Chemistry-Unit 2

4.6 The rate and extent of chemical change

Chemical reactions can occur at vastly different rates. Whilst the reactivity of chemicals is a significant factor in how fast chemical reactions proceed, there are many variables that can be manipulated in order to speed them up or slow them down. Chemical reactions may also be reversible and therefore the effect of different variables needs to be established in order to identify how to maximise the yield of desired product. Understanding energy changes that accompany chemical reactions is important for this process. In industry, chemists and chemical engineers determine the effect of different variables on reaction rate and yield of product. Whilst there may be compromises to be made, they carry out optimisation processes to ensure that enough product is produced within a sufficient time, and in an energy-efficient way.

4.6.1 Rate of reaction

Calculating rates of reactions

The rate of a chemical reaction can be found by measuring the quantity of a reactant used or the quantity of product formed over time:

$$\text{Mean rate of reaction} = \frac{\text{quantity of reactant used}}{\text{Time taken}}$$

$$\text{Mean rate of reaction} = \frac{\text{quantity of product formed}}{\text{Time taken}}$$

The quantity of reactant or product can be measured by the mass in grams or by a volume in cm^3.
The units of rate of reaction may be given as g/s or cm^3/s.

Factors which affect the rates of chemical reactions

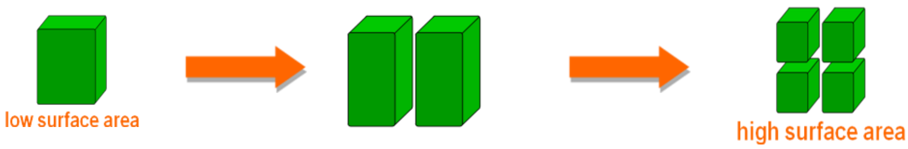
Chemical reactions can only occur when reacting particles collide with each other and with sufficient energy. The minimum amount of energy particles must have to react is called the activation energy. Factors which affect the rates of chemical reactions include: the concentrations of reactants in solution, the pressure of reacting gases, the surface area of solid reactants, the temperature and the presence of catalysts.

Collision theory and activation energy

Collision theory explains how various factors affect rates of reactions.
According to this theory, chemical reactions can occur only when reacting particles collide with each other and with sufficient energy. The minimum amount of energy that particles must have to react is called the activation energy.
Increasing the temperature increases the speed of the reacting particles so that they collide more frequently and more energetically. This increases the rate of reaction.

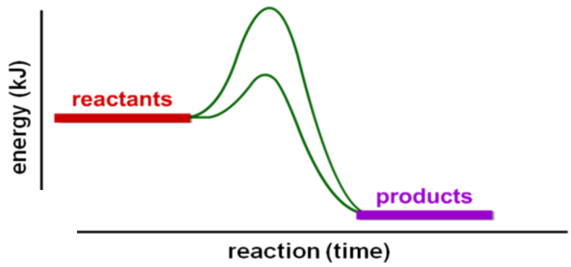
Increasing the pressure of reacting gases increases the frequency of collisions and so increases the rate of reaction. Increasing the concentration of reactants in solutions increases the frequency of collisions and so increases the rate of reaction.

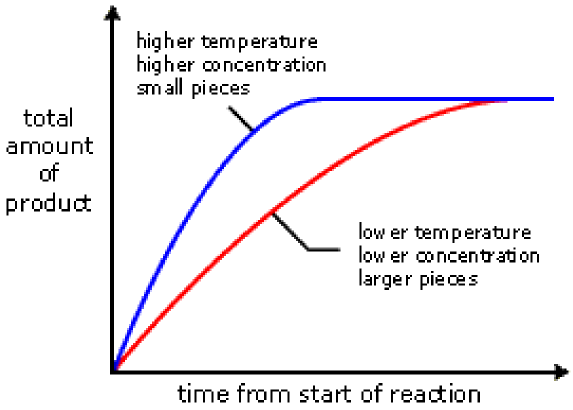
Increasing the surface area of solid reactants increases the frequency of collisions and so increases the rate of reaction.



Catalysts

Catalysts change the rate of chemical reactions but are not used up during the reaction. Different reactions need different catalysts. Catalysts are important in increasing the rates of chemical reactions used in industrial processes to reduce costs. They lower the activation energy.





4.6.2 Reversible reactions and dynamic equilibrium

Reversible reactions

In some chemical reactions, the products of the reaction can react to produce the original reactants. Such reactions are called reversible reactions and are represented:

$$A + B \rightleftharpoons C + D$$

The direction of reversible reactions can be changed by changing the conditions.

For example: ammonium chloride $\underset{\text{cool}}{\overset{\text{heat}}{\rightleftharpoons}}$ ammonia + hydrogen chloride

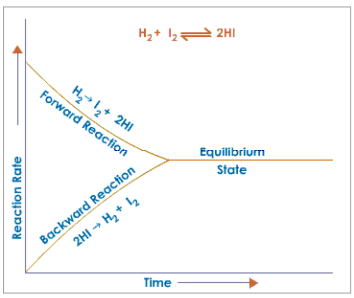
Energy changes and reversible reactions

If a reversible reaction is exothermic in one direction, it is endothermic in the opposite direction. The same amount of energy is transferred in each case. For example:

hydrated copper sulfate (blue) $\underset{\text{exothermic}}{\overset{\text{endothermic}}{\rightleftharpoons}}$ anhydrous copper sulfate (white) + water

Equilibrium

When a reversible reaction occurs in apparatus which prevents the escape of reactants and products, equilibrium is reached when the forward and reverse reactions occur at exactly the same rate.



