_2)	COLOURLESS, PUNGENT CHOKING SMELL	ADD TO ACIDIFIED AQUEOUS POTASSIUM MANGANATE(VII)	TURNS FROM PURPLE TO COLOURLESS

EXAM TIP

It is easy to confuse the tests for hydrogen and oxygen. Try to remember that:

- a ligHted splint has an H for Hydrogen, while a glOwing splint has an O for Oxygen.

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A student wanted to prepare copper(II) sulfate crystals by reacting solid copper(II) oxide to a solution of hot sulfuric acid.

An extract from the method section of the experimental handout is shown below:

Add the copper(II) oxide in small amounts to the hot acid in the reaction flask and stir until it is …..**1**….. When the reaction has gone to completion the copper(II) oxide will no longer …..**2**….., …..**3**….. and …..**4**….. the solution to obtain the copper(II) sulfate crystals.

	1	2	3	4
A	in excess	precipitate	cool	dissolve
B	in excess	dissolve	filter	cool
C	reacting	dissolve	cool	filter
D	reacting	precipitate	filter	cool

QUESTION 2

Which of the following methods to prepare a salt can be achieved using a burette and a pipette?

A Nitric acid and calcium carbonate to prepare calcium nitrate.

B Sulfuric acid and copper(II) oxide to prepare copper(II) sulfate.

C Hydrochloric acid and zinc to prepare zinc chloride.

D Hydrochloric acid and potassium hydroxide to prepare potassium chloride.

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Copper(II) sulfate can be prepared by reacting solid copper(II) carbonate with hot sulfuric acid. The alkali solid is always added in excess.

Why is the solid reactant added in excess?

A To ensure all of the acid reacts.

B To make the reaction go faster.

C To ensure all of the solid reactant has reacted.

D To increase the product yield.

9 THE PERIODIC TABLE

YOUR NOTES

CONTENTS:

9.1 THE PERIODIC TABLE & TRENDS

9.1.1 THE PERIODIC TABLE

Classifying Elements & Predicting Properties

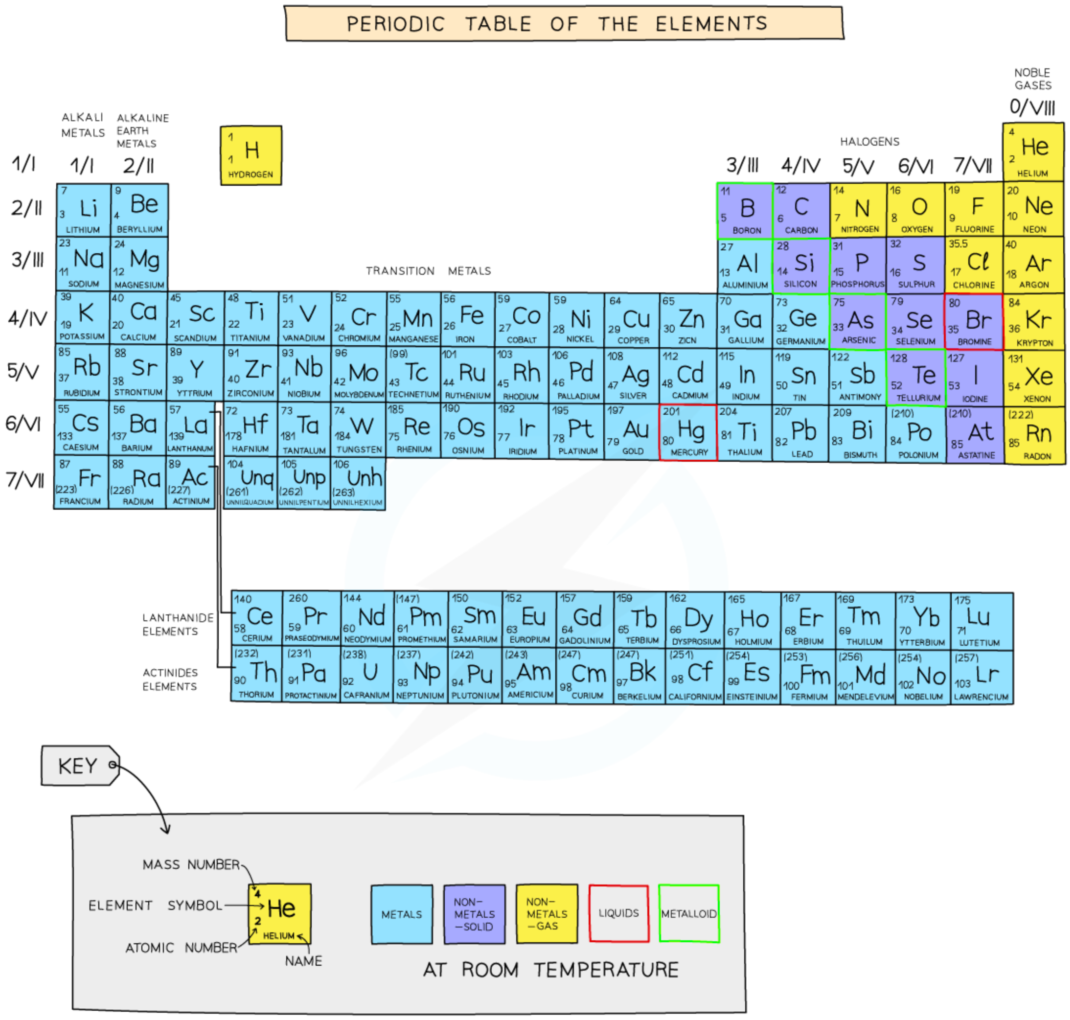
Periodic table

- Elements are arranged on the **periodic table** in order of increasing atomic number, where each element has one proton **more** than the element preceding it
- The table is arranged in vertical columns called **Groups** numbered 1 – 8 and in rows called **Periods**
- **Period**: these are the horizontal rows that show the number of shells of electrons an atom has
    - E.g: elements in Period 2 have two electron shells, elements in Period 3 have three electron shells
- **Group**: these are the vertical columns that show how many outer electrons each atom has
    - E.g: Group 4 elements have atoms with 4 electrons in the outermost shell, Group 6 elements have atoms with 6 electrons in the outermost shell

YOUR NOTES

9.1.1 THE PERIODIC TABLE cont...

Rates of Reaction Factors



All elements are arranged in the order of increasing atomic number from left to right

Predicting properties using the Periodic table

- Because there are **patterns** in the way the elements are arranged on the Periodic table, there are also **patterns** and **trends** in the chemical behaviour of the elements
- There are trends in properties down Groups and across a Period
- All of the Group I elements, for example, react very quickly with water
- In this way the Periodic table can be used to **predict** how a particular element will behave

9 THE PERIODIC TABLE

YOUR NOTES

9.1.2 PERIODIC TRENDS

Element Trends & Electronic Configurations

The metallic character of the elements

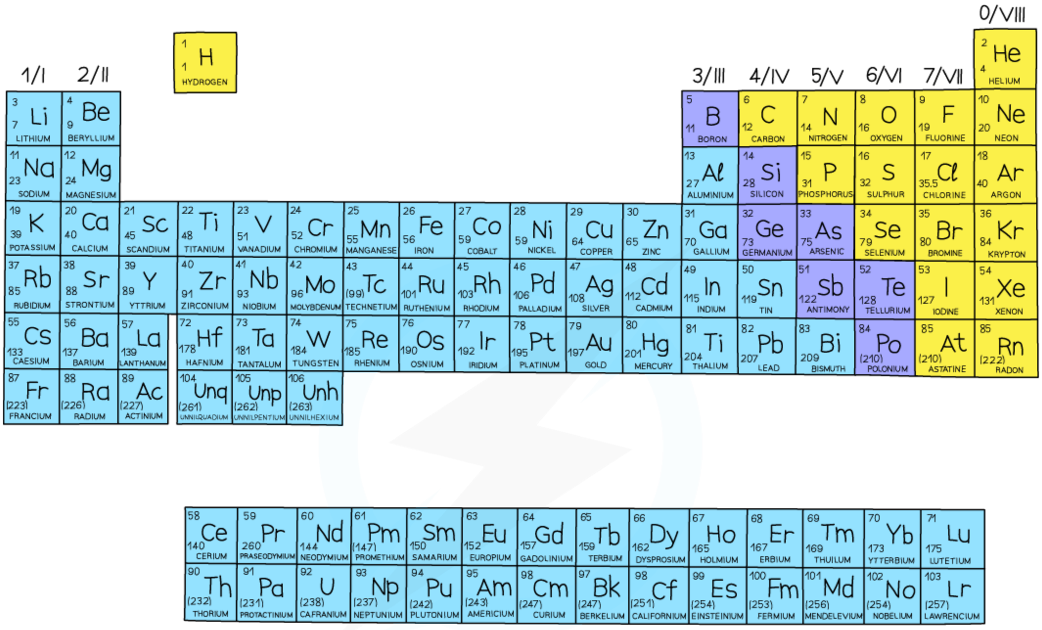
- The metallic character of the elements **decreases** as you move across a Period on the Periodic table, from **left to right**, and it **increases** as you move down a Group
- This trend occurs due to atoms more **readily accepting** electrons to fill their **valence shells** rather than losing them to have the below, already full, electron shell as their outer shell
- Metals occur on the **left-hand** side of the Periodic table and nonmetals on the **right-hand** side
- Between the metals and the nonmetals lie the elements which display some properties of **both**
- These elements are referred to as **metalloids** or semi-metals

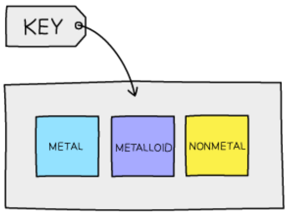
Properties of metals and nonmetals

PROPERTY	METALS	NON-METALS
ELECTRON ARRANGEMENT	1 – 3 (MORE IN PERIODS 5 & 6) OUTER SHELL ELECTRONS	4 – 7 ELECTRONS IN THE OUTER SHELL
BONDING	METALLIC DUE TO LOSS OF OUTER SHELL ELECTRONS	COVALENT BY SHARING OF OUTER SHELL ELECTRONS
ELECTRICAL CONDUCTIVITY	GOOD CONDUCTORS OF ELECTRICITY	POOR CONDUCTORS OF ELECTRICITY
TYPE OF OXIDE	BASIC OXIDES (A FEW ARE AMPHOTERIC)	ACIDIC OXIDES (SOME ARE NEUTRAL)
REACTION WITH ACIDS	MANY REACT WITH ACIDS	DO NOT REACT WITH ACIDS
PHYSICAL CHARACTERISTICS	MALLEABLE, CAN BE BENT AND SHAPED HIGH MELTING AND BOILING POINT	FLAKY, BRITTLE LOW MELTING AND BOILING POINT

9 THE PERIODIC TABLE

9.1.2 PERIODIC TRENDS cont...





A zig – zag line in this diagram separates the metals on the left, from the non – metals on the right

Electronic configuration & the Periodic table

- The electronic configuration is the arrangement of electrons into shells for an atom (e.g electronic configuration of carbon is 2, 4)
- There is a link between the electronic configuration of the elements and their position on the Periodic table
- The number of notations in the electronic configuration will show the number of shells of electrons the atom has, showing the **Period**
- The last notation shows the number of outer electrons the atom has, showing the **Group** number

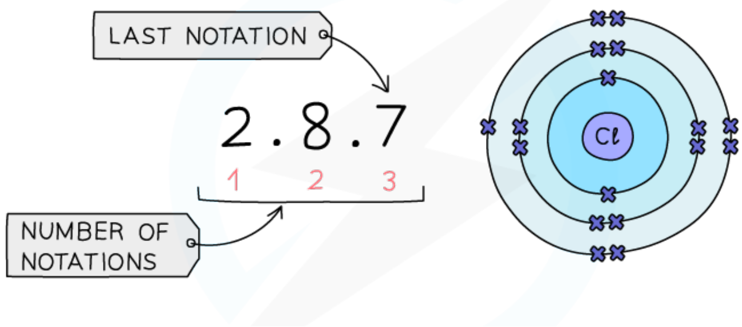
Example: Electronic configuration of **Chlorine**:

YOUR NOTES

9 THE PERIODIC TABLE

YOUR NOTES

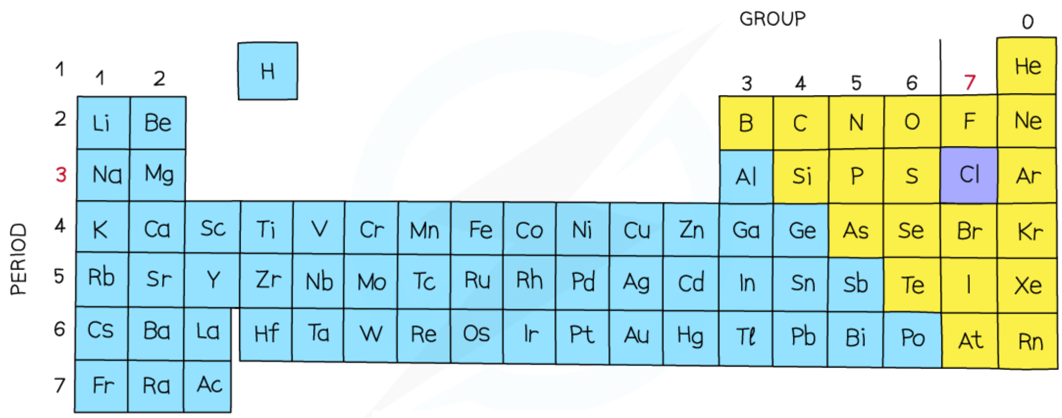
9.1.2 PERIODIC TRENDS cont...



The electronic configuration of chlorine as it should be written

Period: The red numbers at the bottom show the number of notations which is 3, showing that a chlorine atom has 3 shells of electrons

Group: The green box highlights the last notation which is 7, showing that a chlorine atom has 7 outer electrons



The position of chlorine on the Periodic table

Chemical properties of elements in the same group

- Elements in the same Group in the Periodic table have similar chemical properties
- When atoms collide and react, it is the **outermost electrons** that interact
- The similarity in their chemical properties stems from having the **same number** of electrons in their outer shell
- For example, both lithium and sodium are in Group 1 and can react with elements in Group 7 to form an ionic compound (charges of Group 1 ions are +1, charges of Group 7 ions are -1)

> NOW TRY SOME EXAM QUESTIONS

9 THE PERIODIC TABLE

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which one of the following names does not correspond to a group of elements on the Periodic table?

A Alkali

B Group VI

C Alloys

D Halogens

QUESTION 2

Group VIII elements are known as the noble gases. What name is given to the elements in Group II?

A Transition metals

B Alkali metals

C Alkaline earth metals

D None of the above

QUESTION 2

Which class of elements are useful for making semiconductors?

A Elements from Group III

B Some transition metals

C Group VI elements

D Semi-metal elements

9 THE PERIODIC TABLE

YOUR NOTES

9.2 GROUP & ELEMENT PROPERTIES

9.2.1 GROUP PROPERTIES

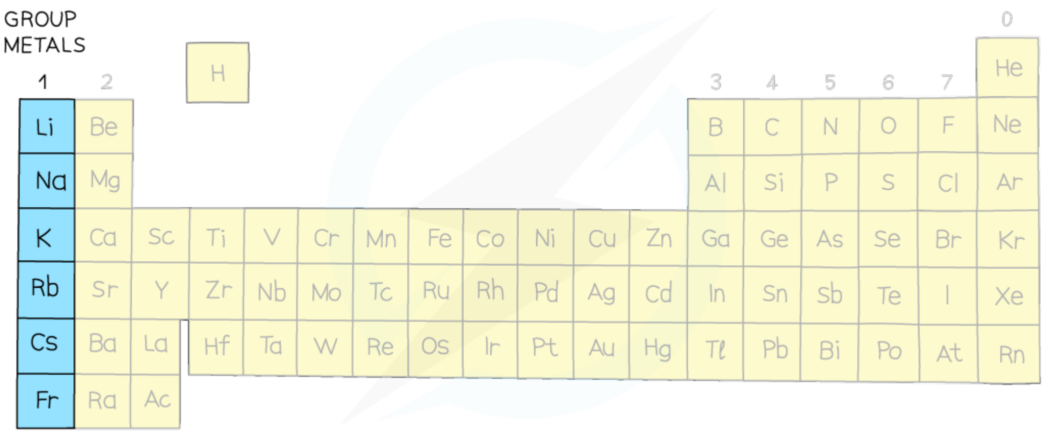
Element Trends & Electronic Configurations

The Group I metals

- The Group I metals are also called the alkali metals as they form **alkaline solutions** with high pH values when reacted with water
- Group 1 metals are lithium, sodium, potassium, rubidium, caesium and francium
- They all contain just **one electron** in their outer shell

Physical properties of the Group I metals

- The Group I metals:
  - Are soft and easy to cut, getting **softer** and **more dense** as you move down the Group (sodium and potassium do not follow the trend in density)
  - Have **shiny** silvery surfaces when freshly cut
  - Conduct **heat** and **electricity**
  - They all have **low** melting points and low densities and the melting point **decreases** as you move down the Group



The alkali metals lie on the far left-hand side of the Periodic table

Chemical properties of the Group I metals

- They react readily with oxygen and water vapour in air so they are usually kept under **oil** to stop them from reacting.
- Group 1 metals will react similarly with water, reacting vigorously to produce an **alkaline** metal hydroxide solution and hydrogen gas.

9 THE PERIODIC TABLE

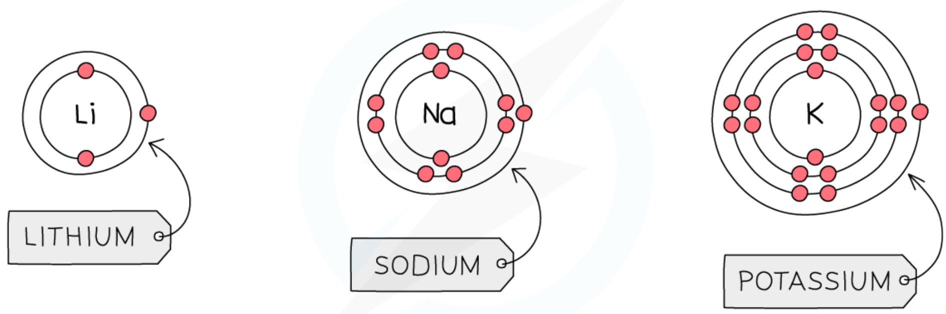
YOUR NOTES

9.2.1 GROUP PROPERTIES cont...

Reactions of the Group I metals and water

ELEMENT	REACTION
LITHIUM	$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$ – REACTION SLOWER THAN WITH SODIUM – BUBBLES OF HYDROGEN GAS – LITHIUM'S MELTING POINT IS HIGHER AND HEAT ISN'T PRODUCED SO QUICKLY, SO THE LITHIUM DOESN'T MELT.
SODIUM	$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$ – BUBBLES OF HYDROGEN GAS – MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE – FLOATS ON WATER BECAUSE IT IS LESS DENSE – MELTS BECAUSE SODIUM HAS A LOW MELTING POINT AND A LOT OF HEAT IS MADE IN THE REACTION – HYDROGEN IS EVOLVED WHICH CAUSES THE BALL OF SODIUM TO MOVE AROUND THE SURFACE OF THE WATER. – WHITE TRAIL OF SODIUM HYDROXIDE PRODUCED WHICH DISSOLVES IN THE WATER PRODUCING A HIGHLY ALKALINE SOLUTION.
POTASSIUM	$2K(s) + 2H_2O(l) \rightarrow 2KOH(aq) + H_2(g)$ – REACTS MORE VIOLENTLY THAN SODIUM – BUBBLES OF GAS – MELTS INTO A SHINY BALL THAT DASHES AROUND THE SURFACE – ENOUGH HEAT PRODUCED SO HYDROGEN BURNS WITH A LILAC – COLOURED FLAME

Electronic configuration and reactivity in Group I



The electronic configuration of the first three elements in Group I

9 THE PERIODIC TABLE

YOUR NOTES

9.2.1 GROUP PROPERTIES cont...

Explaining the trend in reactivity in Group I

- The reactivity of the Group 1 metals increases as you go down the group
- Each outer shell contains only one electron so when they react, they lose the outer electron which empties the outermost shell
- The next shell down automatically becomes the outermost shell and is **already full**, hence the atom obtains an electronic configuration which has a full outer shell of electrons
- As you go down Group 1, the number of shells of electrons increases by 1 (Period number increases down the Periodic table)
- This means that the outer electron is further away from the nucleus so there are **weaker electrostatic** forces of attraction
- This requires **less energy** to overcome the electrostatic forces of attraction between the negatively charged electron and the positively charged nucleus
- This allows the electron to be lost easily, making it more reactive as you go down the Group

Properties of other Alkali Metals (Rubidium, Caesium & Francium):

- As the reactivity of alkali metals increases down the Group, rubidium, caesium and francium will react more vigorously with air and water
- Lithium will be the **least** reactive at the top and francium will be the most reactive at the bottom
- Francium is rare and radioactive so is difficult to confirm predictions

Predicted Reaction with Water

ELEMENT	REACTION
RUBIDIUM	– EXPLODES WITH SPARKS – RUBIDIUM HYDROXIDE PRODUCED.
CAESIUM	– VIOLENT EXPLOSION DUE TO RAPID PRODUCTION OF HEAT AND HYDROGEN – CAESIUM HYDROXIDE PRODUCED.
FRANCIUM	– TOO REACTIVE TO PREDICT

9 THE PERIODIC TABLE

9.2.1 GROUP PROPERTIES cont...

Group VII Properties & Trends

The halogens

- These are the Group 7 non-metals that are **poisonous** and include fluorine, chlorine, bromine, iodine and astatine
- Halogens are **diatomic**, meaning they form molecules of **two** atoms
- All halogens have seven electrons in their outer shell
- They form **halide** ions by gaining one more electron to complete their outer shells

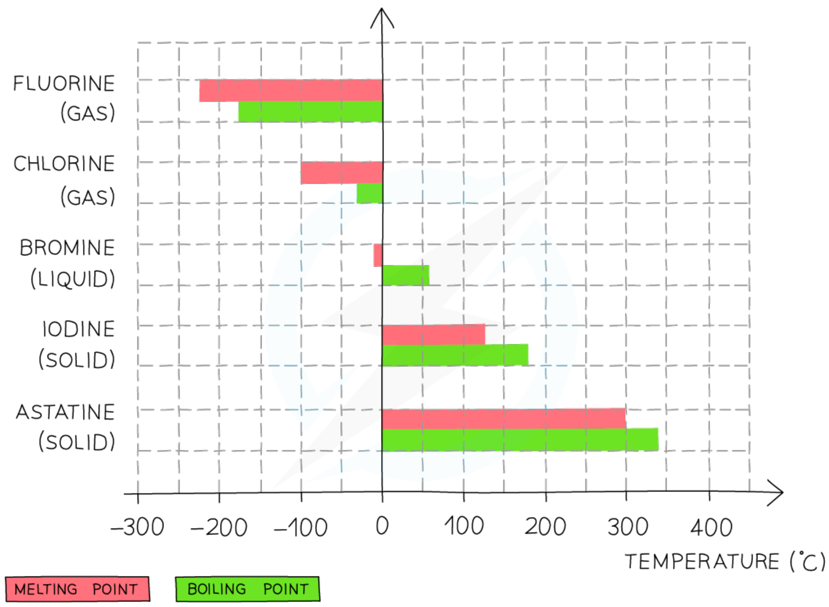
Colours and States at Room Temperature

HALOGEN	PHYSICAL STATE AT ROOM TEMPERATURE	COLOUR	COLOUR IN SOLUTION
FLUORINE	GAS	YELLOW	–
CHLORINE	GAS	PALE GREEN	GREEN–BLUE
BROMINE	LIQUID	RED–BROWN (READILY EVAPORATES TO FORM A BROWN GAS)	ORANGE
IODINE	SOLID	BLACK (SUBLIMES TO FORM A PURPLE GAS)	DARK BROWN

Trends in Physical Properties of the halogens

Melting Point

The density and melting and boiling points of the halogens increase as you go down the Group



