

# CHEMISTRY

## 10 - 12

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## Preface

I love to write. I get real pleasure from taking a ‘perceived complicated subject’ turning it around until I see it clearly, and then explaining it in simple words. I write to explain chemistry to pupils today the way I wish it had been explained to me years ago.

I have made every effort to make this booklet as effective, clear, and readable as possible; to show the beauty and logic of chemistry; and to make chemistry enjoyable to learn. I believe that ‘to teach is to learn twice’.

Worked examples are included to give students a frame of reference. Each example has a worked out solution, and then is followed by an exercise for each student to try on his or her own.

**To my chemistry students, if you can’t swim, at least try to float. But if you can’t swim and you can’t float, then there is very little I can do to help you. Remember, you cannot fail but you can only discover ways which cannot work.**

**I regret that I have been unable to contact the copyright holders of some Publications used in the preparation of this book**

### **Some Publications used in the preparation of this book**

Examination council of Zambia *Joint Examination for the School Certificate and General Certificate of Education Ordinary Level, Chemistry paper 1 and 2*

Examination council of Zambia *Joint Examination for the School Certificate and General Certificate of Education Ordinary Level, Science paper 1 and 3*

Mukuma J, Swazi H and Chirwa C.S (1997) CHEMISTRY 12. Macmillan Publishers Ltd. Lusaka, Zambia.

Mukuma J, Swazi H, Wamundila E, Silumesii L, Kasengele M and Chirwa C.S (1994) CHEMISTRY 10. Macmillan Publishers Ltd. Lusaka, Zambia.

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What is chemistry?

Chemistry is the study of matter and the properties of the forms of matter.

### **Matter**

Matter is anything that occupies space and has mass.

### **Basic units of matter**

There are three basic units of matter. These are:

- Atoms
- Ions
- Molecules

### State of matter

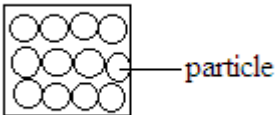
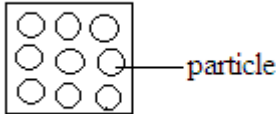
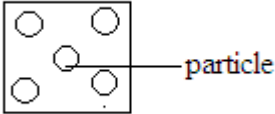
State of matter is the form in which a substance exists. Matter exists in three forms. These are:

- Solids
- Liquids
- Gases

Examples of solids	Examples of liquids	Examples of gases
Stone Glass block Wooden block Copper metal	Water Cooking oil Paraffin Petrol	Oxygen Hydrogen Carbon dioxide Carbon monoxide

### Characteristic properties of the three states of matter

	Solids	Liquids	Gases
<b>Shape</b>	Fixed shape	No fixed shape. They take the shape of the container in which they are placed.	No fixed shape
<b>Volume</b>	Fixed volume	Fixed volume	No fixed volume. Particles spread to fill the space available.
<b>Compressibility</b>	Can not be compressed	Can not be compressed	Can be compressed.

<b>Arrangement of particles</b>	Particles are closely packed and arranged in a regular pattern. The particles are held together by strong electrostatic forces of attraction called cohesive forces. 	Particles are slightly further apart than in solids. Particles are held together by weak electrostatic forces of attraction. 	Particles are much further apart from each other. The forces which hold the particles together are negligible. 
<b>Movement of particles</b>	Particles move by vibrating at fixed positions	Particles move by vibrating rapidly over short distances. Particles move from one position to the other.	Particles move at random at a very high speed.

Solids and liquids are incompressible because their particles are close together. However, gases are compressible because the gas particles are far apart from each other and can be forced to move closer by exerting pressure.

## Changes in state

Changes in state are physical changes that occur when the particles of a substance absorb or lose energy.

A substance can change from one state to another when it is either heated or cooled.

## Heating

Heating involves the addition or supply of heat to a substance.

As a substance is heated, it absorbs energy and changes from a solid to a liquid and finally to a gas. The kinetic energy possessed by its particles increases and they move vigorously.

## Effects of heating substances

### Melting

Melting is change of state from solid to liquid.

For example, ice changes to water when heated

Melting takes place when the particles of a solid absorb energy to overcome the forces holding them in fixed positions and move. They rearrange themselves to form a liquid.

