Topic 5:

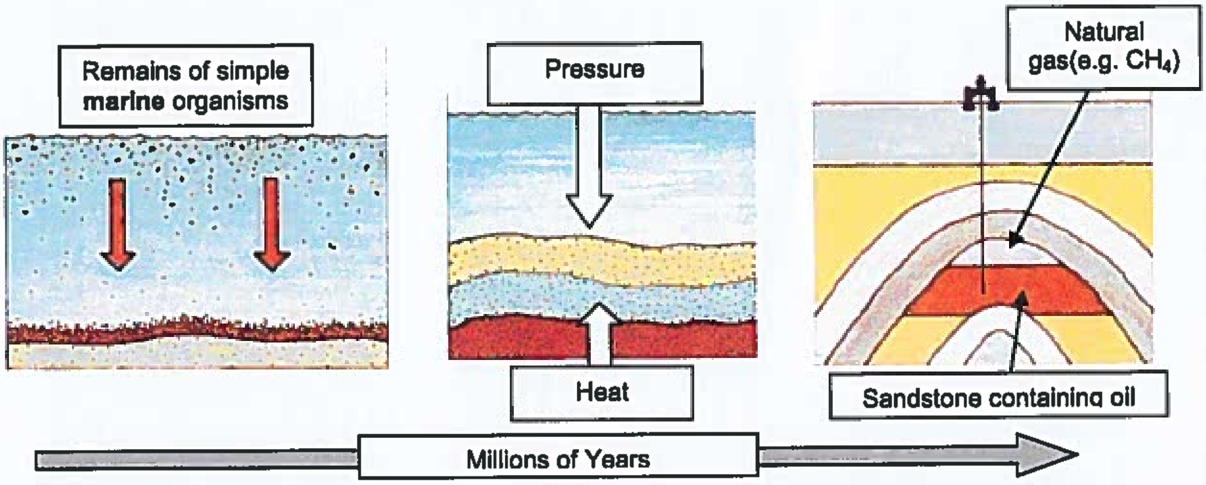
Crude Oil, Fuels and Organic Chemistry

C70

Production and uses of fuels

Crude oil (petroleum)

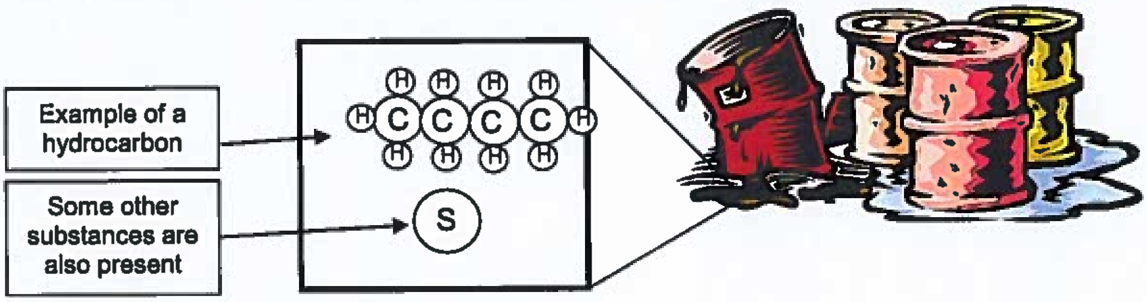
Formed over millions of years from the remains of simple marine organisms



There is a limit to coal, crude oil (petroleum) and natural gas life as they will run out over time – they are **finite** – or **non-renewable.**

Crude oil is a mixture of hydrocarbons

Hydrocarbons are compounds that contain the elements **hydrogen** and **carbon** only.

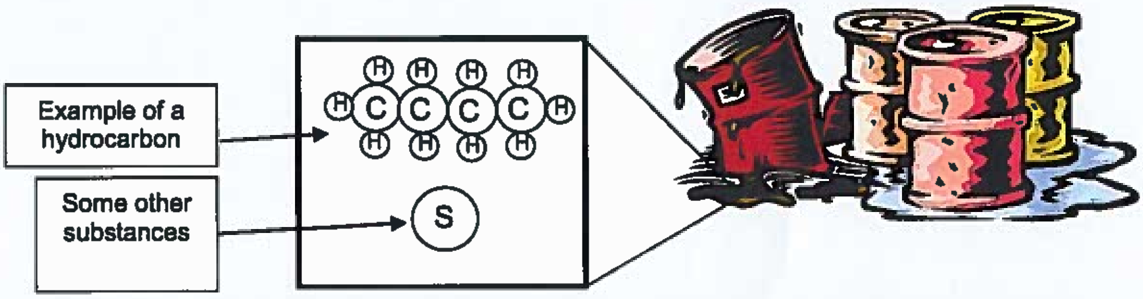


Carbon has the ability to form bonds with other carbon atoms resulting in the formation of carbon atom chains, e.g.

Crude oil contains a mixture of different sized hydrocarbon chains

Fractional Distillation

Crude oil is a mixture of different substances, most of them being hydrocarbons

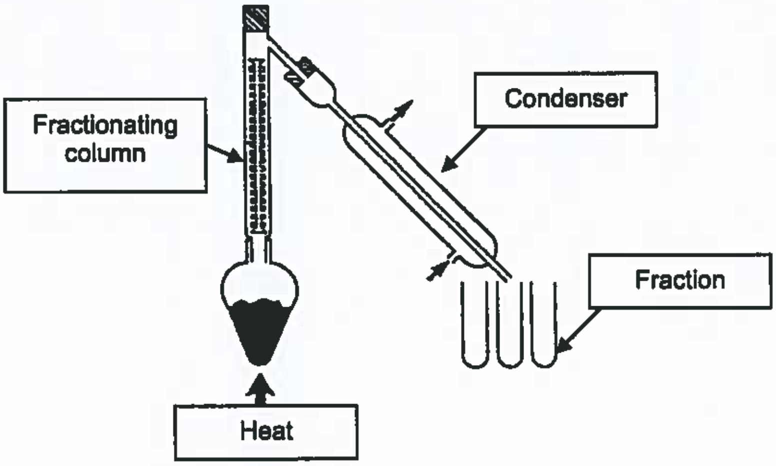


Hydrocarbons are molecules which contain the elements hydrogen and carbon only.

Fractional Distillation – it is possible to separate hydrocarbons by fractional distillation because hydrocarbons boil at different temperature ranges

Fractional Distillation in a laboratory

The reaction is carried out in a fume cupboard as poisonous gases such as sulphur dioxide can form.



As some of the hydrocarbons have similar boiling points a group of them will collect together. **Fraction** is the name given to a group of hydrocarbons that collect this way.

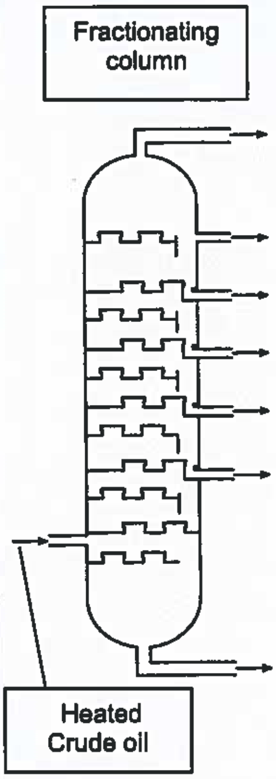
The hydrocarbon boiling point increases with the size of the carbon chain.

In the industrial process the crude oil is vaporized. The vapour is let into the column where it is hot at the bottom an cools up the column. The fractions with shorter chains have lower boiling points and can condense higher up the column. The longer hydrocarbons condense at a lower level in the column.

Fractional Distillation

Crude oil is separated into fractions

The process is called **Fractional Distillation**



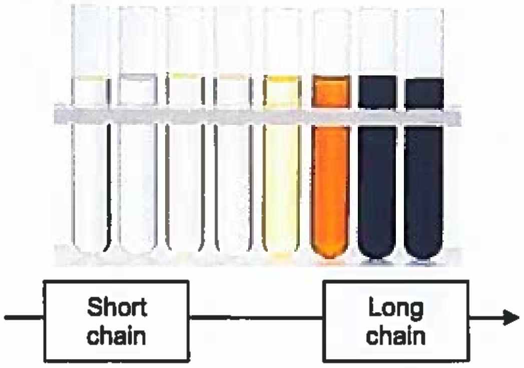
Fraction	Number of carbon atoms in a chain	Boiling point range / °C	Use
Gas	1 – 4	-160 to 25	Fuel
Petrol	4 – 12	40 to 100	Car fuel
Naphtha	7 – 14	100 to 150	Chemicals
Kerosene	11 – 15	150 to 250	Jet fuel
Diesel oil	15 – 19	250 to 350	Heating fuel
Lubricating oil	20 – 30	over 350	Car oil
Bitumen	C30 – above	over 400	Road pitch

Crude oil is separated into less complex mixtures, these are called fractions. Fractions contain hydrocarbons with **boiling points in the same range**, e.g. the petrol fraction has hydrocarbons with boiling points in the range 40-100 °C

Long chain hydrocarbons are at the **bottom** of the column as they do not boil until a very high temperature.

Some of the fractions are used as **fuels** (e.g. kerosine - aeroplane fuel) others are further processed by **cracking**.

Properties of the fractions



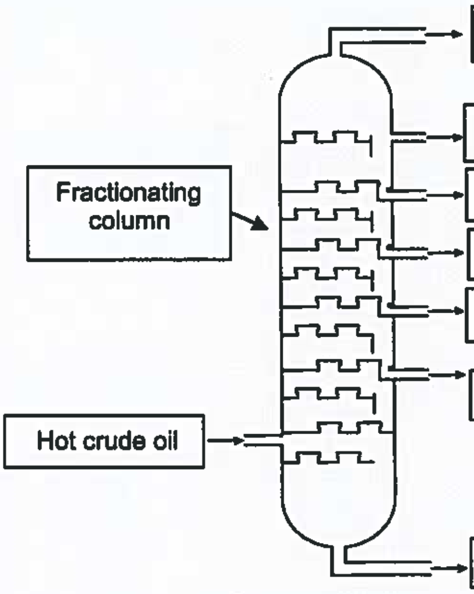
As the length of the chain increases:

1. The colour of the fraction turns from colourless - yellow - brown.
2. They are harder to ignite.
3. They burn dirtier.
4. They get more viscous

Production and uses of fuels

Crude oil is separated into fractions

The process is called **Fractional Distillation**



Fraction	No. of Carbon atoms in chain	Boiling point range / °C
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paraffin/kerosine	11 – 15	150 to 250
diesel oil	15 – 19	250 to 350
Lubricating oil	20 – 30	over 350
Bitumen	C30 – and above	over 400

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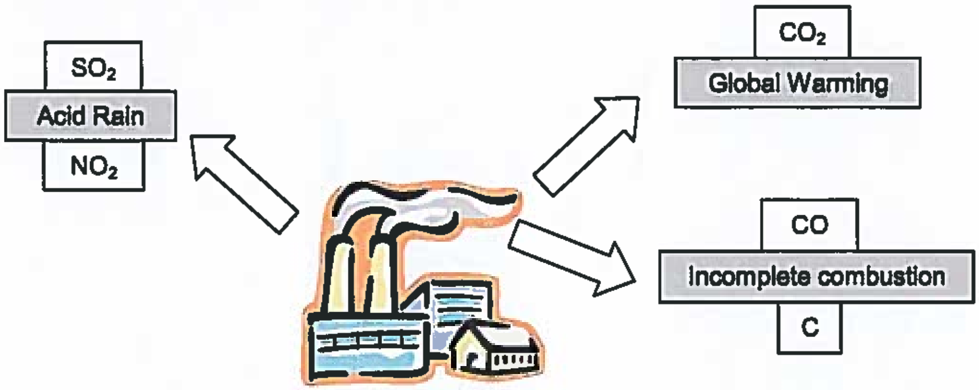
Problems with burning fossil fuels



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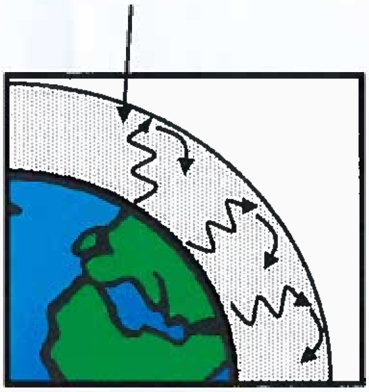
Global Warming

There is evidence to suggest that the Earth is warming but scientists do not all agree on the cause of this.

Many think that it is due mainly to increased levels of carbon dioxide in the atmosphere as a result of the combustion of fossil fuels and deforestation.

As a result the carbon cycles has been imbalanced



Higher level of carbon dioxide causes the temperature of the Earth to rise. Heat can not escape as easily

The effects of global warming

Global warming can cause :-

1. Changing weather patterns e.g. drier, hotter summers in some parts of the world leading to drought.
2. Flooding due to increase rainfall in some areas
3. Quicker melting of ice caps and glaciers
4. Rising sea levels

Carbon capture
Scientists are thinking of storing the CO_2 produced by burning fossil fuels under the sea or underground in geological formations

C75

Acid Rain

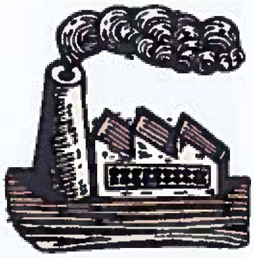
In fuels such as oil and petrol there are **impurities** (i.e. oil is not pure hydrocarbons), compounds such as sulphur and nitrogen are present.

When these burn they form **polluting gases**, such as **sulfur dioxide** and **oxides of nitrogen**.

Acid rain forms when sulfur dioxide is released from factories. Acid rain forms when **sulfur dioxide** reacts with **rain** to form **sulfuric acid**.