Graph showing the melting and boiling points of halogens

YOUR NOTES

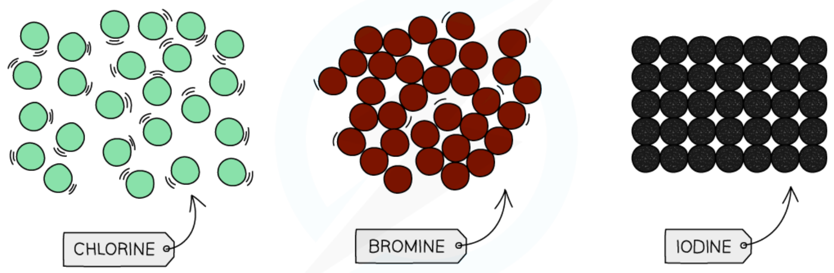
9 THE PERIODIC TABLE

YOUR NOTES

9.2.1 GROUP PROPERTIES cont...

State at Room Temperature

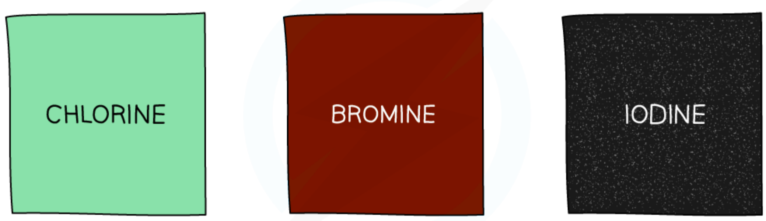
- At room temperature (20 °C), the physical state of the halogens changes as you go down the Group
- Chlorine is a **gas**, bromine is a **liquid** and iodine is a **solid**



The physical state of the halogens at room temperature

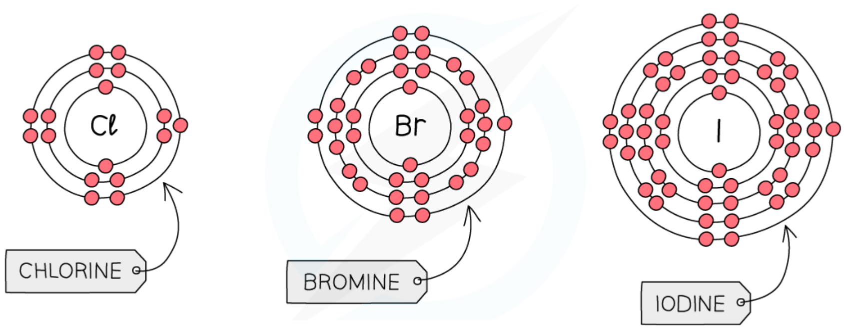
Colour

- The halogens become **darker** as you go down the group
- Chlorine is pale **green**, bromine is **red-brown** and iodine is **black**



The colours of the halogens

Electronic configuration and reactivity in Group VII



The electronic configuration of the first three elements in Group VII

9.2.1 GROUP PROPERTIES cont...

YOUR NOTES

Explaining the trend in reactivity in Group I

- Reactivity of Group 7 non-metals **increases** as you go up the Group
- Each outer shell contains seven electrons and when they react, they will need to gain one outer electron to get a full outer shell of electrons
- As you go up Group 7, the number of shells of electrons **decreases** (Period number decreases moving up the Periodic Table)
- This means that the outer electrons are **closer** to the nucleus so there are stronger electrostatic forces of attraction that attract the extra electron needed
- This allows an electron to be attracted more readily, so the higher up the element is in Group 7 then the **more reactive** it is

Reaction of the halogens with halide ions in displacement reactions

- A **halogen displacement reaction** occurs when a more reactive halogen displaces a less reactive halogen from an aqueous solution of its halide
- The reactivity of Group 7 non-metals increases as you move up the Group
- Out of the 3 halogens, chlorine, bromine and iodine, chlorine is the most reactive and iodine is the least reactive

Aqueous Solution Colour of Halogens

AQUEOUS SOLUTION	COLOUR
CHLORINE	VERY PALE GREEN, BUT USUALLY APPEARS COLOURLESS AS IT IS VERY DILUTE
BROMINE	ORANGE BUT WILL TURN YELLOW WHEN DILUTED
IODINE	BROWN

Halogen displacement reactions

Chlorine and bromine

- If you add chlorine solution to colourless potassium bromide solution, the solution becomes orange as bromine is formed
- Chlorine is **above** bromine in Group 7 so is more reactive
- Chlorine will therefore **displace** bromine from an aqueous solution of metal bromide

Potassium Bromide + Chlorine → Potassium Chloride + Bromine

$$2KBr\,(aq) + Cl_2\,(aq) \rightarrow 2KCl\,(aq) + Br_2(aq)$$

9 THE PERIODIC TABLE

YOUR NOTES

9.2.1 GROUP PROPERTIES cont...

Bromine and iodine

- Bromine is above iodine in Group 7 so is **more** reactive
- Bromine will therefore displace iodine from an aqueous solution of metal iodide

Bromine + Magnesium Iodide → Magnesium Bromide + Iodine

Br_2 (l) + 2MgI (aq) → 2MgBr (aq) + I_2 (aq or s)

Properties of the other Halogens (Fluorine & Astatine)

Melting and Boiling Point

- The melting and boiling point of the halogens **increases** as you go down the Group
- Fluorine is at the top of Group 7 so will have the **lowest** melting and boiling point
- Astatine is at the bottom of Group 7 so will have the **highest** melting and boiling point

Physical States

- The halogens become **harder** as you go down the Group
- Fluorine is at the top of Group 7 so will be a **gas**
- Astatine is at the bottom of Group 7 so will be a **solid**

Colour

- The colour of the halogens becomes **darker** as you go down the Group
- Fluorine is at the top of Group 7 so the colour will be **lighter**, so fluorine is **yellow**
- Astatine is at the bottom of Group 7 so the colour will be **darker**, so astatine is **black**

EXAM TIP

Iodine solid, solution and vapour are different colours

Solid iodine is dark **grey-black**, iodine vapour is **purple** and aqueous iodine is **brown**

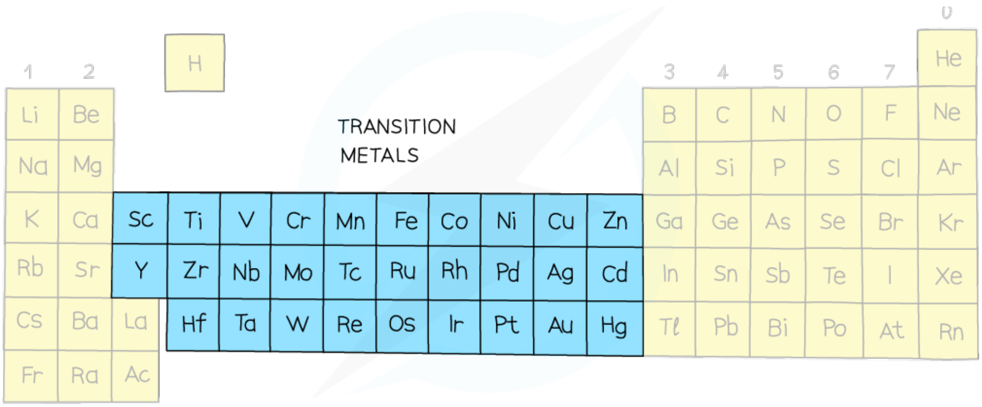
9 THE PERIODIC TABLE

9.2.2 TRANSITION ELEMENTS

Transition Elements

General properties of the transition elements

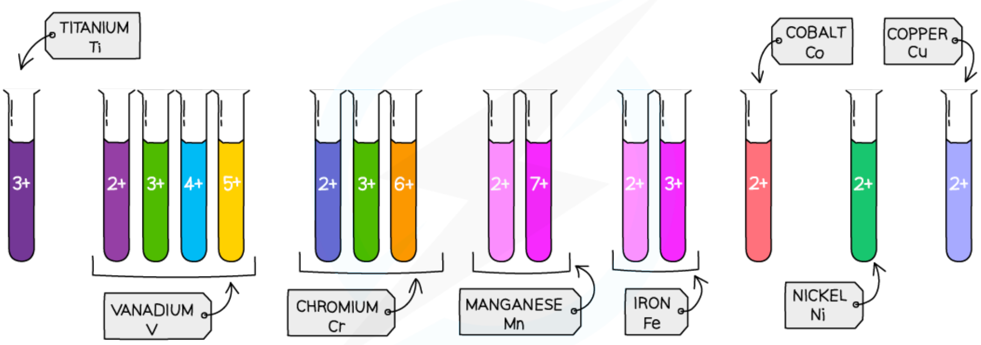
- They are very **hard** and strong metals and are good conductors of heat and **electricity**
- They have very **high melting** points and are highly **dense** metals
- E.g: the melting point of titanium is 1,688°C whereas potassium melts at only 63.5°C, slightly warmer than the average cup of hot chocolate!
- The transition metals form **coloured** compounds and often have more than one oxidation state
- Transition metals are often used as **catalysts**



The transition elements on the Periodic table

Variable oxidation states

- The transition elements have more than one **oxidation state**, as they can lose a different number of electrons, depending on the chemical environment they are in
- Iron for example can lose **two** electrons to form Fe^{2+} or **three** electrons to form Fe^{3+}
- Compounds containing transition elements in different oxidation states will have different **properties** and colours



The colours produced by ions of the transition elements

YOUR NOTES

9 THE PERIODIC TABLE

YOUR NOTES

9.2.2 TRANSITION ELEMENTS cont...

Uses of the transition elements

- The transition elements are used extensively as **catalysts** due to their ability to interchange between a range of oxidation states
- This allows them to form complexes with reagents which can easily **donate** and **accept** electrons from other chemical species within a reaction system
- They are used in **medicine** and **surgical** applications such as limb and joint replacement (titanium is often used for this as it can bond with bones due to its high biocompatibility)
- They are also used to form coloured compounds in **dyes** and **paints**, **stained** glass **jewellery**

EXAM TIP

Although scandium and zinc are in the transition metal area of the Periodic table, they are not considered transition elements as they do not form coloured compounds and have only **one** oxidation state.

9.2.3 NOBLE GASES

Noble Gases Properties & Electronic Structure

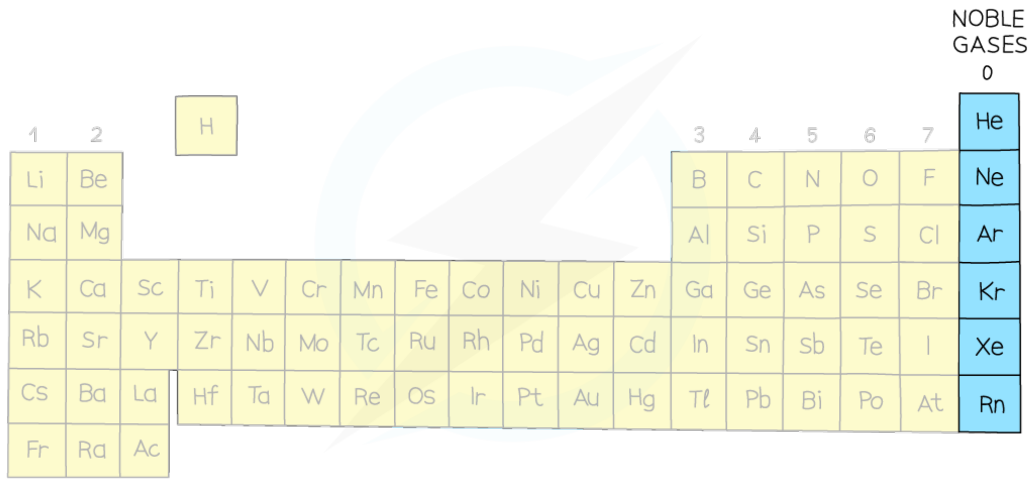
The Noble gases

- The Noble gases are in Group VIII (or Group O) and have very **low melting** and **boiling** points
- They are all **monatomic**, **colourless** gases
- The Group 0 elements all have **full outer shells**
- This electronic configuration is **extremely stable** so these elements are unreactive and are **inert**
- Electronic configurations of the Noble gases:
  - He 2
  - Ne 2, 8
  - Ar 2, 8, 8
  - Kr 2, 8, 18, 8
  - Xe 2, 8, 18, 18, 8

9 THE PERIODIC TABLE

9.2.3 NOBLE GASES cont...

YOUR NOTES



Noble gases are inert (unreactive) as they have a full outer shell of electrons so do not easily lose or gain electrons

Uses of the Noble gases

- Helium is used for filling balloons and weather balloons as it is **less dense** than air and does not burn
- Neon, argon and xenon are used in **advertising** signs
- Argon is used to provide an **inert atmosphere** for **welding**
- Argon is also used to fill **electric light** bulbs as it is inert

> NOW TRY SOME EXAM QUESTIONS

9 THE PERIODIC TABLE

YOUR NOTES

EXAM QUESTIONS

QUESTION 1

Which of the following observations does not apply to Group I elements?

A They are relatively soft metals.

B They corrode quickly when exposed to air.

C They react very quickly with water releasing hydrogen gas

D They produce acidic solutions in reaction with water.

QUESTION 2

Which statement about the Alkali metals is correct?

A Potassium is more dense than lithium.

B Lithium has a higher density than sodium.

C Potassium is less reactive than sodium.

D The melting point of sodium is higher than lithium.

QUESTION 3

Bromine and rubidium react together to form the compound rubidium bromide.
Which row correctly describes the formula and colour of rubidium bromide?

	formula	colour
A	RbBr	dark grey
B	RbBr2	dark grey
C	RbBr	white
D	RbBr2	white

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10 METALS

CONTENTS:

YOUR NOTES

10.1 PROPERTIES OF METALS

10.1.1 PROPERTIES OF METALS

Physical & Chemical Properties of Metals

PROPERTY	REASON
HIGH MELTING AND BOILING POINT	THERE ARE MANY STRONG METALLIC BONDS IN GIANT METALLIC STRUCTURES SO LARGE AMOUNTS OF HEAT ENERGY ARE NEEDED TO OVERCOME FORCES AND BREAK THESE BONDS.
GOOD CONDUCTORS OF ELECTRICITY AND HEAT	METALS ARE GOOD CONDUCTORS BECAUSE OF THE FREE ELECTRONS THAT ARE AVAILABLE TO MOVE AND CARRY CHARGE. WHEN A METAL IS USED IN AN ELECTRICAL CIRCUIT, ELECTRONS ENTERING ONE END OF THE METAL CAUSE A DELOCALISED ELECTRON TO DISPLACE ITSELF FROM THE OTHER END. HENCE ELECTRONS CAN FLOW SO ELECTRICITY IS CONDUCTED.
MALLEABLE AND DUCTILE	LAYERS OF POSITIVE IONS CAN EASILY SLIDE OVER ONE ANOTHER AND TAKE UP DIFFERENT POSITIONS. THIS DOES NOT DISRUPT THE METALLIC BONDING AS THE VALENCE ELECTRONS DO NOT BELONG TO ANY PARTICULAR METAL ATOM AND SO THEY CAN MOVE WITH THE LAYERS OF POSITIVE IONS, MAINTAINING THE ELECTROSTATIC FORCES. THE METALLIC BONDS ARE THUS NOT BROKEN AND AS A RESULT METALLIC BONDS ARE STRONG BUT FLEXIBLE. THEREFORE, THEY CAN BE HAMMERED INTO DIFFERENT SHAPES WITHOUT BREAKING.

10 METALS

10.1.1 PROPERTIES OF METALS cont...

YOUR NOTES

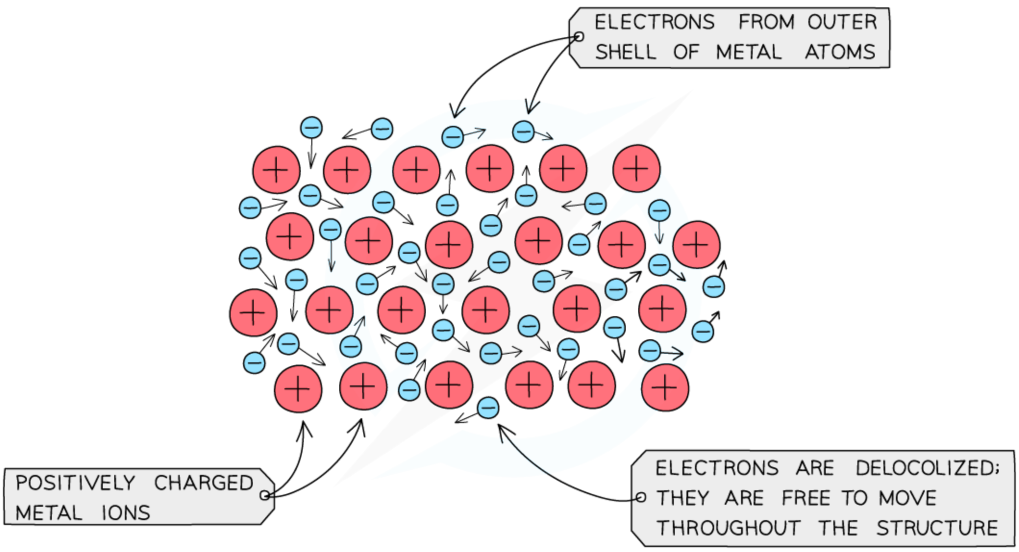


Diagram showing bonding and structure in metals

General chemical properties of Metals

- The chemistry of metals is studied by analysing their reactions with water, dilute acid and oxygen
- Based on these reactions a **reactivity series** of metals can be produced
- Reactivity with water

Some metals react with water, either warm or cold, or with steam

- Metals that react with cold water form a metal hydroxide and hydrogen gas, for example calcium:

$$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$$

- Metals that react with steam form metal oxide and hydrogen gas, for example zinc:

$$Zn + H_2O \rightarrow ZnO + H_2$$

Reactivity with acids

- Most metals react with dilute acids such as HCl
- When acids and metals react, the hydrogen atom in the acid is replaced by the metal atom to produce a salt and hydrogen gas, for example iron:

$$Fe + 2HCl \rightarrow FeCl_2 + H_2$$

Reactivity with oxygen

10 METALS

10.1.1 PROPERTIES OF METALS cont...

YOUR NOTES

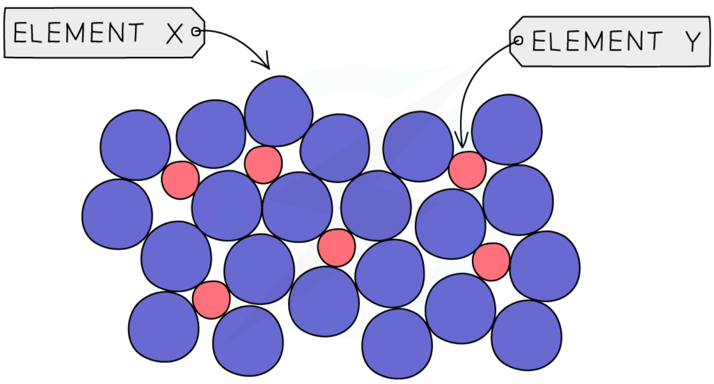
- Unreactive metals such as gold and copper do not react with acids
- Some reactive metals such as the alkali metals react with oxygen
- Copper and iron can also react with oxygen although much more slowly
- When metals react with oxygen a metal oxide is formed, for example copper:

$$2Cu + O_2 \rightarrow 2CuO$$

Structure & Uses of Alloys

Alloys

- An **alloy** is a **mixture** of two or more metals or a metal and a nonmetal
- Alloys often have **properties** that can be very **different** to the metals they contain, for example can have more **strength**, **hardness** or **resistance** to **corrosion** or extreme **temperatures**
- Alloys contain atoms of **different** sizes, which **distorts** normally regular arrangements of atoms in metals
- This makes it more difficult for the layers to **slide** over each other, so alloys are usually much harder than the pure metal



The regular arrangement of a metal lattice structure is distorted in alloys

Common alloys and their uses

- Brass is an alloy of copper and zinc and is much **stronger** than either metal
- Alloys of iron with tungsten are extremely **hard** and resistant to high **temperatures**
- Alloys of iron mixed with chromium or nickel are resistant to **corrosion**
- Aluminium is mixed with copper, manganese and silicon for aircraft body production as the alloy is **stronger** but still has a low **density**

10 METALS

10.1.1 PROPERTIES OF METALS cont...

EXAM TIP

Alloys are mixtures of substances.

They are not **chemically combined**.

An alloy is not a compound.

YOUR NOTES

10.1.2 REACTIVITY SERIES

The Reactivity Series

- The chemistry of the metals is studied by analysing their reactions with water, dilute acid and oxygen
- Based on these reactions a reactivity series of metals can be produced
- The series can be used to place a group of metals in **order of reactivity** based on the observations of their reactions with water, acid and oxygen

METAL	REACTION WITH WATER	REACTION WITH ACID	REACTION WITH OXYGEN
MOST REACTIVE			
POTASSIUM	REACTS VIOLENTLY	REACTS VIOLENTLY	REACTS QUICKLY IN AIR
SODIUM	REACTS QUICKLY	REACTS VIOLENTLY	REACTS QUICKLY IN AIR
CALCIUM	REACTS LESS STRONGLY	REACTS VIGOROUSLY	REACTS READILY
MAGNESIUM		REACTS VIGOROUSLY	REACTS READILY
ZINC		REACTS LESS STRONGLY	REACTS
IRON		REACTS LESS STRONGLY	REACTS
HYDROGEN			REACTS
COPPER			REACTS
LEAST REACTIVE			

YOUR NOTES

10.1.2 REACTIVITY SERIES cont...

Carbon and the reactivity series mnemonic

- Carbon is an important element and has its own place on the reactivity series
- Its use in the extraction of metals from their oxides is discussed in this section but a more complete reactivity series with an accompanying mnemonic to help you memorise it is below

The reactivity series mnemonic

- “Please send lions, cats, monkeys and cute zebras into hot countries signed Gordon”

METAL	ABBREVIATION
MOST REACTIVE	
POTASSIUM	P – PLEASE
SODIUM	S – SEND
LITHIUM	L – LIONS,
CALCIUM	C – CATS,
MAGNESIUM	M – MONKEYS,
ALUMINIUM	A – AND
CARBON	C – CUTE
ZINC	Z – ZEBRAS
IRON	I – INTO
HYDROGEN	H – HOT
COPPER	C – COUNTRIES
SILVER	S – SIGNED
GOLD	G – GORDON
LEAST REACTIVE	

10.1.2 REACTIVITY SERIES cont...

YOUR NOTES

EXTENDED ONLY

Reactions with Aqueous Ions & Oxides

Displacement reactions between metals and metal oxides

- The reactivity of metals increases going up the reactivity series
- This means that a more reactive metal can **displace** a less reactive metal from its oxide by heating

Example: Copper(II) Oxide

- It is possible to reduce copper(II) oxide by heating it with magnesium
- As magnesium is above copper in the reactivity series, magnesium is more reactive so can displace copper
- The reducing agent in the reaction is magnesium:

$$CuO\ (s) + Mg\ (s) \rightarrow Cu\ (s) + MgO\ (s)$$

Other Common Reactions

MIXTURE	PRODUCTS	EQUATION FOR REACTION
IRON (III) OXIDE AND ALUMINIUM (THERMIT REACTION)	IRON AND ALUMINIUM OXIDE	$Fe_2O_3 + 2Al \rightarrow 2Fe + Al_2O_3$
SODIUM OXIDE AND MAGNESIUM	NO REACTION AS SODIUM IS ABOVE MAGNESIUM	–
SILVER OXIDE AND COPPER	SILVER AND COPPER(II) OXIDE	$Ag_2O + Cu \rightarrow 2Ag + CuO$
ZINC OXIDE AND CALCIUM	ZINC AND CALCIUM OXIDE	$ZnO + Ca \rightarrow Zn + CaO$
LEAD (II) OXIDE AND SILVER	NO REACTION AS LEAD IS MORE REACTIVE THAN SILVER	–

10.1.2 REACTIVITY SERIES cont...

YOUR NOTES

EXTENDED ONLY cont...

