UNIVERSITY OF CAMBRIDGE

IGCSE

Complete Chemistry Notes According to Syllabus

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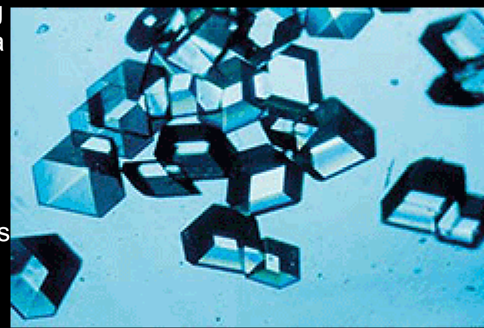
IGCSE Chemistry Textbook
IGCSE Chemistry Syllabus

Compilation by : WooWooWoo

Chapter 1: The Particulate nature of matter

Matter is anything that has mass and occupies space. There are 3 states of matter, solids, liquids and gases.

Solids:



The particles are packed closely together. The forces between particles are strong enough so that the particles cannot move freely but can only vibrate. As a result, a solid has a stable, definite shape, and a definite volume. Solids can only change their shape by force, as when broken or cut.

In crystalline solids, the particles (atoms, molecules, or ions) are packed in a regularly ordered, repeating pattern. There are many different crystal structures, and the same substance can have more than one structure (or solid phase). Solids can be transformed into liquids by melting, and liquids can be transformed into solids by freezing. Solids can also change directly into gases through the process of sublimation.

Liquids:

A liquid is a nearly incompressible fluid which is able to conform to the shape of its container but retains a (nearly) constant volume independent of pressure.

The volume is definite if the temperature and pressure are constant. When a solid is heated above its melting point, it becomes liquid.

This means that the shape of a liquid is not definite but is determined by its container, the most well known exception being water, H_2O.

Gases:

A gas is a compressible fluid. Not only will a gas conform to the shape of its container but it will also expand to fill the container.

In a gas, the molecules have enough kinetic energy so that the effect of forces is small, and the typical distance between neighboring molecules is much greater than the molecular size.

A gas has no definite shape or volume, but occupies the entire container in which it is confined. A liquid may be converted to a gas by heating to the boiling point.

The Kinetic Theory of Matter States:

The kinetic theory is a theory put together by the finest chemists and physicians of all time. It consists of a number of true facts related to matter and their states. The theory explains the behavior of matter and their physical properties.

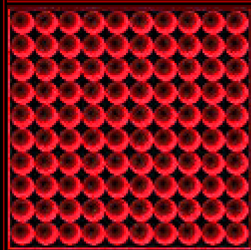
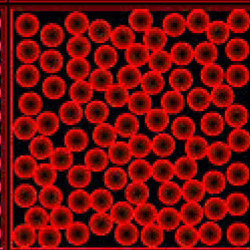
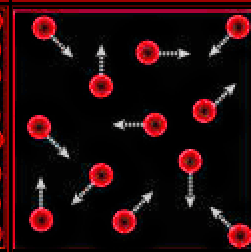
The kinetic theory of matter states:

- All matter is made up of tiny, microscopic moving particles. And each matter has a different type of particles with different size and mass.

- Particles are in continuous movement. All particles are moving all the time in random directions (Brownian motion).
- The speed of movement depends on the mass of the particle, temperature and several other factors that you will know later on.

Kinetic means movement, and so kinetic energy means movement energy.

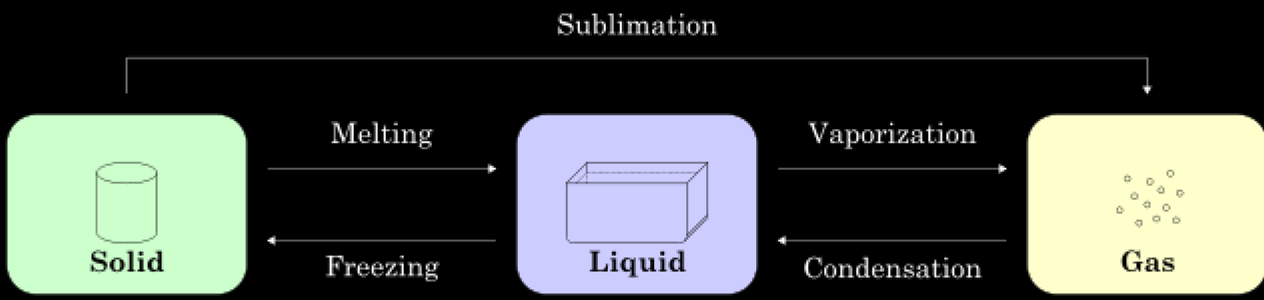
Comparing Properties of Solids, Liquids and Gases:

	Solid	Liquid	Gas
Molecular Structure			
Particles Arrangement	Very closely packed Regularly arranged in lattice	Closely packed Irregular arrangement	Very far apart Very irregular arrangement
Intermolecular Spaces	Almost none Negligible	Minimal Tiny spaces	Very large
Intermolecular Forces	Extremely strong	Not weak Weaker than in solids	Very weak
Movement of Particles	Vibrating in a fixed position	Slowly slide over each other randomly	Fast movement in random direction
Shape	Fixed definite shape	No fixed shape Depends on the container	No fixed shape
Volume	fixed	fixed	No fixed volume Depends on the container
Compressibility	Cannot be compressed	Can be hardly compressed	Very compressible
Diffusion	Cannot diffuse	Diffuses slowly	Diffuses quickly

Physical Changes (Change in State):

Physical changes are changes in which no new substance is formed. For example melting and ice cube or dissolving salt in water. Physical changes are reversible. For instance if you heat and melt and ice cube to water, you can put it in a freezer and have it changed back to ice.

Changing the state of a matter is a physical change. And it is done by either heating or cooling. The following diagram represents changes in state:



Melting: The change of state from solid to liquid. The temperature at which a solid melts is called the melting point.

Evaporation: The change of state from liquid to gas. The temperature at which a liquid evaporates is called the boiling point.

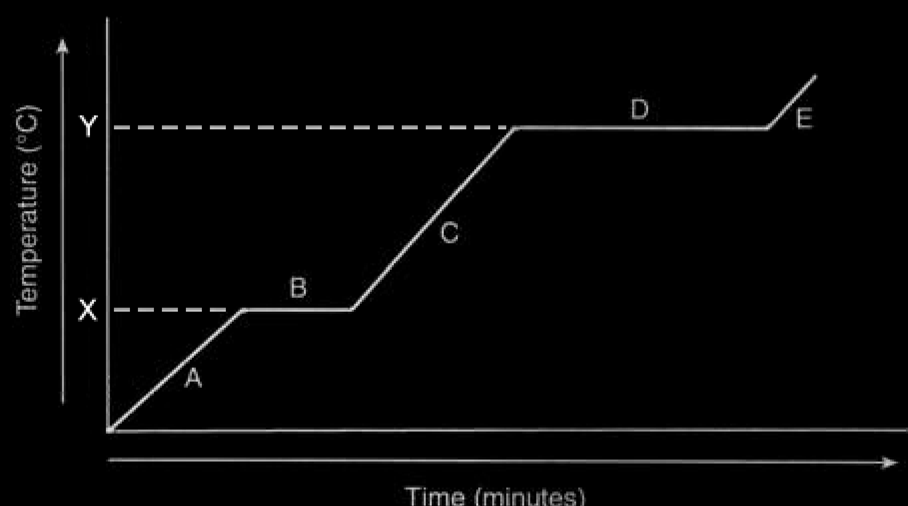
Some substances never exist in a liquid form. If they are solid and you heat them they turn into a gas, and if they are a gas and you cool them they turn into a solid. This process is called **Sublimation**.

The change in state occurs when the temperature is raised or dropped. Melting occurs when you heat a solid because heating gives the particles more kinetic energy making them move faster and further apart, making the solid expand. Until at some point they have enough energy to break the forces of attraction between them and the lattice turning into liquid. If you keep heating the liquid, particles will gain even more kinetic energy and start moving even faster, pushing each other away. The particles at the surface have the highest amount of energy that they can break the forces of attraction and escape as a gas; this is the start of evaporation. At some point, particles will try to escape so quickly that they form bubbles of gas in the liquid. This is the boiling point at which the pressure of the gas forming above the liquid is the same as atmospheric pressure.

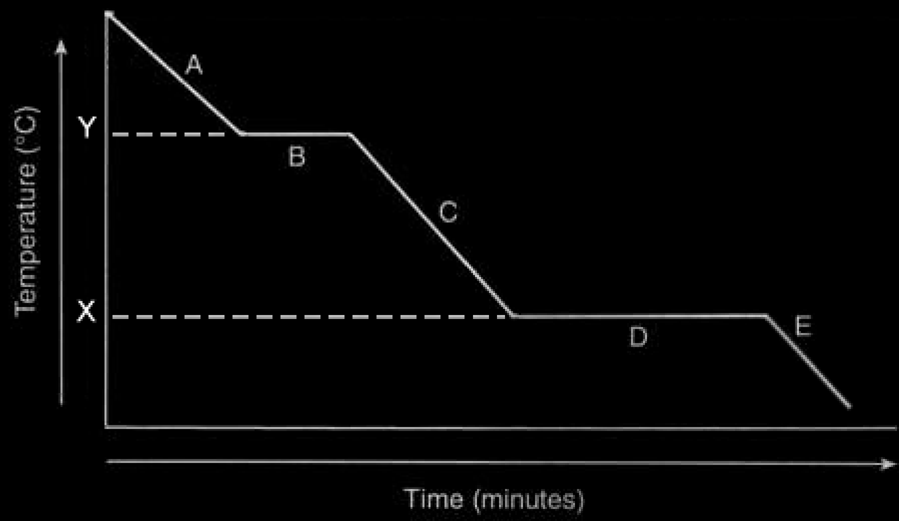
On the other hand, cooling a gas will make its particles lose their kinetic energy and move closer and slower. Eventually the forces of attraction will hold them together forming a liquid (condensation). And if a liquid is cooled, its particles will move closer and slower until the forces of attraction are strong enough to hold them tight together forming a solid (freezing).

During the actual change of the state, the temperature of the matter is constant because any heat energy supplied is used to break the bonds. So if you record the temperature change during heating a solid, the temperature will first rise, then it will remain constant for a while (this is the melting point) and then it will rise again.

The following figure is a heating curve of a solid. At point 'A' the state is solid. At point 'B' the solid is melting; it is a mixture of solid and liquid. At point 'C' the state is liquid. At point 'D' the liquid is evaporating, it is a mixture of liquid and gas. At point 'E' the state is gas. Temperature 'X' is the melting point while temperature 'Y' is the boiling point.



The following figure is a cooling curve of a gas. At point ‘A’ the state is gas. At point ‘B’ the gas is condensing; the state is a mixture of gas and liquid. At point ‘C’ the state is liquid. At point ‘D’ the liquid is freezing, the state is a mixture of liquid and solid. At point ‘E’ the state is solid. Temperature ‘X’ is the melting point and temperature ‘Y’ is the boiling point.

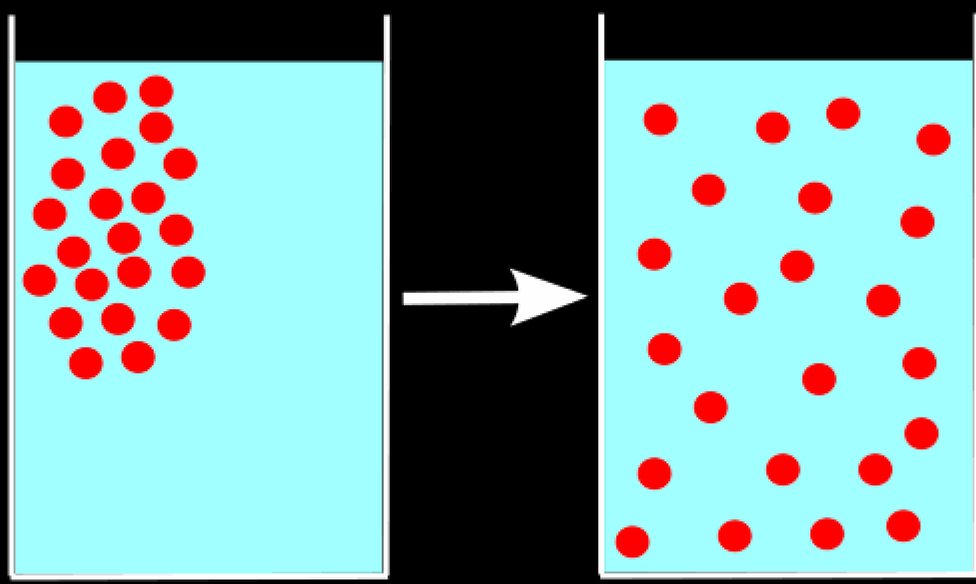


Some liquids evaporate extremely quickly at room temperature, they are said to be **volatile liquids**.

The purity of substances can be easily determined by testing its boiling and melting points. This is because pure substances have sharp boiling and melting points, while those of impure substances are ranging.

Diffusion:

Diffusion is the random movement of liquid or gas particles to fill the available space and spread evenly. For instance, if you pass by a trash can, you can smell the ugly scent of trash. This is because molecules from the garbage diffused out of the can to the air which you breathed in.



Diffusion rate depends on several factors, these are:

- Mass of the substance. The lighter the substance (lower M_r or A_r) the faster it diffuses
- Temperature. The more kinetic energy the particles have, the faster they move and diffuse.

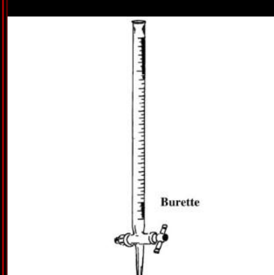
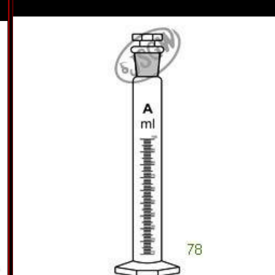
- Presence of other substance. Diffusion is faster when it occurs in an area where there are fewer particles of other substances present. This is why diffusion is extremely fast in vacuums. This is because the diffusing particles have less other particles to stand in their way.
- Intermolecular spaces. This is why gases diffuse faster than liquids and solids do not diffuse.

Diffusion of gases can be proved very easily. We can prove it by putting some bromine liquid in a cylinder and sealing it, then putting another inverted cylinder above it. When the bromine liquid evaporates, we remove the lid between the two cylinders, the brown bromine gas will diffuse upwards filling the available space.

We can also prove diffusion in liquids by a very simple experiment. Pour some water in a beaker, then add a drop of blue ink in the water. After a period of time, you will find that the black ink spread throughout the water and turned it into a blue solution. This was caused by diffusion.

Chapter 2: Experimental techniques

There are different apparatus required for taking measurement in Chemistry. We need to focus on time, temperature, mass and volume.

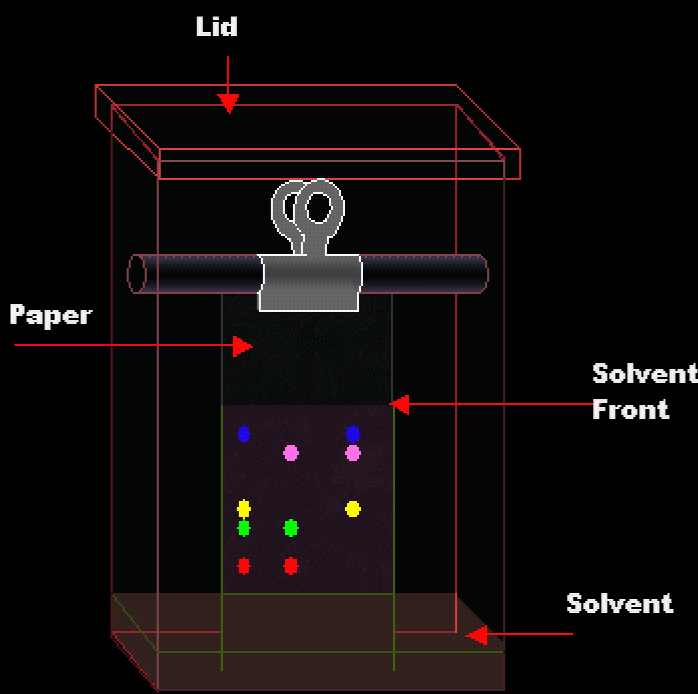
Measurement Unit	Apparatus		
Time	Stopwatch 		
Temperature	Thermometre 		
Mass	Balance 		
Volume	Burette 	Pipette 	Measuring Cylinder 

Chapter 2.2: Criteria of purity

Chromatography:

Chromatography is a process used to separate and identify two or more substances from a mixture. This method depends on the solubility of the tested substances. Chromatography, for instance, is also used to find out the number of components in a drink.

Let's say we want to find the number of colored dyes present in black ink. First we get a piece of filter paper or chromatography paper. We draw a line, in pencil, at the bottom of the paper. This line is called the base line, and the reason it is drawn in pencil is because pencil is insoluble so it won't interfere with the solubility of the ink. Then we place a spot of the black ink on the base line. The chromatography paper is now put with its bottom soaked in a suitable solvent, which is in our case water. The chromatography paper is going to absorb the solvent, which moves upwards. When the solvent reaches the base line, the spot of black ink will dissolve in it. The solvent will keep moving upwards taking with it the black ink. The more soluble the contents of the ink the higher it will move until it can't anymore.



Sometimes the substance we are testing is in solid form. In this case we have to crush and dissolve it in water and filter it. We then take the filtrate and evaporate some of it water to get the most concentrated sample. Then we are ready to do the experiment.

When dealing with ethanol in concentrating the sample. We have to heat it in a water bath because it is flammable. And when we use it a solvent in chromatography, it has to be performed in a covered beaker because ethanol is volatile.

The solvent front is the furthest distance travelled by the solvent.

Sometimes, the sample is separated into colorless spots. In this case the chromatography paper is sprayed with a locating agent to that locates the spots. The number of spots indicates the number of components in the sample.

To identify the substances which were formed when the sample was separated, we measure what's called the **R_f Value**. The R_fValue is the rate of the distance travelled by the solute (the spot) to the distance travelled by the solvent line. It's calculated by measuring the distance travelled by the spot ($Distance_1$) from the base line, measuring the distance from the base line to the solvent front ($Distance_2$), and dividing $Distance_1$ by $Distance_2$.

$$R_f \text{ value} = \frac{\text{Distance travelled by spot}}{\text{Distance travelled by the solvent}}$$

This value is always less than one because the distance travelled by the solvent is always larger than the distance travelled by the spot. Each substance has a different R_f Value.

Chromatography can be used to test purity of substances. If a substance gives only one spot, it means it is pure because it contains one substance.

If two spots have the same R_f value they are made of the same substance.

Melting and boiling point

Chemist use some complex methods to check purity but we can use one simple method to find the purity of a substance, we can check the melting and the boiling point.

- A pure substance has a definite, sharp, melting point and boiling point.
- When a substance contains an impurity, the melting point decreases and the boiling point increases.

Water melts at 0°C and boils at 100°C.

Important of purity in substances

Does purity matter?
Often it does not matter if a substance is not pure. We wash in tap water; without thinking too much about what is in it, but sometimes purity is very important. If you are making a new medical drug, or a flavouring for food, you must make sure it contains nothing that could harm people.

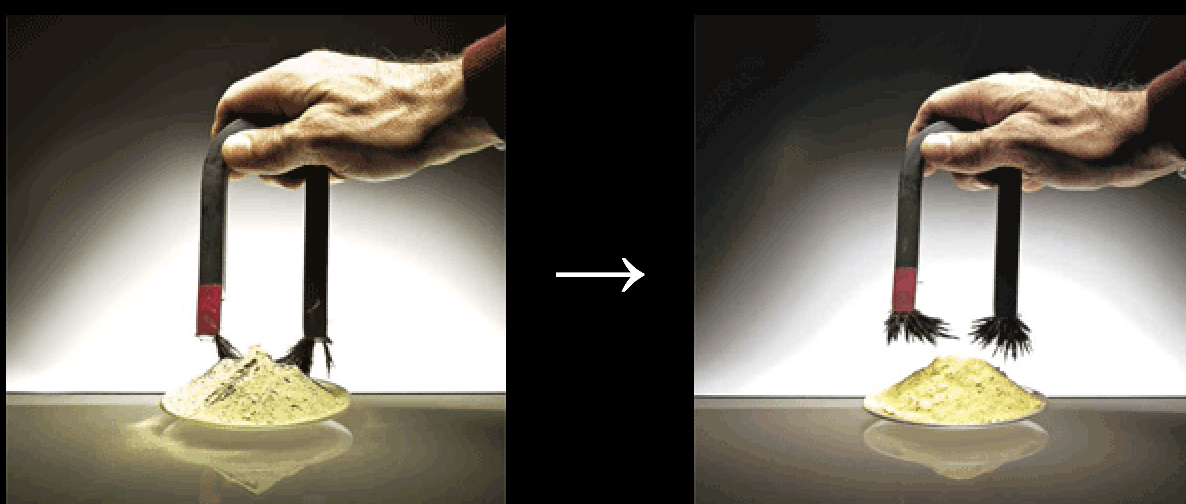
An unwanted substance, mixed with the substance you want, is called an **impurity.**

Separating Solid/Solid Mixtures:

By Magnet:

This method is used to separate a mixture of two solids. One condition must be present though. This is that one of the solids is magnetic. For example if we have a mixture of sand and iron chips. We can separate them by:

- Pouring the mixture in a dish,
- Introducing a magnet just above the mixture.



The iron chips will immediately get attracted to the magnet leaving sand behind.

By Sublimation:

If we have a mixture of two solids, one of them undergoes sublimation we can easily separate them by heating the mixture using a Bunsen burner.

One solid might melt while the other one will directly sublime into a gas. This process must be done in a fume cupboard in order to collect the gas.

By Solvent Extraction Method:

This method is used one of the solids is water soluble, while the other is insoluble, for example a sand and salt mixture. In this method, the mixture is put in a beaker and water is added to it. The mixture is stirred on gentle heating to make the salt dissolve in the water quickly. Then the mixture is filtered using a filter funnel and filter paper. The residue will be the insoluble sand and the filtrate will be the salt solution. The sand is dried and collected. The salt is obtained from the solution by either the evaporation or the crystallisation method which will be studied later on.

Separating Solid/Liquid Mixtures:

Solubility:

A solution is formed when a solute is dissolved in a solvent.

Solute: This is a substance that dissolves in a solvent forming a solution

Solvent: This is a substance in which a solute dissolves forming a solution

Solution: A uniform mixture which is formed when a solute is dissolved in a solvent.

Dilute Solution: A solution with a small amount of solute/dm3.

Concentrated Solution: A solution with large amounts of solute/dm3.

Concentration: The amount of solute (in grams or moles) that can dissolve in 1dm3 of a solvent.

Saturated Solution: A very concentrated solution with the maximum amount of solute that dissolves in it already dissolved in it.

If you leave a hot saturated solution to cool, crystals of the solute will form. This is because as the temperature decreases the solvent can hold less solute so excess will form in the form of crystals.

The rate of dissolving can be increased by:

- Increasing temperature,
- More stirring,
- Crushed solute (larger surface area).

Solubility: The maximum amount of solute that can dissolve in 100g of water at a particular temperature.

If we want to find the solubility of table salt (sodium chloride) at 30oC, we do the follow these steps:

- Use a balance to measure 100g of water accurately,
- Pour the 100g of water into a beaker,
- Heat the water to 30ºC using a Bunsen burner and a thermometer,
- Using a spatula, add a considerable mass of the table salt into the water and stir,
- If the mass of salt dissolves completely, add the same amount again and stir, repeat this if the mass keeps dissolving completely until you start seeing excess of the salt not dissolving at the bottom of the beaker,
- You have to record the masses of salt you are adding each time and when you start seeing the excess stop adding salt and sum up the amount of salt you added. Call this $Mass_1$,
- Filter the solution. The excess of salt will be the residue, dry it and weigh it. Call this $Mass_2$,
- The amount of table salt that was dissolved in water is $Mass_1 - Mass_2$,
- This is the solubility of table salt at 30ºC.

Solubility increases as temperature increases. This is because the intermolecular spaces between the water molecules increase with temperature, giving more space for the solute's molecules.

By Evaporation (For Soluble Solid/Liquid Solutions):

- Put solution in a beaker,
- Set the apparatus (Tripod with a gauze above it and a Bunsen burner below it),
- Put the beaker on the gauze,
- Start heating the solution slowly.

The liquid will evaporate completely leaving the solute behind in powder form.

By Crystallization (For Soluble Solid/Liquid Solutions):

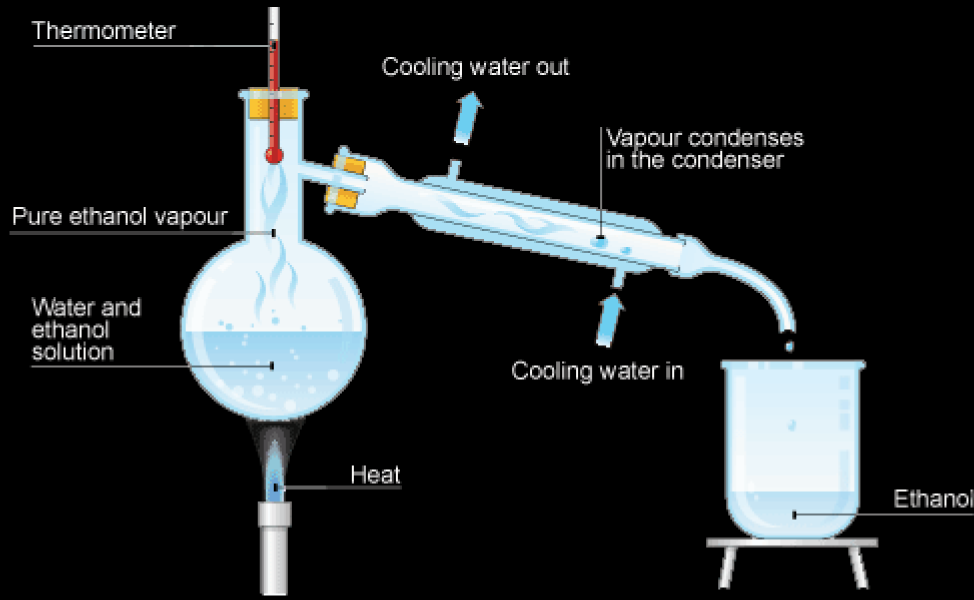
- Put solution in a beaker,
- Set the apparatus (Tripod with a gauze above it and a Bunsen burner below it),
- Insert a glass rod in the beaker,
- Turn on the Bunsen burner and continuously dip the glass rod in the solution,
- When you see crystals of the solute starting to form on the glass rod, turn of the Bunsen burner. (This is crystallization point),
- Leave the solution to cool,
- Filter the solution and take the crystals, which will be the residue,
- Wash the crystals with distilled water then dry them between two filter papers.

Note: Do not dry the crystals in oven because it will evaporate the water of crystallization.

By Simple Distillation (For Soluble Solid/Liquid Solutions):

- Set the apparatus as shown in the diagram below,
- Turn on the Bunsen burner,
- The solvent will evaporate and rise as vapor into the condenser,
- The cold water surrounding the tube where the water is in the condenser will make the vapor condense into liquid,
- The solvent is collected in the tube or beaker on the other side of the condenser, it's called the distillate,
- The solute is collected in the flask as powder,

- The thermometer must be where the vapor passes the measure the boiling point of the solvent.



This method is ideal for distilling sea water.

Filtration (For Insoluble Solid/Liquid Mixtures):

- Set the apparatus as shown below,
- Pour the mixture into the filter funnel,
- The solvent will go through and be collected in the beaker as the filtrate,
- The insoluble solid will be collected from the funnel as the residue.

Decantation (For Insoluble Solid/Liquid Mixtures):

This method is very simple. It involves letting the insoluble solid rest at the bottom of the beaker. Then pouring the liquid in another beaker leaving the solid behind.

Centrifugation (For Insoluble Solid/Liquid Mixtures):

- Put the mixture in a test tube,
- Place the test tube in the centrifugation machine,
- Start the machine.

The centrifugation force will make the mixture separate into two layers, the liquid at the top, and solid at the bottom. They are then separated by decantation.

Separating Liquid/Liquid Mixtures:

Separating Funnel (For Immiscible Liquids):

Immiscible liquids do not mix together; like oil and water.

If they are put in one container, the denser liquid will settle at the bottom and the lighter one will go above it.

To separate and oil and water mixture, we pour the mixture into the separating funnel.

The water is denser than oil, it settles below it.

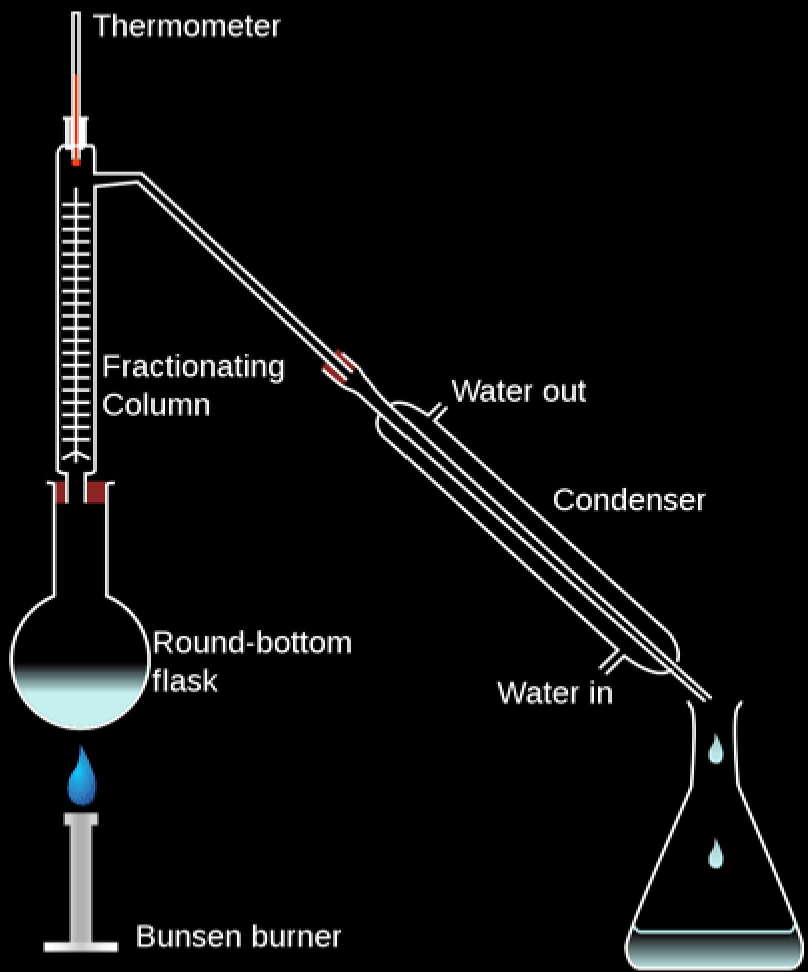
The tap is opened to let the water flow into the beaker.

The tap is closed when all the water is poured, the beaker is replaced by and empty one and the oil is now poured.