It kills plants (forests) and aquatic life such as fish. It also damages buildings and statues made of limestone (calcium carbonate) and metals e.g. bridges.

Sulfur dioxide



Acid rain

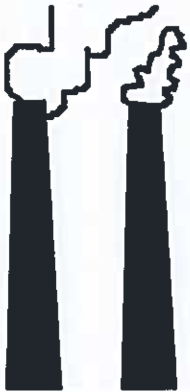
Acid rain lowers pH of lakes

Natural rain water has a pH of 5.5

Acid rain has a pH range of 2-4

Sulfur Scrubbing

The process of removing sulphur dioxide from exhaust flue gases of fossil fuel powered plants



Combustion of Fuels

Fuels are compounds are called **hydrocarbons.** They contain **carbon** and **hydrogen** atoms only bonded together.

Examples of fuels: crude oil, natural gas (methane), coal, petrol, diesel, ethanol, kerosene

Combustion (burning) fuels requires oxygen from the air. The hydrocarbons in the fuel react with the oxygen.

Burning hydrocarbons makes the products carbon dioxide and water.

fuel + oxygen (in air) → carbon dioxide + water

Example:

methane + oxygen → carbon dioxide + water

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

All combustion reactions are exothermic. Heat energy is given out into the surroundings. The temperature increases.

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Determination of the amount of energy released by a fuel

Introduction

Fuels react with oxygen when they burn, releasing energy. You will burn four different alcohols and compare the energy they give off.

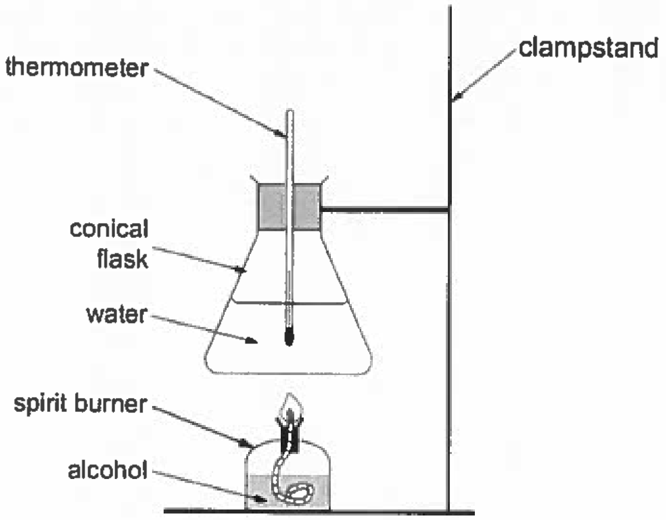
alcohol + oxygen ⟶ carbon dioxide + water

Apparatus

clamp stand, clamp and boss
250 cm^3 conical flask
100 cm^3 measuring cylinder
thermometer

Access to:
electronic balance ±0.01 g
4 × spirit burners containing methanol, ethanol, propanol, butanol

Diagram of Apparatus



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Method

1. Measure 100 cm^3 of water into the conical flask.
2. Clamp the flask at a suitable height so the spirit burner can be placed below it (as shown in the diagram - make sure that the thermometer does not touch the bottom of the flask).
3. Record the temperature of the water.
4. Record the mass of the spirit burner (including the lid and alcohol).
5. Place the spirit burner under the conical flask and light it.
6. Allow the burner to heat the water until the temperature rises by about 40 °C. Record the temperature of the water.
7. Extinguish the flame carefully and record the mass of the burner.
8. Repeat steps 1-7 with each of the other alcohols.

Risk Assessment

Hazard	Risk	Control measure
Methanol is harmful and highly flammable	May set light to / burn individuals or equipment Vapour can cause irreversible damage	Work in a well ventilated lab Wear eye protection and ensure work station is clear
Ethanol is highly flammable	May set light to / burn individuals or equipment	Work in a well ventilated lab Wear eye protection and ensure work station is clear
Propanol is highly flammable and an irritant	May set light to / burn individuals or equipment	Work in a well ventilated lab Wear eye protection and ensure work station is clear
Butanol is highly flammable and harmful if swallowed	Vapour may irritate respiratory system and may irritate skin if spilt	Work in a well ventilated lab Wear eye protection and ensure work station is clear Rinse immediately if spilt on skin

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Results

Alcohol	Initial mass of burner (g)	Final mass of burner (g)	Mass of fuel burnt (g)	Initial temperature (°C)	Final temperature (°C)	Temperature increase (°C)	Energy released per gram (J)

Analysis

1. Calculate the temperature rise for each alcohol
2. Calculate the mass of each alcohol burnt
3. Calculate the energy released by burning 1g of each alcohol using the equation below:

energy released from alcohol per gram (J) = $\frac{\text{mass of water (g)} \times \text{temperature increase (}^{\circ}\text{C)} \times 4.2}{\text{mass of alcohol}}$

C80

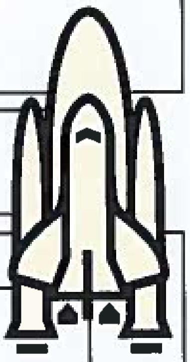
Hydrogen as a fuel

Hydrogen burns in air to make only water. The reaction is exothermic and produces a lot of energy. [exothermic – releases energy]

Hydrogen + Oxygen ⟶ Water

$$\boxed{2}H_{2\,(g)} + O_{2\,(g)} \longrightarrow \boxed{2}H_2O_{\,(l)}$$

Advantages and Disadvantages of Hydrogen as a fuel



The Chevrolet Sequel car

Hydrogen is a rocket fuel.

It is also used to power hydrogen fuel cell cars.

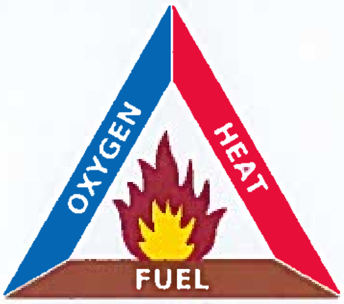
Fuel cells were invented by a Welshman Sir William Grove in 1839. It is only recently that they have been used to power cars. The technology has benefits and drawbacks.

Advantages	**Disadvantages**
Only water is produced and no carbon dioxide released – therefore it does not contribute to global warming.	Large amount of electricity needed to produce hydrogen in the first place
Does not contribute to acid rain	Storage requires bulky and heavy pressurised containers
	Safe storage is also important as hydrogen makes an explosive mixture with air

NOTE: In order for the process to remain green Hydrogen must be made by the electrolysis of water using renewable energy (solar/wind)

The Fire Triangle

The fire triangle is a simple way of understanding the factors essential for fire. Each side of the triangle represents one of the three factors required for the creation and maintenance of any fire; **oxygen, heat and fuel**. Remove any one of these, the triangle is broken and the fire is stopped.



Removing Heat
Heat can be removed by the addition of something to reduce it. Water is used to put housefires and bonfires out.

Removing Oxygen
Cover things that are burning with foam, carbon dioxide or a fire blanket to remove the air supply.

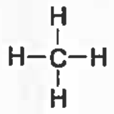
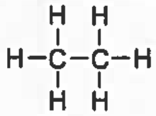
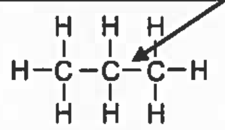
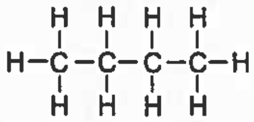
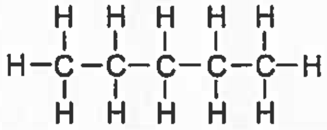
- A fire blanket is used to extinguish a chip pan fire or a person on fire.
- Carbon dioxide powder is used to put out indoor fires, chemical and electrical fires.
- Foam is used to extinguish aircraft fire.

Removing Fuel
Without fuel a fire will stop.
Switch off the electrical or gas supply,
Fire-breaks are used to put forest fires out. This is when a section of trees is cleared deliberately to remove the fuel.

Basic Organic Chemistry

Alkanes

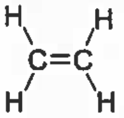
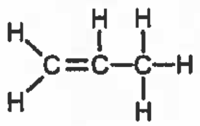
These are hydrocarbons with **single covalent bonds** between the carbon atoms. They are referred to as **saturated hydrocarbon** for this reason. Alkanes have the general formula C_nH_{2n+2}

Name	Formula	Structural Formula
Methane	CH_4	 $H-\underset{H}{\overset{H}{C}}-H$
Ethane	C_2H_6	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$
Propane	C_3H_8	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$ Single bond
Butane	C_4H_{10}	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$
Pentane	C_5H_{12}	 $H-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-\underset{H}{\overset{H}{C}}-H$

Alkanes are fairly unreactive, they combust well only.

Alkenes

When there are **double bonds** between two carbon atoms the name given to the group is **alkenes**. For this reason they are described as **unsaturated** molecules. Alkenes have the general formula C_nH_{2n}

Name	Formula	Structural formula
Ethene	C_2H_4	
Propene	C_3H_6	

As a result of the double bond the alkenes are very reactive molecules, the double bond can be broken to form single bonds with other atoms (addition reaction).

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Cracking and Addition Polymerisation

Cracking

At high temperature long hydrocarbon chains are broken down into smaller, more useful hydrocarbons.

This can create **ethene**.

Decane → Octane + Ethene

Octane: Shorter more useful

Ethene: Used to make the plastic polythene

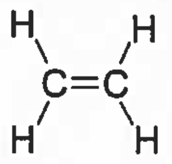
Ethene is a **small reactive molecule, a monomer**

If many ethene molecules are linked together it is called polythene which is used to make many plastics

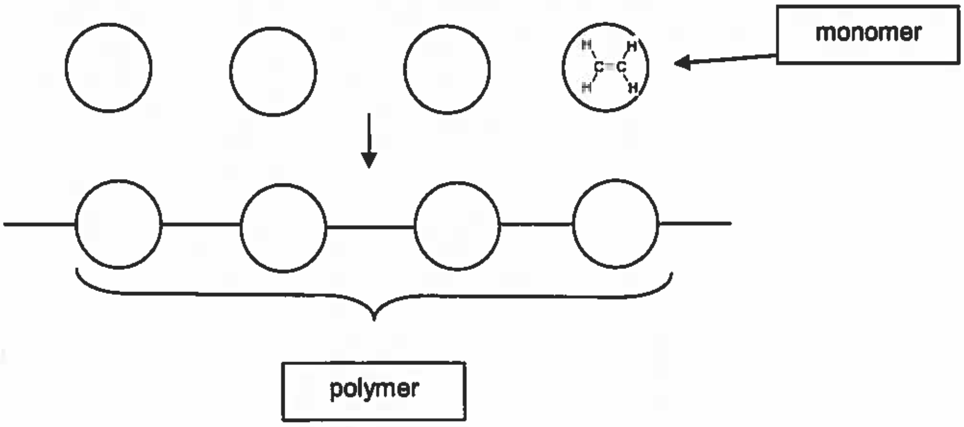
Creating Plastics

When small **reactive** molecules such as ethene react together in a chemical reaction a long chain molecule called a **polymer** is formed.

Monomer is the name given to small reactive organic molecule



Ethene has a double bond. One of the bond breaks to allow the molecule to join with another



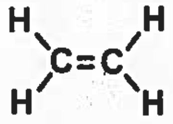
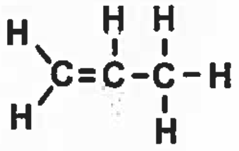
The process whereby **monomers link** to create a polymer is **polymerisation.**

The type of polymerisation that happen here is **addition polymerisation** as there is only **one product formed**

Alkenes

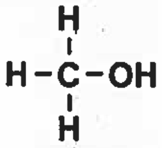
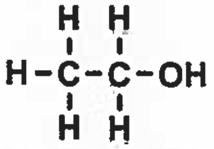
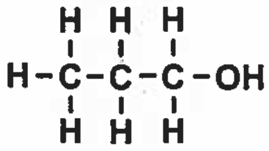
An alkene is an organic compound that contains a double bond between two carbon atoms. For this reason an alkene is referred to as an **unsaturated hydrocarbon.**

The general formula for an alkene – C_nH_{2n}

Name	**Molecular Formula**	**Structural formula**
Ethene	C_2H_4	
Propene	C_3H_6	

Alcohols

The general formula for a simple alcohol – $C_nH_{(2n+1)}OH$

Name	**Molecular Formula**	**Structural formula**
Methanol	CH_3OH	 $\begin{array}{ccccc} & & H & & \\ & & \vert & & \\ H & - & C & - & OH \\ & & \vert & & \\ & & H & & \end{array}$
Ethanol	C_2H_5OH	 $\begin{array}{ccccccc} & & H & & H & & \\ & & \vert & & \vert & & \\ H & - & C & - & C & - & OH \\ & & \vert & & \vert & & \\ & & H & & H & & \end{array}$
Propanol	C_3H_7OH	 $\begin{array}{ccccccccc} & & H & & H & & H & & \\ & & \vert & & \vert & & \vert & & \\ H & - & C & - & C & - & C & - & OH \\ & & \vert & & \vert & & \vert & & \\ & & H & & H & & H & & \end{array}$

Functional group

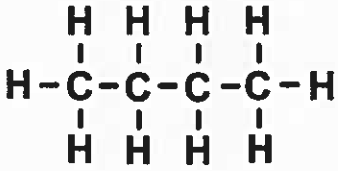
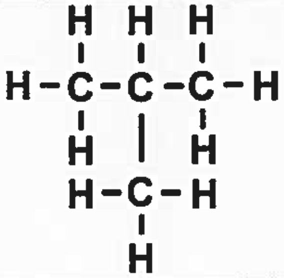
Functional groups are groups of atoms within molecules that are responsible for the characteristic chemical reactions of those molecules. The same functional group will undergo the same or similar chemical reaction(s) regardless of the size of the molecule it is a part of. The functional group for alkenes is the double bond between the carbon atoms C=C. The functional group for alcohols is the –OH group.