Displacement reactions between metals and aqueous solutions of metal salts

- Any metal will displace another metal that is **below** it in the reactivity series from a solution of one of its salts
- This is because more reactive metals lose electrons and form ions more readily than less reactive metals, making them better **reducing agents**
- The less reactive metal is a better electron acceptor than the more reactive metal, thus the less reactive metal is reduced. (OIL-RIG: reduction is gain of electrons)

Example: Zinc and copper(II) sulfate

- As Zinc is above copper in the reactivity series, zinc is more reactive so can displace copper from copper(II) sulfate solution:

$$Zn\,(s) + CuSO_4\,(aq) \rightarrow ZnSO_4\,(aq) + Cu\,(s)$$

Other Common Reactions

MIXTURE	PRODUCTS	EQUATION FOR REACTION
MAGNESIUM AND IRON(II) SULFATE	MAGNESIUM SULFATE AND IRON	$Mg + FeSO_4 \rightarrow MgSO_4 + Fe$
ZINC AND SODIUM CHLORIDE	NO REACTION AS SODIUM IS ABOVE ZINC	–
LEAD AND SILVER NITRATE	LEAD (II) NITRATE AND SILVER	$Pb + 2AgNO_3 \rightarrow Pb\,(NO_3)_2 + 2Ag$
COPPER AND CALCIUM CHLORIDE	NO REACTION AS CALCIUM IS MORE REACTIVE THAN COPPER	–
IRON AND COPPER(II) SULFATE	IRON (II) SULFATE AND COPPER	$Fe + CuSO_4 \rightarrow FeSO_4 + Cu$

10.1.2 REACTIVITY SERIES cont...

EXTENDED ONLY cont...

Thermal decomposition reactions

- Some compounds **decompose** or **breakdown** when they are heated to sufficiently high temperatures
- These reactions are called **thermal decomposition** reactions
- A common example is the thermal decomposition of calcium carbonate (limestone), which occurs at temperatures above 800°C:

$$CaCO_3 \rightarrow CaO + CO_2$$

Thermal decomposition of metal hydroxides

- Most metal hydroxides undergo thermal decomposition
- **Water** and the corresponding **metal oxide** are the products formed, for example zinc hydroxide thermally decomposes as follows:

$$Zn(OH)_2 \rightarrow ZnO + H_2O$$

- Group II metal hydroxides decompose similarly but the Group I hydroxides (apart from lithium) do not decompose due to their having a higher thermal stability

Thermal decomposition of metal carbonates

- Most of the metal carbonates and hydrogen carbonates undergo thermal decomposition
- The **metal** oxide and **carbon** dioxide are the products formed, for example magnesium carbonate thermally decomposes as follows:

$$MgCO_3 \rightarrow MgO + CO_2$$

- Group I carbonates (again apart from lithium carbonate) do not decompose when heated
- This is due to the high thermal stability of reactive metals; the more reactive the metal then the more difficult it is to decompose its carbonate
- $CuCO_3$ for example is relatively easy to thermally decompose but K_2CO_3 does not decompose

YOUR NOTES

10 METALS

10.1.2 REACTIVITY SERIES cont...

EXTENDED ONLY cont...

Thermal decomposition of metal nitrates

- All of the metal nitrates decompose when they are heated
- Group I nitrates decompose forming the metal **nitrite** and **oxygen**, for example sodium nitrate decomposes as follows:

$$2NaNO_3 \rightarrow 2NaNO_2 + O_2$$

- Most other metal nitrates form the corresponding **metal** oxide, **nitrogen** dioxide and **oxygen** when heated, for example copper nitrate:

$$2Cu(NO_3)_2 \rightarrow 2CuO + 4NO_2 + O_2$$

Aluminium and its apparent lack of reactivity

- Aluminium is a curious metal in terms of its reactivity
- It is placed **high** on the reactivity series but it doesn't react with water or acids
- This is because the surface of aluminium metal reacts with oxygen in the air forming a protective coating of **aluminium** oxide:

$$4Al + 3O_2 \rightarrow 2Al_2O_3$$

- The aluminium oxide layer is **tough**, **unreactive** and **resistant** to **corrosion**
- It adheres very strongly to the aluminium surface and protects it from reaction with other substances, hence making it appear unreactive

EXAM TIP

For the thermal decomposition reactions, you will need to be able to describe how the Group I nitrates differ from the other metals.

You should be able to write out the balanced symbol equations for these reactions.

> NOW TRY SOME EXAM QUESTIONS

YOUR NOTES

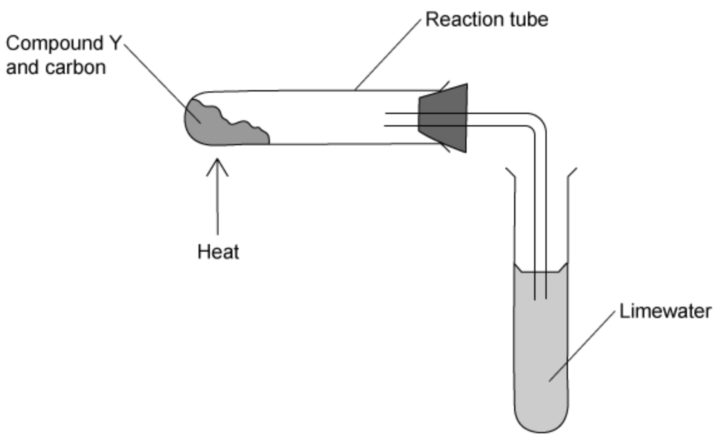
10 METALS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Compound Y is thermally decomposed with carbon using the apparatus below:



A brown solid is formed in the reaction tube and the limewater turns cloudy.

What is compound Y?

A Copper (II) oxide

B Calcium oxide

C Magnesium oxide

D Sodium oxide

QUESTION 2

A sample of element Y is shiny and can be shaped by hammering.

Which row of the table corresponds to the properties of element Y?

	conducts electricity	melts below 25°
A	✗	✓
B	✗	✗
C	✓	✓
D	✓	✗

10 METALS

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Properties of four elements are shown below.

Which of these elements is a metal?

	electrical conductivity when solid	electrical conductivity when liquid	melting point °C
A	low	low	-7
B	high	low	801
C	high	high	1535
D	low	low	3550

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10 METALS

10.2 EXTRACTION & USES OF METALS

10.2.1 EXTRACTION OF METALS

YOUR NOTES

Obtaining Metals from their Ores

Extraction of ores from the Earth's crust

- The Earth's crust contains metals and metal compounds such as gold, iron oxide and aluminium oxide
- When found in the Earth, these are often mixed with other substances
- To be useful, the metals have to be extracted from their ores through processes such as electrolysis, using a blast furnace or by reacting with more reactive material
- The extraction of metals is a reduction process
- Unreactive metals do not have to be extracted as they are often found as the uncombined element as they do not easily react with other substances

Extraction of metal and the reactivity series

- The position of the metal on the reactivity series influences the method of extraction
- Those metals placed higher up on the series (above carbon) have to be extracted using electrolysis
- Metals lower down on the series can be extracted by heating with carbon

The reactivity series and extraction of metals

METAL	ABBREVIATION
MOST REACTIVE	
POTASSIUM	EXTRACTED BY ELECTROLYSIS OF THE MOLTEN CHLORIDE OR MOLTEN OXIDE LARGE AMOUNTS OF ELECTRICITY REQUIRED SO EXPENSIVE PROCESS
SODIUM	
LITHIUM	
CALCIUM	
MAGNESIUM	
ALUMINIUM	
CARBON	
ZINC	EXTRACTED BY HEATING WITH A REDUCING AGENT SUCH AS CARBON OR CARBON MONOXIDE IN A BLAST FURNACE CHEAP PROCESS AS CARBON IS CHEAP AND CAN BE SOURCE OF HEAT AS WELL
IRON	
HYDROGEN	
COPPER	
SILVER	FOUND AS PURE ELEMENTS
GOLD	
LEAST REACTIVE	

YOUR NOTES

10.2.1 EXTRACTION OF METALS cont...

Extraction of Iron from Hematite

The extraction of iron in the blast furnace

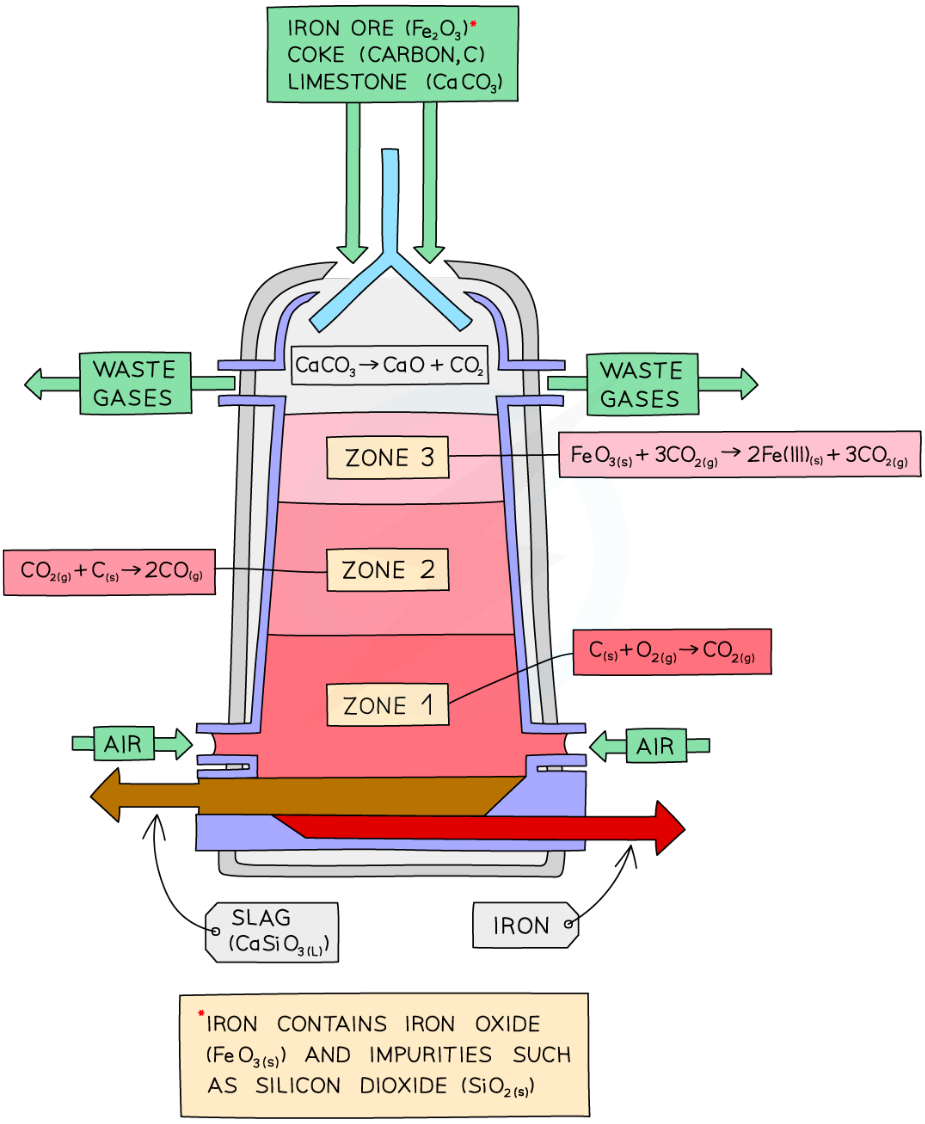

Diagram Showing the Carbon Extraction of Iron

Raw Materials:

Iron Ore (Haematite), Coke, Limestone and Air

Explanation:

Iron Ore, Coke and Limestone are mixed together and fed into the top of the blast furnace. Hot air is blasted into the bottom of the blast furnace

YOUR NOTES

10.2.1 EXTRACTION OF METALS cont...

Zone 1

Coke is used as the starting material. It is an impure carbon and it burns in the hot air blast to form carbon dioxide. This is a strongly **exothermic reaction**:

$$C\ (s)\ +\ O_2\ (g)\ \rightarrow\ CO_2\ (g)$$

Zone 2

At the high temperatures in the furnace, carbon dioxide reacts with coke to form carbon monoxide:

$$CO_2\ (g)\ +\ C\ (s)\ \rightarrow\ 2CO\ (g)$$

Zone 3

Carbon Monoxide (the reducing agent) reduces the Iron (III) Oxide in the Iron Ore to form Iron, which will melt and collect at the bottom of the furnace, where it is tapped off:

$$Fe_2O_3\ (s)\ +\ 3CO\ (g)\ \rightarrow\ 2Fe\ (III)\ +\ 3CO_2\ (g)$$

Limestone is added to the furnace to remove impurities in the ore. The Calcium Carbonate in the limestone decomposes to form calcium Oxide:

$$CaCO_3\ (s)\ \rightarrow\ CaO\ (s)\ +\ CO_2\ (g)$$

The Calcium Oxide reacts with the Silicon Dioxide, which is an impurity in the Iron Ore, to form Calcium Silicate. This melts and collects as a molten slag floating on top of the molten Iron which is tapped off separately:

$$CaO\ (s)\ +SiO_2\ (s)\ \rightarrow\ CaSiO_3\ (l)$$

The Conversion of Iron into Steel

Making steel from iron

- Molten iron is an alloy of 96% iron, with carbon, phosphorus, silicon and sulfur impurities
- It is too brittle for most uses, so most of it is converted into steel by removing some of the impurities
- Not all of the carbon is removed as steel contains some carbon, the percentage of which depends on the use of the steel
- The molten iron is transferred to a **tilting furnace** where the conversion to steel takes place
- **Oxygen** and **powdered calcium oxide** are added to the iron
- The oxygen oxidises the carbon, phosphorus, silicon and sulfur to their oxides which are all **acidic**
- CO_2 and SO_2 are gaseous so escape from the furnace
- The acidic silicon and phosphorus oxides react with the powdered calcium oxide and from a slag which is mainly calcium silicate:

$$SiO_2(l)\ +\ CaO(s)\ \rightarrow\ CaSiO_3(s)$$

- The slag floats on the surface of the molten iron and is removed

10 METALS

10.2.1 EXTRACTION OF METALS cont...

Aluminium Extraction & Benefits of Recycling

Extraction of aluminium

- Aluminium is a reactive metal which sits above carbon on the reactivity series
- It cannot be extracted from its ore (bauxite) by carbon reduction, so electrolysis is used

Recycling metals: iron, steel and aluminium

Advantages

- Raw materials are conserved (bauxite and haematite)
- Energy use is reduced, especially in the electrolysis of aluminium
- Less pollution is produced as both processes contribute to air pollution

Disadvantages

- More transport on roads carrying used metals to recycling centres
- Energy consumed in collecting materials and sorting them per material type

EXTENDED ONLY cont..

The Process of Alumium Extraction by Electrolysis

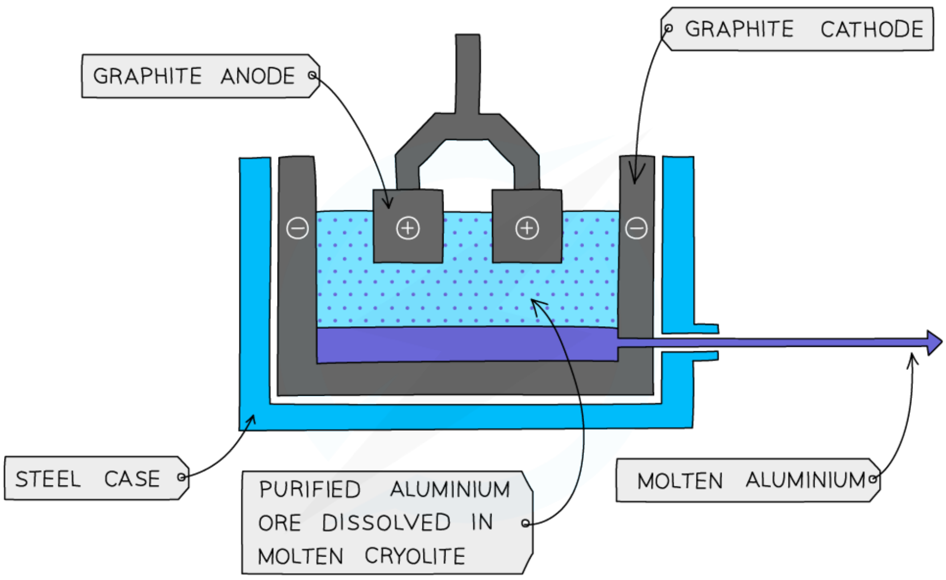

Diagram Showing the Extraction of Aluminium by Electrolysis

10 METALS

10.2.1 EXTRACTION OF METALS cont...

EXTENDED ONLY cont...

Raw Materials:

Aluminium Ore (Bauxite)

Explanation:

The Bauxite is first purified to produce Aluminium Oxide Al_2O_3

Aluminium Oxide has a very high melting point so it is first dissolved in molten Cryolite producing an electrolyte with a lower melting point, as well as a better conductor of electricity than molten aluminium oxide. This also reduces expense considerably.

The electrolyte is a solution of aluminium oxide in molten cryolite at a temperature of about 1000 °C. The molten aluminium is siphoned off from time to time and fresh aluminium oxide is added to the cell. The cell operates at 5-6 volts and with a current of 100,000 amps. The heat generated by the huge current keeps the electrolyte molten.

A lot of electricity is required for this process of extraction, this is a major expense.

Reaction at the Negative Electrode:

The Aluminium melts and collects at the bottom of the cell and is then tapped off:

$$Al_3^+ + 3e^- \rightarrow Al$$

Reaction at the Positive Electrode:

$$2O_2^- - 4e^- \rightarrow O_2$$

Some of the Oxygen Produced at the positive electrode then reacts with the Graphite (Carbon) electrode to produce Carbon Dioxide Gas:

$$C\,(s) + O_2\,(g) \rightarrow CO_2\,(g)$$

*This causes the carbon anodes to burn away, so they must be replaced regularly.

YOUR NOTES

10.2.1 EXTRACTION OF METALS cont...

YOUR NOTES

EXTENDED ONLY cont...

The Process of Zinc Extraction

Extraction of zinc

- Zinc ore is called zinc blende, ZnS
- The zinc blende is first converted to zinc oxide by heating with air:

$$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$$

- The reducing agent is carbon monoxide which is formed inside the furnace through a series of reactions
- Carbon burns in a blast of very hot air to form carbon dioxide:

$$C + O_2 \rightarrow CO_2$$

- The carbon dioxide produced reacts with more coke to form carbon monoxide:

$$CO_2 + C \rightarrow 2CO$$

- The carbon monoxide is the reducing agent and reduces the zinc oxide to zinc:

$$ZnO(s) + CO(g) \rightarrow Zn(g) + CO_2(g)$$

- Note that the zinc produced is in the **gaseous** state
- This passes out of the furnace and is cooled and condensed in a tray placed at the top of the furnace
- This is a key difference between the extraction of iron and aluminium, both of which are collected at the **bottom** of the furnace / electrolytic cell in the **liquid**
- Extended Candidates can read about the uses of zinc for galvanising and making brass in Section 10.4

10 METALS

YOUR NOTES

10.2.2 USES OF METALS

Uses of Aluminium, Copper & Mild Steel

Uses of Aluminium

USE	MOST IMPORTANT PROPERTY
AEROPLANE BODIES	HIGH STRENGTH–TO–WEIGHT RATIO (LOW DENSITY)
OVERHEAD POWER CABLES	GOOD CONDUCTOR OF ELECTRICITY
SAUCEPANS	GOOD CONDUCTOR OF HEAT
FOOD CANS	NON–TOXIC, RESISTANT TO CORROSION AND ACIDIC FOOD STUFFS
WINDOW FRAMES	RESISTANT TO CORROSION

Uses of Copper

USE	MOST IMPORTANT PROPERTY
ELECTRICAL WIRES	GOOD CONDUCTOR OF ELECTRICITY AND MALLEABLE
WATER PIPES	EASY TO WORK WITH AND BEND, NON–TOXIC AND UNREACTIVE (DOES NOT REACT WITH WATER)

Uses of Steel

TYPE OF STEEL	IRON ALLOYED WITH	USE	MOST IMPORTANT PROPERTY
MILD STEEL	0.25% CARBON	CAR BODY PANELS, WIRES	SOFT AND MALLEABLE
HIGH CARBON STEEL	0.5 – 1.4% CARBON	TOOLS AND CHISELS	HARD
LOW ALLOY STEEL	1 – 5% OF OTHER METALS (CR, NI, TI)	CONSTRUCTION, BRIDGES, HIGH SPEED TOOLS	HARD AND STRONG, LOW DUCTILITY AND MALLEABILITY
STAINLESS STEEL	20% CHROMIUM AND 10% NICKEL	CUTLERY AND SINKS, CHEMICAL PLANTS	STRONG AND RESISTANT TO CORROSION

10.2.2 USES OF METALS cont...

EXTENDED ONLY

Steel Alloys & Their Properties

- The amount of carbon removed depends on the amount of oxygen used
- By carefully controlling the amount of carbon removed and subsequent addition of other metals such as **chromium**, **manganese** or **nickel**, the particular type of steel alloy is produced

TYPE OF STEEL	IRON ALLOYED WITH	USE	MOST IMPORTANT PROPERTY
STAINLESS STEEL	20% CHROMIUM AND 10% NICKEL	CUTLERY AND SINKS, CHEMICAL PLANTS	STRONG AND RESISTANT TO CORROSION
TUNGSTEN STEEL	5% TUNGSTEN	EDGES OF HIGH SPEED CUTTING TOOLS	TOUGH AND HARD AT VERY HIGH TEMPERATURES
MANGANESE STEEL	13% MANGANESE	DRILL BITS, SPRINGS	VERY TOUGH AND SPRINGLY

Uses of Zinc

- Zinc is used in galvanising, the process of coating a metal such as iron or steel with a protective coating of zinc to prevent corrosion or rusting
- Galvanising is an effective way of rust protection as it works even if the zinc coating becomes scratched or damaged
- The process can be done **electrolytically** or by dipping the metal parts into **baths** of **molten zinc**
- Zinc is also used to make an alloy called **brass**
- Brass contains 70% copper and 30% zinc
- The addition of zinc makes the alloy much **harder** and **corrosion** resistant than copper alone

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

The three statements about aluminium are all correct.

1 Aluminium has an oxide ore.

2 Aluminium is extracted from its ore by electrolysis.

3 Aluminium is used to make cooking utensils.

Which of the statements would still be correct if aluminium was replaced with iron?

	1	2	3
A	✗	✓	✓
B	✓	✗	✓
C	✓	✓	✓
D	✓	✗	✗

QUESTION 2

Tin is less reactive than iron and the metal is extracted from its ore cassiterite, SNO_2.

Which of the following statements are correct?

1 Tin does not conduct electricity.

2 Tin is hard and shiny.

3 Tin can be extracted from cassiterite using carbon.

A 1, 2 & 3 **B** 1 & 2 only **C** 1 & 3 only **D** 2 & 3 only

10 METALS

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

In a blast furnace, iron (III) oxide is converted into iron and carbon monoxide is converted into carbon dioxide, as shown in the equation:

$$Fe_2O_3 + 3CO \rightarrow 2\,Fe + 3\,CO_2$$

What happens to each of these reactants?

A Iron (III) oxide is reduced and carbon monoxide is oxidised.

B Iron (III) oxide is oxidised and carbon monoxide is reduced.

C Both iron (III) oxide and carbon monoxide are oxidised.

D Both iron (III) oxide and carbon monoxide are reduced.