The effect of changing conditions on equilibrium (HT only)

The relative amounts of all the reactants and products at equilibrium depend on the conditions of the reaction. If a system is at equilibrium and a change is made to any of the conditions, then the system responds to counteract the change. The effects of changing conditions on a system at equilibrium can be predicted using Le Chatelier’s Principle.

The effect of changing concentration (HT only)

If the concentration of one of the reactants or products is changed, the system is no longer at equilibrium and the concentrations of all the substances will change until equilibrium is reached again.

If the concentration of a reactant is increased, more products will be formed until equilibrium is reached again.

If the concentration of a product is decreased, more reactants will react until equilibrium is reached again.

The effect of temperature changes on equilibrium (HT only)
If the temperature of a system at equilibrium is increased:

- the relative amount of products at equilibrium increases for an endothermic reaction
- the relative amount of products at equilibrium decreases for an exothermic reaction.

If the temperature of a system at equilibrium is decreased:

- the relative amount of products at equilibrium decreases for an endothermic reaction
- the relative amount of products at equilibrium increases for an exothermic reaction.

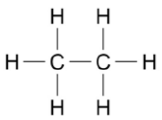
The effect of pressure changes on equilibrium (HT only)
For gaseous reactions at equilibrium:

- an increase in pressure causes the equilibrium position to shift towards the side with the smaller number of molecules as shown by the symbol equation for that reaction
- a decrease in pressure causes the equilibrium position to shift towards the side with the larger number of molecules as shown by the symbol equation for that reaction.

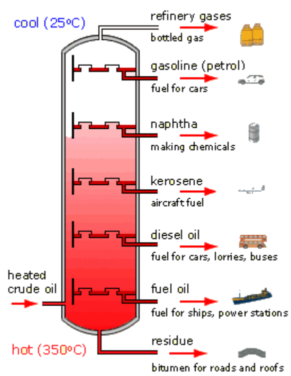
4.7 Organic chemistry

4.7.1 Carbon compounds as fuels and feedstock

Crude oil, hydrocarbons and alkanes
Crude oil is a finite resource found in rocks. Crude oil is the remains of an ancient biomass consisting mainly of plankton that was buried in mud.
Crude oil is a mixture of a very large number of compounds. Most of the compounds in crude oil are hydrocarbons, which are molecules made up of hydrogen and carbon atoms only. Most of the hydrocarbons in crude oil are hydrocarbons called alkanes. The general formula for the homologous series of alkanes is C_nH_{2n+2}. The first four members of the alkanes are methane, ethane, propane and butane.
Alkane molecules can be represented in the following forms:
C_2H_6 or



Fractional distillation and petrochemicals
The many hydrocarbons in crude oil may be separated into fractions, each of which contains molecules with a similar number of carbon atoms, by fractional distillation, by evaporating the oil and allowing it to condense at a number of different temperatures. Crude oil fed in at the bottom, temperature decreases up the column. Hydrocarbons with smaller chains found nearer the top.
The fractions can be processed to produce fuels and feedstock for the petrochemical industry. Many of the fuels on which we depend for our modern lifestyle, such as petrol, diesel oil, kerosene, heavy fuel oil and liquefied petroleum gases, are produced from crude oil. Many useful materials on which modern life depends are produced by the petrochemical industry, such as solvents, lubricants, polymers, detergents. The vast array of natural and synthetic carbon compounds occur due to the ability of carbon atoms to form families of similar compounds.



Properties of hydrocarbons
Some properties of hydrocarbons depend on the size of their molecules, including boiling point, viscosity and flammability. These properties influence how hydrocarbons are used as fuels.
SHORT CHAINS ARE:

- Very flammable
- Have low boiling points
- Highly volatile (tend to turn into gases)
- Have low viscosity (they flow easily)

Long chains have the opposite of these!

The combustion of hydrocarbon fuels releases energy. During combustion, the carbon and hydrogen in the fuels are oxidised. The complete combustion of a hydrocarbon produces carbon dioxide and water.

Propane + oxygen → carbon dioxide + water

Cracking and alkenes

Hydrocarbons can be broken down (cracked) to produce smaller, more useful molecules.
Cracking can be done by various methods including catalytic cracking and steam cracking.
The products of cracking include alkanes and another type of hydrocarbon called alkenes.

EXAMPLE OF CRACKING

Cracking is a thermal decomposition reaction:

$$\mathbf{C_{10}H_{22} \longrightarrow C_5H_{12} + C_3H_6 + C_2H_4}$$

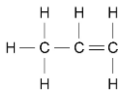
Decane → pentane + propene + ethene

Alkenes are more reactive than alkanes and react with bromine water, turning it from orange to colourless, which is used as a test for alkenes.
There is a high demand for fuels with small molecules and so some of the products of cracking are useful as fuels. Alkenes are used to produce polymers and as starting materials for the production of many other chemicals.