The temperature at which a substance changes from solid to liquid is called melting point.

### Uses of melting

- (a) It is used in welding
- (b) It is used in cutting and shaping of metals in the industry

### Evaporation

Evaporation is the change of state from liquid to gas.

For example, water changes to steam (water vapour) when heated.

### Uses of evaporation

- (a) It is used in drying clothes
- (b) It is used in obtaining crystals from solutions

### Factors that affect rate of evaporation

- Surface area
- Wind current
- Humidity
- Temperature

**Note:** Evaporation and boiling are both physical processes that change a liquid into a gas. The liquid absorbs heat energy during these physical changes in state.

### Differences between evaporation and boiling

Evaporation	Boiling
Occurs at any temperature below boiling	Occurs at boiling point
Occurs only at the surface of the liquid	Occurs throughout the liquid

No bubbles are observed	Bubbles are observed
Occurs slowly	Occurs rapidly

## Sublimation

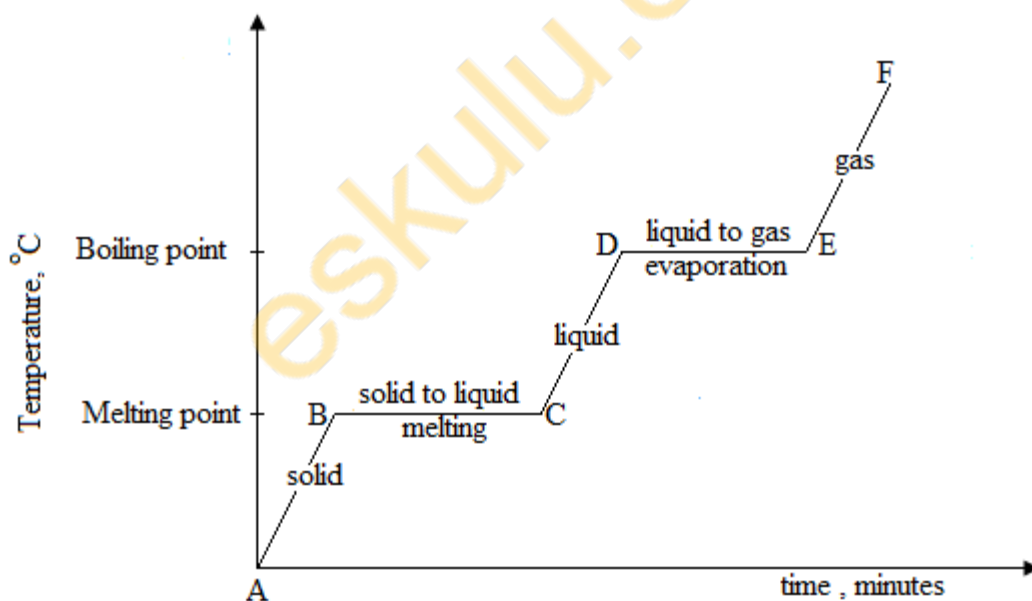
Sublimation is the direct change of state from solid to gas by heating or gas to solid by cooling without passing through the liquid state.

### Examples of substances that can sublime

- Iodine
- Ammonium sulphate
- Ammonium chloride
- Carbon dioxide (upon cooling to form ice)

### The heating curve

The heating curve is a graph showing changes in temperature with time for a substance being heated



**Section AB:** The substance remains in solid state. The heat energy provided is absorbed by the solid particles and they vibrate harder about their fixed positions.

**Section BC:** A mixture of solid and liquid will be observed at this temperature which is called the melting point of the substance. At point C, the solid has turned completely into a liquid.

**Section CD:** The substance remains in liquid state. The liquid particles continue to absorb heat energy and their kinetic energy increases, causing the temperature of the liquid to rise.

**Section DE:** A mixture of liquid and gas will be observed at this temperature which is called boiling point of the substance. At point E, the liquid has turned completely into a gas.

**Section EF:** The gas particles will absorb energy and move further apart as they become more energetic. The temperature of the gas will rise.

## Summary

**Slope sections of the heating curve:** As a substance is heated, it absorbs heat energy and its temperature rises, then it changes from solid to liquid and finally to gas.