Isomers

In organic chemistry, isomers are molecules with the same molecular formula (i.e. the same number of atoms of each element), but different structural or spatial arrangements of the atoms within the molecule.

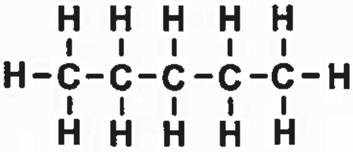
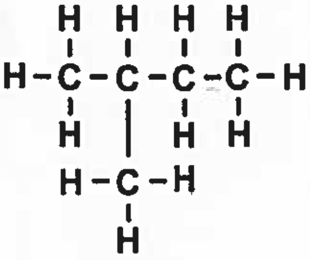
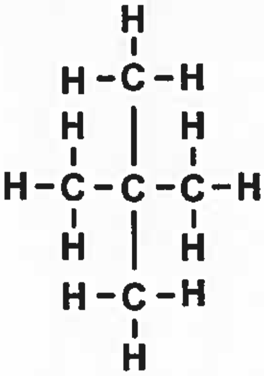
Isomer – has the same molecular formula but has a different structure.

Structural isomers of Butane

butane	methylpropane / 2-methylpropane
	

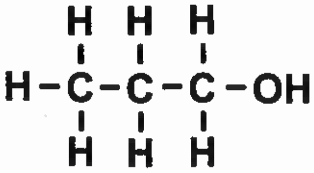
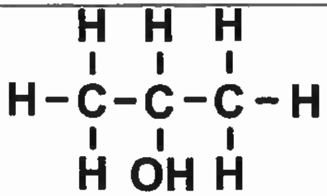
Note: You will not be required to remember the names of the isomers

Structural isomers of Pentane

pentane	2-methylbutane	2,2-di-methylpropane
		

Positional isomers of Propanol

Positional isomers occur when the 'functional group' of the molecule changes position.

propan-1-ol	Propan-2-ol
	

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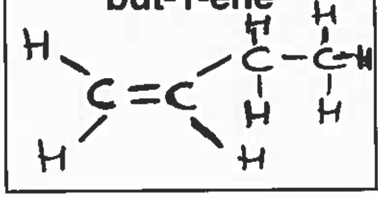
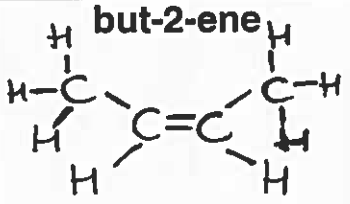
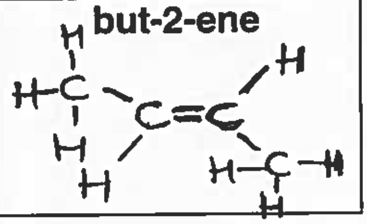
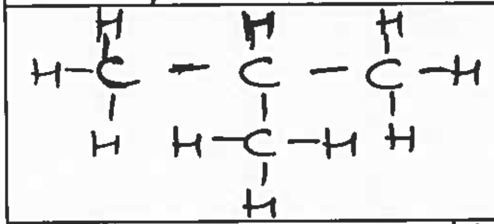
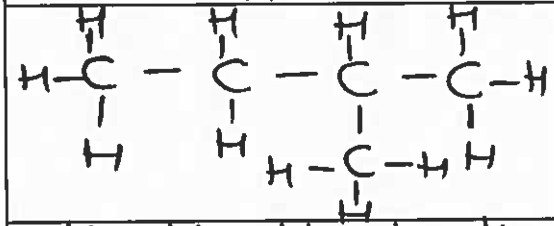
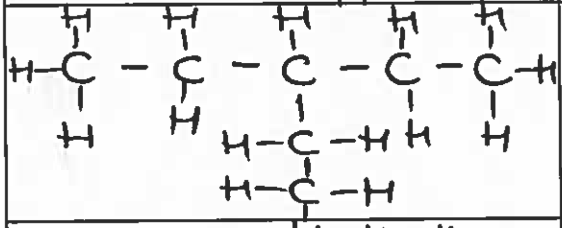
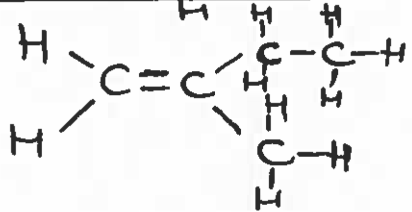
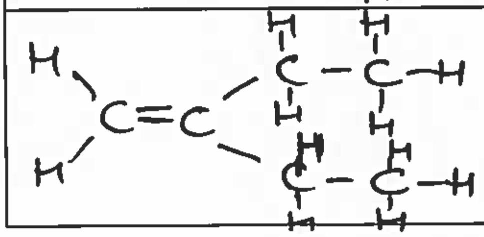
Isomerism in alkenes (Higher Tier only)

Isomers of the alkene C_4H_8 (molecular formula): 3 isomers

but-1-ene	**but-2-ene**	**but-2-ene**
		

These diagrams above show the **structural formula** of the isomers.

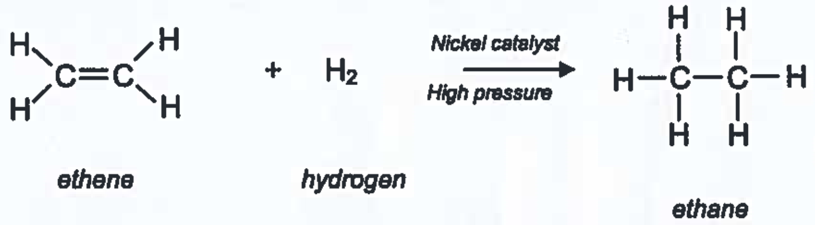
Names of more complex alkanes and alkenes (Higher Tier only)

Example: structural formula	*Name and molecular formula*
	2-methylpropane C_4H_{10}
	2-methylbutane C_5H_{12}
	3-ethylpentane C_7H_{16}
	2-methylbut-1-ene C_5H_{10}
	2-ethylbut-1-ene C_6H_{12}

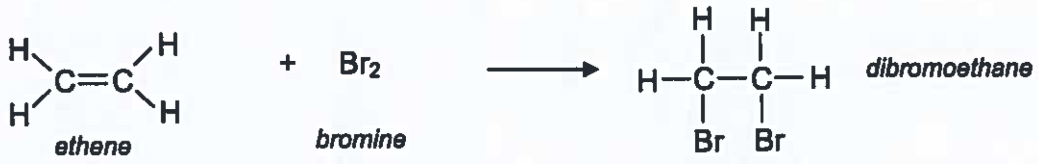
Alkenes - Addition Reactions

Reaction with Hydrogen (Hydrogenation) (Higher Tier)

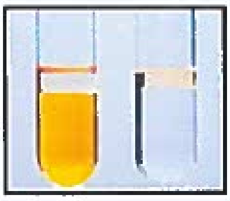
Can you write the equation for propene?



Reaction with Bromine Water (Higher Tier)



This reaction is a way of identifying alkenes. Brown bromine water turns colourless

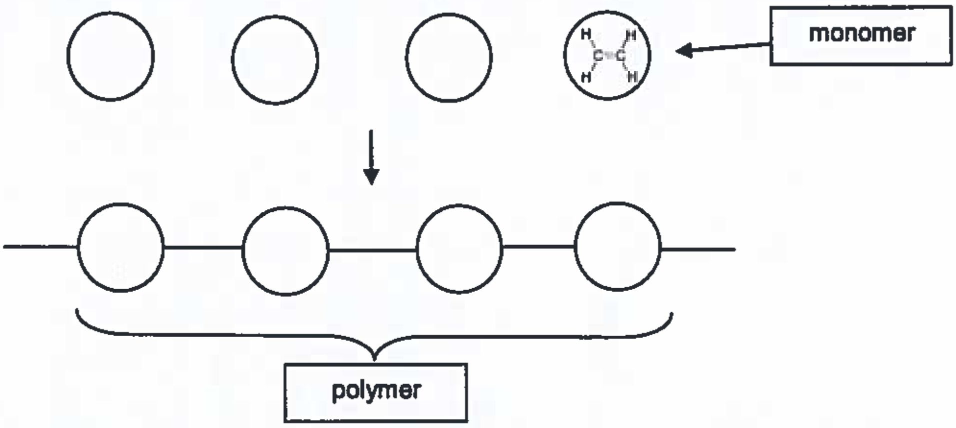


Addition Polymerisation

Creating Plastics

When small **reactive** molecules such as ethene react together in a chemical reaction a long chain molecule is formed called a **polymer**.

Monomer is the name given to small reactive organic molecule

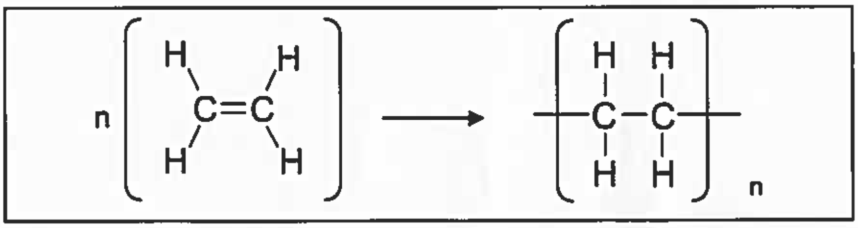


The process whereby **monomers link** to create a polymer is **polymerisation**.

The type of polymerisation that happen here is **addition polymerisation** as there is only **one product** formed

Addition Polymerisation

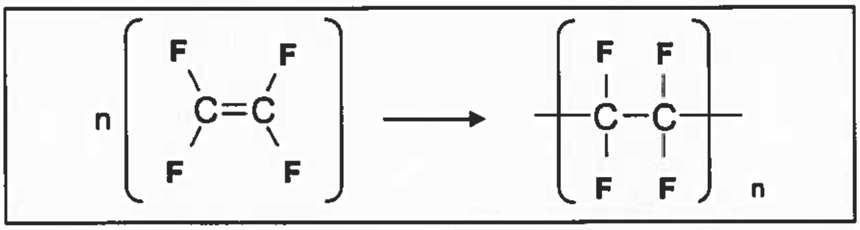
The process of making **poly(ethene)** is an example of addition polymerisation. The unsaturated monomers used are **ethene**.



ethene polythene

$${}_n(H_2C{=}CH_2) \longrightarrow \left(CH_2 - CH_2 \right)_n$$

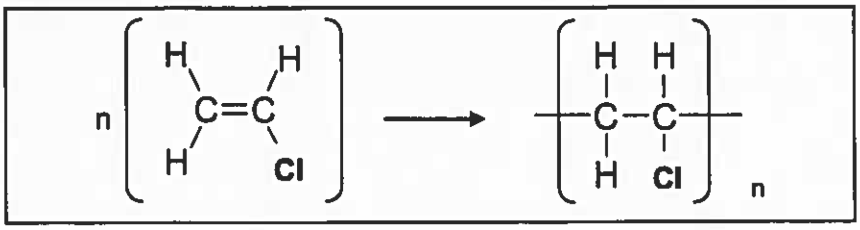
PTFE / Poly(tetrafluoroethene) /Teflon



Tetrafluoroethene Poly(tetrafluoroethene)

$${}_n(F_2C{=}CF_2) \longrightarrow \left(CF_2 - CF_2 \right)_n$$

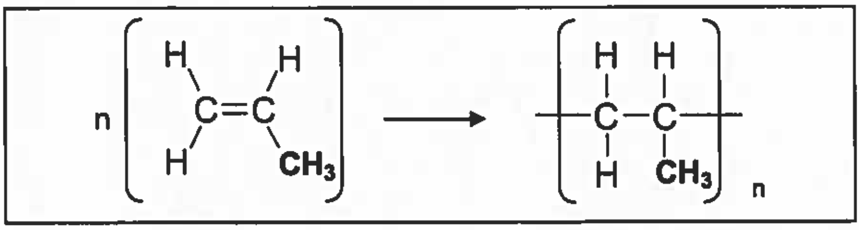
Polyvinyl chloride (PVC)



Vinyl chloride Polyvinylchloride

$${}_n(H_2C{=}CHCl) \quad \left(CH_2 - CHCl \right)_n$$

Polypropene



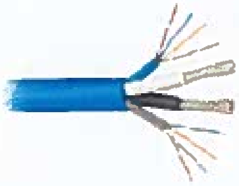
propene Polypropene

$${}_n(H_2C{=}CHCH_3) \quad \left(CH_2 - CHCH_3 \right)_n$$

C89

Properties of Plastics

There are many types of plastics, all made by polymerisation, e.g. polythene, PVC, PTFE (Teflon) and polystyrene.



Electrical insulator / flexible

Strong / low density

Thermal insulator

Strong / low density

Transparent / flexible

Plastics versus traditional materials

Plastics are used widely in place of natural materials such as paper and iron

PVC plastic is used to make water pipes/guttering because they are light, do not rust like iron, cheaper and last longer

Polythene is used to make plastic bags in place of paper as they are stronger, do not rip and are waterproof

The disadvantages of plastics are that the do not rot i.e. the do not decompose (takes hundreds of years) and fill landfill sites.

With heat some plastics **melt** easily ☠

If plastics burn they form **poisonous gases**

Recycling waste plastic:

1. reduces the amount of waste but equally importantly
2. conserves crude oil reserves and
3. requires less energy than making new plastics

Properties and Uses of Plastics (polymers)

Polymer plastic	Properties	Uses
polythene also called poly(ethene)	flexible, cheap, good insulator, low density	bags, plastic drinks bottles, cling film food wrapping, insulation for electrical wires
poly(propene)	flexible, shatterproof	ropes, crates, buckets, bowls
poly(vinylchloride) pvc also called poly(chloroethene)	Tough, cheap, good thermal and electrical insulator, does not rot	window frames, drain pipes, gutters
poly(tetrafluoroethene) PTFE sometimes called Teflon	tough, slippery, does not corrode or rust, good thermal and electrical insulator	non-stick coating for cooking pans, low friction surface for skis, insulation for electrical wires

Fermentation

Ethanol is produced from the fermentation of glucose by yeast.