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11 AIR & WATER

YOUR NOTES

CONTENTS:

11.1 WATER & AIR

11.1.1 WATER

Water: Chemical Tests, Treatment & Uses

Chemical Tests for Water

- Cobalt (II) chloride turns **blue** to **pink** on the addition of water. This test is usually done using cobalt chloride paper
- The equation is:

$$CoCl_2(s) + 6H_2O(l) \rightarrow CoCl_2.6H_2O(s)$$

- Anhydrous copper (II) sulfate turns **white** to **blue** on the addition of water
- The equation is:

$$CuSO_4(s) + 5H_2O(l) \rightarrow CuSO_4.5H_2O(s)$$

Water Treatment

- Untreated water contains **soluble** and **insoluble** impurities
- Insoluble impurities include soil, pieces of plants and other organic matter
- Soluble impurities include dissolved calcium, metallic compounds and inorganic pollutants
- **Filtration** is the process used to remove large insoluble particles by passing the water through layers of sand and gravel filters that trap larger particles
- But bacteria and other microorganisms are too small to be trapped by the filters so **chlorination** is used
- This involves the careful addition of chlorine to the water supply which kills bacteria and other unwanted microorganisms
- Cholera and typhoid are examples of bacterial diseases which can arise by the consumption of untreated water

YOUR NOTES

11.1.1 WATER cont...

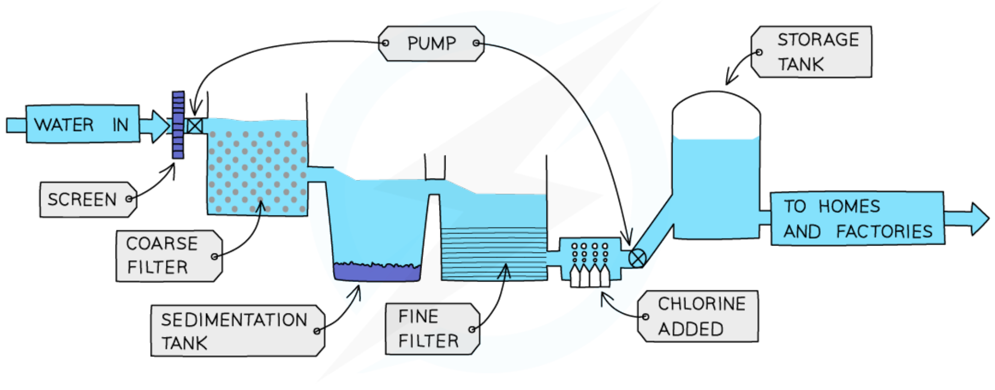


Diagram showing the stages in the treatment of water

Uses of Water

Water in industry

- As a coolant to reduce the temperature of some industrial processes e.g: in nuclear power plants
- Watering crops
- As a solvent in many chemical production processes
- Hydroelectric power stations to generate electricity
- As a first raw material for many processes e.g: the production of ethanol from ethene and steam (water)

Water in homes

- Drinking, cooking and washing
- General sanitation
- In car radiators, for gardens and plants

EXAM TIP

Exam questions on water treatment always focus on either filtration or chlorination.

You should be able to explain how each process works and the reason for each one.

11 AIR & WATER

YOUR NOTES

11.1.1 WATER cont...

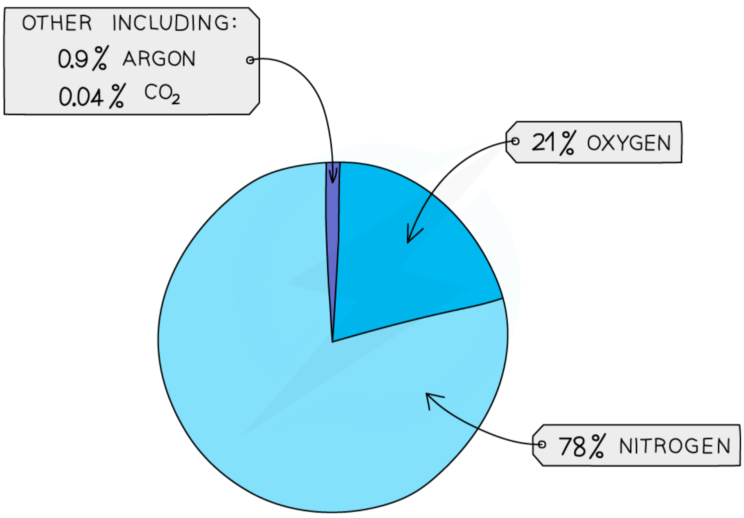
EXTENDED ONLY

An Inadequate Supply of Water

- Clean and safe water supply is very important to mankind
- Many problems arise in the event of an inadequate water supply, including:
    - **Food shortages** and **famine** due to a lack of crops which cannot grow without a clean water supply
    - Poor sanitation leads to spread of **bacteria** and **disease** as drinking water becomes infected

11.1.2 AIR

The Composition of Air



Pie chart showing the approximate percentages by volume of the main gases in unpolluted, dry air

Uses of air

- The gases available in the air have many important applications
- Oxygen is used in **steel** making, **welding** and in **breathing** apparatus
- Nitrogen is used in **food packaging**, the production of **ammonia** and in the production of **silicon chips**
- Both of these gases are separated from air by fractional distillation

11 AIR & WATER

11.1.2 AIR cont...

YOUR NOTES

EXTENDED ONLY

Fractional Distillation of Air

- The air is first filtered to remove dust, and then cooled in stages until it reaches –200°C
- At this temperature the air is in the liquid state
- Water vapour and carbon dioxide freeze at higher temperatures and are removed using absorbent filters
- The Noble gases are still in the gaseous state at -200°C, leaving a mixture of liquid nitrogen and oxygen
- The liquefied mixture is passed into the bottom of a fractionating column
- Note that the column is warmer at the **bottom** than it is at the top
- Oxygen liquefies at -183°C and nitrogen liquefies at -196°C
- Nitrogen has a lower boiling point than oxygen so it vaporises first and is collected as it rises in the gaseous state to the **top** of the column
- The liquid O2 is then removed from the **bottom** of the column

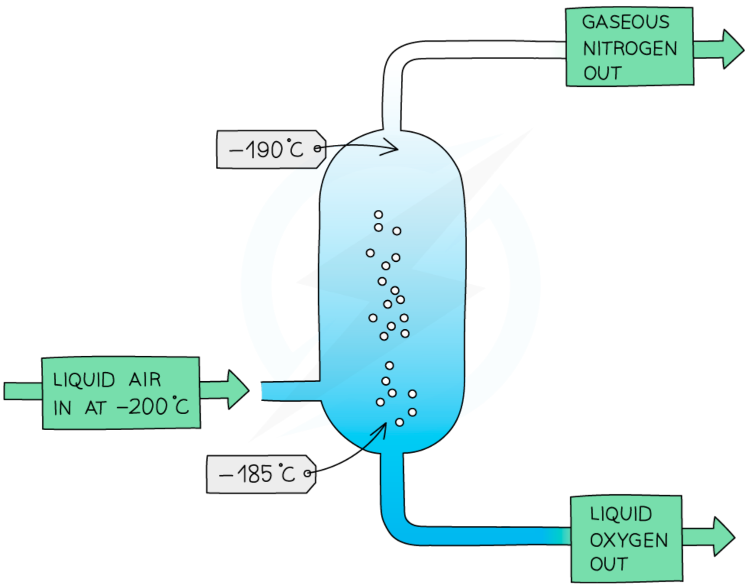


Diagram showing the fractional distillation of liquid air to produce N_2 gas and liquid O_2

11.1.2 AIR cont...

YOUR NOTES

Air Pollution

Carbon monoxide

- **Sources**: incomplete combustion of fossil fuels e.g: incomplete combustion of gasoline:

$$C_8H_{18} + 9O_2 \rightarrow 5CO + 2CO_2 + 9H_2O$$

- Adverse effects: poisonous, combining with hemoglobin in blood and prevents it from carrying oxygen

Sulfur dioxide

- **Sources**: combustion of fuels, natural gas and sulfide ores e.g: zinc blende (ZnS) in the extraction of zinc:

$$2ZnS + 3O_2 \rightarrow 2ZnO + 2SO_2$$

- **Adverse effects**: acid rain which causes corrosion to metal structures, buildings and statues made of carbonate rocks, damage to aquatic organisms. Pollutes crops and water supplies, irritates lungs, throats and eyes

Oxides of nitrogen

- **Sources**: reaction of nitrogen with oxygen in car engines and high temperature furnaces and as a product of bacterial action in soil
- **Adverse effects**: acid rain with similar effects as SO2 as well as producing photochemical smog and breathing difficulties, in particular for people suffering from asthma

Compounds of lead

- **Sources**: old water pipes, old paints, petrol in some kinds of racing cars and from very old engines
- **Adverse effects**: causes significant damage to the central nervous system, young infants are particularly susceptible to lead poisoning

EXAM TIP

Complete and incomplete combustion of hydrocarbons produce different products.

Complete combustion occurs in excess oxygen and produces CO_2 and H_2O.

Incomplete combustion occurs oxygen deficient conditions and produces CO, H_2O and sometimes carbon.

11 AIR & WATER

11.2 AIR cont...

YOUR NOTES

EXTENDED ONLY

Nitrogen Oxides in Car Engines

Nitrogen oxides

- These compounds (NO and NO2) are formed when nitrogen and oxygen react in the **high pressure** and **temperature** conditions of **internal combustion engines** and blast furnaces
- Exhaust gases also contain unburned hydrocarbons and carbon monoxide
- Cars are fitted with catalytic converters which form a part of their exhaust systems
- Their function is to render these exhaust gases harmless

Catalytic converters

- They contain a series of **transition metal catalysts** including platinum and rhodium
- The metal catalysts are in a **honeycomb** within the converter to increase the surface area available for reaction
- A series of redox reactions occurs which neutralises the pollutant gases
- Carbon monoxide is oxidised to carbon dioxide:

$$2CO + O_2 \rightarrow 2CO_2$$

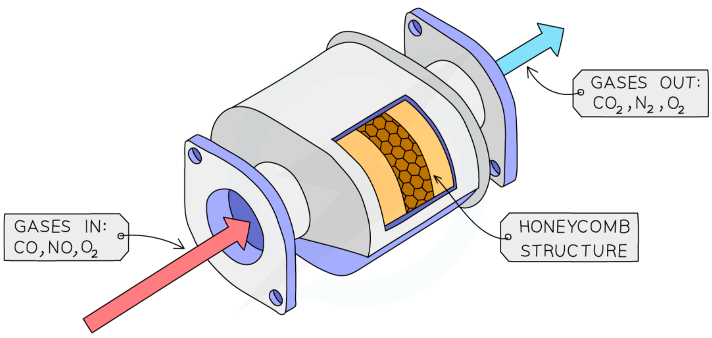
- Nitrogen oxides are reduced to N2 gas:

$$2NO \rightarrow N_2 + O_2$$

$$2NO_2 \rightarrow N_2 + 2O_2$$

- Unburned hydrocarbons are oxidised to carbon dioxide and water:

$$C_8H_{18} + 12\tfrac{1}{2}O_2 \rightarrow 8CO_2 + 9H_2O$$



Catalytic converters are designed to reduce the polluting gases produced in car exhausts

11 AIR & WATER

11.2 AIR cont...

YOUR NOTES

The Rusting of Iron

Rusting of iron

- Rusting is a chemical reaction between iron, water and oxygen that forms the compound iron (III) oxide
- Oxygen and water must be present for rust to occur
- Rusting is a redox process and it occurs faster in salty water since the presence of sodium chloride increases the electrical conductivity of the water

Iron + Water + Oxygen → Hydrated Iron (III) Oxide

$$4Fe(s) + 3O_2(g) + xH_2O(l) \rightarrow 2Fe_2O_3.xH_2O(s)$$

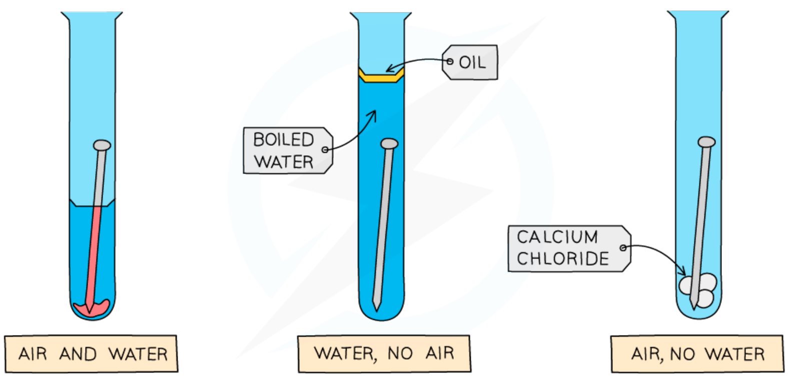


Diagram showing the requirements of oxygen and water for rust to occur: only the nail on the left rusts

Barrier Methods of Rust Prevention

- Rust can be prevented by coating iron with barriers that prevent the iron from coming into contact with water and oxygen
- However, if the coatings are washed away or scratched, the iron is once again exposed to water and oxygen and will rust.

COMMON BARRIER METHODS	
GREASE	OIL
PAINT	PLASTIC

11.1.2 AIR cont...

YOUR NOTES

EXAM TIP

Corrosion and rust are not the same process.

Corrosion is the general term used to describe the degradation of metal surfaces whereas rusting is the specific type of corrosion that happens to iron.

EXTENDED ONLY

Galvanising / Sacrificial Protection

- Iron can be prevented from rusting using the **reactivity** series
- **Galvanising** is a process where the iron to be protected is coated with a layer of zinc
- ZnCO3 is formed when zinc reacts with oxygen and carbon dioxide in the air and protects the iron by the barrier method
- If the coating is damaged or scratched, the iron is still protected from rusting by the **sacrificial** method (magnesium can also be used)
- This is because zinc is more reactive than iron and so it loses its electrons more readily:

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

- The iron stays protected as it accepts the electrons released by zinc, remaining in the reduced state and thus it does not undergo oxidation
- The electrons donated by the zinc react with hydrogen ions in the water producing hydrogen gas:

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

- Zinc therefore reacts with oxygen and water and corrodes instead of the iron

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A student added anhydrous copper(II) sulfate to a test tube containing an aqueous solution.

Which row correctly describes the colour change the student observed?

	before addition	after addition
A	white	pink
B	white	blue
C	blue	white
D	pink	blue

QUESTION 2

Hydrated cobalt(II) chloride undergoes thermal decomposition when heated to produce anhydrous cobalt(II) chloride and water.

$$CoCl_2{\bullet}6H_2O \rightleftharpoons CoCl_2 + 6\ H_2O$$

The addition of water to $CoCl_2$ rehydrates the compound.

Which row correctly describes the reverse reaction?

	reaction type	colour change
A	exothermic	blue to pink
B	endothermic	blue to pink
C	exothermic	pink to blue
D	endothermic	pink to blue

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Potable water is produced from a water source near a country spring as shown in the flow diagram.

water source → settling tank → **P** → **Q** → potable water

Which processes occur at P and Q?

	P	Q
A	chlorination	filtration
B	chlorination	distillation
C	filtration	distillation
D	filtration	chlorination

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11 AIR & WATER

11.2 NITROGEN & GREENHOUSE GASES

11.2.1 NITROGEN & FERTILISERS

YOUR NOTES

Fertilisers & Ammonia

NPK Fertilisers

- Fertilisers contain **nitrogen**, **potassium** and **phosphorus**
- Nitrogen promotes healthy leaves, potassium promotes **growth** and healthy **fruit** and **flowers** and phosphorus promotes healthy **roots**
- Fertiliser compounds contain the following water-soluble ions:
- Ammonium ions, NH_4^+ and nitrate ions, NO_3^-, are sources of soluble nitrogen
- Phosphate ions, $PO_4 3^-$ are a source of soluble phosphorus
- Most common potassium compounds dissolve in water to produce potassium ions, K^+

Displacement of ammonia

- Ammonia can be **displaced** from its salts by the addition of an alkali substance
- Farmers regularly add basic substances such as **calcium** hydroxide to their soil to neutralise any excess soil acidity
- If **too** much of the basic substance is added or if it has been added **too** soon after fertiliser has been added, then an ammonia displacement reaction may occur
- This involves the loss of nitrogen from the fertiliser, nullifying its effectiveness as a fertiliser
- For example, the salt ammonium chloride is used extensively in fertilisers and reacts with calcium hydroxide:

$$2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O$$

EXTENDED ONLY

Manufacture of Ammonia

Ammonia is manufactured using **The Haber Process** which occurs in five stages:

- **Stage 1:** H2 and N2 are obtained from natural gas and the air respectively and are pumped into the compressor through pipes
- **Stage 2**: The gases are compressed to about 200 atmospheres inside the compressor
- **Stage 3:** The pressurised gases are pumped into a tank containing layers of catalytic iron beads at a temperature of 450°C. Some of the hydrogen and nitrogen react to form ammonia:

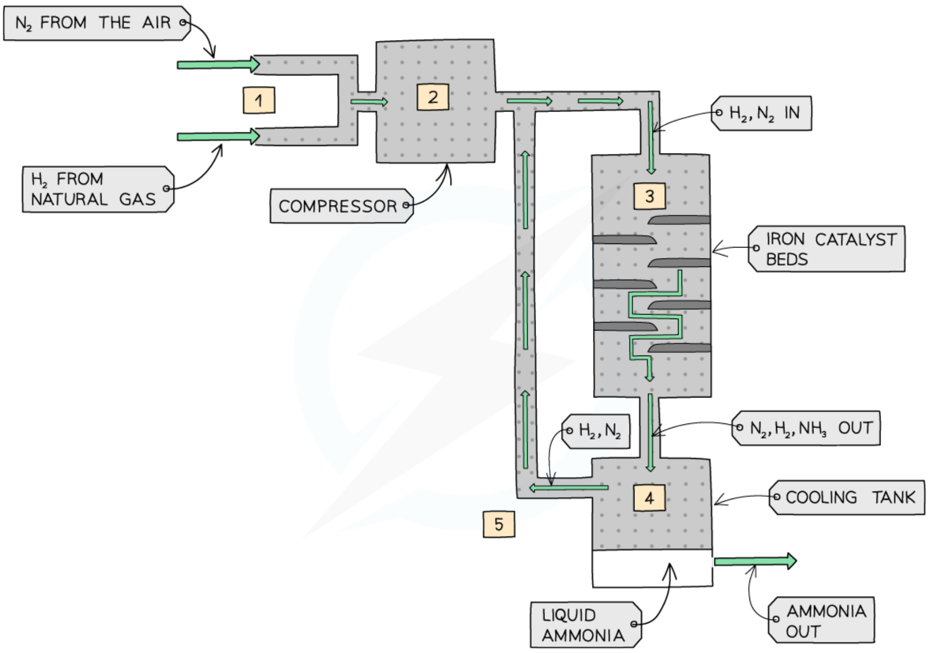
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

11.2.1 NITROGEN & FERTILISERS

YOUR NOTES

EXTENDED ONLY cont...

- **Stage 4**: Unreacted H2 and N2 and product ammonia pass into a cooling tank. The ammonia is liquefied and removed to pressurised storage vessels
- **Stage 5**: the unreacted H_2 and N_2 gases are recycled back into the system and start over again



The production of ammonia by the Haber Process

Conditions

Temperature: 450°C

- A **higher** temperature would favour the reverse reaction as it is endothermic (takes in heat) so a higher yield of **reactants** would be made
- If a **lower** temperature is used it favours the forward reaction as it is exothermic (releases heat) so a higher yield of **products** will be made
- However at a lower temperature the rate of reaction is very **slow**
- So 450°C is a compromise temperature between having a **lower yield** of products but being made more quickly

11 AIR & WATER

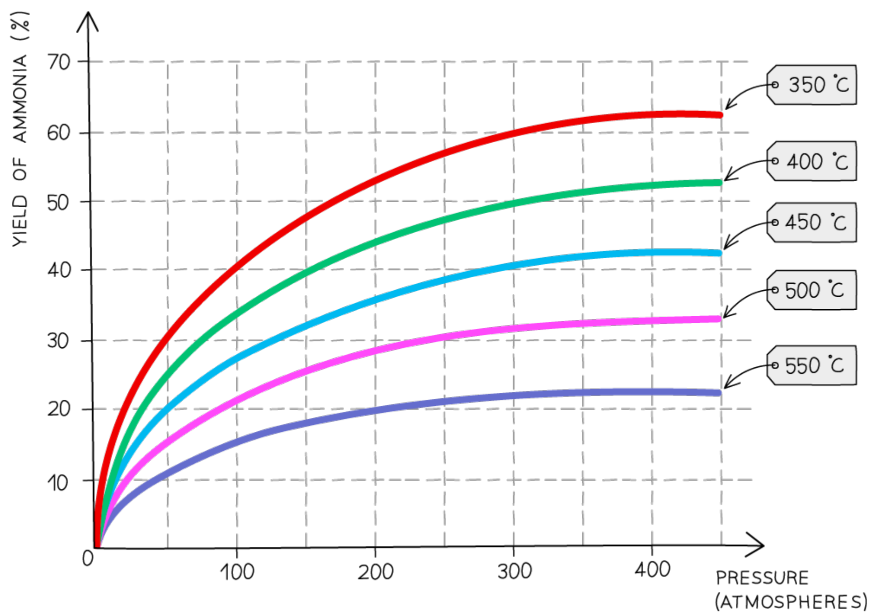
11.2.1 NITROGEN & FERTILISERS cont...

YOUR NOTES

EXTENDED ONLY cont...

Pressure: 200 atm

- A **lower** pressure would favour the reverse reaction as the system will try to increase the pressure by creating more molecules (4 molecules of gaseous reactants) so a higher yield of **reactants** will be made
- A **higher** pressure would favour the forward reaction as it will try to decrease the pressure by creating less molecules (2 molecules of gaseous products) so a higher yield of **products** will be made
- However high pressures can be dangerous and very expensive equipment is needed
- So 200 atm is a **compromise** pressure between a lower yield of products being made **safely** and **economically**



Choosing the conditions for the Haber Process

YOUR NOTES

11.2.1 NITROGEN & FERTILISERS cont...

EXAM TIP

The reaction conditions chosen for the Haber process are not ideal in terms of the yield but do provide balance between product yield, reaction rate and production cost.

These are called **compromise conditions** as they are chosen to give a good compromise between the yield, rate and cost.

11.2.2 CARBON DIOXIDE & METHANE

Greenhouse Gases, Carbon Dioxide & Methane

Greenhouse gases

- When shortwave radiation from the sun strikes the Earth's surface it is absorbed and re-emitted from the surface of the Earth as infrared radiation
- However much of the I.R. energy is trapped inside the Earth's atmosphere by **Greenhouse gases** which can absorb and hold the radiation
- Two such gases are carbon dioxide and methane
- They both lead to climate change as they trap heat energy from escaping the Earth's atmosphere, leading to **global warming**

Carbon dioxide

- **Sources**: combustion of wood and fossil fuels, respiration of plants and animals, thermal decomposition of carbonate rocks and the effect of acids on carbonates

Methane

- **Sources**: digestive processes of animals, decomposition of vegetation, bacterial action in swamps and in rice paddy fields

The Greenhouse effect

- Caused by the increased concentration and effect of Greenhouse gases, mainly methane and carbon dioxide

YOUR NOTES

11.2.2 CARBON DIOXIDE & METHANE cont...

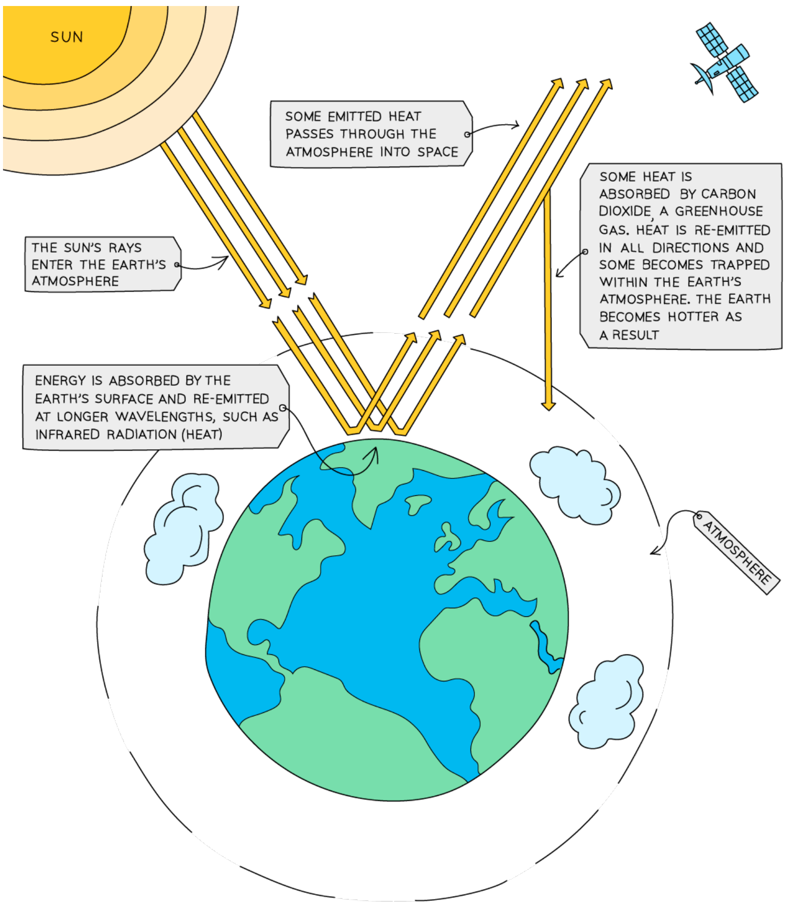


Diagram Showing How the Greenhouse Effect Occurs

Explanation:

- The Sun emits rays that enter the Earth's Atmosphere
- The heat is emitted back from the Earth's surface
- Some heat is reflected back out into Space
- But some heat is absorbed by Greenhouse gases such as carbon dioxide and methane and is trapped within the Earth's Atmosphere, causing the Earth's average temperature to rise as a result

Consequences:

- Climate change due to the increase in Earth's temperature
- Water levels will rise as glaciers melt because of high temperatures, causing flooding in low-lying countries
- Extinction of species due to the destruction of natural habitats
- Migration of species as they will move to areas that are more habitable (no droughts)
- Spread of diseases caused by warmer climate
- Loss of habitat due to climate change (animals that live on glaciers)

11.2.2 CARBON DIOXIDE & METHANE cont...

YOUR NOTES

EXTENDED ONLY

The Carbon Cycle

The carbon cycle describes the movement of carbon between the seas, land and atmosphere.