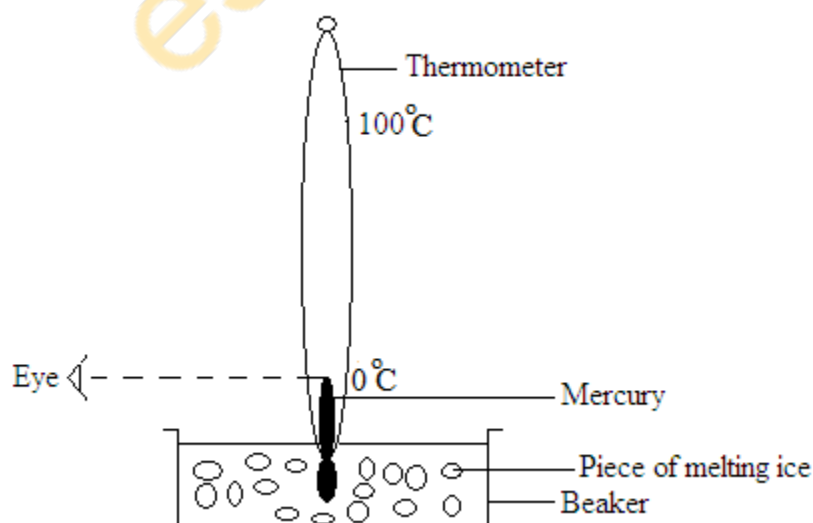
**Flat sections of the heating curve:** The flat section shows the melting point and boiling point. Here the temperature remains constant over a period of time as energy being absorbed is used to change the state of a substance.

**Note:** A pure substance has a fixed temperature. It has an exact boiling point and melting point.

Impurities raise the boiling point and lower the melting point.

## Example

1. The diagram below shows an experiment on changes of state.



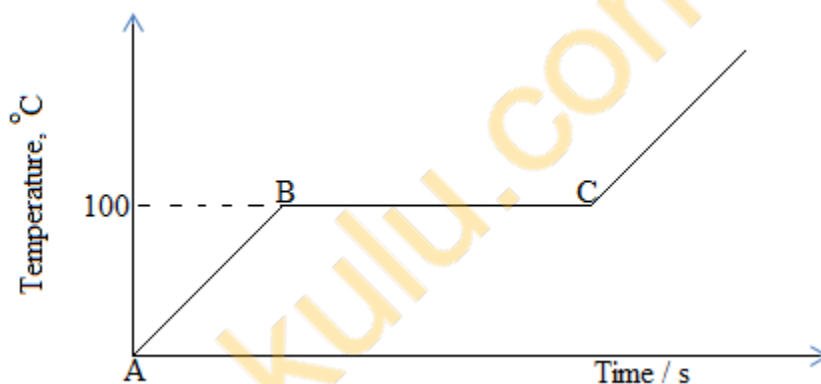
- (a) What is the reading on the thermometer?



- (b) What must be done to the melting ice for it to completely change to the next state of matter?
- (c) Describe the change of state that the ice will undergo in question (b) above
- (d) What term is used to describe the temperature at ice changes its state?
- (e) Some substances can change from solid state into gaseous state without becoming a liquid. What term is used to describe such a reaction?

### Solution

- (a)  $0^{\circ}$  (Temperature for melting ice)
  - (b) It must be heated/warmed/put in sunlight
  - (c) Melting
  - (d) Melting point
  - (e) Sublimation
2. Consider the graph below



- (a) What are the two possible states of matter at A and B?
- (b) Name the change of state at A and B