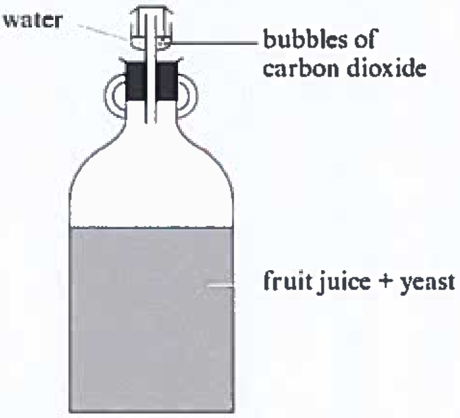
Yeast is a living, single – cell microorganism that belongs to the fungi kingdom.

Yeast contains enzymes that catalyse the breakdown of glucose to ethanol and carbon dioxide.

Beer and **wine** are produced by **fermenting glucose** with **yeast.**

$$\text{glucose} \xrightarrow{\text{yeast enzymes}} \text{ethanol + carbon dioxide}$$

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$



Conditions necessary for fermentation to occur

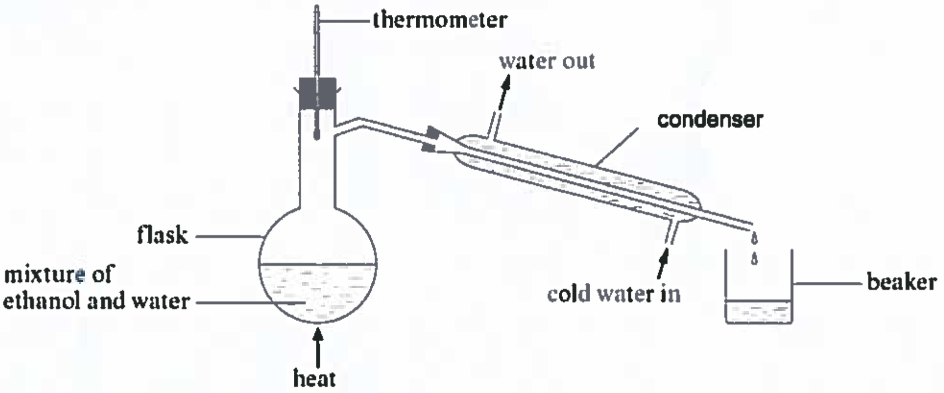
For the yeast enzymes to work they need

- a glucose solution (glucose and water)
- a temperature in the range of 20-40°C
- absence of oxygen
- a pH in the range of 4 to 7

To obtain ethanol from the mixture, yeast is removed by **filtering.**

Then the ethanol and water (and some sugar) mixture is **distilled.**

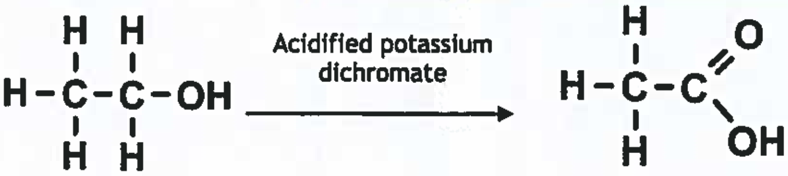
Ethanol has a lower boiling point (79°C) than water (100°C) or water glucose mixture (100-110°C). This physical property allows ethanol to evaporate quicker in the flask. A cold condenser will allow this vapour to change state into liquid ethanol leaving the water/glucose solution behind.



Chemical Tests for Organic Compounds

Oxidation of alcohols

Alcohols are oxidised to carboxylic acids with acidified potassium dichromate



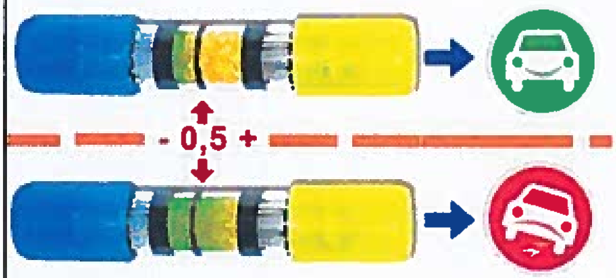
Ethanol
C_2H_5OH

Ethanoic Acid
CH_3COOH

Orange → Green

The solution changes colour from orange to green

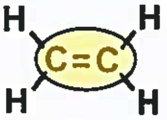
The early breathalyser



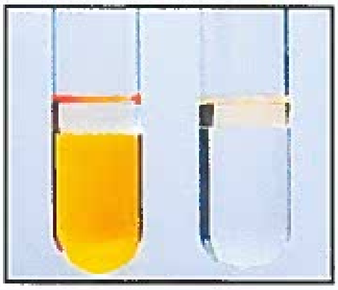
The oxidation reaction above was the basis of the early breathalyser. Tubes were used that contained orange dichromate crystals, the driver blew through the tube, if the driver had been drinking alcohol the crystals would turn green, the amount of crystals that were changed to green corresponded to the amount of alcohol in the drivers breath. More accurate techniques such as infrared are used in police stations today.

Testing for an alkene

Add bromine water



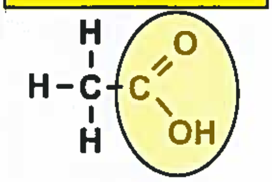
If a you think a compound has a C=C bond use the bromine water test



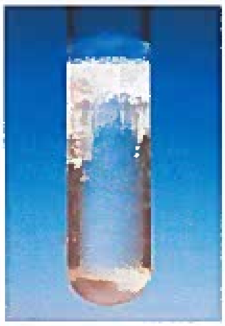
Orange bromine water turns colourless

Testing for a carboxylic acid

Add sodium carbonate (Na_2CO_3)



If a you think a compound has a -COOH functional group, add sodium carbonate, it will fizz and turn limewater milky



Effervescence - Bubbles of CO_2 produced which turns limewater milky

Ethanol - Health, Social and Economic Impacts

Health problems with excessive use of alcohol over many years can include

- liver or kidney damage
- vitamin deficiency
- heart disease
- memory loss
- depression
- stomach disorders
- cancer
- brain damage
- high blood pressure

Drinking excessively can lead to a number of harmful effects such as **alcohol poisoning** and **cirrhosis of the liver.**

Alcohol poisoning*

Alcohol poisoning occurs when excessive amounts of alcohol start to interfere with the body's automatic functions such as:
- breathing
- heart rate
- gag reflex, which prevents you choking

Alcohol poisoning can cause a person to fall into a coma and could lead to their death.

Cirrhosis of the liver*

Cirrhosis is scarring of the liver as a result of continuous, long-term liver damage. Scar tissue replaces healthy tissue in the liver and prevents the liver from working properly.
The damage caused by cirrhosis can't be reversed and eventually can become so extensive your liver stops functioning. This is called **liver failure.**

Social and economic impact of alcoholic drinks

Excessive use of alcohol can result in anti-social behaviour

- Aggressive behaviour
- Domestic violence
- Road accidents due to drink driving
- Wasting emergency services time
- Increases the cost of emergency services
- Tax on alcoholic drinks
- The tax raised from sale of alcoholic drinks generates significant revenue for the government.

*NHS Direct

Ethanol as a fuel

Ethanol can be produced from the fermentation of plants such as sugar cane. These are referred to as fuel crops and after distillation results in the production of bioethanol.

Bioethanol produces only carbon dioxide and water as waste products.

Bioethanol is **carbon neutral** because the carbon dioxide released during fermentation and combustion is equivalent to the amount removed from the atmosphere while the crop is growing.

Bioethanol is also **renewable**.

To decrease on the dependence on fossil fuels and increase the energy from renewable sources, European governments have agreed to add some bioethanol to some petrol blends.

(Less sulfur dioxide will be formed which prevents acid rain forming.)

Some critics warn of deforestation, and land being grabbed from food crops. This will increase food poverty as food prices are forced up.

Ethanol as a solvent

Not all substances dissolve in water. Ethanol is used extensively as a solvent:-

- in the manufacture of varnishes and perfumes;
- as a preservative for biological specimens;
- in the preparation of essences and flavorings;
- in many medicines and drugs;
- as a disinfectant

Positional Isomers of Alcohols (Higher Tier only)

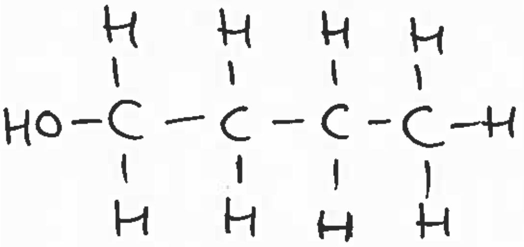
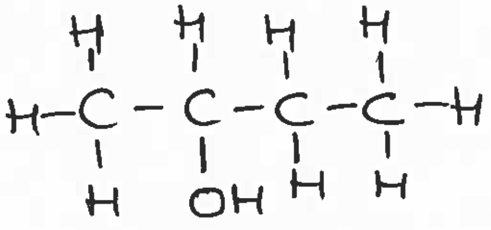
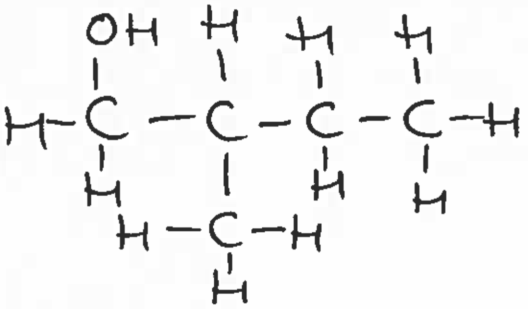
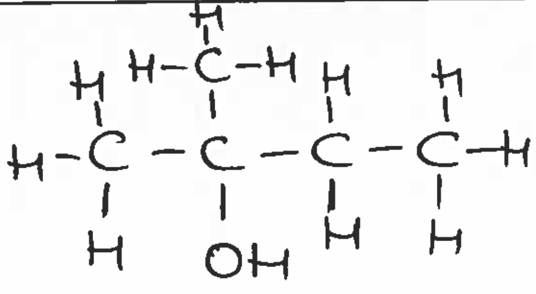
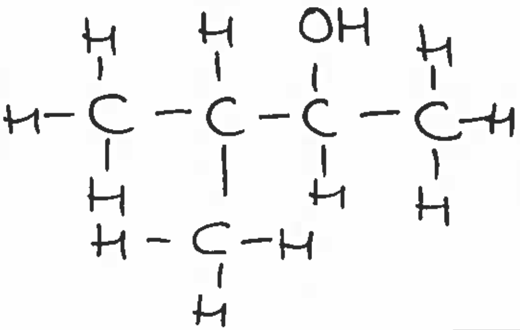
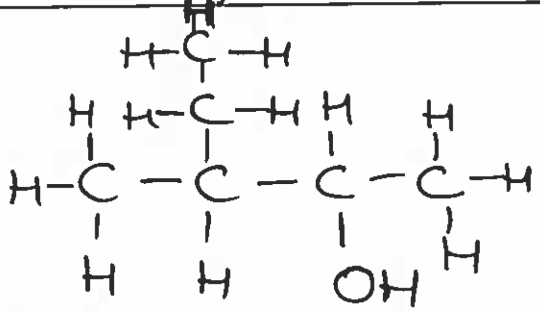
The **functional group** of the **alcohols** is the **–OH group.**

The general formula that can be used to work out the number of carbon, hydrogen and oxygen atoms in alcohols is **$C_n H_{(2n+1)}OH$**

The -OH group can be placed in different positions in the carbon chain to produce positional isomers.

Positional isomers have the same molecular formula but different structural formulae (because the –OH group can be in different positions).

Examples:

butan-1-ol	butan-2-ol
	
2-methylbutan-1-ol	2-methylbutan-2-ol
	
2-methylbutan-3-ol	2-ethylbutan-3-ol
	

Oxidation of Alcohols by microbes: Microbial oxidation of Ethanol

When **alcohol** (e.g. **ethanol** in beer and wine) is left exposed to the **oxygen in the air for a few days**, the **ethanol is oxidised by microbes** (e.g. bacteria). This produces **ethanoic acid**. This is the same chemical that is in vinegar! This is why the wine or beer starts to taste acidic.

Ethanoic acid is an example of another homologous series (organic group) of chemicals called **CARBOXYLIC ACIDS.**

Alcohols can be oxidised by oxygen in the air to form carboxylic acids.

e.g.

- ethanol **C_2H_5OH** can be oxidised to form ethanoic acid **CH_3COOH**
- propanol can be oxidised to form propanoic acid
- butanol can be oxidised to form butanoic acid

Higher Tier only:

The functional group of a carboxylic acid is **–COOH.**

The oxidation of alcohols produces a carboxylic acid with a:

- greater proportion of oxygen in the carboxylic acid
- lower proportion of hydrogen in the carboxylic acid.