4.7.2 Reactions of alkenes and alcohols (chemistry only)

Structure and formulae of alkenes

Alkenes are hydrocarbons with a double carbon-carbon bond. The general formula for the homologous series of alkenes is C_nH_{2n}.
Alkene molecules are unsaturated because they contain two fewer hydrogen atoms than the alkane with the same number of carbon atoms.
The first four members of the homologous series of alkenes are ethene, propene, butene and pentene.
Alkene molecules can be represented in the following forms:

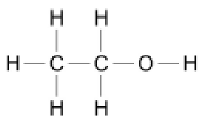
C_3H_6 or 

Reactions of alkenes

Alkenes are hydrocarbons with the functional group C=C.
It is the generality of reactions of functional groups that determine the reactions of organic compounds.
Alkenes react with oxygen in combustion reactions in the same way as other hydrocarbons, but they tend to burn in air with smoky flames because of incomplete combustion.
Alkenes react with hydrogen, water and the halogens, by the addition of atoms across the carbon-carbon double bond so that the double bond becomes a single carbon-carbon bond.

Alcohols

Alcohols contain the functional group –OH.
Methanol, ethanol, propanol and butanol are the first four members of a homologous series of alcohols.
Alcohols can be represented in the following forms: CH_3CH_2OH or



Alcohols are used as solvents and fuels, and ethanol is the main alcohol in alcoholic drinks
Ethanol can be produced by hydration of ethene with steam in the presence of a catalyst.

Ethene + Steam → Ethanol

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$

+ Continuous process – lots made!
+ Produces no waste products
- Requires lots of heat and energy
- Relies on a non-renewable resource

Ethanol can also be produced by fermentation with yeast, using renewable resources. This can be represented by: Sugar ⟶ carbon dioxide + ethanol

80% of ethanol is made this way

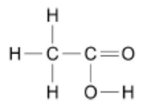
+ Uses renewable resources

- Takes longer to produce
- CO_2 is given off

Alcohols react with sodium, burn in air, are added to water, react with an oxidising agent
ethanol + sodium → sodium ethoxide + hydrogen
ethanol + oxygen → carbon dioxide + water
ethanol + [O] → ethanoic acid

Carboxylic acids

Carboxylic acids have the functional group –COOH.
The first four members of a homologous series of carboxylic acids are methanoic acid, ethanoic acid, propanoic acid and butanoic acid.
The structures of carboxylic acids can be represented in the following forms: CH_3COOH or



Carboxylic acids:

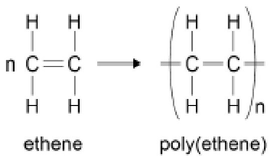
- dissolve in water to produce acidic solutions
- react with carbonates to produce carbon dioxide
- react with alcohols in the presence of an acid catalyst to produce esters
- do not ionise completely when dissolved in water and so are weak acids
- aqueous solutions of weak acids have a higher pH value than aqueous solutions of strong acids with the same concentration.

4.7.3 Synthetic and naturally occurring polymers (chemistry only)

Addition polymerisation

Alkenes can be used to make polymers such as poly(ethene) and poly(propene) by addition polymerisation.
In addition polymerisation reactions, many small molecules (monomers) join together to form very large molecules (polymers).

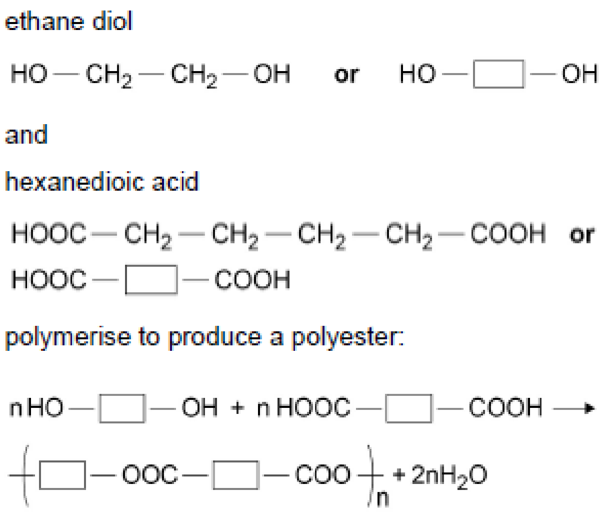
For example:



In addition polymers the repeating unit has the same atoms as the monomer because no other molecule is formed in the reaction.

Condensation polymerisation (HT only)

Condensation polymerisation involves monomers with two functional groups. When these types of monomers react they join together, usually losing small molecules such as water, and so the reactions are called condensation reactions.
The simplest polymers are produced from two different monomers with two of the same functional groups on each monomer.
For example:



Amino acids (HT only)

Amino acids have two different functional groups in a molecule.
Amino acids react by condensation polymerisation to produce polypeptides.
For example: glycine is H_2NCH_2COOH and polymerises to produce the polypeptide
$(-HNCH_2COO-)n$ and nH_2O
Different amino acids can be combined in the same chain to produce proteins.