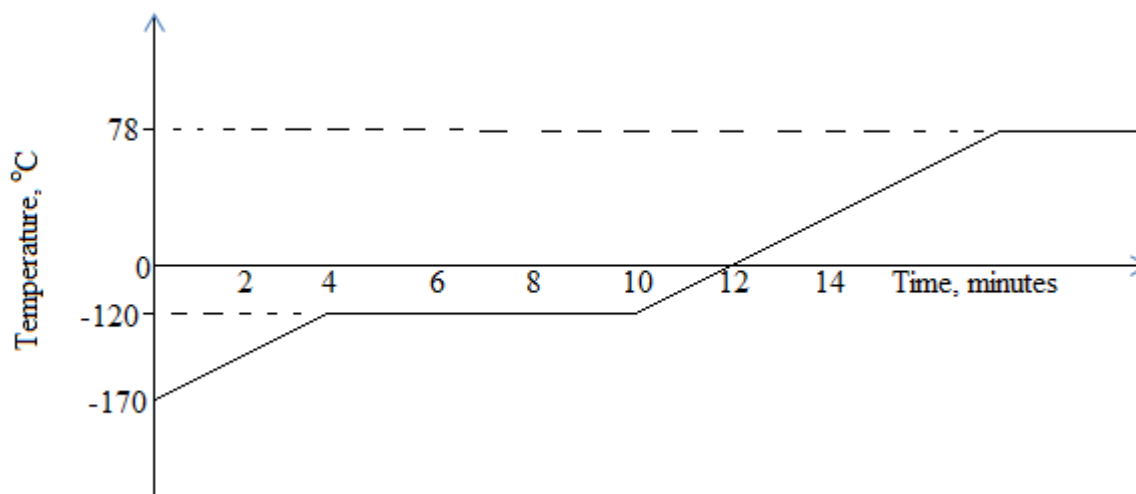
### Solution

- (a) At A: Solid and liquid  
At B: Liquid and gas
- (b) At A: Melting  
At B: Evaporation

### Cooling

### Exercise

1. The graph below shows the temperature of a sample of ethanol varied with time.



- (a) What is the melting point of ethanol?
- (b) What is the boiling point of ethanol?
- (c) For how long did the sample of ethanol melt?
- (d) How are you able to tell from the graph that the sample of ethanol is pure?

### Cooling

Cooling involves the removal of heat from a substance

### Effects of cooling a substance

### Condensation

Condensation is the change of state from gas to liquid

For example, steam changes to water when cooled

### Freezing

Alternative term: Solidification

Freezing is the change of state from liquid to solid

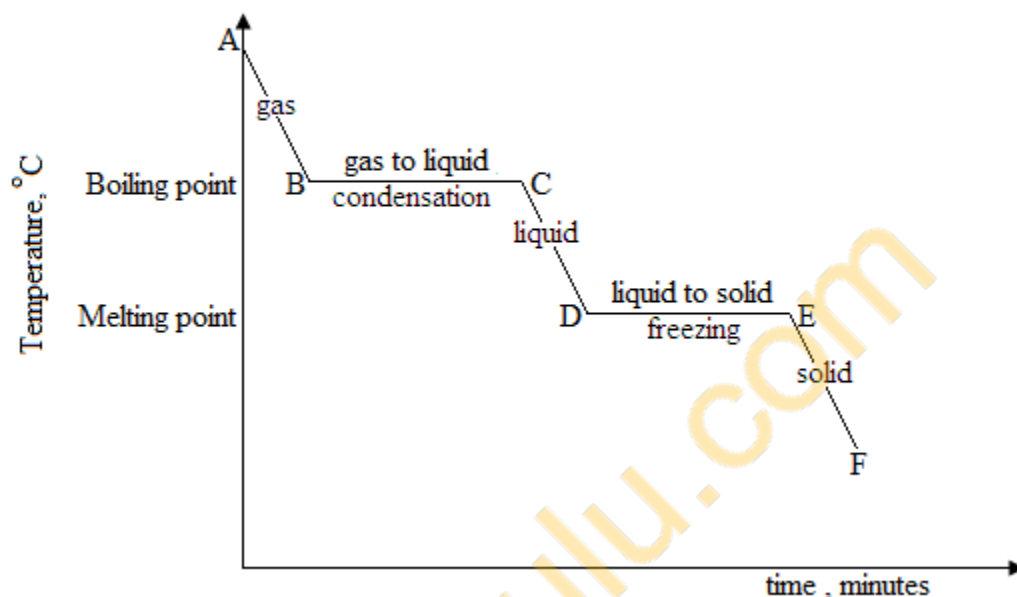
For example, water changes to ice when cooled

The temperature at which a liquid changes into a solid is called freezing point.