Fractional Distillation (For Miscible Liquids):

Fractional distillation is a method of separating a mixture of two or more liquids provided that they have different boiling points:

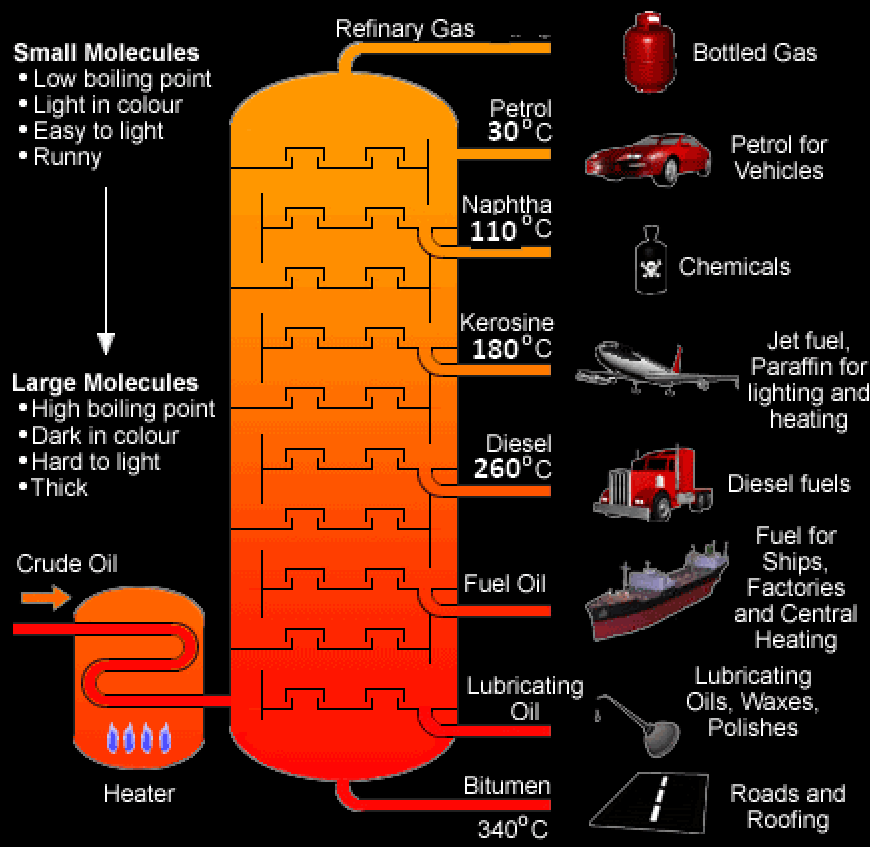
- The apparatus is set as in the diagram below,
- When the heat is turned on the vapor of all the liquids rises,
- The liquid with the lowest boiling point goes all the way through the glass beads and into the condenser and out on the other side as liquid. The temperature is constant during this,
- The liquids with the higher boiling points condense on the glass beads. When all of the liquid with the lowest boiling point have evaporated and collected, the temperature starts rising again. The liquid with the second lowest boiling point evaporates now, and gets collected on the other side.



The glass beads are to provide a cool large surface area for condensation.

Fractional Distillation of Crude Oil:

Crude oil is a mixture of hydrocarbons. It is the major source of fuel. It is refined and separated into several very useful fractions by fractional distillation in a fractionating tower. The higher the fraction is obtained in the fractionating tower the lower its boiling point.



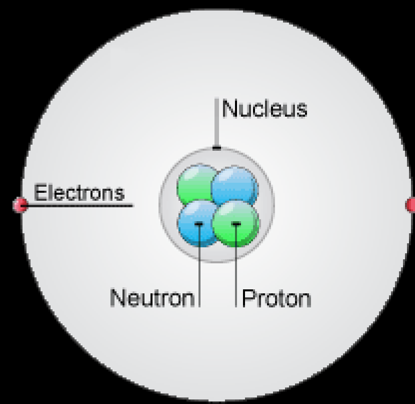
Fuel is a substance that releases energy (E.g.: Coal, Natural gas, Ethanol)
Lubricant is a substance that reduces friction between two surfaces.
Hydrocarbons are organic compounds containing carbon and hydrogen only.

Different hydrocarbons are collected at different levels according to their boiling points. The higher they are collected the lower their boiling point.

Chapter 3: Atoms, elements and compounds

Earlier, we've studied that elements are the purest substances of all. And each element has its own type of atoms. When scientists first discovered the atom, they believed it was a spherical structure like marbles. Later on other scientists discovered that there the
atom is made up of even smaller sub-atomic particles.

The Atomic Structure:



It was discovered that an atom is made up of three types of sub-atomic particles; these are **protons**, **neutrons** and **electrons**.

It was also discovered that in the center of an atom, there is a **Nucleus** which is made up of protons and neutrons.

Around the nucleus there are energy shells in which **electrons** are. Electrons are always orbiting the nucleus in the energy shells.

Protons and Neutrons are said to be Nucleons because together they make the nucleus. Each type of these sub-atomic particles has its own physical properties which are explained in this table:

Particle	Symbol	Mass	Charge
Proton	p	1	+1
Neutron	n	1	no charge
Electron	e	1/200 (Negligible)	-1

These physical properties tell us several factors:

- The mass of the atom is concentrated in the nucleus; this is because the mass of an electron is negligible,
- A neutron has no charge, it is neutral,
- An atom is also neutral; this is because it always contains as much positive protons as negative electrons.

The mass of the sub-atomic particles is in atomic mass unit (AMU). This is because they are so light that they can't be measured in grams.

There are two numbers given to each type of atoms:

Atomic/Proton Number: it is the number of protons in an atom. And since an atom has an equal number of protons and electrons, it is the number of electrons in the atom too.

Mass/Nucleon Number: it is the number of protons + number of nucleons in the nucleus of an atom. It is called mass number because its value is also mass of the atom.

If the atomic number is the number of protons, and the mass number is the number of protons and neutrons, then subtracting the proton number from the mass number will give you the number of neutrons in the atom.

When we represent the atom of an element, we give it a symbol of one or two letters where the first letter is always in capitals and the second one is in lowercase. The mass number goes above the symbol and the atomic number goes below the symbol.

Example:

$$4He_2$$

- This represents the Helium Atom,

- Its symbol is He,
- Its mass number is 4,
- Its atomic number is 2,
- It has 2 protons, 2 neutrons (4 - 2 = 2), and 2 electrons.

$24Mg_{12}$

- This represents the Magnesium Atom,
- Its symbol is Mg,
- Its mass number is 24,
- Its atomic number is 12,
- It has 12 protons, 12 neutrons (24 - 12 = 12), and 12 electrons.

Always remember that:
An atom has an equal number of positive protons and negative electrons which makes it neutral in charge

The Electronic Configuration of Atoms:

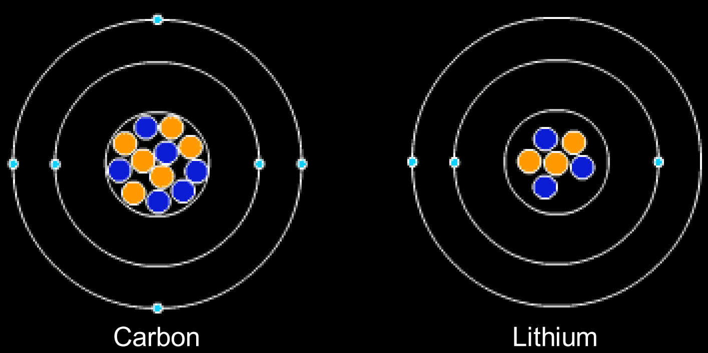
Electrons are arranged in energy shells or energy levels. But each energy shell can hold up to a certain amount of electrons.

- 1st energy shell holds up to 2e,
- 2nd energy shell holds up to 8e,
- 3rd energy shell holds up to 18e, but stable with only 8e.

If an atom has its 3rd energy shell holding 8e, if it receives 2 more they go to the 4th energy shell. If further 10e are received, they go to the 3rd energy shell making it saturated with 18e.

Valency electrons are the electrons in the outer most energy shell.

Electronic arrangments in some elements:



The Isotope:

Some elements have different versions of their atoms. These versions are called isotopes. Isotopes of the same element are similar, only that they have a different number of neutrons. Chlorine for example has two isotopes, Chlorine-35 and Chlorine-37. Isotopes of the same elements do not differ in Behavior or anything, only their masses differ, as a result of having a different number of neutrons.

There are two kinds of isotopes, stable ones and unstable ones. Unstable ones have a lot of neutrons, and they are radioactive. They are called radioisotopes.

Radioactive-Isotopes are used in the medical and the industrial field.
Medical uses of radioactive isotopes:

- treatment of cancer
- radiotherapy
- treatment of thyroid gland
- X rays
- tracer
- studies in body
- sterilising equipment
- locating tumours

Industrial use of radioactive isotopes:

- detection of leaks
- thickness of paper etc.
- nuclear fuel for generating electricity
- nuclear weapons
- radiographs of welds
- measuring wear
- sterilising food

Calculating the Relative Atomic Mass (A_r):

The relative atomic mass of an element is the average mass of all its isotopes compared to one-twelfth the mass of an atom of Carbon-12.
The rule of calculating the A_r of an element is:

$$A_r = \frac{(M\ of\ 1^{st}\ isotope \times \%\ of\ abundance) + (\ M\ of\ 2^{nd}\ isotope \times \%\ of\ abundance)}{100}$$

M is the mass number

If we have two isotopes of Chlorine; Chlorine-35 and Chlorine 37. The percentage of abundance of these two isotopes in the world is 75% and 25% respectively. We could calculate the A_r by:

$$\frac{(35 \times 75) + (37 \times 25)}{100} = 35.5\ amu$$

Noble Gases:

These are elements in group 8 of the periodic table. They are colorless gases. They are extremely unreactive; this is because they have their outer energy shell full with electrons. So they are stable, this is why they exist as single atoms. They have some uses however, for example argon is used in light bulbs to prevent the tungsten filament from reacting with air, making the bulb last longer. Neon is also used in the advertising and laser beams. These gases are Helium, Neon, Argon, Krypton, Xenon and Radon (radioactive).

Alloys:

An alloy is a mixture of metals or metals and non-metals. Sometimes, and alloy is better than a metal because they have better properties. They are harder, more resistant to corrosion and have a more attractive appearance than the metals they are formed of.

Alloys are harder than metals because they have different sized atoms which prevent the layers from sliding over each other.

And alloy is made by heating the metals or metals and non-metals together until they all melt, and leaving them to cool mixed.

Examples of alloys and their content:

- Brass: Copper-Zinc,
- Bronze: Copper-Tin,
- Steel: Iron-Carbon,
- Stainless Steel: Iron-Carbon-Chromium-Nickel.

Bonding Structures

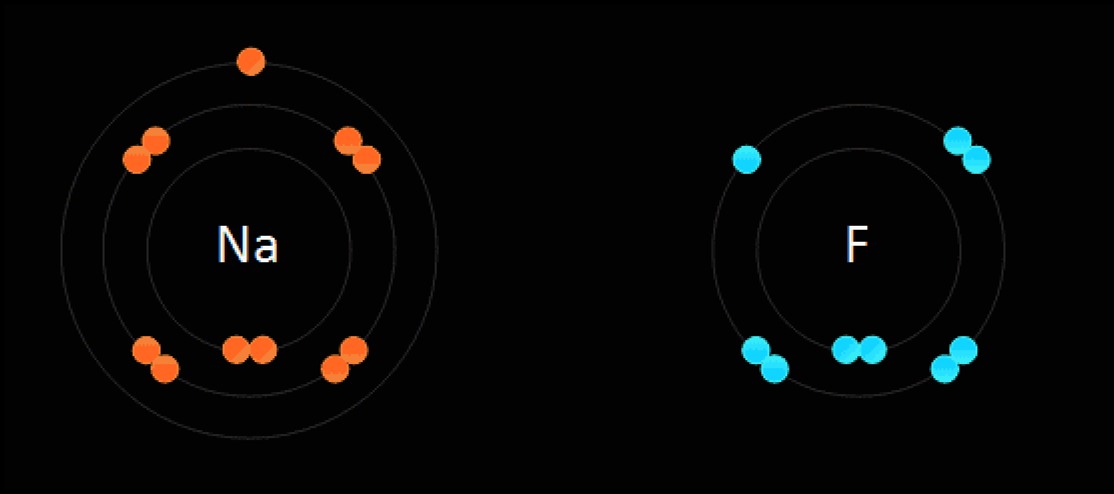
The Ion:

During chemical reactions involving two or more atoms, some types of atoms lose one or more electron turning into a positive ion. It is called a positive ion because when it loses electrons, the number of positive protons becomes larger than the number of negative electrons, so the overall charge of the particle is positive. If it loses two electrons its charge will be +2. If it loses 3, its charge will be +3 and so on.

Other types of atoms gain the electrons lost by the positive ions. In this case they become negative ions. This is because the number of negative electrons becomes larger than the number of positive protons, making the overall charge of the ion negative. If it gains two electrons its charge becomes -2. If it gains 3 electrons its charge becomes -3, and so on.

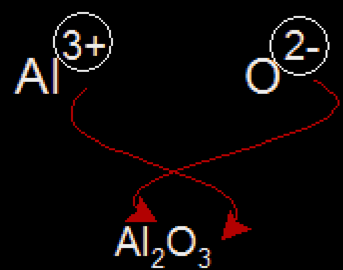
Ionic Bonding:

This type of bonding is based on the electrostatic force of attraction between the ions in the molecule. For example, when sodium, which is in group one and has one electron in its outer most shell, reacts with chlorine, which is in group 7 and has 7 electrons in its outer most shell, the sodium gets rid of the only electron in its outer shell, thus the sodium atom will have its second most outer shell which is full become its most outer shell forming a positive ion. The electron which is lost by the sodium atom is gained by the chlorine atom to 8 electrons, thus filling its outer most shell and becoming a negative ion. This electron transfer causes the electrostatic force of attraction which holds the oppositely charged ions together in a molecule. When an atom becomes an ion, it gets the properties of the noble gas which is nearest to it in the periodic table. Ionic bonds are only formed between metals and non-metals.



Formulae of Ionic Compounds:

To find the formula for an ionic compound, we use a method similar to cross multiplication. We multiply the valency (valency is the number of electrons an atom loses or gains to form an ion) to the other atom as shown below:



Properties of Ionic Compounds:

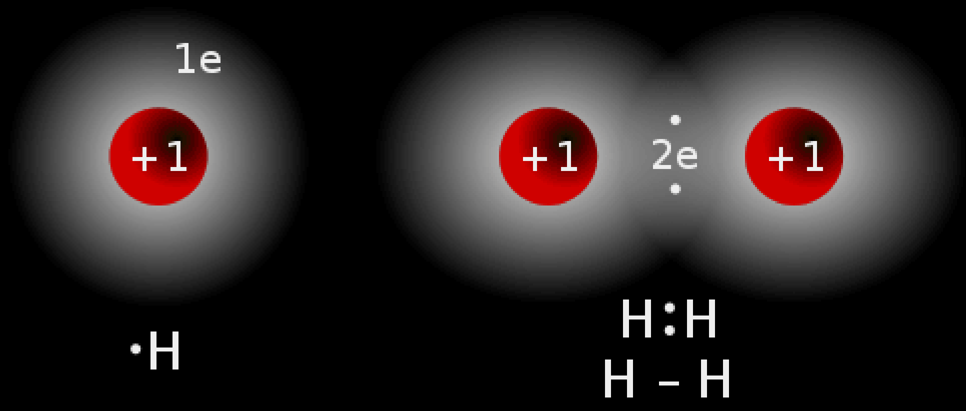
- Hard solids at room temperature,
- High melting and boiling points because of strong attraction forces,
- When solid they are electrical insulators but conduct electricity when molten or aqueous,
- Water soluble.

Covalent Bonding:

This type of bonding occurs between non-metals only. In order to obtain a full outer most energy shell, the atoms tend to share the electrons of their outer most energy shell, some or all of them.

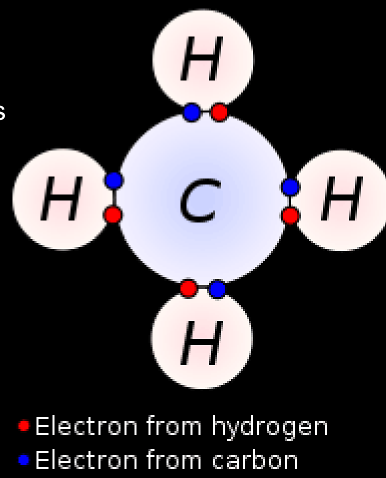
Example #1: A hydrogen molecule:

Each hydrogen atoms has 1 electron in its outer most shell. When it bonds covalently, it shares this electron with another hydrogen atom, which also shares its only valence electron. This causes each atom in the molecule to have 2 electrons in its outer most shell, which is also the 1st and only shell; this means it is holding the maximum number of electrons making it stable.



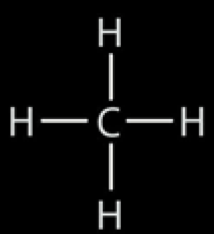
If two atoms each share one electron, it is called a single covalent bond, if each shares two electrons; it is a double covalent bond. The single covalent bond above can be represented by H - H.
A double covalent bond between two carbon atoms can be represented b C = C.

Example #2: Methane molecule:



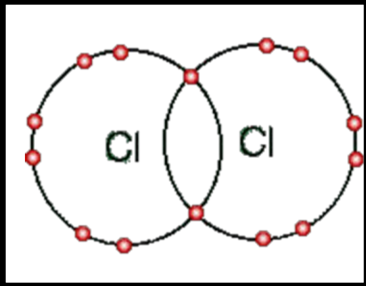
Each carbon atom has 4 valence electrons, this means it can bond with 4 hydrogen atoms (1 valence electron) covalently as shown on the right.

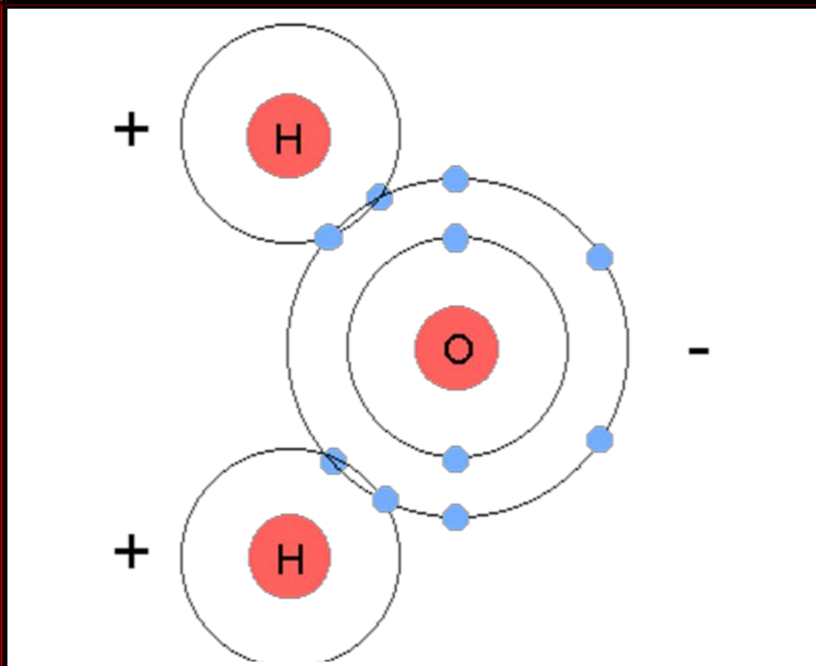
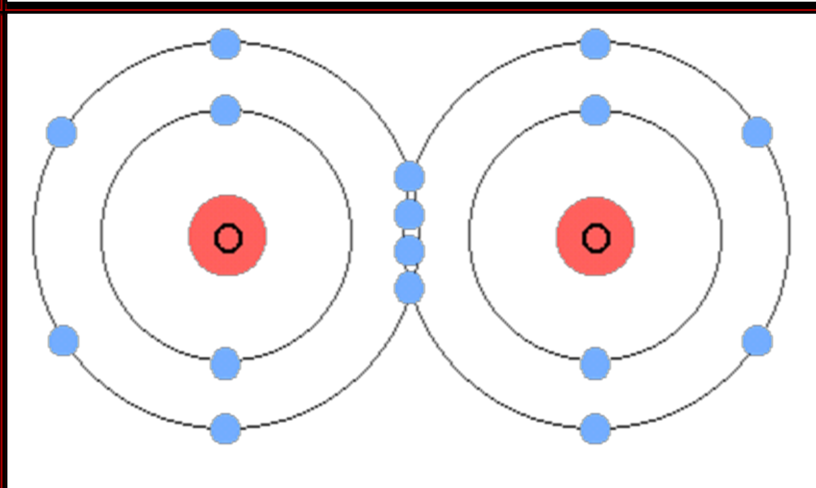
This molecule can also be represented like this:

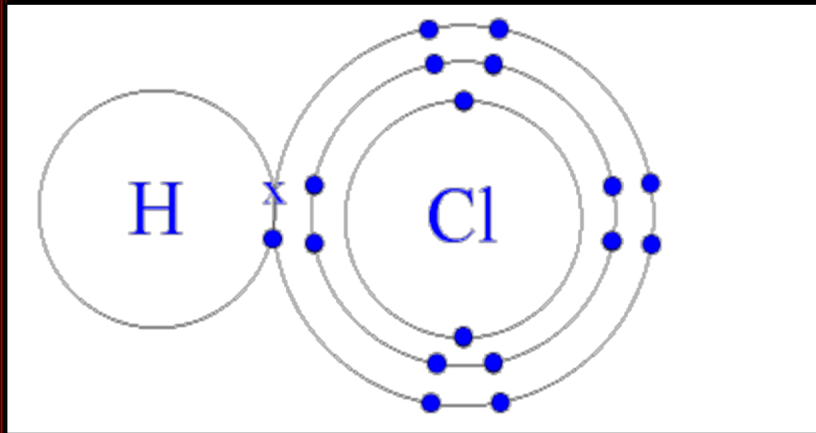
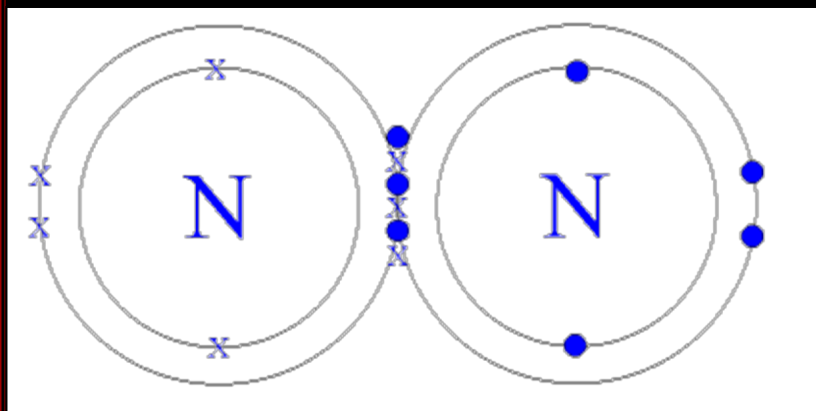
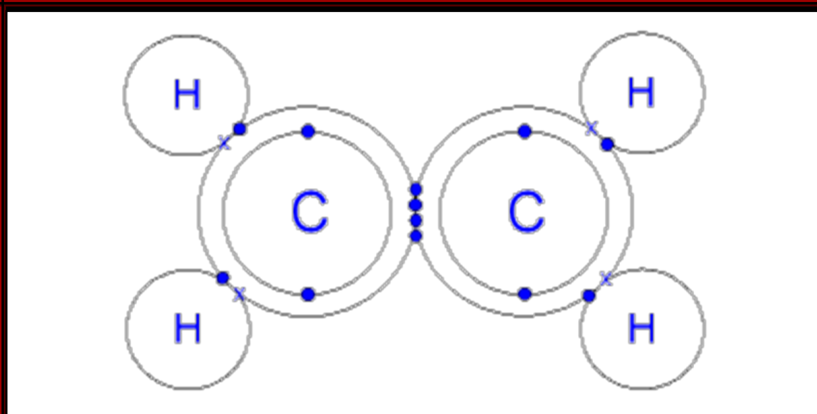


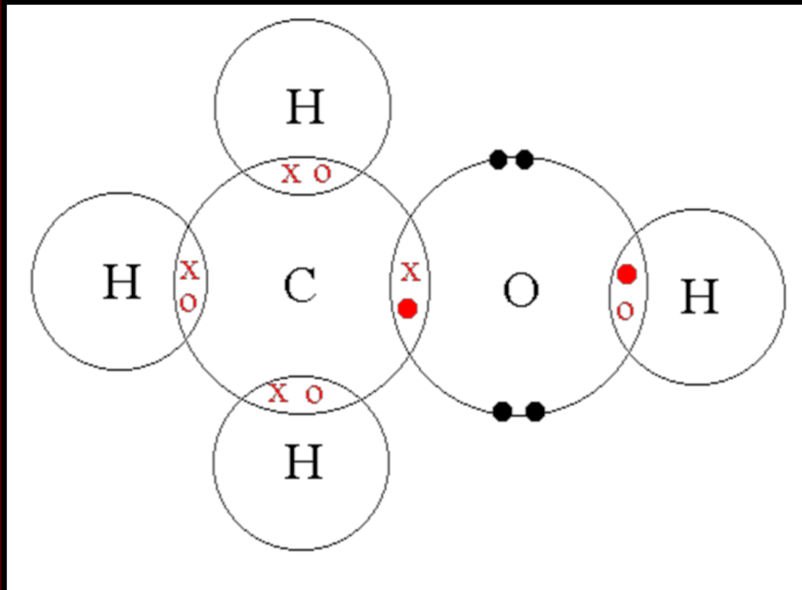
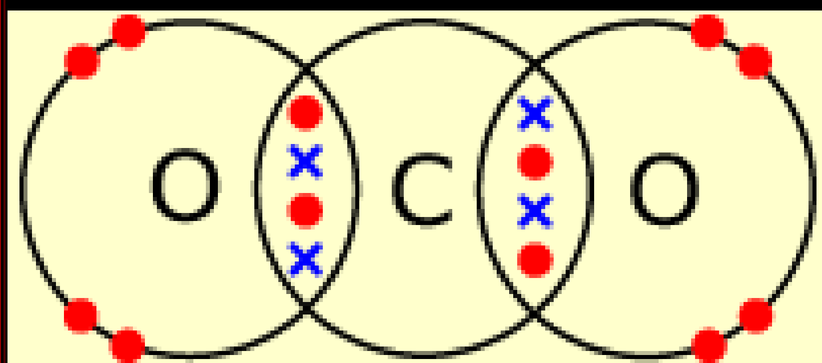
Example #3: Chlorine molecule:

A chlorine atom needs a share in one more electron, to obtain a stable outer shell of eight electrons. So two chlorine atoms bond covalently like this →



Element	Structure
Water (H2O)	
Oxygen(O2)	

Hydrogen Chloride (HCl)	
Nitrogen (N2)	
Ethene (C2H4)	

Methanol (CH3OH)	
Carbon Dioxide (CO2)	

Types of Covalent Structures:

There are two types of covalent structures:

- Simple Molecular Structure
- Giant Molecular Structure

Simple Molecular Structure:

They are simple and contain only a few atoms in one molecule. Covalent bonds between the atoms within a molecule (intermolecular bonds) are strong but they have weak bonds between molecules (intermolecular bonds). These forces increase as the size of the molecule increases.

Giant Molecular Structure:

They are also known as macromolecular structures. One molecule contains hundreds of thousands of atoms. They have extremely strong bonds between the atoms (intermolecular bonds).

Properties of Covalent Compounds:

- Simple molecular structures are usually gases or liquids and sometimes solids with low melting points; this is because of weak forces of attraction between the molecules which can be broken easily.
- Giant molecular structures have very high melting points because the whole structure is held together with very strong covalent bonds.
- Most of them do not conduct electricity
- Most of them are insoluble in water

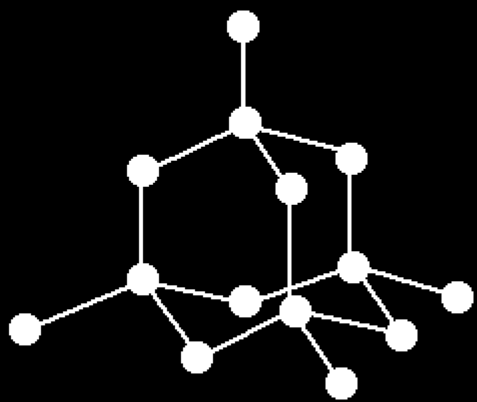
Allotropes of Carbon:

What are allotropes?

When an element exists in several physical forms of the same state, it is said to exhibit allotropy. Each form of this element is an allotrope. Lots of elements exhibit allotropy. Carbon has two very popular allotropes, diamond and graphite. Diamond and graphite are both made of carbon only. However, they look very different and have different physical properties. They are both giant molecular structures.

Diamond:

In diamond's structure, each carbon atom is covalently bonded to four other carbon atoms by very strong bonds forming a 3D tetrahedral shape.



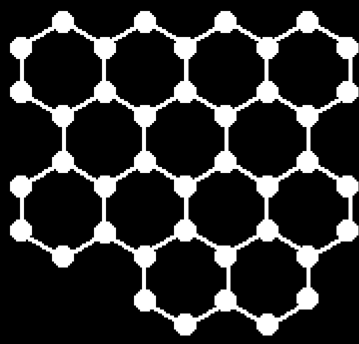
The physical properties of diamond:

- Has a very high melting point (almost 4000°C). Very strong carbon-carbon covalent bonds have to be broken throughout the structure before melting occurs,
- Is very hard. This is again due to the need to break very strong covalent bonds operating in 3-dimensions,
- Doesn't conduct electricity. All the electrons are held tightly between the atoms, and aren't free to move,
- Is insoluble in water and organic solvents. There are no possible attractions

which could occur between solvent molecules and carbon atoms which could outweigh the attractions between the covalently bound carbon atoms.

Graphite:

In the graphite structure, each carbon atom is strongly bonded covalently to three other carbon atoms forming layers of linked hexagons. Each layer acts as a molecule, the intermolecular forces between the layers is very weak allowing layers to slide over each other. This makes graphite a good lubricant.



The physical properties of graphite:

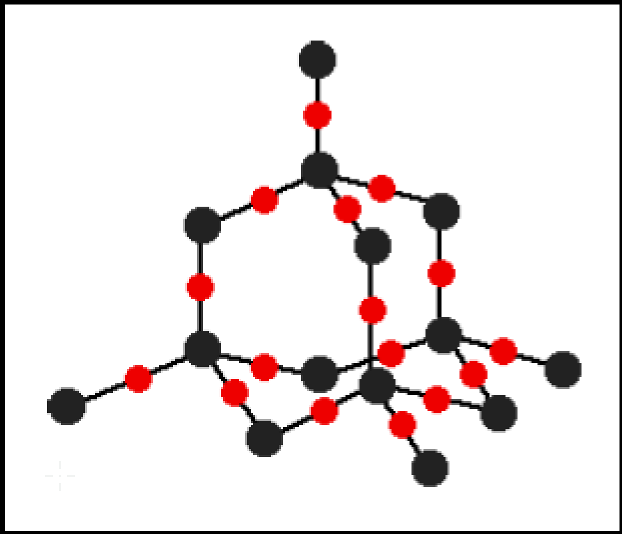
- Has a high melting point, similar to that of diamond. In order to melt graphite, it isn't enough to loosen one sheet from another. You have to break the covalent bonding throughout the whole structure,
- Has a soft, slippery feel, and is used in pencils and as a dry lubricant for things like locks. You can think of graphite

rather like a pack of cards - each card is strong, but the cards will slide over each other, or even fall off the pack altogether. When you use a pencil, sheets are rubbed off and stick to the paper,

- Has a lower density than diamond. This is because of the relatively large amount of space that is "wasted" between the sheets,
- Is insoluble in water and organic solvents - for the same reason that diamond is insoluble. Attractions between solvent molecules and carbon atoms will never be strong enough to overcome the strong covalent bonds in graphite,
- Conducts electricity. The delocalised electrons are free to move throughout the sheets. If a piece of graphite is connected into a circuit, electrons can fall off one end of the sheet and be replaced with new ones at the other end.