Example:

	Ethanol (alcohol)	**Ethanoic acid (carboxylic acid)**
Structural formula	**C_2H_5OH**	**CH_3COOH**
No. of oxygen atoms	1	2
No. of hydrogen atoms	6	4
% composition by mass of oxygen	34.8%	53.3%
% composition by mass of hydrogen	13.0%	6.7%

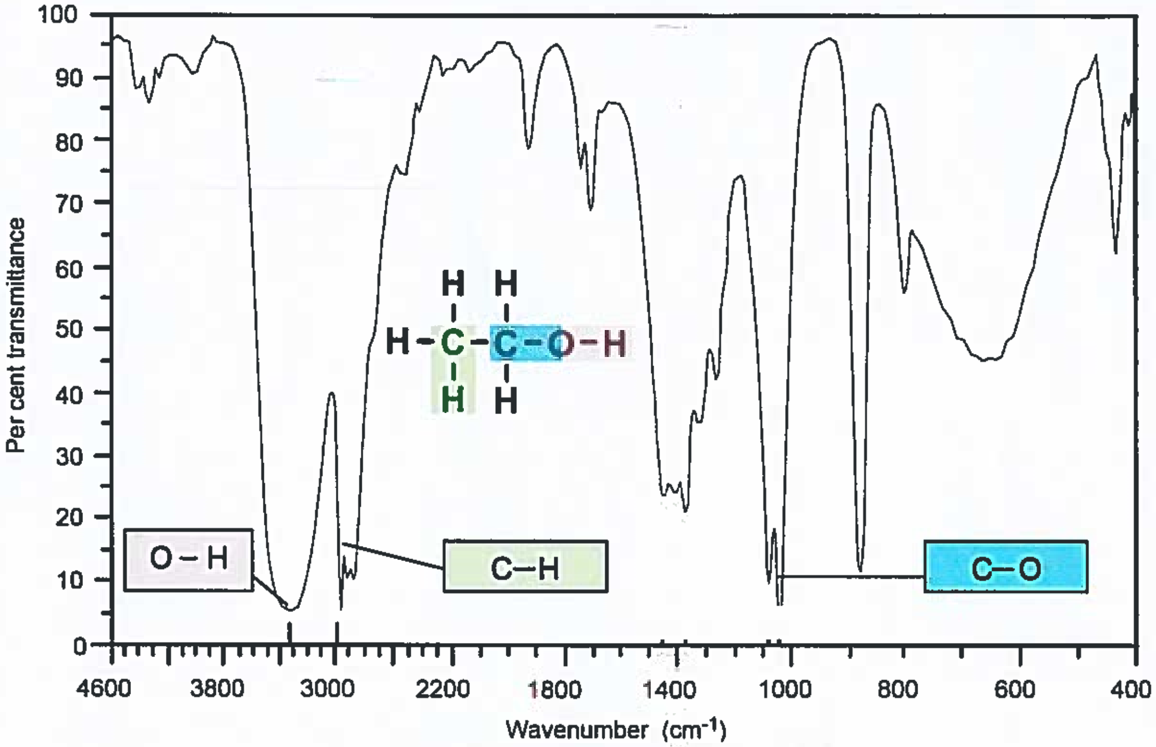
C97

Infrared Spectroscopy

Infrared spectroscopy is used to identify the presence of certain bonds in organic molecules. All bonds in a molecule vibrate; different bonds will vibrate at different frequencies. The absorption values will be given in the exam, examples are shown below;

Infrared spectroscopy characteristic absorption values	
Bond	**Wavenumber / cm^{-1}**
C—O	1000 - 1300
C=C	1620 – 1670
C=O	1650 – 1750
C—H	2800 – 3100
O—H	2500 - 3550

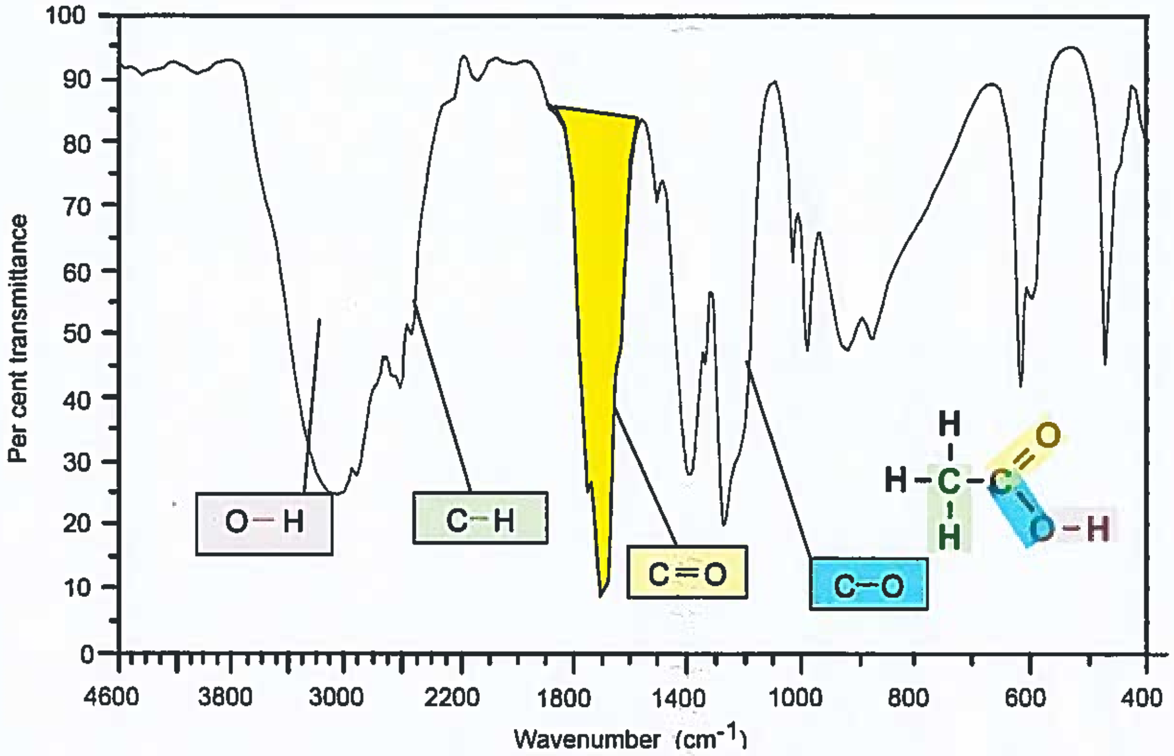
The infrared spectrum below shows the characteristic frequencies for Ethanol



The infrared spectrum of ethanol

Infrared spectroscopy can be used as a tool to identify important functional groups in a molecule. It can also be used to check if reactions have been successful. Consider the reaction of ethanol with acidified potassium dichromate, in this reaction ethanol is oxidised to ethanoic acid. The infrared spectrum of the ethanoic acid produced is shown on the next page.

C98



The infrared spectrum of ethanoic acid

The <u>appearance of the peak at 1700 cm^{-1}</u> (C=O) proves that ethanol has been oxidised. This was not present in the infrared spectrum of ethanol. This spectrum is typical of a carboxylic acid which has the C=O and -OH groups (-COOH).

Uses of Infrared Spectroscopy (IR)

As spectroscopic techniques are <u>simple, fast and accurate</u> they have replaced the need for chemical test in large laboratories, spectroscopy is an important tool in drug development for medicine and the development of new products in industry.

C99

Topic 6:

Reversible Reactions , Industrial Processes and Important Chemicals

Industrial Processes

Creating Ammonia – The Haber process

Hydrogen and atmospheric nitrogen need to react to form ammonia. This reaction is different to most because it is **reversible.** This means the reaction can go forwards or backwards depending on the conditions.

The theoretical conditions needed for a high yield, forward reaction to occur would be *low temperature* with *high pressure*.

The word and symbol equation for this are:-

$$\text{Nitrogen} + \text{Hydrogen} \rightleftharpoons \text{Ammonia}$$

$$N_2(g) + 3\ H_2(g) \rightleftharpoons 2\ NH_3(g)$$

The industrial process of making ammonia is called the **Haber process.**

The conditions used in the manufacture of ammonia are:-

350-450°C	(relatively high temperature)
150-200 atmospheres	(relatively low pressure)
Iron catalyst	

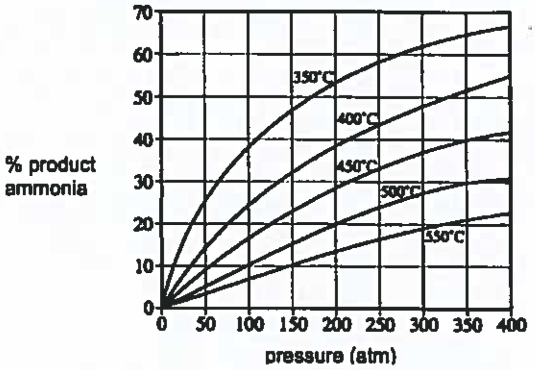
This is an exothermic reaction that creates liquid ammonia on condensing.

From an industrial point of view, a lower temperature would cause the process to be too slow. This explains the moderately high temperature chosen.

A pressure of 150-200 atmospheres is used as creating equipment to maintain a higher pressure is too expensive.

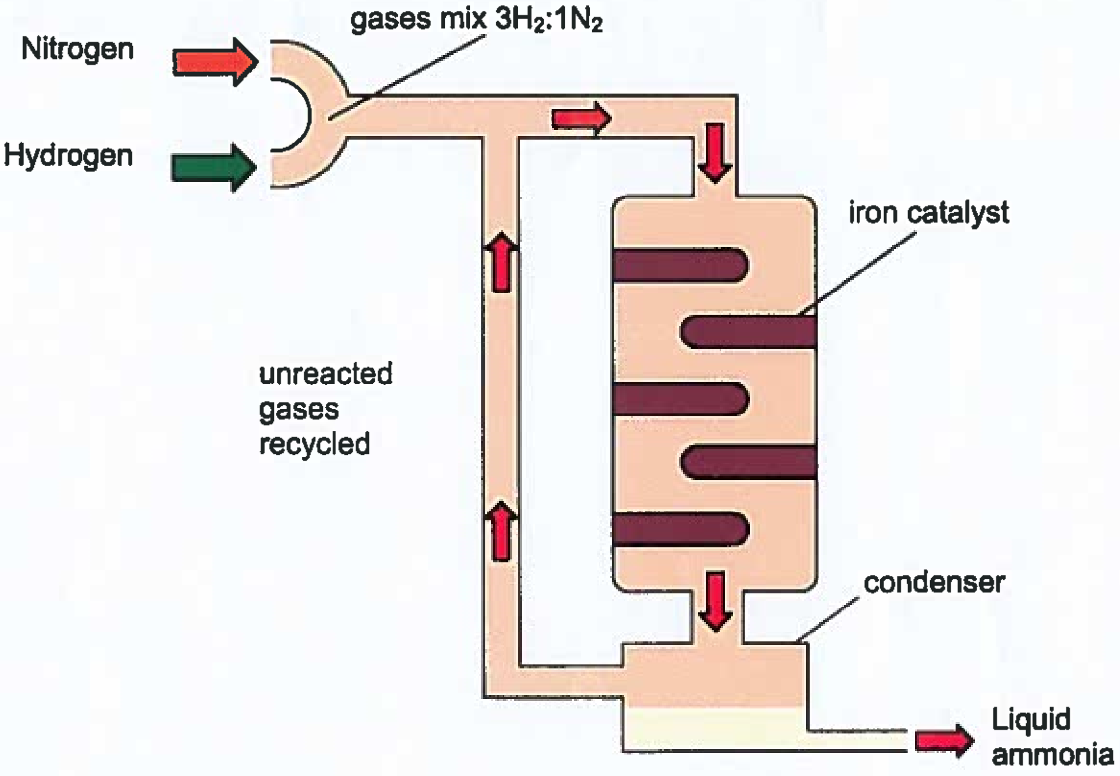
The yield is compromised to 15-40%. The unreacted nitrogen and hydrogen are recycled. This way the greatest amount of ammonia per day/week/month is achieved.

The following graph illustrates the effect of temperature and pressure on the yield of ammonia formed



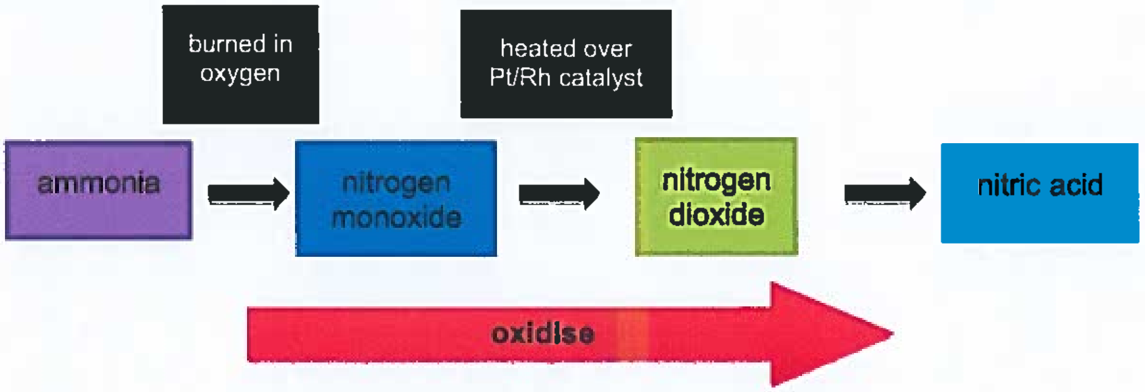
Although the iron catalyst speeds up the reaction, over time this will become poisoned and will reduced the speed at which ammonia is created.

Here is a diagram to show how ammonia is formed and the unreacted gases recycled.



Formation of nitric acid

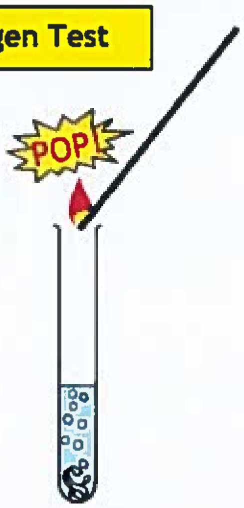
Some ammonia is converted into nitric acid by oxidation. A **platinum/rhodium** catalyst is used to speed up the reaction.