In the atmosphere, the main source of carbon is carbon dioxide.

Sources of CO_2 in the atmosphere

- Combustion of fossil fuels, e.g: methane:

$$CH_4 + 2O_2 \rightarrow CO_2 + H_2O$$

- Respiration: the production of energy in living things. The overall reaction of respiration is represented by the equation:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

- Decomposition of limestone
- Reactions of acids with carbonates

Removal of carbon dioxide from the atmosphere

- Photosynthesis: the process of producing glucose and oxygen from carbon and water in plants in the presence of chlorophyll and light:

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

- Carbon dioxide dissolves in the water in sea and oceans and is removed by shellfish for making their calcium carbonate shells

Balancing the carbon

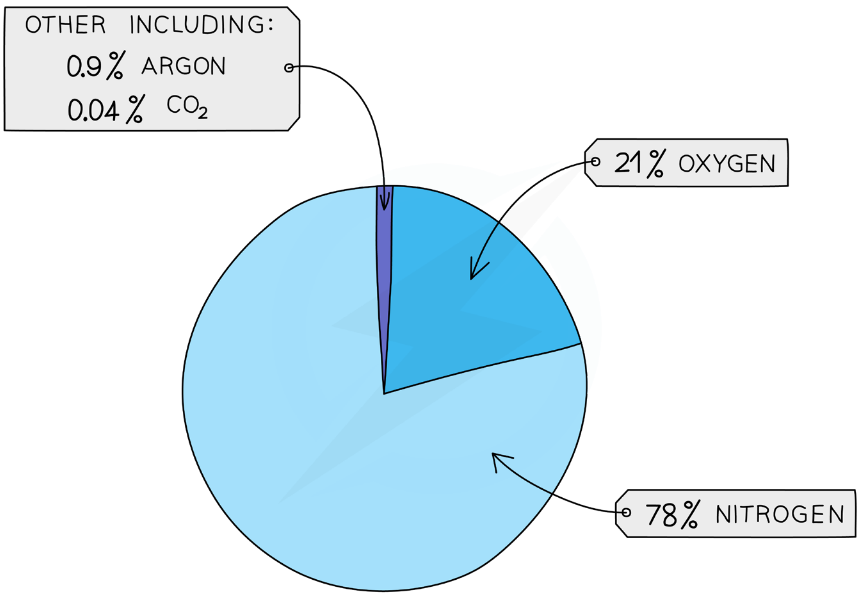
- Carbon as carbonate, carbon dioxide or organic carbon compounds is present in the sea, the air and under the Earth
- There is a continuous cycle of these compounds between these sources called the carbon cycle
- There is a constant amount of carbon compounds in the sea, atmosphere and under the Earth
- As long as these are balanced, the amount of carbon dioxide in the atmosphere remains **constant**
- Scientists are worried that increasing the amounts of fossil fuels burned will increase global warming and unbalance the carbon cycle

11 AIR & WATER

11.2.2 CARBON DIOXIDE & METHANE cont...

YOUR NOTES

EXTENDED ONLY cont...



The Carbon Cycle showing the movement of carbon through the Earth

> NOW TRY SOME EXAM QUESTIONS

11 AIR & WATER

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A company studied a number of compounds for use in producing fertilisers. The compounds studied are shown below. Which combination of compounds could the company use?

A K_2SO_4, NH_4NO_3, $CaSO_4$

B $Ca_3(PO_4)_2$, NH_4NO_3

C KI, $(NH_4)_3PO_4$

D $Co(NH_2)_2$, KCl

QUESTION 2

A student wanted to produce ammonia from ammonium sulfate by displacement reaction.

Which method could the student use?

A By reacting ammonium sulfate with an alkali.

B By heating ammonium sulfate with an oxidising agent.

C By reacting ammonium sulfate with an acid.

D By heating ammonium sulfate with a reducing agent.

11 AIR & WATER

EXAM QUESTIONS

YOUR NOTES

QUESTION 3

Astronomers have detected four neighbouring planets with the following composition of gases in their atmospheres.

planet	atmosphere contains
P	methane, carbon dioxide, oxygen
Q	oxygen, nitrogen
R	carbon dioxide, hydrogen
S	carbon dioxide, methane, hydrogen

In which planet is the Greenhouse Effect most likely to take place?

A P & S **B** P, Q & R **C** Q, R & S **D** P, R & S

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12 SULFUR

YOUR NOTES

CONTENTS:

12.1 SULFUR

Sulfur: Sources & Uses

Sources of sulfur

- Sulfur is found in its elemental state underground in the USA, Mexico and Poland
- It is also a by-product from the removal of sulfur from **petroleum** and **natural** gas
- Sulfur can also be obtained from **sulfide** ores

Uses of sulfur

- The main use of sulfur is in making **sulphuric** acid which is a very important chemical used in many industries
- It is also used extensively in making **rubber** tyres more flexible (vulcanising), where the rubber is heated with sulfur

Sulfur dioxide

- Sulfur dioxide can be made by the direct combination of sulphur with oxygen
- This is the method used in the first stage of the manufacture of sulfuric acid:

$$S + O_2 \rightarrow SO_2$$

Uses of sulfur dioxide

- As a bleach in the manufacture of wood pulp for paper
- As a preservative for foods and drinks by killing bacteria
- Sulfites are often added to foods and these release sulfur dioxide in acidic conditions

12 SULFUR

12.1 SULFUR cont...

YOUR NOTES

EXTENDED ONLY

Sulfuric Acid: Manufacture, Properties & Uses

Manufacture of Sulfuric Acid

- Sulfuric acid is synthesised by the **Contact process** which uses sulfur and oxygen from air and is done in three distinct stages

Stage 1

- The first stage is the oxidation of sulfur:

$$S + O_2 \rightarrow SO_2$$

Stage 2

- The main stage is the oxidation of sulfur dioxide to sulfur trioxide using a V_2O_5 catalyst:

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

- The conditions for the main stage of production of sulfur trioxide need to be considered:

Conditions during Stage 2

Temperature: 450°C

- The reaction is **exothermic**, so increasing the temperature shifts the position of equilibrium to the left in the direction of the reactants
- Therefore the higher the temperature, the **lower** the yield of sulfur trioxide
- The optimum temperature is a compromise between a higher rate of reaction at a higher temperature and a lower equilibrium yield at a higher temperature

Pressure: 2 atm

- An increase in pressure shifts the position of equilibrium to the **right** in the direction of a smaller number of gaseous molecules
- However the position of equilibrium lies far to the right (the equilibrium mixture contains about 96% sulfur trioxide)
- So the reaction is carried out at just above atmospheric pressure because:

a) it is not worth spending the extra energy or money required to produce high pressures

b) a higher pressure would increase the problems of dealing with the corrosive mixture of gases

12 SULFUR

12.1 SULFUR cont...

YOUR NOTES

EXTENDED ONLY cont...

Stage 3

- Once stage 2 is completed, the sulfur trioxide is absorbed into a solution of 98% sulphuric acid to produce a thick liquid called **oleum**:

$$SO_3 + H_2SO_4 \rightarrow H_2S_2O7$$

- It is not absorbed into water because a fine mist of sulfuric acid would be produced and this would be difficult to condense and is also highly dangerous
- Oleum is added to water to form concentrated sulfuric acid:

$$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$$

Properties of Sulfuric Acid

- Sulfuric acid is a **strong** dibasic acid as two of its hydrogen atoms can be replaced by a metal
- It reacts in a similar way to other acids with metal carbonates, oxides, hydroxides (and ammonia) and metals, e.g:

$$ZnO + H_2SO_4 \rightarrow ZnSO_4 + H_2O$$

$$Mg + H_2SO_4 \rightarrow MgSO_4 + H_2$$

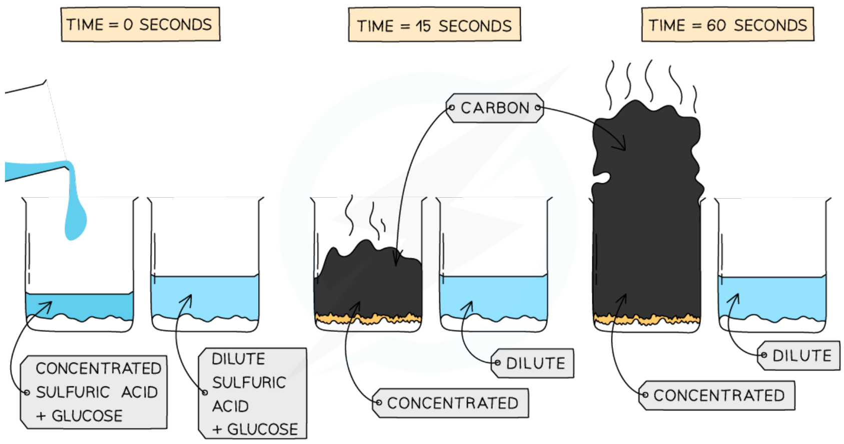
$$Na_2CO_3 + H_2SO_4 \rightarrow Na2SO_4 + CO_2 + H_2O$$

- Concentrated sulphuric acid is **corrosive** and a powerful **oxidising agent**
- Concentrated sulphuric acid is also a very powerful **dehydrating** agent and is very good at removing water from other substances
- For example, if mixed with sugar ($C_6H_{12}O_6$), concentrated H_2SO_4 will remove water molecules and leave behind carbon in a spectacular looking reaction that produces a tower of pure carbon

12 SULFUR

12.1 SULFUR cont...

EXTENDED ONLY cont...



The reaction of concentrated H_2SO_4 and sugar, which dehydrates the sugar leaving behind a tower of carbon

Uses of Sulfuric Acid

Dilute

- Used as a catalyst in many **organic** reactions
- Also used as to clean the **surface** of **metals**

Concentrated

- Used in car batteries, making **phosphate fertilisers**, **soaps** and **detergents**
- It is also used to make **acid drain cleaners** and in the production of **paints** and dyes

EXAM TIP

You need to know the conditions used in both the **Haber process** and the Contact process (see above) and be able to explain the reasons why the conditions of Stage 2 of sulfuric acid manufacture are chosen in terms of the equilibrium reactions.

> NOW TRY SOME EXAM QUESTIONS

YOUR NOTES

12 SULFUR

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which of the following are sources of sulfur?

A The soil of mountainous regions.

B Fractional distillation of air.

C Volcano craters.

D Steam reforming of methane.

QUESTION 2

Which of the following are sources of sulfur?

A The soil of mountainous regions.

B Fractional distillation of air.

C Volcano craters.

D Steam reforming of methane.

QUESTION 3

Which statement about sulfur is not correct?

A The main use of sulfur is in the production of sulfuric acid.

B The atomic number of sulfur is 15.

C Pure sulfur is a yellow solid.

D The relative atomic mass of sulfur is 32.

13 CARBONATES

YOUR NOTES

CONTENTS:

13.1 CARBONATES

Calcium Oxide & Calcium Carbonate

Manufacture of lime

- Limestone consists mainly of calcium carbonate, $CaCO_3$
- Lime which is calcium oxide, is manufactured from calcium carbonate by **thermal** decomposition:

$$CaCO_3 \rightarrow CaO + CO_2$$

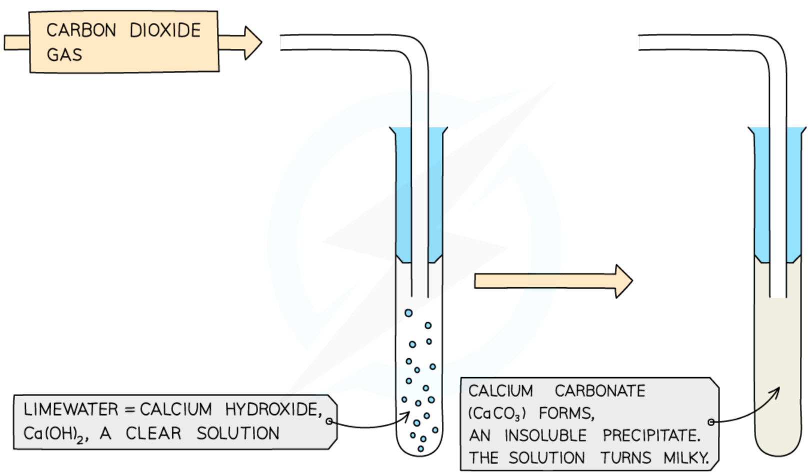
- **Slaked** lime, calcium hydroxide, is made by adding a small amount of water slowly to calcium oxide:

$$CaO + H_2O \rightarrow Ca(OH)_2$$

- Limewater is a solution of calcium hydroxide in water, hence it is **alkaline**
- The addition of carbon dioxide to calcium hydroxide produces the initial starting material, calcium carbonate:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

- This reaction is the basis of the standard chemical test for CO2



$Ca(OH)_2$ solution turns cloudy when in the presence of CO_2 gas due to the formation of insoluble white calcium carbonate

13 CARBONATES

13.1 CARBONATES cont...

YOUR NOTES

The combination of these three reactions constitutes the limestone cycle:

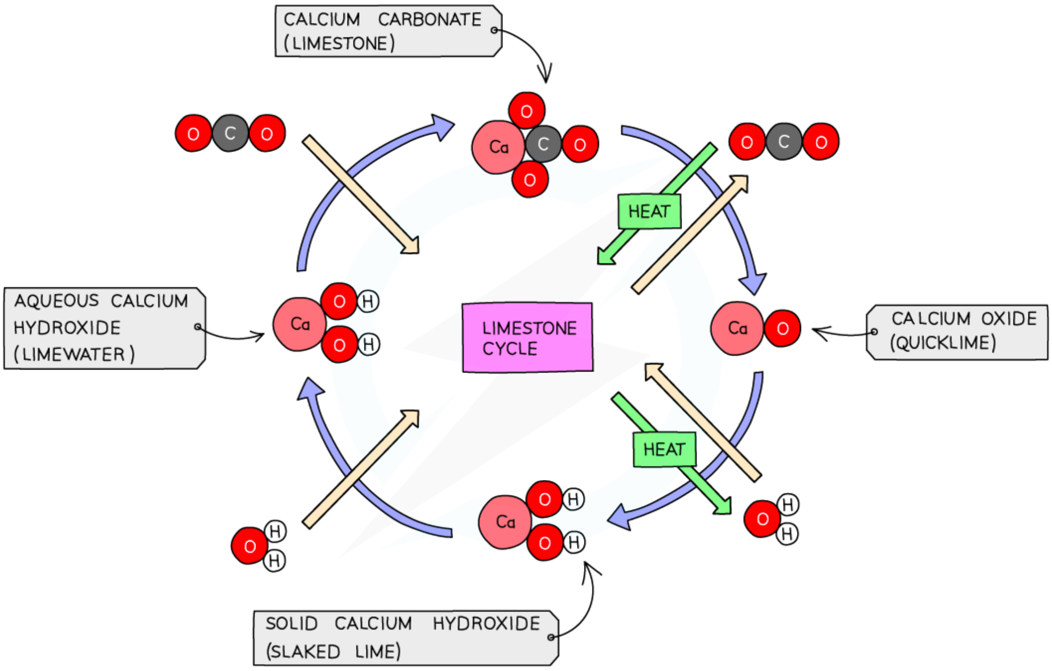


Diagram showing the stages in the limestone cycle

Uses of limestone and limestone products

- Limestone (calcium carbonate) is used in the manufacture of **iron** and **cement**
- In the production of iron, limestone is added to the blast furnace where it decomposes to form lime (CaO) and carbon dioxide
- The lime reacts with silica impurities to form calcium silicate, which floats to the top of the molten iron and is removed:

$$CaO + SiO_2 \rightarrow CaSiO_3$$

- Cement is manufactured by heating a mixture of powdered limestone and clay in a rotary kiln
- Once heated, calcium sulfate and water are added which produce cement
- Cement is a hardened, interlocked structure of calcium aluminate ($Ca(AlO_2)_2$) and calcium silicate ($CaSiO_3$)
- $CaCO_3$ is also used in treating excess acidity in soils and lakes where it is often preferred to lime because it does not make the water in the soil alkaline
- Lime (calcium oxide) is used in **lime** mortar and in **flue-gas** desulfurization

13 CARBONATES

YOUR NOTES

13.1 CARBONATES cont...

- Flue-gas desulfurization involves spraying acidic sulfur dioxide emissions with jets of slaked lime to reduce pollution by neutralising these gases before they leave the factory chimneys
- Lime is also used in treating excess **acidity** in soils and lakes. If excess lime is used, however, the water in the soil may become too alkaline
- Slaked lime (calcium hydroxide) is used in treating acidic soils and neutralising acidic industrial wasted products

> NOW TRY SOME EXAM QUESTIONS

13 CARBONATES

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

A solid compound **WX** is heated to a high temperature and produces solid compound **Y** and gas **Z**. No other reagent is used.

$$\textbf{WX}(s) \rightarrow \textbf{Y}(s) + \textbf{Z}(g)$$

What type of reaction has occurred?

A Neutralisation reaction

B Redox reaction

C Thermal decomposition reaction

D Metal displacement reaction

QUESTION 2

A student is given a solid compound X to analyse. The student heats the solid and observes a colour change from green to black. A gas is released which turns limewater cloudy.

What is the solid compound and the gas produced?

	X	gas
A	copper carbonate	carbon dioxide
B	copper carbonate	oxygen
C	calcium carbonate	carbon dioxide
D	calcium carbonate	oxygen

13 CARBONATES

YOUR NOTES

EXAM QUESTIONS

QUESTION 3

In which of the following processes is carbon dioxide not a product?

A Addition of lime to acidic soil

B Producing lime from limestone

C Respiration

D Fractional distillation

> CHECK YOUR ANSWERS AT SAVEMYEXAMS.CO.UK

14 ORGANIC CHEMISTRY

YOUR NOTES

CONTENTS:

14.1 ORGANIC CHEMISTRY & FUELS

14.1.1. NAMES OF COMPOUNDS

Organic Compound Names, Structures & Types

Introduction

- Organic Chemistry is the scientific study of the structure, properties, and reactions of organic compounds. Organic compounds are those which contain carbon
- For conventional reasons metal carbonates, carbon dioxide and carbon monoxide are not included in organic compounds

Definition of a hydrocarbon

- A compound that contains only hydrogen and carbon atoms

EXAM TIP

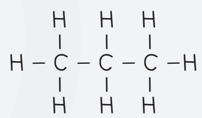
For defining a hydrocarbon, you must specify that they are compounds which contain hydrogen and carbon atoms only: no other element is present.

14 ORGANIC CHEMISTRY

14.1.1. NAMES OF COMPOUNDS cont...

YOUR NOTES

Different types of formulae in organic chemistry

TERM	DEFINITION	EXAMPLE FOR PROPANE
GENERAL FORMULA	A FORMULA THAT STATES THE RATIO OF ATOMS OF EACH ELEMENT IN THE FORMULA OF EVERY COMPOUND IN A PARTICULAR HOMOLOGOUS SERIES	C_3H_8
STRUCTURAL FORMULA	CONDENSED REPRESENTATION THAT SHOWS THE SYMBOLS FOR EACH ATOM IN A COMPOUND, WITH STRAIGHT LINES JOINING THEM TO REPRESENT THE COVALENT BONDS	
DISPLAYED FORMULA	GRAPHIC REPRESENTATION THAT SHOWS THE SYMBOLS FOR EACH ATOM IN A COMPOUND, WITH STRAIGHT LINES JOINING THEM TO REPRESENT THE COVALENT BONDS	$CH_3CH_2CH_3$

Combustion of hydrocarbons

- These compounds undergo complete and incomplete combustion
- Complete combustion occurs when there is **excess oxygen** so water and carbon dioxide form e.g:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- Incomplete combustion occurs when there is **insufficient oxygen** to burn so either carbon monoxide and water or carbon and water form e.g:

$$2CH_4 + 3O_2 \rightarrow 2CO + 4H_2O$$

$$CH_4 + O_2 \rightarrow C + 2H_2O$$

Names of compounds

- The names of organic compounds have two parts: the prefix or stem and the end part (or suffix)
- The prefix tells you how many carbon atoms are present in the longest continuous chain in the compound
- The suffix tells you what **functional group** is on the compound.

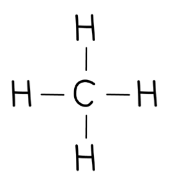
14 ORGANIC CHEMISTRY

14.1.1. NAMES OF COMPOUNDS cont...

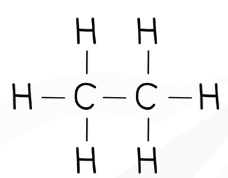
FIRST PART OF NAME		SECOND PART OF NAME		
NAME	NUMBER OF CARBON ATOMS	NAME	FUNCTIONAL GROUP	FAMILY
METH...	1	...ANE	NONE	ALKANE
ETH...	2	...ENE	C=C BOND	ALKENE
PROP...	3	...ANOL	R–OH	ALCOHOL
BUT...	4	...ANOIC ACID	R–C=O–OH	CARBOXYLIC ACID
PENT...	5	...AMINE	$R–NH_2$	AMINE
HEX...	6	...YL ...ANOATE	R–C=O–O–R	ESTER

Structures

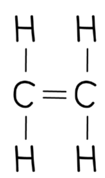
METHANE



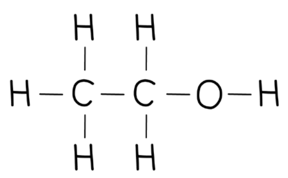
ETHANE



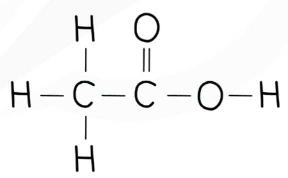
ETHENE



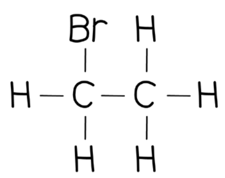
ETHANOL



ETHANOIC ACID



BROMOETHANE



YOUR NOTES

14 ORGANIC CHEMISTRY

YOUR NOTES

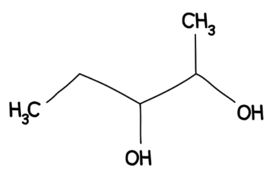
14.1.1. NAMES OF COMPOUNDS cont...

Further rules for naming compounds

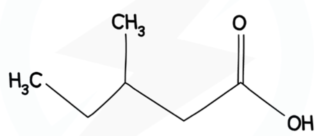
- When there is more than one carbon atom where a functional group can be located it is important to distinguish exactly **which carbon** the functional group is on
- Each carbon is numbered and these numbers are used to describe where the functional group is
- When 2 functional groups are present **di-** is used as a prefix to the second part of the name
- **Branching** also needs to be considered, the carbon atoms with the branches are described by their number
- When the location of functional groups and branches needs to be described the functional group takes **precedence** so the functional group has the **lowest** number.

Examples of branched molecules

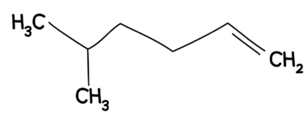
2,3-PENTANEDIOL



3-METHYLPENTANOIC ACID



5-METHYL-HEXENE



EXAM TIP

For the CIE 0620 course you will not be asked to name branched chain organic compounds but you will come across them.