Silicon (IV) oxide

There are three different crystal forms of silicon dioxide. The easiest one to remember and draw is based on the diamond structure. Crystalline silicon has the same structure as diamond. To turn it into silicon dioxide, all you need to do is to modify the silicon structure by including some oxygen atoms.



Notice that each silicon atom is bridged to its neighbours by an oxygen atom. Don't forget that this is just a tiny part of a giant structure extending on all 3 dimensions.

The physical properties of Silicon (IV) Oxide:

- It has a high melting point - varying depending on what the particular structure is (remember that the structure given is only one of three possible structures), but around 1700°C. Very strong silicon-oxygen covalent bonds have to be broken throughout the structure before melting occurs.
- It is hard. This is due to the need to break the very strong covalent bonds.
- It doesn't conduct electricity. There aren't any delocalised electrons. All the electrons are held tightly between the atoms, and aren't free to move.
- It is insoluble in water and organic solvents. There are no possible attractions which could occur between solvent molecules and the silicon or oxygen atoms which could overcome the covalent bonds in the giant structure.

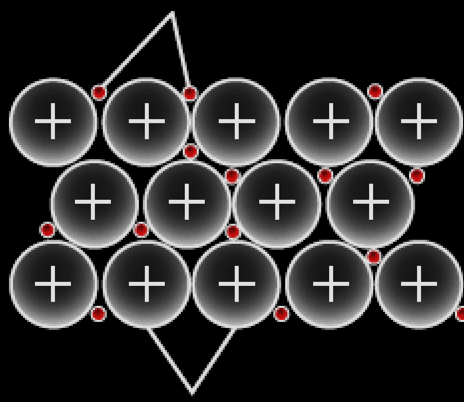
Metallic Structures:

Pure metals have a very unique structure. Each atom lets go of the valence electrons and become a positive ion. These electrons altogether form a sea of delocalized electrons.

Since the electrons are negatively charged and the ions are positively charged, an electrostatic force of attraction is formed between the sea of delocalized electrons and layers of positive ions.

The metallic lattice is the regular arrangement of positive ions embedded in a sea of delocalized electrons.

The metallic bond is the electrostatic force of attraction between the layers of positive ions and the sea of delocalized electrons.



Properties of metals:

- **Malleable and ductile:** Layers of positive ions are able to slide over each other, the shape changes without breaking.
- **Conducts electricity:** Sea of delocalized electrons is present to move freely around the structure and carry the charge.
- **High melting and boiling points:** Electrostatic forces of attraction between the ions and electrons are very strong, lots of energy is needed to break them.

Chapter 4: Stoichiometry

Stoichiometry deals with the relative quantities of reactants and products in chemical reactions. In a balanced chemical reaction, the relations among quantities of reactants and products typically form a ratio of whole numbers. For example, in a reaction that forms ammonia (NH_3), exactly one molecule of nitrogen (N_2) reacts with three molecules of hydrogen (H_2) to produce two molecules of NH_3

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

Stoichiometry can be used to calculate quantities such as the amount of products (in mass, moles, volume, etc.) that can be produced with given reactants and percent yield (the percentage of the given reactant that is made into the product). Stoichiometry calculations can predict how elements and components diluted in a standard solution react in experimental conditions. Stoichiometry is founded on the law of conservation of mass: the mass of the reactants equals the mass of the products.

The Periodic Table and Charges:

Group (Charge)	1 (+1)	2 (+2)	Transition metals	3 (+3)	4 (±4)	5 (-3)	6 (-2)	7 (-1)
Ions present	Li^+ Na^+ K^+	Be^{2+} Mg^{2+} Ca^{2+} Ba^{2+}	Cu^{2+} / Cu^+ Fe^{2+} / Fe^{3+} Zn^{2+} Ag^+	Al^{3+}	C Si Pb^{2+}	N^{3-} P^{3-}	O^{2-} S^{2-}	F^- Cl^- Br^- I^-

Compound Ions:

They are like molecules but with a charge on them:

Oxidation State	Name	Symbol
+1	Ammonium Ion	NH_4^+
-1	Hydroxide Ion Nitrate Ion Nitrite Ion Manganate(VII) Oxide Ion Hydrogen Carbonate Ion	OH^- NO_3^- NO_2^- MnO_4^- HCO_3^-
-2	Carbonate Ion Sulfate Ion Sulfite Ion Dichromate (Vi) Ion	CO_3^{2-} SO_4^{2-} SO_3^{2-} $Cr_2O_7^{2-}$
-3	Phosphate Ion Phostphite Ion	PO_4^{3-} PO_3^{3-}

Acids and Their Formulae:

Acid	Formula
Carbonic Acid	H_2CO_3
Hydrochloric Acid	HCl
Nitric Acid	HNO_3
Phosphoric Acid	H_3PO_4
Sulfuric Acid	H_2SO_4

Chemical Changes:

When chemical reactions take place, a certain change is certain. This change could be in color, energy or something like bubbles or a precipitate formation.

Color Change in Reactions:

When iron, which is grey, reacts with sulfur, which is yellow, a black solid, iron sulfide is formed. The color changed from grey and yellow to black.

Iron + Sulpher → Iron Sulfide

(grey fillings) (yellow powder) (black solid)

Energy Change in Reactions:

Energy is not necessarily heat, there are several forms of energy like Light and sound energy too.

When magnesium reacts with oxygen in air to make a combustion reaction, it burns with a very bright flame forming magnesium oxide. This bright flame is light energy which indicates a reaction took place.

Some reactions also release energy in form of sound like explosive reactions.

Effervescence in Reactions:

In some reactions, bubbles are formed rapidly. Those bubbles are indication that a gas was formed which is a new substance, this means a reaction took place.

When calcium carbonate reacts with hydrochloric acid, carbon dioxide gas is released in bubbles.

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

Precipitation in Reactions:

When two solutions react together, sometimes one of the products is an insoluble solid called precipitate. When silver nitrate solution reacts with a potassium chloride solution, white insoluble silver chloride is formed which is a precipitate.

$$AgNO_3 + KCl \rightarrow AgCl + KNO_3$$

Writing and Balancing Equations:

Chemical reactions are always represented by chemical equations to show the reactants and the products. There are two types of chemical equations. These are **word equations** and **symbolic equations**.

For example if we want to represent the reaction between sodium and chlorine which produces sodium chloride as a word equation it will be like this:

Sodium + Chlorine → Sodium Chloride

If we want to represent the same reaction by a symbolic equation it will be like this:

$$Na + Cl_2 \rightarrow NaCl$$

The above symbolic equation however, is not chemically accurate. This is why chemists prefer to use what's called a **balanced symbolic equation**. In this type of equation, we make sure that the number of atoms of each element in the reactants is the same in the products. If you look at the equation above you will find that we have one Na atom in the reactants and one Na^+ ion in the product, but we have 2 Cl atoms in the reactants and only one Cl ion in the product. This is why this equation needs to be balanced as follows:

$$2Na + Cl_2 \rightarrow 2NaCl$$

Types of Chemical Reactions:

Combustion (oxidation) Reactions:

These are reactions between metals and oxygen or the oxidation of any other element.

$$2Mg \quad + \quad O_2 \quad \rightarrow \quad 2Li_2O$$

(Magnesium) (Oxygen) (Magnesium Oxide)

Hydration Reactions:

These are reactions between metals and water forming a metal hydroxide and hydrogen gas. It could also be a reaction between a salt and water forming a hydrated salt.

$$2Na \quad + \quad 2H_2O \quad \rightarrow \quad 2NaOH \quad + \quad H_2$$

(Sodium) (Water) (Sodium Hydroxide) (Hydrogen)

$$CuSO_4 \quad + \quad 5H_2O \quad \rightarrow \quad CuSO_4.5H_2O$$

(Copper Sulfate) (Water) (Hydrated Copper Sulfate)

Displacement Reactions:

These are the reactions in which the more reactive metal displaces the less reactive positive ion. In the following reaction, sodium displaces Hydrogen ion from the hydrochloric acid because sodium is more reactive. The products are sodium chloride and hydrogen gas.

$$2Na \quad + \quad 2HCl \quad \rightarrow \quad 2NaCl \quad + \quad H_2$$

(Sodium) (Hydrochloric Acid) (Sodium Chloride) (Hydrogen)

Neutralization Reactions:

These are reactions between an alkaline compound or and alkali and an acidic compound or an acid forming a salt, water and sometimes carbon dioxide.

In the following reaction sodium hydroxide is a base which reacts with sulfuric acid. Neutralization takes place producing a salt called sodium sulfate and water.

$$2NaOH \quad + \quad H_2SO_4 \quad \rightarrow \quad Na_2SO_4 \quad + \quad 2H_2O$$

(Sodium Hydroxide) (Sulfuric Acid) (Sodium Sulfate) (Water)

In the following reaction calcium carbonate which is a basic compound reacts with nitric acid forming a salt called calcium nitrate, water and carbon dioxide.

$$CaCO_3 + 2HNO_3 \rightarrow Ca(NO_3)_2 + H_2O + CO_2$$

(Calcium Carbonate) (Nitric Acid) (Calcium Nitrate) (Water) (Carbon dioxide)

Chapter 4.1: The mole concept

The Mole Concept:

A mole is a unit to count the number of atoms, ions or molecules. They believed that, for example, if one molecule of carbon dioxide (CO_2) contained 1 carbon atom and 2 oxygen atoms, then the ratio of carbon atoms to oxygen atoms is 1:2. So if we wanted to make 100 molecules of carbon dioxide without any excess of the re-actants we will use 200 atoms of oxygen. We got this by:

1	2
Carbon	Oxygen

Amount of carbon atoms = 1 x 100 = 100

Amount of oxygen atoms= 2 x 100 = 200

Chemists use a method similar to that one, but on a larger scale, in industries to prevent wasting money by buying excess substances that will not be used. This is called **Avogadro's Constant**.

Avogadro's Constant in Solids:

Avogadro was a scientist in the 19th century. He discovered a relationship between a certain amount of substance (atoms, ions or molecules) and the A_r (Relative atomic mass) or M_r (Relative Molecular Mass) of the substance.

The A_r of an element is its Mass Number in the periodic table. For example:

The A_r of sodium is 23

The M_r of a compound is the sum of the A_r of all the atoms present in one molecule of the compound.

The M_r of Carbon dioxide (CO_2) is:
The A_r of carbon atom + (2 x the A_r of oxygen atom)
12 + (2 x 16) = 44
So the M_r of carbon dioxide is 44

What Avogadro discovered is that if I am holding $6x10^{23}$ atoms in my hand, its mass is equal to the A_r of Iron (Fe). This unit is called **Mole**.

$6x10^{23}$ is not an equation; it is the number of atoms, ions or molecules in one mole. If you put $6x10^{23}$ in a calculator, you will find out that this number is 600,000,000,000,000,000,000.

So if I am holding in my hands 600,000,000,000,000,000,000 atoms of iron, then I am holding 1 mole of iron.

This is 56 grams heavy because the A_r of iron is 56.

From this we conclude that the mass of one mole of any substance is the A_r of it (if it was an element) or the M_r of it (if it was a compound). The mass of one mole of any substance is expressed as the molar mass, and the word mole can be abbreviated with mol. The molar mass is always expressed in grams.

Molar mass of carbon is 12g
Molar mass of oxygen is 16g
Molar mass of sodium is 23g
Molar mass of iron is 56g

The molar mass of a compound is M_r of it:

The molar mass of an oxygen molecule (O_2) is: 2x16= 32g
The molar mass of sodium chloride (NaCl) is: 23+35.5= 58.5g
The molar mass of sulphuric acid (H_2SO_4) is: (2x1)+32+ (4x16) = 98g

The mass of 2 moles of a substance is 2x (A_r or M_r), the mass of 3 moles of a substance is 3x (A_r or M_r)..

The mass of 6 moles of water (H_2O) is:
M_r of H_2O: (2x1) +16= 18
6mol of (H2O) is: 6x18= 108g

The mass of 9 moles of hydrated copper sulphate ($CuSO_4.5H_2O$) is:
M_r of $CuSO_4.5H_2O$: 64+32+ (9x16) + (10x1) = 250
9mol of CuSO4.5H2O is: 9x250= 2250g or 2.25kg

If we wanted the mass of a sample of a compound, we had to know its M_r and the numbers of moles of it we have, and multiply both. We can also find the number of moles in a sample of a compound if we know the mass of the sample and the M_r of it.

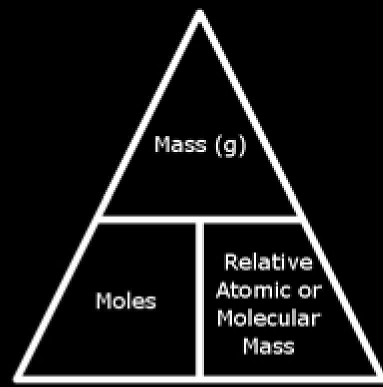
Remember that the M_r of a substance is how much one mole of it weighs.

How many moles are in 36 grams of water (H_2O)?
M_r of water: (2 x 1) + 16 = 18
If one mole of water weighs 18g, then 32g of water must be:
Mole = 32 ÷ 18 = 2mol

How many moles are there in 4 grams of sodium hydroxide (NaOH)?
M_r of $NaSO_4$ = 23 + 16 + 1= 40
Moles = 4 ÷ 40 = 0.1mol

From this we conclude that there is a relation between the mass of a substance, its molar mass, and the number of moles in it.

Mass of sample = Moles × Molar Mass (A_r or M_r) Moles = Mass of sample ÷ Molar Mass (A_r or M_r) Molar Mass (A_r or M_r) = Mass of sample ÷ Moles



Avogadro's Constant in Solutions:

Sometimes we need to find concentration of a solution. The unit of concentration can be g/dm^3 or mol/dm^3.

Literally, mol/dm^3 means how many moles of the solute are dissolved in every dm^3 of the solvent. So if salt and water solution has a concentration of 3 mol/dm^3, then in every dm^3 of water, there are 3 mols of salt dissolved. This means that in order for us to find the concentration of a solution, we divide the amount of solute (in moles) in the solution by the total volume of the solution.

> Calculate the concentration (mol/dm^3) of a solution containing 4 moles of sulphuric acid and has a volume of 2 dm^3.
>
> Concentration = Moles of solute ÷ Volume of solution
> Concentration = 4 ÷ 2 = 2 mol/dm^3

If we want to find the number of moles dissolved in a solution, we'll need to know both concentration and the volume of the solution.

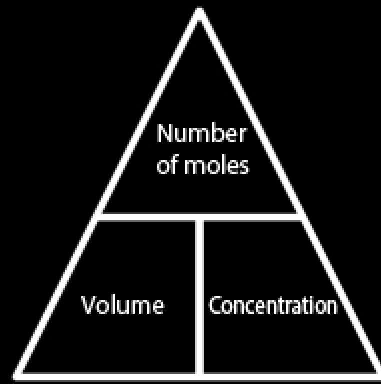
> Find the number of moles of sulphuric acid dissolved in water if the solution has a concentration 2 mol/dm^{3}and a volume of 25 dm^3.
>
> Moles of solute = Concentration x Volume of solution
> Moles of solute = 2 x 25 = 50 mol of sulphuric acid

We can also find the volume of a solution, if we know the concentration and number of moles of solute dissolved; we divide the number of moles by the concentration.

> Find the volume of a solution containing 4 moles of sulphuric acid with concentration 2 mol/dm^3.
>
> Volume of solution = Moles of solute ÷ Concentration
> Volume of solution = 4 ÷ 2 = 2dm^3

From this we conclude that the relation between the volume, concentration and number of moles dissolved in a solution is:

Number of moles = Volume × Concentration Concentration = Number of moles ÷ Volume Volume = Number of moles ÷ Concentration



Avogadro's Constant in Gases:

In gases it is a different story to solutions and solids because weighing a gas is very difficult, and we have no concentration. So in gases, we use volume of the gas to find how many moles are in it.

Scientists have proved that any gas, will have a volume of 24 dm^3 provided that is it is at room temperature and pressure (R.T.P). That means that all gases at r.t.p occupy 24 dm^3. We use this theory to find out how many moles are present in some gas if we have its volume, we just divide it by 24.

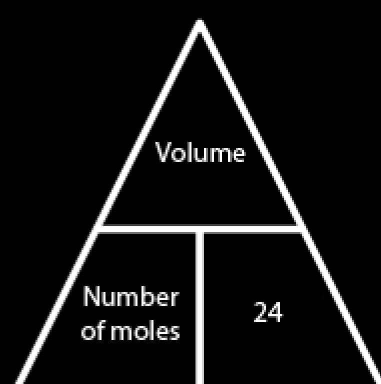
> How many moles of carbon dioxide are there, if the gas occupied 72 dm^3?
>
> We know that every 1 mole occupies 24 dm^3, so 72 dm^3 are occupied by:
> Number of moles = Volume of gas ÷ 24
> Number of moles = 72 ÷ 24 = 3 mol

We could also find the volume of a gas if we know the number of moles we have in it, we simply multiply it by 24.

> What is volume occupied by nitrogen gas, if 6 moles of it are present?
>
> We know that each mole occupies 24dm^3 and that we have 6 moles, so they will occupy:
> Volume = Number of moles x 24
> Volume = 6 x 24 = 144dm^3

So we conclude that the relation between the number of moles present in a gas and its volume is:

Volume = Number of moles × 24 Number of moles = Volume ÷ 24



Reactions and Mole Ratio:

What volume of carbon dioxide (CO_2) at R.T.P will be produced when 50g of calcium carbonate react with an excess of hydrochloric acid:

$$CaCO_3 + 2HCl \rightarrow CaCl_2 + H_2O + CO_2$$
$$1 : 2 \quad 1 : 1 : 1$$

First we write the mole ratio of each reactant and product.
Now we find the number of moles in 50g of $CaCO_3$:
Number of moles = Mass ÷ M_r
Number of moles = 50 ÷ 100 = 0.5 mol

If the mole ratio of $CaCO_3$ to CO_2 is 1:1, then we must also have 0.5 mol of CO_2, if we have 0.5 mol of CO_2, then we can get the volume produced:
Volume = Number of moles x 24
Volume = 0.5 x 24 = 12dm^3
Volume of CO_2 Produced is 12dm^3

If all reactants are gases, then the mole ratio is also the volume ratio:

Calculate the volume of methane needed to react with 70 dm^3 of oxygen:

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$1 : 2 \quad 1 : 2$$

First we write the mole ratio of all reactants and products.
If both reactants are gases, then the mole ratio is also the volume ratio, that means if we have 70 dm^3 of $O_2$and the ratio of O_2 to CH_4 is 2:1, then the volume of CH_4 is half the volume of O_2:

$$0.5 \times 70 = 35$$

Volume of methane needed is 35 dm^3.

Note: The total mass of the reactants must always equal the total mass of the products.

200g of pure calcium carbonate decomposes to calcium oxide and carbon dioxide. Calculate the mass of CaO produced and the volume of CO_2 produced at R.T.P.:

$$CaCO_3 \rightarrow CaO + CO_2$$
$$1 \quad 1 : 1$$

First we write the mole ratio of the reactant and the products.
M_r of $CaCO_3$ is 40 + 12 + (3 x 16) = 100; moles of $CaCO_3$= 200 ÷ 100 = 2 mols
Then we have 2 mols of CaO, because the mole ratio is 1:1, mass of CaO = 2 x 56 = 112g of CaO is produced.
And if we have 2mols of CO_2, because the ratio is 1:1, then the volume of CO_2 produced is: 2 x 24 = 48.
48 dm^3 of CO_2 is produced.

Percentage Purity:

If we have a sample of reactant that is not pure, we can find how pure it is by finding the mass of it that reacted. The impurities are assumed to not interfere with the reaction. Then we divide the mass that reacted by the total mass and multiply it by 100 to get the percentage.

$$\textbf{Percentage Purity} = \frac{\textbf{Pure mass}}{\textbf{Total mass}} \times 100$$

When 10g of impure zinc reacted with dilute sulphuric acid, 2.4 dm^3 of hydrogen gas were collected at R.T.P. Calculate the percentage purity of zinc:

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$$

1 : 1 1 : 1

First we have to find the number of moles in any of the chemicals in the reaction to find the number of moles of zinc that reacted. We know that we 2.4 dm^3 of hydrogen are produced, we can find how many moles this is by:
Number of moles = Volume ÷ 24
Number of moles = 2.4 ÷ 24 = 0.1 mol

If we have 0.1 mol of hydrogen and the mole ratio of hydrogen to zinc is 1:1 then we must also have 0.1 mol of zinc. Now we have to find how much 0.1 mol of zinc weigh:
Mass = Moles x A_r
Mass = 0.1 x 65 = 6.5g

If 6.5g of zinc are present in the sample, then the percentage purity is:
% Purity = (Pure mass ÷ Total mass) x 100
% Purity = (6.5 ÷ 10) x 100 = 65%

Percentage Yield:

Percentage yield is the mass of a substance produced in a reaction as a percentage of the calculated mass. That means that in a reaction, the calculations showed that the 50 grams of calcium oxide will be produced, but practically, only 45 grams were produced then the percentage yield is 45 divided by 50 multiplied by 100, which is 90%:

$$\textbf{Percentage yield} = \frac{\textbf{Mass produced}}{\textbf{Mass predicted}} \times 100$$

Heating 12.4g of Copper (II) Carbonate Produced only 7g of Copper (II) Oxide. Find the percentage yield of Copper (II) Oxide:

$$CuCO_3 \rightarrow CuO + CO_2$$

1 1 : 1

First we calculate the mass of CuO that is supposed to be produced:
We write the mole ratio of the reactant and the products.

M_r of CuCO3 is 124 we have 12.4g so the number of moles is 12.4 ÷ 124 = 0.1; if the ratio of $CuCO_3$ to

CuO is 1:1, then we must also have 0.1 mol of CuO, the M_r of CuO is 80. Then the mass of CuO must be 0.1 x 80 = 8g. We actually got 7g so the percentage yield is:

Percentage yield = (Mass produced ÷ Mass predicted) x 100
Percentage yield = (7 ÷ 8) x 100 = 87.5%
So the percentage yield is 87.5%

Composition Percentage of Elements in Compounds:

This is a way to find the percentage of an element in a whole compound. For example, if we have the compound $CaCO_3$, we can find the percentage of any of the elements in it by the following rule:

$$\textbf{Composition percentage} = \frac{\textbf{Number of atoms of the element in a molecule x } A_r}{M_r \textbf{ of the compound}} \textbf{ x 100}$$

Find the percentage of nitrogen in the following compounds:

1. Ammonium Nitrate, NH_4NO_3:
2. Ammonium Sulphate, $(NH_4)2SO_4$:
3. Urea, $CO(NH_2)_2$:

Answers:

1. [(14 x 2) ÷ 80] x 100 = 35%
2. [(14 x 2) ÷ 132] x 100 = 21.21%
3. [(2 x 14) ÷ 60] x 100 = 46.6%

The Empirical Formula:

The molecular formula shows the actual number of atoms of each element in a compound, but the empirical formula is a formula that shows the simplest ratio of atoms present in a compound. For example if a compound has the molecular formula C_4H_8, its empirical formula would be$(CH_2)n$, n is the number to multiply by to get the molecular formula, which is 4 in this case, the 8 is divided by the 4 to give the simplest ratio between them. The empirical formula is widely used with hydrocarbons which are compounds containing hydrogen and carbon, and carbohydrates, which are compounds containing carbon and water.

A carbohydrate has 40% of its mass carbon, 6.66% hydrogen. Find the compound's empirical and molecular formula given that is M_r is 180:

We assume that we've got 100g of this carbohydrate. Then we have 40g of carbon and 6.66g of hydrogen, we can now find oxygen's mass and the number of moles we have of each element, thus we can get the simplest ratio between them and get the empirical formula.

	Carbon	Hydrogen	Oxygen
Mass %	40	6.66	100 - 46.6 = 53.34
A_r	12	1	16

Moles	(40 ÷ 12) = 3.33	(6.66 ÷ 1) = 6.66	(53.34 ÷ 16) = 3.33
Simple ratio	1	2	1
Empirical formula	C	H_2	O

Emperical formula: CH_2O

N = Molecular M_r ÷ Empirical M_r
N = 180 ÷ 30 = 6

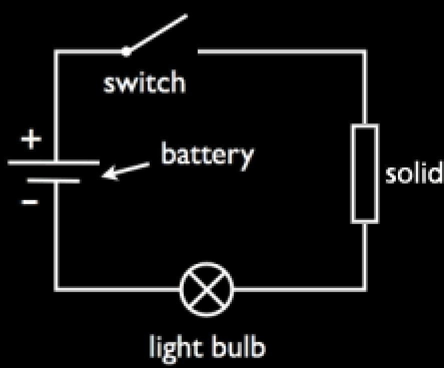
Molecular Formula = $C_6H_{12}O_6$

Chapter 5: Electricity and Chemistry

Electrolysis is a process of breaking down a compound by electricity. An electric current is the flow of charged particles.

Conductivity:

In solids, substances that conduct electricity are called **Conductors**. These are mostly metals and graphite. This is because metals and graphite contain free electrons in their structures to carry the charge. The solids which do not conduct electricity are called **Insulators**.



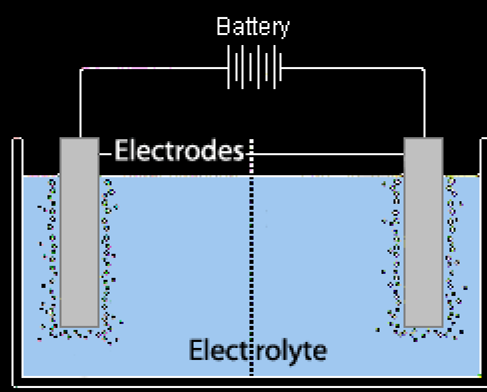
To test a solid for electrical conductivity, we put it an electrical circuit like the one below. If the bulb lights or the ammeter gives a reading, then the solid is a conductor.

For liquids however, the ones that conduct electricity are called **electrolytes**. The ones that do not are called **non-electrolytes**. Electrolytes include acids, alkalis, and ionic compounds in molten or aqueous form.

The Electrolysis Cell:

The electrolysis cell is a battery each pole connected to an electrode and both electrodes are dipped in the liquid to be electrolysed.

- The electrode connected to the positive pole is called the **anode**.
- The electrode connected to the negative pole is called the **cathode**.



There are two types of electrodes, active electrodes and inert electrodes. Active electrodes take place in the process its self. Inert electrodes are just there to conduct the current without interfering.

Inert electrodes can be either graphite or platinum but graphite is more widely used because it’s cheaper.

Inert electrodes are always used in electrolysis; active ones are used in electroplating.

How It Works:

Electrolysis separates an ionic compound back to the elements that form it. For example by electrolysis we can obtain sodium and chlorine from sodium chloride.

When the current is turned on, the negative ion in the electrolyte gets attracted to the positive electrode because they are oppositely charged. When this happens, the negative ion loses the electrons it gained from the positive ion during bond formation and becomes an atom. The electrons lost are transferred through the wire in the outer circuit from the anode to the cathode. At the same time, the positive ion from the electrolyte is attracted to the cathode, where it gains the electrons lost by the negative ion and becomes an atom too.

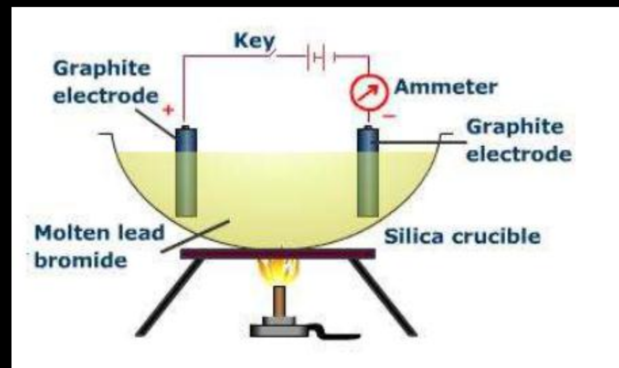
In ionic compounds the positive ion is a metal and it is collected at the cathode. And the negative ion is a non-metal and collected at the anode.

The electrons are transferred from the anode to the cathode through the wires.

The electrolyte is an ionic compound either in its molten or aqueous form. Ionic compounds conduct electricity only when they are in these forms because they contain free mobile ions which can carry the current but they don't in solid form.

Electrolysis of Molten Ionic Compounds:

An idealized cell for the electrolysis of sodium chloride is shown in the figure below. A source of direct current is connected to a pair of inert electrodes immersed in molten sodium chloride. Because the salt has been heated until it melts, the Na^+ ions flow toward the negative electrode and the Cl^- ions flow toward the positive electrode.



Negative electrode (cathode): $Pb^{2+} + 2e^- \rightarrow Pb$

Lead (II) bromide PbBr2 is made from lead ions Pb2+ and 2 bromide ions Br-.

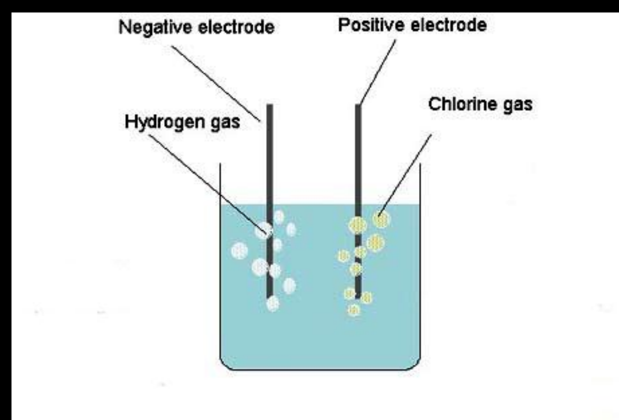
When the compound is molten (hot and runny), the ions are free to move and drift towards the oppositely charged electrode where the ions are turned into either atoms or molecules.

Positive electrode (anode): $2Br^- \rightarrow Br_2 + 2e^-$

$$PbBr_2(l) \rightarrow Pb(l) + Br_2(g)$$

This example explains why the process is called electrolysis. The suffix -*lysis* comes from the Greek stem meaning to loosen or split up. Electrolysis literally uses an electric current to split a compound into its elements.

Electrolysis of Concentrated Compounds:



Negative electrode (cathode): $2H^+ + 2e^- \rightarrow H_2$

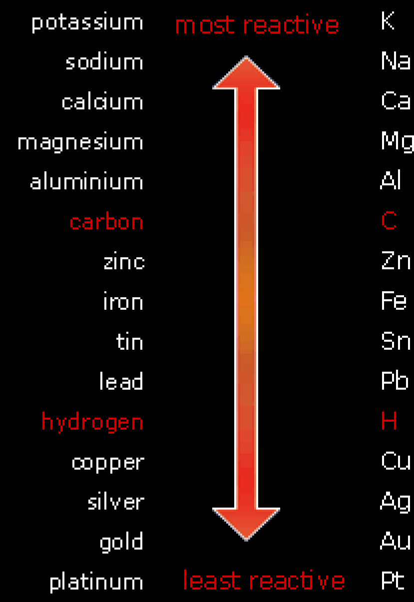
Hydrochloric acid is a strong acid and ionizes like so

HCl = H+ + Cl-

These ions drift to the oppositely charged electrode and get turned into molecules

Positive electrode (anode): $2Cl^- \rightarrow Cl_2 + 2e^-$

Electrolysis of Aqueous Ionic Compounds:



Electrolysing an ionic compound in its solution is very much different to electrolysing it when it's molten. This is because in a solution we have 4 ions, H^+ and OH^- from water and a positive and a negative ion from the compound. But only one type of ions gets discharged at each electrode.

For the positive ions, the one that gets discharged at the cathode is the least reactive one. This is because least reactive elements have more tendencies to be an atom.

So if the ion from the ionic compound is above hydrogen in the reactivity series (more reactive), H^+ gets discharged at the anode And if the ion from the compound is below hydrogen in the reactivity series (less reactive), this ion gets discharged at the cathode.

