

# CHEMISTRY

## "O" Level Notes

Syllabus Code 5070

Name: \_\_\_\_\_

Class: \_\_\_\_\_

My aim for O Level is \_\_\_\_\_

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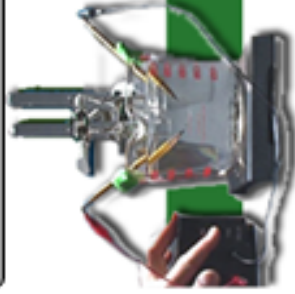
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**GCE O LEVEL SYLLABUS 2010  
CHEMISTRY (5070)**

Name: \_\_\_\_\_ Date: \_\_\_\_\_

**CHAPTER 1 – EXPERIMENTAL CHEMISTRY**

**1.1 Experimental Design**

**Volumes of Liquids**

SI unit: cubic metre (m<sup>3</sup>)

Large volume measurement: decimetres (dm<sup>3</sup>)

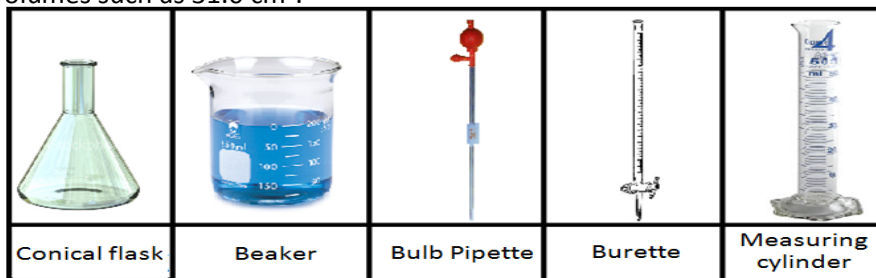
$$1 \text{ dm}^3 = 1\,000 \text{ cm}^3$$

Daily life measurement: millilitres (ml) or litres(l)

$$1 \text{ litre} = 1\,000 \text{ ml}$$

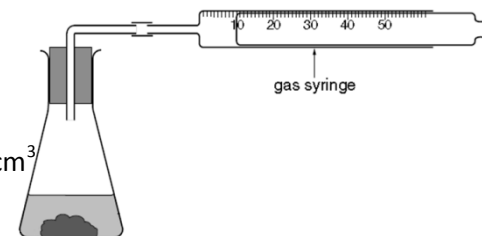
Apparatus for measuring liquids depends on:

- The volume being measured
- How accurate the measurement needs to be
- *Beaker* hold approximate volume of 100 cm<sup>3</sup> and 250 cm<sup>3</sup>.
- *Conical flask* hold approximate volume of 100 cm<sup>3</sup> and 250 cm<sup>3</sup>.
- *Measuring cylinder* has accuracy to 1 cm<sup>3</sup>.
  - Reading to be taken nearer to the meniscus (bottom line).
  - If reading is 23 cm<sup>3</sup>, should not write 23.0 cm<sup>3</sup> as the '0' means accurate to 0.1 cm<sup>3</sup>.
- *Burette* has long scale of 0 – 50 cm<sup>3</sup>, accurate to 0.1 cm<sup>3</sup>
  - Liquid level to be measured before and after top opening. The difference of volume gives the liquid volume poured off.
- *Bulb pipette* measures exact volumes such as 20.0, 25.0 or 50.0 cm<sup>3</sup>, not odd volumes such as 31.0 cm<sup>3</sup>.



**Volumes of Gases**

Measured with gas syringe, up to 100 cm<sup>3</sup>



**Temperature**

Measured with thermometer. 2 types are:

- a) Mercury-in-glass
- b) Alcohol-in-glass

SI Unit: Kelvin (K)

Daily life measurement: degree Celsius (°C)

$$K = ^\circ C + 273$$

**Time**

SI Unit: seconds (s)

Other Units: minutes (min)/hour (h)

Measured with:

- (a) Clock
- (b) Digital stopwatch



**Mass**

Mass – the measure of amount of matter in a substance

SI Unit: kilogram (kg)

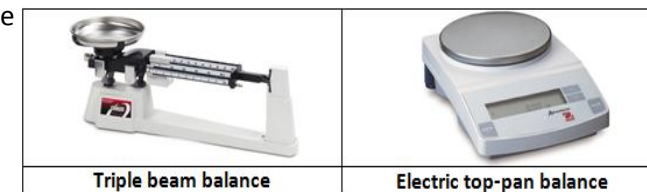
Other Units: grams (g)/milligrams (mg)

Large volume measurements: tonnes (t)

$$1 \text{ tonne} = 1\,000 \text{ kg}$$

Measured with:

- (a) Electric “top-pan” balance
- (b) Triple beam balance



### 1.2 Methods of Purification and Analysis

*Pure substance* – single substance not mixed with anything else

**E.g:** white sugar, copper sulfate crystals, distilled water

*Mixture* – contains two or more substances. Its quantity is more on Earth.

**E.g:** seawater (salt, water & dissolved solids), milk (fats & dissolved solids)

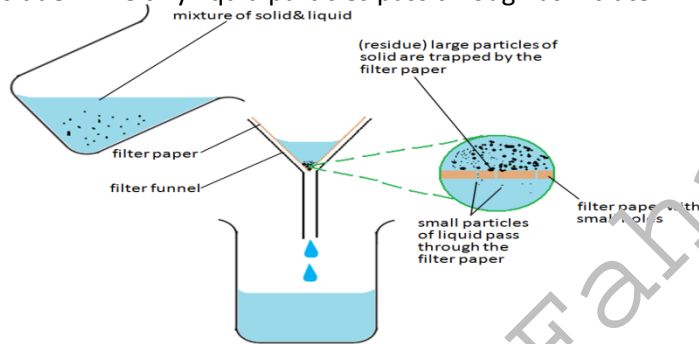
### 2.2 Obtaining Pure Substances

*Purification* – The separation process of mixtures into pure substances by using physical methods without chemical reactions.

#### Filtration

*Filtration* – separates insoluble solid from a liquid.

- Mixture is poured through a filter with tiny holes made of paper.
- Large solid particles cannot pass through the pores and trapped in it as residue while tiny liquid particles pass through as filtrate.

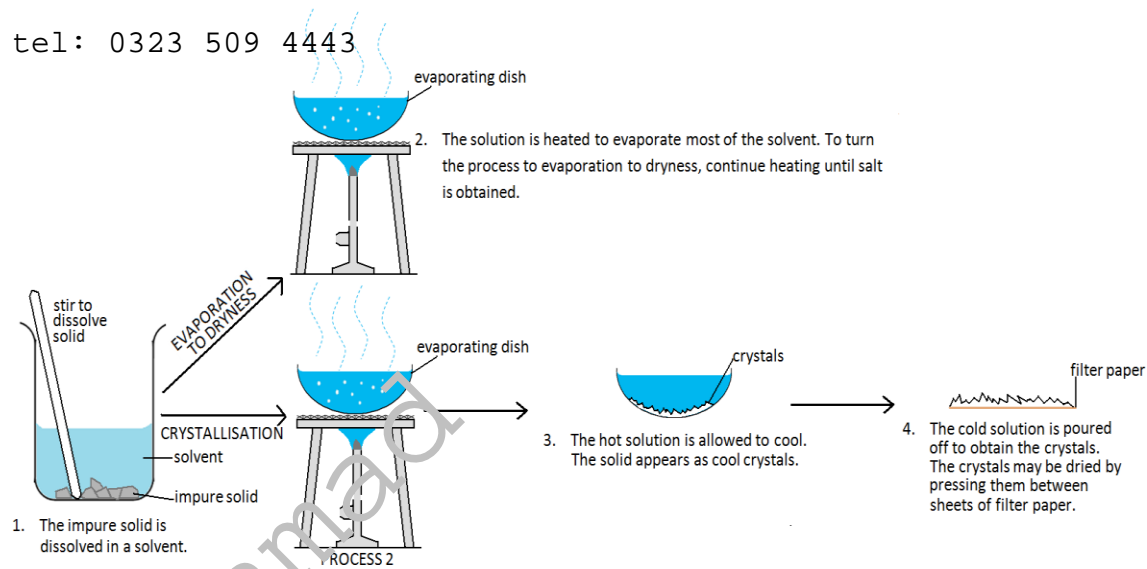


#### Crystallisation & Evaporation to Dryness

*Crystallisation* – separation of dissolved solid from a solution as well-formed crystals

*Evaporation to Dryness* – separation of dissolved solid from a solution as crystals of salt by evaporating all the liquid off.

FULL OVERVIEW PROCESS ON THE RIGHT:

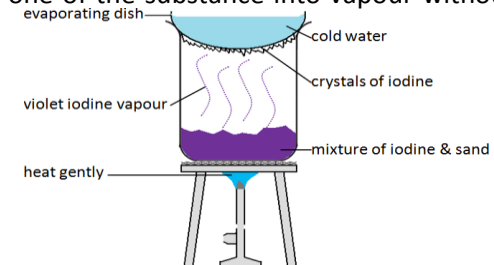


*Why crystallisation occur?*

- Solubility of most solutes decrease as temperature decrease, when solution cools, solution can't hold more solute (*saturated*) so the extra solute separates as pure crystals.

#### Sublimation

*Sublimation* – separation of a mixture of solids which one of it sublimates (by heating the solid mixture to turn one of the substance into vapour without going through liquid state).



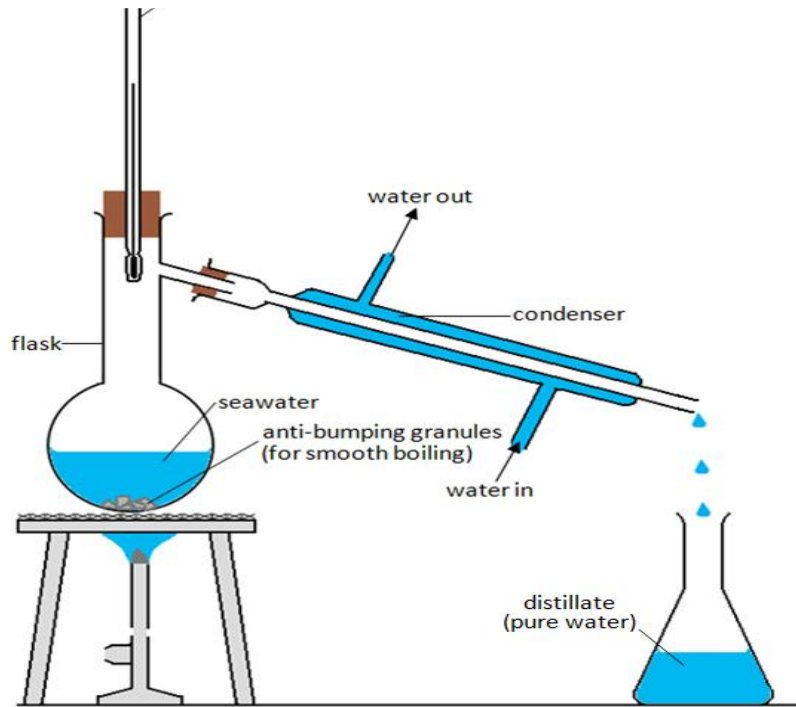
When mixture of iodine and sand is heated, iodine sublimates (turns into vapour directly) then cools and crystallises when it reaches cold water area

**Examples of sublimable solids:** CO<sub>2</sub> (s), dry FeCl<sub>3</sub> (s), dry AlCl<sub>3</sub> (s)

#### Simple Distillation

*Simple Distillation* – separation of pure liquid from a solution by condensing vaporised liquid

Condensed pure liquid – *distillate*



**Process of Distillation:**

Solution is heated, and steam (pure vapour) is produced. The steam is cooled in condenser to form pure liquid. Solute remains in the flask.

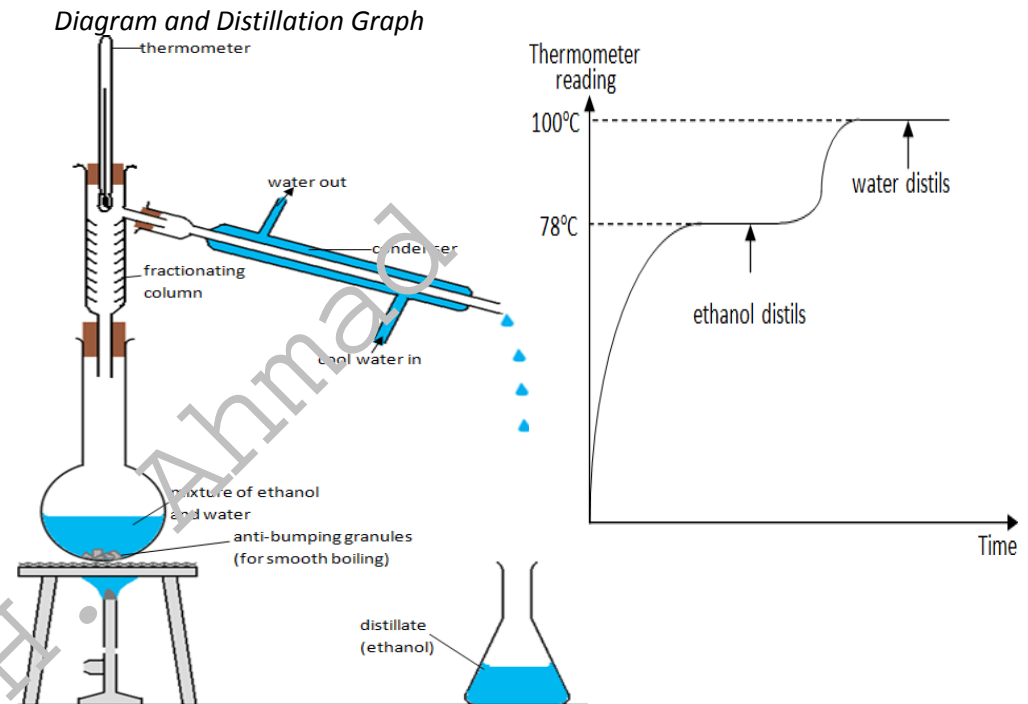
**Fractional Distillation**

*Fractional Distillation* – separates mixture of miscible (soluble) liquids with widely differing boiling points.

Use of **fractionating column** separates them

Process of Fractional Distillation: E.g. ethanol and water

Mixture of ethanol and water is placed in flask and heated. Ethanol with lower boiling point boils and vaporises first and reach fractionating column then cools and condenses into ethanol as it passes through condenser. Temperature will stay constant until all ethanol is distilled. Water will distil the same way after all ethanol is distilled.

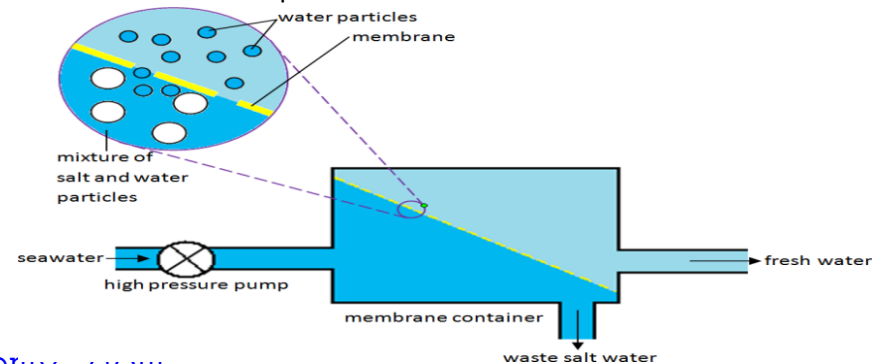


**Uses of fractional distillation:**

- Separates pure oxygen and pure nitrogen from liquefied air
- Separates substances in petroleum (crude oil) into fractions
- Separates alcohol to produce alcoholic drinks

**Reverse Osmosis**

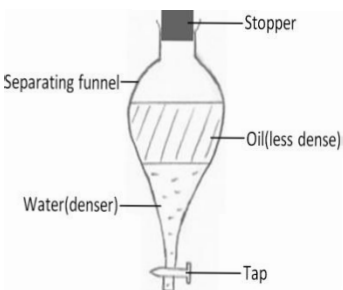
*Reverse Osmosis* – separates a solution (e.g. seawater) by pressurizing the mixture against a membrane which separates the solute and the solvent



- Seawater is pumped under great pressure into a closed container onto a membrane forcing water particles but salt particles to pass through. Some salt particles may still pass through.

### Use of Separating Funnel

Separating Funnel is used to separate immiscible liquids



- two liquids insoluble to each other will create two layers of overlying liquids of each type. To separate, take the stopper off and turn the tap on to run the denser liquid at the bottom off the funnel and leave the less dense liquid in the funnel by turning the tap off and reset the stopper at its original position.

### Chromatography

Chromatography – a method of separating and identifying mixtures.

#### The need for Chromatography

- Separates and identify mixtures of coloured substances in dyes
- Separates substances in urine, drugs & blood for medicinal uses
- To find out whether athletes have been using banned drugs

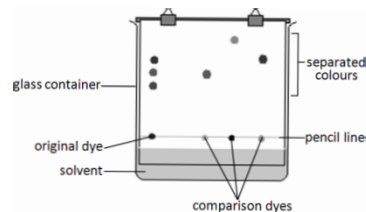
### Separating Mixtures of Coloured Substances

Obtain a dye sample then put a drop of the sample on a pencil line drawn on the filter paper then dip the paper into a solvent with the level below the spot. The dye will dissolve in solvent and travel up the paper at different speed. Hence they are separated.

### Identifying Mixtures of Coloured Substances

In the diagram on the right, drop of sample dye is placed on pencil line. The result shows that:

- The sample dye is made of 3 colours.



- 2 comparison dyes are of one of the compositions of the original dye as the spots are of same colour and distance.
- a comparison dye isn't part of sample.

### Separating and Identifying Mixtures of Colourless Substances

To do this a locating agent is to be sprayed on filter paper.

**Locating Agent** – a substance that reacts with substances (e.g. sugars) on paper to produce a coloured product

### R<sub>f</sub> Values

To identify unknown dye in the diagram at the very top:

$R_f \text{ value} = \frac{x}{y}$

Where  $x$  = distance moved by the substance and;

$y$  = distance moved by the solvent

### Checking the Purity of Substances

- Pure substances have FIXED MELTING AND BOILING POINTS.

- ❖ Pure water boils at 100°C and melts at 0°C.

- Impure substances have NO FIXED MELTING AND BOILING POINTS. They melt and boil at a RANGE OF TEMPERATURES

- ❖ e.g. starts boil at 70°C, completes boil at 78°C
  - Also, it can VARY melting and boiling points of pure substances.
- ❖ e.g. pure water boil at 100°C, but with salt is at 102°C

### 1.3 Identification of Ions and Gases

Refer to Insert 1. Everything lies there.

**END OF CHAPTER 1**

## CHAPTER 2 – THE PARTICULATE NATURE OF MATTER

### 2.1 Kinetic Particle Theory

**Matter** – anything that has mass and takes up space. Three forms – solids, liquids, gas.

#### SOLIDS

- fixed volume
- fixed shape
- incompressible
- do not flow

#### LIQUIDS

- fixed volume
- no fixed shape – takes the shape of container
- incompressible
- flow easily

#### GASES

- no fixed volume
- no fixed shape
- compressible
- flow in all direction

#### The Kinetic Particle Theory of Matter

- particles are too small to be seen directly
- there are spaces between particles of matter; the amount of space varies between each states
- the particles are constantly move; each state moves in different speed

### DIFFUSION

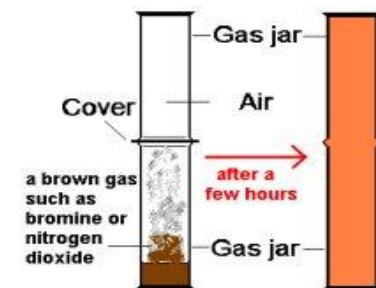
**Diffusion** is the spreading and mixing of particles in gases and liquids.

#### Diffusion of gases

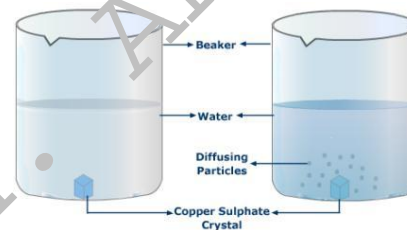
Bromine drops are placed into a jar. Another jar full of air is placed on top of jar with bromine, separated with cover. Cover is removed and bromine evaporates, filling both jars with dense reddish-brown bromine vapour.

*Explanation:*

Bromine particles move from lower jar into spaces between air particles in upper jar. At the same time, air particles move down from upper jar to mix with bromine particles in lower jar. Eventually, bromine and air particles are mixed completely.



#### Diffusion of liquids



$\text{CuSO}_4$  crystals placed in beaker of water, blue particles of the crystals is spread throughout the water to form uniformly blue solution.

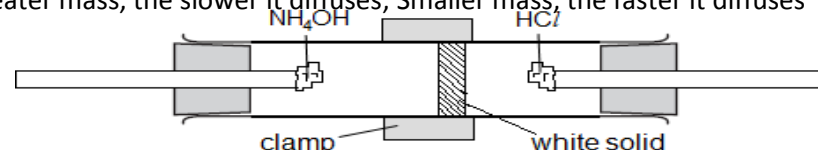
#### Factors Affecting Rate of Diffusion

##### - Temperature

The higher the temperature, the more particles of matter absorb energy making them move faster, the higher the rate of diffusion; the lower the temperature, the slower the rate of diffusion

##### - Mass of particles

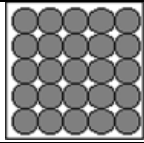
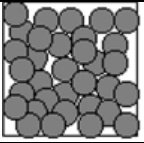
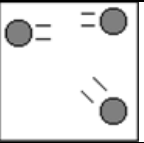
Greater mass, the slower it diffuses; Smaller mass, the faster it diffuses



A cotton soaked in aqueous ammonia and another soaked in hydrochloric acid are placed on opposite sides of the tube.  $\text{NH}_4\text{OH}$  vapor and  $\text{HCl}$  vapor diffuses in the tube and a compound is produced inside the tube closer to  $\text{HCl}$  soaked cotton as the particles are heavier. The greater mass, the slower particles diffuse. The smaller mass, the faster particles diffuse.

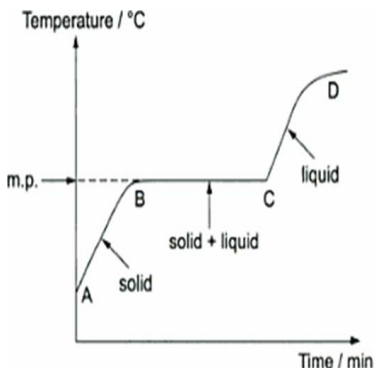


**Particulate Models of Matter**

Solid	Liquid	Gas
		
<b>Particles in solid:</b> <ul style="list-style-type: none"> <li>- Are packed close together in orderly arrangement</li> <li>- Have little empty space between them</li> <li>- Can vibrate but cannot move freely about their fixed position</li> </ul>	<b>Particles in liquid:</b> <ul style="list-style-type: none"> <li>- Are packed closely but not orderly arranged</li> <li>- Have little empty space between them but more than in solids</li> <li>- Are not held fixed but free to move throughout liquid</li> </ul>	<b>Particles in gas:</b> <ul style="list-style-type: none"> <li>- Are far apart and in random arrangement</li> <li>- Are free to move anywhere in the container</li> </ul>

**Differences between properties of matter and particles in them.**

1. Matter can be coloured (e.g. sulphur is yellow) but particles are not.
2. Substances feel hot/cold but particles don't get hot/cold. The temperature is due to speed of movement of particles. If hot, particles move fast.
3. Matter expands when heated but particles don't. They increase distance between particles during expansion.

**Changes of State****Melting**

*Melting* is change from solid to liquid by absorbing heat to break force of attraction holding particles together. The temperature at which solid melts is *melting point*.

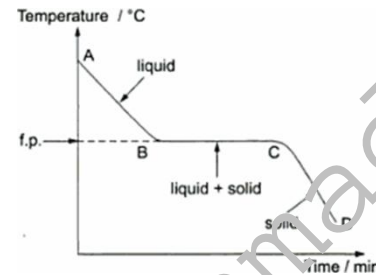
From the graph:

- A-B: the temperature of solid increases to melting point.  
 B-C: the temperature remains constant as heat is absorbed to break forces of attraction instead for raising temperature. Solid and liquid are present.  
 C-D: liquid heats as heat energy increases temperature.

**Freezing**

*Freezing* is the change of liquid to solid by cooling down of liquid.

*Freezing point* is the temperature at which liquid freezes.



A-B: liquid temperature decreases to freezing point.

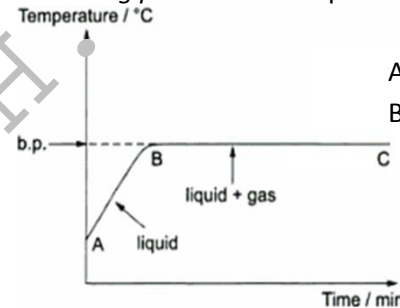
B-C: heat energy is released as particles slow down to take up fixed and orderly position of a solid. The temperature remain constant release of energy compensates for loss of heat to surroundings.

C-D: solid cools to the temperature of surroundings.

**Boiling**

*Boiling* is the change of liquid to gas by absorbing heat to break the forces holding them together.

*Boiling point* is the temperature at which liquid boils.



A-B: liquid temperature rises to boiling point.

B-C: heat energy is absorbed by particles to break the attractive forces so that they move freely and far apart as gas particles. That's why the temperature remain constant

**Evaporation**

*Evaporation* is change of liquid to gas without boiling, occurs below boiling point on water surface. It gives cooling effect – heat energy absorbed from surroundings.

**Condensation**

*Condensation* is the change of gas to liquid. Heat energy is given out as gas particles slow down and move closer to one another to form liquid.

**Sublimation** is the change of solid to gas without melting. Heat is absorbed.

## 2.2 Atomic Structure

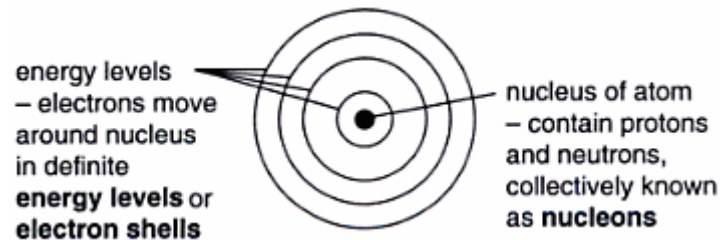
Atoms contain PROTONS, NEUTRONS, and ELECTRONS

Protons have positive charge while neutrons has neutral charge but same mass as protons. Since an atom is electrically neutral, electrons has to carry a negative charge and the amount of electrons is the same as the amount of protons.

Particle	Symbol	Relative mass	Charge
Proton	p	1	+ 1
Neutron	n	1	0
Electron	e <sup>-</sup>	$\frac{1}{1836}$	- 1

Protons and neutrons are located in nucleus. These make up **nucleon number**.

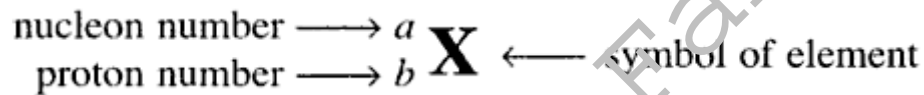
Electrons move around nucleus in an orbit called **electron shells**.



**PROTON NUMBER** is the number of protons in an atom.

**NUCLEON NUMBER** is the number of protons and neutrons in nucleus of an atom. Therefore, to find the number of neutrons, we subtract proton number from nucleon number, i.e.: **Nucleon number – Proton number = Neutrons**

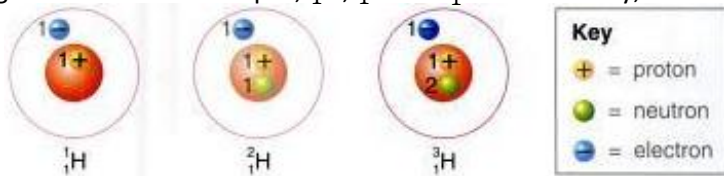
**ELECTRONS** have the same number as protons to balance the charges.



**ISOTOPES** are atoms of the same element with different number of neutrons.

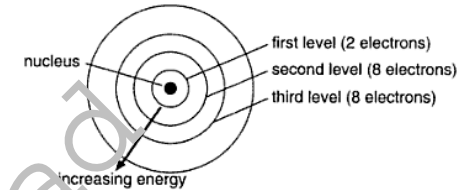
Therefore, their **nucleon number is different**.

E.g. Hydrogen atoms has 3 isotopes,  $^1_1\text{H}$ ,  $^2_1\text{H}$  and  $^3_1\text{H}$ . Structurally, it's drawn:



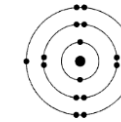
## ELECTRONIC CONFIGURATION

Electrons are placed in orbits. First shell contains maximum 2 electrons. Second shell and so and so for has maximum of 8 electrons.



To write electronic configuration we write as *n.n.n....* where first *n* denotes the first shell, second the second shell and so and so for.

E.g. Sulfur has electronic configuration of 2.8.6



The valence electrons is the number of electrons of the outermost shell. Sulphur has 6 valence electrons.

## Relation with Periodic Table

Elements in same horizontal row: **Period**

Elements in same vertical column: **Group**

Group 1 has 1 valency, Group 2 has 2 valency, Group 3 has 3 valency and so on.

Group 0 has full valency which makes it having **stable electronic configuration**.

Down the period the number of shells increases.

Group number	I	II	III	IV	V	VI	VII	0
	3 LITHIUM	4 BERYLLIUM	5 BORON	6 CARBON	7 NITROGEN	8 OXYGEN	9 FLUORINE	10 NEON
Proton number	Li 2.1	Be 2.2	B 2.3	C 2.4	N 2.5	O 2.6	F 2.7	Ne 2.8
Name of element	SODIUM	MAGNESIUM	ALUMINIUM	SILICON	PHOSPHORUS	SULFUR	CHLORINE	ARGON
Full electronic structure	Na 2.8.1	Mg 2.8.2	Al 2.8.3	Si 2.8.4	P 2.8.5	S 2.8.6	Cl 2.8.7	Ar 2.8.8
Symbol of element	Na	Mg	Al	Si	P	S	Cl	Ar
Electronic configuration	19 POTASSIUM	20 CALCIUM						
	K 2.8.8.1	Ca 2.8.8.2						

## 2.3 Structure and Properties of Materials

### Elements

**Element** is a substance that cannot be broken down into simpler substances by chemical nor physical methods.

#### *Classifying Elements*

- **Classifying by state.** E.g. some elements are solids, some liquids, some gases.
- **Classifying by metals and non-metals.** E.g. most elements are metals, semi-metals are *metalloids* (having properties of metals & non-metals), some are non-metals
- **Classifying by periodicity.** From left-right elements change from metal to non-metal

### COMPOSITION OF ELEMENTS

#### **Elements are made of atoms**

**Atom** is smallest unit of an element, having properties of that element.

**Molecule** is group of two or more atoms chemically joined together, e.g. chlorine molecule has 2 chlorine atoms

**Chemical formula** shows the number and kinds of atoms in a molecule, e.g. chlorine molecule has formula  $Cl_2$ , where  $Cl$  is chlorine symbol and the subscript number (2) shows that there are 2 atoms in a chlorine gas molecule.

### Compounds

**Compound** is substance containing 2 or more elements chemically joined together e.g. Magnesium is an element; oxygen is an element – they can only be burnt to form magnesium oxide compound.

### COMPOSITION OF COMPOUNDS

#### **Ions or molecules make up compounds**

**Ions** are atoms having electrical charge

E.g.  $NaCl$  made up of 2 ions; positively charged  $Na$ , negatively charged  $Cl$ .

### Mixtures

**Mixture** contains 2 or more substances not chemically joined together.

e.g. seawater is made up of water and  $NaCl$  (salt); oxygen in air varies.