DNA (deoxyribonucleic acid) and other naturally occurring polymers

DNA (deoxyribonucleic acid) is a large molecule essential for life. DNA encodes genetic instructions for the development and functioning of living organisms and viruses.
Most DNA molecules are two polymer chains, made from four different monomers called nucleotides, in the form of a double helix.
Other naturally occurring polymers important for life include proteins, starch and cellulose.

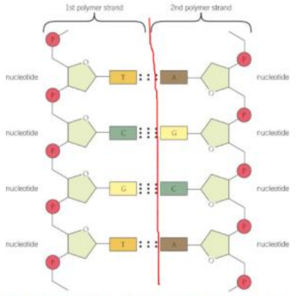


Figure 3 A simplified (flattened) structure of part of the DNA molecule, showing how the nucleotides bond to each other in each strand (via covalent bonds) and how the strands are linked to each other by intermolecular forces

4.8 Chemical analysis

Analysts have developed a range of qualitative tests to detect specific chemicals. The tests are based on reactions that produce a gas with distinctive properties, or a colour change or an insoluble solid that appears as a precipitate.
Instrumental methods provide fast, sensitive and accurate means of analysing chemicals, and are particularly useful when the amount of chemical being analysed is small. Forensic scientists and drug control scientists rely on such instrumental methods in their work.

4.8.1 Purity, formulations and chromatography

Pure substances

In chemistry, a pure substance is a single element or compound, not mixed with any other substance.
Pure elements and compounds melt and boil at specific temperatures. Melting point and boiling point data can be used to distinguish pure substances from mixtures.
In everyday language, a pure substance can mean a substance that has had nothing added to it, so it is unadulterated and in its natural state, eg pure milk.

Formulations

A formulation is a mixture that has been designed as a useful product. Many products are complex mixtures in which each chemical has a particular purpose. Formulations are made by mixing the components in carefully measured quantities to ensure that the product has the required properties. Formulations include fuels, cleaning agents, paints, medicines, alloys, fertilisers and foods.

Chromatography

Chromatography can be used to separate mixtures and can give information to help identify substances. Chromatography involves a stationary phase and a mobile phase. Separation depends on the distribution of substances between the phases.

Figure 2 Black ink can be separated out into its different colours on a chromatogram

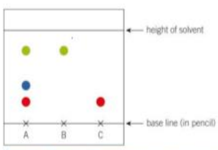


Figure 3 This chromatogram shows that A is a mixture of three substances, B and C plus one other unknown substance

The ratio of the distance moved by a compound (centre of spot from origin) to the distance moved by the solvent can be expressed as its Rf value:

$$Rf = \frac{distance\ moved\ by\ sustance}{distance\ moved\ by\ solvent}$$

Different compounds have different Rf values in different solvents, which can be used to help identify the compounds. The compounds in a mixture may separate into different spots depending on the solvent but a pure compound will produce a single spot in all solvents.

4.8.2 Identification of common gases

Test for hydrogen

The test for hydrogen uses a burning splint held at the open end of a test tube of the gas. Hydrogen burns rapidly with a pop sound.

Test for oxygen
The test for oxygen uses a glowing splint inserted into a test tube of the gas. The splint relights in oxygen.

Test for carbon dioxide
The test for carbon dioxide uses an aqueous solution of calcium hydroxide (lime water). When carbon dioxide is shaken with or bubbled through limewater the limewater turns milky (cloudy).

Test for chlorine
The test for chlorine uses litmus paper. When damp litmus paper is put into chlorine gas the litmus paper is bleached and turns white.

4.8.3 Identification of ions by chemical and spectroscopic means (chemistry only)

Flame tests
Flame tests can be used to identify some metal ions (cations).

- Lithium, sodium, potassium, calcium and copper compounds produce distinctive colours in flame tests:
- lithium compounds result in a crimson flame
- sodium compounds result in a yellow flame
- potassium compounds result in a lilac flame
- calcium compounds result in an orange-red flame
- copper compounds result in a green flame.

If a sample containing a mixture of ions is used some flame colours can be masked.

Metal hydroxides
Sodium hydroxide solution can be used to identify some metal ions (cations).
Solutions of aluminium, calcium and magnesium ions form white precipitates when sodium hydroxide solution is added but only the aluminium hydroxide precipitate dissolves in excess sodium hydroxide solution.
Solutions of copper(II), iron(II) and iron(III) ions form coloured precipitates when sodium hydroxide solution is added. Copper(II) forms a blue precipitate, iron(II) a green precipitate and iron(III) a brown precipitate.
The general equation of the reaction is: (where M is the metal ion e.g Cu, Fe, etc)

$$MSO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO_4(aq) + M(OH)_2(s)$$

The reaction can also be shown by an ionic equation:

$$M^{2+}(aq) + 2OH^{-}(aq) \rightarrow M(OH)_2(s)$$

Carbonates
Carbonates react with dilute acids to form carbon dioxide gas. Carbon dioxide can be identified with limewater.

Halides
Halide ions in solution produce precipitates with silver nitrate solution in the presence of dilute nitric acid. Silver chloride is white, silver bromide is cream and silver iodide is yellow.