So for example if we are electrolysing aqueous sodium chloride, H^+ ions will get discharged at the cathode because sodium is more reactive than hydrogen. And if we are electrolysing aqueous copper iodide, Cu2+ ions will get discharged at the cathode because copper is less reactive than hydrogen.

For the negative ions however it is different. Oxygen from OH^- from water is always discharged at the anode except in one case, this is if the other negative ion is a halide. If oxygen from OH^- is discharged, the equation will be:

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

If the other negative ion is a halide, there are two probabilities:

1. Oxygen from OH^- gets discharged at the cathode,
2. The halide ion gets discharged at the cathode.

It all depends on the concentration of the halide. If the electrolyte is a concentrated solution, then there are many of the halide ions, more than OH^-. So the halide ion gets discharged at the cathode. If the electrolyte is a dilute solution, then there are more OH^- ions than halide ions, so oxygen from OH^- gets discharged.

So for example if the electrolyte is a concentrated solution of sodium chloride, hydrogen gas is formed at the cathode because hydrogen is less reactive than sodium. And chlorine gas is formed at the anode because the solution is concentrated.

If the electrolyte is a dilute solution of silver sulfate, silver is formed at the cathode because it is less reactive than hydrogen and oxygen gas is formed at the anode.

Electrolysis of Brine (concentrated aqueous sodium chloride):

The ions present in the electrolyte are H^+ and OH^- from water and Na^+ and Cl^- from sodium chloride.

Since sodium is more reactive than hydrogen, the H^+ ions will be discharged at the cathode and hydrogen gas will evolve. And because the solution is concentrated, Cl^- will be discharged and chlorine gas will evolve. But keep in mind that chlorine is soluble in water, it would take time for it to evolve and some oxygen can be formed too. Gases should be collected in an inverted measuring cylinder.

This leaves us with two other ions, Na^+ and OH^-. They bond together forming sodium hydroxide which is an alkali and extracted later.

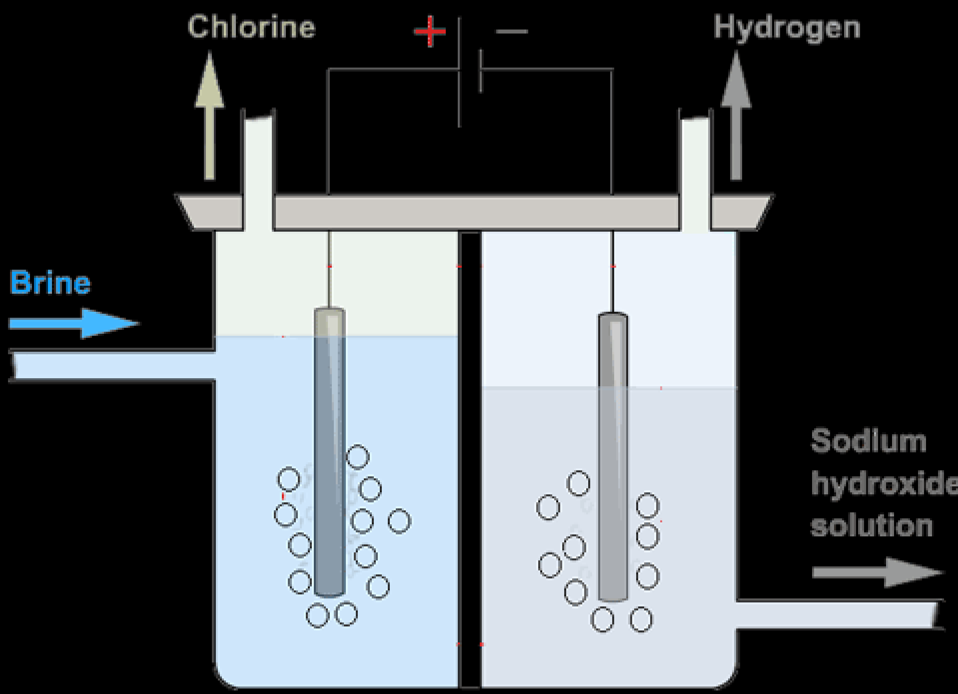
At the cathode: $2H^+ + 2e^- \rightarrow H2$
Hydrogen gas evolves. Observation is bubbles of colorless gas.
Test to make sure by approaching a lighted splint, if positive it will burn with a pop sound.

At the anode: $2Cl^- - 2e^- \rightarrow Cl2$
Chlorine gas evolves. Observation is bubbles of green gas. Test to make sure by approaching a damp blue litmus paper, if positive it will turn red then bleach.

$$2NaCl + 2H_2O \rightarrow H_2 + Cl_2 + 2NaOH$$

Electrolysing Brine in a Membrane Cell:

In order to obtain the purest products possible, a membrane cell like the one below is used.



In this cell, there is a membrane between both electrodes that separate Cl^- ions from OH^- ions. When the solution is added to the membrane, the membrane allows Na^+, H^+ and OH^- ions to pass to the cathode chamber and Cl^- stays in the anode chamber. Cl^- gets discharge while the OH^- is trapped in the cathode chamber and can't pollute the chlorine gas being collected. H^+ gets discharged at the anode and collected. Na^+ and OH^- bond together forming sodium hydroxide which is extracted from the bottom of the cathode chamber.

Electrolysis of Copper(II) Sulfate Solution:

Ions present in the electrolyte are H^+ and OH^- from water and Cu^{+2} and SO_4^- from copper(ii) sulfate.

At the Cathode: $4OH^- - 4e^- \rightarrow O_2 + 2H_2O$
Oxygen from OH^- ions is formed. Bubbles of colorless gas are formed. To test for oxygen, approach a glowing splint, if positive it relights.

At the anode: $Cu^{+2} + 2e^- \rightarrow Cu$
Cu^{+2} are discharged because copper is less reactive than hydrogen. A red brown metal is formed.

This leaves us with H^+ and SO_4^- ions which bond together forming sulfuric acid.

Note: a copper sulfate solution is blue in color. In this process, the blue color gradually fades away because copper sulfate is being broken down. The solution becomes acidic becomes acidic because sulfuric acid is formed.

Note:

- When a product of electrolysis is a halogen, bear in mind that it is soluble in water so it could take time to evolve and might be replaced by oxygen from OH^-.
- When a product of electrolysis is a halogen, perform it in a fume cupboard because halogens are toxic.

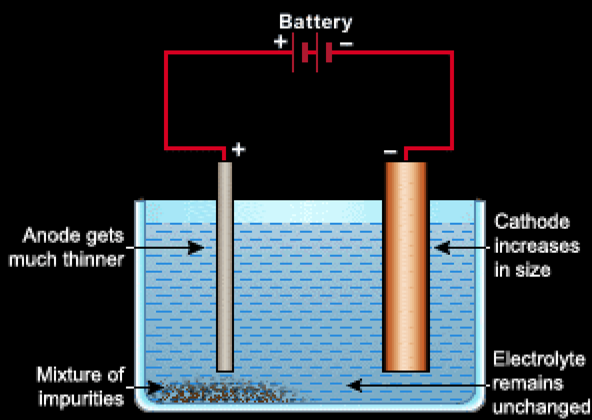
Electrolysis and Refining:

Electrolysis can be used to refine metals. For example if we have a sample of impure copper that we want to refine, we set up a unique electrolysis cell to do that.

- The cathode will be made of pure copper.
- The anode will be made of the impure copper sample.
- The electrolyte will be a solution of a copper salt (copper sulfate/nitrate)

When the battery is switched on, the sea of delocalized electrons in impure copper sample will be absorbed by the battery. The impure copper then will turn into copper ions and fall into the electrolyte. Now the electrolyte has copper ions from the copper salt and the anode. When the electrons reach the cathode, the copper ions which fell from the anode will get attracted to the cathode and take their electrons back turning into atoms.

The anode gradually gets thinner and disappears because the copper ions are falling of it.
The cathode gets larger because the copper of the anode gets attracted to it.
The electrolyte remains unchanged.
The impurities of the anode will settle at the bottom of the cell.



So for generally, for refining a metal, the electrolysis cell must be set up as follows:

- The cathode is a pure sample of the metal to be refined
- The anode is the impure sample to be refined
- The electrolyte is a salt solution of the same metal (preferred a nitrate or sulfate)

Electroplating:

Electroplating is covering a metal object with another metal by electrolysis.

Purposes of electroplating are:

- To give the object a protective layer from corrosion
- To give the object a shiny better look

The idea of the electroplating cell is very similar to that of refining:

- The Anode is the metal to electroplate with
- The cathode is the object to be electroplated
- The electrolyte is a salt solution of the metal to electroplate with

When the current is turned on, the atoms of the metal of the anode will become ions and fall into the solution. The electrons are transferred from the anode to the cathode in the outer circuit. When electrons reach the cathode, the metal ions in the electrolyte get attracted to the surface of the object covering it completely, thus it gets electroplated.

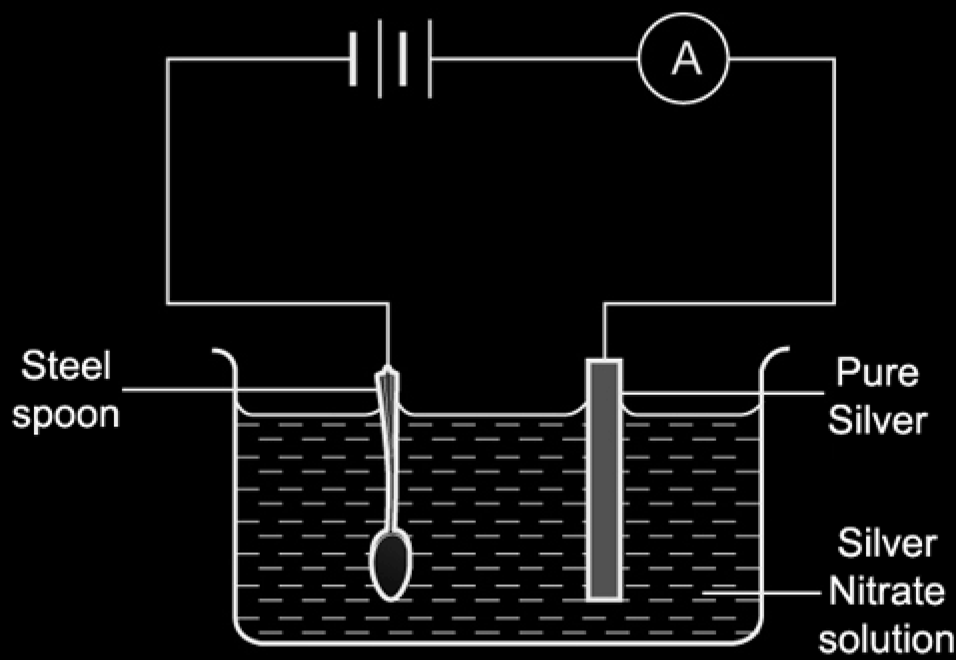
Note:

- The object to be electroplated must be rubbed and cleaned with sand paper to remove any stains that won't let the metal cover the whole object firmly
- The object to be electroplated must be dipped completely in the electrolyte and rotated continuously to make sure all the object gets covered uniformly.
- The object to be electroplated must be made of an electrical conductor.

Example:

If we want to electroplate a steel fork with silver:

- The anode will be a pure sample of silver,
- The cathode will be the fork,
- The electrolyte will be a silver nitrate solution.



Anode:
Equation: $Ag - e^- \rightarrow Ag^+$
Observation: Gets thinner.

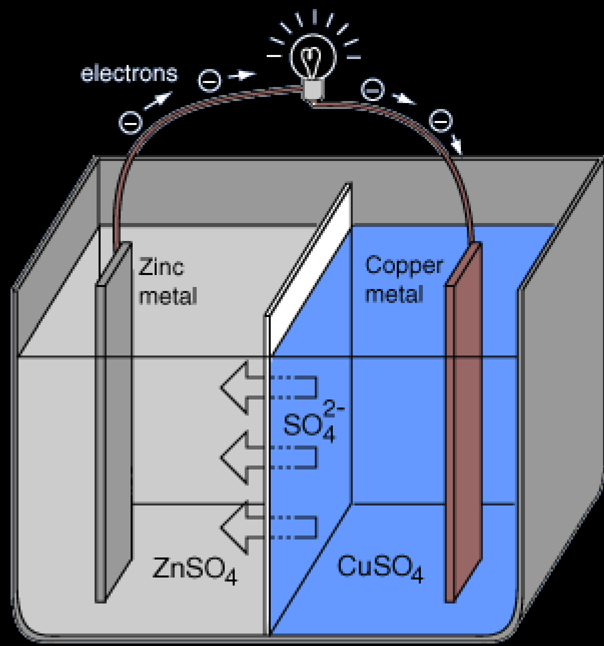
Cathode:
Equation: $Ag^+ + e^- \rightarrow Ag$
Observation: Gets covered with silver layer, increases in size.

Simple Chemical Cell:

A simple cell is a system that converts chemical energy into electrical energy. A simple cell is made of two metals (electrodes), one more reactive than the other, connected together by a wire and dipped in an electrolyte. If a light bulb is inserted between the two electrodes, it will light up.

If cell consists of a zinc electrode and a copper electrode dipped in sulfuric acid, this is how it works:

- Zinc is more reactive than copper, it loses electrons much easier. Electrons move from the zinc electrode to the copper electrode through the wires, the zinc atoms become ions and fall into the electrolyte,
- Electrons always move from the anode to the cathode, so we will call the zinc electrode anode and the copper electrode cathode,
- The zinc is the negative pole of the cell because it gives out electrons, the copper is the positive pole of the cell, and it receives them,
- H^+ ions from the sulfuric acid electrolyte gets attracted to the cathode (copper) and discharged. Hydrogen gas evolves,
- The movement of electrons from the negative pole (anode, zinc) to the positive pole (cathode, copper) causes an electric current which is used in devices like the light bulb.



At the negative pole (Zinc Anode):
Equation: $Zn - 2e^- \rightarrow Zn^{+2}$
Observation: Anode gets thinner

At the positive pole (Copper Cathode):
Equation: $2H^+ + 2e^- \rightarrow H_2$
Observation: Bubbles of colorless gas.

The bulb stops glowing when H^+ ions are finished or when the anode is used up.

The larger the difference in reactivity between the two metals the larger the voltage produced.

Electrolysis of Aluminium

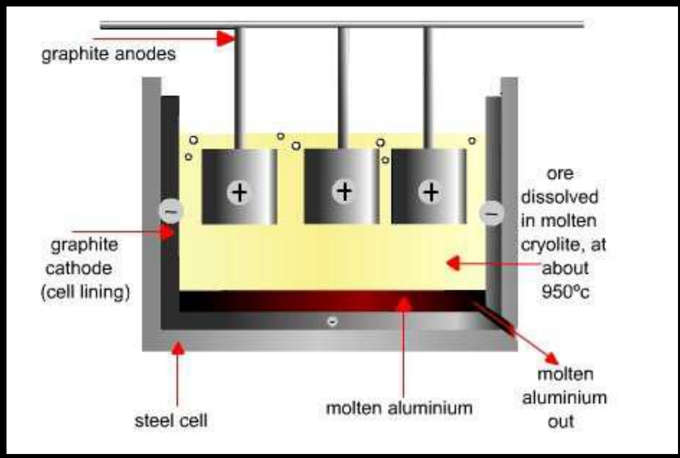
Negative electrode (cathode): $Al^{3+} + 3e^- \rightarrow Al$

Aluminium is extracted from the ore BAUXITE or aluminium oxide Al2O3.

The aluminium oxide is INSOLUBLE so it is MELTED to allow the ions to move when the electric current is passed through it . Remember that electrolysis can only take place when the ions are MOLTEN or IN SOLUTION.

The anodes are made from CARBON and the cathode is a carbon-lined STEEL CASE.

Positive electrode (anode): $2O^{2-} \rightarrow O_2 + 4e^-$



Chapter 6: Chemical energies

During any **chemical** reaction, an energy change occurs. Reactions release heat energy, or absorb heat energy from the surroundings. The ones that release heat energy to the surroundings are called **Exothermic Reactions**; the ones that absorb energy from the surroundings are called Endothermic Reactions. In exothermic reactions, the reactants are higher in energy than the products, in endothermic reactions; the reactants are lower in energy than the products.

What makes a reaction exothermic or endothermic:

To start a reaction, a certain amount of energy is given to the reactants; this is called the **Energy of activation** because it activates the reaction. This energy is used to break the bonds between the atoms or molecules of the reactants, then the reactants rearrange and bond again, this bond formation releases energy. If the energy given to activate the reaction is less than the energy released during the bond formation, then the reaction gave out more energy than it took, so it is exothermic. If the energy given to activate the reaction is more than the energy released during bond formation, then the reaction took more energy than it gave out, so it is endothermic. The total energy change is called the enthalpy change or simply energy changed (ΔH). When the bonds are broken, the reaction is endothermic the ΔH value is positive, when bonds are formed, it is exothermic and the ΔH value is negative, the overall enthalpy change is:

$$\text{Energy in} - \text{Energy out} = \Delta H$$

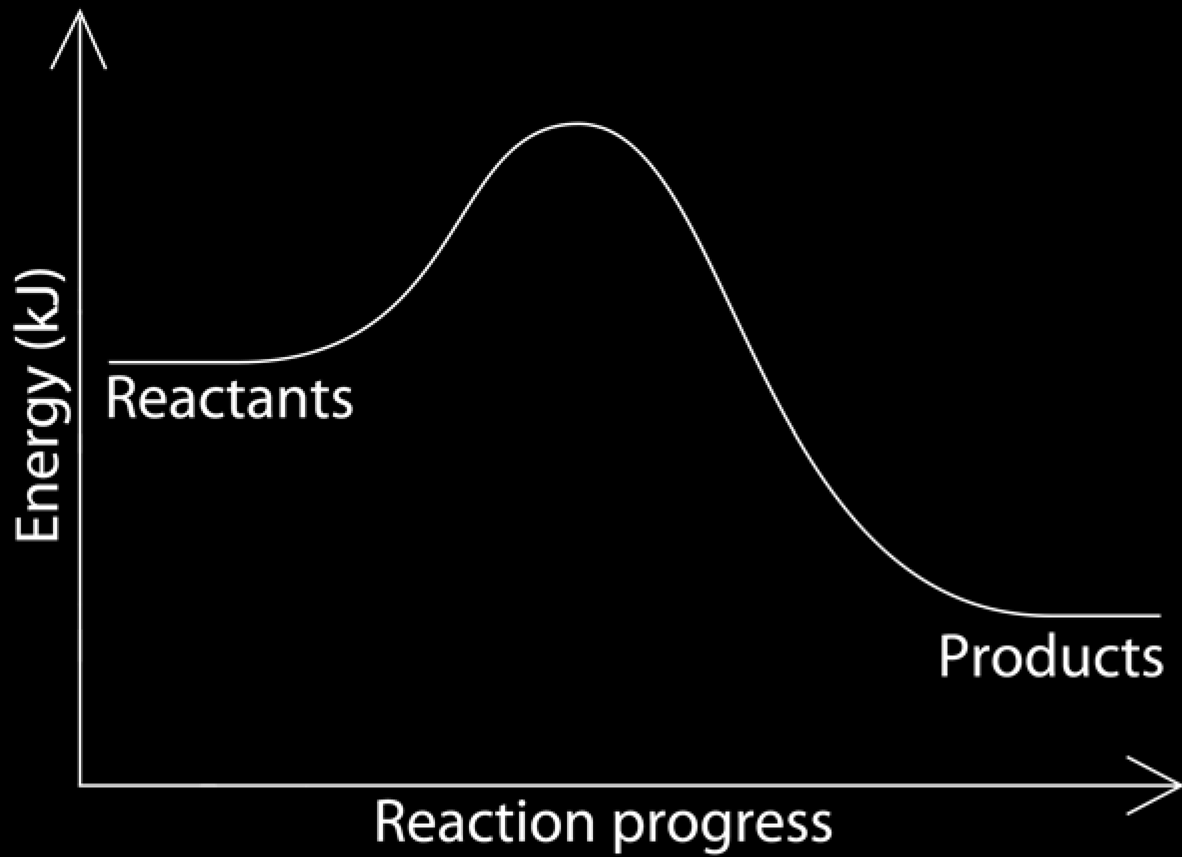
Endothermic reactions always have a positive ΔH and exothermic reactions always have a negative ΔH. Energy is measured in joules (J) or Kilojoules (KJ).

Reaction and Energy Graph:

The energy change can be represented by a graph, the energy is on the y axis and the reaction progress is on the x axis. Endothermic and exothermic reactions have different graphs.

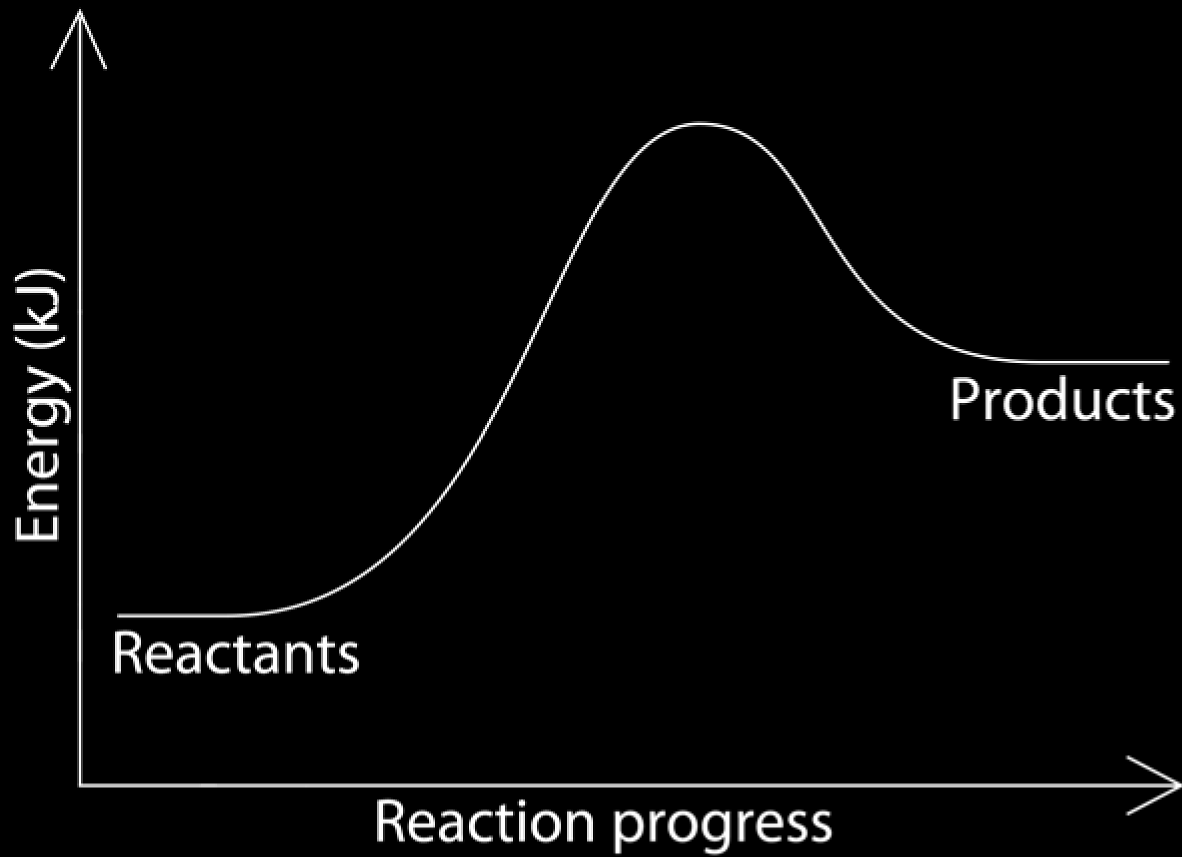
Exothermic Reactions:

In exothermic reactions, the reactants have more energy then the products, that is why small amounts of energy is required to activate the, and that is what makes is exothermic. The reactants having more energy than the products, make the amount of energy at the beginning of the reaction higher than at the end, the energy in between is given off creating a curve in the graph.



Endothermic Reactions:

It is the opposite here, in endothermic reactions, the reactants have lower energy in them than the products, this makes them less stable, needing more energy to activate the reactions, that is why they are endothermic. Because of that, the beginning of the reaction has less energy than at end of it; the difference of amount of values is caused by absorbing energy from the surroundings.



The overall energy change is determined by the amount of energy needed to activate the reaction and break the bonds and the amount of energy released during bond formation. So to calculate the overall energy change we have to know the amount of energy needed to break the bonds between the reactants and the amount of energy released during bond formation.

Calculate the enthalpy change when methane (CH_4) reacts with oxygen (O_2), given the following information.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

Bond	Bong Energy (KJ/Mol)
C-H	435
O=O	497
C=O	803
H-O	464
C-C	347
C-O	358

Energy needed to break bonds:

4 (C-H): 435 x 4 = 1740 KJ/Mol
2 (O=O): 497 x 1 = 994 KJ/Mol
Total energy in: 1740 + 994 = 2734 KJ/Mol

Energy needed to form bonds:
2 (C=O): 803 x 2 = 1606 KJ/Mol
4 (H-O): 464 x 4 = 1856 KJ/Mol
Total energy out: 1606 + 1856 = 3462 KJ/Mol

ΔH= 2734 – 3462 = -728 KJ/Mol r
Therefore reaction is **Exothermic**

When the ΔH is negative, the reaction is exothermic because the negative means that the reactants LOST energy to the surroundings. If it was positive the reaction is endothermic because the positive means that the reactants GAINED or ABSORBED energy from the surroundings.

Examples of Exothermic Reactions:

Combustion:

This is the reaction of any carbon containing fuel with oxygen producing carbon dioxide if complete combustion and carbon monoxide if incomplete combustion and large amounts of energy.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + \text{Energy}$$

Respiration:

Burning food (glucose) in living organisms to produce energy and carbon dioxide.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Hydration:

Adding water to salt powder, it is not dissolving. The powder changes to crystals.

$$CuSO_4 + 5H_2O \rightarrow CuSO_4.5H_2O + \text{Energy}$$

Displacement:

A more reactive metal displaces the less reactive one.

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu + \text{Energy}$$

Neutralization:

Adding and acid to an alkali forming salt, water and energy.

$$HCl + NaOH \rightarrow NaCl + H_2O$$

Examples of Endothermic Reactions:

Photosynthesis:

Using carbon dioxide and water to make glucose and oxygen in the presence of light energy and chlorophyll.

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

Dehydration:

Supplying heat to hydrated salt crystals evaropates the water of crystallization, leaving the powered crystals.

$$CuSO_4.5H_2O + \text{Heat energy} \rightarrow CuSO_4 + 5H_2O$$

Thermal Decomposition:

The breaking down of a compound by heating it.

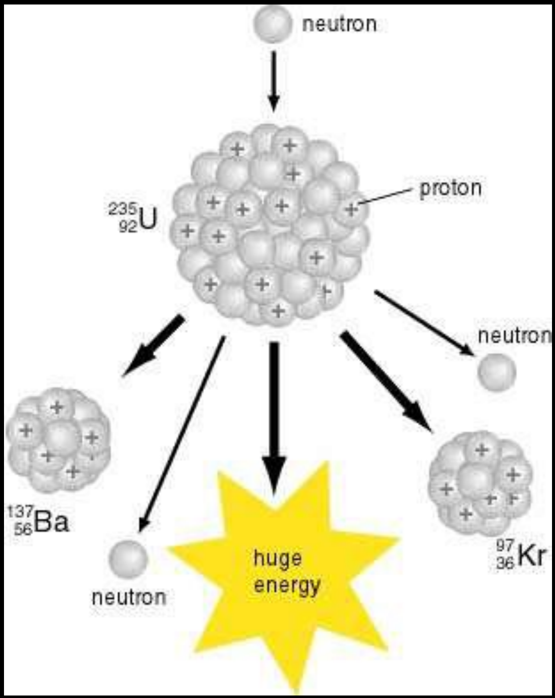
$$CaCO_3 + \text{Heat Energy} \rightarrow CaO + CO_2$$

Endothermic reactions break the bonds whereas Exothermic reaction form bonds.

Hydrogen as a Fuel

The reaction between hydrogen gas and oxygen gas is VERY EXOTHERMIC. It produces lots of heat energy.
2H2(g) + 02(g) = 2H20(l)
Burning only 2 grams of hydrogen gives out 485 joules of energy. This reaction is used for powering space rockets using hydrogen as ROCKET FUEL.

Radioactive Isotopes



Nuclear power stations use immense heat produced by the decay of radioactive isotopes. The heat that s generated is used to boil water to make steam which then turns a turbine. This produces the electricity. Uranium-235 or U235 IS THE RADIOACTIVE ISOTOPE used as a fuel in nuclear reactors. The radioactive reaction produces heat energy

Chapter 7: Chemical reactions

The rate of a reaction can be measured by the rate at which a **reactant** is used up, or the rate at which a **product** is formed.

The temperature, concentration, pressure of reacting gases, surface area of reacting solids, and the use of catalysts, are all factors which affect the rate of a reaction.

Chemical reactions can only happen if reactant particles collide with enough energy. The more frequently particles collide, and the greater the proportion of collisions with enough energy, the greater the rate of reaction.

Measuring rates of reaction

There are two ways to find the rate of a reaction:

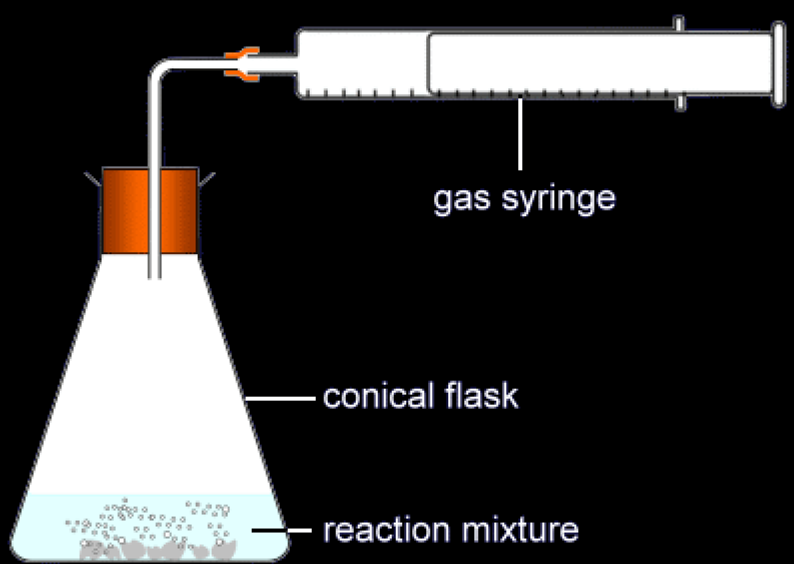
- Measure the rate at which a reactant is used up,
- Measure the rate at which a product is formed.

The method chosen depends on the reaction being studied. Sometimes it is easier to measure the change in the amount of a reactant that has been used up; sometimes it is easier to measure the change in the amount of a product that has been produced.

Things to measure:

The measurement itself depends on the nature of the reactant or product:

- The mass of a substance - solid, liquid or gas - is measured with a balance
- The volume of a gas is usually measured with a gas syringe, or sometimes an upside-down measuring cylinder or burette



Measuring the production of a gas using a gas syringe

It is usual to record the mass or total volume at regular intervals and plot a graph. The readings go on the vertical axis, and the time goes on the horizontal axis.

$$\text{rate of reaction} = \frac{\text{amount of reactant used or amount of product formed}}{\text{time taken}}$$

For example, if $24 cm^3$ of hydrogen gas is produced in two minutes, the mean rate of reaction = 24 ÷ 2 = $12 cm^3$ hydrogen / min.