	Compound	Mixture
1	Component substances cannot be separated by physical methods; a chemical method is required for separation.	Component substances can be separated by physical methods.
2	Its physical and chemical properties are different from that of its elements.	Its physical and chemical properties are the same as its component substances.
3	Fixed composition by mass.	Variable composition by mass.
4	Has fixed melting and boiling points.	Has variable melting and boiling points.

## 2.4 Ionic Bonding

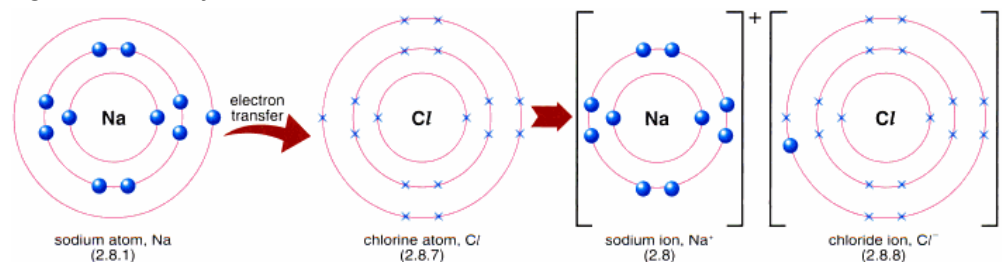
**Ionic bonding** is the transfer of electrons from one atom to another to become achieve an inert gas configuration, forming ions.

Ionic bonds are formed between **METALLIC** and **NON-METALLIC ATOMS ONLY**.

- Metals lose electrons to form positive ions (cations)
- Non-metals gain electrons to form negative ions (anions)

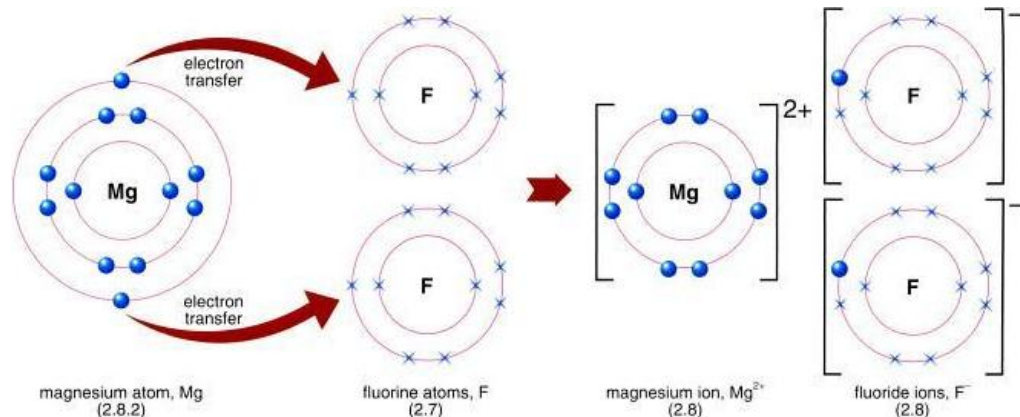
The formation of ions is resulted from transfer of atoms from one atom to another atom(s), which the ions produced are of opposite charges, and unlike charges attract, causing them to be held together with a strong force.

*E.g. Formation of  $NaCl$*



Sodium atom loses an electron by transferring the electron to chlorine atom, making both stable. The loss of electron forms cation,  $Na^+$ , and the gain of electron forms anion,  $Cl^-$ . The opposite charges acquired by both ions attract to each other, forming a strong ionic bond of  $NaCl$ .

E.g. Formation of  $MgF_2$



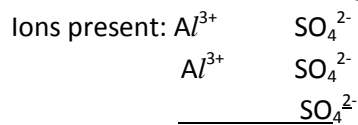
Sodium atom loses two electrons by transferring the electrons to fluorine atoms, one each, making both stable. The loss of electron forms cation,  $Mg^{2+}$ , as it loses 2 electrons, and the gain of electron forms anion,  $F^-$ . The opposite charges acquired by both ions attract to each other, forming a strong ionic bond of  $MgF_2$ .

### Deducing formula ionic compounds

We can know the charge of elements by looking at groups of periodic table. Group I to group III elements has charge of +1, increasing to +3, going to the right. Group V to group VII elements has charge of -3, decreasing to -1, going to the right.

E.g. Aluminium sulfate

We have to balance the charges to make a stable bond



Total change: 6+      6-

Therefore, the formula is  $Al_2(SO_4)_3$

1. The symbol of metal ion should always be first, e.g.  $NaCl$
2. Polyatomic ion should be placed in brackets, e.g.  $Fe(NO_3)_2$

## STRUCTURE AND PROPERTIES OF IONIC BONDS

### Structure

Ionic substances appear as giant lattice structures which the ions are held together by electrostatic force between oppositely charged ions. To find the formula of ionic bond, say sodium chloride bond, by looking at lattice structure, we count the ratio of amount of metal ions to non-metal ions. E.g. in sodium chloride, the ratio  $Na:Cl$  is 1:1, therefore the ionic formula is  $NaCl$ .

### Properties

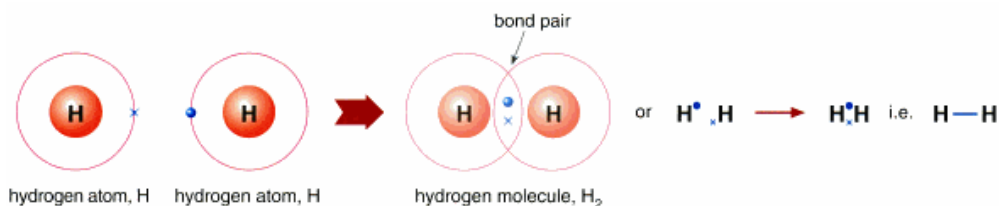
1. Ionic compounds are hard crystalline solids with flat sides and regular shapes because the ions are arranged in straight rows in strong ionic bonds.
2. Ionic compounds have very high melting points and boiling points.
3. The strong forces holding ionic compounds prevents them to evaporate easily. Hence, ionic compounds have no smell.
4. Solid ionic compounds don't conduct electricity but they do when they are aqueous or molten. This is because in liquid/aqueous state the ions which conduct electricity are free to move. In solids, these ions are fixed in place.
5. Ionic compounds are soluble in water but insoluble in organic compounds. This is because the ions attract water molecules which disrupts the crystal structure, causing them separate & go into solution. Vice versa is when in organic solvent.

### 2.5 Covalent Bonding

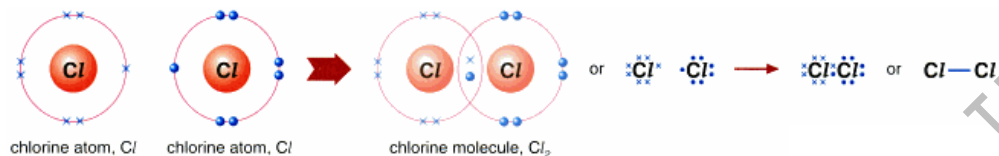
**Covalent bonding** is the sharing a pair of electrons to gain electronic configuration of an inert gas, usually for molecules.

Covalent bonds occur between **NON-METALLIC ATOMS ONLY**.

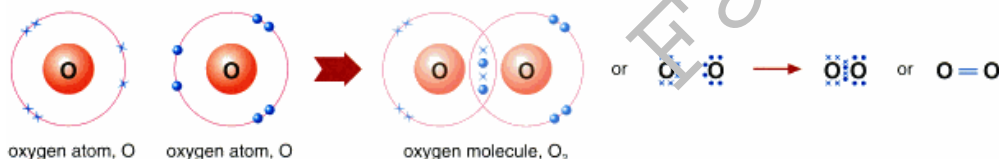
In covalent bond, **WE TRY TO SUBSTITUTE THE SHORT OF ELECTRONS OF TWO/MORE ATOMS BETWEEN EACH OTHER TO FORM THE 2 OR 8 VALENCE ELECTRONS. THE SHARED ELECTRONS APPEAR IN PAIRS!**

*E.g. H<sub>2</sub> molecule*

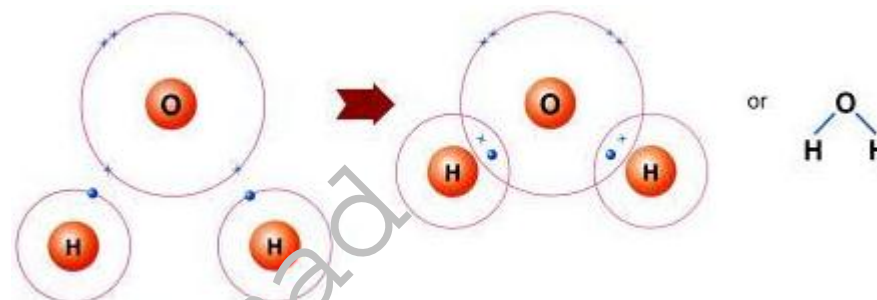
Hydrogen atom has one valency. To become stable with hydrogen atom, it needs one more electron, just like helium which has 2 valency. When 2 hydrogen atoms join, they share their electrons, on which, the share becomes 2 electrons, which is now a noble gas configuration, being shared between these 2 atoms. We write the bond as H – H single bond, which means they share an electron pair (2 electrons).

*E.g. Cl<sub>2</sub> molecule*

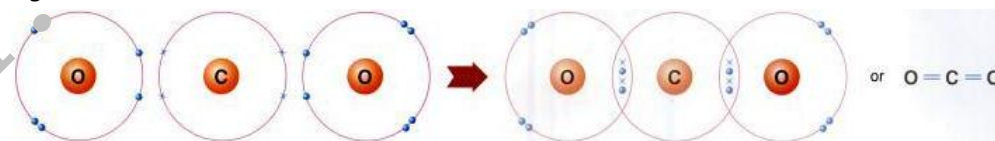
Cl atom has 7 valency and needs one electron, each, to form a noble gas configuration between two Cl atoms. Hence they share an electron EACH, to hence share 2 electrons between the atoms. Hence, each Cl atom now has 8 valency which is a noble gas configuration.

*E.g. O<sub>2</sub> molecule*

An O atom has 6 valency and needs 2 electrons, each, to form a noble gas configuration. Hence, EACH SHARE THE AMOUNT OF ELECTRONS EACH SHORT OF, in this case – 2 electrons, to form stable molecule. The contribution hence now become 4 electrons and what left on each oxygen atom is 4 electrons. We combine each 4 electrons on oxygen atom with the 4 electrons shared and hence we get 8 valency for each oxygen atom – a noble gas configuration!

*E.g. H<sub>2</sub>O molecule*

Apart from oxygen sharing between oxygen atoms, it can have electrons with other atoms. Oxygen needs 2 electrons and when bonded with hydrogen, which need an atom each, they combine to provide 2 electrons on both sides of oxygen bonded with hydrogen atoms. Each hydrogen with oxygen atom form a single bond: O – H.

*E.g. CO<sub>2</sub> molecule*

Carbon needs 4, oxygen needs 2. We share two from oxygen part, WHICH HAS THE SMALLEST NUMBER OF SHORT ELECTRONS, TO SHARE THE AMOUNT OF ELECTRONS THAT ATOM NEEDS, to form 4 shared atoms. Now oxygen is stable but carbon needs 2 more, which we now know they can get from another oxygen atom. The atoms are now stable and since each bond has 2 pairs of electrons, we call this double bond: C = O.

A pair of shared electrons between 2 atoms forms **SINGLE BOND**, X – Y.

Two pairs of shared electrons between 2 atoms forms **DOUBLE BOND**, X = Y.

Three pairs of shared electrons between 2 atoms forms **TRIPLE BOND**, X ≡ Y.

This information is important when you want to know the bond forces between atoms in exothermic/endothermic reactions.

## STRUCTURE AND PROPERTIES OF COVALENT BONDS

### Structure

#### Giant Covalent Bond

##### Diamond

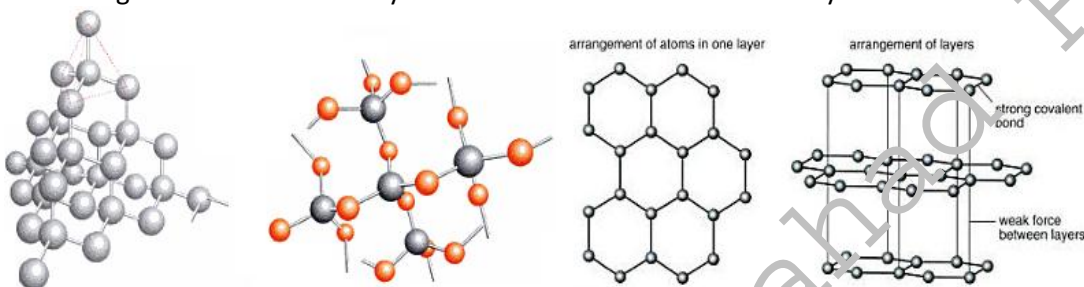
Diamond has carbon atoms bonded with another carbon atoms in a tetrahedral arrangement which each carbon atom uses all its valence electrons to form 4 single covalent bonds with other 4 carbon atoms.

##### Silicon Dioxide

Silicon dioxide,  $\text{SiO}_2$ , has silicon atoms bonded with another oxygen atoms in a tetrahedral arrangement which each silicon atom uses all its valence electrons to form 4 single covalent bonds with other 4 oxygen atoms.

##### Graphite

Graphite has flat layers of carbon atoms bonded strongly in hexagonal arrangement in which the layers are bonded to each other weakly.



Diamond  
Properties

Silicon Dioxide

Graphite

1. It is a hard solid because it consists of many strong covalent bonds between atoms. This property makes it suitable as abrasives.
2. It has *very high* melting and boiling points.
3. It does not conduct electricity (except graphite) because there are no free electrons in covalent bonds since they are used to form bonds; hence electrons are in fixed positions. To conduct electricity, there must be free electrons.
4. All covalent structures are insoluble in water.

## 2.6 Metallic Bonding

**Metallic bonding** is bonding within atoms of metals caused by attractive force between positively charged metal ions and negatively charged free electrons. The atoms are packed closely together in **giant lattice structures**.

### BOND FORMING

Each atom in metal gives up valence electrons to form positive ions. There are free electrons moving between the spaces and positive metal ions are attracted to the sea of electrons which hold the atoms together.

## STRUCTURE AND PROPERTIES OF METALLIC BONDS

1. Metals can be bent (ductile) and can be stretched (malleable) because the layers of atoms in metals slide over each other when force is applied but will not break due to attractive force between electrons and metal ions.
2. Metals conduct electricity as it has free electrons which carries current.
3. Metals conduct heat as it has free electrons which gains energy when heated and moves faster to collide with metal atoms, releasing heat in collisions.
4. Metals have high melting and boiling points because the bonds between metals is very strong. Hence very high heat energy needed to break the bonds.

## 2.7 Simple Molecular Substances

1. Simple molecular substances are usually liquids/gases at r.t.p. because the molecules are not tightly bonded like in solids, hence free to move.
2. They have low melting and boiling points because the force of attraction is weak that they can be easily broken by heat.
3. Since they have low boiling points, they evaporate easily.
4. They don't conduct electricity because they don't have free electrons/ions which helps to conduct electricity.
5. Most of these are insoluble in water but soluble in organic solvent.

END OF CHAPTER 2

**CHAPTER 3 – FORMULAE, STOICHIOMETRY AND THE MOLE CONCEPT****3.1 Relative Atomic Mass****Comparing Atomic Masses with the Carbon Atom**

To compare to a carbon atom, a carbon-12 atom is used. The mass of the isotope is 12 times greater than hydrogen atom so  $\frac{1}{12}$  of carbon-12 atoms is equivalent to the mass of one hydrogen atom.

*Relative Atomic Mass* - the average mass of one atom of the element (averaging isotopes) when compared with  $\frac{1}{12}$  mass of a carbon-12 atom.

$$\therefore A_r = \frac{\text{Average Mass of one atom of the element}}{\frac{1}{12} \times \text{the mass of one atom of carbon-12}}$$

In short is:

$$A_r = \frac{\text{total mass of all isotopes}}{\text{number of isotopes formed} \times \frac{1}{12}}$$

The Relative Atomic Masses are already stated on the periodic table above each chemical formula.

**3.2 Relative Molecular Mass and Relative Formula Mass**

Using  $A_r$ , we calculate Relative Masses of molecules and ionic compounds

**Relative Molecular Mass**

Molecules contains atoms joined together, e.g.  $Cl_2$

Average mass (molecular mass) of  $Cl_2$  = add relative masses of both atoms.

*Relative Molecular Mass* – the average mass of one molecule of substance (averaging isotopes) when compared with  $\frac{1}{12}$  mass of a carbon-12 atom.

$$\text{In short: } M_r = \frac{\text{total mass of all atoms}}{\frac{1}{12} \times 12}$$

**Relative Formula Mass** – same as relative molecular mass but for ions only

*Relative Formula Mass* – total  $A_r$  of all atoms in formula of ionic compound

e.g. Relative formula mass of  $MgSO_4$ ?

$$M_r = 24 + 32 + 4(16) = 120$$

**3.3 Percentage Composition**

e.g. Determine which oxides of iron of  $Fe_2O_3$  or  $Fe_3O_4$  has more iron.

*Solution next page*

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$$M_r(Fe_2O_3) = 2(56) + 3(16) = 160$$

$$\begin{aligned} \text{Percentage of Fe in } Fe_2O_3 &= \frac{A_r(Fe_2)}{M_r(Fe_2O_3)} \times 100\% \\ &= \frac{2(56)}{160} \times 100\% \\ &= 70\% \end{aligned}$$

$$M_r(Fe_3O_4) = 3(56) + 4(16) = 232$$

$$\begin{aligned} \text{Percentage of Fe in } Fe_3O_4 &= \frac{A_r(Fe_3)}{M_r(Fe_3O_4)} \times 100\% \\ &= \frac{3(56)}{232} \times 100\% \\ &= 72\% \end{aligned}$$

$\therefore Fe_3O_4$  has more iron composition than that of  $Fe_2O_3$ .

**Calculating the Mass of an Element in a Compound**

Use the example of  $Fe_2O_3$  in the example above. The percentage mass of iron in iron(III) oxide is 70%. Therefore to calculate mass of iron in a 200g compound of iron(III) oxide is  $(0.7 \times 200)g = 140g$

e.g. Determine the mass of iron in 200g of  $Fe_2O_3$ .

$$M_r(Fe_2O_3) = 2(56) + 3(16) = 160$$

$$\begin{aligned} \text{Mass of Fe in } Fe_2O_3 &= \frac{A_r(Fe_2)}{M_r(Fe_2O_3)} \times 200g \\ &= \frac{2(56)}{160} \times 200g \\ &= 140g \end{aligned}$$

**Calculating the Mass of Water in a Compound**

Compound with water mass is 'hydrated' and has  $H_2O$  in their formula.

e.g. Calculate water mass in 12.5g hydrated copper sulfate,  $CuSO_4 \cdot 5H_2O$

$$\begin{aligned} \text{Mass of } 5H_2O \text{ in } CuSO_4 \cdot 5H_2O &= \frac{A_r(5H_2O)}{M_r(CuSO_4 \cdot 5H_2O)} \times \text{mass of sample} \\ &= \frac{5(18)}{250} \times 12.5g \\ &= 4.5g \end{aligned}$$

**MOLE****3.4 Counting Particles**

Unit for particles = **mole**

Symbol = **mol**

1 mol =  $6 \times 10^{23}$  atoms

### 3.5 Moles of Particles

#### Calculating the Number of Moles

$$n = \frac{\text{Number of particles}}{6 \times 10^{23}}$$

e.g 1: How many molecules in  $6 \times 10^{24}$  molecules of water,  $\text{H}_2\text{O}$ ?

$$n = \frac{3 \times 10^{24}}{6 \times 10^{23}}$$

$$= 5 \text{ mol}$$

e.g 2: Calculate the number of molecules in 0.25 mole of  $\text{CO}_2$ . Hence, how many atoms are present?

$$0.25 \text{ mol} = \frac{\text{Number of particles}}{6 \times 10^{23}}$$

$$\text{Number of particles} = 0.25 \text{ mol} \times 6 \times 10^{23}$$

$$= 1.5 \times 10^{23} \text{ molecules}$$

Number of atoms = total number of atoms in  $\text{CO}_2$  x number of particles

$$= 3 \times 1.5 \times 10^{23}$$

$$= 4.5 \times 10^{23} \text{ atoms}$$

### 3.6 Molar Mass

*Molar mass* – the mass of one mole of any substances

#### For substances consisting of atoms

It is the  $A_r$  of the element in grams. Eg.  $A_r(\text{C}) = 12$ , molar mass = 12g

#### For substances consisting of molecules

It is the  $A_r$  of the substance in grams. Eg.  $A_r(\text{H}_2\text{O}) = 18$ , molar mass = 18g

#### For substances consisting of ions

It is the  $A_r$  of substance in grams. Eg.  $A_r(\text{NaCl}) = 58.5$ , molar mass = 58.5g

#### Calculations Using Molar Mass

$$n = \frac{\text{mass (m)}}{\text{molar mass (M}_r)}$$

e.g. Find the mass of 0.4 mol of iron atom.

$$n = \frac{m}{M_r}$$

$$m = n \times M_r$$

$$m = 0.4 \times 56 = 22.4 \text{ g}$$

e.g. Argon Fluorohydride gas,  $\text{HArF}$ , first known noble gas compound, has molar mass of 60g. Find the number of moles Argon atom in 6.66g of  $\text{HArF}$ .

$$n(\text{HArF}) = \frac{6.66}{60}$$

$$= 0.111 \text{ mol}$$

$$n(\text{Ar}) = 0.111 \text{ mol} \times 1 \text{ Ar atom in HArF}$$

$$= 0.111 \text{ mol}$$

### 3.7 Different Kinds of Chemical Formulae

Ethene formula is  $\text{C}_2\text{H}_6$

*Molecular Formula* – shows the actual formula and kinds of atoms present, e.g.

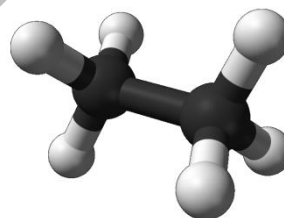
$\text{C}_2\text{H}_6$

*Empirical Formula* – shows the simplest whole number ratio of the atoms present,

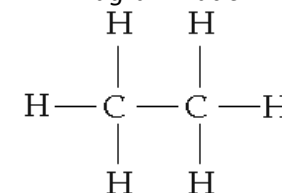
e.g.  $\text{C}_2\text{H}_6$ , ratio 1:3, therefore  $\text{C}_1\text{H}_3$ , simply  $\text{CH}_3$

*Structural Formula* – shows how atoms are joined in the molecule. It can be represented by ball-and-stick model or diagrammatically.

Ball-and-Stick



Diagrammatic



#### Calculating the Empirical Formula of a Compound

Find the empirical formula of an oxide of magnesium consisting of 0.32g of oxygen and 0.96g of magnesium.

Step 1: find the number of moles of the 2 elements.

$$n(\text{Mg}) = \frac{0.96\text{g}}{24\text{g}}$$

$$= 0.04 \text{ mol}$$

$$n(\text{O}) = \frac{0.32\text{g}}{16\text{g}}$$

$$= 0.02 \text{ mol}$$

Step 2: Divide the moles by the smallest number.

$$\text{Mg} = \frac{0.04}{0.02}$$

$$= 2$$

$$\text{O} = \frac{0.04}{0.02}$$

$$= 1$$

Therefore, the empirical formula is  $\text{Mg}_2\text{O}$



**Calculating the Empirical Formula from Percentage Composition**

An oxide of sulphur consists of 40% sulphur and 60% oxygen.

Take the total 100% to be 100g.

Step 1: find the number of moles of the 2 elements.

$$\begin{aligned} n(\text{S}) &= \frac{40\text{g}}{32\text{g}} & n(\text{O}) &= \frac{60\text{g}}{16\text{g}} \\ &= 1.25 \text{ mol} & &= 3.75 \text{ mol} \end{aligned}$$

Step 2: Divide the moles by the smallest number.

$$\begin{aligned} \text{S} &= \frac{1.25}{1.25} & \text{O} &= \frac{3.75}{1.25} \\ &= 1 & &= 3 \end{aligned}$$

Therefore, the empirical formula is  $\text{SO}_3$

**From Empirical formula to Molecular Formula**

Find the molecular formula of propene,  $\text{CH}_2$ , having molecular mass of 42.

Molecular formula will be  $\text{C}_n\text{H}_{2n}$

Relative molecular mass =  $12n(\text{from carbon } A_r) + 2n(2 \times \text{hydrogen } A_r) = 14n$

$$14n = 42 \quad \text{Therefore, } \text{C}_3\text{H}_6$$

$$n = \frac{42}{14} = 3$$

**3.8 Molar Volume of Gases****The Avogadro's Law**

Equal volume of gases at same temperature and volume contain equal number of particles or molecules.

**Molar Volume of Gas** – volume occupied by one mole of gas

All gases at room temperature and pressure (r.t.p.) =  $24 \text{ dm}^3$

$$1 \text{ dm}^3 = 1000 \text{ cm}^3$$

Formulae:

$$\text{Number of moles of a gas (n)} = \frac{\text{volume of gas (V)}}{\text{molar volume of gas (M}_r)}$$

$$\text{Volume of a gas} = \text{Number of moles (n)} \times \text{Molar volume (M}_r)$$

e.g. What is the number of moles of  $240 \text{ cm}^3$  of  $\text{Cl}_2$  at r.t.p.?

$$\begin{aligned} n &= \frac{\text{volume of gas (V)}}{\text{molar volume of gas (M}_r)} \\ &= \frac{240}{24000} \text{ (or } \frac{0.24}{24} \text{ using } \text{dm}^3) \\ &= 0.01 \text{ mol} \end{aligned}$$

**Molar Volume and Molar Mass**

Gases have same volume but not necessarily same mass

Example: Hydrogen  $\rightarrow$  2g Carbon Dioxide  $\rightarrow$  44g

e.g. Find the volume of 7g of  $\text{N}_2$  at r.t.p.

Step 1: Find the number of moles from the mass of nitrogen

$$n = \frac{7\text{g}}{28\text{g}} = 0.25 \text{ mol}$$

Step 2: Find the volume of nitrogen, now with formula of gas

$$0.25 \text{ mol} = \frac{\text{volume of gas (V)}}{24}$$

$$\begin{aligned} \text{Volume of gas} &= 0.25 \text{ mol} \times 24 \\ &= 6 \text{ dm}^3 \text{ (or } 6000 \text{ cm}^3) \end{aligned}$$

**3.9 Concentration of Solutions**

Concentration of solution tells the number of solute in a volume of solution

$$\text{Concentration (C)} = \frac{\text{number of grams (if } \frac{\text{g}}{\text{dm}^3}) \text{ or moles (if } \frac{\text{mol}}{\text{dm}^3}) \text{ of solute}}{\text{Volume of solution (in } \text{dm}^3)}$$

**Calculating the Amount of Solute**

$$\text{Moles of solute (n)} = \text{Concentration (} \frac{\text{mol}}{\text{dm}^3}) \times \text{Volume of solution (dm}^3)$$

e.g. What is the mass of solute in  $600 \text{ cm}^3$  of  $1.5 \frac{\text{mol}}{\text{dm}^3}$  NaOH solution?

$$\text{Volume of solution in } \text{dm}^3 = 0.60 \text{ dm}^3$$

$$n = 1.5 \times 0.60$$

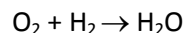
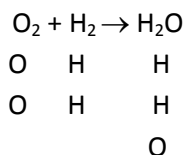
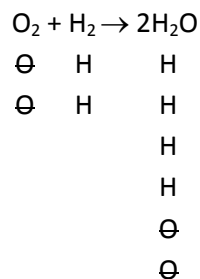
$$= 0.9 \text{ mol}$$

$$\text{Number of moles of NaOH} = \frac{m}{M_r}$$

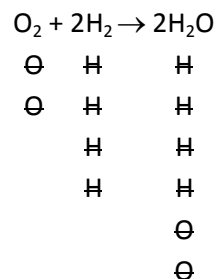
$$0.9 = \frac{m}{40}$$

$$m = 0.9 \times 40$$

$$= 36\text{g}$$

**CALCULATIONS USING CHEMICAL EQUATIONS****3.10 Constructing Chemical Equations****E.g. 1: Reaction Between Hydrogen and Oxygen****Word Equation:** Oxygen + Hydrogen → WaterTo write the **chemical equation**, we use symbols of atoms/molecules:BUT THIS IS IMBALANCED! A BALANCED EQUATION **MUST** HAVE THE SAME NUMBER OF ATOMS OF EACH ELEMENTS ON BOTH SIDES! THEREFORE...From above, we know that H<sub>2</sub>O is short 1 oxygen atom. Therefore we multiply product by 2 first. Note: all atoms in molecules are automatically multiplied by 2.

Now we can cancel off oxygen atoms. However, hydrogen atoms from reactant is short 2 atoms. Therefore, we multiply the hydrogen molecule by 2 so that the short is balanced. The equation is fully balanced when we are able to cancel off all atoms of that element on both sides.

**3.11 Calculations from Equations****Reacting Masses**

In every equation, each atom is rational to each other. Suppose we want to find moles of X atoms that reacted to form 0.25 mole of Y atoms. We always put the atom we want to find as numerator and the denominator being the atom we know.

E.g.  $X + 2Z \rightarrow 2Y$ 

Find the ratio first:

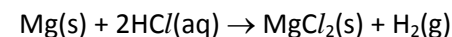
$$\frac{\text{No of moles of X}}{\text{No of moles of Y}} = \frac{1}{2}$$

Then multiply the ratio by no. of moles of Y to find the reacting mole of X.

$$\frac{1}{2} \times 0.25 = 0.125 \text{ mole}$$

Therefore 0.125 mole of X reacted with 0.25 mole of Y. To find the reacting mass of X, e.g. Y is given as 35g, we just multiply the mole by the mass of Y as they are always in ratio:

$$0.125 \times 35 = 4.375 \text{ g}$$

**Reacting Masses and Volumes**First, find the ratio of moles and multiply the mole of the gas volume you want to find with the volume of gas at room temperature (24dm<sup>3</sup>)**Example**MgCl<sub>2</sub> is formed by reacting Mg and HCl according to equation:Find the amount of hydrogen gas, in cm<sup>3</sup>, formed when 14.6g of HCl is reacted.

$$\text{Ratio: } \frac{\text{No. of moles of H}_2}{\text{No of moles of HCl}} = \frac{1}{2}$$

$$\begin{aligned} m(\text{HCl}) &= \frac{14.6}{36.5} \\ &= 0.4 \text{ mol} \end{aligned}$$

$$\text{Multiply ratio by mole of HCl} = \frac{1}{2} \times 0.4 = 0.2 \text{ mol}$$

$$\text{Multiply mole by molar volume of gas at r.t.p.} = 0.2 \times 24 \text{ dm}^3 = 4.8 \text{ dm}^3$$

$$1 \text{ dm}^3 = 1000 \text{ cm}^3$$

$$\therefore 4.8 \text{ dm}^3 \times 1000 = 4800 \text{ cm}^3$$

4800cm<sup>3</sup> of gas is formed

## CHEMICAL ANALYSIS

### 3.12 Introductory Chemical Analysis

Analysis is finding out what a substance or product is made of

Chemical analyst is the person who does chemical analysis

2 kinds of chemical analysis:

#### - Qualitative analysis

is the identification of elements/compounds present in an unknown substance

#### - Quantitative analysis

Is the measurement of concentration of elements/compounds in unknown substance

### 3.13 Use of Physical Tests to Identify Substances

- Colour – some substances have distinctive colours.