C102

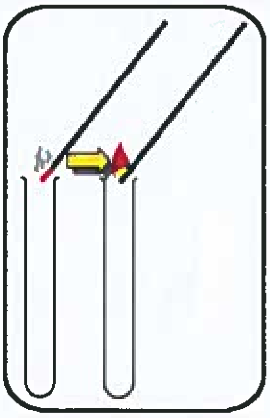
Chemical Analysis - Chemical tests for gases

Hydrogen Test



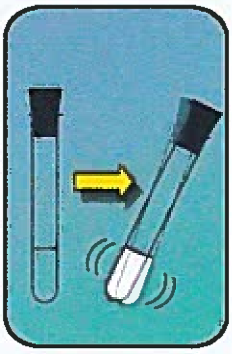
If a lit splint is placed in hydrogen it will create a squeaky 'pop' sound.

Oxygen Test



Oxygen re-lights a glowing splint

Carbon dioxide test

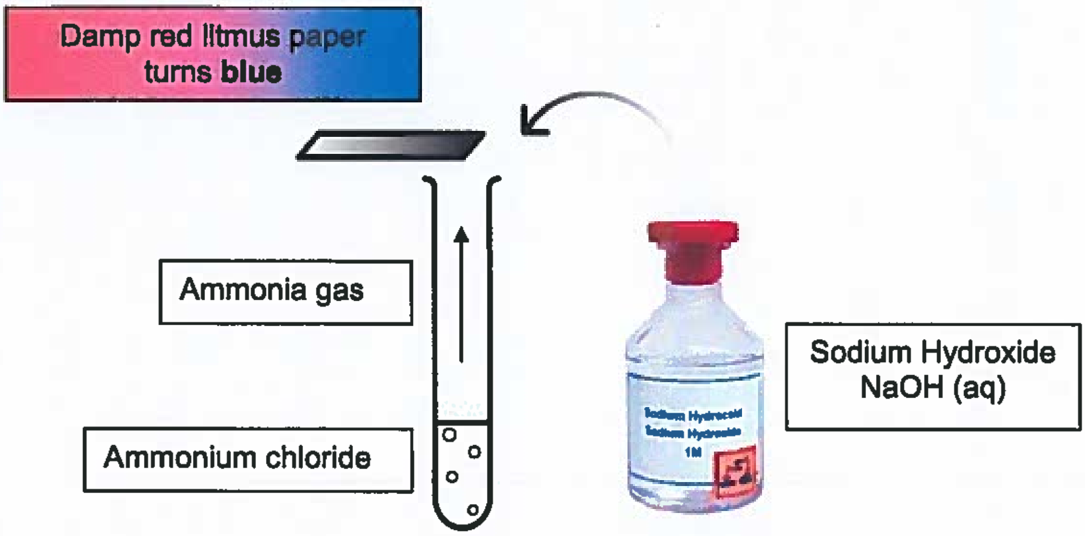


Carbon dioxide turns clear limewater milky.

Ammonia - identifying ammonium salt

If a salt containing ammonium reacts with sodium hydroxide it forms ammonia gas.

Ammonia gas will change damp red litmus paper blue.



ammonium chloride + sodium hydroxide ⟶ sodium chloride + **ammonia** + water

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C103

Uses of sulphuric acid

The chemical formula for sulphuric acid is **H_2SO_4**.

Sulphuric acid is a very useful resource with a broad range of uses to produce:

- **Manufacture of fertilisers:** Reaction of sulphuric acid with ammonia to produce the fertiliser ammonium sulphate. This is a neutralisation reaction. The ammonia solution is neutralised with sulphuric acid.

  ammonia + sulphuric acid → ammonium sulphate

  $$2NH_3\ (g) + H_2SO_4\ (aq) \rightarrow (NH_4)_2SO_4\ (s)$$

- Paints
- Dyes
- Fibres
- Plastics
- Detergents

Formation of sulfuric acid – The Contact Process

The industrial process of making sulfuric acid is called the **Contact process.**

There are three stages to the process.

Stage 1 – Production of Sulfur dioxide

Sulfur dioxide is obtained by burning sulphur in air;

sulfur + oxygen ⟶ sulfur dioxide

$$S\,(s) + O_2\,(g) \longrightarrow SO_2\,(g)$$

Stage 2 – Production of Sulfur trioxide (Important step)

The sulfur dioxide is then oxidised to sulfur trioxide by reacting with **excess air** over a **vanadium oxide (V_2O_5)** catalyst (a transition metal compound) at **420°C** at pressures not much above **atmospheric**. A yield of about **95 %** is obtained.

$$\text{sulfur dioxide + oxygen} \underset{420°C}{\overset{\text{vanadium oxide catalyst}}{\rightleftharpoons}} \text{sulfur trioxide}$$

$$2SO_2\,(g) + O_2\,(g) \underset{420°C}{\overset{V_2O_5}{\rightleftharpoons}} 2SO_3\,(g)$$

As the reaction is exothermic a low temperature favours a forward reaction. The speed of sulfur trioxide formation at low temperature would be too slow, therefore a temperature of 420°C is chosen.

Stage 3 – Conversion to Sulfuric Acid

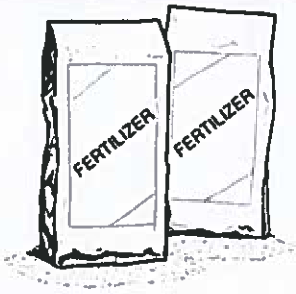
Sulfur trioxide is **absorbed in sulfuric acid** (98% H_2SO_4, 2 % water). Sulfur trioxide cannot be absorbed directly in 100% water, as the reaction is violent and produces a mist of the acid. The SO_3 reacts with the small quantity of water.

sulfur trioxide + water ⟶ sulfuric acid

$$SO_3\,(g) + H_2O\,(l) \longrightarrow H_2SO_4\,(l)$$

C105

Fertilizers



Most of the ammonia formed is used to make fertilizers. These are nitrogen rich compounds which are spread on farmlands for better plant growth.

When these dissolve in rainwater nitrogen is released to the soil.

Healthy plants need nitrogen to make protein.

Ammonia is an alkali and can be **neutralised** with acids to form ammonium salts.

Formation of two fertilizers

ammonium sulfate

ammonia + sulphuric acid → ammonium sulfate

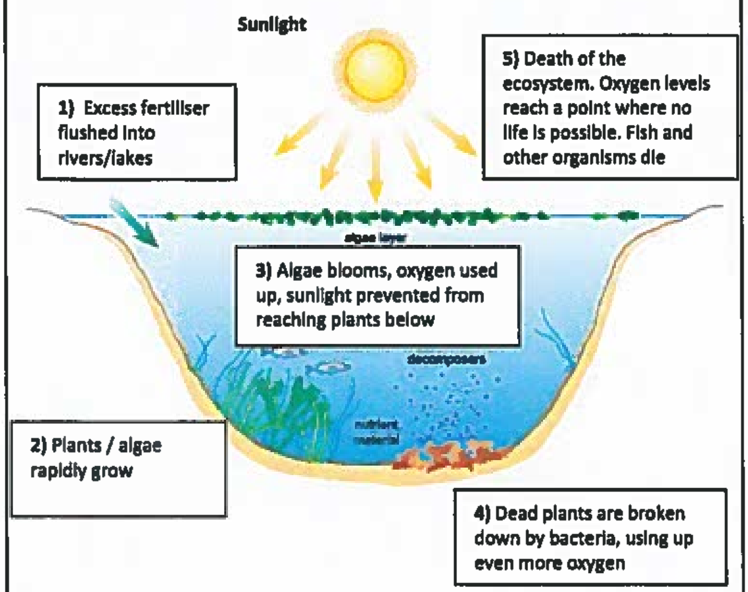
ammonium nitrate

ammonia + nitric acid → ammonium nitrate

Advantages and disadvantages of fertilizers

Advantages	Disadvantages
Increases crop yields	Eutrophication
Healthier plants	Could enter water supply
Relatively cheap	Blue baby syndrome
Improves poor quality land	

Eutrophication: If large amounts of fertilisers, especially nitrates, are washed out of the soil into rivers/lakes they can seriously unbalance the equilibria of the natural food chains and life cycles. Fertilisers are used up by water plants which rapidly cover the water. Underwater plants die and decompose as they do not get enough sunlight, as a result creatures such as fish die as the oxygen has been used up by decomposing bacteria. The result is an overgrowth of algae



1) Excess fertiliser flushed into rivers/lakes

2) Plants / algae rapidly grow

3) Algae blooms, oxygen used up, sunlight prevented from reaching plants below

4) Dead plants are broken down by bacteria, using up even more oxygen

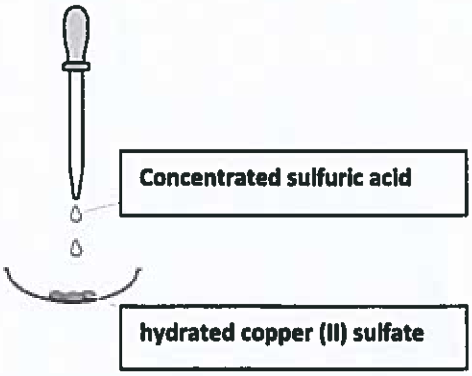
5) Death of the ecosystem. Oxygen levels reach a point where no life is possible. Fish and other organisms die

Nitrates in the water supply: High concentration of nitrates from nitrogenous fertilisers can cause cancer in humans. Toxic chemicals are formed due to the presence of nitrates. Nitrates can interfere with the transport of oxygen in the blood in particular in infants where **blue baby syndrome** can occur.

Other uses of sulfuric acid

Sulfuric acid can be used as a **dehydrating agent**. This means that the elements of water can be removed from a substance.

Dehydration of copper sulfate.



The blue hydrated copper(II) sulfate turns white.

The crystalline hydrated copper (II) sulfate turns powdery and crumbly losing its crystalline appearance.

Dehydration of sugar

When concentrated sulfuric acid is added to sugar a black solid is formed.

Acid dehydrates the sugar removing the elements of water namely hydrogen and oxygen. The black mass left is due to the carbon.

Year 11 GCSE Double Award Chemistry

and

Year 11 GCSE Chemistry

This section of the Year 11 Revision Guide contains work from Year 10.

You are expected to know and be able to use these ideas in your Year 11 Exams.

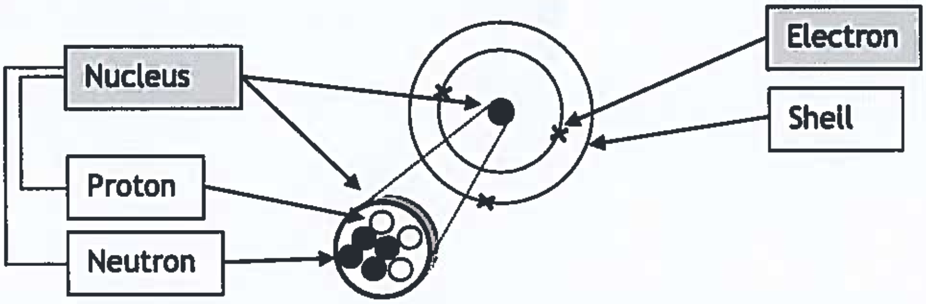
Atomic Structure

Atoms contain a **nucleus** and **electrons**

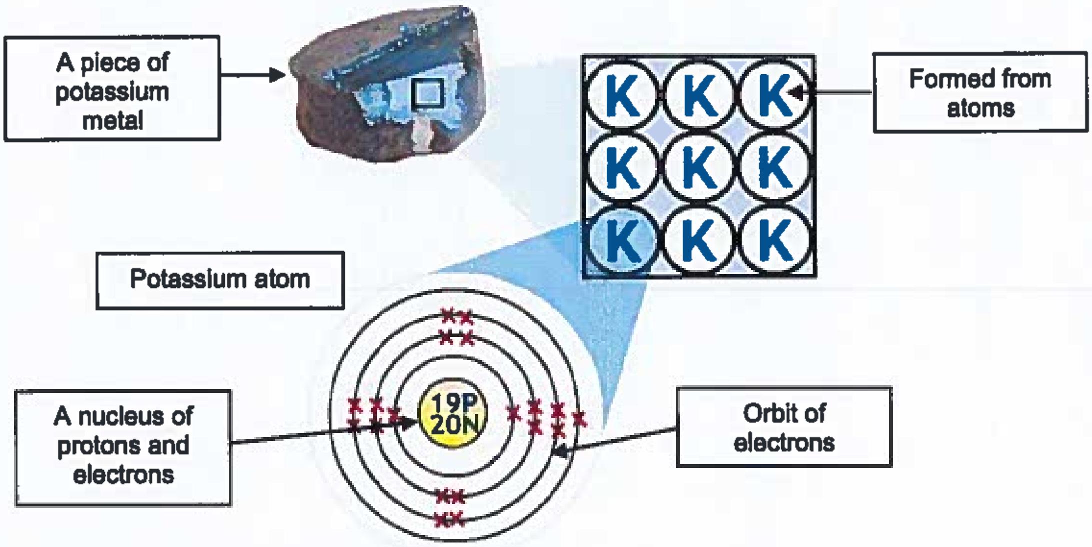
The small central nucleus is made from **protons** and **neutrons**.

Around these are **orbits** (shells) of **electrons**.

Here is a diagram showing an atom of **Lithium**



This diagram shows that a piece of **Potassium** is made up of millions of the same atom.



Atoms of **different** elements are different.

The number of **protons** is always different with different elements.