It is useful to know that the numbers in the names of these compounds refer to the position of the side chains with respect to the main chain.

14 ORGANIC CHEMISTRY

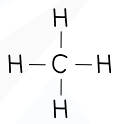
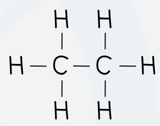
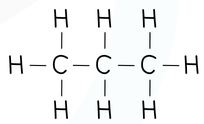
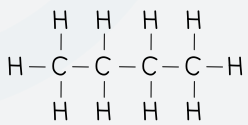
14.1.1. NAMES OF COMPOUNDS cont...

YOUR NOTES

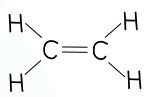
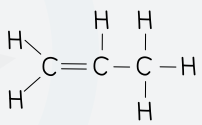
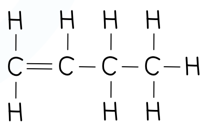
EXTENDED ONLY

Structures & Formulae

Alkanes

ALKANE	STRUCTURAL FORMULA	DISPLAYED FORMULA
METHANE	CH_4	
ETHANE	CH_3CH_3	
PROPANE	$CH_3CH_2CH_3$	
BUTANE	$CH_3\,CH_2\,CH_2\,CH_3$	

Alkenes

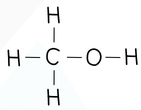
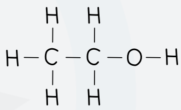
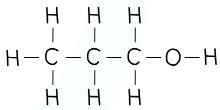
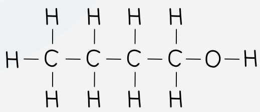
ALKENE	STRUCTURAL FORMULA	DISPLAYED FORMULA
ETHENE	$CH_2 = CH_2$	
PROPENE	$CH_2 = CHCH_3$	
BUTENE	$CH_2 = CHCH_2CH_3$	

14 ORGANIC CHEMISTRY

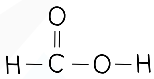
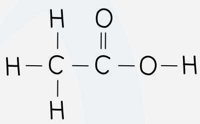
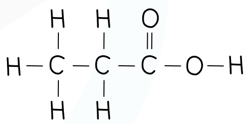
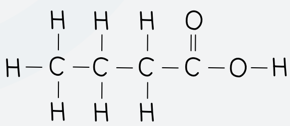
14.1.1. NAMES OF COMPOUNDS cont...

EXTENDED ONLY cont...

Alcohols

ALCOHOL	STRUCTURAL FORMULA	DISPLAYED FORMULA
METHANOL	CH_3OH	
ETHANOL	CH_3CH_2OH	
PROPANOL	$CH_3CH_2CH_2OH$	
BUTANOL	$CH_3CH_2CH_2CH_2OH$	

Carboxylic acids

ALKENE	STRUCTURAL FORMULA	DISPLAYED FORMULA
METHANOIC ACID	HCOOH	
ETHANOIC ACID	CH_3COOH	
PROPANOIC ACID	CH_3CH_2COOH	
BUTANOIC ACID	$CH_3CH_2CH_2COOH$	

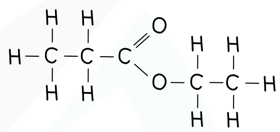
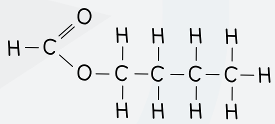
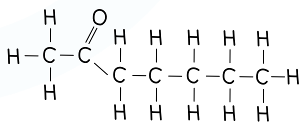
14 ORGANIC CHEMISTRY

YOUR NOTES

14.1.1. NAMES OF COMPOUNDS cont...

EXTENDED ONLY cont...

Esters

NAME OF ALCOHOL	NAME OF CARBOXYLIC ACID	NAME OF ESTER
ETHANOL	PROPANOIC ACID	ETHYL PROPANOATE 
BUTANOL	METHANOIC ACID	BUTYL METHANOATE 
PENTANOL	ETHANOIC ACID	PENTYL ETHANOATE 

14.1.2 FUELS

Common Fossil Fuels

- A fuel is a substance which when burned, releases heat energy
- This heat can be transferred into electricity, which we use in our daily lives
- Most common fossil fuels include coal, natural gas and hydrocarbons such as methane and propane which are obtained from crude oil
- The main constituent of natural gas is **methane**, CH_4

YOUR NOTES

14.1.2 FUELS cont...

Petroleum & Fractional Distillation

Petroleum

- Petroleum is also called **crude oil** and is a complex mixture of hydrocarbons which also contains natural gas
- It is a thick, sticky, black liquid that is found under porous rock (under the ground and under the sea)

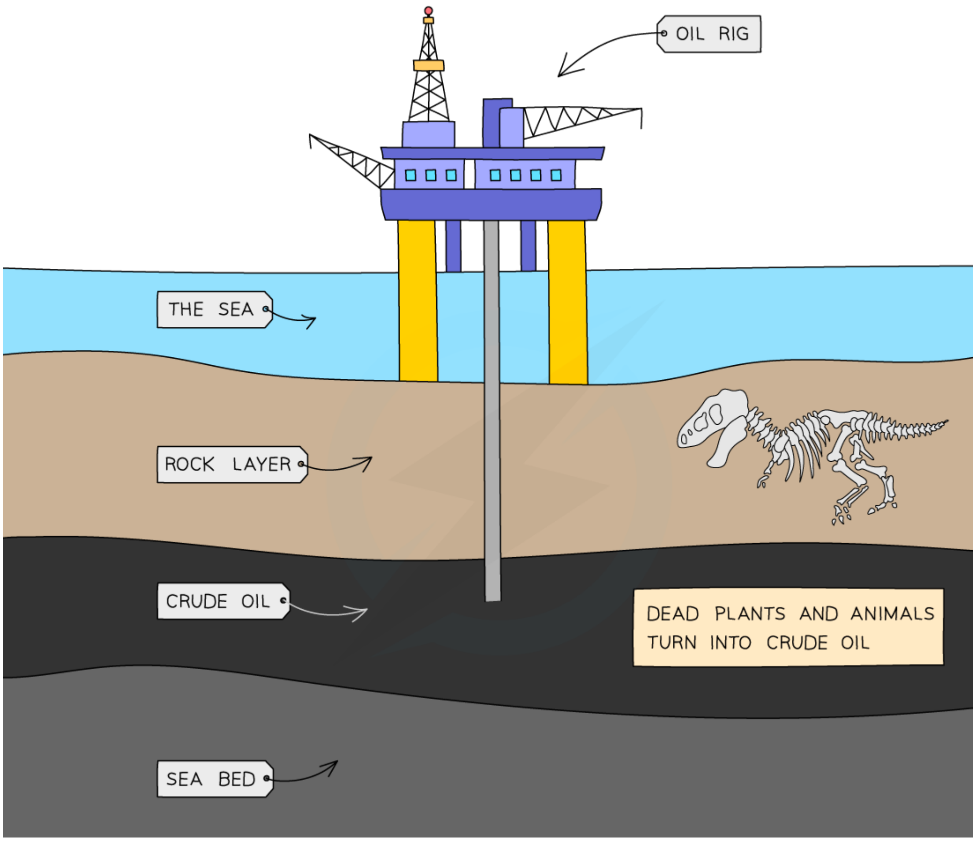


Diagram Showing Crude Oil Under the Sea

- Petroleum itself as a mixture isn't very useful but each component part of the mixture, called a **fraction**, is useful and each fraction has different applications
- The fractions in petroleum are separated from each other in a process called **fractional distillation**
- The molecules in each fraction have similar **properties** and **boiling points**, which depend on the number of carbon atoms in the chain
- The **boiling point** and **viscosity** of each fraction increases as the carbon chain gets longer

YOUR NOTES

14.1.2 FUELS cont...

Process of fractional distillation of crude oil

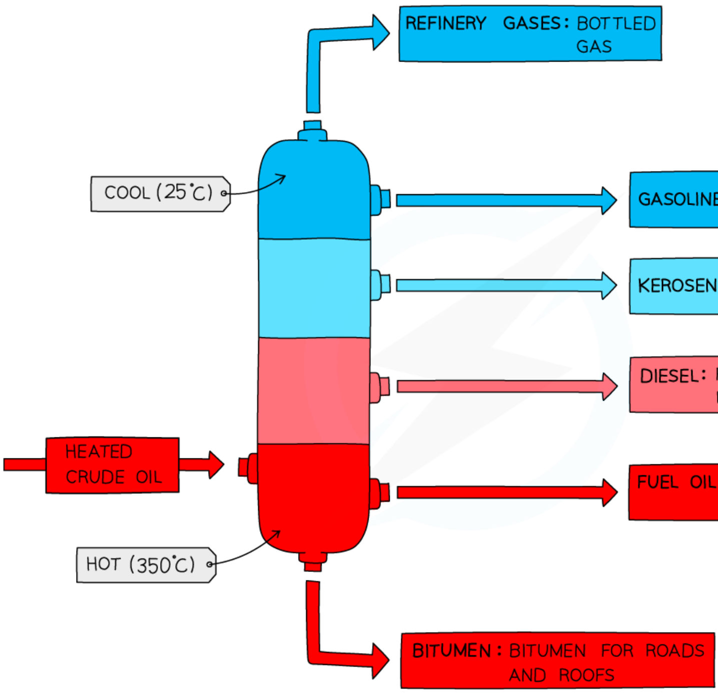


Diagram showing the process of fractional distillation to separate crude oil in a fractionating column

Explanation

- Fractional distillation is carried out in a fractionating column
- The fractionating column is hot at the bottom and cool at the top
- Crude oil enters the fractionating column and is heated so vapours rise
- Vapours of hydrocarbons with very high boiling points will immediately turn into liquid and are tapped off at the bottom of the column
- Vapours of hydrocarbons with low boiling points will rise up the column and condense at the top to be tapped off
- The different fractions condense at different heights according to their boiling points and are tapped off as liquids
- The fractions containing smaller hydrocarbons are collected at the top of the fractionating column as gases
- The fractions containing bigger hydrocarbons are collected at the lower sections of the fractionating column

14.1.2 FUELS cont...

YOUR NOTES

Properties of the main fractions of crude oil

- **Viscosity**: This refers to the ease of flow of a liquid. High **viscosity** liquids are thick and flow less easily. If the number of carbon atoms increases, the attraction between the hydrocarbon molecules also increases which results in the liquid becoming more viscous with the increasing length of the hydrocarbon chain. The liquid flows less easily with increasing molecular mass
- **Colour**: As carbon chain length increases the colour of the liquid gets darker as it gets thicker and more viscous
- **Melting point/boiling point**: As the molecules get larger, the intermolecular attraction becomes greater. So more heat is needed to separate the molecules. With increasing molecular size there is an increase in boiling point
- **Volatility**: Volatility refers to the tendency of a substance to vaporise. With increasing molecular size hydrocarbon liquids become less volatile. This is because the attraction between the molecules increases with increasing molecular size

Uses of the different fractions obtained from petroleum (crude oil)

- Refinery gas: heating and cooking
- Gasoline: fuel for cars (petrol)
- Naphtha: raw product for producing chemicals
- Kerosene: for making jet fuel (paraffin)
- Diesel: fuel for diesel engines (gas oil)
- Fuel oil: fuel for ships and for home heating
- Lubricating oil: for lubricants, polishes, waxes
- Bitumen: for surfacing roads

14 ORGANIC CHEMISTRY

YOUR NOTES

14.1.2 FUELS cont...

Trend in boiling point of the main fractions

FRACTION	NUMBER OF CARBON ATOMS	BOILING POINT RANGE / °C	BOILING POINT & VISCOSITY INCREASE GOING DOWN
REFINERY GAS	1 – 4	BELOW 25	↓
GASOLINE / PETROL	4 – 12	40 – 100	
NAPHTHA	7 – 14	90 – 150	
KEROSENE / PARAFFIN	12 – 16	150 – 240	
DIESEL / GAS OIL	14 – 18	220 – 300	
FUEL OIL	19 – 25	250 – 320	
LUBRICATING OIL	20 – 40	300 – 350	
BITUMEN	MORE THAN 70	MORE THAN 350	

EXAM TIP

Some fractions may have different names in the UK and the USA.

Names above in brackets are used in the UK while those underlined are the names used in the USA.

E.g. gasoline is the name used in the USA for petrol.

14 ORGANIC CHEMISTRY

14.1.3 HOMOLOGOUS SERIES

YOUR NOTES

Homologous Series

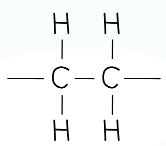
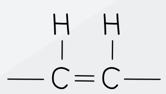
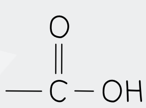
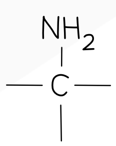
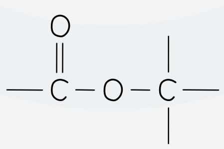
Homologous series

- This is a series or family of organic compounds that have similar features and chemical properties due to them having the same functional group
- All members of a homologous series have:
  - The same general formula
  - Same functional group
  - Similar chemical properties
  - They have **gradation** in their physical properties
  - The difference in the molecular formula between one member and the next is CH_2

Functional group

- This is a group of atoms which are bonded in a specific arrangement that is responsible for the characteristic reactions of each member of a homologous series

Names and structures of the functional groups

FAMILY	FUNCTIONAL GROUP	NAME
ALKANE		–ANE
ALKENE		–ENE
ALCOHOL	—C–OH	–ANOL
CARBOXYLIC ACID		–ANOIC ACID
AMINE		–AMINE
ESTER		–YL –ANOATE

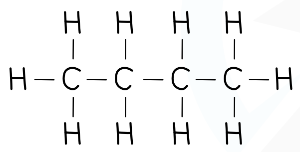
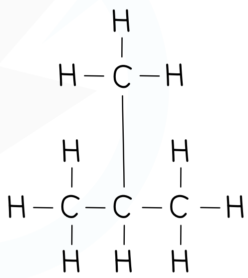
14.1.3 HOMOLOGOUS SERIES cont...

YOUR NOTES

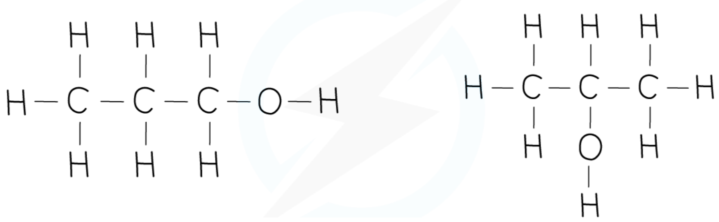
Structural isomers

- Compounds that have the **same molecular** formula but **different structural** formulae
- This is due to the different arrangement of their atoms in space
- There are two types: **chain** and **position**
- In chain isomerism the structure of the carbon chain differs
- In position isomerism, the position of the functional group differs

Example of chain isomerism

BUTANE	METHYLPROPANE
$C4H10$	$C4H10$
	

Example of position isomerism



Position isomers of propanol:
1–propanol or propan–1–ol on the left and propan–2–ol on the right

> NOW TRY SOME EXAM QUESTIONS

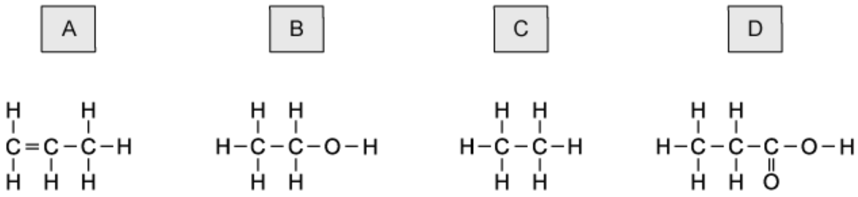
14 ORGANIC CHEMISTRY

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which one of the following structures is correctly named?



A Propane | B Ethanol | C Ethene | D Ethanoic acid

QUESTION 2

Organic compounds can have names that have the suffixes of -ane, -ene, -ol or -oic acid.

How many of these have at least one double bond in their structure

A 1 **B** 2 **C** 3 **D** 4

QUESTION 3

When the number of atoms in a molecule of a hydrocarbon increases, the amount of energy released when it burns increases.

What is the correct order?

	less energy	→	more energy released
A	methane	ethene	ethane
B	ethene	ethane	methane
C	ethene	methane	ethane
D	methane	ethane	ethene

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14 ORGANIC CHEMISTRY

14.2 FUNCTIONAL GROUP CHEMISTRY

14.2.1 ALKANES

YOUR NOTES

Alkanes: Properties & Bonding

Alkanes

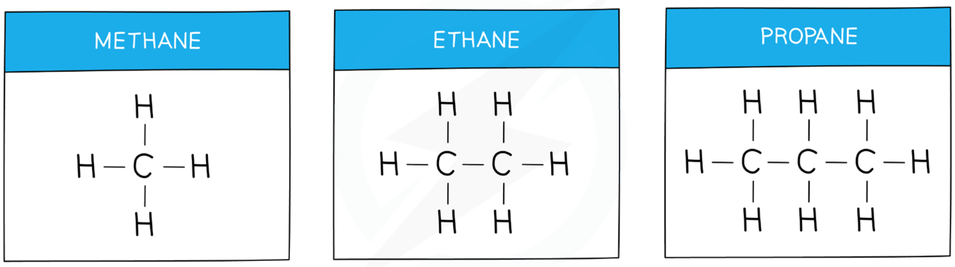
- A homologous series of hydrocarbon compounds with only single carbon bonds, there are no C=C bonds present
- General formula of alkanes:

$$C_nH_{2n} + 2$$

- Alkanes are classified as **saturated** hydrocarbons as all the bonds in alkanes are single bonds
- They are colourless compounds which have a gradual change in their physical properties as the number of carbon atoms in the chain increases
- Alkanes are generally unreactive compounds but they do undergo **combustion** reactions, can be **cracked** into smaller molecules and react with **halogens** in the presence of light
- Methane is an alkane and is the major component of **natural gas**
- Methane undergoes complete combustion forming carbon dioxide and water:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

The first three alkanes



14 ORGANIC CHEMISTRY

YOUR NOTES

14.2.1 ALKANES cont...

EXTENDED ONLY

Substitution Reaction of Alkanes with Halogens

- In a substitution reaction, one atom is swapped with another atom
- Alkanes undergo a substitution reaction with halogens in the presence of ultraviolet radiation

In the presence of ultraviolet (UV) radiation, methane reacts with bromine in a substitution reaction

Methane + Bromine → Bromomethane + Hydrogen Bromide

CH_4 Br_2 CH_3Br HBr

14.2.2 ALKENES

Alkenes: Catalytic Cracking & Distinguishing from Alkanes

Alkenes

- A homologous series of hydrocarbon compounds with carbon-carbon double bonds (C = C)
- General formula:

$$C_nH_{2n}$$

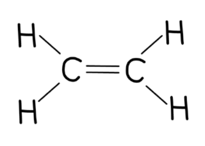
- All alkenes contain a double carbon bond, which is shown as two lines between two of the carbon atoms
- This is the alkene functional group and is what allows alkenes to react in ways that alkanes cannot
- Compounds that have a C=C double bond are also called **unsaturated** compounds.

YOUR NOTES

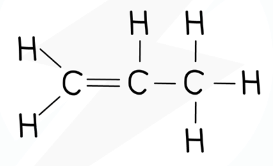
14.2.2 ALKENES cont...

The first three alkenes

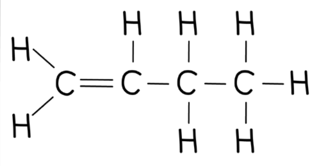
ETHENE



PROPENE



BUT-1-ENE



Manufacture of alkenes and hydrogen

- Although there is use for each fraction obtained from the fractional distillation of crude oil, the amount of longer chain hydrocarbons produced is far greater than needed
- These **long-chain** hydrocarbon molecules are further processed to produce other products
- A process called **catalytic cracking** used to convert longer-chain molecules into **short-chain** and more useful hydrocarbons
- Alkenes and hydrogen are produced from the cracking of alkanes
- Kerosene and diesel oil are often cracked to produce petrol, other alkenes and hydrogen

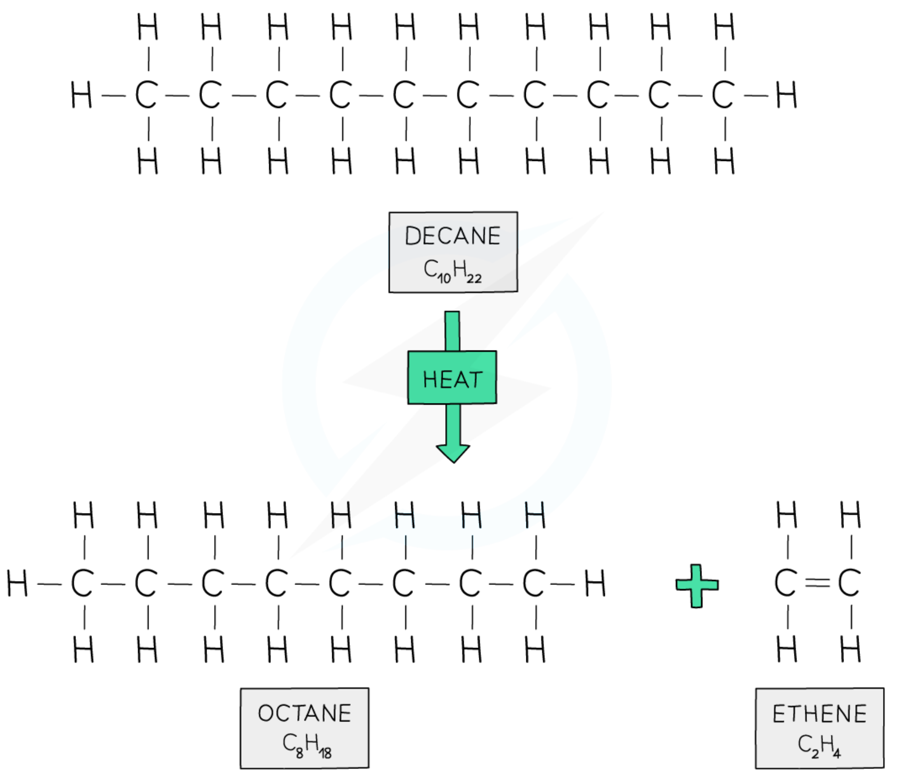
Explanation:

- Cracking allows large hydrocarbon molecules to be broken down into smaller, more useful hydrocarbon molecules
- Fractions containing large hydrocarbon molecules are heated at 600 – 700°C to vaporise them
- Vapours will then pass over a hot catalyst of silica or alumina
- This process breaks covalent bonds in the molecules, causing thermal decomposition reactions
- As a result, cracking produces smaller alkanes and alkenes. The molecules are broken up in a random way which produces a mixture of alkanes and alkenes
- Hydrogen and a higher proportion of alkenes are formed at temperatures of above 700°C and higher pressure

14 ORGANIC CHEMISTRY

YOUR NOTES

14.2.2 ALKENES cont...



The 10 carbon molecule decane is catalytically cracked to produce octane for petrol and ethene for ethanol

Distinguishing between alkanes and alkenes

- Alkanes and alkenes have different molecular structures
- All alkanes are saturated and alkenes are unsaturated
- The presence of the C=C double bond allows alkenes to react in ways that alkanes cannot
- This allows us to tell alkenes apart from alkanes using a simple chemical test:

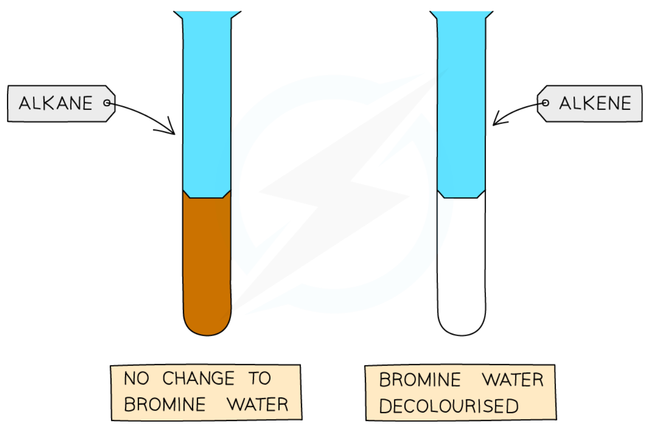


Diagram showing the result of the test using bromine water with alkanes and alkenes