- Ammonium compounds and compounds in Groups I and II are white solids that dissolve in water to form colourless solutions
- Copper(II) compounds are blue/green (except CuO is black)
- Iron(II) compounds are pale green, iron (III) compounds are red or yellowish
- Chlorine gas is greenish-yellow. Most other gases are colourless

- Smell

- Gases like oxygen, hydrogen and carbon dioxide are odourless
- Others like chlorine, ammonia and sulphur dioxide have characteristic smells

- Solubility in Water

Some substances like AgCl and CaSO<sub>4</sub> are insoluble while other does

- pH

If a substance is pH 1 or 2, all alkaline and weakly acidic substances couldn't be the substance.

### 3.14 Volumetric Analysis

Is a measure of concentrations of acids/alkalis in solutions

#### Acid-alkali Titrations in Volumetric Analysis

It needs: - a *standard solution*: a solution of known concentration, and

- a solution of unknown concentration

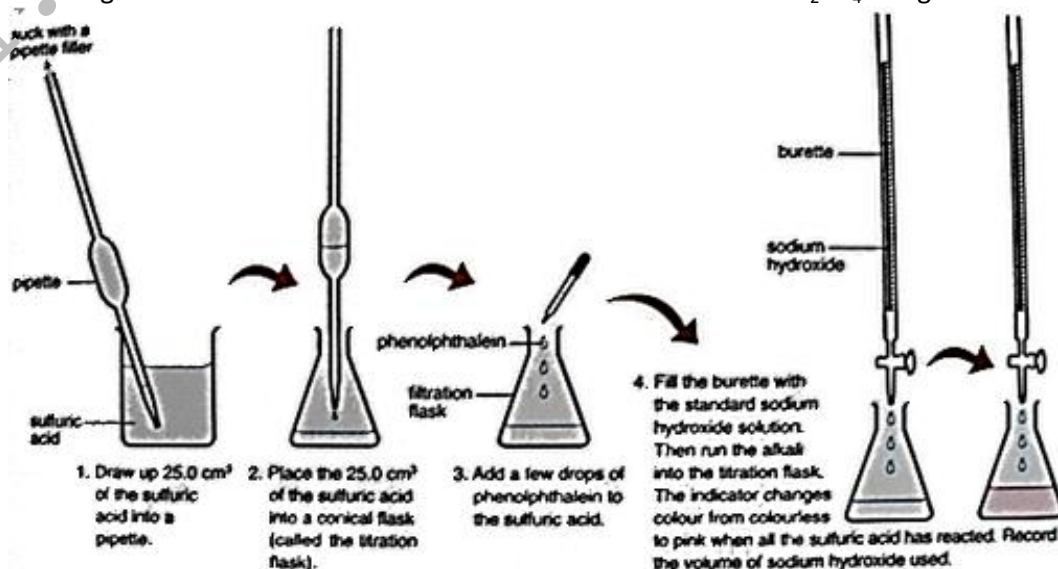
#### Detecting the End Point

End point is the point at which neutralisation of acid and alkali is complete

- Sharp indicators (phenolphthalein and methyl orange) are used to detect end point effectively
- Litmus and universal indicators isn't used as the changes of end point isn't sharp

#### A Typical Acid-alkali Titration

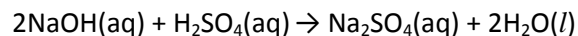
The diagram shows how titration is used to find concentration of H<sub>2</sub>SO<sub>4</sub> using NaOH



Using above example, to find the concentration of H<sub>2</sub>SO<sub>4</sub> is given on the next page

**Example:**

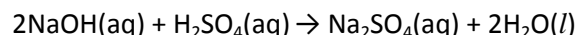
30.0 cm<sup>3</sup> of 0.100 mol/dm<sup>3</sup> NaOH reacted completely with 25.0 cm<sup>3</sup> of H<sub>2</sub>SO<sub>4</sub> in a titration. Calculate the concentration of H<sub>2</sub>SO<sub>4</sub> in mol/dm<sup>3</sup> given that:



**Step 1:** Find the reacting mole of NaOH

$$\begin{aligned} n(\text{NaOH}) &= \text{Concentration} \times \text{Volume in mol/dm}^3 \\ &= 0.100 \times \frac{30.0}{1000} \text{ mol} \end{aligned}$$

**Step 2:** Write the chemical equation for the reaction



**Step 3:** Find the ratio of number of moles of H<sub>2</sub>SO<sub>4</sub> to number of moles of NaOH

$$\frac{n(\text{H}_2\text{SO}_4)}{n(\text{NaOH})} = \frac{1}{2}$$

**Step 4:** Use ratio to find number of moles of H<sub>2</sub>SO<sub>4</sub> that reacted

$$\begin{aligned} n(\text{H}_2\text{SO}_4) &= \frac{1}{2} \times \text{number of moles of NaOH} \\ &= \frac{1}{2} \times 0.100 \times \frac{30.0}{1000} \text{ mol} \\ &= 0.0015 \text{ mol} \end{aligned}$$

**Step 5:** Find the concentration of H<sub>2</sub>SO<sub>4</sub> in mol/dm<sup>3</sup>

$$\begin{aligned} \text{Concentration} &= \frac{n(\text{H}_2\text{SO}_4)}{\text{Volume of H}_2\text{SO}_4 \text{ in dm}^3} \\ &= 0.0015 \text{ mol} \times \frac{1000}{25.0} \\ &= 0.06 \text{ mol/dm}^3 \end{aligned}$$

**Other Titrations**

To find the concentration of a solution of FeSO<sub>4</sub> using KMnO<sub>4</sub> is as below

1. Draw up 25.0 cm<sup>3</sup> of FeSO<sub>4</sub>(aq) into pipette.

2. Place the 25.0 cm<sup>3</sup> of the FeSO<sub>4</sub> into conical flask.

3. Add approximately 20 cm<sup>3</sup> of dilute sulphuric acid to the conical flask (to enable KMnO<sub>4</sub>(aq) to react with FeSO<sub>4</sub>).

4. Fill the burette with the standard KMnO<sub>4</sub>(aq). Then run it into the conical flask. The KMnO<sub>4</sub>(aq) is purple in colour and immediately decolourised by FeSO<sub>4</sub>(aq). As KMnO<sub>4</sub> is run in, the purple colour disappears until, at the end point, one drop of KMnO<sub>4</sub> causes a permanent pink colour. This completes the titration. Record the volume of KMnO<sub>4</sub>(aq) used.

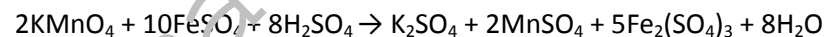
**Example:**

25.0 cm<sup>3</sup> of FeSO<sub>4</sub>(aq), H<sub>2</sub>SO<sub>4</sub> acidified, needs 27.5 cm<sup>3</sup> of 0.020 mol/dm<sup>3</sup> KMnO<sub>4</sub> for reaction in titration. Calculate the concentration of FeSO<sub>4</sub>(aq)

**Step 1:** Find the reacting mole of KMnO<sub>4</sub>

$$\begin{aligned} n(\text{KMnO}_4) &= \text{Concentration} \times \text{Volume in mol/dm}^3 \\ &= 0.020 \times \frac{27.5}{1000} \text{ mol} \end{aligned}$$

**Step 2:** Write the chemical equation for the reaction



**Step 3:** Find the ratio of number of moles of FeSO<sub>4</sub> to number of moles of KMnO<sub>4</sub>

$$\frac{n(\text{FeSO}_4)}{n(\text{KMnO}_4)} = \frac{10}{2} = \frac{5}{1}$$

**Step 4:** Use ratio to find number of moles of FeSO<sub>4</sub> that reacted

$$\begin{aligned} n(\text{FeSO}_4) &= 5 \times \text{number of moles of NaOH} \\ &= 5 \times 0.020 \times \frac{27.5}{1000} \text{ mol} \\ &= 0.00275 \text{ mol} \end{aligned}$$

**Step 5:** Find the concentration of FeSO<sub>4</sub> in mol/dm<sup>3</sup>

$$\begin{aligned} \text{Concentration} &= \frac{n(\text{FeSO}_4)}{\text{Volume of FeSO}_4 \text{ in dm}^3} \\ &= 0.00275 \text{ mol} \times \frac{1000}{25.0} \\ &= 0.11 \text{ mol/dm}^3 \end{aligned}$$

**3.15 Uses of Titrations in Analysis****Identification of Acids and Alkalis****Example:**

An acid has formula of H<sub>2</sub>XO<sub>4</sub>. One mole of H<sub>2</sub>XO<sub>4</sub> reacts with 2 moles of NaOH. A solution of the acid contain 5.0 g/dm<sup>3</sup> of H<sub>2</sub>XO<sub>4</sub>. In titration, 25.0 cm<sup>3</sup> of acid reacted with 25.5 cm<sup>3</sup> of 0.1 mol/dm<sup>3</sup> NaOH. Calculate the concentration of acid in mol/dm<sup>3</sup> and find X of the acid and its identity

$$\begin{aligned} n(\text{NaOH}) &= \text{Concentration} \times \text{Volume in mol/dm}^3 \\ &= 0.01 \times \frac{25.5}{1000} \text{ mol} \end{aligned}$$

Ratio of H<sub>2</sub>XO<sub>4</sub> to NaOH:

$$\frac{n(\text{H}_2\text{XO}_4)}{n(\text{NaOH})} = \frac{1}{2}$$

Continue on next page

$$n(\text{H}_2\text{XO}_4) = \frac{1}{2} \times 0.01 \times \frac{25.5}{1000}$$

$$\therefore \text{Concentration} = \frac{n(\text{H}_2\text{XO}_4)}{\text{Volume of H}_2\text{XO}_4 \text{ in dm}^3}$$

$$= \frac{1}{2} \times 0.01 \times \frac{25.5}{1000} \times \frac{1000}{25.0}$$

$$= 0.051 \text{ mol/dm}^3$$

Since 1 dm<sup>3</sup> of H<sub>2</sub>XO<sub>4</sub> contains 0.051 mol and 5 g of H<sub>2</sub>XO<sub>4</sub>.  $\therefore$  0.051 mol of H<sub>2</sub>XO<sub>4</sub> has a mass of 5g of H<sub>2</sub>XO<sub>4</sub> and 1 mole of H<sub>2</sub>XO<sub>4</sub> has a mass of  $\frac{5.0 \text{ g}}{0.051 \text{ mol}} = 98 \text{ g}$   
Hence, M<sub>r</sub> of X = 98 – 2(1) – 4(16) = 32.

$\therefore$  X is sulphur and H<sub>2</sub>XO<sub>4</sub> is sulphuric acid

### Percentage Purity of Compounds

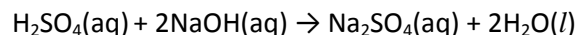
$$\text{Percentage purity} = \frac{\text{Mass of actual substance/dm}^3}{\text{Mass of impure substance/dm}^3}$$

#### Example:

5 g of impure sulphuric acid is dissolved in 1 dm<sup>3</sup> of water. 25.0 cm<sup>3</sup> of the solution required 23.5 cm<sup>3</sup> of 0.1 mol/dm<sup>3</sup> NaOH for complete titration reaction. Calculate the percentage purity of the acid.

$$n(\text{NaOH}) = \text{Concentration} \times \text{Volume in mol/dm}^3$$

$$= 0.1 \times \frac{23.5}{1000} \text{ mol}$$



Ratio of H<sub>2</sub>SO<sub>4</sub> to NaOH according to equation, then find mole according to ratio

$$\frac{n(\text{H}_2\text{SO}_4)}{n(\text{NaOH})} = \frac{1}{2}$$

$$n(\text{H}_2\text{SO}_4) = \frac{1}{2} \times 0.1 \times \frac{23.5}{1000}$$

$$\therefore \text{Concentration} = \frac{n(\text{H}_2\text{SO}_4)}{\text{Volume of H}_2\text{SO}_4 \text{ in dm}^3}$$

$$= \frac{1}{2} \times 0.1 \times \frac{23.5}{1000} \times \frac{1000}{25.0}$$

$$= 0.047 \text{ mol/dm}^3$$

$$\text{Hence mass of H}_2\text{SO}_4 \text{ in } 1 \text{ dm}^3 = 0.047 \times M_r(\text{H}_2\text{SO}_4)$$

$$= 0.047 \times 98 \text{ g}$$

$$= 4.61 \text{ g}$$

$$\text{Hence percentage purity} = \frac{4.61}{5.00} \times 100 = 92.2\%$$

### Formulae of Compounds

#### Example:

Solution Y contains 30.0 g/dm<sup>3</sup> of FeSO<sub>4</sub>·xH<sub>2</sub>O. In a titration, 25.0 cm<sup>3</sup> of Y reacted with 27.0 cm<sup>3</sup> of 0.02 mol/dm<sup>3</sup> KMnO<sub>4</sub>. In the reaction, 5 moles of FeSO<sub>4</sub>·xH<sub>2</sub>O react with 1 mole KMnO<sub>4</sub>. Calculate the concentration of Y in mol/dm<sup>3</sup> and the value of x.

$$n(\text{KMnO}_4) = \text{Concentration} \times \text{Volume in mol/dm}^3$$

$$= 0.02 \times \frac{27.0}{1000} \text{ mol}$$

Ratio of FeSO<sub>4</sub>·xH<sub>2</sub>O to KMnO<sub>4</sub> according to question; find mole according to ratio

$$\frac{n(\text{FeSO}_4 \cdot x\text{H}_2\text{O})}{n(\text{KMnO}_4)} = \frac{5}{1}$$

$$n(\text{FeSO}_4 \cdot x\text{H}_2\text{O}) = 5 \times 0.02 \times \frac{27.0}{1000}$$

$$\therefore \text{Concentration} = \frac{n(\text{FeSO}_4 \cdot x\text{H}_2\text{O})}{\text{Volume of FeSO}_4 \cdot x\text{H}_2\text{O in dm}^3}$$

$$= 5 \times 0.02 \times \frac{27.0}{1000} \times \frac{1000}{25.0}$$

$$= 0.108 \text{ mol/dm}^3$$

Hence 0.108 mol FeSO<sub>4</sub>·xH<sub>2</sub>O = 30.0 g FeSO<sub>4</sub>·xH<sub>2</sub>O

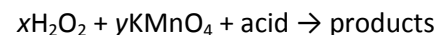
Therefore 1 mole FeSO<sub>4</sub>·xH<sub>2</sub>O has a mass of  $\frac{30.0}{0.108} \text{ g} = 278 \text{ g}$

Therefore M<sub>r</sub>(FeSO<sub>4</sub>·xH<sub>2</sub>O) = 278, Hence  $x = \frac{278 - 152}{18} = 7$

### Number of Reacting Moles in an Equation

#### Example:

In a titration, 25.0 cm<sup>3</sup> of 0.04 mol/dm<sup>3</sup> H<sub>2</sub>O<sub>2</sub> reacted with 20.0 cm<sup>3</sup> of 0.02 mol/dm<sup>3</sup> KMnO<sub>4</sub>. Find the values of x and y given the equation:



$$n(\text{H}_2\text{O}_2) = \text{Concentration} \times \text{Volume in mol/dm}^3$$

$$= 0.04 \times \frac{25.0}{1000} \text{ mol} = 0.001 \text{ mol}$$

$$n(\text{KMnO}_4) = \text{Concentration} \times \text{Volume in mol/dm}^3$$

$$= 0.02 \times \frac{20.0}{1000} \text{ mol} = 0.0004 \text{ mol}$$

Therefore 1 mole KMnO<sub>4</sub> react with  $\frac{0.001}{0.0004} = 2.5$  moles of H<sub>2</sub>O<sub>2</sub>

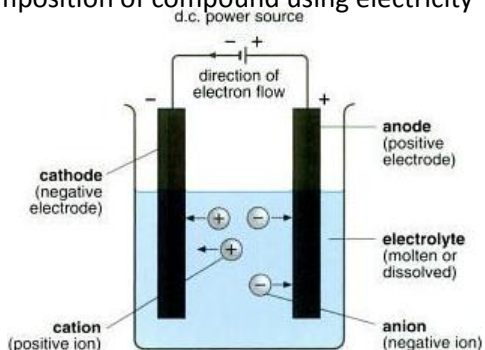
Hence ratio of x:y is 2.5:1 = 5:2 (round off)

Therefore, x=5 and y=2

## CHAPTER 4 – ELECTROLYSIS

### 4.1 Introductory Electrolysis

**Electrolysis** is the decomposition of compound using electricity



**Electrolyte** is an ionic compound which conducts electric current in molten or aqueous solution, being decomposed in the process.

**Electrode** is a rod or plate where electricity enters or leaves electrolyte during electrolysis. Reactions occur at electrodes.

**Discharge** is the removal of electrons from negative ions to form atoms or the gain of electrons of positive ions to become atoms.

**Anode** is positive electrode connected to positive terminal of d.c. source. Oxidation occurs here. **Anode** loses negative charge as electrons flow towards the battery, leaving anode positively charged. This causes anion to discharge its electrons here to replace lost electrons and also, negative charge are attracted to positive charge.

**Cathode** is negative electrode connected to negative terminal of d.c. source. Reduction occurs here. **Cathode** gains negative charge as electrons flow from the battery towards the cathode, making cathode negatively charged. This causes cation to be attracted and gains electrons to be an atom.

**Anion** is negative ion. It's attracted to anode.

**Cation** is positive ion. It's attracted to cathode.

### 4.2 Electrolysis of Molten Compounds

Molten/aqueous ionic compounds conduct electricity because **ions free to move**. In solid state, these ions are **held in fixed position** within the crystal lattice. Hence solid ionic compounds **do not conduct electricity**.

When **molten binary compound** is electrolysed, **metal** is formed on **cathode** while **non-metal** is formed on **anode**.

#### Electrolysis of Molten $PbBr_2$

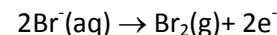
To make molten lead(II) bromide,  $PbBr_2$ , we strongly heat the solid until it melts. To electrolyse it, pass current through the molten  $PbBr_2$ .

#### Ions Present

$Pb^{2+}$  and  $Br^-$

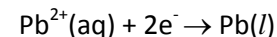
#### Reaction at Anode

$Br^-$  loses electrons at anode to become  $Br$  atoms.  $Br$  atoms created form bond together to make  $Br_2$  gas.

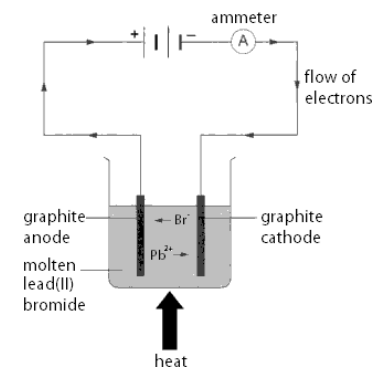
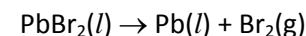


#### Reaction at Cathode

$Pb^{2+}$  gains electrons at cathode to become  $Pb$  atoms becoming liquid lead (II).



#### Overall Equation



Below are other compounds that can be electrolysed. The theory's same as  $PbBr_2$ .

Molten electrolyte	Cathode product	Anode product
Calcium chloride ( $CaCl_2$ )	Calcium, $Ca$	Chlorine, $Cl_2$
Sodium chloride ( $NaCl$ )	Sodium, $Na$	Chlorine, $Cl_2$
Aluminium(III) oxide ( $Al_2O_3$ )	Aluminium, $Al$	Oxygen, $O_2$
Sodium Iodide ( $NaI$ )	Sodium, $Na$	Iodine, $I_2$

### 4.3 Electrolysis of Aqueous Solution

Aqueous solutions contain additional  $H^+$  and  $OH^-$  ions of water, totalling 4 ions in the solution – 2 from electrolyte, 2 from water. Only 2 of these are discharged.

Electrolysis of aqueous solutions use the theory of **selective discharge**.

Ease of discharge	Cation	Product at cathode	Anion	Product at anode
Difficult ↓ Easy	K <sup>+</sup> Na <sup>+</sup> Ca <sup>2+</sup> Mg <sup>2+</sup> Al <sup>3+</sup> Ni <sup>2+</sup> Pb <sup>2+</sup> H <sup>+</sup>	} } Hydrogen } from } water } • Nickel • Lead Hydrogen	SO <sub>4</sub> <sup>2-</sup> NO <sub>3</sub> <sup>-</sup>  Cl <sup>-</sup> Br <sup>-</sup> I <sup>-</sup>  OH <sup>-</sup>	} Oxygen from } water  Chlorine Bromine Iodine  Oxygen
	Cu <sup>2+</sup> Ag <sup>+</sup>	Copper Silver		

**At cathode**

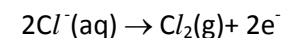
- In CONCENTRATED solutions of nickel/lead compound, nickel/lead will be discharged instead of hydrogen ions of water which is less reactive than nickel/lead.
- In VERY DILUTE solutions, hydrogen, copper and silver ions are preferable to be discharged, according to its ease to be discharged.
- Reactive ions (potassium, sodium, calcium, magnesium, aluminium) will NEVER BE DISCHARGED in either concentrated or dilute condition. Instead, hydrogen ions from water will be discharged at cathode.

**At anode**

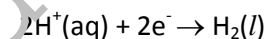
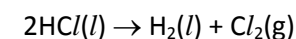
- In CONCENTRATED solutions, iodine/chlorine/bromine ions are preferable to be discharged, although it's harder to discharged compared to hydroxide ions.
- In VERY DILUTE solutions containing iodide/chloride/bromide ions, hydroxide ions of water will be discharged instead of iodide/chloride/bromide, according to ease of discharge.
- Sulphate and nitrate are NEVER DISCHARGED in concentrated/dilute solutions.

**Concentrated Solutions****Electrolysis of Concentrated NaCl****Ions Present**Na<sup>+</sup>, H<sup>+</sup>, OH<sup>-</sup> and Cl<sup>-</sup>**Reaction at Anode**

Cl<sup>-</sup> loses electrons at anode to become Cl atoms, although OH<sup>-</sup> is easier to discharge. Cl atoms created form covalent bond together to make Cl<sub>2</sub> gas.

**Reaction at Cathode**

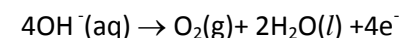
H<sup>+</sup> gains electrons at cathode to become H atoms becoming hydrogen gas.

**Overall Equation**

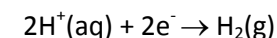
Note: any cation and anion left undischarged in solution forms new bonds between them. E.g. in above, leftovers Na<sup>+</sup> and OH<sup>-</sup> combine to form NaOH.

**Very Dilute Solutions****Electrolysis of Dilute H<sub>2</sub>SO<sub>4</sub>****Ions Present**H<sup>+</sup>, OH<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>**Reaction at Anode**

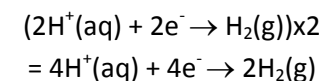
OH<sup>-</sup> loses electrons at anode to become O<sub>2</sub> and H<sub>2</sub>O.

**Reaction at Cathode**

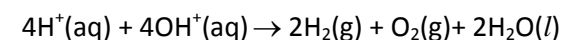
H<sup>+</sup> gains electrons at cathode to become H atoms becoming hydrogen gas.

**Overall Equation**

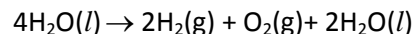
Both equations must be balanced first. The cathode equation is short 2 electrons. Hence, we should first even them by multiplying cathode equation by 2.



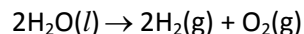
Now we can combine the equations, forming:



$4\text{H}^+$  and  $4\text{OH}^-$  ions, however, combine to form  $4\text{H}_2\text{O}$  molecules. Hence:



$\text{H}_2\text{O}$  molecules are formed on both sides. Therefore, they cancel the coefficients:



Since only water is electrolysed, the sulfuric acid now only becomes concentrated.

#### 4.4 Electrolysis Using Different Types of Electrodes

**Inert Electrodes** are electrodes which do not react with electrolyte or products during electrolysis. Examples are platinum and graphite.

**Active Electrodes** are electrodes which react with products of electrolysis, affecting the course of electrolysis. Example is copper.

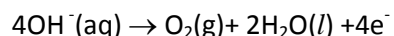
*Electrolysis of  $\text{CuSO}_4$  Using Inert Electrodes (e.g. carbon)*

**Ions Present**



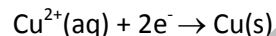
**Reaction at Anode**

$\text{OH}^-$  loses electrons at anode to become  $\text{O}_2$  and  $\text{H}_2\text{O}$ .



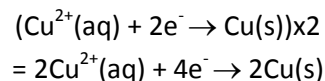
**Reaction at Cathode**

$\text{Cu}^{2+}$  gains electrons at cathode to become Cu atoms becoming liquid copper. Hydrogen ions are not discharged because copper is easier to discharge.

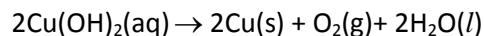


**Overall Equation**

Both equations must be balanced first. The cathode equation is short 2 electrons. Hence, we should first even them by multiplying cathode equation by 2.



Now we can combine the equations, forming:



Since copper ions in solution are used up, the blue colour fades. Hydrogen and sulphate ions left forms sulphuric acid.

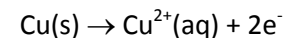
*Electrolysis of  $\text{CuSO}_4$  Using Active Electrodes (e.g. copper)*

**Ions Present**



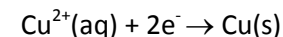
**Reaction at Anode**

Both  $\text{SO}_4^{2-}$  and  $\text{OH}^-$  gets attracted here but not discharged. Instead, the copper anode discharged by losing electrons to form  $\text{Cu}^{2+}$ . So, the electrode size decreases.



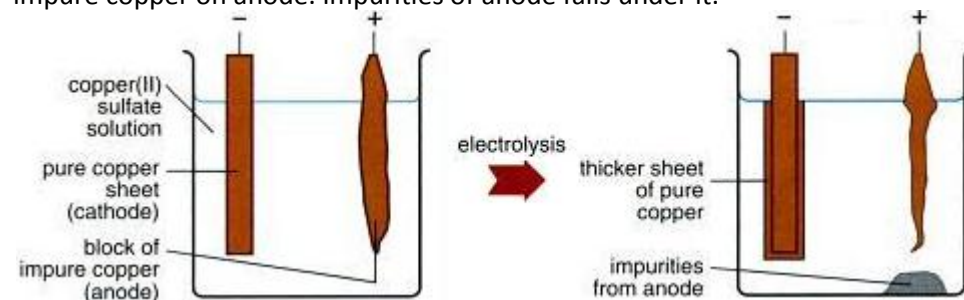
**Reaction at Cathode**

$\text{Cu}^{2+}$  produced from anode gains electrons at cathode to become Cu atoms becoming copper. Hence, the copper is deposited here and the electrode grows.



**Overall Change**

There is no change in solution contents as for every lost of  $\text{Cu}^{2+}$  ions at cathode is replaced by  $\text{Cu}^{2+}$  ions released by dissolving anode. Only the cathode increases size by gaining copper and anode decreases size by losing copper. We can use this method to create pure copper on cathode by using pure copper on cathode and impure copper on anode. Impurities of anode falls under it.



#### 4.5 Electroplating

**Electroplating** is coating an object with thin layer of metal by electrolysis. This makes the object protected and more attractive.



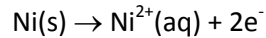
Object to be plated is made to be cathode and the plating metal is made as anode.

The electrolyte MUST contain plating metal cation.

*Plating Iron object with Nickel*

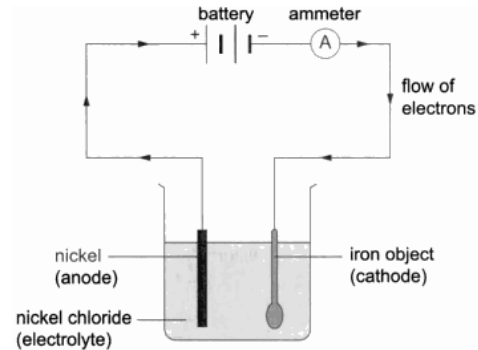
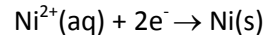
#### Reaction at Anode

$\text{Ni}^{2+}$  discharged from anode into solution. So, the electrode size decreases.



#### Reaction at Cathode

$\text{Ni}^{2+}$  produced from anode gains electrons at cathode to become Ni atoms becoming nickel. Hence, the nickel is deposited here and the electrode grows.



#### Overall Change

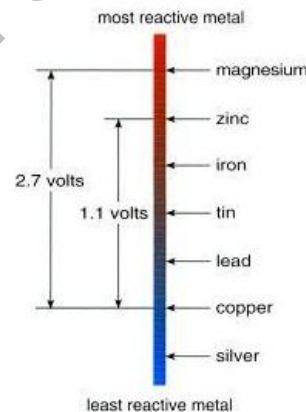
There is no change in solution contents while iron object receives nickel deposit.

#### Uses of Electroplating

Plating Metal	Uses
Chromium	Water taps, motorcar bumpers, bicycle parts
Tin	Tin cans
Silver	Silver sports trophies, plaques, ornaments, cutleries
Nickel	For corrosion-resistant layer
Gold	Watches, plaques, cutleries, water taps, ornaments
Rhodium	Silverware, jewellery, watches, ornaments
Copper	Printed circuit boards, trophies, ornaments

#### 4.6 Creation of Electric Cells by Electrolysis

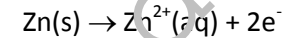
An electric cell consists of 2 electrodes made of 2 metals of different reactivity. The cathode is made of **more reactive metal**. This is because they have more tendency of losing electrons. The anode is made of **less reactive metal**. The more further apart the metals in reactivity series, the higher voltage is created.



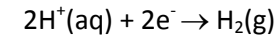
#### How the Voltage is Produced

Use an example of zinc and copper as electrodes and sodium chloride as electrolyte. As zinc is more reactive, it is cathode while copper is anode.

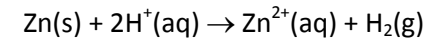
At cathode, Zn atoms in anode loses electrons to form  $\text{Zn}^{2+}$



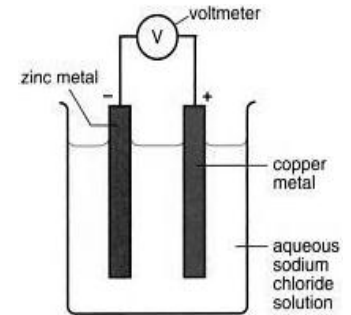
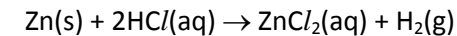
$\text{Zn}^{2+}$  goes into solution while the electrons lost makes the zinc negative. The electrons flow against conventional current towards copper anode. Both  $\text{Na}^{+}$  &  $\text{H}^{+}$  ions in solution are attracted to the copper anode due to electrons in it but only  $\text{H}^{+}$  ions discharged, due to selective discharge, to form hydrogen gas.



Hence the overall ionic equation is:



which comes from the equation:

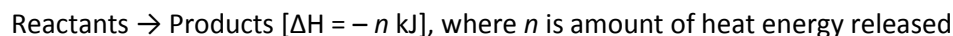
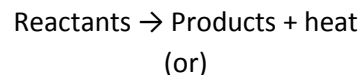


**END OF CHAPTER 4**

**CHAPTER 5 – ENERGY FROM CHEMICALS****5.1 Exothermic Reaction**

**Exothermic change** is one which heat energy is given out. This is to form bonds between the reactants which needs less energy in them.

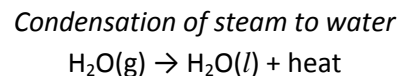
Reaction is written as:



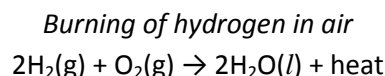
Examples of exothermic changes:

**1. Changes of State**

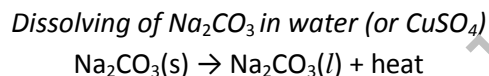
When gas condenses to water or water freezes to solid, heat is given out.

**2. Combustion reactions**

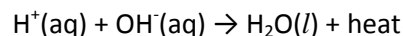
All combustion (burning) reactions are exothermic.