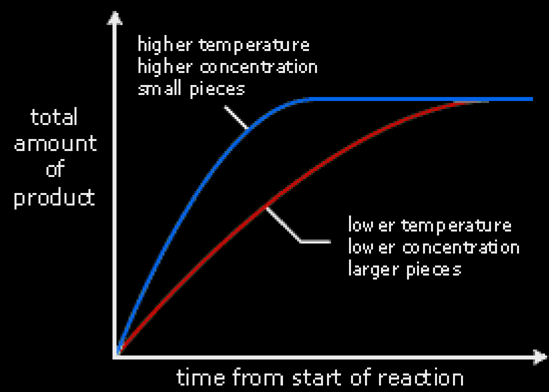
Factors affecting the rate

You will be expected to remember the factors that affect the rate of reactions, and to plot or interpret graphs from rate experiments.

How to increase the rate of a reaction:

The rate of a reaction increases if:

- The temperature is increased,
- The concentration of a dissolved reactant is increased,
- The pressure of a reacting gas is increased,
- Solid reactants are broken into smaller pieces,
- A catalyst is used.



The graph above summarises the differences in the rate of reaction at different temperatures, concentrations and size of pieces. The steeper the line, the greater the rate of reaction. Reactions are usually fastest at the beginning, when the concentration of reactants is greatest. When the line becomes horizontal, the reaction has stopped.

Collisions and reactions

You will be expected to explain, in terms of particles and their collisions, why changing the conditions of a reaction changes its rate.

Collisions:

For a chemical reaction to occur, the reactant particles must collide. Collisions with too little energy do not produce a reaction.

The collision must have enough energy for the particles to react. The minimum energy needed for particles to react is called the activation energy.

Changing concentration or pressure:

If the concentration of a dissolved reactant is increased, or the pressure of a reacting gas is increased:

- There are more reactant particles in the same volume
- There is a greater chance of the particles colliding
- The rate of reaction increases

Changing particle size:

If a solid reactant is broken into small pieces or ground into a powder:

- Its surface area is increased
- More particles are exposed to the other reactant
- There is a greater chance of the particles colliding
- The rate of reaction increases

Changing the temperature:

If the temperature is increased:

- The reactant particles move more quickly
- More particles have the activation energy or greater
- The particles collide more often, and more of the collisions result in a reaction
- The rate of reaction increases

Using a catalyst:

Catalysts increase the rate of reaction without being used up. They do this by lowering the activation energy needed. With a catalyst, more collisions result in a reaction, so the rate of reaction increases. Different reactions need different catalysts.

Catalysts are important in industry because they reduce costs.

Dangers of fine powders

The fine powders in the flour mills have a large surface area, so it can catch fire easily. If there is a lot of flour dust in the air, a small spark can cause a huge explosion

In coal mines, Methane and other flammable gases collect up in the air, a small spark can ignite them to cause an explosion.

Role of light in photochemical reactions

Visible light or ultra-violet light can start or even speed up a chemical rection.
In photography, a camera film is coated with silver compounds called silver chloride (AgCl), silver bromide (AgBr) and silver iodide (AgCl).
All three are sensitive to light but have different rates of sensitivity.
When light hits the camera film, the silver ions gain electrons to form silver metal.
This is called reduction.
$Ag+ + e- = Ag$
Light energy speeds up this process of reduction.
When the film is developed to produce negative images, these show the dark and light patches of the picture that was taken like shown on the left

The darker areas contain the most silver, the lighter areas contain the least silver.
Here is the positive image that forms when the film has been developed.

PHOTOSYNTHESIS is also started by ultraviolet (UV) light being absorbed by the green pigment chlorophyll in the leaves of green plants.
Carbon dioxide + water = glucose + oxygen
$6CO_2(g) + 6H_2O\ (l) = C_6H_{12}O_6(aq) + 6O_2(g)$

Reversible reactions

What is a reversible reaction?

Many chemical reactions continue until one/all reactants are used up and their products do not react together
When a reaction reaches this stage it is said to have reached completion

A reversible reaction is:

A chemical reaction in which the products react together to form the products
Reversible reactions never come to completion

Chemical equilibrium

This is a stage reached in a reversible reaction (in a closed system) when the forward & backward reactions take place at the same rate. Their effects cancel each other out and the concentration of reactants and products stays constant.

Changing Equilibrium

When conditions of equilibrium are changed, this will alter either the forward or backward reaction rates and destroy the chemical equilibrium.

Le Chatelier's Principle:

A law stating that if changes are made to a system in equilibrium the system adjusts itself to oppose the change.
NOTE: This is NOT in syllabus, you do not NEED to know it, but this coupled with basic physics can help you understand how things effect equilibrium. Anything highlighted in **grey in this chapter CAN BE IGNORED.**

Effect of heat on equilibrium

If the temperature is increased, the equilibrium will shift towards the endothermic side.

Le Chatelier's Explanation: This is because when the temperature is increased, the equilibrium will shift to REDUCE THIS CHANGE IN TEMPERATURE ; how can it do this? By promoting the endothermic (heat-absorbing) reaction.

Example:
$A2+B2 \rightleftharpoons 2AB$ $\Delta H=-300kJ$ (forward reaction)
Since the change in enthalpy is negative this means the forward reaction is exothermic.
So to increase rate of forward reaction, decrease temperature.
To increase rate of reverse reaction, increase temperature

Effect of pressure on equilibrium

Liquids and Solids are not really effected by pressure, thus pressure only occurs on gas involving reaction.
If the pressure is increased, the equilibrium will shift towards the side producing the least moles of gas.

Le Chatelier's Explanation: Pressure increases when the volume is squashed/compacted; so the way to reduce the pressure is to decrease the volume! It can do this by producing less gas molecules instead of more.

Decreasing pressure will cause the equilibrium to shift towards the side producing most moles of gas.

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

There are 2 moles of gas being produced by the forward reaction nd two moles of gas being produced by reverse reaction.
If we increase pressure, it will promote the forward reaction (a.k.a. equilibrium shifts to the right)
If we decrease pressure, it will promote the reverse reaction (a.k.a. equilibrium shifts to the left)

Effect of concentration on equilibrium

By now you will know the effect of concentration (review: increased concentration increases rate of reaction). Therefore the side with the highest concentration will react faster; e.g. if the reactants have a higher concentration the forward reaction will be faster than the reverse reaction.

Thereforce concentration can be used in two ways, by decreasing or increasing. Example:
To increase rate of forward reaction, either increase concentration of reactants or decrease concentration of products
To increase rate of reverse reaction, either increase concentration of PRODUCTS or decrease concentration of reactants.

Le Chatelier's Explanation: Simple; when you add reactants, the equilibrium will shift to use up these reactants quickly i.e. promoting forward reaction.

Redox

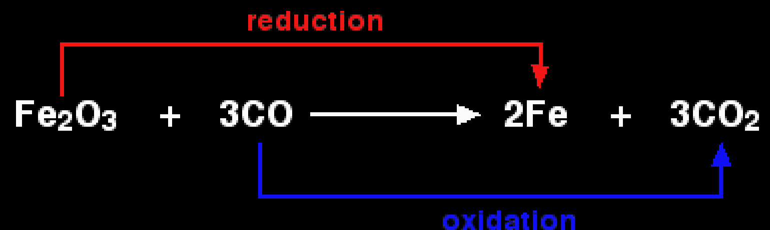
This page looks at the various definitions of oxidation and reduction (redox) in terms of the transfer of oxygen, hydrogen and electrons. It also explains the terms oxidising agent and reducing agent.

Oxidation and reduction in terms of oxygen transfer

Definitions

- Oxidation is gain of oxygen.
- Reduction is loss of oxygen.

For example, in the extraction of iron from its ore:



Because both **red**uction and **oxi**dation are going on side-by-side, this is known as a **redox** reaction.

Oxidising and reducing agents

An oxidising agent is substance which oxidises something else. In the above example, the iron(III) oxide is the oxidising agent.

A reducing agent reduces something else. In the equation, the carbon monoxide is the reducing agent.

- Oxidising agents give oxygen to another substance.
- Reducing agents remove oxygen from another substance.

Oxidation and reduction in terms of hydrogen transfer

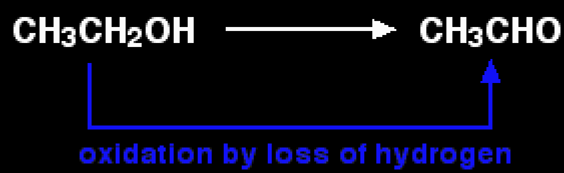
These are old definitions which aren't used very much nowadays. The most likely place you will come across them is in organic chemistry.

Definitions

- Oxidation is loss of hydrogen.
- Reduction is gain of hydrogen.

Notice that these are exactly the opposite of the oxygen definitions.

For example, ethanol can be oxidised to ethanal:



You would need to use an oxidising agent to remove the hydrogen from the ethanol. A commonly used oxidising agent is potassium dichromate(VI) solution acidified with dilute sulphuric acid.

Ethanal can also be reduced back to ethanol again by adding hydrogen to it. A possible reducing agent is sodium tetrahydridoborate, $NaBH_4$. Again the equation is too complicated to be worth bothering about at this point.

An update on oxidising and reducing agents

- Oxidising agents give oxygen to another substance or remove hydrogen from it.
- Reducing agents remove oxygen from another substance or give hydrogen to it.

Oxidation and reduction in terms of electron transfer

This is easily the most important use of the terms oxidation and reduction.

Definitions

- Oxidation is loss of electrons.
- Reduction is gain of electrons.

It is essential that you remember these definitions. There is a very easy way to do this. As long as you remember that you are talking about electron transfer:

OIL **RIG**

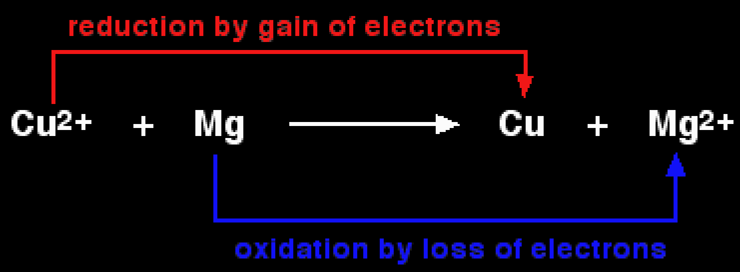
Oxidation **I**s **L**oss **R**eduction **I**s **G**ain

A simple example

The equation shows a simple redox reaction which can obviously be described in terms of oxygen transfer.

$$CuO + Mg \rightarrow Cu + MgO$$

Copper(II) oxide and magnesium oxide are both ionic. The metals obviously aren't. If you rewrite this as an ionic equation, it turns out that the oxide ions are spectator ions and you are left with:



A last comment on oxidising and reducing agents

If you look at the equation above, the magnesium is reducing the copper(II) ions by giving them electrons to neutralise the charge. Magnesium is a reducing agent.

Looking at it the other way round, the copper(II) ions are removing electrons from the magnesium to create the magnesium ions. The copper(II) ions are acting as an oxidising agent.

Warning!

This is potentially very confusing if you try to learn both what oxidation and reduction mean in terms of electron transfer, and also learn definitions of oxidising and reducing agents in the same terms.

It is recommend that you work it out if you need it. The argument (going on inside your head) would go like this if you wanted to know, for example, what an oxidising agent did in terms of electrons:

- An oxidising agent oxidises something else.
- Oxidation is loss of electrons (OIL RIG).
- That means that an oxidising agent takes electrons from that other substance.
- So an oxidising agent must gain electrons.

Or you could think it out like this:

- An oxidising agent oxidises something else.
- That means that the oxidising agent must be being reduced.
- Reduction is gain of electrons (OIL RIG).
- So an oxidising agent must gain electrons.

Understanding is a lot safer than thoughtless learning!

Chapter 8: Acids, Bases and Salts

All substances are acidic, neutral or basic (alkaline). How acidic or basic a substance is shown by its pH. There are several other ways by which we could find out whether a substance is acidic, neutral or basic.

pH Scale:

This is a scale that runs from 0 to 14. Substances with a pH below 7 are acidic. Substances with pH above 7 are basic. And those with pH 7 are neutral.

Indicators:

Indicators are substances that identify acidity or alkalinity of substances. They cannot be used in solid form.

Universal Indicator:

This is a substance that changes color when added to another substance depending on its pH. The indicator and the substance should be in aqueous form.

Litmus Paper or Solution:

This indicator is present in two colors: red and blue. We use blue litmus if we want test a substance for acidity. We use red litmus if we want to test a substance for alkalinity. Its results are:

- Acids: Turns blue litmus paper/ solution red,
- Bases: Turns red litmus paper/ solution blue,
- Neutral: if it is used as paper the color doesn't change. If it is used as solution it turns purple.

Note: use damp litmus paper if testing gases.

Phenolphthalein:

This is an indicator that is used to test for alkalinity because it is colorless if used with an acidic or neutral substance and it is pink if it is used with a basic substance.

Methyl Orange:

This indicator gives fire colors: Red with acids, yellow with neutrals and orange with bases.

Acids:

Acids are substances made of a hydrogen ion and non-metal ions. They have the following properties:

- They dissolve in water producing a hydrogen ion H^+,

- They have a sour taste,
- Strong ones are corrosive,
- Their pH is less than 7.

All acids must be in aqueous form to be called an acid. For example Hydrochloric acid is hydrogen chloride gas dissolved in water. The most common acids are:

- Hydrochloric acid HCl,
- Sulphuric Acid H_2SO_4,
- Nitric Acid HNO_3,
- Cirtric Acid,
- Carbonic Acid H_2CO_3.

Strength of Acids:

One of the most important properties of acids is that it gives hydrogen ion H^+ when dissolved in water. This is why the amount of H^+ ions the acid can give when dissolved in water is what determines its strength. This is called **ionization** or dissociation. The more ionized the acid is the stronger it is, the lower its pH. The more H^+ ions given when the acid is dissolved in water the more ionized the acid is.

Strong Acids:		Weak Acids:
• Have pH's: 0,1,2,3 • They are fully ionized • When dissolved in water, they give large amounts of H+ ions**Examples:** • Hydrochloric Acid • Sulfuric Acid • Nitric Acid	VS.	• Have pH's: 4,5,6 • They are partially ionized • When dissolved in water, they give small amounts of H+ ions**Examples:** • Ethanoic acid (CH_3COOH) • Citric Acid • Carbonic Acid

Hydrochloric acid is a strong acid. When it is dissolved in water all **HCl molecules are ionized into H^+ and Cl^- ions**. It is fully ionized.

Ethanoic acid has the formula CH_3COOH. It is a weak acid. When it is dissolved in water, only some of the CH_3COOH molecules are ionized into CH_3COO^- and H^+ ions. It is partially ionized.

Note: Acids with pH 3 or 4 can be considered moderate in strength.

Solutions of strong acids are better conductors of electricity than solutions of weak acids. This is because they contain much more free mobile ions to carry the charge.

Concentrated acids are not necessarily strong. The concentration of an acid only means the amount of molecules of the acid dissolved in water. Concentrated acids have a large amount of acid molecules dissolved in water. Dilute acids have a small amount of acid molecules dissolved in water. Concentration is not related to strength of the acids. Strong acids are still strong even if they are diluted. And weak acids are still weak even if they are concentrated.

Bases:

Bases are substances made of hydroxide OH^- ions and a metal. Bases can be made of:

- Metal hydroxide (metal ion & OH^- ion)
- Metal oxides

- Metal carbonates (metal ion & CO_3^{2-})
- Metal hydrogen carbonate (Bicarbonate)
- Ammonium hydroxide (NH_4OH)
- Ammonium Carbonate ($(NH_4)_2CO_3$)

Properties of bases:

- Bitter taste
- Soapy feel
- Have pH's above 7
- Strong ones are corrosive

Some bases are water soluble and some bases are water insoluble. Water soluble bases are also called **alkalis**.

Like acids, alkalis' strength is determined by its ability to be ionized into metal and hydroxide OH^- ions. Completely ionized alkalis are the strongest and partially ionized alkalis are the weakest. Ammonium hydroxide is one of the strongest alkalis while weak alkalis include the hydroxides of sodium, potassium and magnesium.

Types of Oxides:

Basic Oxides		Amphoteric Oxides		Acidic Oxides
• They are metal oxides • They react with acids forming a salt and water • They are solids • They are insoluble in water except group 1 metal oxides. • They react with an acid forming salt and water • Examples: Na_2O, CaO and CuO	VS.	• These are oxides of Aluminum, Zinc & Lead • They act as an acid when reacting with an alkali & vice versa • Their element's hydroxides are amphoteric too • They produce salt and water when reacting with an acid or an alkali.	VS.	• They are all non-metal oxides except non-metal monoxides • They are gases • They react with an alkali to form salt and water • Note: metal monoxides are neutral oxides • Examples: CO_2, NO_2, SO_2 (acidic oxides) & CO, NO, H_2O (neutral oxides)

Salts:

A salt is a neutral ionic compound. Salts are one of the products of a reaction between an acid and a base. Salts are formed in reactions I n which the H^+ ion from the acid is replaced by any other metal ion. Some salts are soluble in water and some are insoluble.

Soluble Salts:		Insoluble Salts:
• All Nitrates • All halides EXCEPT AgCl and PbCl2 • All sulfates EXCEPT CaSO4, BASO4, PbSO4 • All group 1 metals salts • All ammonium salts	VS.	• Silver and lead chlorides (AgCl & PbCl2) • Calcium, barium and lead sulphates (CaSO4, BASO4, PbSO4) • All carbonates EXCEPT group 1 metals and

		ammonium carbonates

Preparing Soluble Salts:

Displacement Method (Excess Metal Method):

Metal + Acid → Salt + Hydrogen

Note: this type of method is suitable to for making salts of moderately reactive metals because highly reactive metals like K, Na and Ca will cause an explosion. This method is used with the MAZIT (Magnesium, Aluminum, Zinc, Iron and Tin) metals only.

Example: set up an experiment to obtain magnesium chloride salt.

$$Mg + 2HCl \rightarrow MgCl_2 + H2$$

1. Add 100 cm3 of dilute hydrochloric acid to a beaker
2. Add excess mass of powdered magnesium
3. When the reaction is done, filter the mixture to get rid of excess magnesium (residue)
4. The filtrate is magnesium chloride solution
5. To obtain magnesium chloride powder, evaporate the solution till dryness
6. To obtain magnesium chloride crystals, heat the solution while continuously dipping a glass rod in the solution
7. When you observe crystals starting to form on the glass rod, turn heat off and leave the mixture to cool down slowly
8. When the crystals are obtained, dry them between two filter papers

Observations of this type of reactions:

- Bubbles of colorless gas evolve (hydrogen). To test approach a lighted splint if hydrogen is present it makes a pop sound
- The temperature rises (exothermic reaction)
- The metal disappears

You know the reaction is over when:

- No more gas evolves
- No more magnesium can dissolve
- The temperature stops rising
- The solution becomes neutral

Proton Donor and Acceptor Theory:

When an acid and a base react, water is formed. The acid gives away an H^+ ion and the base accepts it to form water by bonding it with the OH^- ion. A hydrogen ion is also called a proton this is why an acid can be called **Proton Donor** and a base can be called **Proton Acceptor**.

Neutralization Method:

Acis + Base → Salt + Water

Note: This method is used to make salts of metals below hydrogen in the reactivity series. If the base is a metal oxide or metal hydroxide, the products will be salt and water only. If the base is a metal carbonate, the products will be salt, water and carbon dioxide.

Type 1:

Acid + Metal Oxide → Salt + Water

To obtain copper sulfate salt given copper oxide and sulfuric acid:

$$CuO + H_2SO_4 \rightarrow CuSO_4 + H_2O$$

- Add 100 cm3 of sulfuric acid to a beaker
- Add excess mass of Copper oxide
- When the reaction is over, filter the excess copper oxide off
- The filtrate is a copper sulfate solution, to obtain copper sulfate powder evaporate the solution till dryness
- To obtain copper sulfate crystals, heat the solution white continuously dipping a glass rod in it
- When you observe crystals starting to form on the glass rod, turn heat of and leave the mixture to cool down slowly
- When you obtain the crystals dry them between two filter papers

Observations of this reaction:

- The amount of copper oxide decreases
- The solution changes color from colorless to blue
- The temperature rises
- You know the reaction is over when
- No more copper oxide dissolves
- The temperature stops rising
- The solution become neutral

Type 2:

Acid + Metal Hydroxide → Salt + Water

to obtain sodium chloride crystals given sodium hydroxide and hydrochloric acid:

$$HCl + NaOH \rightarrow NaCl + H_2O$$

- Add 100 cm3of dilute hydrochloric acid to a beaker
- Add excess mass of sodium hydroxide
- When the reaction is over, filter the excess sodium hydroxide off
- The filtrate is sodium chloride solution, to obtain sodium chloride powder, evaporate the solution till dryness
- To obtain sodium chloride crystals, hear the solution while continuously dipping a glass rod in it
- When crystals start to form on the glass rod, turn heat off and leave the mixture to cool down slowly
- When the crystals are obtained, dry them between two filter papers

Observations:

- Sodium hydroxide starts disappearing
- Temperature rises

You know the reaction is over when:

- The temperature stops rising

- No more sodium hydroxide can dissolve
- The pH of the solution becomes neutral

Type 3:

Acid + Metal Carbonate → Salt + Water + Carbon Dioxide

To obtain copper sulfate salt given copper carbonate and sulfuric acid:

$$CuCO_3 + H_2SO_4 \rightarrow CuSO_4 + H_2O + CO_2$$

- Add 100 cm3 of dilute sulfuric acid to a beaker
- Add excess mass of copper carbonate
- When the reaction is over, filter excess copper carbonate off
- The filtrate is a copper sulfate solution, to obtain copper sulfate powder evaporate the solution till dryness
- To obtain copper sulfate crystals, heat the solution white continuously dipping a glass rod in it
- When you observe crystals starting to form on the glass rod, turn heat of and leave the mixture to cool down slowly
- When you obtain the crystals dry them between two filter papers

Observations:

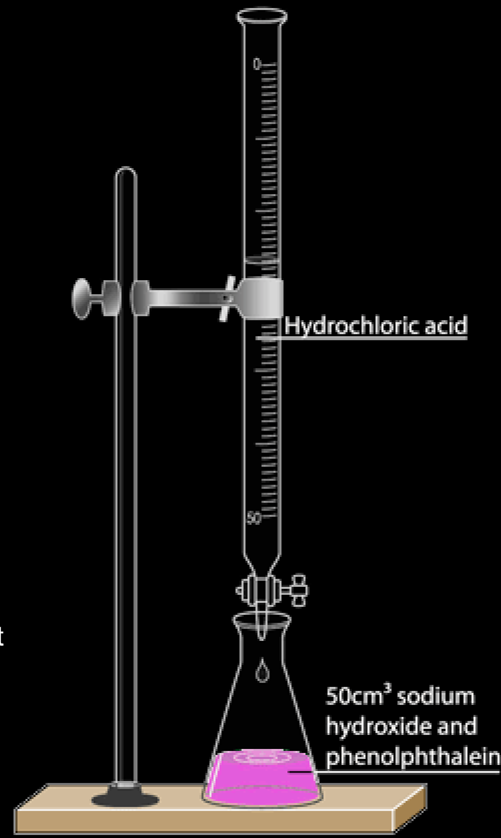
- Bubbles of colorless gas (carbon dioxide) evolve, test by approaching lighted splint, if the CO2 is present the flame will be put off
- Green Copper carbonate starts to disappear
- The temperature rises
- The solution turns blue

You know the reaction is finished when:

- No more bubbles are evolving
- The temperature stops rising
- No more copper carbonate can dissolve
- The pH of the solution becomes neutral

Titration Method:

This is a method to make a neutralization reaction between a base and an acid producing a salt without any excess. In this method, the experiment is preformed twice, the first time is to find the amounts of reactants to use, and the second experiment is the actual one.



1st Experiment:

- Add 50 cm3 of sodium hydroxide using a pipette to be accurate to flask
- Add 5 drops of phenolphthalein indicator to the sodium hydroxide. The solution turns pink indicating presence of a base
- Fill a burette to zero mark with hydrochloric acid
- Add drops of the acid to conical flask
- The pink color of the solution becomes lighter
- When the solution turns colorless, stop adding the acid (End point: is the point at which every base molecule is neutralized by an acid molecule)
- Record the amount of hydrochloric acid used and repeat the experiment without using the indicator
- After the 2nd experiment, you will have a sodium chloride solution. Evaporate it till dryness to obtain powdered sodium chloride or crystalize it to obtain sodium chloride crystals

Preparing Insoluble Salts:

Precipitation Method:

A precipitation reaction is a reaction between two soluble salts. The products of a precipitation reaction are two other salts, one of them is soluble and one is insoluble (precipitate).

Example: To obtain barium sulfate salt given barium chloride and sodium sulfate:

$$BaCl_2 + Na_2SO_4 \rightarrow BaSO_4 + 2NaCl$$
$$\text{Ionic Equation: } Ba^{2+} + SO_4^{2-} \rightarrow BaSO_4$$

- Add the two salt solutions in a beaker
- When the reaction is over, filter and take the residue
- Wash the residue with distilled water and dry it in the oven

Observations:

- Temperature increases
- An insoluble solid precipitate (Barium sulfate) forms

You know the reaction is over when:

- The temperature stops rising
- No more precipitate is being formed

Controlling Soil pH:

If the pH of the soil goes below or above 7, it has to be neutralized using an acid or a base. If the pH of the soil goes below 7, calcium carbonate (lime stone) is used to neutralize it. The pH of the soil can be measured by taking a sample from the soil, crushing it, dissolving in water then measuring the pH of the solution.

Colors of Salts:

Salt	Formula	Solid	In Solution
Hydrated copper sulfate	$CuSO_4.5H_2O$	Blue crystals	Blue
Anhydrous copper sulfate	$CuSO_4$	White powder	Blue
Copper nitrate	$Cu(NO_3)_2$	Blue crystals	Blue
Copper chloride	$CuCl_2$	Green	Green
Copper carbonate	$CuCO_3$	Green	Insoluble
Copper oxide	CuO	Black	Insoluble
Iron(II) salts	E.g.: $FeSO_4$, $Fe(NO_3)_2$	Pale green crystals	Pale green
Iron(III) salts	E.g.: $Fe(NO_3)_3$	Reddish brown	Reddish brown

Tests for Gases:

Gas	Formula	Tests
Ammonia	NH_3	Turns damp red litmus paper blue
Carbon dioxide	CO_2	Turns limewater milky
Oxygen	O_2	Relights a glowing splint
Hydrogen	H_2	'Pops' with a lighted splint
Chlorine	Cl_2	Bleaches damp litmus paper
Nitrogen dioxide	NO_2	Turns damp blue litmus paper red
Sulfur dioxide	SO_2	Turns acidified aqueous potassium dichromate(VI) from orange to green

Tests for Anions:

Anion	Test	Result
Carbonate (CO_3^{2-})	Add dilute acid	Effervescence, carbon dioxide produced
Chloride (Cl^-) (in solution)	Acidify with dilute nitric acid, then add aqueous silver nitrate	White ppt.
Iodide (I^-) (in solution)	Acidify with dilute nitric acid, then add aqueous silver nitrate	Yellow ppt.
Nitrate (NO^{3-}) (in solution)	Add aqueous sodium hydroxide, then aluminium foil; warm carefully	Ammonia produced
Sulfate (SO_4^{2-})	Acidify, then add aqueous barium nitrate	White ppt.

Tests for aqueous cations:

Cation	Effect of aqueous sodium hydroxide	Effect of aqueous ammonia
Aluminium (Al^{3+})	White ppt., soluble in excess giving a colourless solution	White ppt., insoluble in excess
Ammonium (NH_4^+)	Ammonia produced on warming	–
Calcium (Ca^{2+})	White ppt., insoluble in excess	No ppt. or very slight white ppt.
Copper (Cu^{2+})	Light blue ppt., insoluble in excess	Light blue ppt., soluble in excess, giving a dark blue solution
Iron(II) (Fe^{2+})	Green ppt., insoluble in excess	Green ppt., insoluble in excess
Iron(III) (Fe^{3+})	Red-brown ppt., insoluble in excess	Red-brown ppt., insoluble in excess
Zinc (Zn^{2+})	White ppt., soluble in excess, giving a colourless solution	White ppt., soluble in excess, giving a colourless solution

The Periodic Table of Elements:

The periodic table is a table containing all elements arranged in ascending order from the one with lowest atomic number to the one with highest atomic number.

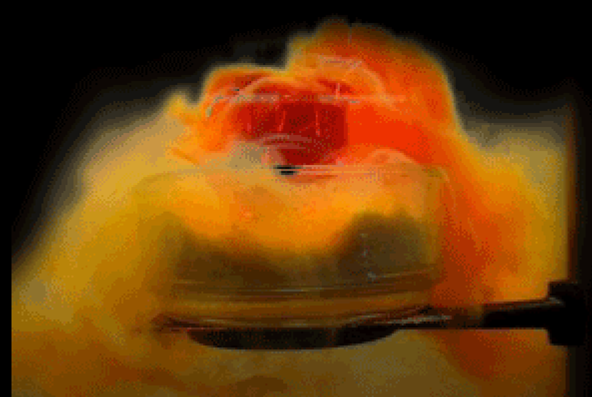
There are there are 8 vertical groups (Columns) in the periodic table. The group number is equal to the number of electrons in the outer most energy shell of the atoms of the elements in the group. This is why elements of the same group share the same chemical properties.

There are seven horizontal periods (rows) in the periodic table. The period number is also the number of occupied energy shells in the atoms of the elements in the period.

So if an element has 3 valence electrons, it will be in group 3. And if it has 4 occupied energy shells, it will be in period 4.

We have two types of elements in the periodic table. These are **Metals** and **Non-metals**. As we move in the periodic table from the left to the right, the metallic properties of elements decrease. Metals include Magnesium, Calcium, and Sodium. Non-metals include Carbon, Oxygen and Chlorine. All metals are solid. All non-metals are either solid or gas, except for bromine which is liquid.

Silver appears as a lustrous white metal



Bromine is a non-metal

Metals and non-metals have different Physical properties:

Physical Property:	Metals	Non-Metals
State In Room Temperature	Solid (Except Mercury, Liquid)	Solid-Gas (Except Bromine, Liquid)
Density	Very Dense (Except Group 1)	Low Density
Appearance	Shiny, Most Are Grey Except Copper And Gold	Most Are Dull (Except Diamond
Melting Point	High (Except Groups 1 & 2)	Low (Except Diamond-Graphite)
Boiling Point	High (Except Groups 1 & 2)	Low (Except Diamond-Graphite)
Malleability	Hard And Malleable	Soft And Brittle
Ductility	Ductile	Not Ductile
Electrical Conductivity	Conductors	Poor Conductors (Except Graphite-Silicon)
Heat Conductivity	Good	Very Poor
Sonority	Sonorous	Non-Sonorous

Malleability: If a metal is malleable it means it can be hammered into shapes without being broken.

Ductility: If a metal is Ductile it means it can be pulled into wires.

Sonority: If a metal is sonorous, it means it makes a pleasant sound when struck.

Metals and non-metals also differ in chemical properties:

Metals	Non-Metals
They have either 1,2 or 3 valence electrons	They have either 4,5,6,7 or 8 valence electrons. Except helium which has 2.
They lose electrons forming positive ions	They gain electrons forming negative ions
They are reducing agents	They are oxidizing agents
They form basic or amphoteric compounds	They form acidic or neutral compounds
Forms ionic compounds with non-metals	Form either ionic compounds with metals, or covalent compounds with other non-metals

Special Elements:

Alkali Metals:

These elements lie in group 1 of the periodic table. They are Lithium, Sodium, Potassium, Rubidium, Caesium and Francium (radioactive). We will study the properties of the first three; Lithium, Sodium and Potassium. Like any metals they are all good conductors of heat and electricity. They are however, soft. Lithium is the hardest of them and potassium is the softest. They are extremely reactive; they have to be stored away from any air or water. They have low densities and melting points.