Freezing point is also called the melting point for a pure substance.

### The cooling curve

The cooling curve is a graph showing changes in temperature with time for a substance being cooled.



**Section CD:** The substance remains a liquid. As cooling takes place, the particles lose kinetic energy and move more slowly.

**Section DE:** A mixture of a liquid and solid is observed as the liquid particles rearrange themselves to form a solid structure.

**Section EF:** The temperature of the solid drops as cooling continues.

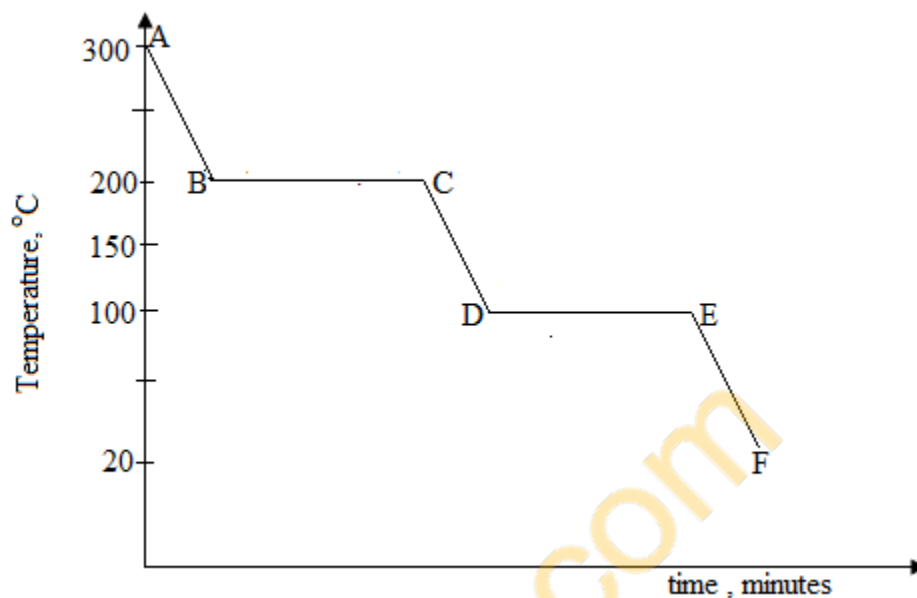
### Summary

**Slope sections of the cooling curve:** As a substance is cooled, it loses heat energy and its temperature falls, then it changes from gas to liquid and finally to solid.

**Flat sections of the cooling curve:** The flat section shows the melting point and boiling point. Here the temperature remains constant over a period of time as energy being lost is used to change the state of a substance.

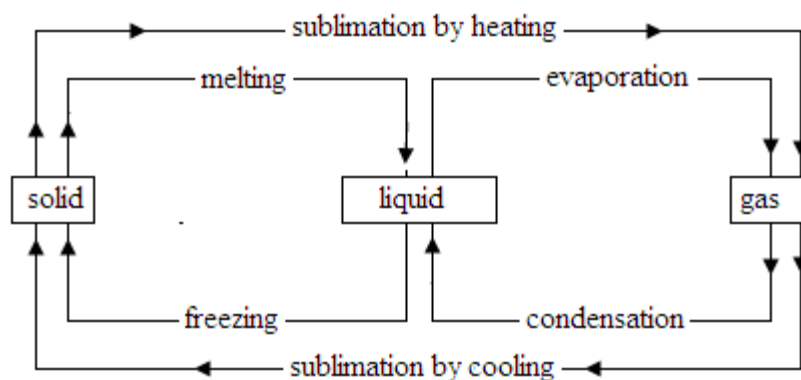
### Exercise

1. The graph below shows a cooling curve of a substance as its temperature falls from  $300^{\circ}\text{C}$  to  $20^{\circ}\text{C}$ .



- (a) At  $250^{\circ}\text{C}$ , is the substance a solid, liquid or gas?  
(b) What was the boiling point of the substance?  
(c) What was the melting point of the substance?  
(d) Why does the temperature stay constant over the section BC and DE despite the fact that the substance is losing energy to the surrounding?