Sulphates
Sulphate ions in solution produce a white precipitate with barium chloride solution in the presence of dilute hydrochloric acid.

Instrumental methods
Elements and compounds can be detected and identified using instrumental methods. Instrumental methods are accurate, sensitive and rapid.

Flame emission spectroscopy
Flame emission spectroscopy is an example of an instrumental method used to analyse metal ions in solutions. The sample is put into a flame and the light given out is passed through a spectroscope. The output is a line spectrum that can be analysed to identify the metal ions in the solution and measure their concentrations.
Students should be able to interpret an instrumental result given appropriate data in chart or tabular form, when accompanied by a reference set in the same form, limited to flame emission spectroscopy.

4.9 Chemistry of the atmosphere

The Earth's atmosphere is dynamic and forever changing. The causes of these changes are sometimes man-made and sometimes part of many natural cycles. Scientists use very complex software to predict weather and climate change as there are many variables that can influence this. The problems caused by increased levels of air pollutants require scientists and engineers to develop solutions that help to reduce the impact of human activity.

4.9.1 The composition and evolution of the Earth's atmosphere

The proportions of different gases in the atmosphere

For 200 million years, the proportions of different gases in the atmosphere have been much the same as they are today:

- about four-fifths (approximately 80%) nitrogen
- about one-fifth (approximately 20%) oxygen
- small proportions of various other gases, including carbon dioxide, water vapour and noble gases.

The Earth's early atmosphere

Theories about what was in the Earth's early atmosphere and how the atmosphere was formed have changed and developed over time. Evidence for the early atmosphere is limited because of the time scale of 4.6 billion years.

One theory suggests that during the first billion years of the Earth's existence there was intense volcanic activity that released gases that formed the early atmosphere and water vapour that condensed to form the oceans. At the start of this period the Earth's atmosphere may have been like the atmospheres of Mars and Venus today, consisting of mainly carbon dioxide with little or no oxygen gas.

Volcanoes also produced nitrogen which gradually built up in the atmosphere and there may have been small proportions of methane and ammonia.

When the oceans formed carbon dioxide dissolved in the water and carbonates were precipitated producing sediments, reducing the amount of carbon dioxide in the atmosphere. No knowledge of other theories is required.

How oxygen increased

Algae and plants produced the oxygen that is now in the atmosphere by photosynthesis, which can be represented by the equation:

$$6CO_2 + 6H_2O \xrightarrow{\text{light}} C_6H_{12}O_6 + 6O_2$$

$$\text{Carbon dioxide} + \text{water} \xrightarrow{\text{light}} \text{glucose} + \text{oxygen}$$

Algae first produced oxygen about 2.7 billion years ago and soon after this oxygen appeared in the atmosphere. Over the next billion years plants evolved and the percentage of oxygen gradually increased to a level that enabled animals to evolve.

How carbon dioxide decreased

Algae and plants decreased the percentage of carbon dioxide in the atmosphere by photosynthesis.

Carbon dioxide was also decreased by the formation of sedimentary rocks and fossil fuels that contain carbon.

4.9.2 Carbon dioxide and methane as greenhouse gases

Greenhouse gases

Greenhouse gases in the atmosphere maintain temperatures on Earth high enough to support life. Water vapour, carbon dioxide and methane are greenhouse gases.

Human activities which contribute to an increase in greenhouse gases in the atmosphere

Some human activities increase the amounts of greenhouse gases in the atmosphere. These include:

- carbon dioxide
- methane

The amount of carbon dioxide in the Earth's atmosphere has risen in the recent past, largely due to the amount of fossil fuels now burnt.

It is difficult to predict with complete certainty the effects on climate of rising levels of greenhouse gases on a global scale.

However, the vast majority of peer reviewed evidence agrees that increased proportions of greenhouse gases from human activities will increase average global temperatures.

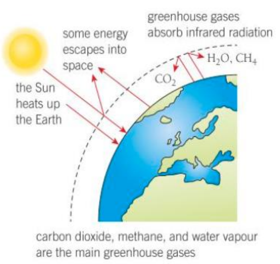


Figure 1 *The molecules of a 'greenhouse gas' absorb the energy radiated by the Earth as it cools down at night. This increases the store of energy of the gases in the atmosphere and warms the Earth*

Global climate change

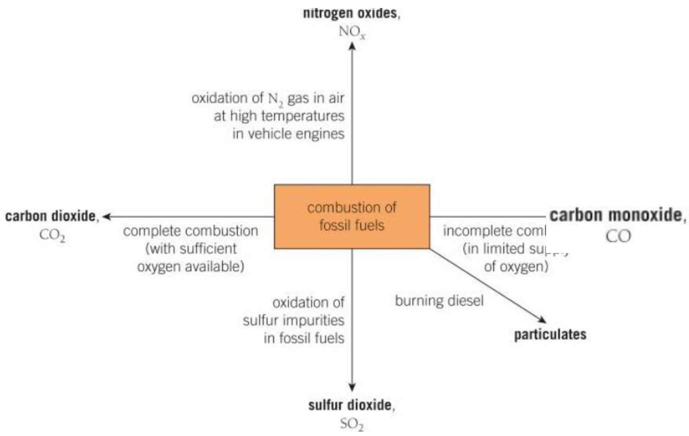
An increase in average global temperature is a major cause of climate change.
There are several potential effects of global climate change.
Reducing greenhouse gases in the atmosphere relies on reducing the use of fossil fuels, mainly by using alternative sources of energy and conserving energy.
The economies of developed countries are based on energy obtained from fossil fuels, so changes will cost money to implement.
However, changes are needed because of the potential risks arising from global climate changes, such as rising sea levels, threats to ecosystems, and different patterns of food production around the world.