Element	*Lithium*	*Potassium*
Protons	**3**	**19**
Neutrons	4	20
Electrons	3	19

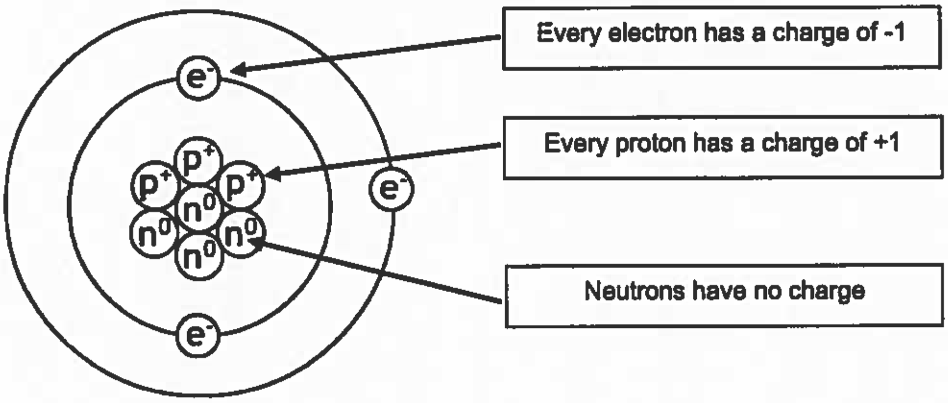
Neutron number for some elements are the same.
Electron number can be the same when the atoms have bonded.

Atomic Structure

Atoms have no charge.

The number of protons (in the nucleus) is always **the same** as the number of electrons (in shells)

Protons are positively charged. (+)
Electrons are negatively charged (-)
Neutrons do not have a charge (0)



Therefore an atom of **lithium** has no charge :- +3p + -3e = **0** **no charge**

Ion has **uneven** number of **protons and electrons**

This happens when an **electron is lost**

Or when an **electron is gained**

The proton number does not change.

Mass and **Charge** of atoms

Here are the relative mass of each particle and their electric charge.

	mass	charge
proton	1	+1
electron	0	-1
neutron	1	0

Protons and **neutrons** have similar mass.
Electrons have no mass, or extremely little amount.

Atomic Structure

Atomic Number → ${}^{7}_{\textcircled{3}}\mathrm{Li}$

Number on the bottom which means the number of protons or electrons

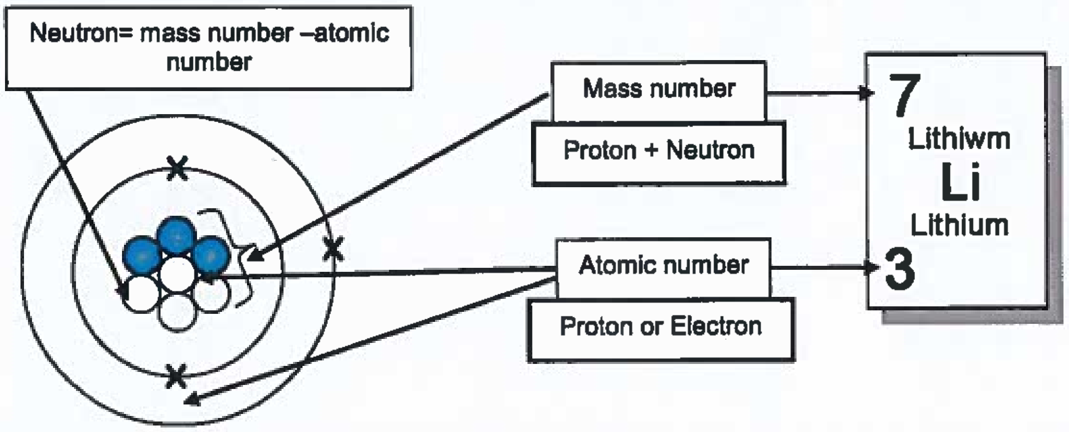
The number increases across the periodic table

Mass Number → ${}^{\textcircled{7}}_{3}\mathrm{Li}$

Number on the top which means the number of protons and neutrons in the nucleus.

Neutron Number

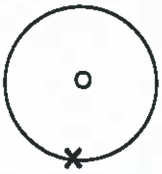
The number of neutrons in an atom is worked out by subtracting the number of protons (Atomic number) from the Mass number.



Isotopes The same element (as it has the same number of protons) but with different number of neutrons (making the mass number different). Hydrogen

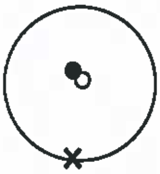
Proton = ○
Electron = ✗
Neutron = ●

${}^{1}_{1}\mathrm{H}$



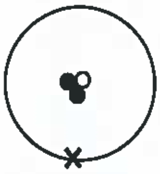
Proton number = 1
Neutron number = 0

${}^{2}_{1}\mathrm{H}$



Proton number = 1
Neutron number = 1

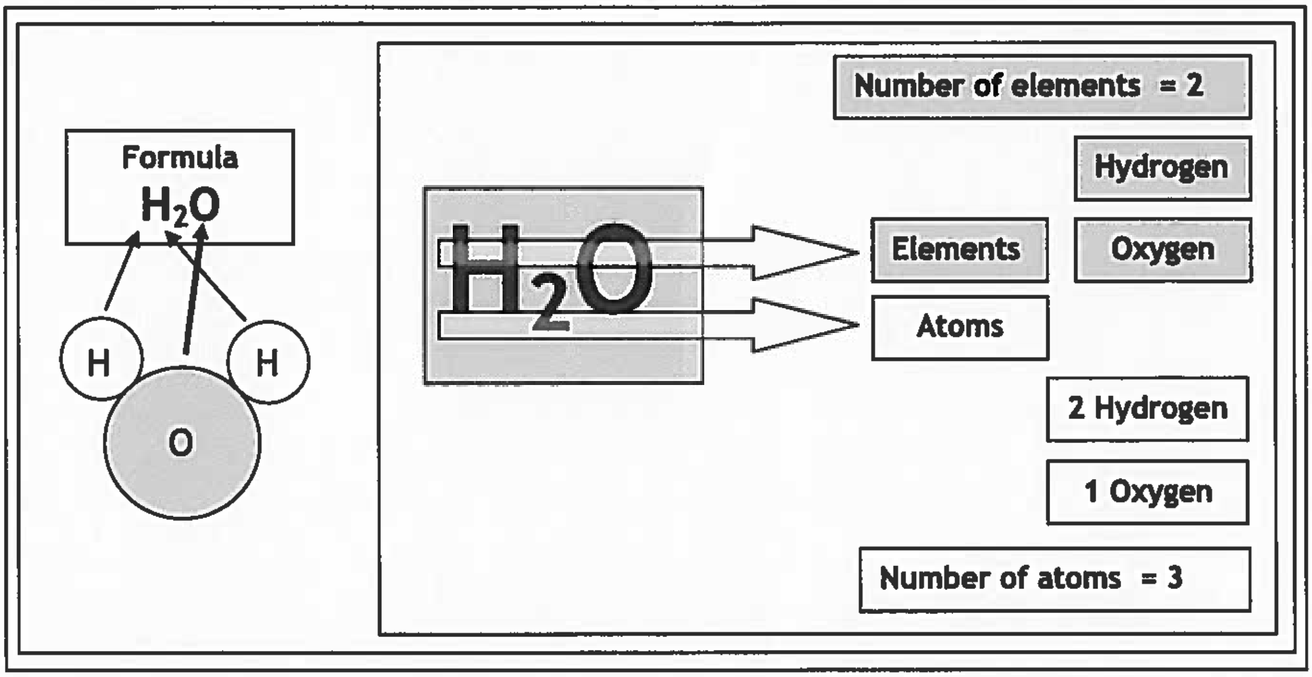
${}^{3}_{1}\mathrm{H}$



Proton number = 1
Neutron number = 2

C111

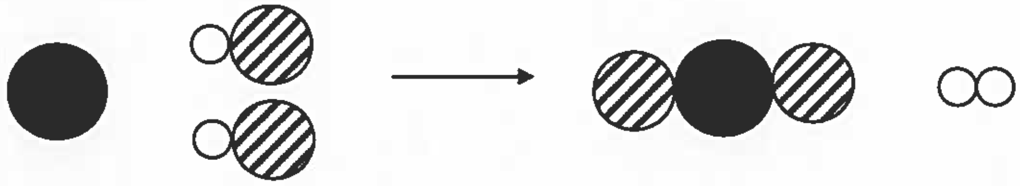
Compounds Substance that contains two or more elements joined together chemically



Compound	**Formula**	**No. of elements**	**No. of atoms**
Sodium Chloride	NaCl	2	2 (1 Na, 1 Cl)
Sodium Hydroxide	NaOH	3	3 (1 Na, 1 O, 1 H)
Sodium Oxide	Na_2O	2	3 (2 Na, 1 O)
Sodium Sulfate	Na_2SO_4	3	7 (2 Na, 1 S, 4 O)
Calcium Carbonate	$CaCO_3$	3	5 (1 Ca, 1 C, 3 O)

Chemical Reactions Atoms are rearranged but none are created or destroyed

e.g.



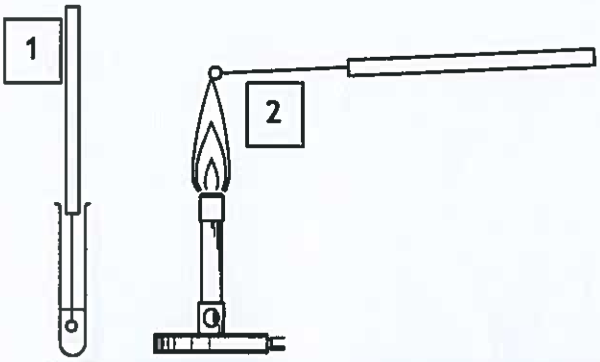
$$Mg + 2HCl \longrightarrow MgCl_2 + H_2$$

Same number of atoms in reactants and products, atoms are differently arranged.

Chemical Analysis – Flame tests

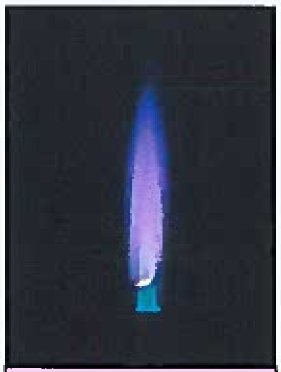
Method

1. Dip a clean wire loop in the sample solution
2. Hold the flame test wire loop at the edge of a Bunsen flame
3. Observe the changed colour of the flame, and decide which metal it indicates
4. Clean the loop in acid, rinse with water and repeat procedure with another sample



Metal	Ion	Flame test
Sodium	Na^+	Yellow-orange
Potassium	K^+	Lilac
Calcium	Ca^{2+}	Brick red
Copper	Cu^{2+}	Green


Sodium


Potassium


Calcium


Copper

Atomic Spectroscopy

This method is used to identify and show the amount (concentration) of specific atoms/ions present in the sample.

The colour of the light emitted during a flame test corresponds to a specific frequency

The intensity of the emission is measured - this corresponds to the amount of the metal present.

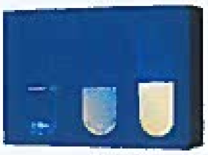
C113

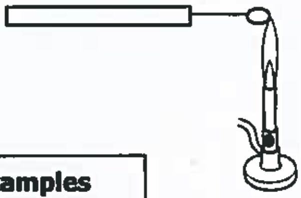
Group 7 The Halogens

Identifying compounds

Metal	Flame test
Lithium	Red
Sodium	Yellow-orange
Potassium	Lilac

Non-metal	Silver Nitrate test
Chloride	white
Bromide	cream
Iodide	yellow





Flame Test
(to identify the metal)

Silver Nitrate Test
(to identify non metal ions)

Examples
Lithium Chloride
Sodium Iodide
Potassium Bromide

Red
due to lithiwm

Yellow-orange
due to sodium

Lilac
due to potassium

White precipitate
due to chloride ions

Yellow precipitate
due to iodide ions

Cream precipitate
Due to bromide ions

Higher Tier: Silver Nitrate ionic equation:
e.e. Ag^+ (aq) + Cl^- (aq) $\Rightarrow$ AgCl (s)

Atomic Spectroscopy (Higher Tier): This method is used to identify and show the amount (concentration) of specific atoms/ions present in the sample.

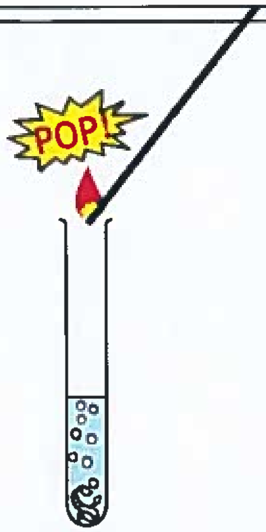
C114

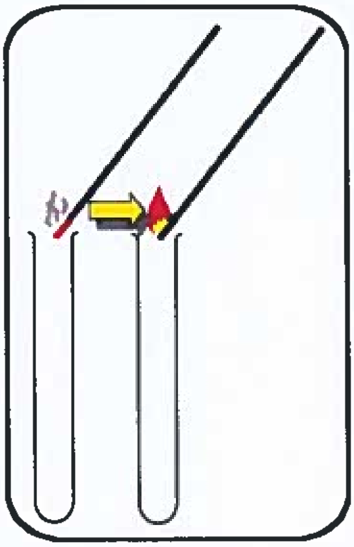
Identifying Hydrogen and oxygen gas

It is possible to test for the gases made by the electrolysis of water

Hydrogen Test

If a lighted splint is placed in hydrogen it will create a squeaky 'pop' sound.





Oxygen Test

Oxygen will re-light a glowing splint

Chemical Analysis – negative ions

Testing for the halide ions

Add dilute nitric acid followed by silver nitrate

Nitric acid is added first to remove impurities. When silver nitrate is then added to a compound that contains a halide ion a precipitate is formed, the colour corresponds to the halide.