**3. Dissolving of anhydrous salts/acids in water**

Dissolving solid salt to aqueous solution of the salt gives out heat

**4. Neutralization**

When acid and alkali react it gives out heat due to combining of H<sup>+</sup> ions from acid and OH<sup>-</sup> ions from alkali to form water

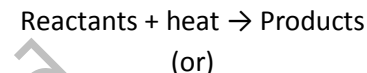
**5. Metal Displacement**

*Magnesium reacting with copper(II) sulphate*

**5.2 Endothermic Reaction**

**Endothermic change** is one which heat energy is absorbed. This is to break bonds between the reactants which needs more energy in them.

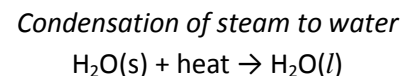
Reaction is written as:



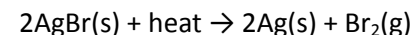
Examples of endothermic changes:

**1. Changes of states**

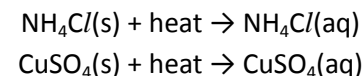
When solid melts to water & boils to steam, heat is absorbed to break the bond.

**2. Photolysis**

*Reaction of light sensitive silver chloride in camera reel in light*

**3. Dissolving of Ionic Compounds**

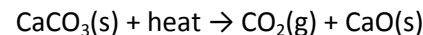
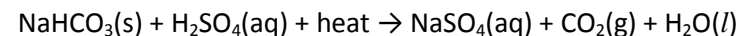
Ionic compounds such as NH<sub>4</sub>Cl, KNO<sub>3</sub>, CaCO<sub>3</sub> absorb heat from surroundings.

**4. Photosynthesis**

Light energy is absorbed by plants to produce starch.

**5. Decomposition by heat**

Many compounds require heat for decomposition, e.g. CaCO<sub>3</sub> to CO<sub>2</sub> + CaO

**6. Acid + Bicarbonates (HCO<sub>3</sub>)****Acid Spill Treatment on Body**

We don't neutralize spilled acid on body as it produces heat. Instead we dilute the solution with water, although it also produces heat, but is less than neutralizing it.

### 5.3 Heat of Reaction

The amount of energy given out or absorbed during a chemical reaction is **enthalpy change**. The symbol is  $\Delta H$  measured in **kilojoules(kJ)**.

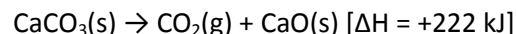
Examples of reactions from back page:

*Exothermic reaction:*



*378 kJ of heat energy is given out when 1 mol of Mg react with 1 mol CuSO<sub>4</sub> to produce 1 mol of MgSO<sub>4</sub> and 1 mol of Cu.*

*Endothermic reaction:*



*222 kJ of heat energy is absorbed when 1 mol of CaCO<sub>3</sub> decompose to 1 mol of CO<sub>2</sub> and 1 mol of CaO.*

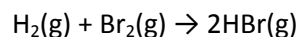
### 5.4 Heat Energy and Enthalpy Change in Reaction

When bonds made, heat energy is given out, it's exothermic and  $\Delta H$  is negative

When bonds broken, heat energy is absorbed, it's endothermic and  $\Delta H$  is positive

#### Question:

Hydrogen bromide is made by reacting H<sub>2</sub> gas with Br<sub>2</sub> gas. Calculate the heat change of the reaction given the equation and bond energy table below.

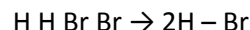


Covalent Bond	Bond energy (kJ/mol)
H – H	436
Br – Br	224
H – Br	366

Bonds of H<sub>2</sub> and Br<sub>2</sub> molecules must be broken first to make HBr. Heat energy is absorbed to break these bonds by endothermic reaction.



Broken bonds are used to make H – Br bonds of HBr. Heat energy is released.



Heat change can be calculated by:

$$\Delta H = \text{heat released in making bonds} + \text{heat absorbed in breaking bonds}$$

Exothermic  $\Delta H$  = the bond energy of 2 H – Br bonds

$$= 2(366)$$

$$= -732 \text{ kJ}$$

Endothermic  $\Delta H$  = the bond energy of 1 H – H bond + 1 Br – Br bond

$$= 436 + 224$$

$$= +660 \text{ kJ}$$

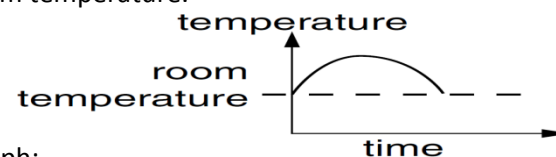
$$\Delta H = -732 + 660$$

$$= -72 \text{ kJ}$$

Therefore more heat is given out in making bond than absorbed in breaking bond. The overall change is to give out heat and it's exothermic with  $\Delta H$  negative.

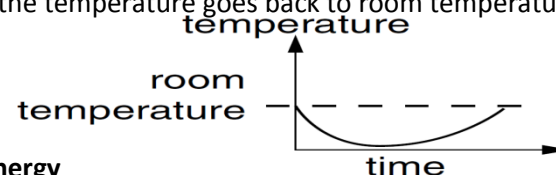
Exothermic graph:

When heat is given out, the solution becomes warm and later the temperature goes back to room temperature.



Endothermic graph:

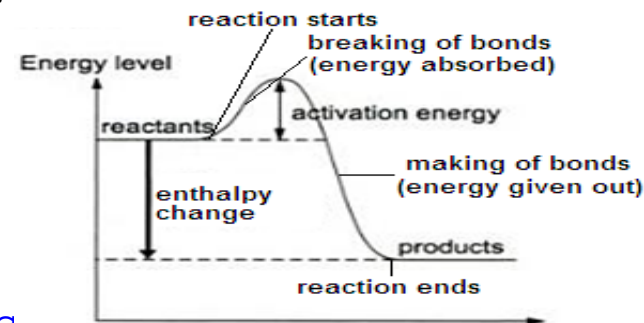
When heat is absorbed from the surrounding of reactant, the solution becomes cooler and later the temperature goes back to room temperature.



### 5.5 Activation Energy

**Activation energy** is the minimum energy needed to start a reaction.

It is the energy needed to break the reactant bonds before new bonds are formed.

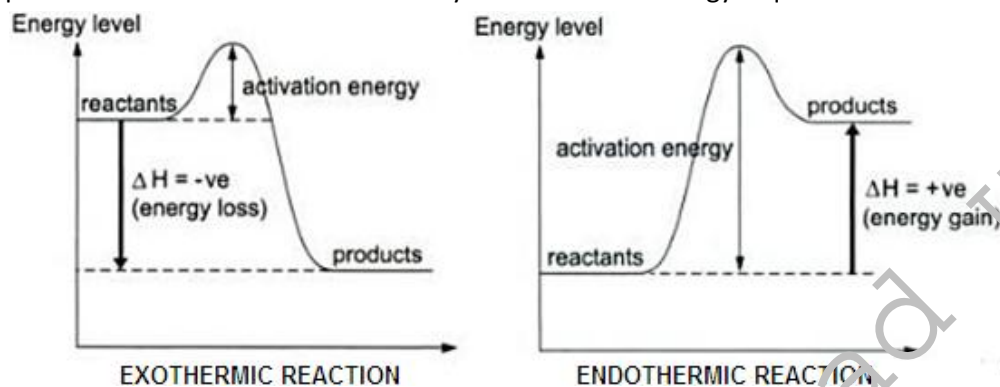


Reactions occur because of collision of particles and sufficient kinetic energy is needed to provide activation energy to break the bonds and start the reaction by providing extra energy from a heat source.

### Exothermic and Endothermic Reaction Graph

In exothermic reaction, enough energy given out in the reaction of particles to provide activation energy therefore less energy is needed to form products.

In endothermic reaction, insufficient energy is given out when bonds are made to provide activation energy for reaction to continue. More energy is needed to form products and heat must be continually added to fulfill energy requirement.



## 5.6 FUELS

The combustion of fuels gives out large amount of energy in industries, transport & homes. These fuel mainly methane from coal, wood, oil, natural gas & hydrogen. Combustion in air provides energy and gives out heat. Hence, exothermic reaction.

### Hydrogen as a Fuel

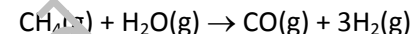
Hydrogen provides twice as much as heat energy per gram than any other fuel and burns cleanly in air to form steam. They are mainly used as rocket fuel.

### Production of Hydrogen

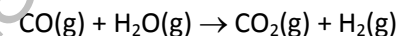
Hydrogen is produced either by electrolysis of water or by cracking of hydrocarbon

#### By cracking of hydrocarbon:

First, methane (hydrocarbon) and steam are passed over a nickel catalyst to form hydrogen and carbon monoxide.



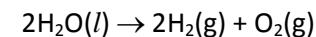
The by-product carbon monoxide is not wasted. It is reacted with more steam to form carbon dioxide and hydrogen.



Now you get more hydrogen.

#### By electrolysis:

Water is electrolysed according to equation:

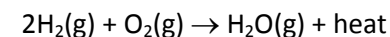


However, electrolysis is costly.

### Creation of the Fuel

#### In Engines:

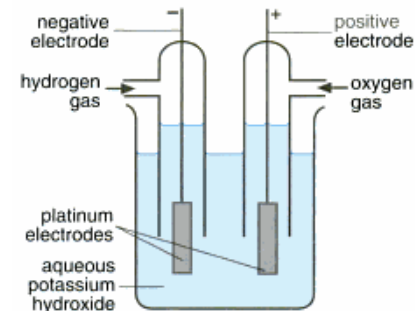
The hydrogen created is reacted with oxygen to form steam and heat energy



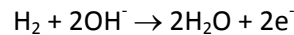
This heat is needed to thrust the vehicle forward. However, we don't use heat energy for our daily appliances. Instead we use electrical energy and to make electrical energy from hydrogen, we use fuel cell.

A **fuel cell** converts chemical energy directly into electrical energy.

#### How Fuel Cells Work

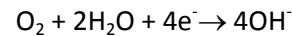


Hydrogen reacts with hydroxide ions into electrolyte on the platinum catalyst on electrode to make the electrode negatively-charged.

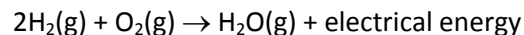


Electrons flows past the load and to the other electrode. That negatively-charged electrode is now anode. Hydroxide ions constantly deposit electrons here to make water. While then, the other electrode is now cathode.

Oxygen reacts with water created on from hydrogen on the cathode to gain electrons from it:



If we combine the ionic equations, we still get water as product of hydrogen and oxygen, but the energy produced is now electrical energy:



#### Advantages of Fuel Cells

- Electrical energy can be generated continuously if there's continuous fuel supply
- The by-product of fuel cells is steam, which do not pollute the environment
- Chemical energy is efficiently converted to electrical energy. Hence there is minimal loss of energy.

#### Disadvantages of Fuel Cells

- Hydrogen-oxygen fuel cells are very expensive, hence limiting their use.

#### Our Main Fuel Resource – PETROLEUM

Petroleum is a mixture of hydrocarbons, which are compounds made up of carbon and hydrogen only.

Crude oil, freshly extracted from underground, undergo **refining** – a process where oil undergoes **fractional distillation** to be separated into its fractions.

First, crude oil is heated up to 350°C and the vapours rise up a tower, divided with trays on some certain heights for the fractions to be collected. The fractionating column is cooler on top, hence upper trays collect fractions of low boiling points while the lower ones, being hotter, collect those with higher boiling points.

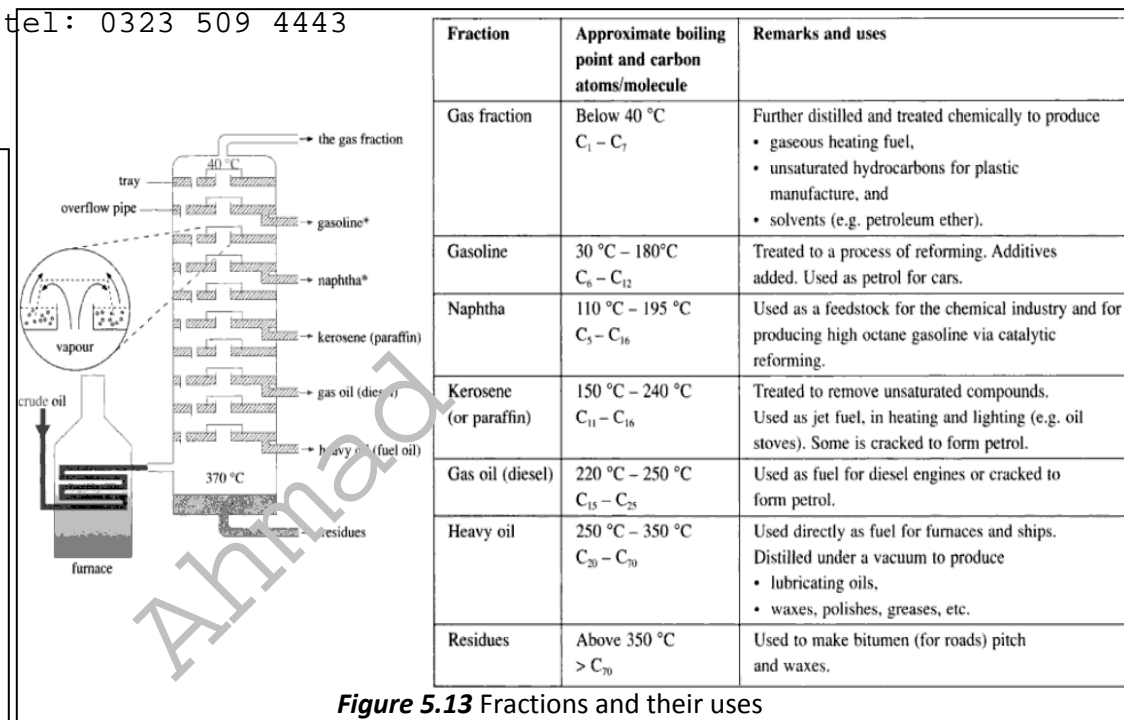
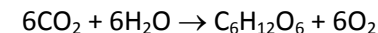


Figure 5.13 Fractions and their uses

#### PHOTOSYNTHESIS AND ENERGY

Plants take in carbon dioxide and water in presence of chlorophyll and synthesize them in the presence of sunlight to produce glucose and release oxygen:



Plants get their energy by using the glucose formed. Scientists believe that we can use the stored energy in glucose as combustible fuels.

First, glucose fermented to make ethanol by microorganisms such as yeast. This is *fermentation*. The glucose is usually derived from corn plant or sugar cane.



Then, water is removed from ethanol by fractional distillation by heating it up until 78°C (boiling point of ethanol). Some water might still be present as the boiling point is close to ethanol. The ethanol produced is then mixed with fuel to be combusted to produce energy. This is *biofuel*, and it's a renewable energy source.

#### END OF CHAPTER 5

## CHAPTER 6 – CHEMICAL REACTIONS

### 6.1 Speed of Reaction

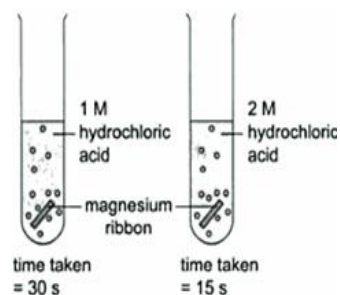
#### Measuring Speed of Reaction

It is the speed for a reactant to be used up or product to be formed.

2 ways to find out speed of reaction

#### 1. Measuring time for reaction to complete

Speed of reaction is *inversely proportional* to time taken; the shorter the time needed for reaction to complete, the faster the speed of reaction is.



$$\text{Speed of reaction} = \frac{1}{\text{time taken}}$$

$$\text{Speed of reaction A} = \frac{1}{30 \text{ s}} = 0.333/\text{s}$$

$$\text{Speed of reaction B} = \frac{1}{15 \text{ s}} = 0.667/\text{s}$$

Therefore reaction B is faster than reaction A as time taken for B is shorter

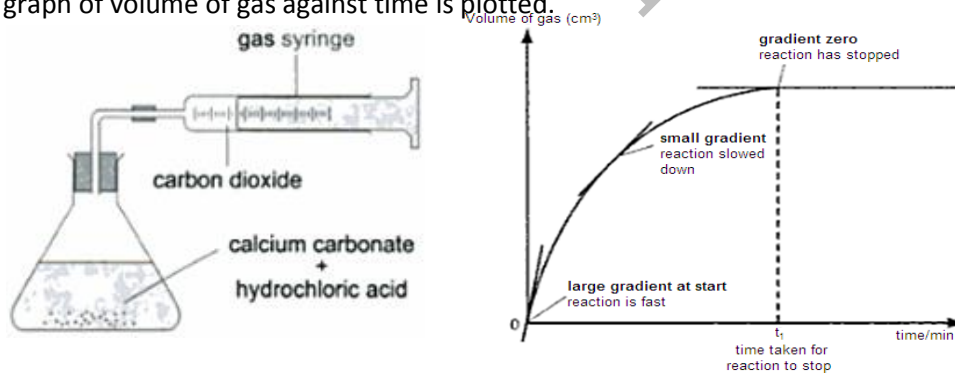
$$\text{Number of times B faster than A} = \frac{0.667}{0.333} = 2 \text{ times}$$

#### 2. Measuring the amount of product produced in a period of time or measuring the amount of reactant remain in a period of time.

Can be measured by plotting change in volume of gas evolved, mass of reaction mixture as reaction proceeds and change of pressure of gas formed.

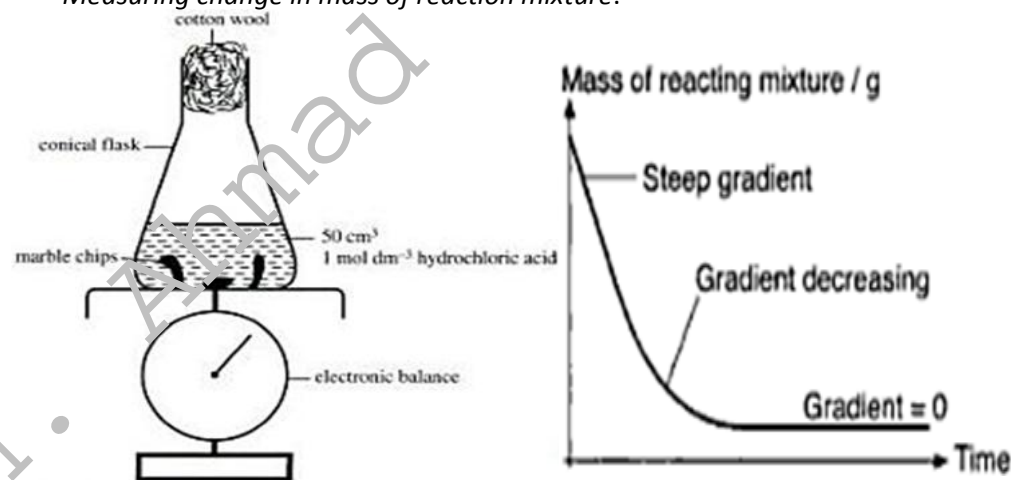
- Measuring the amount of gas evolved.

Consider reaction of limestone with acid to produce carbon dioxide. A syringe is used to help in measurement of gas produced in volume every time interval. A graph of volume of gas against time is plotted.



- Gradient largest at start indicating speed at its greatest.
- Gradient decreases with time – speed decreases with time.
- Gradient becomes zero, speed is zero. The reaction has finished.

- Measuring change in mass of reaction mixture.

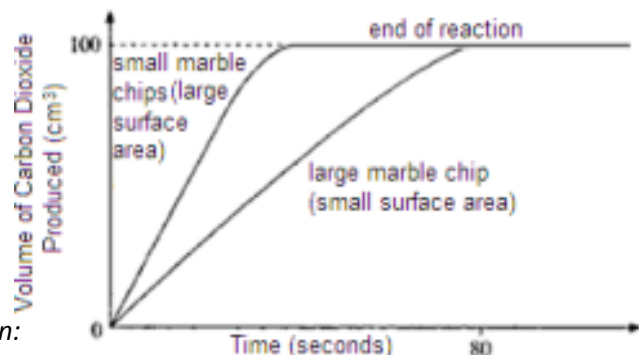


Marble is reacted with acid in a flask with cotton wool stucked at top to prevent splashing during reaction but it allows gas to be free. The reading on balance is plotted on a graph on every time interval.

#### Factors Affecting Speed of Reaction

##### 1. Particle Size of Reactant

When large marble is reacted with acid and compared to reaction of fine marble solids being reacted with acid and the graph of volume of gas against time is plotted, it's found that the reaction involving finer marble chips produces gas faster than the one with larger marble chunk as the graph of finer chips is steeper. The volume of gas at the end is the same for both reactions. Therefore, reactions of solids with liquid/gas is faster when the solids are of smaller pieces.



**Explanation:**

Reactions occur when particles collide. Small particles create a larger surface area for more collisions between reacting particles which increases the speed of reaction.

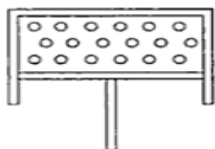
**Explosions:** chemical reactions occurring extremely rapidly producing heat + gas

- Coal dust burns faster than large pieces as it has a larger surface area. In coal mines, when air contains too much coal dust, an explosion can occur from a single spark or match. Water is sprayed into the air to remove coal dust.
- Flour in mills can ignite easily due to its large surface area.

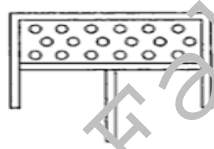
## 2. Concentration of Reactant

An increase in concentration means there are more solute particles per unit volume of the solution which favours more effective collisions resulting in an increase in the speed of reaction.

## 3. Pressure of Reactant



LOW PRESSURE



HIGH PRESSURE

Only gaseous reactions are affected as gas is compressible. At higher pressure, molecules are forced to move closely together, hence increasing the particles per unit volume of gas and effectively increasing the collisions between reacting molecules so the speed of reaction increases.

High pressure is used in industrial processes (e.g. Haber Process Plant) so that the reaction goes faster.

## 4. Temperature of Reaction

The speed of reaction increases when temperature increases. Particles don't always react upon collision but just bounce as they don't have enough activation energy to react. With an increase in temperature, particles absorb the energy and have enough activation energy, they move faster and collide more effectively per second. Therefore, the speed of reaction is increased.

Usually, the speed of reaction doubles for every 10°C rise in temperature.

## 5. Effect of Catalyst

**What are catalysts?**

They are chemical substances which alter the speed of reaction without themselves being used at the end of a reaction. They can be reused and only a small amount of catalyst is needed to affect a reaction.

- transition metals (e.g. Titanium, Nickel, Iron, Copper) are good catalysts
- most catalysts catalyse one kind of reaction (except titanium)

Reaction	Catalyst
Production of sulphur by contact process	Vanadium(V) oxide, $V_2O_5$
Production of ammonia by Haber Process	Iron, Fe
Production of hydrogen by cracking of hydrocarbons	Aluminium oxide, $Al_2O_3$ Silicon dioxide, $SiO_2$
Production of margarine by reacting hydrogen with vegetable oil	Nickel, Ni
Production of plastics	Titanium(IV) chloride, $TiCl_4$
Converting CO into $CO_2$ in catalytic converters	Titanium, Ti Rhodium, Rh

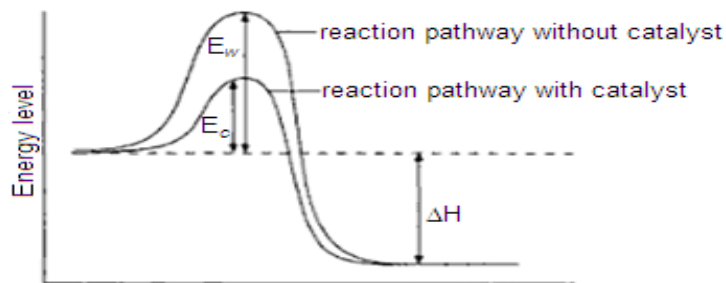
Catalysts lower the need for energy to break bonds so activation energy is lower. Consequently, bond breaking occurs easily and more often when particles collide.

**Factors Affecting Speed of Catalysed Reactions:**

Speed of catalysed reactions can be increased by:

- increasing temperature
- increasing concentration of solutions
- increasing pressure of gas reactions

Catalysts provide "alternative path" which results in lower activation energy.



$E_c$  is activation energy with catalyst  
 $E_w$  is activation energy without catalyst

### Enzymes

Enzymes are biological catalysts

#### Characteristics of enzymes:

- They are very specific. One enzyme catalyse one type of reaction.
- Enzymes are sensitive to temperature. They work best at 40°C. Too high or too low temperatures destroy enzymes.
- Enzymes are sensitive to pH. They function within narrow range of pH.

#### Industrial uses of enzymes:

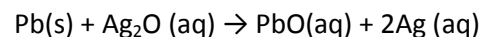
- They are added to detergents from bacteria, and also to make tough meat tender. These enzymes can be found in papaya fruit.
- Yeast convert sugars into alcohol and carbon dioxide by fermentation. Beer, wine and soy sauce are made this way.
- Fungal enzymes can be used to make antibiotics such as penicillin.

## 6.2 Redox

### Oxygen in Reduction-Oxidation reaction

**Oxidation** is the *gain of oxygen* by a substance

**Reduction** is the *loss of oxygen* by a substance



*Pb is oxidized as it gains oxygen from Ag<sub>2</sub>O to form PbO. Ag<sub>2</sub>O is oxidizing agent.*

*Ag<sub>2</sub>O is reduced as it loses oxygen to Pb to form Ag. Pb is reducing agent.*

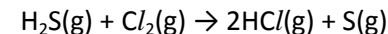
**Oxidizing agent** is a substance which causes *oxidation of another substance*

**Reducing agent** is a substance which causes *reduction of another substance*

### Hydrogen in Reduction-Oxidation reaction

**Oxidation** is the *loss of hydrogen* by a substance

**Reduction** is the *gain of hydrogen* by a substance



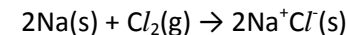
*H<sub>2</sub>S is oxidized as it loses hydrogen to Cl<sub>2</sub> to form S. Cl<sub>2</sub> is oxidizing agent.*

*Cl<sub>2</sub> is reduced as it gains hydrogen from H<sub>2</sub>S to form HCl. H<sub>2</sub>S is reducing agent.*

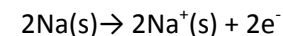
### Electrons in Reduction-Oxidation reaction

**Oxidation** is the *loss of electrons* by a substance

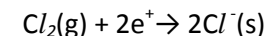
**Reduction** is the *gain of electrons* by a substance



*Na is oxidized as it loses electron to Cl<sub>2</sub> to form Na<sup>+</sup> ions. Cl<sub>2</sub> is oxidizing agent.*



*Cl<sub>2</sub> is reduced as it gains electron from Na to form Cl<sup>-</sup> ions. Na is reducing agent.*



### Redox reactions relating electron transfer:

1. Reaction of metal + dilute acid
2. Displacement reactions

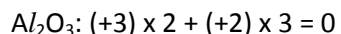
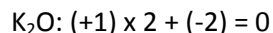
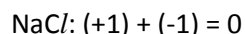
### Oxidation State in Reduction-Oxidation reaction

**Oxidation State** is the charge an atom would have if it existed as an ion

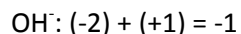
To work out oxidation state, the rules are:

- Free elements have oxidation state zero, e.g. Cu, Fe, N<sub>2</sub>
- Oxidation of an ion is the charge of the ion, e.g. Na<sup>+</sup> = +1, Cu<sup>2+</sup> = +2, O<sup>2-</sup> = -2
- The oxidation state of some elements in their compounds is fixed, e.g.
  - Group I Elements = +1
  - Group II Elements = +2
  - Hydrogen in most compounds = +1
  - Iron or copper can have either +1, +2, +3, so it's not fixed
- Oxidation states of the elements in a compound adds up to zero, e.g.





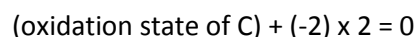
- Sum of oxidation states of elements in an ion is equal to charge on the ion, e.g.



### Examples:

Work out the oxidation states of the underlined elements in these compounds:

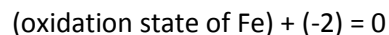
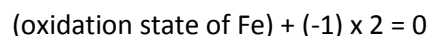
(a) CO<sub>2</sub>



(b) KMnO<sub>4</sub>



(c) Fe(NO<sub>3</sub>)<sub>2</sub>



Note: Transition metals and some common elements may have different oxidation states in different compounds.

Examples of elements with variable oxidation states

Oxidation state	-2	-1	0	+1	+2	+3	+4	+5	+6	+7
Manganese			Mn		MnCl <sub>2</sub>		MnO <sub>2</sub>			KMnO <sub>4</sub>
Chromium			Cr		CrCl <sub>2</sub>	CrCl <sub>3</sub>			K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	
Iron			Fe		FeCl <sub>2</sub>	FeCl <sub>3</sub>				
Sulphur	FeS		S				SO <sub>2</sub>		H <sub>2</sub> SO <sub>4</sub>	
Carbon			C		CO		CaCO <sub>3</sub>			

Some compounds with possible variable oxidation states have roman numeral as a guide about their oxidation state, e.g.

- Iron(II) chloride has formula FeCl<sub>2</sub> and iron oxidation state +2
- Potassium(VI) dichromate has formula K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> and potassium oxidation state +6
- Manganese(IV) oxide has formula MnO<sub>2</sub> and manganese oxidation state +4

**Oxidation** is the *increase of oxidation state* by a substance

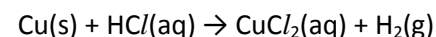
**Reduction** is the *decrease of oxidation state* by a substance

Note:

- Losing electrons means gain in oxidation state
- Gaining electrons means loss in oxidation state

Examples:

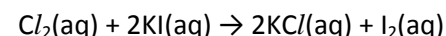
### Metals with acids



*Cu is oxidized as it gains oxidation state from 0 to +2. Cu is reducing agent*

*H<sup>+</sup> ions in HCl reduced as it loses oxidation state from +1 to 0. H<sup>+</sup> ions are oxidising agent*

### Halide (Halogen) Displacement Reactions



*I<sup>-</sup> ions in KI oxidized as it gains oxidation state from -1 to 0. I<sup>-</sup> ions is reducing agent*

*Cl<sub>2</sub> is reduced as it loses oxidation state from 0 to -1. Cl<sub>2</sub> is oxidizing agent*

### Test for Oxidising/Reducing Agents

Oxidizing agents		
Name of compound	Formula	Applications
Potassium dichromate(VI)	K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub>	Test for reducing agent; orange K <sub>2</sub> Cr <sub>2</sub> O <sub>7</sub> reduces to green Cr <sup>3+</sup> ions
Potassium manganate(VII)	KMnO <sub>4</sub>	Test for reducing agent; purple KMnO <sub>4</sub> reduces to colourless Mn <sup>2+</sup> ions
Chlorine	Cl <sub>2</sub>	Oxidizes Br <sup>-</sup> to Br <sub>2</sub> and I <sup>-</sup> to I <sub>2</sub> ; green-yellow Cl <sub>2</sub> reduces to colourless Cl <sup>-</sup> ions

Reducing agents		
Name of compound	Formula	Applications
Potassium Iodide	KI	Test for oxidizing agent; colourless I <sup>-</sup> ions oxidizes to brown I <sub>2</sub>
Carbon monoxide	CO	Reduces metal oxide to metal in heat
Hydrogen	H <sub>2</sub>	Reduces copper(II) oxide to copper
Sulfur dioxide	SO <sub>2</sub>	used as bleach and preservative
Metals (highly reactive)	Na, Mg, etc.	Displaces less reactive metals

**Not Redox!**

- **Decomposition of carbonates by heat:**  $\text{CaCO}_3(\text{s}) \rightarrow \text{CO}_2(\text{g}) + \text{CaO}(\text{s})$

The oxidation state of each element don't change. This is not a redox reaction.

- **Neutralization:**  $\text{NaOH}(\text{aq}) + \text{HCl}(\text{aq}) \rightarrow \text{NaCl}(\text{aq}) + \text{H}_2\text{O}(\text{l})$

The oxidation state of each element don't change. This is not a redox reaction.