They react with oxygen or air forming a metal oxide:

$$4Li + O_2 \rightarrow 2Li_2O$$
(Lithium) (Oxygen) (Lithium Oxide)

Their oxides can dissolve in water forming an alkaline solution of the metal hydroxide:

$$Li_2O + H_2O \rightarrow 2LiOH$$
(Lithium Oxide) (Water) (Lithium Hydroxide)

They react with water vigorously forming metal hydroxide and hydrogen gas:

$$2K + 2H_2O \rightarrow 2KOH + H_2$$
(Potassium) (Water) (Potassium Hydroxide) (Hydrogen)

They React with Halogens forming a metal halide:

$$2Na + Cl_2 \rightarrow 2NaCl$$
(Sodium) (Chlorine) (Sodium Chloride)

For this group, the further you go down the more reactive the metals become, this is the most reactive group.

The Halogens:

These are elements of group 7; Fluorine, Chlorine, Bromine, Iodine and Astatine.

We will study only properties of chlorine, bromine & iodine. They are colored and the color gets darker as we go down the group. They exist as diatomic molecules (Cl_2, Br_2, I_2). As you go down, they gradually change from gas to solid (chlorine is gas, bromine is liquid and iodine is solid).

They react with hydrogen forming hydrogen halide, which is an acid if dissolved in water:

H_2	+	Cl_2	→	2HCl
(Hydrogen)		(Chlorine)		(Hydrochloric Acid)

They react with metals forming metal halide:

2Fe	+	$3Cl_2$	→	$2FeCl_3$
(Iron)		(Chlorine)		(Iron Chloride)

The reactivity also decreases as we do down, chlorine is most reactive, followed by bromine then iodine.
If you bubble chlorine gas through a solution of potassium bromide, chlorine will take bromine's place because it more reactive. This is a **displacement reaction**.

2KBr	+	Cl_2	→	2KCl	+	Br_2
(Potassium Bromide)		(Chlorine)		(Potassium Chloride)		(Bromine)

Transition Elements:

These are metals. They form a big part of the periodic table. Some of them are very common like copper, zinc and iron. They have the following properties:

- They are harder and stronger than metals of groups 1 & 2.
- They have much higher densities than metals other metals.
- They have high melting points except for mercury.
- They are less reactive than metals of group 1 & 2.
- Excellent conductors of heat and electricity.
- They show catalytic activity (act as catalysts)
- They react slowly with oxygen and water
- They form simple ions with several oxidation states and complicated ions with high oxidation states.

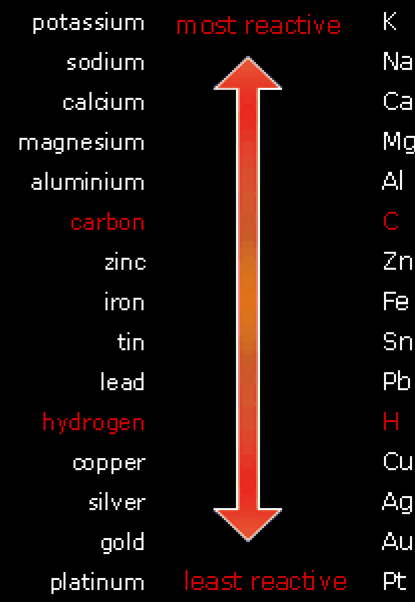
Element: It is a substance which contains only one kind of atom. E.g, Fe (Iron)
Mixture: A mixture contains different substances that are not bonded together.
Compound: A compound is made of atoms of different elements, bonded together.

Noble Gases:

These are elements in group 8 of the periodic table. They are colorless gases. They are extremely unreactive; this is because they have their outer energy shell full with electrons. So they are stable, this is why they exist as single atoms. They have some uses however, for example argon is used in light bulbs to prevent the tungsten filament from reacting with air, making the bulb last longer. Neon is also used in the advertising and laser beams. These gases are Helium, Neon, Argon, Krypton, Xenon and Radon (radioactive).

Chapter 10: Metals

The Reactivity Series of Metals:



The reactivity series is metal is an arrangement of the metals (and carbon and hydrogen) in order of their reactivity starting with the most reactive metal at the top and ending with the least reactive metal at the bottom.

The reactivity of a metal is determined by its ability to form a positive ion. For example, potassium is extremely reactive because it has only one valence electron, so it is very easy to lose it forming a positive ion.

One the other hand, copper is a weakly reactive metal because it has more valence electrons so it is harder for it to become a positive ion.

Reactions of Metals:

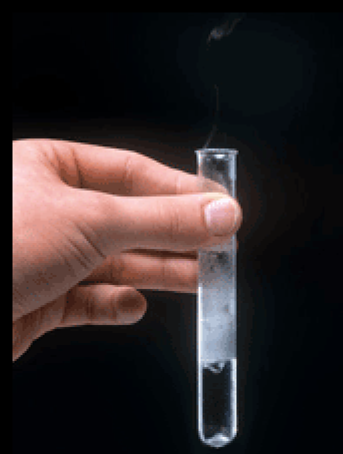
The reactivity series of metals was deduced by performing several experiments in the lab which enabled scientists to arrange metals according to their reactivity with dilute acid, oxygen (air), and water.

Reactions with Dilute Hydrochloric Acid:

In the previous chapter, you studied those reactions involving a metal and an acid are used to prepare soluble salts and that this method is only suitable for preparing salts of moderately reactive metals (MAZIT). This is because any metal more reactive that magnesium will react very violently with acids which is dangerous.

Metal + HCl → Metal Chloride + Hydrogen

The photo on the right shows magnesium reacting with dilute hydrochloric acid. Those effervescences are caused by the evolution of hydrogen gas, which is a product in this reaction. This reaction was repeated using the other metals of the reactivity series. The rate of evolution of hydrogen gas in each experiment was measured. The metals were arranged in order of reactivity starting with the most reactive metal which had the highest rate of effervescence of hydrogen gas. The rate of effervescence is also the rate of this reaction is measured by measuring the volume of hydrogen produced per unit time.



Metals	Reactivity with Dilute HCl
Potassium, Sodium & Calcium	React extremely violently with rapid effervescence and splashing
Magnesium & Aluminum	React violently with rapid effervescence
Zinc, Iron & Lead	React slowly with bubbles
Copper, Silver, Gold & Platinum	Do not react

Reactions with Oxygen in Air:

Most metals react with oxygen from air forming a metal oxide. You have previously studied that metal oxides are basic oxides and that some of them are insoluble in water and some of them are soluble in water forming an alkaline solution. The most reactive metals like potassium, sodium, calcium and magnesium react with oxygen with a very bright flame and producing white ashes and their oxides are soluble. Moderately reactive metals like aluminum and zinc react with oxygen forming white powdered ashes but their oxides are insoluble. Iron and copper react very slowly with oxygen. The result of iron oxygen reactions is rust which is reddish brown iron oxide. When a copper lump reacts with oxygen, a white layer of black copper oxide forms on it. When the lump gets covered by this layer;

the reaction stops. Oxides of iron and copper are insoluble. Metals that are less reactive than copper like silver, gold and platinum do not react with oxygen.

Note: When aluminum reacts with oxygen, a layer of aluminum oxide adheres and covers the aluminum. At this point no further reaction can take place.

Reactions of Metals with Water and Steam:

Some metals are so reactive that they will just react with water immediately if they come in contact. Other metals will react slowly will cold water, but with steam they react much faster. And other metals can only react slowly with steam. Unreactive metals such as silver and gold do not react with water.

Potassium, sodium and calcium react vigorously with cold water and may catch on fire. The products of these reactions are metal hydroxide and hydrogen gas. If hydrogen gas being produced accumulates it may ignite and cause an explosion.

Metal + Water → Metal hydroxide + Hydrogen

E.g.: $2Na + 2H_2O \rightarrow 2NaOH + H_2$

Magnesium, aluminum, zinc and iron are less reactive. They react with steam forming metal oxide and hydrogen. Magnesium and aluminum will react vigorously with steam while zinc and iron react slowly.

Metal + Steam → Metal Oxide + Hydrogen

E.g.: Magnesium + Steam → Magnesium oxide + Hydrogen

Competition Reactions in Solid State:

Previously you've studied displacement reactions which are pre-formed in aqueous states. A very similar reaction takes place in the solid state, it is called **thermite reaction**. This reaction is used to repair damaged railway lines. In this reaction, aluminum and iron (III) oxide are the reactants. In the reaction, aluminum removes the oxygen ion from iron and bonds with it. This happens because aluminum is more reactive than iron. The products are aluminum oxide and iron in molten form. In the fixing procedure, the reactants are put in the cut in the railway line and the reaction is triggered by heating using a magnesium fuse. The reaction leaves aluminum oxide and molten iron with then condenses in the cut welding it. Like displacement reactions, this reaction is exothermic.

$$2Al + Fe_2O_3 \rightarrow Al2_O3 + 2Fe$$

Competition Reactions in Aqueous State:

These are ordinary displacement reactions in which the two positive ions compete for the negative ion. The ion of the more reactive metal wins. Zinc is higher than copper in the reactivity series. If zinc is added to a solution of copper nitrate, a displacement reaction will take place in which the zinc will displace the copper ion from the solution in its salt. The products of this reaction are zinc nitrate and copper. Copper salt solutions have a blue color which fades away as the reaction proceeds because the concentration of the copper salt decreases. This type of reaction also helped in confirming reactivity of metals since the more reactive metal displaces the less reactive one.

$$Zn + Cu(NO_3)_2 \rightarrow Zn(NO_3)_2 + Cu$$

Action of Heat on Metal Compounds:

Applying heat to a metal compound such as potassium nitrate will cause it to decompose into potassium nitrite and oxygen. This is a thermal decomposition reaction.

Metal:	Anion:		
	Nitrate ($NO3$)	Carbonate ($CO3$)	Hydroxide (OH)
Potassium Sodium	Metal Nitrate → Metal nitrite + Oxygen	NO DECOMPOSITION	
Calcium Magnesium Aluminum Zinc Iron Lead Copper	Metal Nitrate → Metal oxide + Nitrogen dioxide + Oxygen	Metal Carbonate → Metal oxide + Carbon dioxide	Metal hydroxide →Metal oxide + Hydrogen
Silver Gold	Metal Nitrate → Metal + Nitrogen dioxide + Oxygen	Metal Carbonate → Metal + Carbon dioxide + Oxygen	-

Silver and gold hydroxides do not exist.

Ions of more reactive metals tend to hold on tightly to their anions and do not decompose easily this is why lots of heat is needed.

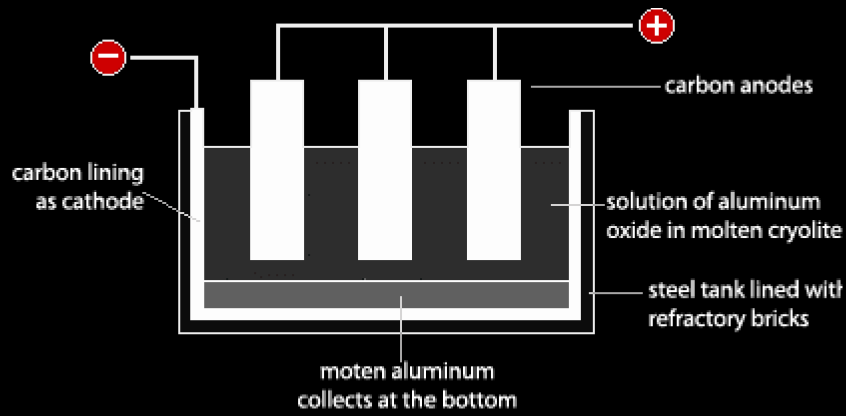
Extracting Metals From Their Ores:

Most metals do not exist in nature as pure elements. Instead, they are found as naturally occurring compounds called **ores**. Ores are naturally occurring minerals from which a metal can be extracted. Most ores are metals oxide, carbonate or sulfide mixed with other impurities. The extraction of metal from ores begun long ago when people started purifying iron from its iron oxide ore by reducing it using charcoal. This was possible because carbon is more reactive than iron so it can reduce it take the oxygen ion from it. But then other metals were discovered which were higher than carbon in the reactivity series. Those metals were not possibly extracted from their ores until in the 19th century when a method of extracting them by electrolysis was invented. The method extracting a metal depends on its reactivity.

Metals - in decreasing order of reactivity	Reactivity
• potassium • sodium • calcium • magnesium • aluminium	Extract by electrolysis
• carbon	
• zinc • iron • tin • lead	Extract by reaction with carbon or carbon monoxide
• hydrogen	
• copper • silver • gold • platinum	Extracted by various chemical reactions

Extraction of Aluminum:

Aluminum exists naturally as aluminum oxide (alumina) in its ore, which is called bauxite. Because aluminum is a very reactive metal, it holds on very tightly to the anion it bonds with, which is oxide in this case. This is why the best way to extract and purify aluminum is by electrolysis in a cell like the one below.



In this cell, the electrodes are made of graphite (Carbon). The cathode is a layer at the bottom of the cell and the anodes are bars dipped in the electrolyte. The electrolyte in this process is a molten mixture of aluminum oxide and cryolite. Aluminum oxide by its self has a very high melting point of 2050oC which is higher than the melting point of the steel container in which this process is done. That means the steel container will melt before the aluminum oxide. This is why aluminum oxide is mixed with cryolite which decreases the melting point of it to under 1000oC, thus saving a lot of money because heating is expensive and preventing the steel container from melting. Heat must be continuously supplied to the mixture to keep it molten. Aluminum oxide does not conduct electricity when solid because it does not have free mobile ions to carry the charge.

- Aluminum oxide is purified from impurities of oxide by adding sodium hydroxide
- Aluminum oxide is mixed with cryolite and put in the electrolysis cell
- Heat is given in until the mixture becomes molten
- Electrolysis start
- Oxide ions get attracted to the anode and discharged (oxidation); **$2O^{2-}$, 4e → O_2**
- Aluminum ions get attracted to the cathode and discharged and settle at the bottom of the container (reduction); **Al^{3+} + 3e → Al**
- Oxygen gas evolves and is collected with waste gases
- Aluminum is sucked out of the container at regular intervals

Oxygen gas which evolves reacts with carbon from the cathode forming CO2. The cathode gets worn away. To solve this, the cathode is replaced at regular intervals. Heat supply is very expensive; this is why cryolite is used to decrease the melting point of aluminum oxide and this process is done in plants which use hydroelectric energy because it is cheap.

Uses of aluminum:

- Construction of air-craft bodies because aluminum is very strong and very light and it is resistant to corrosion
- Food containers because it is resistant to corrosion
- Overhead power cables because it conducts electricity, is very light, malleable and ductile. Although it is strengthened with steel core

Extraction of Iron:

The ore of iron is called hematite. It consists of 60% iron in form of Iron oxide (Fe_2O_3) with other impurities such as silicon
oxide (SiO_2). This process takes place in a tower called a **Blast furnace**.

Substances	Products and Waste Materials
• Iron ore (Hematite) • Coke (heated coal) • Lime stone (Calcium carbonate) • Hot Air	• Pure Iron • Carbon dioxide • Air • Slag (Calcium silicate)

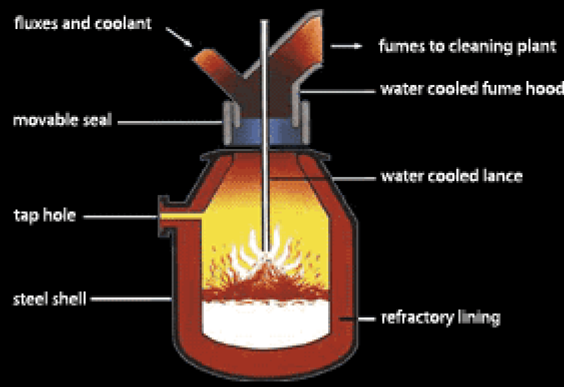
- Substances are put in the blast furnace
- The process starts by blowing in hot air at the bottom of the furnace
- Coke burns in oxygen from the hot air producing carbon dioxide; $C + O_2 \rightarrow CO_2$
- Heat makes lime stone decompose into calcium oxide and carbon dioxide; $CaCO_3 \rightarrow CaO + CO_2$
- Carbon dioxide produced goes up the furnace and reacts with more coke up there producing carbon monoxide; $CO_2 + C \rightarrow 2CO$
- Carbon monoxide is a reducing agent. It rises further up the furnace where it meets iron oxide and starts reducing it producing iron and carbon dioxide; $Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$
- Calcium oxide which was produced from the thermal decomposition of lime stone is a base. It reacts with impurities of hematite such as silicon oxide which is acidic forming calcium silicate which is called slag; $CaO + SiO_2 \rightarrow CaSiO_3$
- Molten Iron and slag produced trickles down and settles at the bottom of the furnace. Iron is denser than slag so it settles beneath it.
  Iron and slag are tapped off separately at regular intervals and pure iron is collected alone
- Waste gases such as carbon dioxide formed in the process and nitrogen and other gases from air blown in escape at the top of the furnace.

Conversion of Iron into Steel:

Iron produced in the blast furnace is called **pig iron**. It contains 4% carbon as well as other impurities such as sulfur, silicon and phosphorus which make it hard and brittle. It got that name from the fact that it has to be poured into mould called pigs before it is converted into steel. Most of produced iron is converted into steel because steel has better properties.

Making steel out of pig iron is a process done in a basic oxygen furnace:

- Molten pig iron is poured into the oxygen furnace
- A water cooled lance is introduced which blows oxygen onto the surface of the molten iron
- Impurities start to react
- Carbon is oxidized into carbon monoxide and carbon dioxide and escape
- Sulfur is oxidized into sulfur dioxide and escapes
- Silicon and phosphorus are oxidized into silicon oxide and phosphorus pentoxide which are solids.
- Calcium oxide (lime) is added to remove the solid impurities as slag which is skimmed off the surface
- Throughout the process, sample of the iron are being taken and analyzed for the percentage of carbon present in it. When the percentage of carbon desired is reached, the furnace is switched off and the steel is collected.



There are many different forms of steel. Each has different components and properties and is used for different purposes.

Steel	Composition	Properties	Uses
Mild Steel	99.5% Iron 0.5% Carbon	Easily worked lost brittleness	Car bodies large structures Machinery
Hard Steel	99% Iron 1% Carbon	Tough and brittle	Cutting tools and chisels
Stainless Steel	87% Iron 13% Manganese	Tough and springy	Drill bits and springs and chemical plants
Manganese Steel	74% Iron 18% Chromium 8% Nickel	Tough and resistant to corrosion	Cutlery and surgical tools, kitchen sinks
Tungsten Steel	95% Iron 5% Tungsten	Tough and hard even at high temperatures	Edges of high speed cutting tools

Extraction of Zinc:

The ore of zinc is called zinc blende and it is made of zinc sulfide. Zinc is obtained from zinc sulfide by converting it into zinc oxide then reducing it using coke, but first zinc sulfide must be concentrated.

Zinc sulfide from zinc blende is concentrated by a process called froth floatation. In this process, the ore is crushed and put into tanks of water containing a frothing agent which makes the mixture froth up. Hot air is blown in and froth starts to form. Rock impurities in the ore get soaked and sink to the bottom of the tank. Zinc sulfide particles cannot be soaked by water; they are lifted by the bubbles of air up with the froth and are then skimmed off. This is now concentrated zinc sulfide.

Then, zinc sulfide gets heated very strongly with hot air in a furnace. Zinc sulfide reacts with oxygen from the air to produce zinc oxide and sulfur dioxide gas which escapes as waste gas.

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

Sulfur dioxide is used in the manufacture of sulfuric acid.

Zinc oxide produced is put into a furnace with powdered coke. The mixture is heated till 1400oC. Carbon from the coke reduces the zinc oxide into zinc producing carbon monoxide which escapes as waste gas.

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

Carbon monoxide produced is hot and is used to heat the furnace to reduce heating costs. The pure zinc produced is collected and left to cool down. Zinc is used in many ways like the production of the alloy brass, galvanization and making car batteries.

Uses of Zinc:

- Making brass
- Galvanizing

Extraction of Copper:

Copper is one of the most popular metals. Native copper occurs in some regions in the world. Otherwise, copper exists in its ore, copper pyrites (2CuFeS2). You have studied before that copper can be purified by electrolysis. It can also be extracted from it ore by converting pyrites into copper sulfide by reacting it with oxygen:

$$2CuFeS_2 + 4O_2 \rightarrow Cu_2S + 3SO_2 + 2FeO$$

Sulfur oxide produced escapes as waste gas and iron oxide impurities are removed by heating the mixture with silicon converting it in to iron silicate which is run off. The remaining copper sulfide is then heated strongly with air. Copper sulfide reacts with oxygen from air producing sulfur oxide which escapes as waste gas and pure copper.

$$Cu_2S + O_2 \rightarrow 2Cu + SO_2$$

Thus copper is extracted.

Uses of Copper:

- In electrical wires because it is a perfect electrical conductor and very ductile, malleable and cheap
- Making alloys such as bronze and brass
- Cooking utensils because it conducts heat and it is has high melting and boiling points and also resists corrosion
- Electrodes because it is a good conductor of electricity
- Water pipes because it is resistant to corrosion

Chapter 11: Air and Water

Water:

Water is perhaps the most known substance. This is perhaps because of its abundance and numerous uses. Water is, H_2O, is the most popular solvent for chemical reaction.

Tests for Water:

There are several tests for water, the easiest one which you can perform at home is physical and doesn't involve any reaction. It is testing its boiling point. Pure water boils at 100°C sharply, and freezes at 0°C sharply.

There are chemical reactions which could be applied to test for water. For example if you add water to anhydrous copper sulphate powder which is white in colour, it forms a blue solution and may give heat out. If you crystallise the solution you will obtain blue crystals of hydrated copper sulphate (see the picture on the left).

Another test for water is adding it to anhydrous cobalt chloride which is blue in colour, if water is added to it the anhydrous salt forms a pink solution. If you crystallise the solution of cobalt chloride you will obtain pink hydrated cobalt chloride crystals (see the picture on the right).

Uses of Water:

The uses of water are many, from drinking and cleaning to irrigating crops and landscapes. Water is used for cooling, for recreation, and dust control. Water is needed for restaurants, most industrial processes, and even some religious ceremonies. On another level, the splash and flow of water in streams and fountains soothes and inspires.

In one way or another, water is a part of almost everything humans make and do. Washing a load of laundry uses 40 gallons, filling a backyard pool takes about 25,000 gallons, growing a pound of cotton consumes 1,000 gallons, while producing a pound of copper uses 20 gallons.

Uses where water is consumed, usually through evaporation or plant growth, are consumptive uses. Examples include water used for irrigation or in evaporative coolers. Non-consumptive uses, such as bathing, hydropower generation and recreation, do no t use up water. Used non-consumptively, the same water can be used again and again, although some uses lower the quality of the water. Once used, wastewater can be treated and used again as reclaimed water or effluent.

The main categories of water use are agricultural, municipal and industrial. Municipal and industrial uses currently are much less, but are growing rapidly. Mining activities and cooling towers used for power generation account for most of the remaining water use.

Water Purification:

Water that exists naturally in earth is never pure. There are always impurities in it, sometimes in large amounts. In fact water could very well be contaminated with diseases and bacteria. This is why water has to be purified before it is put to use. Water purification involves two processes (**Filtration** & **Chlorination**) done in several steps:

1. Water is taken from reservoirs or any other source to the water treatment plant
2. Water is passed through filters to remove large, floating objects such as pieces of rocks or mud

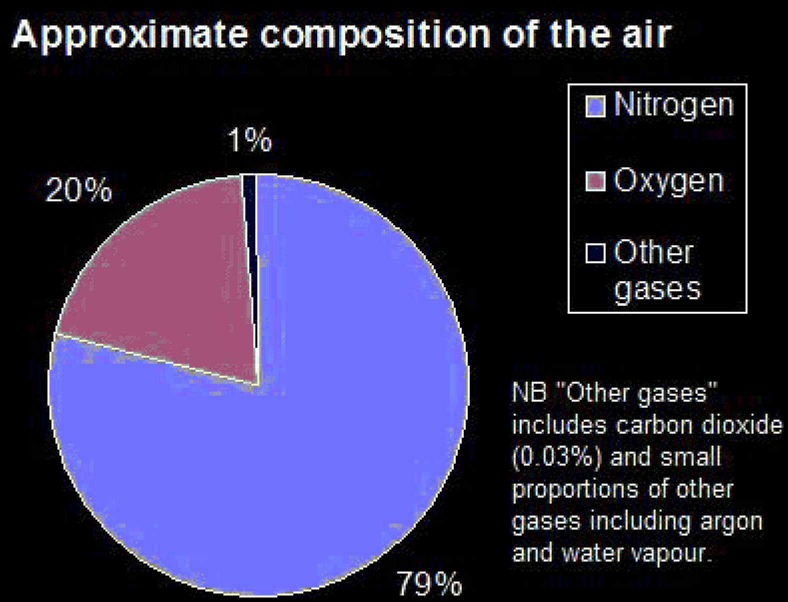
3. Smaller particles are removed by adding aluminum sulfate which makes them stick together in large pieces and settle down
4. Water is passed through sand and gravel filters which filter off small particles and may kill some bacteria (filtration is done)
5. Chlorine gas is bubbled through the water to kill all bacteria living in the water making the water sterile
6. The water may end to be slightly acidic, small amounts of sodium hydroxide are added to treat this. Fluoride might be added to because it helps in preventing tooth decay
7. Water is then delivered to homes

Air:

Air is a mixture of gases that makes up the atmosphere of earth.

Composition of Clean Air:

Clean air is made up of nitrogen, oxygen and traces of other gases including carbon dioxide and noble gases. There are also traces of water vapor in air. Noble gases present in air are mostly argon and some helium, neon, krypton and xenon.



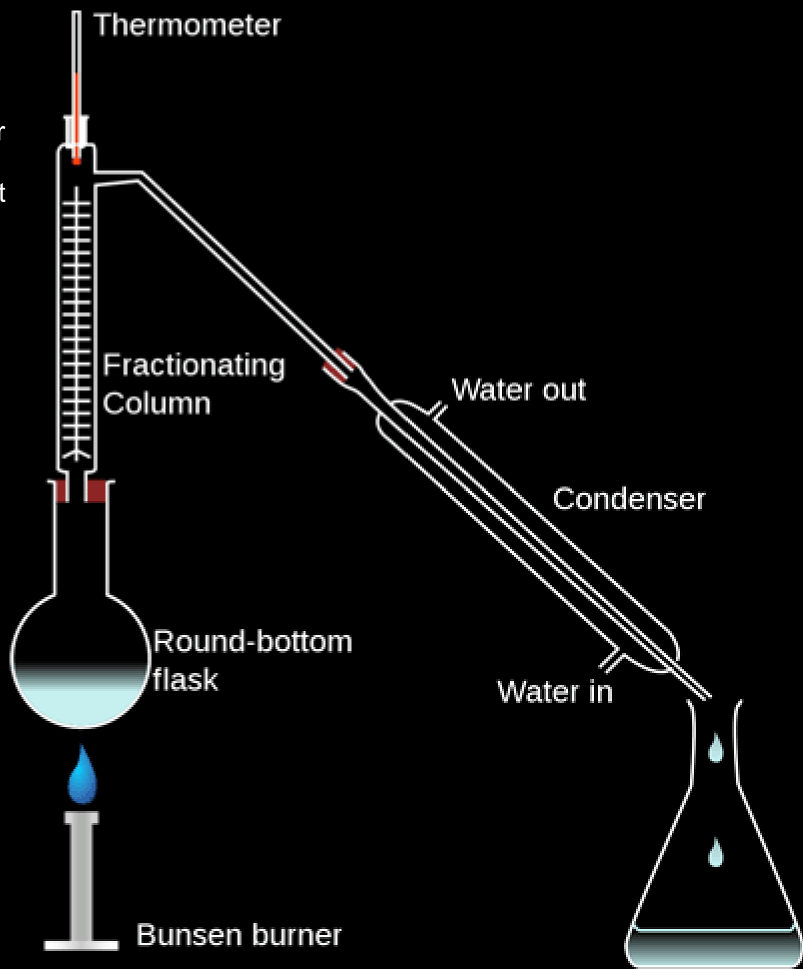
Fractional Distillation of Liquid Air:

Fractional distillation of liquid air is used to separate gases of air, specially nitrogen and oxygen. Like fractional distillation of petroleum, it is based on the boiling points of the components of air.

GAS	Boiling Point:	Percentage Of Air
Carbon Dioxide	-32 °C	<1%
Xenon	-108 °C	<1%
Krypton	-153 °C	<1%
Oxygen	-183 °C	20%
Argon	-186 °C	<1%
Nitrogen	-196 °C	79%
Neon	-246 °C	<1%

Helium	-249 °C	<1%

- Clean air is cooled till -80°C, carbon dioxide sublimes into solid and is collected, water vapour condenses than freezes into ice and is collected too
- The cold air is now put into a compressor which increases its pressure to 100 atm. This causes the air to warm up so it has to be cooled down again
- The re-cooled, compressed air is then allowed to expand and lose its pressure, this causes it cool further
- The air is now recompressed then expanded again to keep cooling it. This stage is repeated until all gases liquefy, this is at a temperature below -200°C
- Then the cold liquid air brought in a fractionating column and left to warm slowly
- Gases separate one after another according to their boiling points. The gas with the lowest boiling point evaporates first, followed by the gas of the second lowest boiling point and so on
- The three main gases of air (nitrogen, oxygen and argon) evaporate in the following order:
  1. Nitrogen (-196 °C)
  2. Argon (-186 °C)
  3. Oxygen (-183 °C)
- Gases are collected and stored separately.



Air Pollution:

Pollution is the presence of harmful substances. Air pollution is the presence of pollutant gases in the air. A pollutant is a substance that causes pollution. These are:

- Carbon monoxide
- Oxides of nitrogen
- Sulphur dioxide
- Lead compounds

Carbon Monoxide: Carbon monoxide (CO) is one of the poisonous pollutants of air. It is considered a pollutant because it can kill living organisms. The main source of carbon monoxide is factories which burn carbon-containing fossil fuels since CO is one of the products of the incomplete combustion of fossil fuels. Carbon monoxide could be treated by installing catalytic converters in chimneys of the factories.

Sulphur Dioxide: Sulphur dioxide (SO_2) is considered a pollutant since it contributes to acidic rain. Sulphur dioxide is a product of two process, these are combustion of sulphur –containing fossil fuels and extraction of metals from their sulphide ores (such as zinc sulphide). The problem associated with sulphur dioxide is that when it rises in the air from chimneys of factories, it mixes with water vapour of clouds and air. This results in the formation of sulphuric acid

(H2SO4). When it rains, rain water which falls becomes acidic. Acid rain causes death to water creatures since it makes water acidic, acidifies soil causing death to plants and deforestation, reacting with limestone from buildings and sculptures corroding it, and may also cause lung cancer. Sulphur dioxide could be treated before it leaves chimneys of factories by reacting it with limestone which is a neutralisation reaction. This process is called desulphurisation.

$$SO_2 + CaCO_3 \rightarrow CaSO_3 + CO_2$$

Oxides of Nitrogen (NO & NO_2): Nitrogen oxides are formed at high temperatures as a result of nitrogen and oxygen reacting. In cars, engines have a very high temperature; this creates a chance for nitrogen and oxygen present in air in the engine to react forming nitrogen monoxide.

$$N_2 + O_2 \rightarrow 2NO$$

The produced carbon monoxide is released through the exhaust with other waste fumes. Nitrogen monoxide reacts with more oxygen from air producing nitrogen dioxide.

$$2NO + O_2 \rightarrow 2NO_2$$

The problem associated with nitrogen dioxide is similar to that of sulphur dioxide. It rises up in the air and mixes with rain water forming nitric acid. This causes acid rain. Nitrogen oxides can also cause health respiratory problems to humans and animals. To treat this issue, cars are now fitted with devices called catalytic converters which eliminate nitrogen oxides.