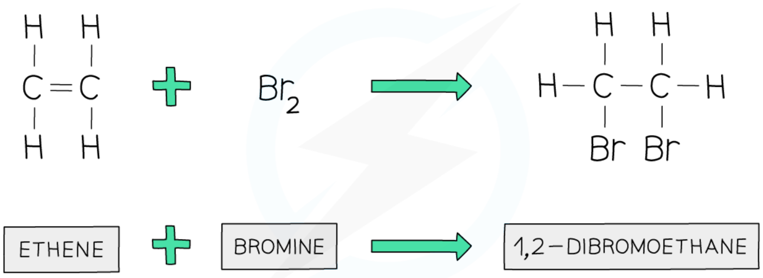
14 ORGANIC CHEMISTRY

YOUR NOTES

14.2.2 ALKENES cont...

Explanation:

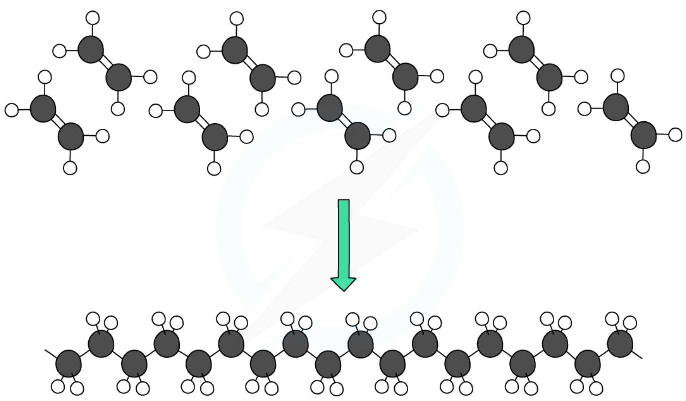
- Bromine water is an orange coloured solution of bromine
- When bromine water is shaken with an Alkane, it will remain as an orange solution as alkanes do not have double carbon bonds (C=C) so the bromine remains in solution
- But when bromine water is shaken with an alkene, the alkene will decolourise the bromine water and turn colourless as alkenes do have double carbon bonds (C=C)
- The bromine atoms add across the C=C double bond hence the solution no longer contains the orange coloured bromine
- This reaction between alkenes and bromine is called an **addition reaction**



Each carbon atom of the double bond accepts a bromine atom, causing the bromine solution to lose its colour

Addition Polymerisation

- Addition polymers are formed by the joining up of many small molecules called **monomers**
- Addition polymerisation only occurs in monomers that contain C=C bonds
- One of the bonds in each double bond breaks and forms a bond with the adjacent monomer
- There are many types of polymers that are synthesized from alkene monomers
- A common example is **poly-ethene (polythene)** which is the addition of many ethene monomers



Polymerisation of ethene monomers to produce polythene

14.2.2 ALKENES cont...

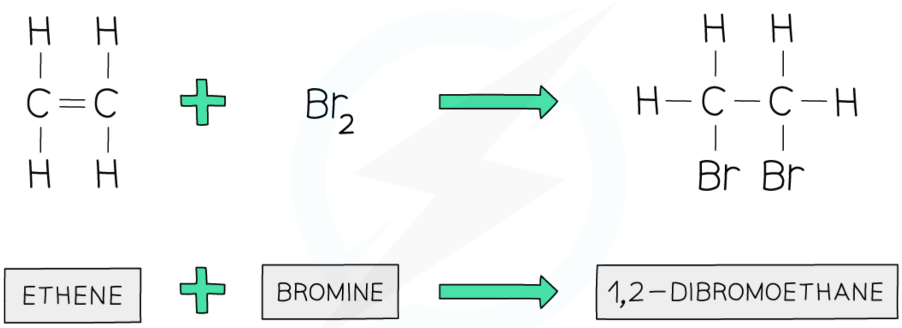
YOUR NOTES

EXTENDED ONLY

Further Addition Reactions

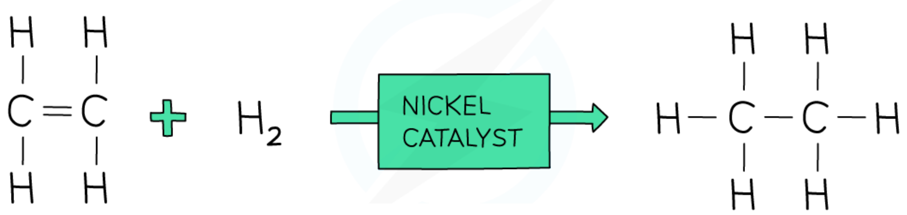
Addition reactions of alkenes

- Alkenes undergo addition reactions in which atoms of a simple molecule add across the C=C double bond
- The reaction between bromine and ethene is an example of an addition reaction



Bromine atoms add across the C=C in the addition reaction of ethene and bromine

- Alkenes also undergo addition reactions with hydrogen in which an **alkane** is formed
- These are hydrogenation reactions and occur at 150°C using a **nickel catalyst**
- Hydrogenation reactions are used to change vegetable oils into margarine to be sold in supermarkets



Hydrogen atoms add across the C=C in the hydrogenation of ethene to produce an alkane

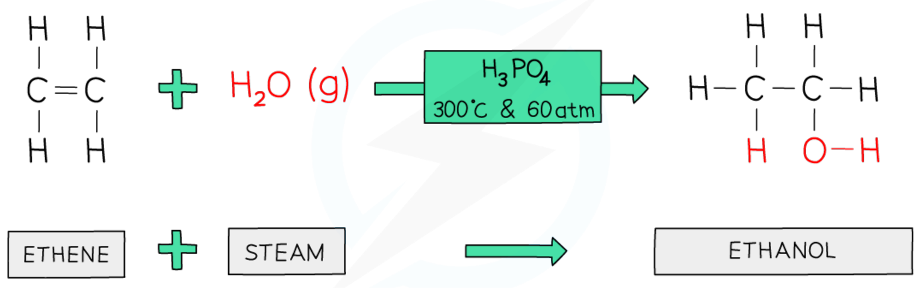
- Alkenes also undergo addition reactions with steam in which an **alcohol** is formed. Since water is being added to the molecule it is also called a **hydration** reaction
- The reaction is very important industrially for the production of alcohols and it occurs using the following conditions:

14 ORGANIC CHEMISTRY

YOUR NOTES

14.2.2 ALKENES cont...

- Temperature of around **330°C**
- Pressure of **60 – 70 atm**
- Concentrated phosphoric **acid catalyst**



A water molecule adds across the C=C in the hydration of ethene to produce ethanol

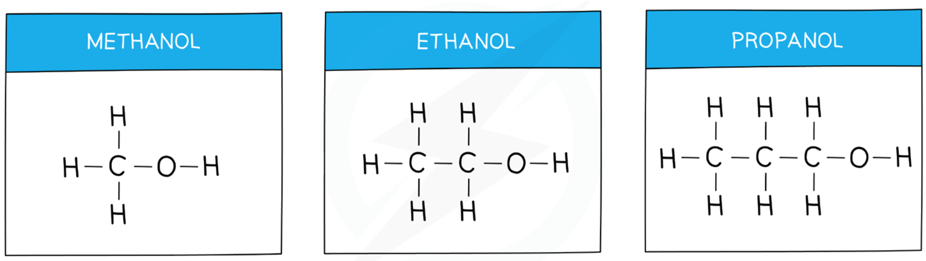
14.2.3 ALCOHOLS

Alcohols

Alcohols

- Family of organic compounds that all contain the -OH functional group
- This is the group of atoms responsible for their chemical properties and reactions

The first three alcohols



Ethanol

- Ethanol (C_2H_5OH) is one of the most important alcohols
- It is the type of alcohol found in **alcoholic drinks** such as wine and beer
- It is also used as fuel for **cars** and as a **solvent**
- Alcohols burn in excess oxygen and produce CO_2 and H_2
- Ethanol undergoes combustion:

$$CH_3CH_2OH + 3O_2 \rightarrow 2CO_2 + 3H_2O$$

14 ORGANIC CHEMISTRY

YOUR NOTES

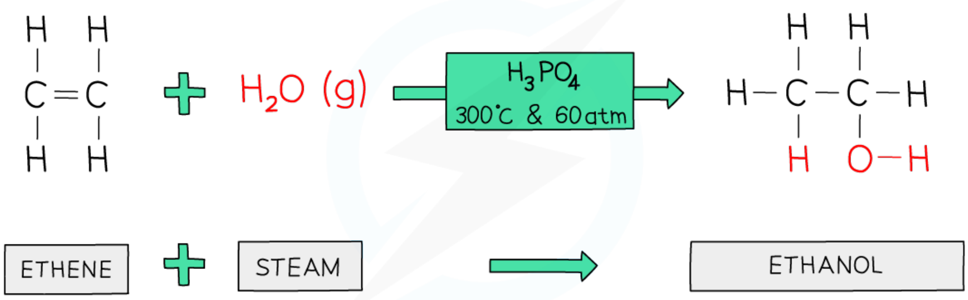
14.2.3 ALCOHOLS cont...

The manufacture of ethanol

- There are two methods used to manufacture ethanol:
  - The **hydration** of **ethene** with steam
  - The **fermentation** of glucose
- Both methods have advantages and disadvantages which are considered

Hydration of ethene

- A mixture of ethene and steam is passed over a hot catalyst of **phosphoric acid** at a temperature of **330°C**
- The pressure is used **60-70** atmosphere
- The gaseous ethanol is then condensed into a liquid for use



A water molecule adds across the C=C in the hydration of ethene to produce ethanol

Fermentation of glucose

- Sugar or starch is dissolved in water and yeast is added
- The mixture is then fermented between **15** and **35°C** with the **absence** of oxygen for a few days
- Yeast contains **enzymes** that break down starch or sugar to glucose
- If the temperature is too **low** the reaction rate will be too slow and if it is too **high** the enzymes will become **denatured**
- The yeast respire anaerobically using the glucose to form ethanol and carbon dioxide:

$$C_6H_{12}O_6 + \text{Enzymes} \rightarrow 2CO_2 + 2C_2H_5OH$$

- The yeast are killed off once the concentration of alcohol reaches around 15%, hence the reaction vessel is emptied and the process is started again
- This is the reason that ethanol production by fermentation is a batch process.

14 ORGANIC CHEMISTRY

YOUR NOTES

14.2.3 ALCOHOLS cont...

Comparing methods of ethanol production

	HYDRATION OF ETHENE	FERMENTATION
EQUIPMENT	COMPLEX SET–UP REQUIRED	SIMPLE EQUIPMENT NEEDED
RAW MATERIALS	USES NON–RENEWABLE RESOURCES (CRUDE OIL)	USES RENEWABLE RESOURCES (SUGAR CANE)
TYPE OF PROCESS	CONTINUOUS PROCESS – A STREAM OF REACTANT IS CONSTANTLY PASSED OVER THE CATALYST. THIS IS MORE EFFICIENT THAN A BATCH PROCESS	BATCH PROCESS – EVERYTHING IS MIXED TOGETHER IN A REACTION VESSEL AND THEN LEFT FOR SEVERAL DAYS. THAT BATCH IS THEN REMOVED AND A NEW REACTION IS SET UP – THIS IS INEFFICIENT
RATE OF REACTION	FAST	VERY SLOW (SEVERAL DAYS)
QUALITY OF PRODUCT	PRODUCES PURE ETHANOL	PRODUCES A DILUTE SOLUTION REQUIRING FURTHER PROCESSING
ATMOSPHERIC EFFECTS	NO GREENHOUSE GAS IS PRODUCED BUT POLLUTANTS ARE FORMED FROM THE BURNING OF FOSSIL FUELS TO MAINTAIN HIGH TEMPERATURE	CARBON DIOXIDE PRODUCED WHICH IS A GREENHOUSE GAS
REACTION CONDITIONS	HIGH TEMPERATURES AND PRESSURES REQUIRED, INCREASING THE ENERGY INPUT AND COST	LOW TEMPERATURES REQUIRED

EXAM TIP

Fermentation is an anaerobic process.

Oxygen is not required for ethanol to be produced by fermentation.

14.2.4 CARBOXYLIC ACIDS

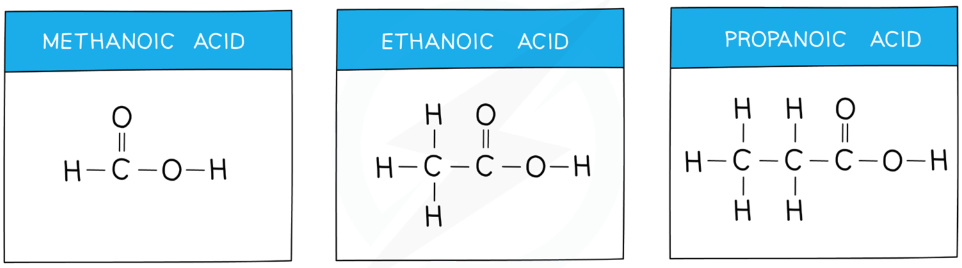
YOUR NOTES

Ethanoic Acid

Carboxylic acids

- These are a homologous series of organic compounds that all contain the same functional group: –COOH
- They are **colourless** liquids which are **weakly acidic** and have typical acidic properties
- They react with **alkaline** solutions, turn blue litmus **red** and form **salts** called **ethanoates**

The first three carboxylic acids



Ethanoic acid

- Ethanoic acid is a typically weak acid and dissociates slightly in water, producing a mildly acidic solution
- The equilibrium lies far to the left during ionization:

$$CH_3COOH \rightleftharpoons H^+ + CH_3COO^-$$

- Ethanoic acid reacts with the more reactive metals, hydroxides and carbonates

Reactions of ethanoic acid

- In the reaction with **metals** a metal salt and hydrogen gas are produced
- For example in reaction with magnesium the salt magnesium ethanoate is formed:

$$2CH_3COOH + Mg \rightarrow (CH_3COO)_2Mg + H_2$$

- In the reaction with **hydroxides** a salt and water are formed in a neutralisation reaction
- For example in reaction with potassium hydroxide the salt potassium ethanoate is formed:

$$CH_3COOH + KOH \rightarrow CH_3COOK + H_2O$$

- In the reaction with **carbonates** a metal salt, water and carbon dioxide gas are produced
- For example in reaction with potassium carbonate the salt potassium ethanoate is formed:

$$2CH_3COOH + K_2CO_3 \rightarrow 2CH_3COOK + H_2O + CO_2$$

14.2.4 CARBOXYLIC ACIDS cont...

YOUR NOTES

EXAM TIP

The carbon atom in the -COOH functional group is counted as part of the molecule and not just the functional group.

E.g. $CH_3CH_2CH_2COOH$ has 4 carbon atoms so is called butanoic acid, not propanoic acid.

EXTENDED ONLY

Ethanoic Acid & Esterification Reactions

Making Carboxylic Acids

Oxidation by fermentation

- The **microbial oxidation** of ethanol will produce a weak solution of vinegar (ethanoic acid)
- This occurs when a bottle of wine is opened as bacteria in the air (acetobacter) will use atmospheric oxygen from air to oxidise the ethanol in the wine:

$$C2H_5OH + O_2 \rightarrow CH_3COOH + H_2O$$

- The acidic, vinegary taste of wine which has been left open for several days is due to the presence of ethanoic acid

Oxidation with potassium manganate (VII)

- Alcohols can also be oxidised to carboxylic acids by heating with **acidified potassium manganate** (VII)
- The heating is performed under **reflux** which involves heating the reaction mixture in a vessel with a condenser attached to the top
- The condenser prevents the volatile alcohol from escaping the reaction vessel as alcohols have low boiling points

14 ORGANIC CHEMISTRY

14.2.4 CARBOXYLIC ACIDS cont...

YOUR NOTES

EXTENDED ONLY cont...

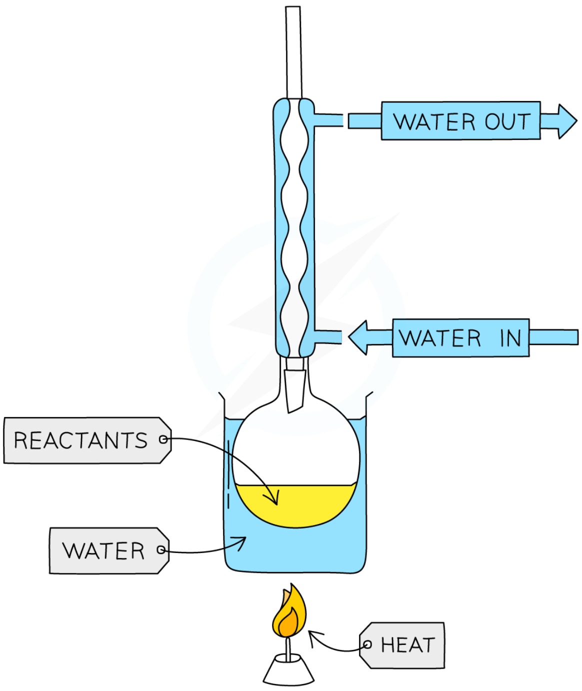


Diagram showing the experimental setup for the oxidation with K_2MnO_4 using reflux apparatus

Making esters

- Alcohols and carboxylic acids react to make esters in **esterification** reactions
- Esters are compounds with the functional group R-COO-R
- Esters are sweet smelling oily liquids used in food flavourings and perfumes
- Ethanoic acid will react with ethanol in the presence of concentrated sulfuric acid (catalyst) to form ethyl ethanoate:

$$CH_3COOH + C_2H_5OH \rightarrow CH_3COOC_2H_5 + H_2O$$

YOUR NOTES

14.2.4 CARBOXYLIC ACIDS cont...

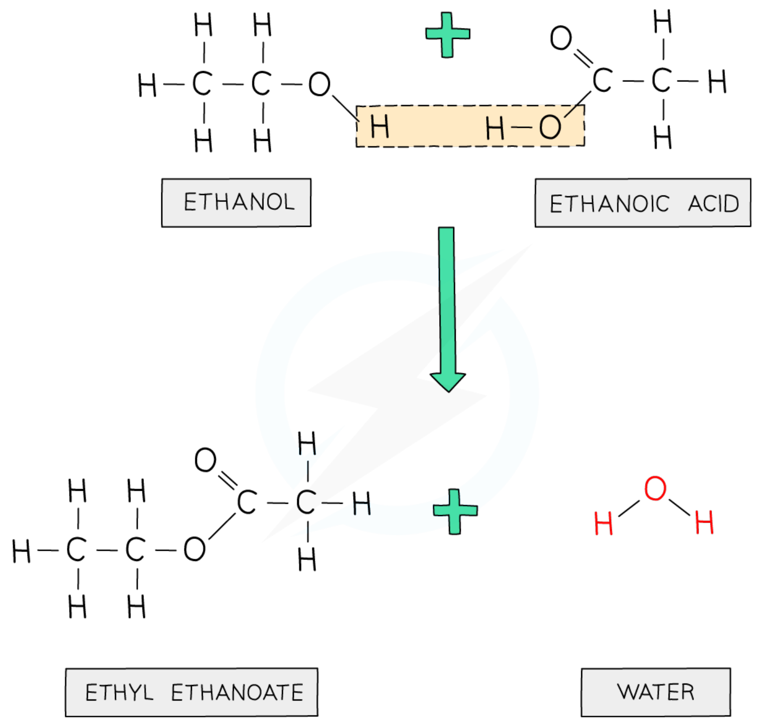


Diagram showing the formation of ethyl ethanoate

Naming esters

- An ester is made from an alcohol and carboxylic acid
- The first part of the name indicates the length of the carbon chain in the alcohol, and it ends with the letters '- yl'
- The second part of the name indicates the length of the carbon chain in the carboxylic acid, and it ends with the letters '- oate'
- E.g. the ester formed from pentanol and butanoic acid is called pentyl butanoate

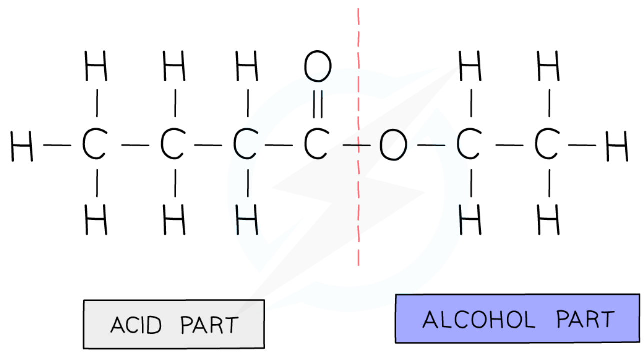


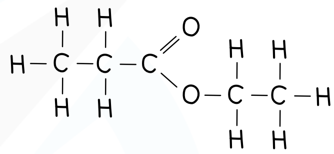
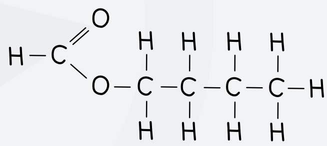
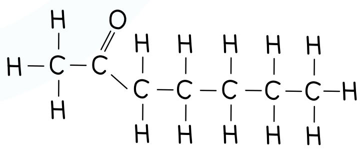
Diagram showing the origin of each carbon chain in ester

14 ORGANIC CHEMISTRY

14.2.4 CARBOXYLIC ACIDS cont...

YOUR NOTES

Examples of esters

NAME OF ALCOHOL	NAME OF CARBOXYLIC ACID	NAME OF ESTER
ETHANOL	PROPANOIC ACID	ETHYL PROPANOATE 
BUTANOL	METHANOIC ACID	BUTYL METHANOATE 
PENTANOL	ETHANOIC ACID	PENTYL ETHANOATE 

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which of the following formulae shows an alkane?

A C_2H_4

B C_4H_8

C C_4H_{10}

D C_5H_{10}

QUESTION 2

Which of the equations show the incomplete combustion of methane?

A $2\ CH_4 + 4O_2 \rightarrow 2\ CO_2 + 4\ H_2O$

B $CH_4 + O_2 \rightarrow C + 2\ H_2O$

C $CH_4 + O_2 \rightarrow C + 2\ H_2$

D $2\ CH_4 + 4\ O_2 \rightarrow 2\ CO_2 + 4\ H_2$

QUESTION 3

The following reaction takes place in the presence of light.

$$CH_4 + Cl_2 + \text{light} \rightarrow CH_3Cl + HCl$$

What is the name for this reaction?

A Combustion

B Polymerisation

C Thermal decomposition

D Substitution

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14 ORGANIC CHEMISTRY

YOUR NOTES

14.3 POLYMERS

14.3.1 POLYMERS

Polymers

- Polymers are large molecules built by linking 50 or more smaller molecules called monomers
- Each repeat unit is connected to the adjacent units via **covalent bonds**
- Some polymers called **homopolymers** contain just one type of unit
- Examples include polythene and polychloroethene, commonly known as PVC
- Others contain two or more different types of monomer units and which are called **copolymers**
- Examples include nylon and biological proteins
- Different **linkages** also exist, depending on the monomers and the type of polymerisation
- Examples of linkages are covalent bonds, **amide links** and **ester links**

14.3.2 SYNTHETIC POLYMERS

Plastics & Man-Made Fibres

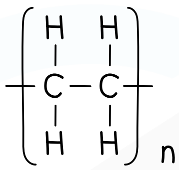
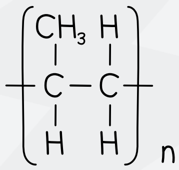
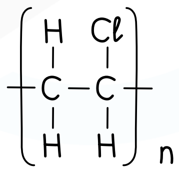
Plastics, nylon and terylene

- These are **synthetic** polymers with many uses
- Nylon is a copolymer used to produce **clothing**, **fabrics**, **nets** and **ropes**
- Terylene is a **polyester** made from monomers which are joined together by **ester links**
- Terylene is used extensively in the **textile** industry and is often mixed with cotton to produce **clothing**
- Synthetic polymerisation also produces plastics that have many different uses in today's society.