- **Precipitation reactions:**  $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$

The oxidation numbers of silver and chloride ions unchanged. This is not redox.

**6.3 Reversible Reactions**

Reversible reactions are denoted by the sign " $\rightleftharpoons$ " where the arrow  $\rightarrow$  denotes **forward reaction**, where reactants react to form products, and the arrow  $\leftarrow$  denotes **backward reaction** where products decompose to reform reactants. The reactions occur at the same time. E.g.  $\text{N}_2(\text{g}) + 3\text{H}_2(\text{g}) \rightleftharpoons 2\text{NH}_3(\text{g})$

*Effect of Temperature on Reversible Reactions*

With higher temperature, the condition is now favored to break the bonds of the product formed (The bonding of products requires low temperatures). Thus, the products decompose to its constituents, leading to backward reaction.

*Effect of Pressure on Reversible Reactions*

Increase in pressure encourages forward reaction because the higher pressure the more reactants collide to react.

*Dynamic equilibrium*

**Dynamic Equilibrium** is the state when the rate of forward reaction is the same as the rate of backward reaction. Both reactants are reacted and products decompose at the same rate. Hence, there is no overall change in the amounts of reactants and products.

When we remove the products, it will also encourage forward reaction as the reaction would try to achieve equilibrium. Similar thing happens when we remove the reactants, that the decomposition of products is encouraged to reach the point

**END OF CHAPTER 6**

## CHAPTER 7 - THE CHEMISTRY AND USES OF ACIDS, BASES AND SALTS

### 7.1 The Characteristics of Acids and Bases

#### Common Acids

Acids in daily life:

- Ethanoic acid – found in vinegar and tomato juice
- Citric acid – found in citrus foods like lemons, oranges and grapefruit
- Lactic acid – found in sour milk and yoghurt, and in muscle respiration
- Tartaric acid – found in grapes
- Tannic acid – found in tea and ant's body
- Formic acid – found in bee stings
- Hydrochloric acid – found in stomach juices

Laboratory acids: 3 common laboratory acids

- Hydrochloric acid (HCl)
- Sulphuric acid (H<sub>2</sub>SO<sub>4</sub>)
- Nitric acid (HNO<sub>3</sub>)

**Dilute acids** – solution containing small amount of acid dissolved in water

**Concentration acids** – solution containing large amount of acid dissolved in water

#### Properties of Dilute Acids

- **Acids have a sour taste**

- **Acids are hazardous**

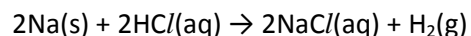
acids are irritants (they cause skin to redden and blister)

- **Acids change the colour of indicators**

Acids turn common indicator litmus – blue litmus to red

- **Acids react with metals**

Acids react with metals to produce hydrogen gas. The gas is tested with a burning splint which shows hydrogen burns with a 'pop' sound.



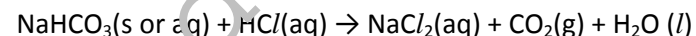
- **Acids react with carbonates and hydrogencarbonates (bicarbonates)**

Carbon dioxide is to be formed. To test this, the gas produced is bubbled into limewater which forms a white precipitate.

Carbonates:

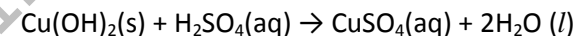


Bicarbonates:



- **Acids react with metal oxides and hydroxides**

Metal oxides & hydroxides react slowly with warm dilute acid to form salt+water



#### Storage of Acids

Acids are stored in claypots, glass or plastic containers as sand, glass and plastic do not react with acids. If it's stored in metal container, metal would react with acids

#### Uses of Acids

- Sulphuric Acid - Used in car batteries
  - Manufacture of ammonium sulphate for fertilisers
  - Manufacture of detergents, paints, dyes, artificial fibres & plastics
- Hydrochloric acid can remove rust (iron(III) oxide) which dissolves in acids
- Acids are used in preservation of foods (e.g. ethanoic acid)

### 7.2 Acids and Hydrogen Ions

#### The Need for Water in Acids

Acids are covalent compounds and do not behave as acids in the absence of water as water reacts with acids to produce H<sup>+</sup> ions, responsible for its acidic properties.

e.g. Citric acid crystals doesn't react with metals and doesn't change colours of indicators; citric acid in water reacts with metals and change turns litmus red.

## Hydrogen Ions

Hydrogen gas is formed by acids as  $H^+(aq)$  ions are present in acid solutions

- This means when a solid/gas acid dissolved in water, they produce  $H^+$  ions in it

Chemical equation:  $HCl(s) \xrightarrow{\text{water}} HCl(aq)$

Ionic Equation:  $HCl(s) \xrightarrow{\text{water}} H^+(aq) + Cl^-(aq)$

\*Note that for ionic equation only aqueous solutions are ionised\*

- However when dissolved in organic solutions, they don't show acidic properties

When metals react with acids, only the hydrogen ions react with metals, e.g.:

Chemical equation:  $2Na(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2(g)$

Ionic equation:  $2Na(s) + 2H^+(aq) \rightarrow 2Na^+(aq) + H_2(g)$

**Basicity of an acid** is maximum number of  $H^+$  ions produced by a molecule of acid

Some Acids With Their Basicity		
Acids	Reaction with water	Basicity
Hydrochloric acid	$HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$	monobasic
Nitric acid	$HNO_3(aq) \rightarrow H^+(aq) + NO_3^-(aq)$	monobasic
Ethanoic acid	$CH_3COOH(aq) \rightleftharpoons H^+(aq) + CH_3COO^-(aq)$	monobasic
Sulphuric acid	$H_2SO_4(aq) \rightarrow 2H^+(aq) + SO_4^{2-}(aq)$	dibasic

### The fizz of drinks

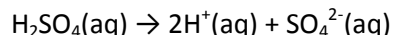
Soft drink tablets contains solid acid (e.g. citric acid,  $C_6H_8O_7$ ) & sodium bicarbonate

- When tablet is added to water, citric acid ionises and the  $H^+$  produced reacts with sodium bicarbonate to produce carbon dioxide gas, making them fizz

## Strong and Weak Acids

**Strong Acid** - acid that completely ionises in water. Their reactions are irreversible.

E.g.  $H_2SO_4$ ,  $HNO_3$ ,  $HCl$

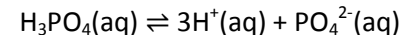


In above  $H_2SO_4$  has completely been ionized in water, forming 3 kinds of particles:

- $H^+$  ions
- $SO_4^{2-}$  ions
- $H_2O$  molecules

*Strong acids react more vigorously with metals than weak acids – hydrogen gas bubbles are produced rapidly*

**Weak Acids** - acids that partially ionise in water. The remaining molecules remain unchanged as acids. Their reactions are reversible. E.g.  $CH_3COOH$ ,  $H_2CO_3$ ,  $H_3PO_4$



*Weak acids react slowly with metals than strong acids – hydrogen gas bubbles are produced slowly.*

## Comparing Strong and Weak Acids with Concentrated and Dilute Acids

CONCENTRATION	STRENGTH
Is the amount of solute (acids or alkalis) dissolved in 1 dm <sup>3</sup> of a solution	Is how much ions can be disassociated into from acid or alkali
It can be diluted by adding more water to solution or concentrated by adding more solute to solution	The strength cannot be changed

Comparing 10 mol/dm<sup>3</sup> and 0.1 mol/dm<sup>3</sup> of hydrochloric acids and 10 mol/dm<sup>3</sup> and 0.1 mol/dm<sup>3</sup> of ethanoic acids

- 10 mol/dm<sup>3</sup> of ethanoic acid solution is a concentrated solution of weak acid
- 0.1 mol/dm<sup>3</sup> of ethanoic acid solution is a dilute solution of weak acid
- 10 mol/dm<sup>3</sup> of hydrochloric acid solution is a concentrated solution of strong acid
- 0.1 mol/dm<sup>3</sup> of hydrochloric acid solution is a dilute solution of strong acid

## Bases and Alkalis

**Bases** are oxides or hydroxides of metals

**Alkalis** are bases which are soluble in water

## Laboratory Alkalis

- Sodium Hydroxide, NaOH
- Aqueous Ammonia,  $NH_4OH$
- Calcium Hydroxide,  $Ca(OH)_2$

All alkalis produces hydroxide ions ( $OH^-$ ) when dissolved in water. Hydroxide ions give the properties of alkalis. They don't behave as acids in absence of water.

**Alkalis** are therefore substances that produce hydroxide ions,  $OH^-(aq)$ , in water.

### Properties of Alkalis

- Alkalis have a slippery feel

- Alkalis are hazardous

- Dilute alkalis are irritants
- Concentrated alkalis are corrosive and burn skin (**caustic**(i.e. burning) **alkalis**)

- Alkalis change the colour of indicators

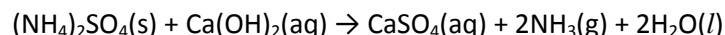
Alkalis turn common indicator litmus – red litmus to blue

- Alkalis react with acids

The reaction is called **neutralisation**

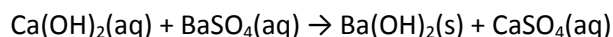
- Alkalis react with ammonium compounds

They react with heated solid ammonium compounds to produce ammonia gas



- Alkalis react with solutions of metal ions

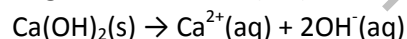
Barium sulphate,  $BaSO_4(aq)$ , contains  $Ba^{2+}(aq)$  ions



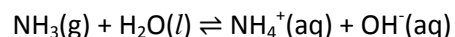
The solid formed is precipitate – the reaction is called **precipitate reaction**

### Strong and Weak Alkalis

**Strong Alkalis** - base that completely ionises in water to form  $OH^-(aq)$  ions. Their reactions are irreversible. E.g. NaOH, KOH,  $Ca(OH)_2$



**Weak Alkalis** - base that partially ionise in water. The remaining molecules remain unchanged as base. Their reactions are reversible. E.g.  $NH_3$



### Uses of Alkalis

- Alkalis neutralise acids in teeth (toothpaste) and stomach (indigestion)
- Soap and detergents contain weak alkalis to dissolve grease

- Floor and oven cleaners contain NaOH (strong alkalis)
- Ammonia (mild alkalis) is used in liquids to remove dirt and grease from glass

### Indicators and pH

**Indicators** are substances that has different colours in acidic and alkaline solutions

*Common indicators:*

➤ **Litmus**

➤ **Methyl orange**

➤ **Phenolphthalein**

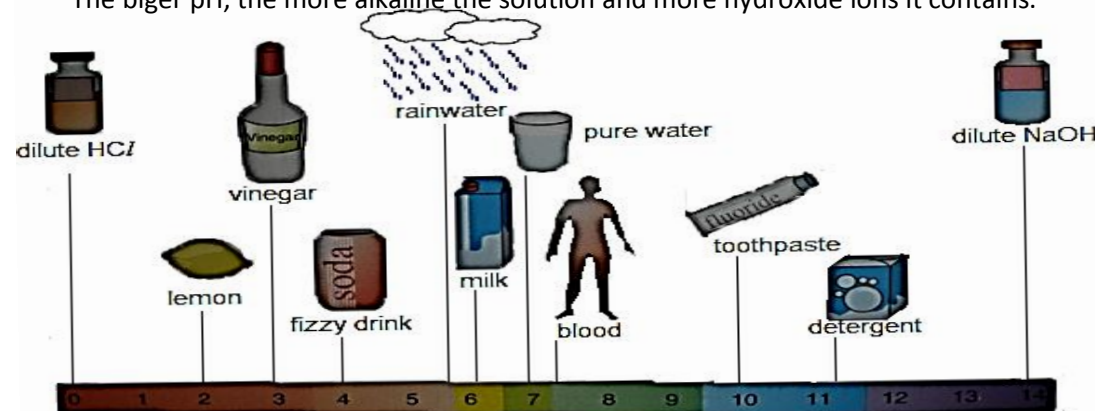
The table shows the change of colours made by some indicators

Indicator	Colour in acids	colour changes at pH	Colour in alkalis
Phenolphthalein	Colourless	9	Pink
Methyl orange	Red	4	Yellow
Litmus	Red	7	Blue
Screened methyl orange	Red	4	Green
Bromothymol blue	Yellow	7	Blue

### The pH Scale

A measure of acidity or alkalinity of a solution is known as **pH**

- pH 7 is neutral – in pure water
- solutions of less than pH 7 are acidic. The solutions contain hydrogen ions. The smaller pH, the more acidic the solution is and more hydrogen ions it contains.
- solutions of more than pH 7 are alkaline. The solution contains hydroxide ions. The bigger pH, the more alkaline the solution and more hydroxide ions it contains.



## Measuring pH of a Solution

### 1. Universal indicators

It can be in paper or solution form. Universal paper can be dipped into a solution then pH found is matched with the colour chart. It gives approximate pH value.

### 2. pH meter

A hand-held pH probe is dipped into solution and meter will show the pH digitally or by a scale. Measures pH water in lakes, water, and streams accurately

### 3. pH sensor and computer

A probe is dipped into solution and will be sent to computer through interface used to measure pH of solution. The pH reading is displayed on computer screen.

### pH Around Us

- Substances in body involved in good digestion have different pH values
- Blood to heart and lungs contains CO<sub>2</sub> making blood slightly acidic
- Acids are used in food preservations (ethanoic acid to preserve vegetables; benzoic acid used in fruit juices, jams and oyster sauce)
- pH affects plant growth – some plants grow in acidic soil; some need alkaline soil
- When hair is cleaned with shampoo which is alkali to dissolve grease, hair can be damaged unless it's rinsed or acid conditioner is used to neutralise excess alkali

### Ionic Equations

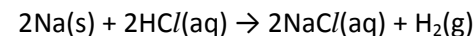
**Ionic equation** is equation involving ions in aqueous solution, showing formation and changes of ions during the reaction

*Rule to make ionic equations:*

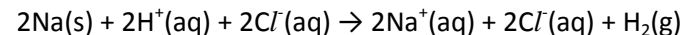
- Only formulae of ions that change is included; ions don't change = omitted
- Only aqueous solutions are written as ions; liquids, solids and gases written in full

#### Reaction Between Metals and Acids

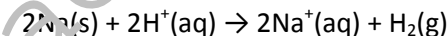
For example, reaction of sodium with hydrochloric acid



Its ionic equation is written as:

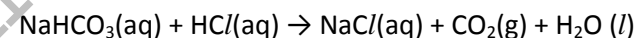


Since 2 Cl<sup>-</sup>(aq) ions don't change, they're not involved in reaction. As ionic equation is used to *show changes in reactions*, we omit Cl<sup>-</sup>(aq) ions. So we're left with:

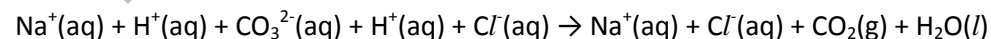


#### Reaction Between Soluble Ionic Compounds and Acids

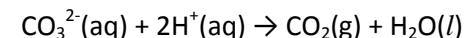
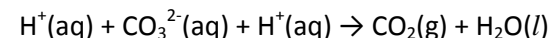
e.g. Reaction of sodium hydrogencarbonate with hydrochloric acid



Its ionic equation is:

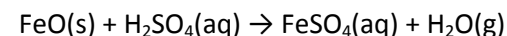


Since Na<sup>+</sup>(aq) and Cl<sup>-</sup>(aq) ions don't change, we omit them, leaving:

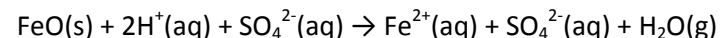


#### Reaction Between Insoluble Ionic Compounds and Acids

e.g. Reaction between iron(II) oxide and sulphuric acid

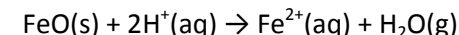


Its ionic equation is:



Note: FeO is written in full as it's solid (although it's an ionic compound)

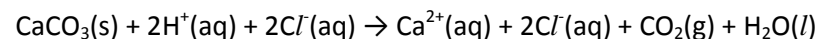
Since SO<sub>4</sub><sup>2-</sup>(aq) ions don't change, we omit SO<sub>4</sub><sup>2-</sup> ions, leaving:



E.g. Reaction between calcium carbonate and hydrochloric acid



Its ionic equation is:

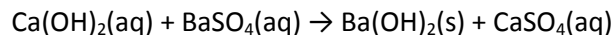


Since 2 Cl<sup>-</sup>(aq) ions don't change, we omit Cl<sup>-</sup> ions, leaving:

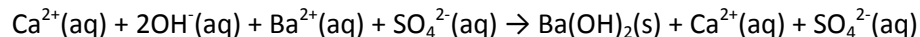


**Reactions Producing Precipitate**

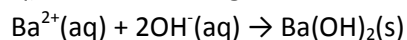
E.g. Reaction between calcium hydroxide and barium sulphate



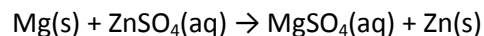
Its ionic equation is written as:



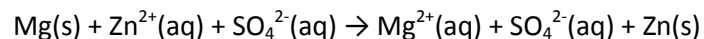
Since  $\text{Ca}^{2+}(\text{aq})$  and  $\text{SO}_4^{2-}(\text{aq})$  ions don't change, we omit them, leaving:

**Displacement Reactions**

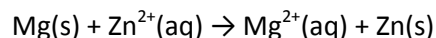
E.g. Reactions between magnesium with zinc sulphate



Its ionic equation is written as:



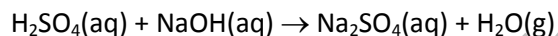
Since  $\text{SO}_4^{2-}(\text{aq})$  ions don't change, we omit them, leaving:



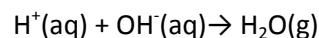
**Neutralization** is the reaction between acid and base to form salt and water only.

From ionic equation, we know that the reaction only involves  $\text{H}^+$  ions from acids with  $\text{OH}^-$  ions from alkali to form water.

E.g.  $\text{NaOH} + \text{H}_2\text{SO}_4$  forms  $\text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$



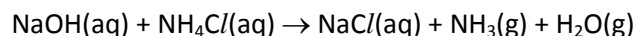
Ionic equation is:



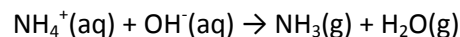
Plants don't grow well in acidic soil. Quicklime (calcium hydroxide) is added to neutralise the acidity of soil according to equation:

**Reaction between Base and Ammonium Salts**

E.g. Reaction between  $\text{NaOH}$  and  $\text{NH}_4\text{OH}$



Ionic equation:

**OXIDES**

Acidic Oxide	Basic Oxide	Amphoteric Oxide	Neutral Oxide
Oxides of non-metals, usually gases which reacts with water to produce acids, e.g. $\text{CO}_2$ , $\text{NO}_3$ , $\text{P}_4\text{O}_{10}$ , $\text{SO}_2$	Oxides of metals, usually solid which reacts with water to produce alkalis, e.g. $\text{CaO}$ , $\text{K}_2\text{O}$ , $\text{BaO}$	Oxides of transition metals, usually solid, which reacts with acids/alkalis to form salt and water, e.g. $\text{Al}_2\text{O}_3$ , $\text{FeO}$ , $\text{PbO}$	Oxides that don't react with either acids/alkalis, hence do not form salts, e.g. $\text{H}_2\text{O}$ , $\text{CO}$ , $\text{NO}$

**7.3 Preparation of Salts****Soluble and Insoluble Salts**

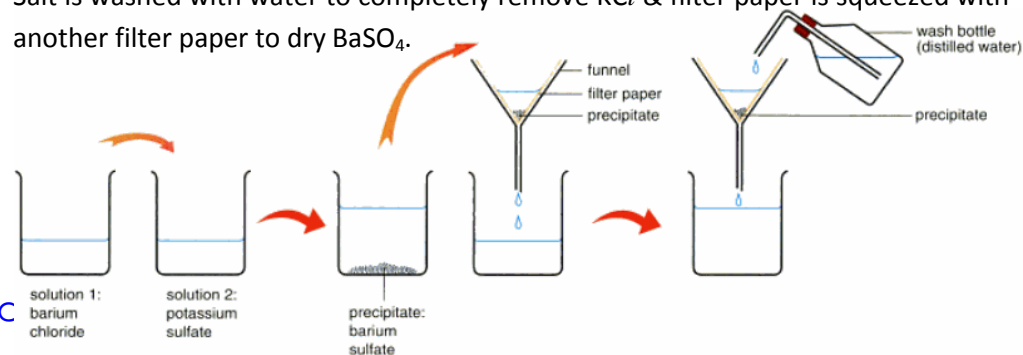
Soluble	Insoluble
All Nitrates	-
All Sulphates	$\text{BaSO}_4$ , $\text{CaSO}_4$ , $\text{PbSO}_4$
All Chlorides	$\text{PbCl}$ , $\text{AgCl}$
Potassium, Sodium, Ammonium salts	-
$\text{K}_2\text{CO}_3$ , $\text{Na}_2\text{CO}_3$ , $\text{NH}_4\text{CO}_3$	All Carbonates
$\text{K}_2\text{O}$ , $\text{Na}_2\text{O}$	All Oxides

**Preparation of Insoluble Salts**

Insoluble salts, e.g.  $\text{BaSO}_4$ ,  $\text{CaSO}_4$ ,  $\text{PbSO}_4$ ,  $\text{PbCl}$ ,  $\text{AgCl}$  and most carbonates, can be prepared by reacting compound containing the wanted cation with another compound containing the wanted anion. This is *precipitation reaction*.

E.g. Preparation of  $\text{BaSO}_4$

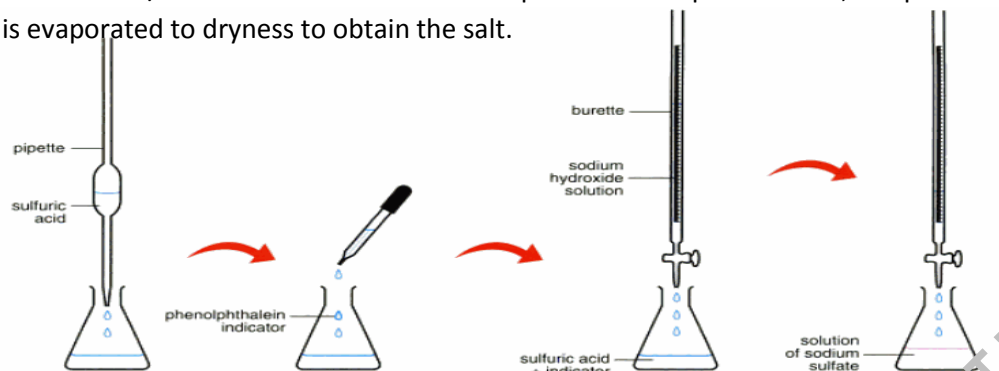
First  $\text{BaCl}$ , since it contains wanted barium ion, is reacted with  $\text{H}_2\text{SO}_4$ , since it contains wanted sulphate ion, to produce solid  $\text{BaSO}_4$  & aqueous  $\text{KCl}$ .  $\text{BaSO}_4$  then separated from  $\text{KCl}$  by filtration, leaving filtrate  $\text{KCl}$  &  $\text{BaSO}_4$  left on filter paper. Salt is washed with water to completely remove  $\text{KCl}$  & filter paper is squeezed with another filter paper to dry  $\text{BaSO}_4$ .



## Preparation of Soluble Salts

### By Neutralization

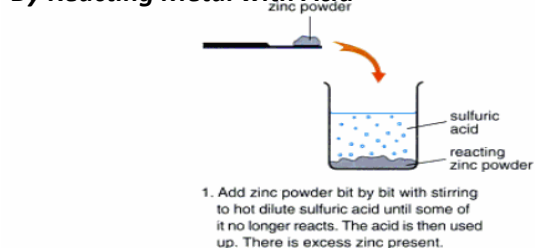
25.0cm<sup>3</sup> acid, as standard solution, is placed in conical flask using pipette. Add few drops of indicator & titrate with alkali from burette until indicator changes colour, showing all acid has just reacted. Volume of alkali added is measured. Prepare new 25.0cm<sup>3</sup> acid again with pipette & add same volume of alkali as before to prevent excess alkali/acid because both reactant & product are aqueous. Next, the product is evaporated to dryness to obtain the salt.



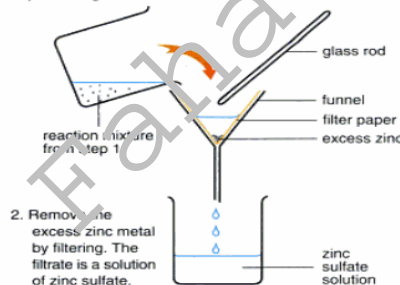
- Using a pipette, 25.0 cm<sup>3</sup> of sulfuric acid is placed in a conical flask. A few drops of indicator are added (e.g. phenolphthalein).
- Dilute sodium hydroxide is placed in a burette and then released into the conical flask until the indicator changes colour (which means all the acid has just reacted). The volume of alkali added from the burette to the acid is measured.

- The experiment is now repeated. 25.0 cm<sup>3</sup> of sulfuric acid is placed in a titration flask (as before), but no indicator is added. The sodium hydroxide is placed in a burette and the same volume of this alkali is added to the flask as before. The flask then contains a solution of sodium sulfate without excess acid or alkali.
- The sodium sulfate is obtained by evaporating most of the water and crystallising the salt.

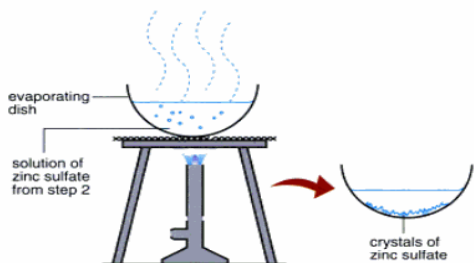
### By Reacting Metal with Acid



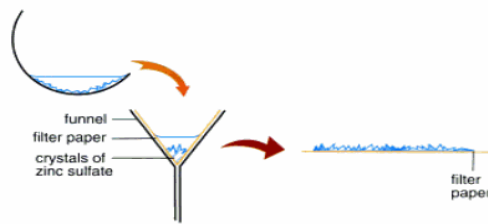
- Add zinc powder bit by bit with stirring to hot dilute sulfuric acid until some of it no longer reacts. The acid is then used up. There is excess zinc present.



- Remove the excess zinc metal by filtering. The filtrate is a solution of zinc sulfate.



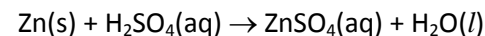
- Pour the solution of zinc sulfate into an evaporating dish and heat to evaporate most of the water. This produces a hot saturated solution of zinc sulfate. Allow the solution to cool.



- Filter the zinc sulfate crystals and dry them by squeezing them between sheets of filter paper.

Only metals like zinc and magnesium, which moderately react with dilute acids, are used.

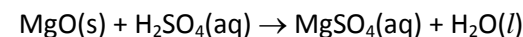
E.g. Reacting Zn with H<sub>2</sub>SO<sub>4</sub> to prepare ZnSO<sub>4</sub>



Zn is added to H<sub>2</sub>SO<sub>4</sub> until in excess to ensure no more H<sub>2</sub>SO<sub>4</sub> is present. Then the mixture is filtered off to separate Zn from ZnSO<sub>4</sub>. The filtrate (ZnSO<sub>4</sub>) is then placed in evaporating dish to evaporate most of water then it's cooled after ZnSO<sub>4</sub> crystals are formed. The crystals then filtered and squeezed between filter papers to dry.

### By Reacting Insoluble Base with Acid

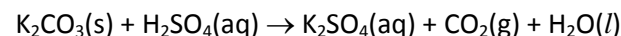
E.g. Reacting MgO with Acids



The same method as reaction of acid with metal is used, so refer to diagram and above explanation, substituting reactants and products.

By Reacting Carbonate with Acid

E.g. Reacting CaCO<sub>3</sub> with Acids



The same process is used as reaction of acid with metal, just that carbon dioxide is produced. Carbon dioxide can be tested by bubbling it into limewater which will turn limewater colourless to milky.

## 7.4 Properties and Uses of Ammonia

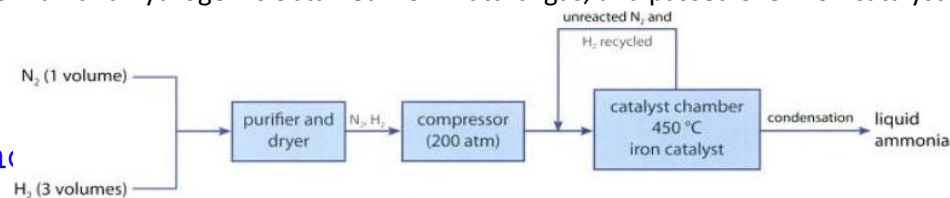
### Ammonia and its Uses

Are produced from nitrogen reacted with hydrogen  
For producing: fertilisers, nitric acid, nylon, dyes, cleaners and dry cell

### The Manufacture of Ammonia: The Haber Process

#### The Process

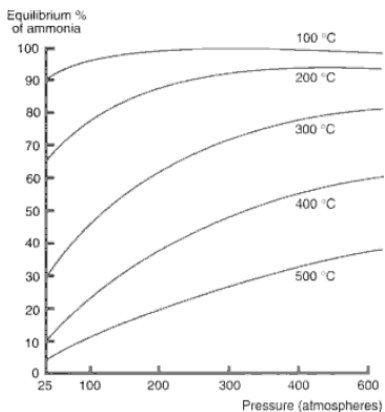
Nitrogen and hydrogen are mixed together in ratio 1:3, where nitrogen is obtained from air and hydrogen is obtained from natural gas, and passed over iron catalyst.





Since the reaction is reversible so  $H_2$  and  $O_2$ , reproduced from decomposition of produced  $NH_3$ , are passed over the catalyst again to produce ammonia.

### Conditions for Manufacturing Ammonia



Graph shows that to have high yield of ammonia we should have:

1. Higher pressure
2. Lower temperature

But in practice, we use lower pressure of 200 atm and higher temperature of 450°C. This is because:

- Using low temperature is too slow to reach equilibrium
- Using high pressure involves safety risk and higher cost

### Ammonia as Fertilizers

Plants need nitrogen as one of component for growth and ammonium fertilizers contain Nitrogen for that.

#### % content of nitrogen in ammonium fertilizers

E.g. Ammonium sulphate,  $(NH_4)_2SO_4$ , and urea,  $(NH_2)_2CO$ , are 2 kinds of fertilizers.

Deduce, in terms of nitrogen content, which of these fertilizers best for plants.

$$\% \text{ mass} = \frac{\text{total mass of element}}{\text{total mass of compound}} \times 100$$

$$\begin{aligned} (NH_4)_2SO_4 &= \frac{2 \times N}{2(N + (4 \times H)) + S + (4 \times O)} \times 100 & (NH_2)_2CO &= \frac{2 \times N}{2(N + (2 \times H)) + C + O} \times 100 \\ &= \frac{2 \times 14}{2(14 + (4 \times 1)) + 32 + (4 \times 16)} \times 100 & &= \frac{2 \times 14}{2(14 + (2 \times 1)) + 12 + 16} \times 100 \\ &= \frac{28}{132} \times 100 & &= \frac{28}{60} \times 100 \\ &= 21.2\% \text{ of N} & &= 46.7\% \text{ of N} \end{aligned}$$

Therefore,  $(NH_2)_2CO$  is a better fertilizer since it contains more nitrogen

### Problems with Ammonia

*Eutrophication* is the increase in organic content of water when fertilizers leach into soil and washed into rivers and streams.

When excess fertilizers washed away by rain, nitrate ions in it gets into rivers and helps aquatic plants like algae to grow swiftly. When too much algae, water turns murky and sunlight would not penetrate into water to help their growth which in turn lead to deaths of algae. Decay of this organic matter uses up oxygen, hence killing aquatic animals. Then even more algae dies and even more animals die

*Water pollution* results from runoff of fertilizer use, leaching from septic tanks, sewage and erosion of natural deposits.