Lead Compounds: Compounds of lead are waste products of fuel burning in cars. They are considered pollutants because they are poisonous and they are said to cause mental disabilities to young children. To treat this problem, gas stations now provide unleaded fuel.

Catalytic Converters:

Car fuels contain carbon; so carbon monoxide gas is released by cars as waste fumes, as well as nitrogen oxides. These are pollutant gases. To prevent these gases from polluting air, a device called catalytic converter is fitted at the end of the exhaust. This device contains a catalyst which catalyses the reaction between these two gases producing two harmless gases, nitrogen and carbon dioxide:

$$2NO + 2CO \rightarrow 2CO_2 + N_2$$
$$2NO_2 + 4CO \rightarrow 4CO_2 + N_2$$

The catalyst of the device works best at temperature around 200°C.

The Carbon Cycle:

The carbon cycle is a natural global cycle of the element carbon. It is what maintains a constant level of carbon dioxide in air (0.03%). The cycle goes as follows:

- Plants absorb carbon dioxide from air and undergo photosynthesis reaction which turns it into glucose and produces
  oxygen: **$6CO_2 + 6H_2O \rightarrow C6H12O6 + 6O_2$**
- The carbon is now stored in plants as glucose. One of two things happen, either the plants get eaten by animals or humans, or the plant dies and decays.
- If the plant is eaten by animals or humans, glucose in the plant is used by them in a process called respiration to release energy for their body.

$C6H12O6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$
Respiration is the opposite of photosynthesis. Carbon dioxide is one of the products of it, which is released by the humans through breathing into the air. Thus carbon dioxide returns to the atmosphere.

- If the plant dies. It is buried underground and by time it decays forming coal and other fossil fuels. These substances contain the carbon which was made and stored by the plants and they are then taken by power stations which put them to use.
- Power stations burn carbon-containing fuels that were obtained as coal or fossil fuels formed by dead plants. This is a combustion reaction.
  $C + O_2 \rightarrow CO_2$
  Carbon dioxide is result of these reactions. Carbon dioxide produced is released to the air through chimneys of power stations. Thus the cycle is completed and all carbon dioxide returns to the atmosphere.

Green House Gases:

The sun sends energy to the earth in two forms, light and heat. Some of the heat energy reflects back to the space, some however are trapped inside the Earth. This is caused by some gases and it is called **the greenhouse effect**. The main greenhouse gases are carbon dioxide and methane.

Carbon dioxide is formed in many ways. It is formed on a large scale in power stations by the combustion of carbon containing fuels. Carbon dioxide is also caused by respiration of living organisms. The gas can also be produced by a reaction between an acid and a carbonate, like that of the corrosion limestone.

Methane, the other greenhouse gas is formed by animals. When animals eat and digest their food, methane gas is one of the waste products of this process. It is released to the atmosphere by animals. When plants die and decompose over many years, methane gas is also produced.

The greenhouse effect poses a threat to the world now days. This is because greenhouse gases, especially carbon dioxide, have increased in amounts in the atmosphere due to activity of humans. Lots of fuel combustion is taking place around the world, increasing the levels of CO_2, while trees are being chopped off to made use of instead of leaving to replace CO_2 with oxygen. These activities cause an increase of the levels of CO_2 in the atmosphere, which leads to more heat trapping in earth. This rises the global temperature of the earth causing what's called **global warming**.

Global warming is the increase of the temperature of the earth due to the increase of levels of greenhouse gases. Global warming has effects on the earth. To start with, it north and south poles, which are made of ice, will start to melt raising sea levels. The sea temperature will also rise causing death to marine lives. This is also accompanied by other natural disasters such as hurricanes and heavy rains.

Humans could prevent this by reducing combustion of fossil fuels and leaving forests to live.

Rusting:

Rusting is the corrosion of iron as a result of reaction with oxygen from air and water. If iron objects are left uncovered and exposed to air & water, iron will react with oxygen forming hydrated iron oxide (also known as rust). Rust is a reddish brown flaky solid which will fall of the object making it thinner and loses it its shape. Iron must come in contact with air and water in order for rusting to happen. The formula of rust is $Fe2O_3 . xH_2O$. Steel can also rust since it is made up of mostly iron.

Rusting can become very dangerous in some cases. For example, bridges that cross rivers stand on columns that are made of iron. The conditions of rusting are present in this case (Water from the river and oxygen from the air). There is a risk that the columns will rust and collapse with the whole bridge. In another case, ships are made of iron. Again, the conditions of rusting are present (water from the sea and oxygen from the air). In fact, this situation is more critical because sea water contains minerals that act as a catalyst to speed up the reaction of rusting.

There some available methods to prevent rusting. These methods are based on covering the iron object with another substance to create a barrier between iron and oxygen and water so that rusting does not take place:

Painting: The iron or steel object is painted all over. The paint creates the desired barrier to prevent iron or steel coming in contact with air and water. This method is used in car bodies and bridges.

Electroplating: The iron or steel object gets electroplated with another metal that doesn't corrode. The object is usually electroplated with tin or chromium since they are very unreactive. This method is used in food cans and car bumpers.

Sacrificial Protection: This method is based on the idea that metals that are higher than iron in the reactivity series will react in preference to it and thus that metal is corroded and the iron is protected. Metals usually used as protectors in this method are zinc and magnesium since they are higher than iron in the reactivity series. In ships for example, zinc or magnesium bars are attached to the iron base of the ship which is in contact with water and oxygen from air. But rusting doesn't take place since zinc or magnesium is the one that gets corroded. These bars must be replaced from time to time because once they all get corroded, iron becomes unprotected and rusts. This method is usually used in ships or bridge columns. The zinc or magnesium bars do not have to completely cover the iron or steel because as long as they are attached to each other the zinc or magnesium bars get corroded and not the iron.

Galvanisation: Galvanisation is a very reliable method for preventing rusting. It is basically covering the whole object by a protective layer of zinc. This can be done either by electroplating the object with zinc or dipping it into molten zinc. The zinc layer provides a barrier that prevents iron or steel from coming in contact with air and water. The zinc gets corroded instead iron thus protecting it. If the a part of the zinc coat falls off and the iron or steel gets exposed to air and water, the bare part still doesn't get corroded since it is protected by sacrificial protection now.

Haber process:

Haber process is the manufacture of ammonia by reacting nitrogen and hydrogen together. Nitrogen needed for this process is obtained from fractional distillation of liquid air. Hydrogen needed could be obtained by three ways, either reacting methane with steam, electrolysis of brine or cracking of alkanes.

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

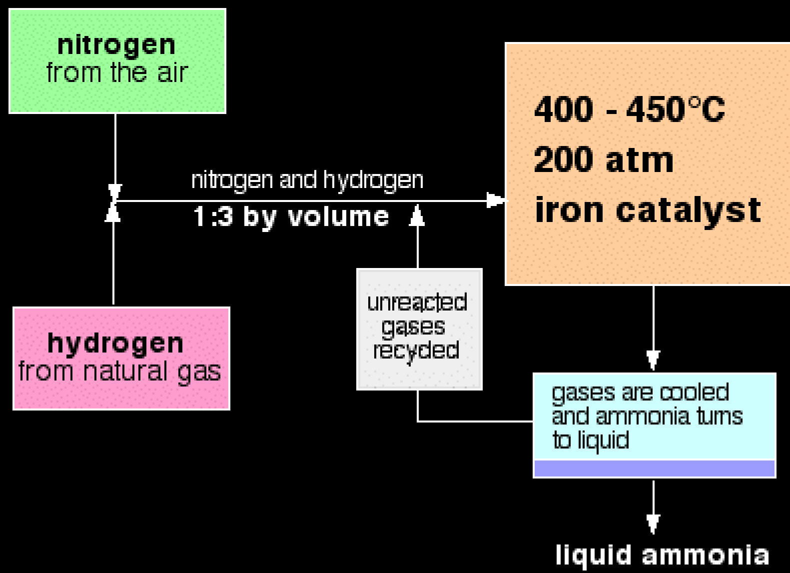
→→→→→→→→→→→	←←←←←←←←←←←
• Exothermic	• Endothermic
• Decreases pressure	• Increases pressure

How to obtain more ammonia:

In this reaction, very little of the reactants react forming ammonia. Some factors must be changed to shift the equilibrium to the right and obtain more ammonia. We want to shift the equilibrium to the right, so we should do the opposite of what the forward reaction does:

- The forward reaction is exothermic. We should decrease the temperature. This reaction should be done at high temperature; we want to lower this temperature. But beware that a very low temperature will make the reaction very slow since particles will lose their kinetic energy. A temperature which is low enough to shift the equilibrium to the left and isn't too low to make the process slow is 450ºC.
- The forward reaction decreases the pressure. This is because we've got 4 moles of gases (1 from nitrogen and 3 from hydrogen); each mole needs a volume of $24dm^3$ which means that the reactants need a volume of $96dm^3$. In the products we have only 2 moles of gas which come from ammonia gas. This means it needs $48dm^3$. The reactants exert more pressure than the products. We should increase the pressure. This will make the equilibrium shift to the right to convert more reactants into products to decrease the high pressure and drop it down to normal. The optimum pressure for this reaction is 200atm. Increasing the pressure also increases the rate since it increases the frequency of effective collisions between the particles.

- To speed the reaction even more, a catalyst could be used. The best catalyst for this reaction is powdered iron. A catalyst increases the rate of both the forward and the backward reaction, but since we've changed other factors, the equilibrium will still be shifted to the right. A catalyst does not have an effect on the position of the equilibrium.



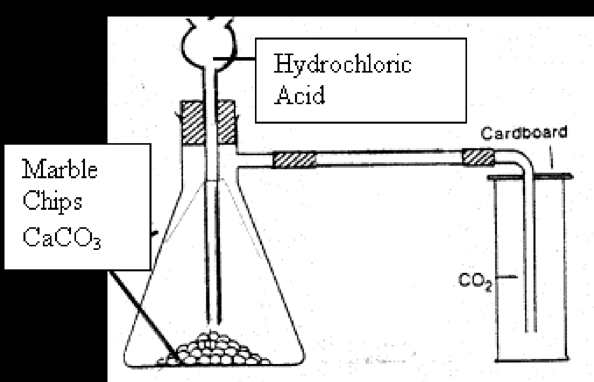
NPK Fertilizers

Fertilizers contain minerals that make a plant grow quick and healthy. THEY ARE OFTEN CALLED NPK FERTILIZERS. They contain the elements nitrogen (N) phosphorus (P) and potassium (K). Nitrogen compounds make plant proteins, phosphorus makes plant roots grow and potassium makes the flowers and fruits of plants.

Displacement of Ammonia from its salt

AMMONIUM SALTS : These salts will react with a base to produce AMMONIA GAS. An example is the reaction of ammonium chloride with calcium hydroxide to make ammonia gas. The gas is tested and is THE ONLY ALKALI GAS. IT TURNS RED LITMUS BLUE

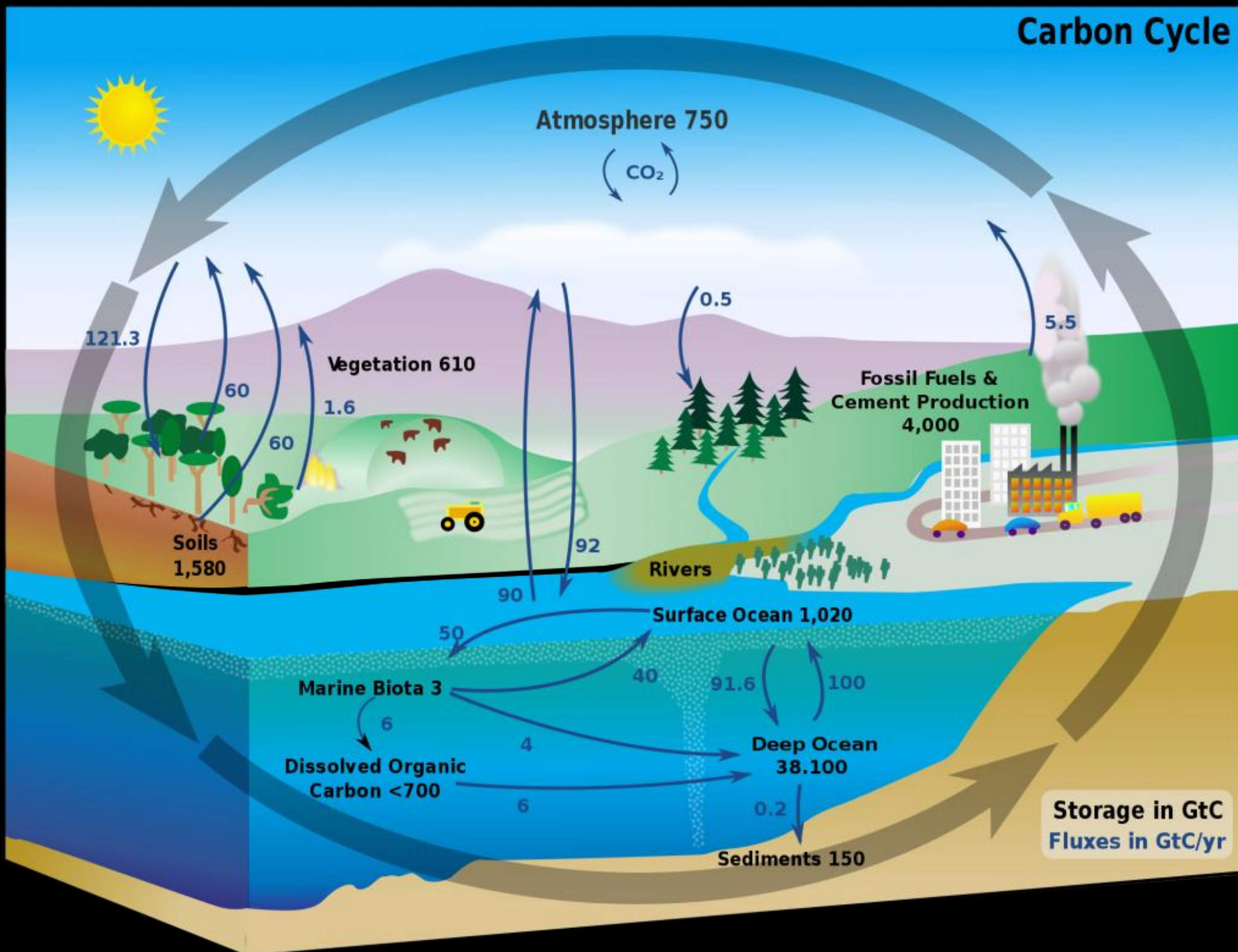
Formation of carbon dioxide

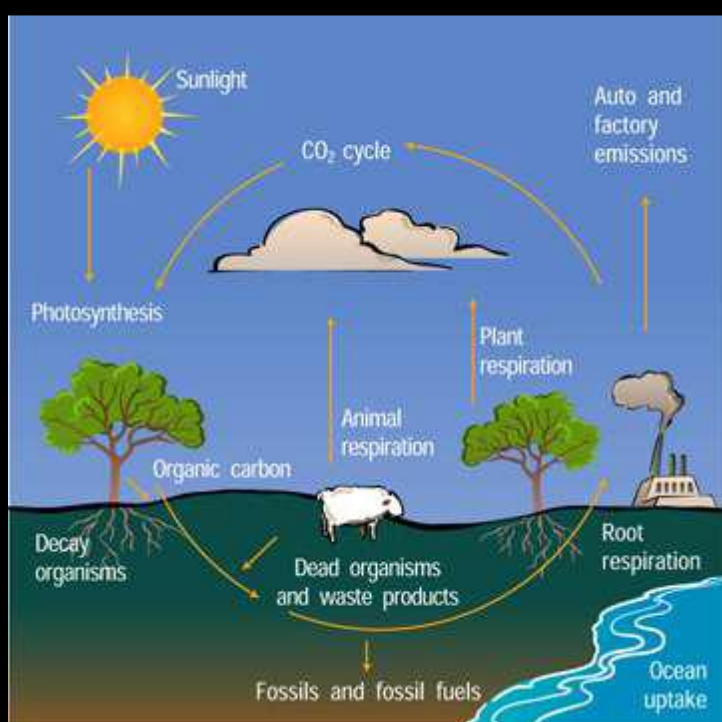


This gas is easily made in the laboratory by adding hydrochloric acid to marble chips. The gas is made by DOWNWARD DELIVERY as it is HEAVIER THAN AIR.

WE CAN TEST FOR CO2 AS IT WILL TURN LIMEWATER MILKY OR PUT OUT A LIGHTED SPLINT.
Carbon dioxide gas is also formed from combustion. Most of the common fuels today are HYDROCARBONS – They contain only HYDROgen and CARBON. When a hydrocarbon is burnt in a large amount of air (complete combustion), It reacts with the oxygen in the air (IT IS OXIDISED) to form CARBON DIOXIDE AND WATER.
This is an EXAMPLE OF COMBUSTION
FUEL + OXYGEN GAS = CARBON DIOXIDE AND WATER BURNING METHANE (NATURAL GAS)
Methane + oxygen = carbon dioxide gas + water
$CH4(g) + 2O2(g) = 2CO2(g) + 2H2O(l)$
Carbon dioxide is also a PRODUCT OF RESPIRATION.
Plants take in carbon dioxide and combine it with water to make sugar + oxygen. This process is called PHOTOSYNTHESIS.

The Carbon Cycle





Chapter 12: Sulphur

Sulphur is a non metal element in group 6 of the periodic table. Sulphur has many useful properties which make it widely used in the industry.

Name some sources of Sulphur

Can be found in elemental form in underground sulphur beds in USA, Texas, Poland, Mexico, Japan, Ethiopia, Australia, Sicily

Methods/Sources:

- Sulphur is found in crude oil/natural gas
- Byproduct of extraction from metal ores (e.g. Zinc Blende, ZnS)
- It's also released by volcanoes

Uses of Sulphur

- Sulphur is used in the manufacture of sulphur dioxide and sulphuric acid in the *contact process.*
- Vulcanising Rubber
- Disinfectant
- Used to make matches & explosives

Uses of Sulphur Dioxide:

- Sulphur Dioxide is manufactured via the heating of sulphur in air
- It is used as bleach in wood pulp manufacture
- It is used as food preservative (as it kills germs)

Contact Process (Manufacturing of Sulphuric Acid):

Sulphuric acid is one of the most important chemicals in the industry since it has a role in the manufacturing of almost every product. Sulphuric acid is manufactured by a process called Contact Process and it involves several steps:

1. Making the sulphur dioxide
2. Converting the sulphur dioxide into sulphur trioxide
3. Converting the sulphur trioxide into sulphuric acid

1. Making the sulphur dioxide

Sulphur is first burned in air producing sulphur dioxide:

$$S(s) + O_2(g) \rightarrow SO_2(g)$$

2. Converting the sulphur dioxide into sulphur trioxide:

This is a reversible reaction, and the formation of the sulphur trioxide is exothermic.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

Step 2 Reaction Conditions:
2atm of pressure
Vanadium Pentoxide (V_2O_5) Catalyst
450 °C

3. Converting the sulphur trioxide into sulphuric acid

This can't be done by simply adding water to the sulphur trioxide - the reaction is so uncontrollable that it creates a fog of sulphuric acid. Instead, the sulphur trioxide is first dissolved in concentrated sulphuric acid:

$$H_2SO_4(l) + SO_3(g) \rightarrow H_2S_2O_7(l)$$

The product is known as **fuming sulphuric acid** or **oleum**.

This can then be reacted safely with water to produce concentrated sulphuric acid - twice as much as you originally used to make the fuming sulphuric acid.

$$H_2S_2O_7(l) + H_2O(l) \rightarrow 2\ H_2SO_4(l)$$

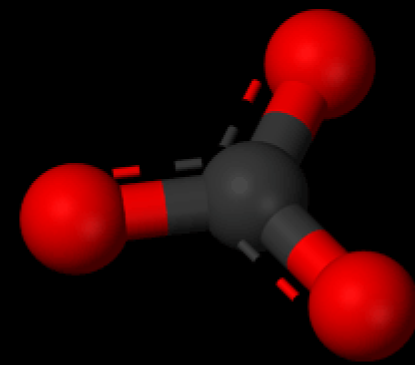
The average percentage yield of this reaction is around 30%.

Properties of Sulphuric Acid

- Dilute sulphuric acid is a typical dibasic acid in respect to metal, carbonate and base reactions.
- Concentrated sulphuric acid is often used as a drying agent.

Chapter 13: Carbonates

Carbonates are salts of carbonic acids (H_2CO_3). Carbonates are very useful salts, specially calcium carbonate ($CaCO_3$).



(Ball-and-stick model of the carbonate ion, CO_3^{2-})

Sources of Calcium Carbonate:

Calcium carbonate can be found in large amounts in the Peak District. It is found as a type of rocks called limestone near rivers.

Forms of Calcium Carbonate:

Limestone is not the only form of calcium carbonate. Marble and chalk are also other forms of this valuable salt. Chalk is made of shells of marine algae. Marble on the other hand, is a metaphoric rock made of limestone at high pressure.

Uses of Calcium Carbonate:

Calcium carbonate has numerous uses. You have previously studied one of them which is helping in the extraction of iron from its ore. Another one of these is the **manufacture of cement**. In this process, limestone or chalk is mixed with clay and heated in a rotary kiln. The substance in the mixture react producing cement which is a mixture of calcium aluminate ($Ca(AlO_2)_2$) and calcium silicate ($CaSiO_3$). This is then made into powder. When it is used, it is sprayed with water make its particles hold tight.

Manufacture of Lime:

One of the industrial uses of calcium carbonate is the manufacturing of lime from it. Lime is calcium oxide salt. This process takes place in a device called lime kiln and it is based on the thermal decomposition of calcium carbonate. Limestone is inserted in the kiln and heating starts. At the bottom of the kiln air is being blown in. this is also where lime is collected. The other product of this reaction, carbon dioxide gas, evolves and escapes at the top of the kiln.

$$\mathbf{CaCO_3 \rightleftharpoons Cao + CO_2}$$

(Limestone) (Lime) (Carbon Dioxide)

Uses of Lime:

Lime can be used to neutralise soil acidity in farms. This is because it is a basic oxide. Slaked lime (Calcium hydroxide; $Ca(OH)_2$) is also a basic oxide can be used as an alternative to lime for neutralising soil acidity. Another use of lime is neutralising sulphur dioxide waste in power stations. This is because sulphur dioxide is an acidic oxide while lime is a basic one. This process is called desulphurisation which you have studied earlier.

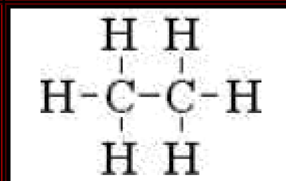
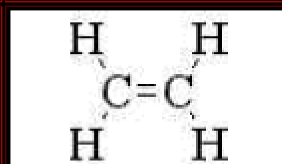
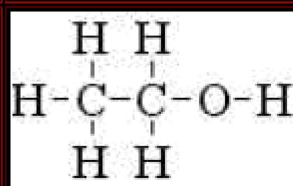
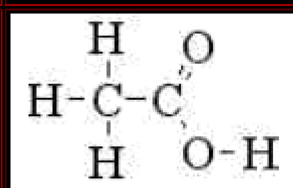
Chapter 14: Organic Chemistry

Structural formulae :

As well as using a normal type of molecular formula to describe an organic molecule, they can be represented by drawing out their structure i.e. by showing how the atoms are connected, or bonded, to each other.

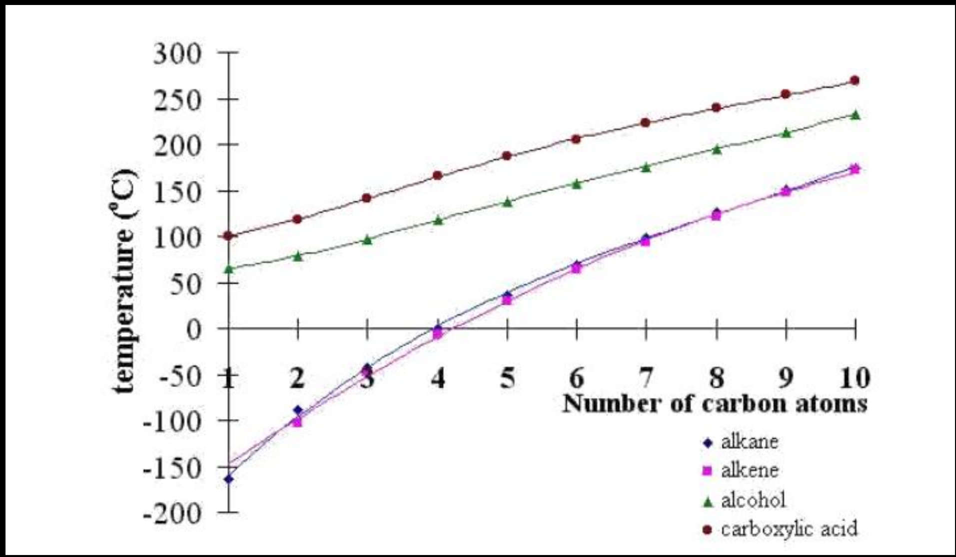
In order to do this a few rules have to be followed –

- carbon atoms must be bonded four times;
- oxygen atoms must be bonded twice;
- hydrogen atoms must bond only once.

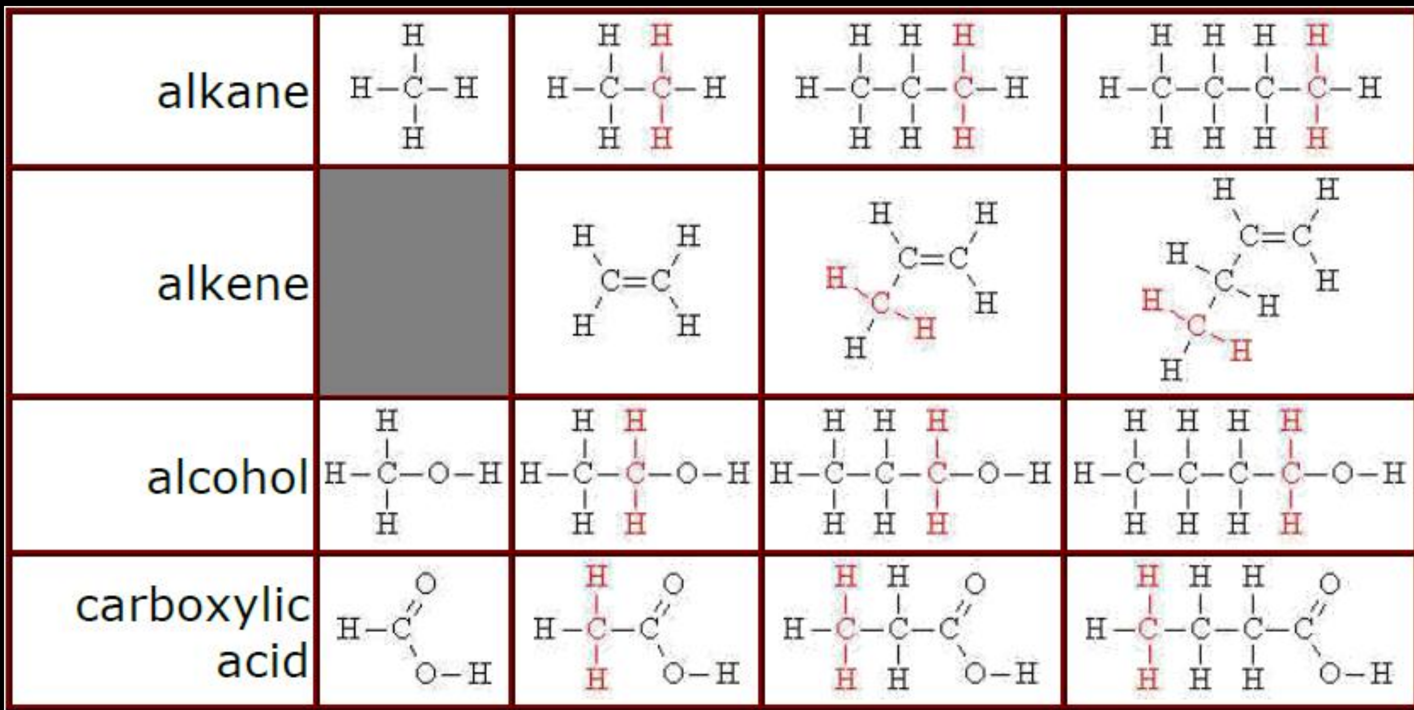
Substance	**Formulae**
Ethane	
Ethene	
Ethanol	
Ethanoic Acid	

Homologous Series :

A homologous series is a group of organic compounds with similar chemical properties and structural formula and a gradual change in physical properties e.g. melting point and boiling point



From the graph above, it can be seen that as the number of carbon atoms in the organic compound increases the boiling points increase.
Also, the boiling points tend to follow a straight line with the higher members of each group i.e. the difference between boiling points tends towards a single value.