The carbon footprint and its reduction

The carbon footprint is the total amount of carbon dioxide and other greenhouse gases emitted over the full life cycle of a product, service or event.
The carbon footprint can be reduced by reducing emissions of carbon dioxide and methane.

4.9.3 Common atmospheric pollutants and their sources

Atmospheric pollutants from fuels



The combustion of fuels is a major source of atmospheric pollutants.
Most fuels, including coal, contain carbon and/or hydrogen and may also contain some sulphur.
The gases released into the atmosphere when a fuel is burned may include carbon dioxide, water vapour, carbon monoxide, sulphur dioxide and oxides of nitrogen.
Solid particles and unburned hydrocarbons may also be released that form particulates in the atmosphere. Sulphur impurities in fuels burn to form sulphur dioxide, which can cause acid rain. Sulphur can be removed from fuels before they are burned, or sulphur dioxide can be removed from flue gas.
In insufficient oxygen, poisonous carbon monoxide gas is formed. Particulates of carbon (soot) and unburnt hydrocarbons can also be produced, especially if the fuel is diesel. They can cause global dimming.
At the high temperatures in engines, nitrogen from the air reacts with oxygen to form oxides of nitrogen.

Properties and effects of atmospheric pollutants

Carbon monoxide is a toxic gas. It is colourless and odourless and so is not easily detected.
Sulphur dioxide and oxides of nitrogen cause respiratory problems in humans and cause acid rain.
Particulates cause global dimming and health problems for humans.

4.10 Using resources

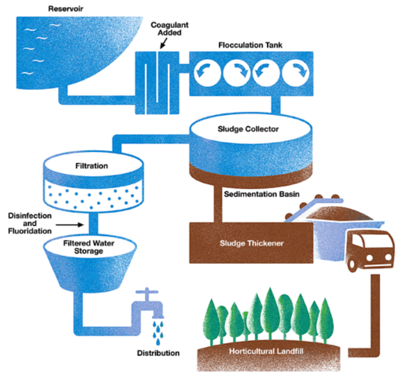
Industries use the Earth's natural resources to manufacture useful products. In order to operate sustainably, chemists seek to minimise the use of limited resources, use of energy, waste and environmental impact in the manufacture of these products. Chemists also aim to develop ways of disposing of products at the end of their useful life in ways that ensure that materials and stored energy are utilised. Pollution, disposal of waste products and changing land use has a significant effect on the environment, and environmental chemists study how human activity has affected the Earth's natural cycles, and how damaging effects can be minimised.

4.10.1 Using the Earth's resources and obtaining potable water

Using the Earth's resources and sustainable development

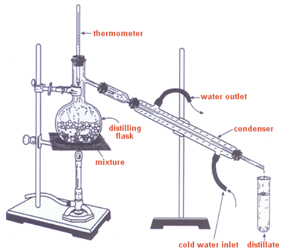
Humans use the Earth's resources to provide warmth, shelter, food and transport.
Natural resources, supplemented by agriculture, provide food, timber, clothing and fuels.
Finite resources from the Earth, oceans and atmosphere are processed to provide energy and materials.
Chemistry plays an important role in improving agricultural and industrial processes to provide new products and in sustainable development, which is development that meets the needs of current generations without compromising the ability of future generations to meet their own needs.

Potable water



Water of appropriate quality is essential for life. For humans, drinking water should have sufficiently low levels of dissolved salts and microbes. Water that is safe to drink is called potable water.
Potable water is not pure water in the chemical sense because it contains dissolved substances.
The methods used to produce potable water depend on available supplies of water and local conditions.
In the United Kingdom (UK), rain provides water with low levels of dissolved substances (fresh water) that collects in the ground and in lakes and rivers, and most potable water is produced by:

- choosing an appropriate source of fresh water
- passing the water through filter beds
- sterilising.



Sterilising agents used for potable water include chlorine, ozone or ultraviolet light.
If supplies of fresh water are limited, desalination of salty water or sea water may be required. Desalination can be done by distillation or by processes that use membranes such as reverse osmosis.
These processes require large amounts of energy.

Waste water treatment

Urban lifestyles and industrial processes produce large amounts of waste water that require treatment before being released into the environment. Sewage and agricultural waste water require removal of organic matter and harmful microbes. Industrial waste water may require removal of organic matter and harmful chemicals.
Sewage treatment includes:

- screening and grit removal
- sedimentation to produce sewage sludge and effluent
- anaerobic digestion of sewage sludge
- aerobic biological treatment of effluent.