Non-metal	Ion	Silver Nitrate test
Chloride	Cl^-	white
Bromide	Br^-	cream
Iodide	I^-	yellow

Example equation

silver nitrate + sodium chloride → silver chloride + sodium nitrate

$$AgNO_3\,(aq) + NaCl\,(aq) \longrightarrow AgCl\,(s) + NaNO_3\,(aq)$$

ionic equation: $Ag^+\,(aq) + Cl^-\,(aq) \longrightarrow AgCl\,(s)$

Testing for a carbonate ion CO_3^{2-}

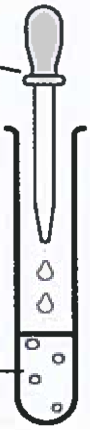
Add acid

When acid reacts with a carbonate fizzing is observed. Bubbles are of CO_2 gas which turns limewater milky

Example equations

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

$$Na_2CO_3\,(aq) + 2HCl\,(aq) \longrightarrow 2NaCl\,(aq) + H_2O\,(l) + CO_2\,(g)$$



bubbles / fizz

Testing for a sulfate ion SO_4^{2-}

Add dilute hydrochloric acid followed by barium chloride

When barium chloride is added to a compound that contains a sulfate ion a white precipitate is seen - the white precipitate is barium sulfate

Example equations

barium chloride + sodium sulfate → sodium chloride + barium sulfate

$$BaCl_2\,(aq) + Na_2SO_4\,(aq) \longrightarrow 2NaCl\,(aq) + BaSO_4\,(s)$$

$$Ba^{2+}\,(aq) + SO_4^{2-}\,(aq) \longrightarrow BaSO_4\,(s)$$

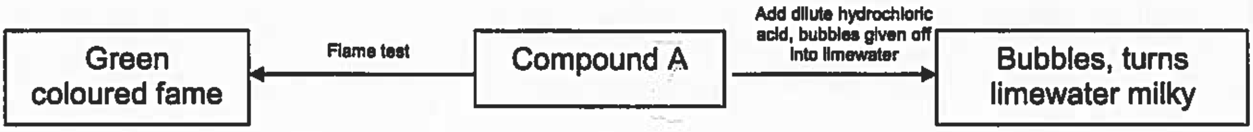
white precipitate forms

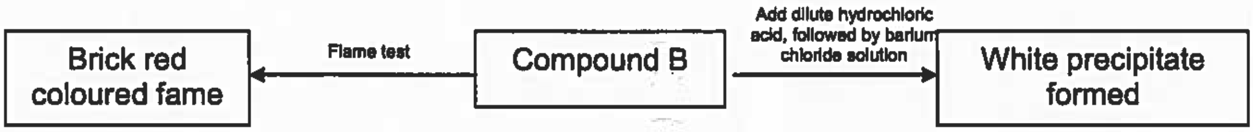
C116

Chemical Analysis – Problem solving

All the tests described so far can be used to identify unknown solutions. The flow charts below show tests carried out on compounds A, B and C and the results of those tests.

NH_4^+ Ca^{2+} Cu^{2+} K^+ Na^+ Cl^- Br^- I^- SO_4^{2-} CO_3^{2-}



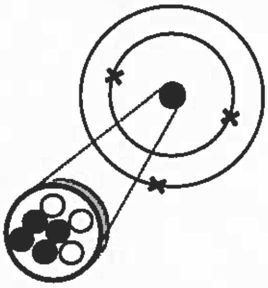


Answers: A is Copper carbonate, B is Calcium sulfate, C is Ammonium chloride, D is Sodium iodide, E is Ammonium carbonate

Chemical Calculations

Every atom has different mass. This is determined by the number of protons and neutrons in the nucleus.

A lithium atom has a mass of 7.



3 protons and 4 neutrons

Relative atomic mass (A_r) is a way of saying how heavy different atoms are compared to each other.

The **A_r** of Lithium is 7 and that of Carbon is 12. We use the top number to determine this; this is called the mass number

Relative formula mass or **relative molecular mass (M_r)** is the mass for a compound (e.g. $MgCl_2$) so the masses for each element are

Mass numbers → **Mg Cl Cl**
24 + 35 + 35 = **94**

What is the molecular mass of ammonium sulphate $(NH_4)_2SO_4$?
(N=14, S=32, O=16, H=1)
Calculate $(NH_4)_2$ first = 14+1+1+1+1 = 18 x 2 = 36
S= 32
4 oxygen atoms 16 x 4 = 64
Mr= ***132***

Calculating % composition

After calculating M_r it is possible to calculate % composition, this shows how much of a specific element is in a compound in percentage form

e.g. % Mg in $MgCl_2$ = $\dfrac{\text{total } M_r \text{ of Mg in } MgCl_2 \text{ x } 100}{M_r\, MgCl_2}$

$\dfrac{24}{94}$ x 100 = 25.5 %

Calculating Reacting Masses

By using relative atomic masses and (Ar) and relative molecular masses (Mr) it is possible to calculate how much of a product is produced or how much reactants are needed.

e.g. (product calculation)

What is the mass of **magnesium oxide** is produced when 60g of magnesium is burned in air?

Symbol Equation

$$\boxed{2Mg + O_2 \rightarrow 2MgO}$$

Mr = 2×24 2 (24+16)
48 80

Therefore 48g (or tonnes) will produce 80g

1g 80 ÷ 48 = 1.67g

60g will produce 60 × 1.67 = 100.2g

e.g. (reactant calculation)

What is the mass of **magnesium** needed to produce 90g of magnesium oxide?

$$\boxed{2Mg + O_2 \rightarrow 2MgO}$$

Mr = 2×24 2 (24+16)
48 80

Therefore 48g (or tonnes) will produce 80g

Or *80g of MgO will be produced with 48g of Mg*

1g 48÷80=0.6g

90g will produce 90 × 0.6 = 54g

Determining the formula of a compound from experimental data

When 4 g of copper oxide is reduced in a steam of hydrogen, 3.2 g of copper remains.

1. Work out how much oxygen was contained in the compound

4 – 3.2 = 0.8 g

	Cu	O
Divide with Ar	$\frac{3.2}{64}$	$\frac{0.8}{16}$
Divide with smallest	$\frac{0.05}{0.05}$	$\frac{0.05}{0.05}$
Whole number	1	1
	1 Cu	1 O

Formula = CuO

Example 2

Find the formula of iron oxide produced when 44.8g of iron react with 19.2g of oxygen. (Ar Fe = 56 and O = 16)

	Fe	O
Mass	44.8	19.2
Divide with Ar	44.8÷56	19.2÷16
	0.8	1.2
Divide with the smallest value	0.8÷0.8	1.2 ÷0.8
	1	1.5

A formula must have whole numbers therefore

	2	3

Formula = Fe_2O_3

Chemical Calculations

Calculating reactants or product masses

	Reactants				Products		
	NaOH	+	HCl	⇒	NaCl	+	H_2O
	23+16 + 1		1 + 35		23+35		1+1+16
	40		36		58		18
	76				76		
Units	g / tones				g / tones		

Calculating the percentage yield

When we want to create a chemical, the aim is to work carefully and to produce the maximum amount possible.

The amount formed or yield is calculated in percentage. It is very unlikely that 100% yield will be achieved e.g. some might be stuck in filter paper, evaporating dish, the product might react with the air.

Example

Magnesium metal dissolves in hydrochloric acid to form magnesium chloride.

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

24g **95g**

(24 + 35.5 + 35.5)

(a) What is the **maximum theoretical mass** of magnesium chloride which can be made from 12g of magnesium?

12g 95/2 = **47.5g**

(b) If only **47.0g** of purified magnesium chloride was obtained after crystallising the salt from the solution, what is the % yield of the salt preparation?

$$\textbf{\% yield} = \frac{\text{actual amount obtained x 100}}{\text{maximum possible}}$$

$$\textbf{\% yield} = \frac{47.0 \text{ x } 100}{47.5} = \textbf{98.9\%} \text{ (to 1 decimal place)}$$

Examination Reference Materials

You are given a copy of the following in your examination paper:

- **The Periodic Table of the Elements**
- **Formulae for some Common Ions.**

You do NOT need to learn these two tables.

You are expected to be able to use the information that they contain in the examination questions.

C122

FORMULAE FOR SOME COMMON IONS

POSITIVE IONS		**NEGATIVE IONS**	
Name	**Formula**	**Name**	**Formula**
Aluminium	Al^{3+}	**Bromide**	Br^-
Ammonium	NH_4^+	**Carbonate**	CO_3^{2-}
Barium	Ba^{2+}	**Chloride**	Cl^-
Calcium	Ca^{2+}	**Fluoride**	F^-
Copper(II)	Cu^{2+}	**Hydroxide**	OH^-
Hydrogen	H^+	**Iodide**	I^-
Iron(II)	Fe^{2+}	**Nitrate**	NO_3^-
Iron(III)	Fe^{3+}	**Oxide**	O^{2-}
Lithium	Li^+	**Sulfate**	SO_4^{2-}
Magnesium	Mg^{2+}		
Nickel	Ni^{2+}		
Potassium	K^+		
Silver	Ag^+		
Sodium	Na^+		
Zinc	Zn^{2+}		

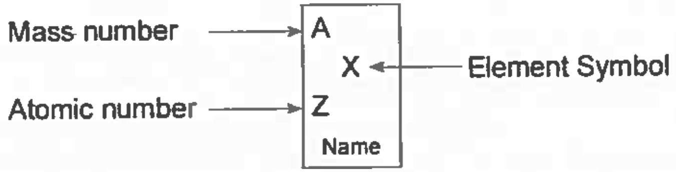
Avogadro's number, $L = 6 \times 10^{23}$

C123

PERIODIC TABLE OF ELEMENTS

1	2					Group						3	4	5	6	7	0
								$^{1}_{1}\text{H}$ Hydrogen									$^{4}_{2}\text{He}$ Helium
$^{7}_{3}\text{Li}$ Lithium	$^{9}_{4}\text{Be}$ Beryllium											$^{11}_{5}\text{B}$ Boron	$^{12}_{6}\text{C}$ Carbon	$^{14}_{7}\text{N}$ Nitrogen	$^{16}_{8}\text{O}$ Oxygen	$^{19}_{9}\text{F}$ Fluorine	$^{20}_{10}\text{Ne}$ Neon
$^{23}_{11}\text{Na}$ Sodium	$^{24}_{12}\text{Mg}$ Magnesium											$^{27}_{13}\text{Al}$ Aluminium	$^{28}_{14}\text{Si}$ Silicon	$^{31}_{15}\text{P}$ Phosphorus	$^{32}_{16}\text{S}$ Sulfur	$^{35}_{17}\text{Cl}$ Chlorine	$^{40}_{18}\text{Ar}$ Argon
$^{39}_{19}\text{K}$ Potassium	$^{40}_{20}\text{Ca}$ Calcium	$^{45}_{21}\text{Sc}$ Scandium	$^{48}_{22}\text{Ti}$ Titanium	$^{51}_{23}\text{V}$ Vanadium	$^{52}_{24}\text{Cr}$ Chromium	$^{55}_{25}\text{Mn}$ Manganese	$^{56}_{26}\text{Fe}$ Iron	$^{59}_{27}\text{Co}$ Cobalt	$^{59}_{28}\text{Ni}$ Nickel	$^{64}_{29}\text{Cu}$ Copper	$^{65}_{30}\text{Zn}$ Zinc	$^{70}_{31}\text{Ga}$ Gallium	$^{73}_{32}\text{Ge}$ Germanium	$^{75}_{33}\text{As}$ Arsenic	$^{79}_{34}\text{Se}$ Selenium	$^{80}_{35}\text{Br}$ Bromine	$^{84}_{36}\text{Kr}$ Krypton
$^{86}_{37}\text{Rb}$ Rubidium	$^{88}_{38}\text{Sr}$ Strontium	$^{89}_{39}\text{Y}$ Yttrium	$^{91}_{40}\text{Zr}$ Zirconium	$^{93}_{41}\text{Nb}$ Niobium	$^{96}_{42}\text{Mo}$ Molybdenum	$^{99}_{43}\text{Tc}$ Technetium	$^{101}_{44}\text{Ru}$ Ruthenium	$^{103}_{45}\text{Rh}$ Rhodium	$^{106}_{46}\text{Pd}$ Palladium	$^{108}_{47}\text{Ag}$ Silver	$^{112}_{48}\text{Cd}$ Cadmium	$^{115}_{49}\text{In}$ Indium	$^{119}_{50}\text{Sn}$ Tin	$^{122}_{51}\text{Sb}$ Antimony	$^{128}_{52}\text{Te}$ Tellurium	$^{127}_{53}\text{I}$ Iodine	$^{131}_{54}\text{Xe}$ Xenon
$^{133}_{55}\text{Cs}$ Caesium	$^{137}_{56}\text{Ba}$ Barium	$^{139}_{57}\text{La}$ Lanthanum	$^{179}_{72}\text{Hf}$ Hafnium	$^{181}_{73}\text{Ta}$ Tantalum	$^{184}_{74}\text{W}$ Tungsten	$^{186}_{75}\text{Re}$ Rhenium	$^{190}_{76}\text{Os}$ Osmium	$^{192}_{77}\text{Ir}$ Iridium	$^{195}_{78}\text{Pt}$ Platinum	$^{197}_{79}\text{Au}$ Gold	$^{201}_{80}\text{Hg}$ Mercury	$^{204}_{81}\text{Tl}$ Thallium	$^{207}_{82}\text{Pb}$ Lead	$^{209}_{83}\text{Bi}$ Bismuth	$^{210}_{84}\text{Po}$ Polonium	$^{210}_{85}\text{At}$ Astatine	$^{222}_{86}\text{Rn}$ Radon
$^{223}_{87}\text{Fr}$ Francium	$^{226}_{88}\text{Ra}$ Radium	$^{227}_{89}\text{Ac}$ Actinium															

Key:



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