YOUR NOTES

14.3.2 SYNTHETIC POLYMERS cont...

Uses of plastics

POLYMER	REPEAT UNIT	USES
POLY(ETHENE) I.e. POLYTHENE		PLASTIC BAGS (LOW DENSITY POLYTHENE) PLASTIC BOTTLES (HIGH DENSITY POLYTHENE)
POLY(PROPENE)		FOOD PACKAGING ROPES CARPETS
POLY(CHLOROETHENE) I.e. PVC		PLASTIC SHEETS ARTIFICIAL LEATHER DRAINPIPES AND GUTTERS INSULATION ON WIRES

Non–biodegradable plastics

- These are plastics which do not degrade over time or take a very long time to degrade, and cause significant pollution problems
- In particular plastic waste has been spilling over into the **seas** and **oceans** and is causing huge disruptions to marine life
- In landfills, waste polymers take up valuable space as they are non-biodegradable so microorganisms cannot break them down. This causes the landfill sites to quickly fill up
- Polymers release a lot of heat energy when **incinerated** and produce **carbon dioxide** which is a greenhouse gas that contributes to climate change
- If incinerated by incomplete combustion, **carbon monoxide** will be produced which is a toxic gas that reduces the capacity of the blood to carry oxygen
- Polymers can be recycled but different polymers must be separated from each other which is a difficult and expensive process.

14.3.2 SYNTHETIC POLYMERS cont...

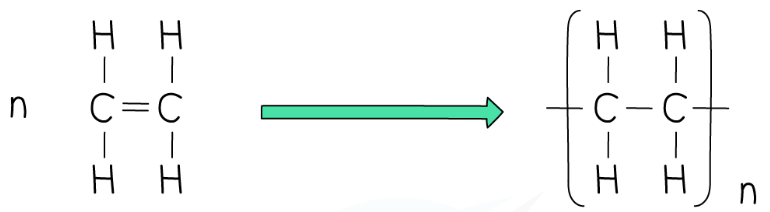
YOUR NOTES

EXTENDED ONLY

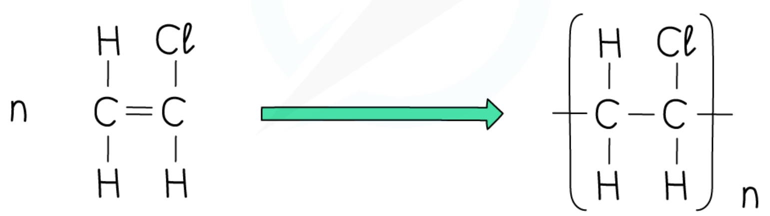
Addition & Condensation Polymers & Deducing Structures

Addition polymerisation

- Addition polymers are formed by the joining up of many monomers and only occurs in monomers that contain C=C bonds
- **One** of the bonds in each C=C bond breaks and forms a bond with the adjacent monomer with the polymer being formed containing single bonds only
- Many polymers can be made by the addition of alkene monomers
- Others are made from alkene monomers with different atoms attached to the monomer such as chlorine or a hydroxyl group
- The name of the polymer is deduced by putting the name of the **monomer** in brackets and adding poly- as the **prefix**
- For example if propene is the alkene monomer used, then the name is **polypropene**



ETHENE   POLY(ETHENE)



CHLOROETHENE   POLY(CHLOROETHENE)

Examples of addition polymerisation: polythene and PVC

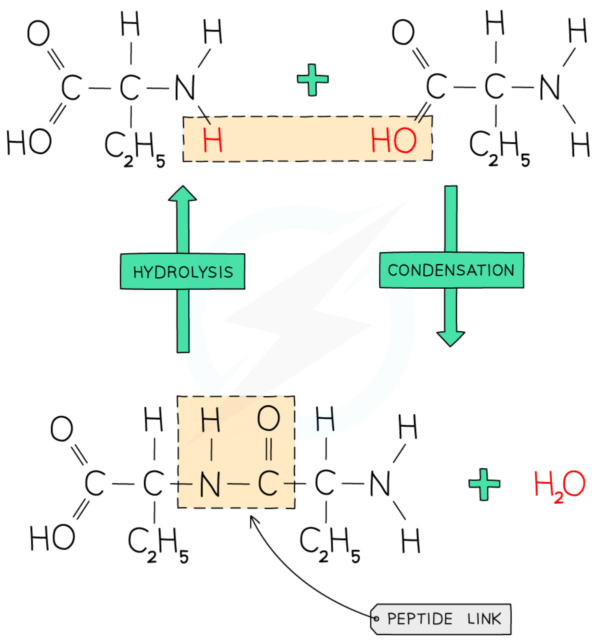
14 ORGANIC CHEMISTRY

14.3.2 SYNTHETIC POLYMERS cont...

EXTENDED ONLY cont...

Condensation polymerisation

- Condensation polymers are formed when monomer molecules are linked together with the **removal** of a small molecule, usually **water**
- Condensation polymerisation usually involves **two different monomers**, each one having a **functional** group on **each end**
- Hydrolysing (adding water) to the compound in acidic conditions usually reverses the reaction and produces the monomers by rupturing the peptide link



Condensation produces the polyamide which is ruptured at the link by hydrolysis in the reverse reaction

Deducing the monomer from the polymer

- Polymer molecules are very large compared with most other molecules
- **Repeat units** are used when displaying the formula:
- Change the double bond in the monomer to a **single bond** in the repeat unit
- Add a bond to each end of the repeat unit
- The bonds on either side of the polymer must **extend** outside the brackets (these are called extension or continuation bonds)
- A small subscript **n** is written on the bottom right-hand side to indicate a large number of repeat units

14 ORGANIC CHEMISTRY

14.3.2 SYNTHETIC POLYMERS cont...

YOUR NOTES

EXTENDED ONLY cont...

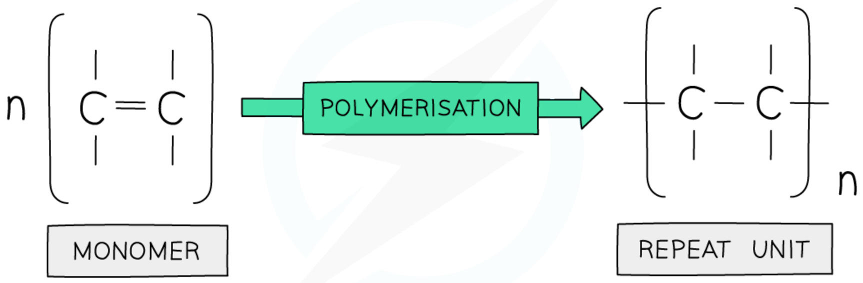


Diagram showing the concept of drawing a repeat unit of a monomer

Deducing the polymer from the monomer

- Identify the repeating unit in the polymer
- Change the single bond in the repeat unit to a **double bond** in the monomer
- Remove the bond from each end of the repeat unit and the subscript n

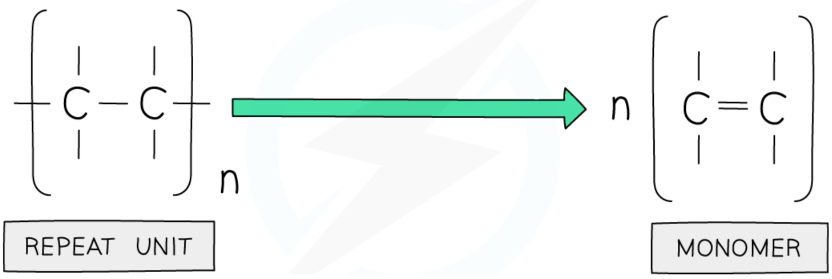


Diagram showing how to deduce the structure of a monomer from a repeat unit

Example: Deducing the structure of chloroethene from a repeat unit of Poly(chloroethene)

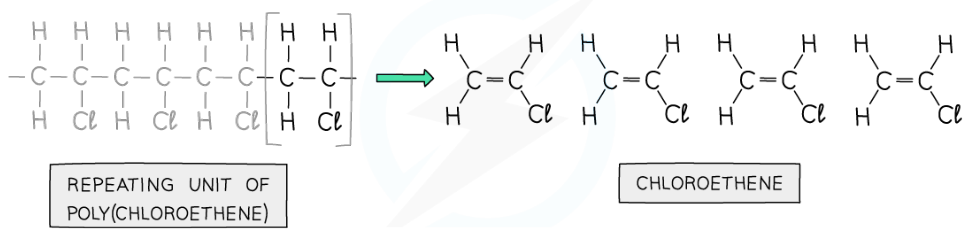


Diagram showing the monomer from the repeat unit of an addition polymer (polychloroethene)

14 ORGANIC CHEMISTRY

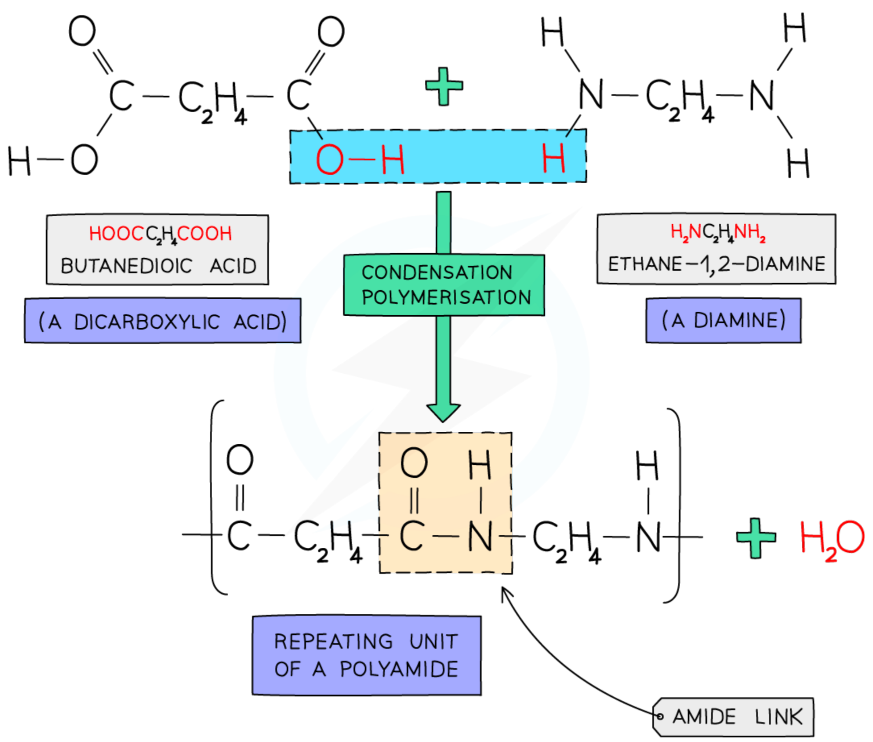
14.3.2 SYNTHETIC POLYMERS cont...

YOUR NOTES

EXTENDED ONLY cont...

Formation of Nylon

- Nylon is a **polyamide** made from **dicarboxylic** acid monomers (a carboxylic with a -COOH group at **either** end) and **diamines** (an amine with an $-NH_2$ group at **either** end)
- Each -COOH group reacts with another -NH2 group on another monomer
- An **amide linkage** is formed with the subsequent loss of **one** water molecule per link



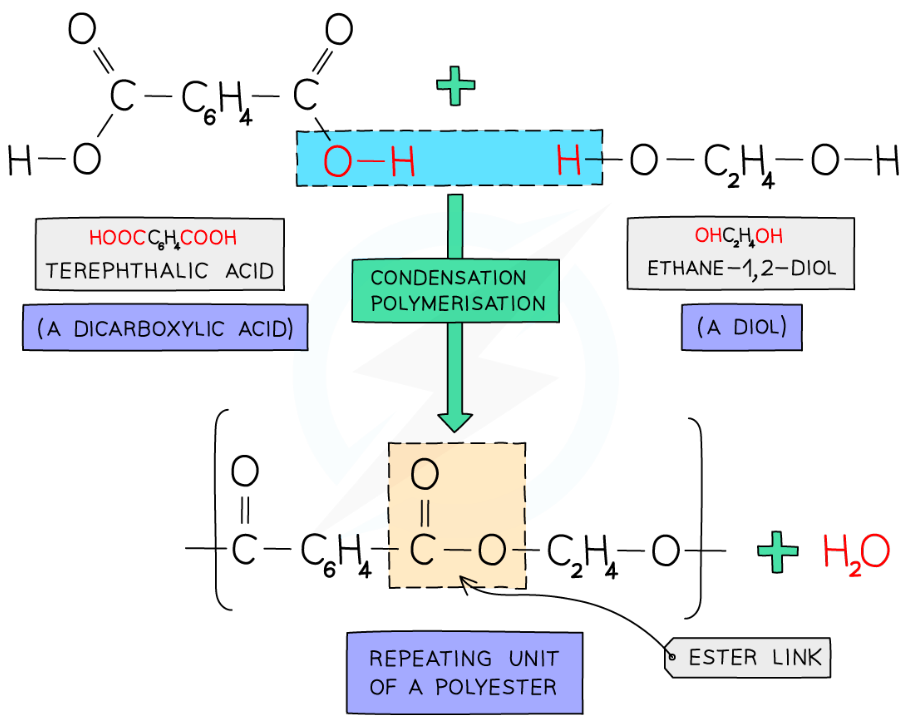
The condensation reaction in which the polyamide Nylon is produced

14.3.2 SYNTHETIC POLYMERS cont...

EXTENDED ONLY cont...

Formation of Terylene

- Terylene is a **polyester** made from **dicarboxylic** acid monomers (a carboxylic with a -COOH group at **either** end) and **diols** (an alcohol with an -OH group at **either** end)
- Each -COOH group reacts with another -OH group on another monomer
- An ester linkage is formed with the subsequent loss of **one** water molecule per link



The condensation reaction in which the polyester Terylene is produced

EXAM TIP

You should be able to draw the **box diagrams** representing polymers where each box represents a part of the repeating hydrocarbon chain.

The **functional groups** on the monomers and the **link** formed in the polymers are the important parts and must be clearly drawn.

YOUR NOTES

14 ORGANIC CHEMISTRY

YOUR NOTES

14.3.3 NATURAL POLYMERS

Proteins

Proteins and carbohydrates

- These are two of the main and most important components of **food**
- **Carbohydrates** provide **energy** which is released during **cellular respiration**
- Proteins are the building blocks of cells and are essential for growth and all of the enzyme catalysts in the body are proteins

Proteins

- Proteins are **condensation polymers** which are formed from **amino acid** monomers joined together by peptide bonds, similar to the structure in Nylon
- The units in proteins are different however, consisting of amino acids
- Amino acids are small molecules containing $\mathbf{NH_2}$ and **COOH** functional groups
- Most proteins contain at least **20 different** amino acids
- These are the monomers which polymerise to form the protein

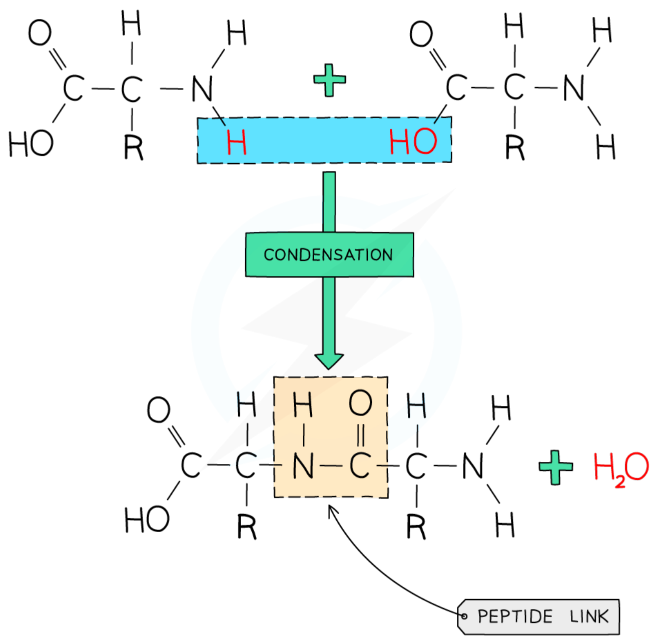


Diagram showing condensation polymerisation to produce a protein

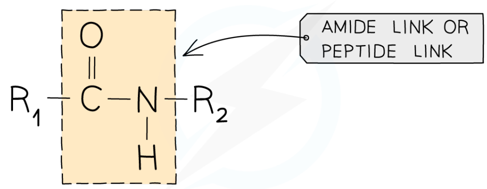


Diagram showing a peptide link which holds proteins together

YOUR NOTES

14.3.3 NATURAL POLYMERS cont...

Hydrolysis of proteins

- Proteins can be **hydrolysed** by the addition of water in acidic or alkaline conditions
- **Heat** and **concentrated** acid (usually 6 mol/dm^3 HCl) are used with a reflux condenser to prevent the acidic vapours from escaping the reaction vessel
- Aqueous ammonia is added after completion to **neutralise** the excess acid
- Enzymes can also be used to hydrolyse some proteins at room temperature, mimicking natural bodily processes

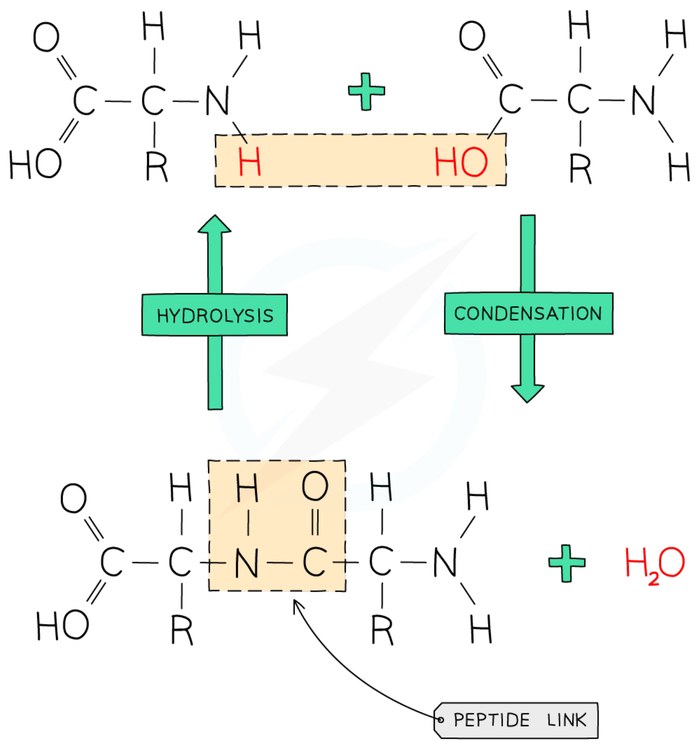


Diagram showing the rupture of a peptide link by hydrolysis

EXAM TIP

When drawing biological polymers it is important that you show the peptide link clearly in your sketch.

14 ORGANIC CHEMISTRY

14.3.3 NATURAL POLYMERS cont...

YOUR NOTES

EXTENDED ONLY

Carbohydrates, Fermentation & Chromatography

Carbohydrates

- Carbohydrates are compounds of **carbon**, **hydrogen** and **oxygen** with the general formula $C_x(H_2O)_y$
- There are **simple** carbohydrates and **complex** carbohydrates
- Simple carbohydrates are called **monosaccharides** and are **sugars** such as fructose and glucose
- Complex carbohydrates are called **polysaccharides** such as **starch** and **cellulose**. These are condensation polymers formed from simple sugar monomers
- Complex carbohydrates, unlike proteins, are usually made up of the same monomers
- A H_2O molecule is eliminated when simple sugars polymerise. The linkage formed is an -O- linkage called a **glycosidic** linkage

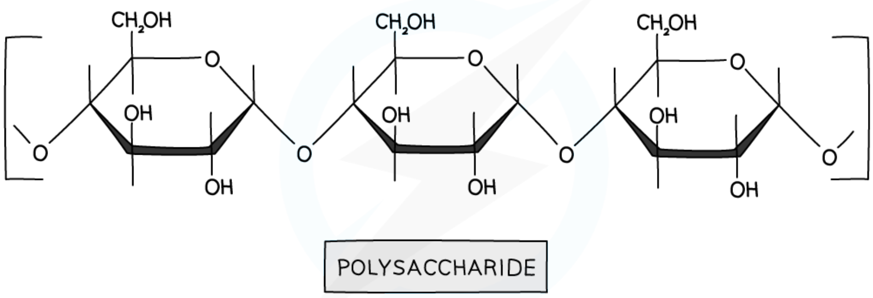


Diagram of a polysaccharide showing the glycosidic linkages (–O–) binding the monomers together

Hydrolysis of carbohydrates

- The complex carbohydrates also undergo hydrolysis and produce the simple sugar monomers from which they were made
- This can be done by refluxing with more moderately concentrated HCl

Fermentation of simple sugars

- **Simple sugars can be fermented to produce alcohol**
- They are dissolved in water and yeast is added to be fermented between **15** and **35°C** in the **absence** of oxygen for a few days
- If the temperature is too **low** the reaction rate will be too slow and if it is too **high** the enzymes will become denatured

14 ORGANIC CHEMISTRY

YOUR NOTES

14.3.3 NATURAL POLYMERS cont...

EXTENDED ONLY cont...

- Yeast contains zymase enzymes (**biological** catalysts) that break down starch or sugar to glucose
- The yeast respires anaerobically using the glucose to form ethanol and carbon dioxide:

$$C_6H_{12}O_6 + \text{Enzymes} \rightarrow 2CO_2 + 2C_2H_5OH$$

Chromatography

- The identification of the products of the hydrolysis of carbohydrates and proteins can be done using **chromatography**
- Originally used for separating coloured substances, chromatography can be used to identify colourless compounds using **locating agents**
- Both carbohydrate and protein monomers are **colourless** so locating agents must be used
- A technique called 2-Dimensional paper chromatography is used as some simple sugars and amino acids have the same R_f
- In this technique a run is carried out in one direction, then the paper is **rotated** by **90°** and performed again using a **different** solvent
- This further separates sample spots that may not have separated in the first run
- The resulting chromatogram is **dried** and **sprayed** with a locating agent
- The Rf value of each solvent used is characteristic for each sugar or amino acid

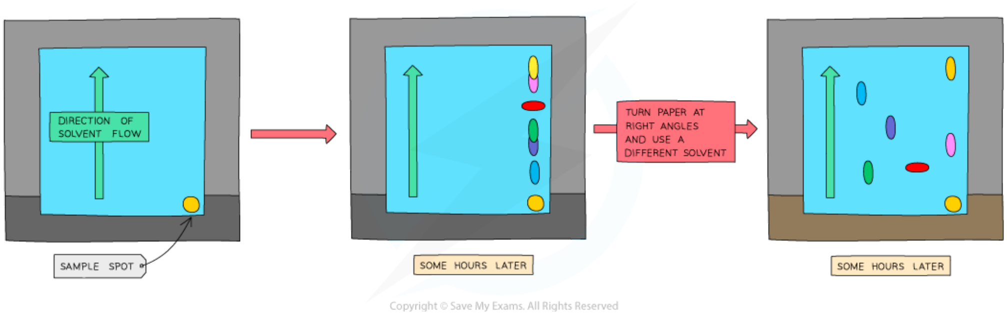


Diagram showing the procedure for performing 2−Dimensional paper chromatography

> NOW TRY SOME EXAM QUESTIONS

EXAM QUESTIONS

YOUR NOTES

QUESTION 1

Which statement about polymers is correct?

A Addition polymers are all biodegradable.

B Condensation polymers can all be hydrolysed to give amino acids.

C Condensation polymers only exist in nature.

D Forming addition polymers produces only one product.

QUESTION 2

A macromolecule is a very large molecule.

Macromolecules can be made by joining smaller molecules together. This is called polymerisation.

Which row in the table describes the formation of a polymer?

	monomer	polymer
A	ethane	poly(ethane)
B	ethene	poly(ethene)
C	ethane	poly(ethene)
D	ethene	poly(ethane)

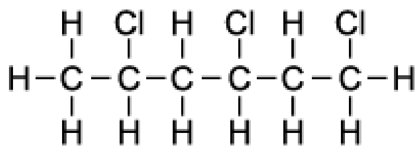
14 ORGANIC CHEMISTRY

EXAM QUESTIONS

YOUR NOTES

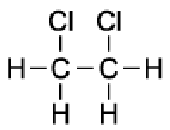
QUESTION 3

The diagram shows three repeat units in the structure of an addition polymer.

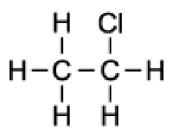


Which alkene monomer is used to make this polymer?

A



B



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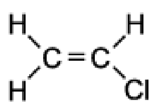

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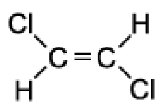

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