Nitrate ions from nitrogen in soil leaches down the soil into groundwater due to its solubility. Since groundwater is our drink source, when humans drink this water, they will get seriously ill and babies may suffer breathlessness to death.

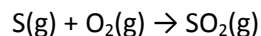
## 7.4 Sulphuric Acid

### About Sulphuric Acid

It is a colourless oily liquid with density slightly higher than water and high boiling point of 338°C. It's soluble in water and emits heat when dissolved.

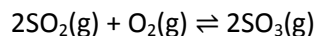
### The Contact Process

1. Sulphur is reacted with oxygen to produce sulphur dioxide, SO<sub>2</sub>

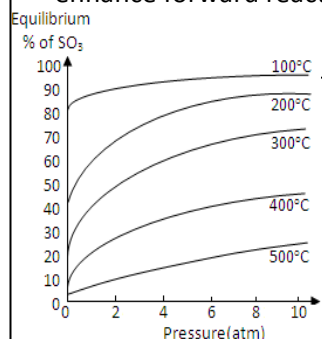


2. SO<sub>2</sub> gas is purified from impurities by passing it through dust settlers and washed with water then dried with concentrated H<sub>2</sub>SO<sub>4</sub>. If there's impurities, the catalyst will be "poisoned" and the reaction will be less effective.

3. Sulphur dioxide is further reacted with oxygen to produce sulphur trioxide.



Since this is a reversible reaction, low temperature and high pressure is needed to enhance forward reaction.



According to graph:

- Low temperatures yields high percentage of sulphur trioxide at equilibrium

*Dynamic equilibrium is the state when forward and backward reaction occurs at same speed and the concentration of reactant and product is equal. The reactions do not stop and some reactants and products always remain.*

Although lower temperature is required for high yield, 450°C is instead used in the process as the reaction will be too slow with low temperatures.

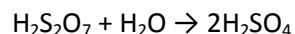
Pressure of 2-3 atm is used in practice.

A catalyst vanadium(V) oxide, V<sub>2</sub>O<sub>5</sub>, is used to increase the yield of sulphur trioxide. Platinum can catalyse more efficiently but it is too expensive.

4. Sulphur trioxide is cooled & reacted in concentrated H<sub>2</sub>SO<sub>4</sub> to produce oleum, H<sub>2</sub>S<sub>2</sub>O<sub>7</sub>. SO<sub>3</sub> is not reacted with water right now as mist forms at this temperature.



5. Oleum is diluted with water to produce sulphuric acid.



### Uses of Sulphuric Acid

- Making of fertilizers such as superphosphate and ammonium sulphate
- Making detergents
- Cleaning surfaces of iron and steel surface before galvanization or electroplating
- To manufacture plastics and fibres
- As electrolyte in car batteries
- In refining of petroleum
- In production of dyes, drugs, explosives, paints, etc.

### Uses of Sulphur Dioxide

Sulphur dioxide is a colourless, toxic gas with suffocating smell, denser than the air and dissolves in water. Sulphur dioxide is emitted from electric power plants and smelting operations to produce copper, zinc, lead and nickel from sulfide ores and it's a major contributor to acid rain. It is used:

- In sulfite manufacturing used in digestion & bleaching wood pulp to make paper
- As food preservatives such as dried fruit and fruit juices. It's not used to preserve meat as it destroys vitamin B<sub>1</sub>
- To bleach straw

**END OF CHAPTER 7**

## CHAPTER 8 – THE PERIODIC TABLE

### *The Progenitor Periodic Table*

First periodic table made by Dimitri Mendeleev in 1869.

### *The Modern Periodic Table*

Differences to Mendeleev's:

- 115 elements while for Mendeleev's is 69.
- Mendeleev arranged the elements according to *relative atomic mass* while today we arrange according *proton number*.

*Period* – horizontal row of elements in periodic table

*Group* – vertical column of elements in periodic table numbered from I to 0

Elements between Group II and Group III – **transition metals**

## 8.1 Patterns in the Periodic Table

### 1) Electronic Structure

Elements in same group has the same number of valence shell electrons which the amount is the same as the group number.

e.g. Group II has elements with valency of 2 electrons.

### 2) Charges on Ions

The charges relates to the group number and number of valence electrons.

- Elements on left side periodic table lose ions to form cation.
- Elements on right side periodic table lose ions to form anion.
- Elements in Group IV can lose or gain electrons depending on reacting element.
- Transition metals may form variable cation of 2+ or 3+

Group Number	I	II	III	IV	V	VI	VII	0
Formula of ion	+1	+2	+3	varies	-3	-2	-1	stable

### 3) Bonding

Elements in same group form same type and number of bonds due to the same number of valence electrons.

e.g. Sodium in Group I forms NaCl, so other elements in Group I does the same.

(RbCl, KCl, LiCl, CsCl)

## 4) Metals and Non-metals

Metals	Non-metals
On the left side of periodic table	On the right side of periodic table
Have fewer ( $\leq 4$ ) valence electrons	Have more ( $> 4$ ) valence electrons

From left to right, elements gradually change from metal to non-metal

Elements close to dividing line in periodic table in back part of the note (in bold) are called **metalloids** having properties of metals and non-metals.

## 5) Changes in Group

- Proton number increase going down the group
- On each sides of periodic table, the change of the proton number small & gradual
- In transition metals, the gradual change is larger

## Using the Periodic Table

### Predicting Properties

#### 1) Formula and Structures

Given chlorine, iodine and bromine of Group VII forms molecules of Cl<sub>2</sub>, I<sub>2</sub> and Br<sub>2</sub> respectively, predict the molecular formula of Fluorine.

$\therefore$  F<sub>2</sub>

From example, we know elements in same group form same formula.

#### 2) Properties of Elements

Properties of element changes down the group.

i.e. given list of Group 7 elements, predict the properties of astatine.

Element	Proton Number	Melting Point (°C)	Boiling Point (°C)
Fluorine	9	-220	-118
Chlorine	17	-101	-35
Bromine	35	-7	59
Iodine	53	114	184
Astatine	85	> 114	> 184

## 8.2 Group Properties

### Group I Elements – The Alkali Metals

These are metals which react with water to form alkaline solutions. The solutions turn red litmus paper blue.

- most reactive metals in periodic table
- have one outer shell electrons
- shiny, silvery solids
- soft, easily cut with scalpel
- low densities & melting points. These increases down the group
- reacts easily in air. So they're kept in oil
- reacts vigorously (may catch fire or explode) with cold water
- they make ionic compounds of +1 charge. They have similar formulae
- they become more reactive down the group

Name	Symbol	Density (g/cm <sup>3</sup> )	Melting point (°C)
Lithium	Li	0.53	180
Sodium	Na	0.97	98
Potassium	K	0.86	64
Rubidium	Rb	1.5	39
Caesium	Cs	1.9	29

Element	Chloride	Nitrate	Sulphate	Oxide
Lithium	LiCl	LiNO <sub>3</sub>	Li <sub>2</sub> SO <sub>4</sub>	Li <sub>2</sub> O
Sodium	NaCl	NaNO <sub>3</sub>	Na <sub>2</sub> SO <sub>4</sub>	Na <sub>2</sub> O
Potassium	KCl	KNO <sub>3</sub>	K <sub>2</sub> SO <sub>4</sub>	K <sub>2</sub> O

Table 12.1: The physical properties and formulae of Group I metals

### Group VII Elements – The Halogens

These are elements which reacts with most metals to form salts

- very reactive elements
- have seven outer shell electrons
- each molecule in the element is diatomic (contains two atoms, eg F<sub>2</sub>)
- elements become darker and solidify down the group
- they have low melting and boiling points which increases down the group
- all halogens are poisonous

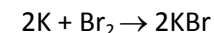
Element	Molecular formula	Melting point (°C)	Boiling point (°C)	State at r.t.p.	Colour
Fluorine	F <sub>2</sub>	-220	-189	gas	Pale yellow
Chlorine	Cl <sub>2</sub>	-101	-35	gas	Greenish yellow
Bromine	Br <sub>2</sub>	-7	59	liquid	Reddish brown
Iodine	I <sub>2</sub>	114	184	solid	Shiny black

### Compounds of the Halogens

Halogens gives a charge of -1, so they give similar formulae, eg: NaBr, NaI

### Reactions of the Halogens

- reacts vigorously with metals to form ionic salts for the equation:

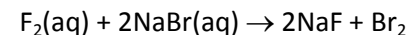


- halogens become less reactive down the group

### Displacement Reactions

More reactive halogen displaces less reactive halogen

eg: aqueous fluorine was added into sodium bromide solution. State the chemical equation of the reaction.



### Group 0 Elements – The Noble Gases

Are least reactive elements in the state of gas. They do not form bonds

- have stable electronic configuration with full electrons on their shells
- coloured gases consisting of single atoms (*monoatomic*)
- low melting and boiling points

### Uses of the Noble Gases

- argon used in light bulbs as it wouldn't react with the hot filament
- neon used in neon advertising strip lights
- helium used in small and weather balloons, and airships for less density

### 8.3 Transition Elements

#### Properties

- First transition series are all metals
- Transition elements have high melting points
- They have high density
- They have variable oxidation state, e.g. Iron (Fe) appear as  $\text{Fe}^{2+}$  or  $\text{Fe}^{3+}$
- They form coloured compounds, e.g.  $\text{CuSO}_4$  is blue,  $\text{FeSO}_4$  is green
- They form complex ions, e.g.  $\text{MnO}_4^-$ , Manganate(VII) ions
- They act as catalysts

#### Uses of Transition Elements

Most transition elements and their compounds act as catalysts which speed up chemical reactions

- Iron is used in Haber Process for manufacture of ammonia
- Vanadium(V) oxide is used in contact process to manufacture sulphuric acid
- Nickel is used in hydrogenation of alkenes to form saturated fats (e.g. margarine)

#### Advantages

- Since transition elements speed up chemical processes in industries, they save time in manufacture
- Less energy is needed for manufacture in industries, hence lower cost
- Since less energy is needed, more energy resources can be conserved, e.g. oil to generate electricity in producing iron.

**END OF CHAPTER 8**

### CHAPTER 9 –METALS

#### 9.1 Properties of Metals

##### Physical properties

- **Ductile** (can be stretched to form wires)
- **Malleable** (can be bent and beaten into different shapes)
- Good **conductors of electricity and heat**
- **Shiny**
- **High melting points and boiling points** (except mercury and sodium)
- **High density** (except sodium)
- **Strong**

#### ALLOYS

*Alloy* – a mixture of metallic elements or metallic with non-metallic.

Pure metals are weak as the layers of atoms slide over each other easily.

∴ in alloy of 2 metals, they have different sizes of atoms so this disrupts the orderly layer of atoms making it difficult for atoms to slide over.

##### Uses of Alloy:

- **Steel** (mixture of iron, little carbon and trace elements)
- **Brass** (copper and zinc) – tough and corrosive-resistant
- **Coin metals** (copper with other metals e.g. nickel) – tough, resistant and stand up to wear

##### Uses of Stainless Steel

is an alloy of iron containing chromium or nickel. Is the most expensive way

##### Applications for:

- Cutlery
- Medical instruments for hospital operations
- Kitchen sinks
- Steel objects in chemical factories and oil refineries

## 9.2 Reactivity Series

### Reaction of Metals with Water

**Potassium, Sodium, and Calcium** reacts with cold water to form:



Metal + Water → Metal Hydroxide + Hydrogen

**Magnesium, Zinc, Iron** reacts with steam to form:



Metal + Water → Metal Oxide + Hydrogen

**Iron** does not react with water

**Copper and Gold** have no reaction with water and steam

### Reaction of Metals with Dilute Hydrochloric Acid

**Potassium, Sodium, Calcium, Magnesium, Zinc and Iron** reacts with dilute hydrochloric acid to form:



Metal + Acid → Metal Chloride + Hydrogen

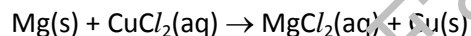
**Lead** reacts with warm hydrochloric acid slowly

**Copper and Gold** have no reaction with dilute hydrochloric acid

### Displacement Reactions

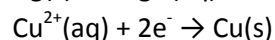
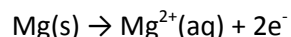
*Displacement reaction* is the displacement of ions of metal from compounds of metals lower in reactivity series by metals higher in reactivity series.

*E.g. Magnesium displaces copper(II) chloride*

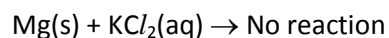


For observation, we'll see silver magnesium metal coated with brown copper metal

Displacement is due to Mg atoms transfer electrons to  $Cu^{2+}$  ions forming Cu atoms.



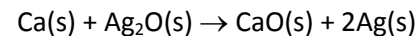
Loss of electrons is due to it's less reactive as less reactive metal has higher chance of losing electrons. That's why when Mg is placed in  $KCl$ , no reaction occurs.



*E.g. Displacement from metal oxides*

Metal higher in reactivity series displaces oxides of metals lower in reactivity series.

When Ca burns with  $Ag_2O$ , Ca displaces Ag to produce CaO and Ag.

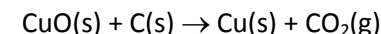


This is called **thermit reaction** large amount of heat is produced.

### Reaction of Metal Oxides with Carbon

*The lower the position of metal in reactivity series, the easier for carbon to remove oxygen from metal oxide by heating. At higher position, stronger heat is needed.*

*E.g. CuO reacts with C can be reduced by bunsen burner flame temperature*

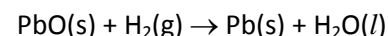


For iron oxide to be reduced, it needs very high temperature.

### Reaction of Metal Oxides with Hydrogen

*The lower position of metal in reactivity series, the easier hydrogen remove oxygen from metal oxide by heating. At higher position, stronger heat is needed.*

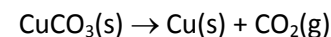
*E.g. PbO reacts with  $H_2$  can be reduced by bunsen burner flame temperature*



### Decomposition of Metal Carbonates

*The lower position of metal in reactivity series, the easier hydrogen remove oxygen from metal oxide by heating. At higher position, stronger heat is needed.*

*E.g.  $CuCO_3$  reacts decomposes by heat of bunsen burner flame temperature*



### 9.3 Extraction of Metals

#### Metals from Rocks

*Minerals* – elements/compounds that make up rocks

*Metal ore* – rock containing metal

#### Extracting these metals

- Metal ores are removed from ground.
- The ores contain useful and unwanted materials. Unwanted materials are separated to obtain concentrated mineral.
- Metal is extracted from the mineral.

#### Occurrence of Metals

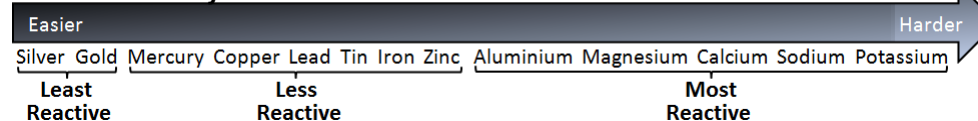
Metal ores are compounds, usually as:

- **Metal oxides** – metal + oxygen, eg:  $Al_2O_3$
- **Metal sulphides** – metal + sulphur, eg:  $HgS$
- **Metal carbonates** – metal + carbon + oxygen, eg:  $MgCO_3$

#### Some important metal ores:

Mineral Metal	Name of ore	Chemical name	Formula
Sodium	Rock salt	Sodium chloride	$NaCl$
Calcium	Limestone	Calcium carbonate	$CaCO_3$
Magnesium	Magnesite	Magnesium carbonate	$MgCO_3$
Aluminium	Bauxite	Aluminium oxide	$Al_2O_3$
Zinc	Zinc Blende	Zinc sulphide	$ZnS$
Iron	Haematite	Iron(III) oxide	$Fe_2O_3$
	Magnetite	Iron(II),(III) oxide	$Fe_3O_4$
Tin	Cassiterite	Tin(IV) oxide	$SnO_2$
Lead	Galena	Lead(II) sulphide	$PbS$
Copper	Chalcopyrite	Copper(II) sulphide + Iron sulphide	$CuFeS_2$ ( $CuS + FeS$ )
Mercury	Cinnabar	Mercury(II) sulphide	$HgS$

#### The Extraction of Metals



**Least Reactive** – easiest to extract; extracted by physical methods

**Less Reactive** – harder to extract than least reactive; by blast furnace; usually occur as compounds of oxides or sulphides.

**Most Reactive** – hardest to extract – strong bonds in compounds; by electrolysis – decomposing compounds with electricity.

#### Uses of Metals

The choice of metals over another depends on 3 factors:

1. Physical properties (e.g. melting point, strength, density, conductivity)
2. Chemical properties (e.g. resists corrosion)
3. Cost

The Uses of Some Metals and Their Reasons		
Metal	Uses	Reason for the choice
Aluminium	- Drink cans - Window frames	- Low density, non-toxic, cheap - Resists corrosion, strong
Copper	- Electrical wires - Water pipes	- Ductile, good conductor of electricity - Strong, malleable, resists corrosion
Gold	- Jewellery - Protective coating	- Shiny and attractive, very malleable - Good reflector of heat and light
Titanium	- Supersonic aircraft - Spacecraft	- Light but strong, resists corrosion

#### Recycling of Metals

##### How Much is Left?

There are many iron on the surface but copper and tin are seriously reducing.

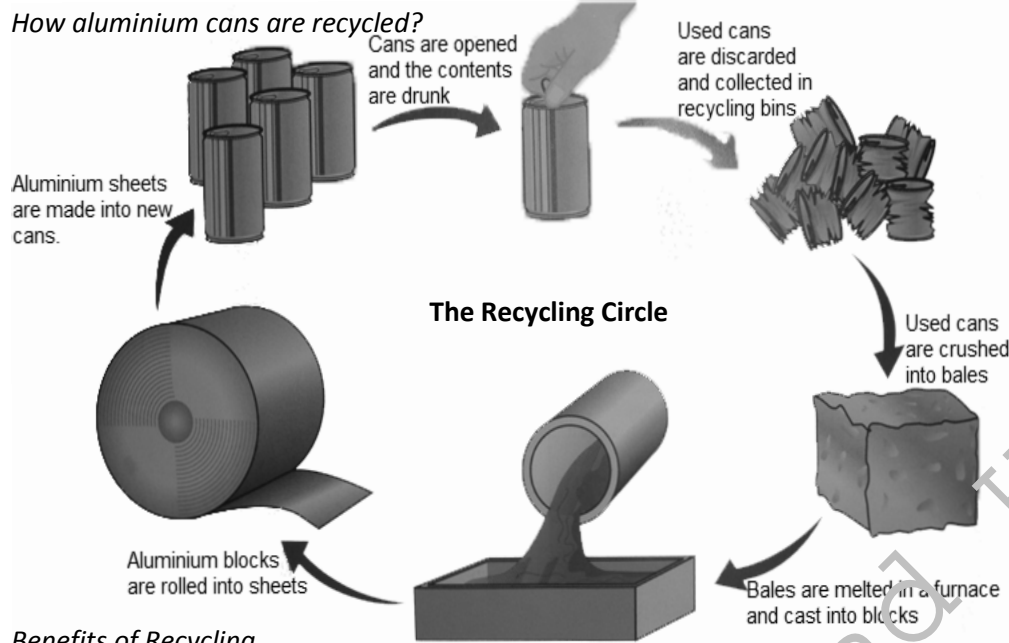
*If you say you have only mined the surface, why don't you mine deeper for more?*

High temperatures and pressures and greater depth increases hazards that prevent mining up to the lower part of crust, although there are more metals further down

**Conservation of metals- Recycling**

- Use alternative materials to replace the use of iron (e.g. use of plastic pipes instead of iron, use of glass bottles for soft drinks instead of aluminium)
- Recycle unused metals by melting them to produce new blocks of clean metal

*How aluminium cans are recycled?*



*Benefits of Recycling*

- Recycling helps conserving metals, especially valuables such as gold and platinum. E.g. used computer parts processed to extract gold used for electrical contacts of processors and memory chips
- Recycling saves the cost of extracting new metals
- Recycling benefits environment, e.g. if there is a car wasteland, it causes eyesore

*Problems with Recycling*

- Metals are recycle if the cost is cheaper than extraction. E.g. Iron, a cheap metal, is more expensive to recycle than to extract new iron

- Recycling metals can damage the environment by smelting process which sends a lot of fumes into the air
- Cost to separate metals from waste is high. E.g. separat metals in alloys is hard
- Transport costs for collecting scrap metal is high, e.g. trucks should be used
- People are not interested in depositing their used materials in recycling bins

**9.4 Iron**

Iron is extracted from the iron ore haematite, Fe<sub>2</sub>O<sub>3</sub>  
 Iron is extracted from the oxide in a blast furnace (next page)

**The Blast Furnace**

1. Oxygen in the air reacts with coke to give carbon dioxide:  

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$$
2. Carbon dioxide produced in 1 reacts with more coke to produce carbon monoxide  

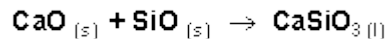
$$CO_{2(g)} + C_{(s)} \rightarrow 2CO_{(g)}$$
3. The carbon monoxide reacts with iron(III) oxide to produce molten iron, which runs down to the bottom of the furnace  

$$3CO_{(g)} + Fe_2O_{3(s)} \rightarrow 2Fe_{(l)} + 3CO_{2(g)}$$
4. The limestone decomposed by heat to form calcium oxide and carbon dioxide  

$$CaCO_{3(s)} \rightarrow CO_{2(g)} + CaO_{(s)}$$

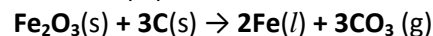


5. Iron ore contains many impurities (silicon, sulphur, phosphorus, etc.) Sand,  $\text{SiO}_2$ , reacts with calcium oxide to produce slag (calcium silicate). Slag runs down to the bottom of the furnace, floating on top of molten iron



6. Molten iron & slag tapped off separately in furnace. Slag is for road construction.

7. Referring to equation, not all iron(III) oxide reacted with carbon, only small amount



### Steel

Iron made from blast furnace is not good as:

- it contains impurities which makes it brittle (can break easily)
- it cannot be bent or stretched

Most iron is converted into steel which is an alloy of iron and carbon with small amounts of other elements. Advantages of steel:

- it is strong and tough
- it can be bent and stretched without shattering

### Making Steel:

- Impurities of iron is removed by blowing oxygen into molten iron to change the impurities into oxides. They are then combined with CaO and removed as slag.
- Carbon and other metals are added in certain amount to make steel.

### Different Types of Steel:

- Mild steel – is a low carbon steel with 0.25% carbon
  - It is strong and quite malleable. It is used for car bodies, ships, railway lines and steel rods to reinforce concrete
- Hard steel – is a high-carbon steel with about 1% carbon
  - It is harder than mild steel and less malleable. It is used to make tools
- Stainless steel – is iron with large amounts of chromium and nickel
  - It is hard, shiny and doesn't rust. It is used to make cutleries, medical instrument and pipes in chemical industries.

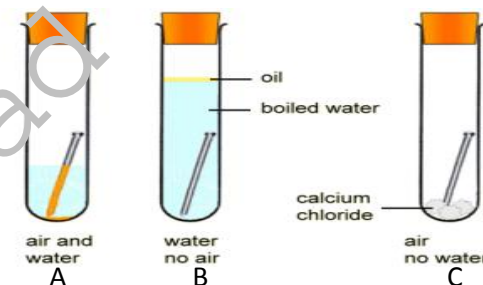
### Rusting

*Rusting* – corrosion of iron and steel

*Rust* – brown solid product formed during rusting

Rust is hydrated iron(III) oxide  $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$  where water molecules varies.

### Conditions for Rusting



Tubes

After a few days, only nail in tube A rust. This shows that air and water is needed for rust. In boiled water, the nail doesn't rust in B as boiled water removes dissolved air while in C, CaCl keeps air dry so there's no water.

Other factor → dissolved salt

### Preventing Rusting

- Surface protection
- Sacrificial protection
- Use of stainless steel

**Surface Protection** – covers metal with a layer of substance

- 1) **Paint**
- 2) **Grease or oil** (also help to lubricate)
- 3) **Plastic**
- 4) **Metal Plating** – covering metal with thin layer of another metal (e.g. tin, chromium, silver)

**Advantage** – These methods are cheap (except metal plating)

**Disadvantage** – If the layer is broken, air and water can reach metal to rust

**Sacrificial Protection**

is to sacrifice more reactive metal to corrode with water and air by layering it over less reactive metal (e.g. iron covered by magnesium). If layer is broken, water & air reach underneath layer, overlying metal still protect it.

*Applications:*

- 1) Galvanised Iron** – is steel coated with zinc, usually used on roofs.
- 2) Protecting ships** – blocks of zinc are attached to hulls to corrode instead of steel which is the ship metal.
- 3) Underground steel pipes** – these are attached to magnesium block using insulated copper cables. Magnesium corrodes first than steel.

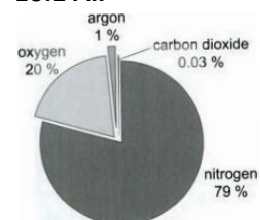
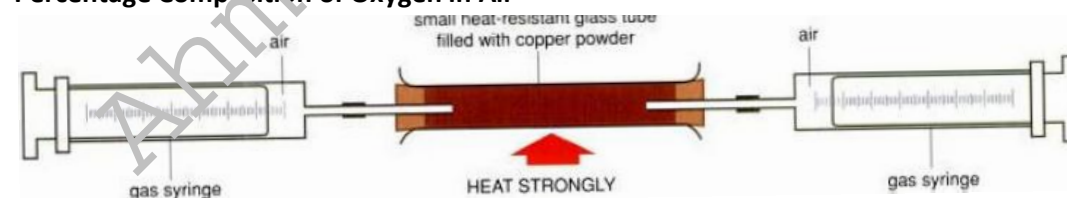
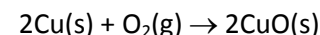
**END OF CHAPTER 9****CHAPTER 10 – ATMOSPHERE AND ENVIRONMENT****10.1 Air**

Fig. 23.1 Composition of dry air

The atmosphere is a layer of air containing mixture of several gases. This mixture composition varies according to time and place. The composition of water vapour varies from 0-5%, depending on the humidity of air.

**Percentage Composition of Oxygen in Air**

A known volume of air is passed through tube with burning copper powder and oxygen in air will react with hot copper powder to produce black copper oxide:



If oxygen is depleted, the readings on both syringes will be steady and the reaction has completed. Hence, to find the volume of oxygen in air collected in syringe:

$$\text{Volume of O}_2 = \text{Initial volume of air} - \text{Final volume of air}$$

For instance, the initial volume of air in one syringe is  $80\text{cm}^3$  and the final volume is  $64\text{cm}^3$ . Hence, the percentage volume of  $\text{O}_2$  in air is:

$$\begin{aligned} \% \text{ Volume of O}_2 &= \frac{\text{Volume of O}_2 \text{ in one syringe}}{\text{Initial volume of gas in one syringe}} \times 100\% \\ &= \frac{16\text{cm}^3}{80\text{cm}^3} \times 100\% \\ &= 20\% \end{aligned}$$

**Liquefaction of Air**

First,  $\text{CO}_2$  is removed by passing air through  $\text{NaOH}$ . Then, the air is cooled to  $-25^\circ\text{C}$  to freeze water vapour to be removed and the remaining air is cooled and compressed to become liquid which is then separated into its singular constituents by fractional distillation as each constituent has different boiling point.

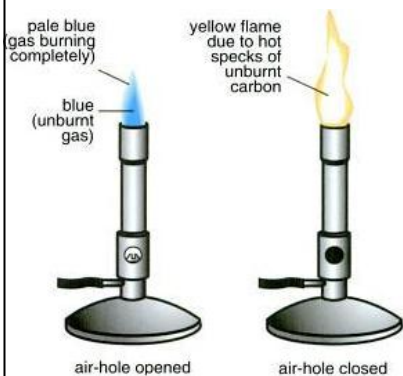
**OXYGEN – THEY'RE AROUND US!****Oxygen Reaction – Combustion**

MOST substances react with  $O_2$  to in exothermic reaction, which is called **combustion**. If flames are produced during combustion, it's called **burning**.

ALL carbon compounds burn in  $O_2$  to produce  $CO_2$  while ALL hydrogen containing compounds burn in  $O_2$  to produce  $H_2O$ .

When adequate supply of oxygen is available during burning, it will create a complete combustion. If otherwise, the combustion is **incomplete**.

E.g.  $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(g)$ , makes up a complete combustion

**A Test for Combustion**

When air hole is closed, air cannot enter supplying oxygen, and hence soot (unburnt carbon) and CO is produced from incomplete hydrocarbon gas combustion. As a result, flame is yellow due to glowing specks of hot soot in heat and the flame is not hot. When air hole is opened, air supplies plenty of oxygen, allowing complete combustion.

**Significance of Oxygen**

- As rocket fuel
- In steel making, to burn off impurities
- In oxy-acetylene cutting and welding
- In oxygen tanks for deep sea divers and mountain climbers to provide oxygen
- For respiration for most animals
- Used as oxygen tents in hospital to aid patients with respiratory problems

**Air Pollution**

**Pollutants** are substances in atmosphere which are harmful for living things and environment, for contributing to **air pollution**.

From nature, pollutant sources are volcanoes, forest fires, decay of dead matter, etc. but from humans, they're exhaust fumes, power stations, oil and gas, etc.

The main air pollutants are:

**1. Carbon monoxide****Where it comes from?**

Unburnt hydrocarbons; exhaust fumes; forest fires

**What hazard it brings?**

Combines with haemoglobin when inhaled, which produces carboxyhaemoglobin that reduces efficiency of haemoglobin to transport oxygen. Cells then die.

**How to prevent this?**

- Install catalytic converters in cars
- Reduce number of cars on road
- Create efficient engines in cars to ensure complete hydrocarbon combustion

**2. Sulphur dioxide****Where it comes from?**

Combustion of fossil fuels containing sulphur impurities; volcanic eruptions

**What hazard it brings?**

Lung irritant, eye irritant, acid rain

**How to prevent this?**

- Prevent using fuels containing sulphur impurities, e.g. coal
- Reduce the sulphur impurities inside fossil fuels
- Spray exhaust gases from factories with water/hydrated CaO/alkalis to absorb sulphur dioxide before it's released into the atmosphere
- Add CaO to soil and rivers to neutralize acid rain

**3. Oxides of nitrogen (NO, NO<sub>2</sub>, ...)****Where it comes from?**

Lightning activity; forest fires; internal combustion engines (as nitrogen oxides are formed by oxygen and nitrogen under high temperature); power stations

**What hazard it brings?**

Eutrophication, lung damage, acid rain

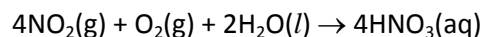
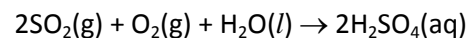
**How to prevent this?**

- Install catalytic converters in cars
- Design car engines which run at lower temperatures

**Chemistry around us: ACID RAIN**

Acid rain is formed by 2 main constituents – SO<sub>2</sub> and NO<sub>2</sub>

Sulphur dioxide/nitrogen dioxide, both react with oxygen and water to form sulphuric acid/nitric acid. This is called *hydrolysis*.

**Effects of Acid Rain**

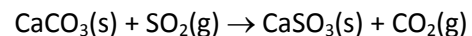
- The acid corrodes buildings, CaCO<sub>3</sub> materials and metal statues.
- Acid rain damages trees
- Acid rain increases acidity of soil, making soil unsuitable for plant growth
- Fish cannot survive in acidic water
- Aggravates respiratory ailments such as bronchitis and asthma

**Tackling Acid Rain**

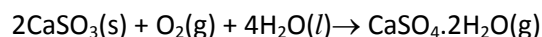
- Remove sulphur dioxide from flue gases by *desulphurization*
- Add Ca(OH)<sub>2</sub> to soil to neutralize acid from acid rain
- Burn fuels with less sulphur

**Desulphurization**

It is the removal of sulphur dioxide from flue (waste) gases. The product is CO<sub>2</sub>, which is non-polluting gas, and calcium sulphite.