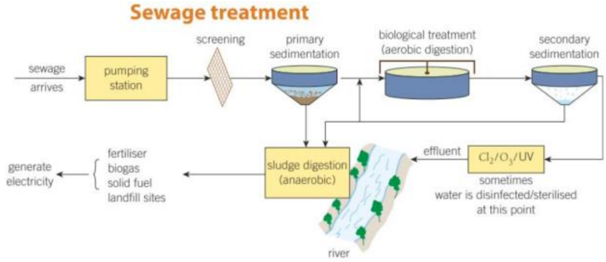


Figure 1 *The steps needed to make our waste water from urban and rural sources safe to return to the environment*

Alternative methods of extracting metals (HT only)

The Earth's resources of metal ores are limited.
Copper ores are becoming scarce and new ways of extracting copper from low-grade ores include phytomining, and bioleaching.
These methods avoid traditional mining methods of digging, moving and disposing of large amounts of rock.
Phytomining uses plants to absorb metal compounds. The plants are harvested and then burned to produce ash that contains metal compounds.
Bioleaching uses bacteria to produce leachate solutions that contain metal compounds.
The metal compounds can be processed to obtain the metal. For example, copper can be obtained from solutions of copper compounds by displacement using scrap iron or by electrolysis.

4.10.2 Life cycle assessment and recycling

Life cycle assessment

Life cycle assessments (LCAs) are carried out to assess the environmental impact of products in each of these stages:

- extracting and processing raw materials
- manufacturing and packaging
- use and operation during its lifetime
- disposal at the end of its useful life, including transport and distribution at each stage.

Use of water, resources, energy sources and production of some wastes can be fairly easily quantified.
Allocating numerical values to pollutant effects is less straightforward and requires value judgements, so LCA is not a purely objective process.
Selective or abbreviated LCAs can be devised to evaluate a product but these can be misused to reach pre-determined conclusions, eg in support of claims for advertising purposes.

Ways of reducing the use of resources skills

The reduction in use, reuse and recycling of materials by end users reduces the use of limited resources, use of energy sources, waste and environmental impacts.

Metals, glass, building materials, clay ceramics and most plastics are produced from limited raw materials. Much of the energy for the processes comes from limited resources. Obtaining raw materials from the Earth by quarrying and mining causes environmental impacts.

Some products, such as glass bottles, can be reused. Glass bottles can be crushed and melted to make different glass products. Other products cannot be reused and so are recycled for a different use.

Metals can be recycled by melting and recasting or reforming into different products. The amount of separation required for recycling depends on the material and the properties required of the final product. For example, some scrap steel can be added to iron from a blast furnace to reduce the amount of iron that needs to be extracted from iron ore.

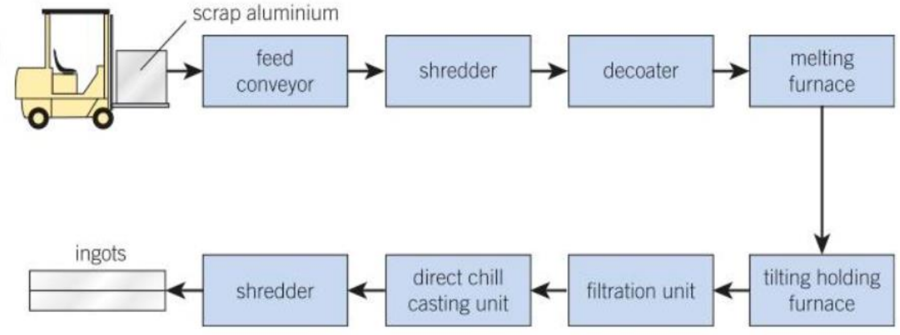


Figure 2 *The recycling of aluminium involves melting the scrap metal, but still uses a lot less energy than extracting aluminium from its ore, bauxite*

4.10.3 Using materials (chemistry only)

Corrosion and its prevention

Corrosion is the destruction of materials by chemical reactions with substances in the environment. Rusting is an example of corrosion.

Both air and water are necessary for iron to rust.

Corrosion can be prevented by applying a coating that acts as a barrier, such as greasing, painting or electroplating. Aluminium has an oxide coating that protects the metal from further corrosion.

Some coatings are reactive and contain a more reactive metal to provide sacrificial protection, eg zinc is used to galvanise iron.

Alloys as useful materials

Most metals in everyday use are alloys.

Bronze is an alloy of copper and tin. Brass is an alloy of copper and zinc.

Gold used as jewellery is usually an alloy with silver, copper and zinc. The proportion of gold in the alloy is measured in carats. 24 carat being 100% (pure gold), and 18 carat being 75% gold.

Steels are alloys of iron that contain specific amounts of carbon and other metals. High carbon steel is strong but brittle. Low carbon steel is softer and more easily shaped. Steels containing chromium and nickel (stainless steels) are hard and resistant to corrosion.