#### Summary of the changes in state



#### Example

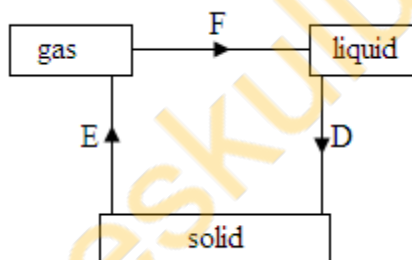
1. Choose from the following terms to answer this question  
Sublimation, diffusion, matter, liquefaction, ion  
Which of the terms above describes:  
(a) The physical material of the universe  
(b) A basic unit of matter  
(c) Carbon dioxide gas changing to dry ice  
(d) The spreading movement of particles  
(e) A gas changing to a liquid

### Solution

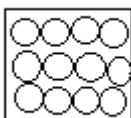
- (a) Matter  
(b) Ion  
(c) Sublimation  
(d) Diffusion  
(e) Liquefaction

### Exercise

1. Study the diagram below and answer the questions that follow



- (a) Name the processes D, E and F  
(b) Describe what you would do to convert a liquid into a solid  
(c) State one of the basic units of matter
2. Matter is classified as solid, liquid or gas. State two physical properties of each of the following:  
(a) Solid  
(b) Liquid  
(c) Gas
3. The diagram represents the arrangement of the particles in a solid



- (a) Describe the movement of particles in the solid

- (b) How does this movement alter as the temperature of the solid is increased
- (c) How does this movement alter as the solid melts
- (d) Samples of the gases carbon dioxide,  $M_r = 44$ , and hydrogen,  $M_r = 2$ , are at same temperature.
- Compare the speeds of the molecules in these two gases
  - Equal masses of steam and water contain the same number of molecules. Explain why the volume of the steam is much greater than that of water

### Physical changes

A physical change is change in which no new substance is formed.

### Chemical changes

A chemical change is a change in which a new substance is formed

### Differences between physical and chemical changes

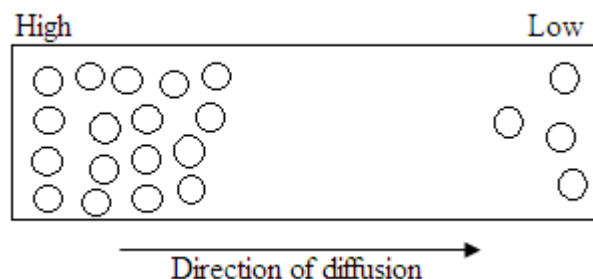
Physical change	Chemical change
No new substance is formed e.g. melting a solid	A new substance is formed e.g. burning substances
Usually the change is easily reversible e.g. boiling a liquid	Usually the change is not easily reversible e.g. precipitation of a solid by the reactions of two solutions
Usually no energy is given out or taken in e.g. heating a wire by electricity	Usually energy is given out or taken in e.g. decomposition of substances by electricity
The mass of the substance remains the same e.g. magnetizing iron	The mass of the new substance is different from that of the starting substance e.g. rusting of iron

### The kinetic theory of matter

The theory states that: Matter is made up of tiny particles which are in a continuous random motion.

### Diffusion

Definition: Diffusion is the movement of particles from the region of high concentration to the region of low concentration.



### Rate of diffusion

Rate of diffusion is the amount of gas or liquid diffusion in a unit of time.

### Factors that affect the rate of diffusion

**Temperature:** Rate of diffusion is faster if the temperature is high and slower if the temperature is low.

**Concentration:** Rate of diffusion is faster if there is a large difference in the concentration of particles between two points.

**Size of particles:** Rate of diffusion is faster if size of particles is small and slower if the size of particles is large.