To increase profit, calcium sulphite further oxidized to produce gypsum to be sold

**4. Methane****Where it comes from?**

Decomposition of vegetable matter; rice field; cattle ranching; natural gas; mines

**What hazard it brings?**

It is highly flammable, green house gas

**How to prevent this?**

- Cattle and other ruminant animals should be given improved diet
- Animal manure and rotting vegetation can be used as biomass fuel

**5. Unburnt hydrocarbons****Where it comes from?**

Internal combustion engines; incomplete combustion of hydrocarbons

**What hazard it brings?**

Carcinogenic, forms photochemical smog

**How to prevent this?**

- Install catalytic converters in cars
- Reduce number of cars on road
- Create efficient engines in cars to ensure complete hydrocarbon combustion

**6. Ozone****Where it comes from?**

It is an allotrope (two/three different forms of a pure element) of oxygen having structural formula O<sub>3</sub> having characteristic odour. It's created by reaction of nitrogen oxides with volatile organic compounds in presence of UV radiation.

**What hazard it brings?**

- It reacts with unburnt hydrocarbons to form photochemical smog that causes headache, eye, nose and throat irritation.

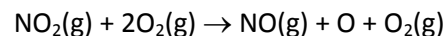
- It corrodes and kills plants and trees

#### How to prevent this?

- Don't use CFCs/replace it with HCFCs which destroys faster.

#### Chemistry around us: PHOTOCHEMICAL SMOG

It is a hazy brown air, which is a mixture of fog and smog, that reduces visibility, causes eye irritation and breathing difficulties. It is produced by reaction between  $\text{NO}_2$  and  $\text{O}_2$  in the presence of sunlight to form  $\text{NO}$ ,  $\text{O}$  and  $\text{O}_3$ . This reaction is called *photochemical reaction*.

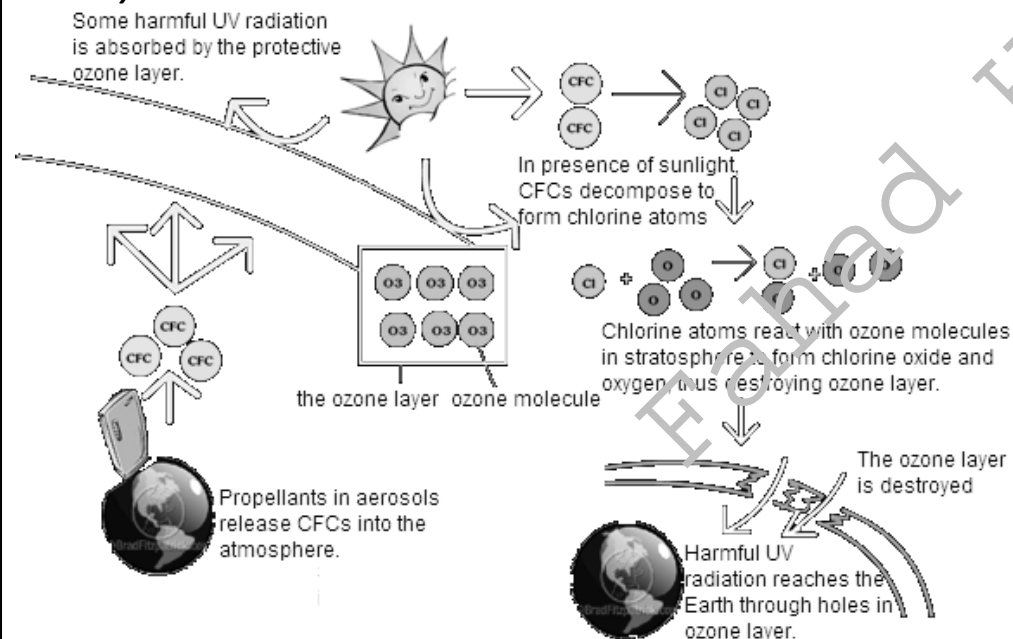


The oxygen atom is reacted with the oxygen molecules formed to form ozone,  $\text{O}_3$ .



Ozone can react with unburnt hydrocarbons to produce eye-irritating substances.

#### Chemistry around us: DESTRUCTION OF OZONE LAYER

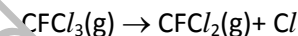


#### Use of ozone layer in stratosphere:

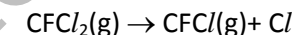
It blocks UV rays from sun which causes skin cancer; acts as blanket to block out high sun energy radiation and prevent it from penetrating into Earth's surface.

#### How is it depleted?

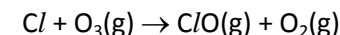
Ozone layer absorbs some UV radiation and reflects some back to space. CFCs, found in coolants in refrigerator and air conditioners, propellants in aerosols and blowing agents, are released into the atmosphere. In the presence of light, CFC decompose into  $\text{Cl}_2$  at the stratosphere where ozone is located.



$\text{CFCl}_2$  further decomposes to produce more chlorine atoms,  $\text{Cl}$ , and  $\text{CFCI}$



As a result, the  $\text{Cl}$  atoms produced react with  $\text{O}_3$  molecules to form chlorine oxide,  $\text{ClO}$ , and oxygen,  $\text{O}_2$ .



The reaction uses up ozone which covers the earth and hence creating a hole in the layer. Harmful UV rays from sun can now reach Earth through these holes.

#### Tackling Depletion of ozone layer:

- Don't use CFCs/replace it with HCFCs which destroys faster.

#### Chemistry around us: GLOBAL WARMING

**Greenhouse effect** is the trapping of heat from sun by greenhouse gases to regulate Earth temperature so that not all heat is reradiated back to space. However, increased industrialization releases more greenhouse gases to atmosphere, contributing to **Global Warming** (increase in temperature of Earth's atmosphere due to trapping of heat by greenhouse gases).

#### EXAMPLES OF GREENHOUSE GASES ARE:

1. **Carbon Dioxide** which is naturally occurring or by combustion of hydrocarbons.
2. **Methane** which occur naturally or emitted during production of fuels or from decaying vegetable matter.
3. **Nitrous Oxide** is produced by industrial and agricultural activities, and by incomplete combustion of hydrocarbons

#### Hazards of Global Warming

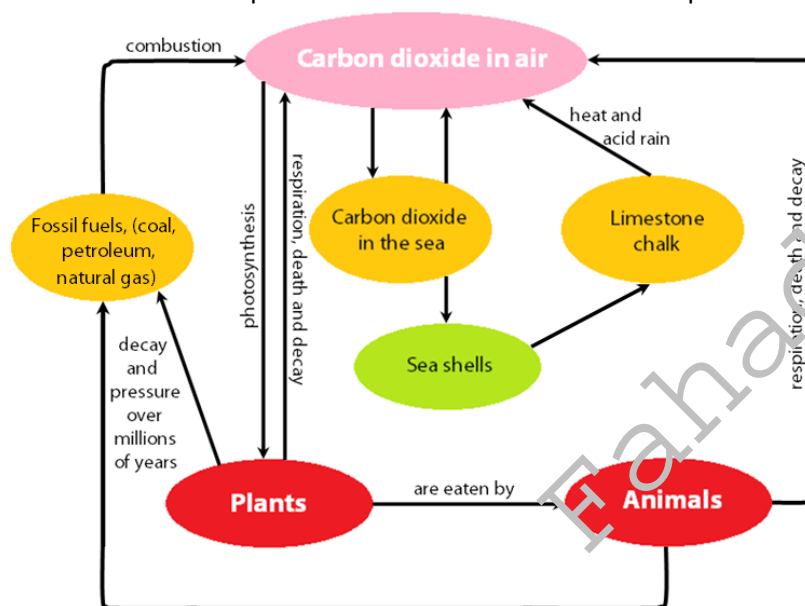
It melts polar icebergs, floods low lying areas and coastal regions, alter the climatic conditions of certain places, alter crop yield, and evaporation of water supply.

TACKLING GLOBAL WARMING

- Reduce the use of fossil fuels
- Use alternative forms of energy such as wind, tidal and hydroelectric power
- Use more electric vehicles
- Reduce number of cars on road
- Create efficient engines in cars to ensure complete hydrocarbon combustion

Chemistry around us: CARBON CYCLE

0.03% of the atmosphere is carbon dioxide and this is kept constant by the process *carbon cycle*. **Carbon cycle** is the removal of carbon dioxide by plants by photosynthesis and the replacement of these carbon molecules by combustion, respiration and natural processes. In the past the rate of absorption of carbon dioxide balances the rate of production of carbon dioxide. Man upset this balance.

WHAT LIVING THINGS DIDPlants:

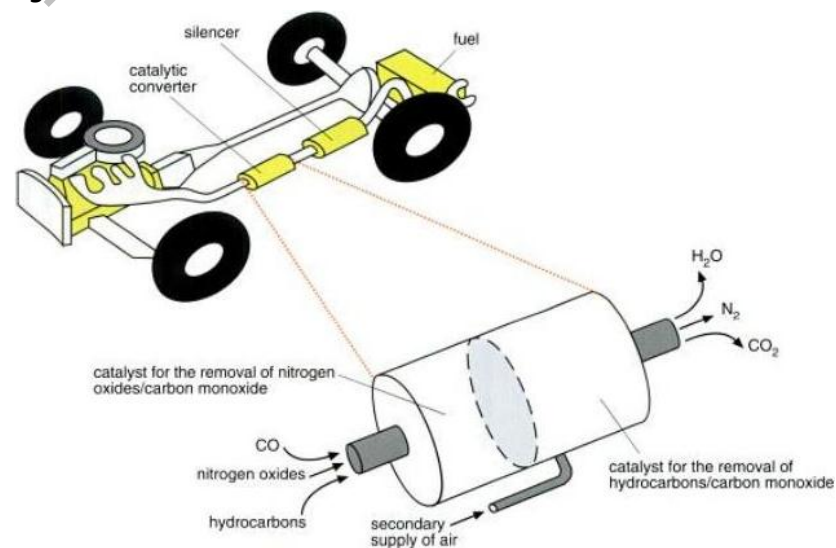
Plants use carbon dioxide from atmosphere, sunlight and chlorophyll for photosynthesis of sugars. Some carbon is used up in plants for growth and development, while some others are released to atmosphere during respiration. When plants die & decomposed by microorganisms, CO<sub>2</sub> released to atmosphere.

Animals:

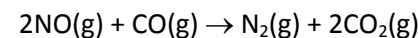
When herbivores and omnivores eat plants, they gain carbon from them to grow and develop. Carnivores eating these animals also gain the carbon. When animals respire, they release carbon dioxide. When they die and decay due to microorganism, they release carbon dioxide which is later taken in by plants.

WHAT NON-LIVING THINGS DID

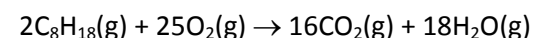
Carbon monoxide and carbon dioxide are released from electric power plants, exhaust fumes and factory emissions. Man burns fossil fuels, which needs millions of years to form, that takes in oxygen and releases carbon dioxide. This makes man depleting natural resource as they use them rapidly than the time needed to reform, damages natural environment and upsetting balance of carbon cycle.

Balancing Chemicals in Nature: CATALYTIC CONVERTERS

First, nitrogen oxides reacts with carbon monoxide as they pass a platinum catalyst.



In second half of converter, unburnt hydrocarbons (e.g. octane, C<sub>8</sub>H<sub>18</sub>) reacts with more air to form CO<sub>2</sub> and H<sub>2</sub>O.



CO<sub>2</sub>, H<sub>2</sub>O and N<sub>2</sub> are all non-pollutants. These reactions are all redox.

**7. Lead compounds*****Where it comes from?***

- Combustion of leaded petrol in car engines

***What hazard it brings?***

- Causes lead poisoning which leads to brain damage.

**10.2 Water**

Water is most available liquid on Earth covering 70% of the planet surface.

**We use water at home for:** drinking, cooking, washing and bathing

**While in industries, we use as:** heat exchanger, raw material for food and drinks, as a solvent, cleaning and purification, irrigation, dyeing and bleaching process.

**Inside that Water*****Naturally Occuring Substances***

- Mineral salts – aluminium, calcium, potassium, etc.
- Dissolved oxygen given out by aquatic animals by photosynthesis
- Organic matter (living/dead plants, animals, microorganisms)

***Pollutants***

- Metal compounds such as cadmium, iron, manganese, etc. from waste discharge
- Phosphates from fertilizers, detergents or sewage treatment plants
- Nitrates from fertilizers or sewage treatment plants
- Sewage from sewage treatment plants or septic systems
- Harmful microbes from sewage treatment plants, septic systems, naturally occurring in water or growing in abundance due to pollution
- Acid from industrial discharges
- Oil spills from oil tankers

**Important or Silent Killer?*****Beneficial Stuff*****Mineral salts**

- Needed for basic functions of human body such as bone growth, fluid regulation, normalize nerve and muscle functionality, metabolism control, growth, etc.

- Needed for growth of aquatic plants to make food and produce oxygen for aquatic organisms.

**Dissolved oxygen**

- Needed for respiration and growth of aquatic life. Water without O<sub>2</sub> is stagnant.

**Organic matter**

- Needed for growth of aquatic organisms

***Harmful Stuff*****Acid**

- Kills aquatic organisms and plants
- Makes water acidic and corrosive – unsafe to drink

**Nitrates**

- Causes eutrophication which deprives marine organisms of oxygen
- Nitrate ions may cause breathlessness or kill babies when consumed

**Phosphates**

- Can cause eutrophication as it encourages the growth of algae, hence killing aquatic organisms when they die and takes away oxygen

**Heavy metal ions**

- These are carcinogenics that can cause skin cancer, liver cancer, lung cancer, etc.

**Sewage**

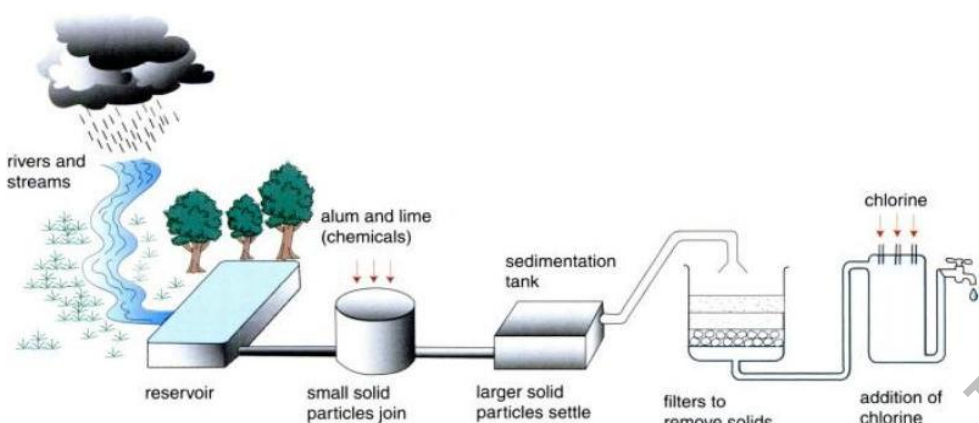
- Contains pathogens which when consumed carries diseases such as diarrhoea.

**Oil**

- Traps bird's feathers and kills them eventually
- Depletes oxygen as air cannot mix with water to provide sufficient oxygen

**Tackling Water Pollution**

- Proper disposal of rubbish to prevent more water pollution
- Prohibit activities potentially causing water pollution near rivers/reservoirs such as camping or swimming.
- Dispatch monitor ships to prevent accidents between ships so oil will not spill

**Purification – Taking care of those harmful stuffs**

1. Water from rain and river downstream is collected in reservoir.
2. Water is transported via pipe to a flocculation tank where alum,  $\text{Al}_2(\text{SO}_4)_3$ , and lime,  $\text{Ca}(\text{OH})_2$  are added to water so that small solid clay particles join together into large lumps of solid (**coagulation**).
3. Water is moved to sedimentation tank where the lumps of solid settle to the bottom of the tank. This is called **sedimentation**. Carbon, in form of activated charcoal, is added to remove the taste and smell of water.
4. Water is filtered off in filtration tank, where there are sand particles filter which traps the remaining solid particles in water.
5. Chlorine and fluorine are added in chlorination tank. This is called **chlorination**. Chlorine is used to kill bacteria while fluorine is used to strengthen teeth.

**Desalination**

Ocean is vast source of water. Salts in seawater must be removed so it's drinkable. **Desalination** is the process where seawater is distilled until it becomes steam (free of salt) which is then cooled and condensed into drinking water.

END OF CHAPTER 10

**CHAPTER 11 – ORGANIC CHEMISTRY****Compounds from Living Things**

*Organic Compounds* – compounds found in living organisms

**Examples:** sugar, fats, plant oils, urea

**Characteristics of Organic Compounds**

- All contain carbon element
- Most come with hydrogen
- Others with oxygen, nitrogen, or a halogen

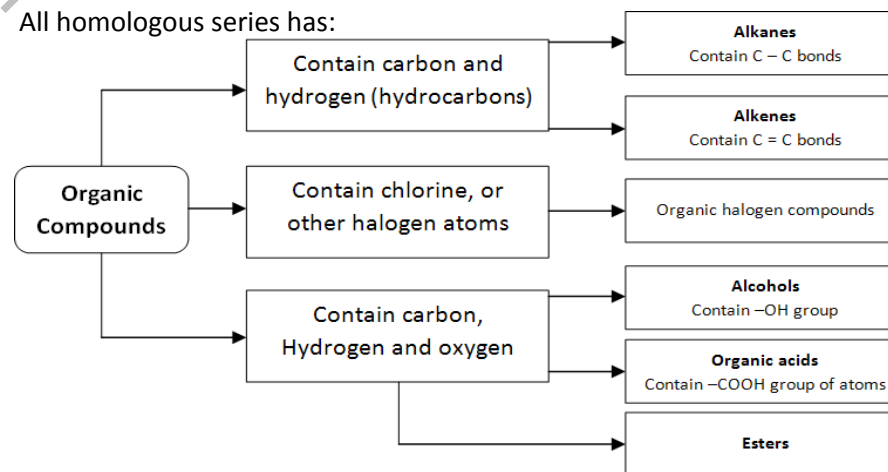
**Uses of Organic Compounds**

*Fuels, plastic, rubber, detergents, insecticides, most medicines*

**Classifying Organic Compounds**

**Homologous series** – a family of organic compounds with a general formula and a similar chemical properties

All homologous series has:

**Functional Groups**

- Is the special group of atoms available in homologous series compounds which responsible for the chemical properties of the compound



- All compounds in homologous series have functional group except alkanes.

**Examples of functional group homologous series:** *alcohol*

### Production of Organic Compounds

*From crude oil refinery:*

Crude oil is a mixture of complex hydrocarbons with varying boiling points, depending on the number of carbon atoms and how they are arranged. Fractional distillation uses this property to separate the hydrocarbons in crude oil.

*From naphtha:*

Naphtha fraction is used for production of petrochemicals, such as medicines, plastics and synthetic fibres, aside from fuels. When naphtha is treated, not only it becomes a better fuel, it also contain more aromatic hydrocarbons, alkene and cyclic hydrocarbons which are important for petrochemical industry.

Crude oil is mostly used as fuel, though some allocated for chemical feedstock. As oil reserves deplete, competition between 2 main uses of oil will be more intense.

### Saturated or Unsaturated?

**Saturated hydrocarbons** are hydrocarbons which the combining capacity of the carbon atoms is as fully used as possible in bonding with hydrogen atoms. They only have single bond (–) only.

**Unsaturated hydrocarbons** are hydrocarbons which the combining capacity of the carbon atoms is not fully used, e.g. only 2 or 3 hydrogen are attached to a carbon atom. This is usually indicated by double bond (=) or triple bond (≡) with another carbon atoms.

#### 11.1 Alkanes

- Usually in fuels, **examples:** *natural gas, petrol, diesel*
- Are homologous series
- Have a formula of  $C_nH_{2n+2}$

- example:** propane has three carbon atom, thus  $n=3$ . Then the formula of propane is  $C_3H_8$

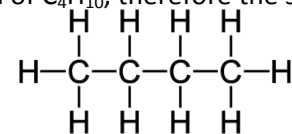
- Ends with suffix **–ane**

- Next alkane formula differ by  $-CH_2$  atoms. Eg: methane:  $CH_4$ , ethane:  $C_2H_6$

### **Structure of Alkanes**

Shows how all atoms in a molecule joined together by drawing lines between atoms to represent the bonds

**Example:** butane has a formula of  $C_4H_{10}$ , therefore the structural formula is:



It has 4 carbon atoms bonded together with 10 hydrogen atoms

Organic compound containing only single bond is **saturated**. Eg: *methane*

All alkanes are saturated. All alkenes are unsaturated

### **Physical Properties of Alkanes**

Name	Molecular formula	M.p. (°C)	B.p. (°C)	State at r.t.p.*	Density (g/cm <sup>3</sup> )
methane	$CH_4$	-182	-162	gas	0.000 68
ethane	$C_2H_6$	-172	-89		0.001 27
propane	$C_3H_8$	-187	-42		0.001 86
butane	$C_4H_{10}$	-138	-0.5		0.002 45
pentane	$C_5H_{12}$	-130	36	liquid	0.63
hexane	$C_6H_{14}$	-95	69		0.66
⋮	⋮	⋮	⋮		⋮
heptadecane	$C_{17}H_{36}$	22	292		0.77
octadecane	$C_{18}H_{38}$	28	308	solid	0.78
nonadecane	$C_{19}H_{40}$	32	320		0.78

From the table,

- **Melting points and boiling points increase** as the bonds become larger and heavier which increases the forces of attraction between molecules so more energy (from heat) is needed to separate them with the increase of strength of forces of attraction

- Alkanes are **insoluble** in water but **soluble** in organic solvents such as tetrachloromethane as alkanes are organic compounds

- Alkane density **increases** down the series; all alkenes are less than  $1\text{g/cm}^3$

- Alkanes become more **viscous** (uneasily flow) going down the series as the longer molecules tangles together when it flows

- Alkanes become **less flammable** down the series as B.P. becomes larger

- Alkanes are **unreactive** with either metals, water, acids or bases because the C – C and C – H covalent bonds are harder to break

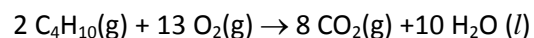
### Reaction of Alkanes

Have same chemical properties – they don't react with most chemicals

### Combustion

Alkanes burn in air to ALWAYS form carbon dioxide and water. When there is insufficient oxygen, the product is ALWAYS carbon monoxide and unburnt carbon.

**Example:** Butane is commonly used camping gas. State the chemical equation of combustion of butane in air.



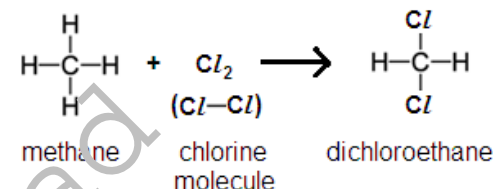
High alkanes burn less completely and gives soot (unburnt carbon) and CO

### Reaction with Chlorine/Other Halogens (Alkyl Halides)

Chlorine molecule replaces alkane hydrogen atom with chlorine atom

**Substitution reaction** – the reaction in which one or more atoms replace other atoms in a molecule

**Light is needed** to break covalent bond between chlorine molecule → atoms



### 11.2 Alkenes

- have general formula  $\text{C}_n\text{H}_{2n}$ .

- all alkene names end with **–ene**.

- the formula of one alkene differs from the next by  $-\text{CH}_2$ .

- have similar properties like alkane going down the series.

No. of C atoms	Name	Molecular formula	Structural formula	Condensed structural formula
2	ethene	$\text{C}_2\text{H}_4$		$\text{CH}_2 = \text{CH}_2$
3	propene	$\text{C}_3\text{H}_6$		$\text{CH}_3\text{CH}_2 = \text{CH}_2$
4	butene	$\text{C}_4\text{H}_8$		$\text{CH}_3\text{CH}_2\text{CH} = \text{CH}_2$

**Table 25.3** First three alkenes; they appear as gas

### Structure of Alkenes

Is organic compound containing C = C double bond, said to be **unsaturated**

*Reason:* not all C atoms are bonded to the maximum no. of 4 other atoms

### The Importance of Ethene

**Ethanol** – solvent & fuel

**Ethanoic acid** – vinegar

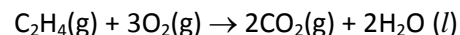
**Poly(ethene)** – PE plastic variations

## Reactions of Alkenes

### Combustion

Burns in air to form carbon dioxide and water

**Example:** Ethene burns in air. Write the balanced equation for the reaction



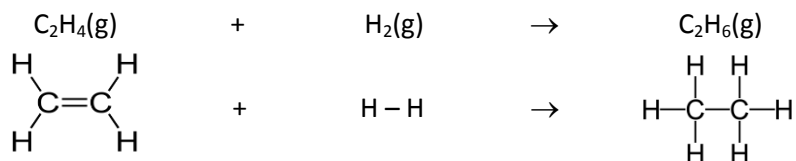
Incomplete combustion forms soot and CO. It's produced more than alkane

### Addition Reaction

Is the reaction of 2 or more molecules to form a single product

#### - Addition of hydrogen

Alkenes react with hydrogen to form alkanes, called **hydrogenation**. Must use nickel as catalyst and heat.



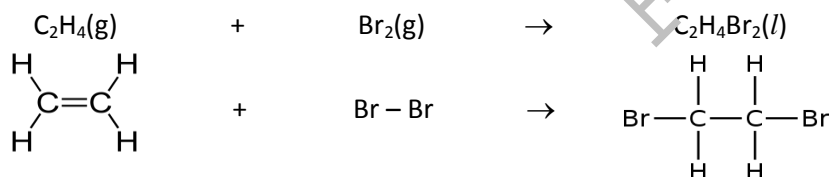
#### Nomenclature

Product's an ALKANE with name according to number of carbon atoms it contain.

#### - Addition of bromine

Bromine adds to C = C double bond of alkane molecules. Phosphoric acid ( $\text{H}_3\text{PO}_4$ ), high temperature of  $300^\circ\text{C}$  and 60-70 atm pressure are needed as catalyst.

Eg: ethene to 1,2 – dibromoethene



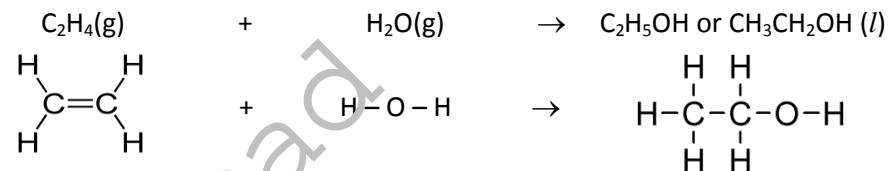
#### Nomenclature

(n) + (bromo) + (alkene name), where n is the number of bromine atoms.

E.g. Above, Ethene reacts with 2 bromine atoms producing DI(2)BROMO(Bromine) ETHENE(alkene name). Hence we call the product DIBROMOETHENE.

#### - Addition of water

Alkene reacts with water, in the form of steam, to produce alcohol. Alkene + steam is passed over phosphoric acid ( $\text{H}_3\text{PO}_4$ ) catalyst and temperature of  $300^\circ\text{C}$ .  $\text{H}_2\text{O}$  molecule adds to C = C bonds to form alcohol.



#### Nomenclature

(alkene name) + (ol)

E.g. in above, the alkene ethane ( $\text{C}_2\text{H}_4$ ) reacts with steam to form *ETHANOL* (alkene name – ETHANE + OL group of alcohol)

#### - Polymerization

The joining of several identical alkene molecules to form a big molecule

Eg: Ethene  $\rightarrow$  poly(ethene)

## Testing for Unsaturated Compounds

Mix bromine solution with alkene (for liquid alkenes – shake). Reddish-brown colour of bromine disappears. This shows that the compound is an alkene.

## Characteristics of a Homologous Series

- All members of homologous series have same general formula
- Formula of each member differs by  $-\text{CH}_2$  group
- Physical properties changes gradually in the increase of carbon atoms
- The members have similar chemical properties

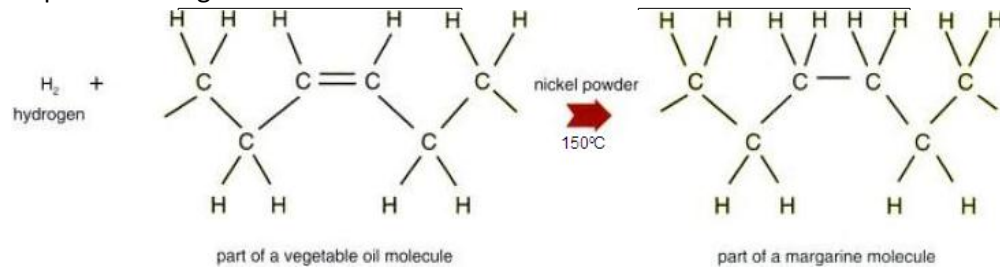
## Foods and Unsaturated Compounds

### The Manufacture of Margarine

Polyunsaturated food – food containing C=C bond in their molecules

Eg: Vegetable oil

To produce margarine:



Hydrogen is reacted with vegetable oil with presence of nickel catalyst and heat, which adds to C=C bond, increasing the molecular mass of the compound

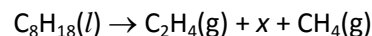
- With increase in mass, the compound has higher boiling point. Therefore, margarine is solid at room temperature.
- Since only some C=C bonds react with hydrogen, margarine is partially hydrogenated and each has different hardness, depending on the number of C=C bonds.

### The Cracking of Alkanes

Alkanes can be cracked into shorter chain hydrocarbons because of the higher value it has that it can create more variety of products in petrochemical industries.

We crack alkane by catalytic cracking, which is, using catalyst to break alkane into simpler hydrocarbons. We crack alkane to get more valuable hydrocarbons. The total number of carbon and hydrogen atoms from products should equal to the total number of carbon and hydrogen atoms in cracked alkane.

E.g. Octane can be cracked into simpler hydrocarbons such as the reaction below. Suggest the possible identity of product x.



$$\begin{aligned} \text{Number of C atoms in x} &= 8 - 2 - 1 \\ &= 5 \end{aligned}$$

$$\begin{aligned} \text{Number of H atoms in x} &= 18 - 4 - 4 \\ &= 10 \end{aligned}$$

∴ Product x is  $\text{C}_5\text{H}_{10}$

### Isomers

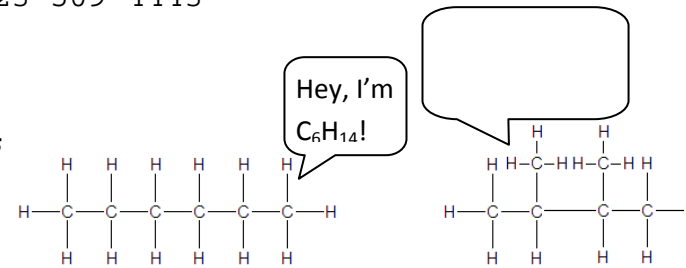


Figure 11 Isomerism

Look at the figure above and count the number of carbon and hydrogen atoms in each case. You will end up with the same  $\text{C}_6\text{H}_{14}$ . We can't deny that they have the same molecular formula. However, their structures are different. Therefore:

**Isomers** are compounds with same molecular formula but different structural formula. Due to different chain length, they have different physical properties (e.g. boiling point). Isomerism can occur in both alkanes and alkenes.

We therefore can't just say that  $\text{C}_6\text{H}_{14}$  is simply hexane because there are more variations of  $\text{C}_6\text{H}_{14}$  and each variation has its own name. The figure below shows the nomenclature (i.e. how to name) these isomers.

#### ISOMERISM INVOLVING METHYL GROUP IN ALKANE

Example: Draw and name 3 of the isomers of  $\text{C}_6\text{H}_{14}$ , with at least one methyl group in it.