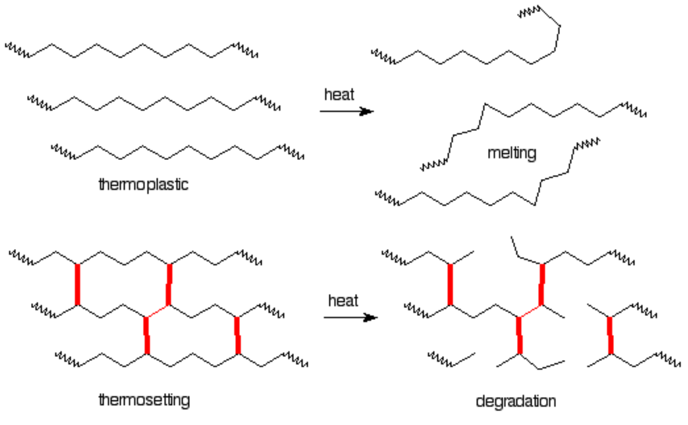
Aluminium alloys are low density.

Ceramics, polymers and composites

Most of the glass we use is soda-lime glass, made by heating a mixture of sand, sodium carbonate and limestone. Borosilicate glass, made from sand and boron trioxide, melts at higher temperatures than soda-lime glass.

Clay ceramics, including pottery and bricks, are made by shaping wet clay and then heating in a furnace.

The properties of polymers depend on what monomers they are made from and the conditions under which they are made. For example, low density (LD) and high density (HD) poly(ethene) are produced from ethene.The properties of polymers depend on what they are made from and the conditions under which they are made.



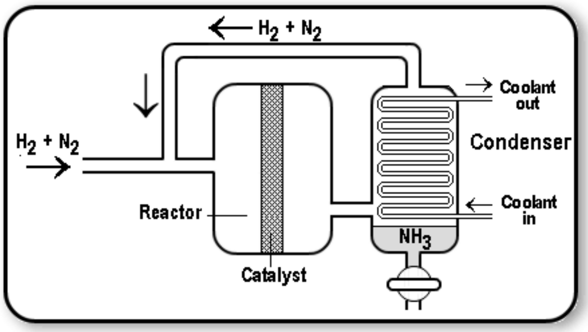
For example, low density (LD) and high density (HD) poly (ethene) are produced using different catalysts and reaction conditions.
Thermosoftening polymers consist of individual, tangled polymer chains. Thermosetting polymers consist of polymer chains with cross-links between them so that they do not melt when they are heated.

Most composites are made of two materials, a matrix or binder surrounding and binding together fibres or fragments of the other material, which is called the reinforcement.
Examples of ceramics include brick, cement, glass, tile, dinnerware, porcelain, porcelain enamel

4.10.4 The Haber process and the use of NPK fertilisers (chemistry only)

The Haber process

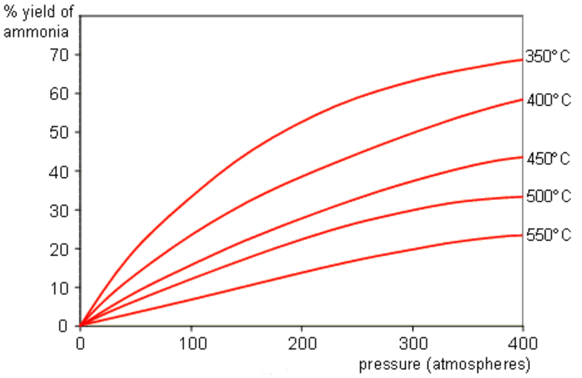
The Haber process is used to manufacture ammonia, which can be used to produce nitrogen-based fertilisers.
The raw materials for the Haber process are nitrogen and hydrogen. Nitrogen is obtained from the air and hydrogen may be obtained from natural gas or other sources.
The purified gases are passed over a catalyst of iron at a high temperature (about 450 °C) and a high pressure (about 200 atmospheres). Some of the hydrogen and nitrogen reacts to form ammonia.
The reaction is reversible so ammonia breaks down again into nitrogen and hydrogen:



nitrogen + hydrogen $\rightleftharpoons$ *ammonia*

On cooling, the ammonia liquefies and is removed. The remaining hydrogen and nitrogen are recycled.

These reaction conditions, together with reaction rates, are important when determining the optimum conditions in industrial processes, including the Haber process.
TEMPERATURE: **LOW** enough for a **reasonable yield** but **HIGH** enough for a **fast reaction**
PRESSURE: **LOW** enough to not need **expensive** reinforced apparatus but **HIGH** enough to give a **reasonable yield**



Production and uses of NPK fertilisers

Compounds of nitrogen, phosphorus and potassium are used as fertilisers to improve agricultural productivity.
NPK fertilisers contain compounds of all three elements. Industrial production of NPK fertilisers can be achieved using a variety of raw materials in several integrated processes. NPK fertilisers are formulations of various salts containing appropriate percentages of the elements.
Ammonia can be used to manufacture ammonium salts and nitric acid.
Potassium chloride, potassium sulphate and phosphate rock are obtained by mining, but phosphate rock cannot be used directly as a fertiliser.
Phosphate rock is treated with nitric acid or sulphuric acid to produce soluble salts that can be used as fertilisers.
There are differences between industrial production of fertilisers and laboratory preparations of the same compounds.