Alkane:

Alkanes are the simplest homologous series of compounds and their names follow this pattern,
CH_4 - methane
C_2H_6 - ethane
C_3H_8 - propane
C_4H_{10} - butane
C_5H_{12} – pentane

The general chemical formula for an alkane is C_nH_{2n+2}.
Branched alkanes -
When the alkane is not just a simple straight chain of carbon atoms joined together the names become a little more complex.
The longest connected chain of carbon atoms must be found as before and the alkane name generated as usual. Then the name for the pendent group is found, again by counting the number of carbon atoms present, and used as a prefix.
CH_3- group : methyl___
CH_3CH_2- group : ethyl___
$CH_3CH_2CH_2$- group : propyl___
$CH_3CH_2CH_2CH_2$- group : butyl___

Reactions of alkanes :

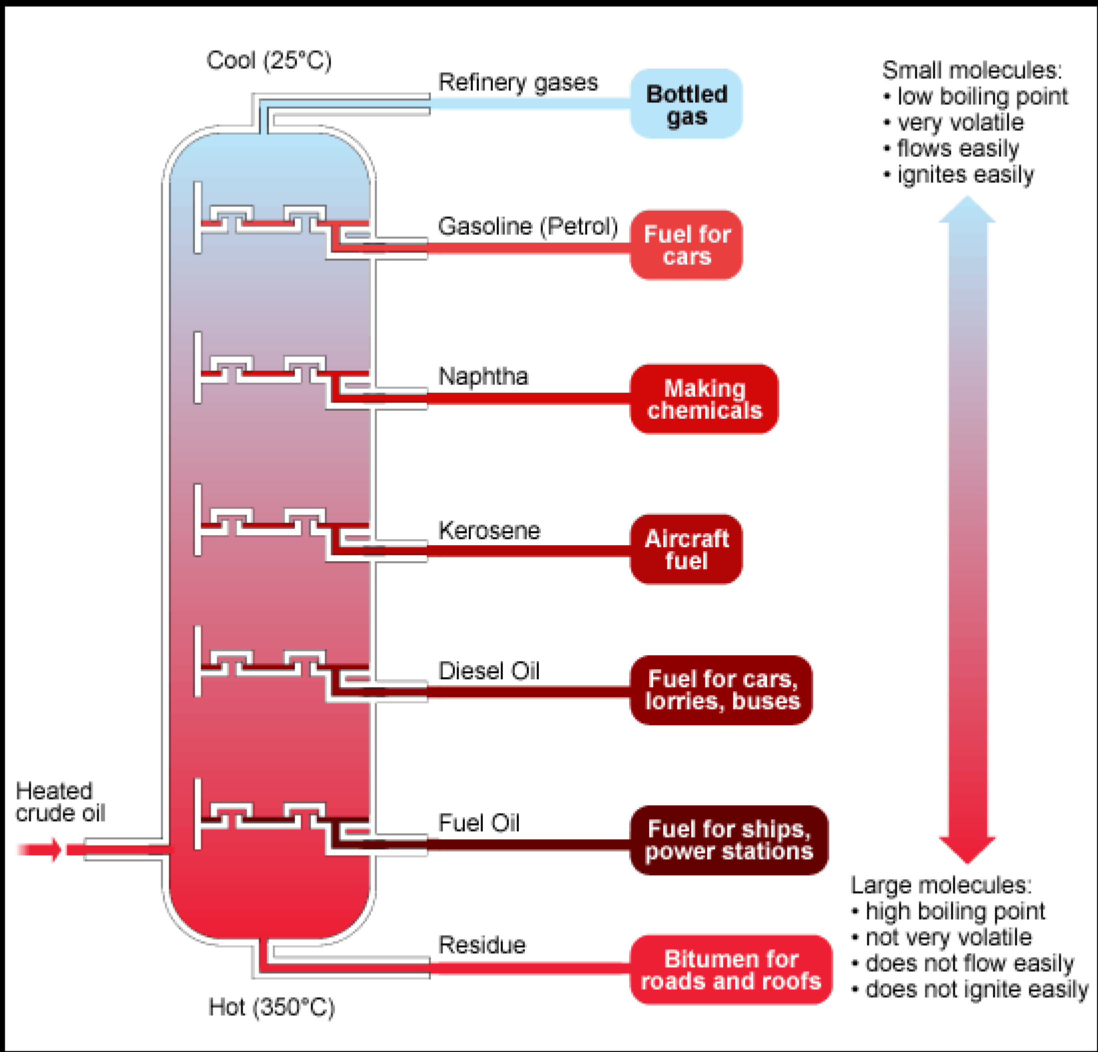
(i) Combustion -
Alkanes, along with all other types of hydrocarbon, will burn in an excess of oxygen to give carbon dioxide and water only as the products,
e.g. $CH_4(g) + 2O_2(g)\ CO_2(g) + 2H_2O(g)$
in general,
$C_nH_{2n+2}(g) + (1.5n+0.5)O_2(g)\ nCO_2(g) + (n+1)H_2O(g)$
If there is not enough oxygen present then instead of carbon dioxide, carbon monoxide, CO, is produced. Carbon monoxide is particularly toxic and absorbed into blood, through respiration, very easily. For domestic heating systems

it is particularly important that enough air can get to the flame to avoid carbon monoxide being generated in the home. Car engines also require a lot of air and there is a lot of research going on to make the internal combustion engine more efficient, and so put out less carbon monoxide.
Note also that both alkanes and carbon dioxide are green house gases, i.e. they trap infra-red (i.-r.) radiation inside the Earth's atmosphere, gradually increasing global temperatures.

(ii) Halogenation -
The only other reaction that an alkane will undergo is a reaction with a halogen (chlorine or bromine typically) with UV light present as an initiator of the reaction,
e.g. CH4(g) + Br2(g) CH3Br(g) + HBr(g)
The UV light causes the formation of free radical halogen atoms by providing enough energy for the bond between the two halogen atoms to break. A halogen atom attacks the alkane, substituting itself for a hydrogen atom. This substitution may occur many times in an alkane before the reaction is finished.
A similar process occurs high up in the earth's atmosphere when CFC's and other organic solvents react with intense sunlight to produce free radicals, chlorine atoms in this case. These attack molecules of ozone (O3) depleting ozone's concentration and leading to the "holes".

Fractional Distillation:

Crude oil is a mixture of many different hydrocarbon compounds, some of them liquid and some of them gases. These compounds can be separated because the different length of alkanes will have different boiling points. The crude oil is heated up to about 350 C and is fed into a fractionating column, as in the diagram below



The vapours with the lowest boiling points pass all the way up the column and come off as gases, e.g. methane, ethane and propane. The temperature of the column gradually decreases the higher up the vapours go, and so various fractions will condense to liquids at different heights.
The fractions with the highest boiling points do not vaporize and are collected at the bottom of the fractionating column, e.g. bitumen

Cracking

In industry the fractions obtained from the fractional distillation of crude oil are heated at high pressure in the presence of a catalyst to produce shorter chain alkanes and alkenes. e.g. C10H22 C5H12 + C5H10

Alkane

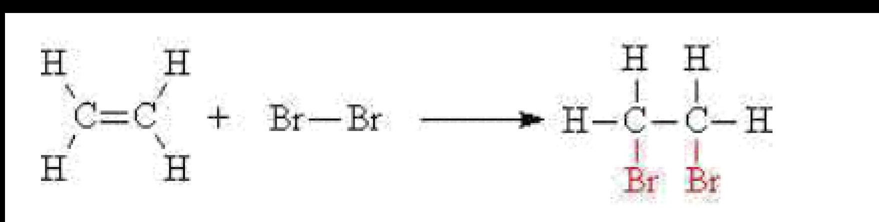
Alkenes all have a C=C double bond in their structure and their names follow this pattern,

C2H4 – ethane
C3H6 – propene
C4H8 – butane
C5H10 - pentene

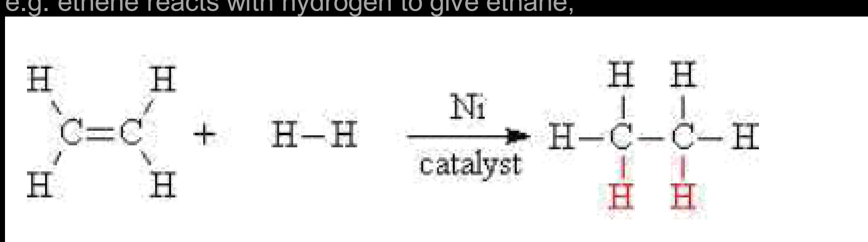
The general chemical formula for an alkene is C_nH_{2n}

Addition reactions of alkenes :

The double bond of an alkene will undergo an addition reaction with aqueous bromine to give a dibromo compound. The orange bromine water is decolourised in the process.
e.g. ethene reacts with bromine water to give 1,2-dibromoethane,

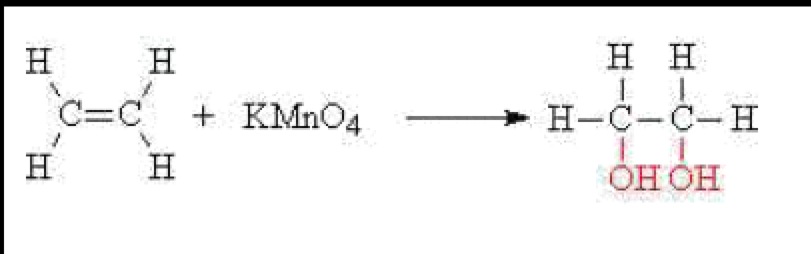


Hydrogenation -
Alkenes may be turned into alkanes by reacting the alkene with hydrogen gas at a high temperature and high pressure. A nickel catalyst is also needed to accomplish this addition reaction.
e.g. ethene reacts with hydrogen to give ethane,



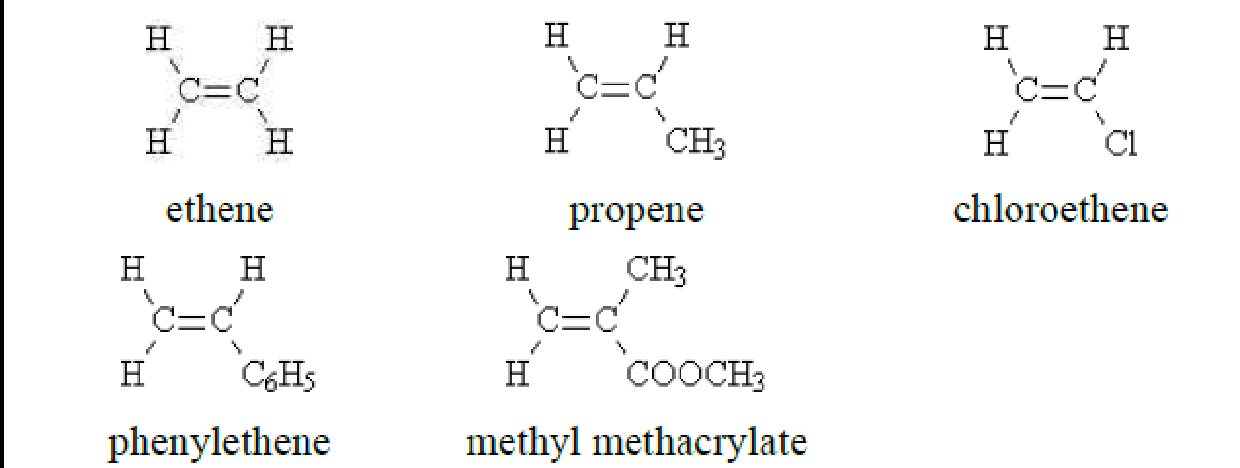
This reaction is also called saturation of the double bond. In ethene the carbon atoms are said to be unsaturated. In ethane the carbon atoms have the maximum number of hydrogen atoms bonded to them, and are said to be saturated.

Oxidation -
The carbon-carbon double bond may also be oxidised i.e. have oxygen added to it.
This is accomplished by using acidified potassium manganate(VII) solution at room temperature and pressure. The purple manganate(VII) solution is decolourised during the reaction.
e.g. ethene reacts with acidified potassium manganate(VII)(aq) to give ethan-1,2-diol,

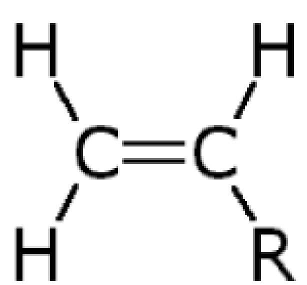


Addition Polymerisation

All alkenes will react with free radical initiators to form polymers by a free radicaladdition reaction.
Some definitions - monomer - a single unit e.g. an alkene.

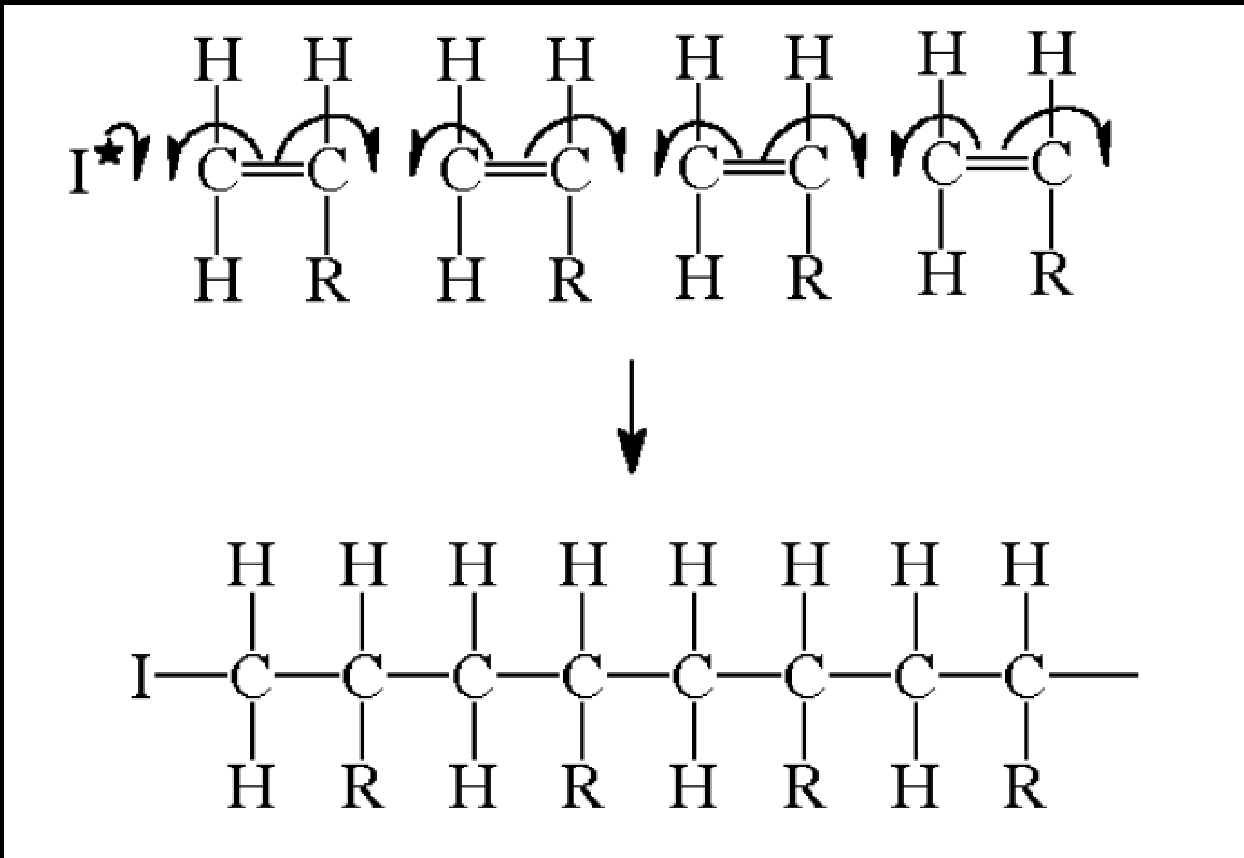


The alkene monomer has the general formula :



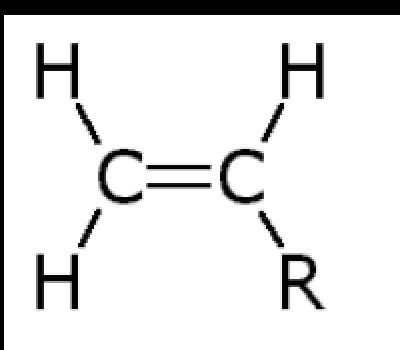
where R is any group of atoms, *e.g.* R=CH_3 for propene.

The reaction progresses by the separate units joining up to form giant, long chains –



polymer- a material produced from many separate single monomer units joined up together.
An addition polymer is simply named after the monomer alkene that it is prepared from,
e.g. ethene makes poly(ethene)
propene makes poly(propene)
phenylethene makes poly(phenylethene)
chloroethene makes poly(chloroethene)
methyl acrylate makes poly(methyl acrylate)

The structure above shows just 4 separate monomer units joined together. In a real polymer, however, there could be 1000's of units joined up to form the chains. This would be extremely difficult to draw out and so the structure is often shortened to a repeat unit. There are 3 stages to think about when drawing a repeat unit for a polymer –



Draw the structure of the desired monomer :
Change the double bond into a single bond and draw bonds going left and right from the carbon atoms :
Place large brackets around the structure and a subscript n and there is the repeat unit.
where R= H for ethene
= CH_3 for propene
= C_6H_5 for phenylethene
= Cl for chloroethene
= $COOCH_3$ for methyl acrylate

Polymer structure and properties –

When the individual alkene units join together to give a polymer they result in the formation of long chains of carbon atoms joined together. In any sample of a polymer there are many separate chains present. These chains will be of varying lengths, depending on the number of alkene units that make them up.

These separate chains entwine with one-another, much as cooked spaghetti does, forming weak attractions between the chains - but with no actual bonds between the chains,

Alcohol

Alcohols all have an -OH group and their names follow this pattern,

CH3OH - methanol
C2H5OH - ethanol
C3H7OH - propanol
C4H9OH - butanol
C5H11OH - pentanol

The general chemical formula for an alcohol is $C_nH_{2n}OH$.

Preparation of ethanol by fermentation –

Ethanol is prepared in the laboratory and in the alcoholic drinks industry, by the process of fermentation. This involves the use of an enzyme (yeast) that changes a carbohydrate, e.g. sucrose, into ethanol and carbon dioxide gas,
C6H12O6(aq) 2CH3CH2OH(aq) + 2CO2(g)

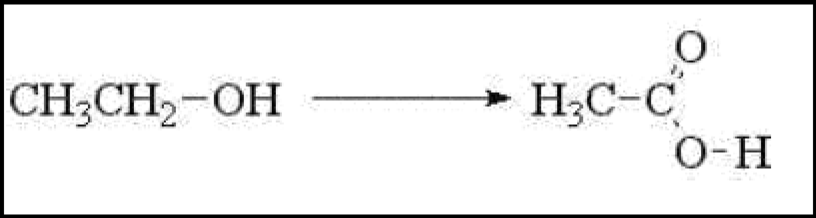
The yeast used requires a certain temperature to be active - somewhere between 15 and 37 °C. Too high a temperature and the yeast "dies" and too low a temperature causes the yeast to become dormant.
The production of carbon dioxide gas can be monitored by bubbling any gases produced during the reaction through limewater (calcium hydroxide(aq)). The formation of a white precipitate (calcium carbonate) in the limewater shows that carbon dioxide has been given off.

Dehydration of ethanol -

Experimental sheet for the dehydration of ethanol.
All alcohols contain hydrogen and oxygen (as well as carbon) and these atoms can be removed from an alcohol as a molecule of water (H2O). This type of reaction is called dehydration. It can be accomplished by passing alcohol vapour over a heated aluminium oxide catalyst.
e.g. ethanol can be turned into ethene,
CH3CH2OH(g) CH2=CH2(g) + H2O(g)

Oxidation of ethanol -

Experimental sheet for the oxidation of ethanol.
Oxidation can be defined as the addition of oxygen to a substance. This can be accomplished with alcohols by the use of acidified potassium dichromate(VI)(aq). This turns the alcohol into a carboxylic acid.
e.g. ethanol can be turned into ethanoic acid,



Carboxylic Acids

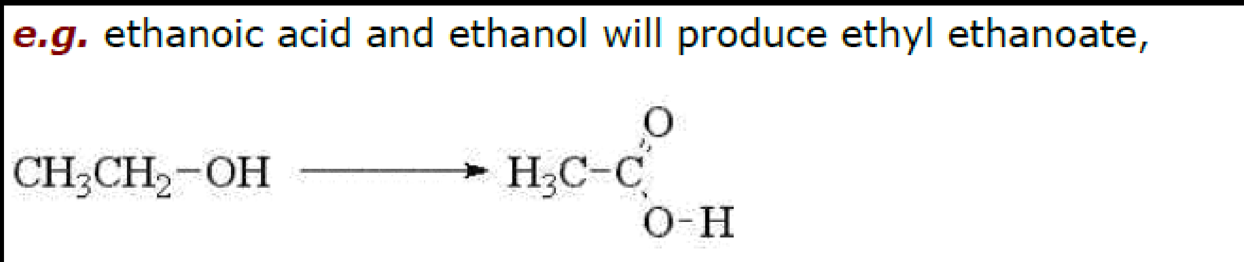
Carboxylic acids all have the -COOH structural group in them and their names follow this pattern,

HCOOH - methanoic acid
CH3COOH - ethanoic acid
C2H5COOH - propanoic acid
C3H7COOH - butanoic acid
C4H9COOH - pentanoic acid
The general chemical formula for a carboxylic acid is $C_nH_{2n1-}COOH$.

The Esterification of Ethanol to Ethyl Ethanoate

Introduction

Apart from the normal reactions of acids, such as reactions with metals and bases, ethanoic acid (along with all the carboxylic acids) will react with ethanol (or other alcohols) to give ethyl ethanoate (an ester) in a simple process.



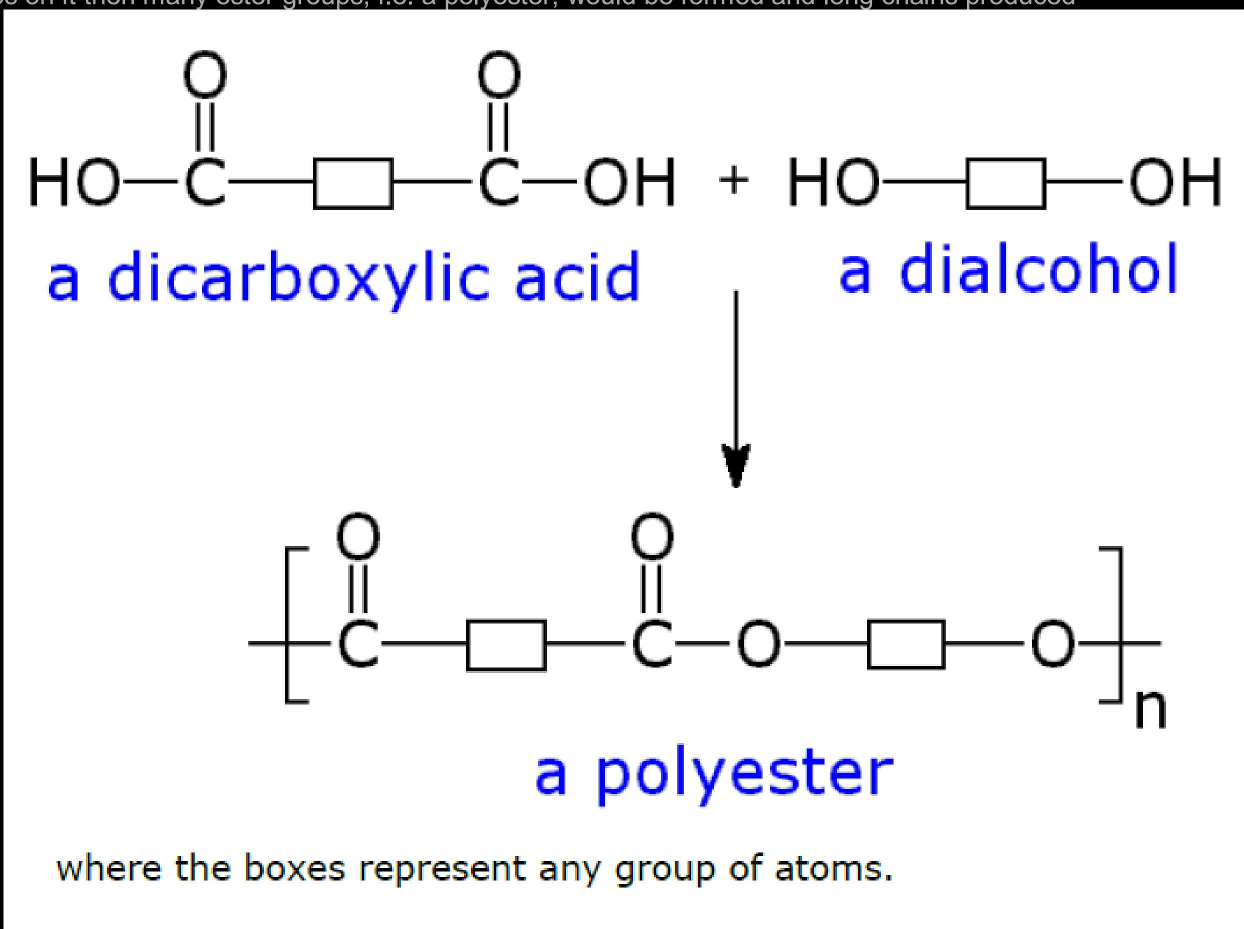
Condensation polymerisation :

As well as the addition polymers formed from alkenes and free radical initiators already mentioned, there is another method of preparing long chain polymers.

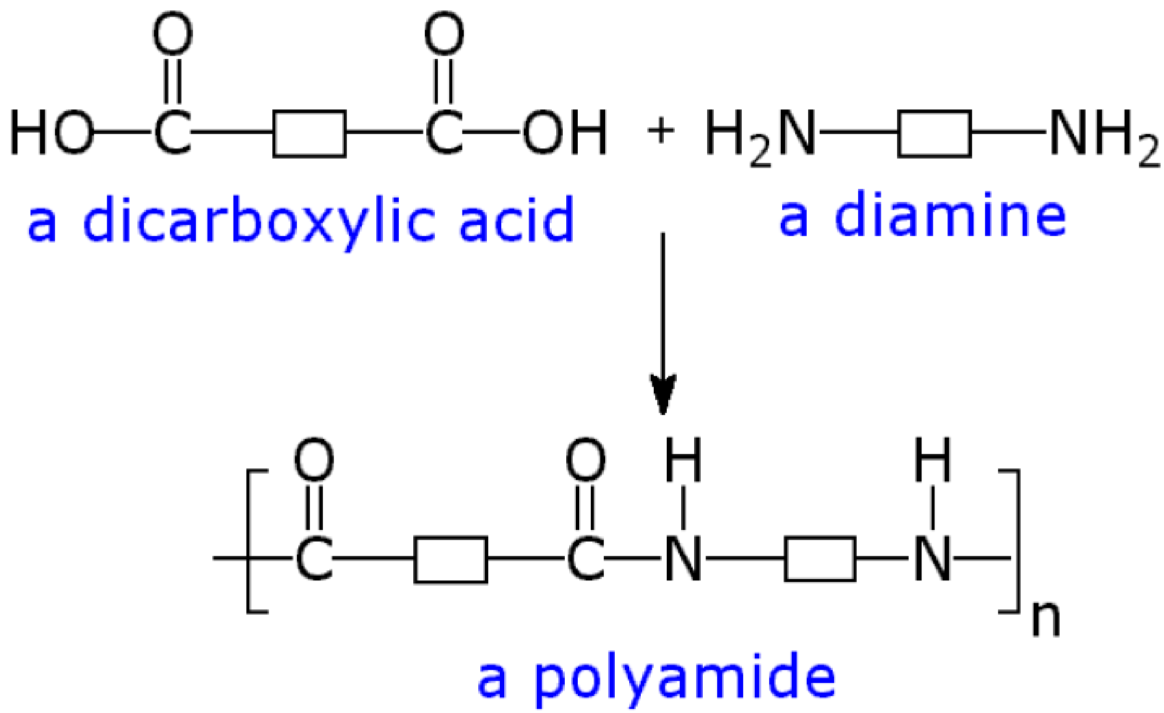
This second method of polymerisation relies on the reaction between a dicarboxylic acid and an dialcohol (or a diamine) and is called condensation polymerisation since water is released during the formation of the polymer chains.

A monocarboxylic acid will react with an alcohol to give an ester (see equation above).

If a molecule had two carboxylic acid groups on it, one at each end, and it reacted with a molecule with two -OH groups on it then many ester groups, i.e. a polyester, would be formed and long chains produced –



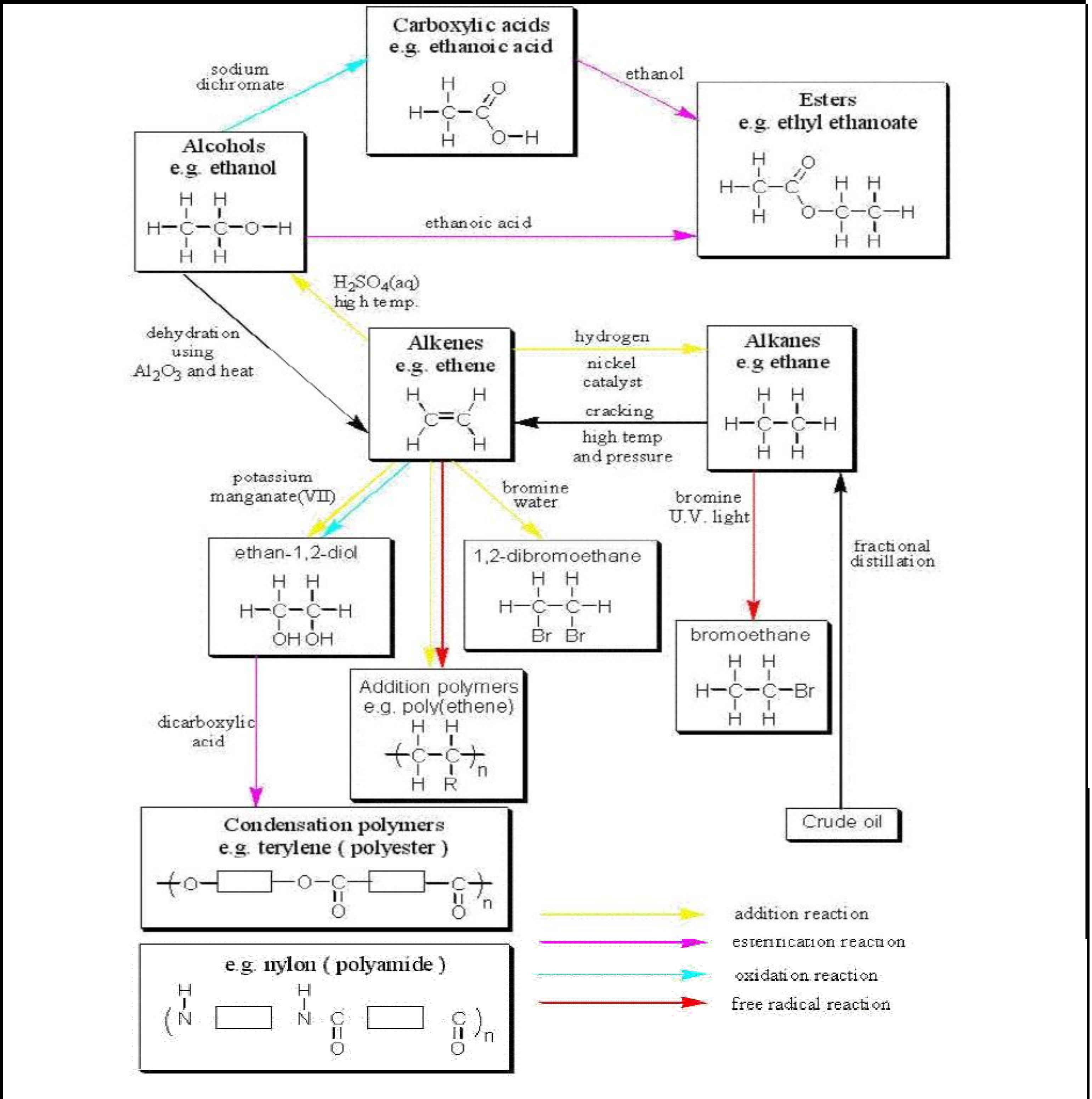
If the dialcohol is replaced by a diamine then a ***polyamide*** or ***nylon*** is formed -



Natural condensation polymers :
The above picture encompasses only the synthetic part of the organic work. There are a number of natural polymers required.
These are :
(i) Fats :
These natural materials contain the ester link found in the synthetic polyesters shown above.
They may be hydrolysed (broken down) by a reaction with sodium hydroxide (a strong base) and heat.
Once hydrolysed they form soaps (sodium salts of carboxylic acids) and glycerol (propan-1,2,3-triol).

Proteins :
These naturally occurring materials contain the amide link found in the synthetic polyamides shown above.
These compounds may also be hydrolysed by a reaction with enzymes and/or aqueous acid. Proteins in the food we ingest are broken down by stomach acids and enzymes which work at body temperature.
Once hydrolysed they form amino acids which can then be used by the human body to prepare vital chemicals needed to sustain life.

Saponification :
Saponification means "soap-making" and is a reaction in which a fat, or oil, is turned into a salt of a carboxylic acid. The oil is heated with a concentrated solution of a caustic base, such as sodium hydroxide. The base breaks down the ester links, forming alcohol groups and carboxylate ion groups on different molecules.



Carboxylic acids
e.g. ethanoic acid
sodium dichromate
ethanol
Esters
e.g. ethyl ethanoate
Alcohols
e.g. ethanol
ethanoic acid
H_2SO_4(aq)
high temp.
dehydration using
Al_2O_3 and heat
Alkenes
e.g. ethene
hydrogen
nickel catalyst
Alkanes
e.g ethane
cracking
high temp
and pressure
potassium
manganate(VII)
bromine
water
bromine
U.V. light
fractional
distillation
ethan-1,2-diol
1,2-dibromoethane
bromoethane
dicarboxylic
acid
Addition polymers
e.g. poly(ethene)
Crude oil
Condensation polymers
e.g. terylene (polyester)
e.g. nylon (polyamide)
addition reaction
esterification reaction
oxidation reaction
free radical reaction