ISOMER 1: hexane

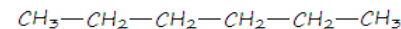
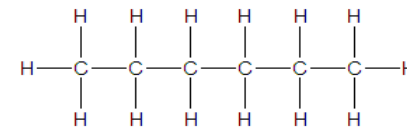
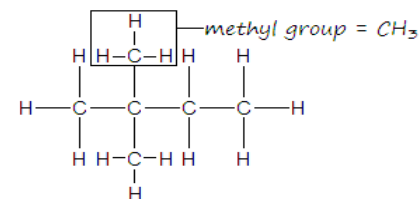


Figure 12(a)

Closest position of first methyl group relative to isomer end

ISOMER 2: 2, 2-dimethylbutane → no. of methyl groups

Closest position of second methyl group relative to isomer end



CAN ALSO BE WRITTEN AS

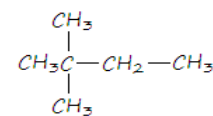


Figure 12(b)(i)

2, 2-dimethylbutane

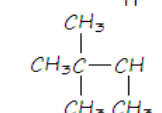
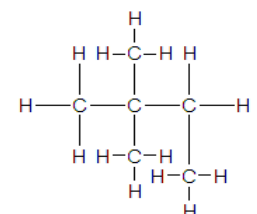


Figure 12(b)(ii)

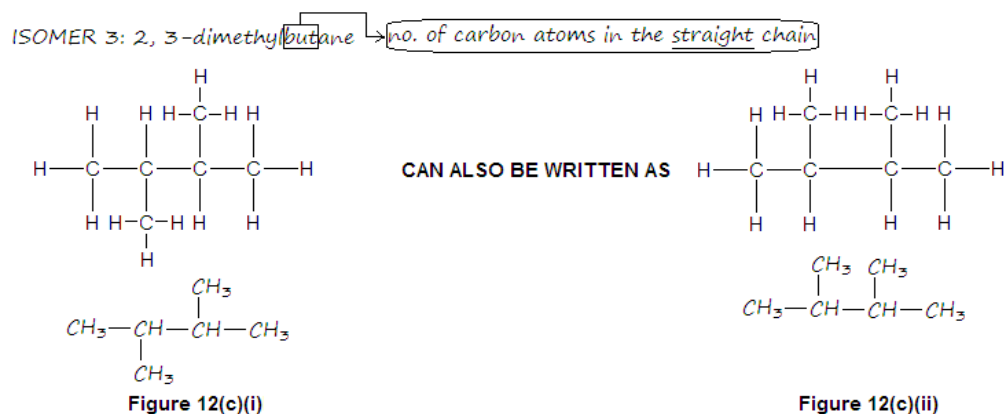


Figure 12

Figure 12(a) is the full long chained isomer of  $C_6H_{14}$ : hexane. This is so not useful.

Figure 12(b)(i) is another isomer called 2,2-dimethylbutane.

- Note that the first number 2 indicates the position of methyl group ( $CH_3$ ) attached to a carbon atom from the nearest end. There are 2 possible numbers: 2 or 3. Since 2 is closer, we put 2 in place. The second number 2 indicates the position of the second methyl group attached to carbon atom. Since it's attached to the same carbon atom as the first methyl group, we put the same number 2.

- Also note that the name is now "butane". This comes from the number of carbon atoms in the **STRAIGHT** chain only. The turns leading to methyl is ignored.

- Bear in mind that "di" in "dimethyl" indicates the number of methyl groups in the isomer ("di" means two). One methyl has no prefix, if it's three is "tri" and so on.

Figure 12(b)(ii) is another variation of the isomer 2,2-dimethylbutane

- Students often misinterpret this as 1,2,2-trimethylpropane while in fact, we don't take the last bend in the chain as another methyl group. Instead, we consider it as **PART OF THE STRAIGHT CHAIN**.

Figure 12(c)(i) and Figure 12(b)(ii) is another isomer called 2,3-dimethylbutane

- See that we can flip the positions of methyl group without changing formula

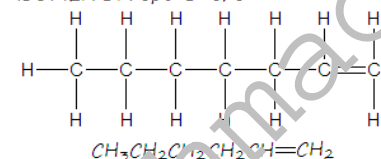
- Note that the second number is 3 while in fact, the position closest to the end of isomer is 2. This is to avoid confusion that the isomer would be that of **figure 12(b)(i)** and **figure 12(b)(ii)**. In this case, we put the number as the **POSITION THE SECOND NEAREST TO THE END OF THE ISOMER**, that is, 3.

#### ISOMERISM INVOLVING ALKENE

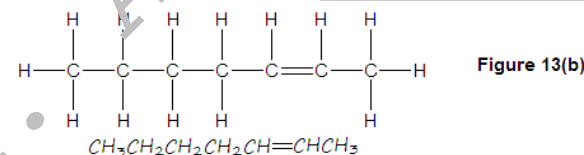
Involves C=C double bond:

E.g. Draw and name 3 of the isomers of  $C_7H_{14}$

ISOMER 1: hept-1-ene



ISOMER 2: hept-2-ene → closest position no. of double bond relative to isomer end



closest position of first methyl group relative to isomer end → no. of methyl groups in isomer

ISOMER 3: 2, 3-dimethylpent-1-ene

closest position of second methyl group relative to isomer end → no. of carbon atoms in the straight chain

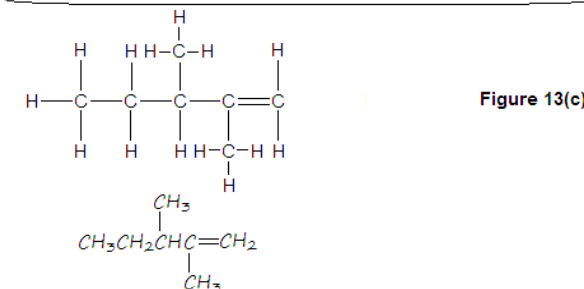


Figure 13

For isomerism in alkene in **Figure 13(c)**, we apply the same theory as isomerism in alkane, and just to only add a double bond indication.

For alkene, double bond position can be changed. In **Figure 13(a)**, it's hept-1-ene, can be called heptene, can be changed to hept-2-ene in **Figure 13(b)**, where the number in between indicates position of double bond from nearest isomer end.

### 11.3 Alcohols

Are homologous series with general formula  $C_nH_{2n+1}OH$

- They have  $-OH$  functional group (**hydroxyl group**)
- All alcohols end with suffix **-ol**

First three members of the series (so that you'd have idea on the next)

- Methanol,  $CH_3OH$
- Ethanol,  $C_2H_5OH$  or  $CH_3CH_2OH$
- Propanol,  $C_3H_7OH$  or  $CH_3CH_2CH_2OH$

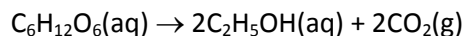
For alcohol, the  $-OH$  is not of hydroxide ion,  $OH^-$ , but is covalent bond between oxygen and hydrogen,  $O-H$

#### Making Ethanol

- Fermentation of sugars with yeast
- Reacting ethene with steam

#### Fermenting glucose

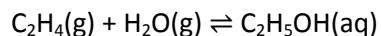
Fermentation is breakdown of sugars into smaller molecules by microorganisms.



Temperature is kept constant at  $37^\circ C$  to prevent destruction of yeast at higher temperatures. Oxygen is removed by limewater and carbon dioxide is produced during fermentation. Alcohol is separated from solution by fractional distillation.

#### Reacting Ethene with Steam

Ethene and steam are passed over phosphoric acid  $H_3PO_4$  (as a catalyst) under high temperature of  $300^\circ C$  and pressure of 65 atm.



Since this is reversible reaction, both ethene and water are produced aside from ethanol. The ethanol is separated by fractional distillation.

#### Uses of Alcohol

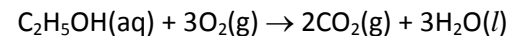
As organic solvent; alcoholic drink; preservatives; vehicle fuel

### REACTIONS OF ALCOHOL

#### Combustion

Alcohols burn in air to produce carbon dioxide and water.

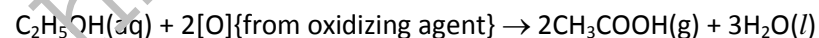
E.g. combustion of ethanol



#### Oxidation

1. Alcohol can be prepared in laboratory by warming alcohol with oxidizing agent (e.g. acidified potassium chromate(VI)). The product is carboxylic acid and water.

E.g. oxidation of ethanol produces water and ethanoic acid



2. Alcohol can be oxidized when left in air with bacterial enzymes as catalyst. The products are carboxylic acid and water.

E.g. ethanol produces water and ethanoic acid when left in air.



#### Esterification

This will be discussed in Chapter 11.4

### 11.4 Carboxylic Acids

homologous series with general formula  $C_nH_{2n+1}COOH$  (first serie,  $n = 0$ , ascending)

- They have  $-COOH$  functional group (**carboxyl group**)
- All carboxylic acids end with suffix **-oic acid**

First three members of the series (so that you'd have idea on the next)

- Methanoic acid,  $HCOOH$
- Ethanoic acid,  $CH_3COOH$
- Propanoic acid,  $C_2H_5COOH$

## PREPARATION OF CARBOXYLIC ACIDS

### 1. From natural gas

Natural gas is passed over air and catalyst to form ethanoic acid and water.

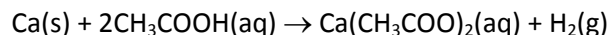
E.g. production of ethanoic acid from methane



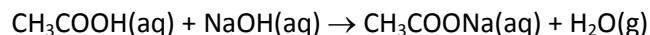
### 2. Oxidation (explained in Chapter 11.3)

## PROPERTIES OF CARBOXYLIC ACIDS

- **Carboxylic acids are weak acids** (partially ionises in water)
- **Carboxylic acids react with metals to form metal ethanoate (salt) and hydrogen**  
E.g. Reaction between calcium and ethanoic acid forming calcium ethanoate and hydrogen



- **Carboxylic acids react with bases to form salt and water (neutralization)**  
E.g. Ethanoic acid reacts with sodium hydroxide to form sodium ethanoate and water.



- **Carboxylic acids react with carbonates and bicarbonates to form salt, carbon dioxide and hydrogen.**

E.g. Ethanoic acid reacts with sodium carbonate to form sodium ethanoate and water.

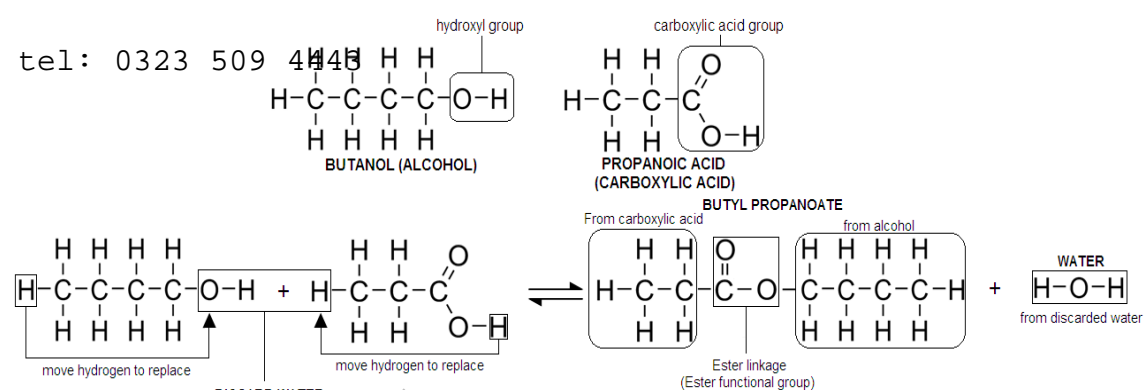


## ESTERIFICATION

**Ester** is organic compound made from carboxylic acid and alcohol with the removal of one molecule of water. **Sulfuric acid is added as catalyst** then heat mixture.

The next page shows the reaction between an alcohol and carboxylic acid.

The reaction is **reversible**. We can **add sodium hydroxide** and heat mixture to obtain carboxylic acid and alcohol from ester. This is **HYDROLYSIS**.



### ESTER NOMENCLATURE:

Ester name is [alcohol]yl [carboxylic acid]oate. For instance, example above is *butyl propanoate*, where "butyl" is from butanol; "propanoate" is from propanoic acid.

## 11.5 Synthetic Macromolecules

**Macromolecule** is a large molecule made by joining together many small molecules

**Polymer** is a long-chain macromolecule made by joining together many monomers

**Polymerisation** is the addition of monomers to make one large polymer

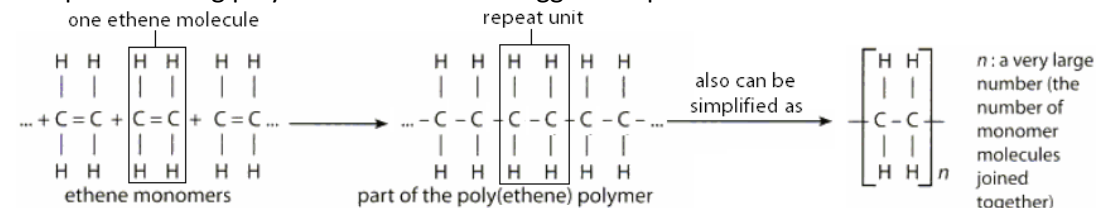
### ADDITION POLYMERISATION

**Addition polymerisation** is which small molecules (monomers) join together to form one molecule as the only product.

#### From monomer to polymer

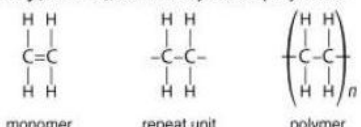
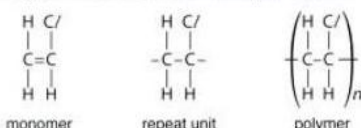
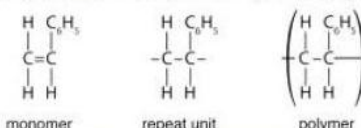
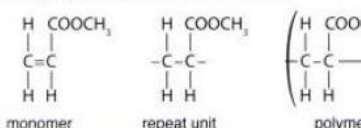

Example: Formation of poly(ethene) from ethene

Ethene has double bond. Another ethene molecules add to this unsaturated compound during polymerisation to form bigger compound.



**Repeat unit** is the simplest part of the polymer which is repeated many times to form the polymer. We take the repeat unit to write the simplified formula of the polymer, where  $n$  is a large number. From this repeat unit, to find the monomer formula, we add double bond between C – C and remove the bonds on each of their sides.

Some plastic variations and their uses are shown:

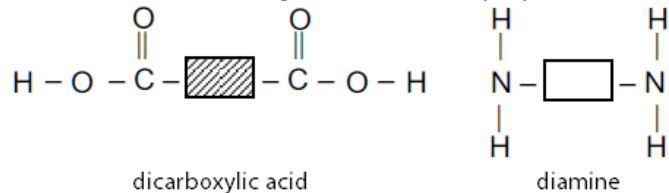
Addition polymers	Uses
<p><b>Poly(ethene)</b>, commonly called polythene</p>  <p>monomer      repeat unit      polymer</p>	plastic film for wrapping fresh vegetables and meat; plastic bottles; plastic bags; buckets; pipes
<p><b>Poly(chloroethene)</b>, commonly called PVC</p>  <p>monomer      repeat unit      polymer</p>	for water pipes; water-proof plastic sheeting; insulating for electric cables and wires
<p><b>Poly(phenylethene)</b>, commonly called polystyrene</p>  <p>monomer      repeat unit      polymer</p>	for packaging and containers for electrical goods; disposable cups and food containers used in 'fast food' restaurants and hawker centres
<p><b>Perspex</b>, (this is the common name)</p>  <p>monomer      repeat unit      polymer</p>	used for plastic windows and to make models of machines and buildings as it is transparent and does not break as easily as glass
<p><b>Poly(tetrafluoroethene)</b>, commonly called PTFE</p>  <p>monomer      repeat unit      polymer</p>	used to coat 'non-stick' pots and pans as it is chemically inert, heat-resistant and repels water

**CONDENSATION POLYMERISATION**

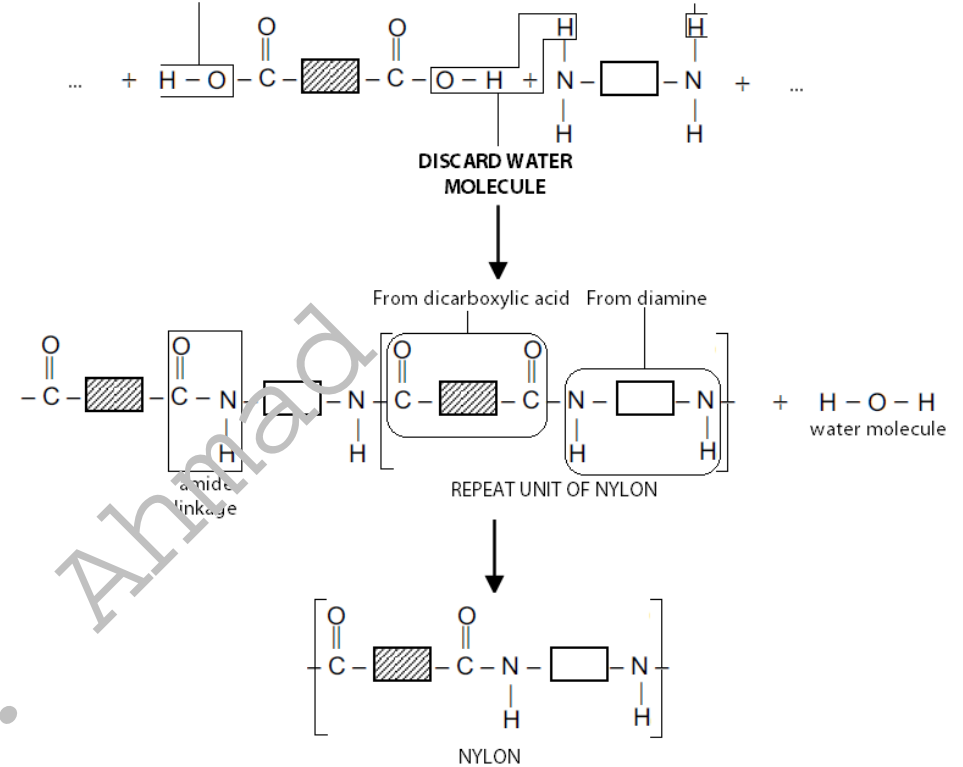
Condensation Polymerisation is the joining of monomers together to form polymers along with the elimination of water molecules.

Nylon

Dicarboxylic acid and diamine undergo condensation polymerisations to form nylon.



H REMOVED WITH OTHER H FROM DIAMINE TO FORM WATER  
O - H FROM DICARBOXYLIC ACID TO FORM WATER



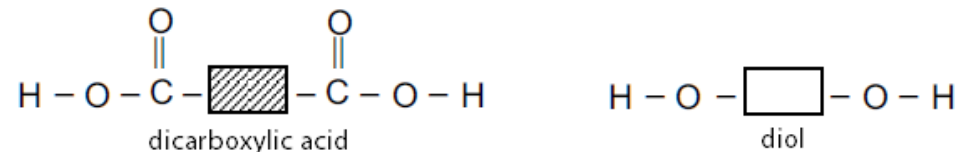
The linkage between monomers in nylon is called **amide linkage**. Therefore we can also call nylon as **polyamide**.

Today, we use nylon as:

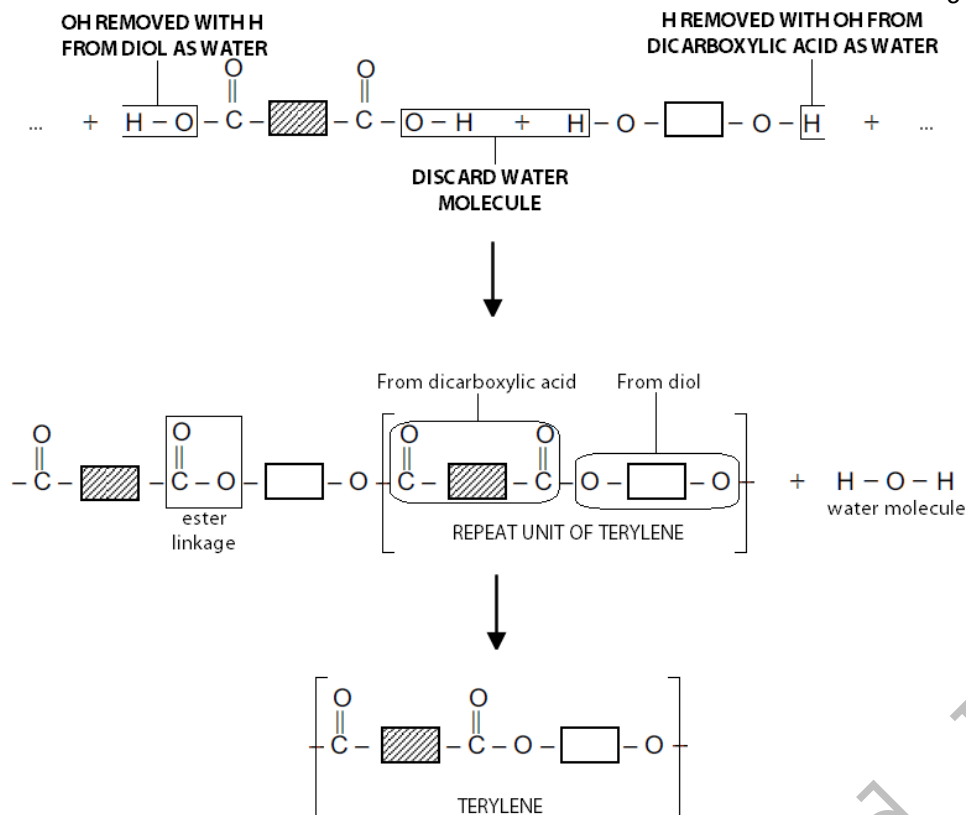
- a replacement of stockings and manufacture of garments to replace silk
- make tents and parachutes due to strength
- fishing lines
- rugs and carpets

Terylene

Dicarboxylic acid (acid with 2 -COOH groups) and diol (alcohol with 2 -OH groups) undergo condensation polymerisation to form terylene







The linkage between the monomers in terylene is called **ester linkage**. Therefore we can call this polymer as **polyester**.

Today, we use terylene in fabrics as it's strong, resists stretching and sinking and doesn't crumple when washed.

#### PROBLEMS ASSOCIATED WITH PLASTICS

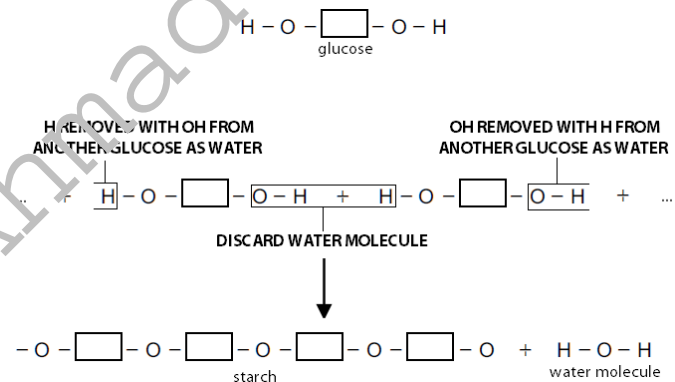
- Plastics are non-biodegradable – they cannot be decomposed by bacteria. Therefore, many plastic waste will pollute the Earth
- Plastics produce toxic gas (such as hydrogen chloride) when burnt and this contributes to acid rain.
- Plastics produce carbon dioxide when burnt – increases global warming.
- Plastics that require CFC during production may contribute to global warming when the CFC is allowed to escape.

#### 11.6 Natural Macromolecules

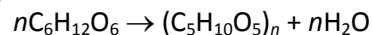
##### CARBOHYDRATES

Carbohydrates contain **carbon, hydrogen & oxygen**. General formula is  $C_n(H_2O)_n$ . The simplest carbohydrate is  $C_6H_{12}O_6$  (glucose).

Glucose polymerise each other to form **starch**.



The overall reaction is:



Starch can also be broken down into glucose by heating with **sulfuric acid**. This is **HYDROLYSIS**.

##### PROTEINS

Proteins have similar linkage to that of a nylon. Only that their monomers are only **amino acids** joined together. They are formed by condensation polymerisation.

Proteins can be called as **polyamide** as it has **amide linkage**. Proteins can also be broken down into amino acids by **boiling protein with sulfuric acid**. This adds water molecule into the polymer.



# INSERT I

## Tests for anions

<i>anion</i>	<i>test</i>	<i>test result</i>
carbonate ( $\text{CO}_3^{2-}$ )	add dilute acid	effervescence, carbon dioxide produced
chloride ( $\text{Cl}^-$ ) [in solution]	acidify with dilute nitric acid, then add aqueous silver nitrate	white ppt.
iodide ( $\text{I}^-$ ) [in solution]	acidify with dilute nitric acid, then add aqueous lead(II) nitrate	yellow ppt.
nitrate ( $\text{NO}_3^-$ ) [in solution]	add aqueous sodium hydroxide then aluminium foil; warm carefully	ammonia produced
sulfate ( $\text{SO}_4^{2-}$ ) [in solution]	acidify with dilute nitric acid then add aqueous barium nitrate	white ppt.

## Tests for aqueous cations

<i>cation</i>	<i>effect of aqueous sodium hydroxide</i>	<i>effect of aqueous ammonia</i>
aluminium ( $\text{Al}^{3+}$ )	white ppt., soluble in excess giving a colourless solution	white ppt., insoluble in excess
ammonium ( $\text{NH}_4^+$ )	ammonia produced on warming	-
calcium ( $\text{Ca}^{2+}$ )	white ppt., insoluble in excess	no ppt. or very slight white ppt.
copper(II) ( $\text{Cu}^{2+}$ )	light blue ppt., insoluble in excess	light blue ppt., soluble in excess giving a dark blue solution
iron(II) ( $\text{Fe}^{2+}$ )	green ppt., insoluble in excess	green ppt., insoluble in excess
iron(III) ( $\text{Fe}^{3+}$ )	red-brown ppt., insoluble in excess	red-brown ppt., insoluble in excess
zinc ( $\text{Zn}^{2+}$ )	white ppt., soluble in excess giving a colourless solution	white ppt., soluble in excess giving a colourless solution

## Tests for gases

<i>gas</i>	<i>test and test result</i>
ammonia ( $\text{NH}_3$ )	turns damp red litmus paper blue
carbon dioxide ( $\text{CO}_2$ )	turns limewater milky
chlorine ( $\text{Cl}_2$ )	bleaches damp litmus paper
hydrogen ( $\text{H}_2$ )	"pops" with a lighted splint
oxygen ( $\text{O}_2$ )	relights a glowing splint
sulfur dioxide ( $\text{SO}_2$ )	turns acidified aqueous potassium dichromate(VI) from orange to green
water vapour ( $\text{H}_2\text{O}$ )	turns blue cobalt(II) chloride paper pink

## DATA SHEET The Periodic Table of the Elements

**INSERT II**

Group																		
I	II											III	IV	V	VI	VII	0	
												1 <b>H</b> Hydrogen 1						4 <b>He</b> Helium 2
7 <b>Li</b> Lithium 3	9 <b>Be</b> Beryllium 4											11 <b>B</b> Boron 5	12 <b>C</b> Carbon 6	14 <b>N</b> Nitrogen 7	16 <b>O</b> Oxygen 8	19 <b>F</b> Fluorine 9	20 <b>Ne</b> Neon 10	
23 <b>Na</b> Sodium 11	24 <b>Mg</b> Magnesium 12											27 <b>Al</b> Aluminium 13	28 <b>Si</b> Silicon 14	31 <b>P</b> Phosphorus 15	32 <b>S</b> Sulfur 16	35.5 <b>Cl</b> Chlorine 17	40 <b>Ar</b> Argon 18	
39 <b>K</b> Potassium 19	40 <b>Ca</b> Calcium 20	45 <b>Sc</b> Scandium 21	48 <b>Ti</b> Titanium 22	51 <b>V</b> Vanadium 23	52 <b>Cr</b> Chromium 24	55 <b>Mn</b> Manganese 25	56 <b>Fe</b> Iron 26	59 <b>Co</b> Cobalt 27	59 <b>Ni</b> Nickel 28	64 <b>Cu</b> Copper 29	65 <b>Zn</b> Zinc 30	70 <b>Ga</b> Gallium 31	73 <b>Ge</b> Germanium 32	75 <b>As</b> Arsenic 33	79 <b>Se</b> Selenium 34	80 <b>Br</b> Bromine 35	84 <b>Kr</b> Krypton 36	
85 <b>Rb</b> Rubidium 37	88 <b>Sr</b> Strontium 38	89 <b>Y</b> Yttrium 39	91 <b>Zr</b> Zirconium 40	93 <b>Nb</b> Niobium 41	96 <b>Mo</b> Molybdenum 42	98 <b>Tc</b> Technetium 43	101 <b>Ru</b> Ruthenium 44	103 <b>Rh</b> Rhodium 45	106 <b>Pd</b> Palladium 46	108 <b>Ag</b> Silver 47	112 <b>Cd</b> Cadmium 48	115 <b>In</b> Indium 49	119 <b>Sn</b> Tin 50	122 <b>Sb</b> Antimony 51	128 <b>Te</b> Tellurium 52	127 <b>I</b> Iodine 53	131 <b>Xe</b> Xenon 54	
133 <b>Cs</b> Caesium 55	137 <b>Ba</b> Barium 56	139 <b>La</b> Lanthanum 57 *	178 <b>Hf</b> Hafnium 72	181 <b>Ta</b> Tantalum 73	184 <b>W</b> Tungsten 74	186 <b>Re</b> Rhenium 75	190 <b>Os</b> Osmium 76	192 <b>Ir</b> Iridium 77	195 <b>Pt</b> Platinum 78	197 <b>Au</b> Gold 79	201 <b>Hg</b> Mercury 80	204 <b>Tl</b> Thallium 81	207 <b>Pb</b> Lead 82	209 <b>Bi</b> Bismuth 83	210 <b>Po</b> Polonium 84	210 <b>At</b> Astatine 85	210 <b>Rn</b> Radon 86	
87 <b>Fr</b> Francium	226 <b>Ra</b> Radium 88	227 <b>Ac</b> Actinium 89 †																

140 <b>Ce</b> Cerium 58	141 <b>Pr</b> Praseodymium 59	144 <b>Nd</b> Neodymium 60	147 <b>Pm</b> Promethium 61	150 <b>Sm</b> Samarium 62	152 <b>Eu</b> Europium 63	157 <b>Gd</b> Gadolinium 64	159 <b>Tb</b> Terbium 65	162 <b>Dy</b> Dysprosium 66	165 <b>Ho</b> Holmium 67	167 <b>Er</b> Erbium 68	169 <b>Tm</b> Thulium 69	173 <b>Yb</b> Ytterbium 70	175 <b>Lu</b> Lutetium 71
232 <b>Th</b> Thorium 90	234 <b>Pa</b> Protactinium 91	238 <b>U</b> Uranium 92	237 <b>Np</b> Neptunium 93	244 <b>Pu</b> Plutonium 94	247 <b>Am</b> Americium 95	251 <b>Cm</b> Curium 96	259 <b>Bk</b> Berkelium 97	261 <b>Cf</b> Californium 98	267 <b>Es</b> Einsteinium 99	271 <b>Fm</b> Fermium 100	277 <b>Md</b> Mendelevium 101	289 <b>No</b> Nobelium 102	289 <b>Lr</b> Lawrencium 103

	a	a = relative atomic mass
<b>X</b>		X = atomic symbol
b		b = proton (atomic) number

\*58-71 Lanthanoid series  
†90-103 Actinoid series

The volume of one mole of any gas is 24 dm<sup>3</sup> at room temperature and pressure (r.t.p.).

\*Periodic table and qualitative analysis notes are reproduced with permission from Cambridge International Examination Syndicate which itself is a subordinate of University of Cambridge. The information published should not be reproduced for other intent other than creation of this notes.