**Note:** The states of matter in which diffusion takes place are liquids and gases.

### Diffusion in liquids

#### Experiment

**Aim:** To demonstrate diffusion in liquids

#### Apparatus

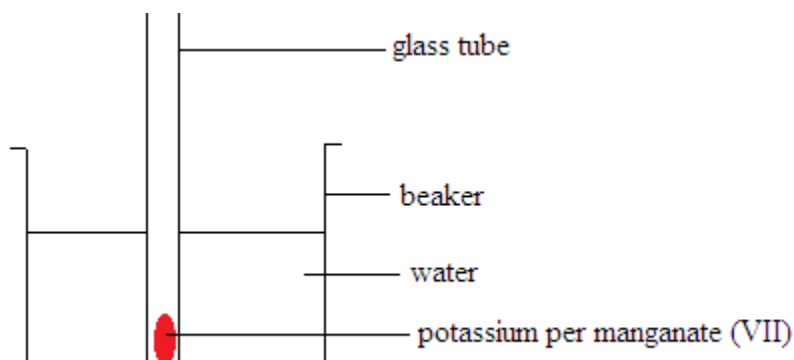
Potassium permanganate (VII)

Water

Glass tube

#### Method

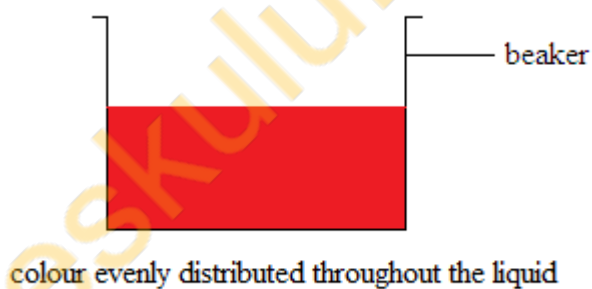
Using a glass tube, place a crystal of potassium permanganate (VII) in the middle of the beaker filled with water. The glass tube is used to ensure that the mixing with water does not occur before the crystal is in place.



Leave the beaker undisturbed and observe carefully.

### Observation

The crystal of potassium permanganate (VII) dissolves and the purple colour slowly spread to the bottom of the beaker and eventually the colour distributes itself throughout the liquid.



### Conclusion

Diffusion has taken place and water turns purple because the particles of potassium permanganate (VII) have diffused to all parts of the water.

### Diffusion in gases

Diffusion in gases is faster than in liquids. The gas molecules move randomly at a very high speed.

### Experiment

**Aim:** To demonstrate diffusion of oxygen gas and nitrogen dioxide gas



## Apparatus

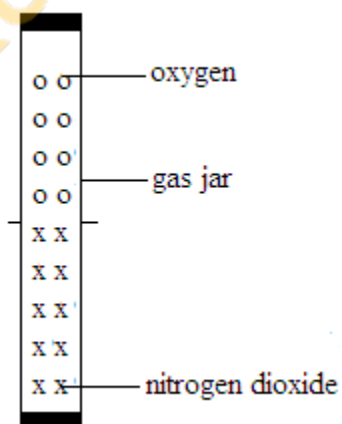
Oxygen gas

Nitrogen dioxide gas

Two gas jars

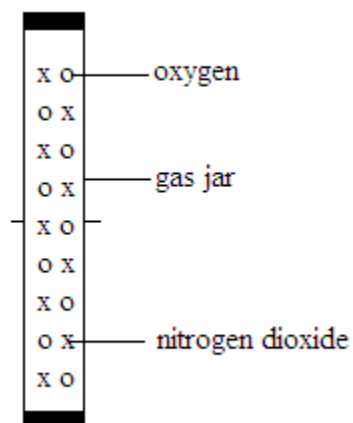
## Method

Invert a gas jar containing oxygen and place it on top of a gas jar containing nitrogen dioxide gas.



## Observation

The brown fumes of nitrogen dioxide gas diffuses slowly into a gas jar containing oxygen gas and spread out and mix evenly.



## Conclusion

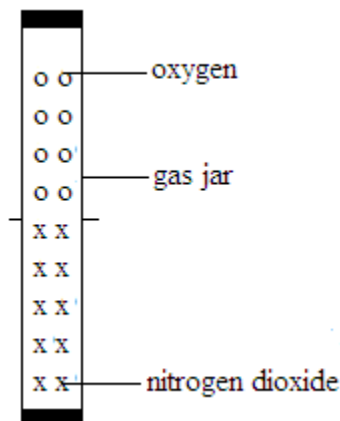
Diffusion has taken place since the nitrogen dioxide molecules have moved randomly and mix evenly with the oxygen molecules.

## Other examples of diffusion

When a stopper is taken out of the perfume bottle, the smell is noticed because the particles move from a region of high concentration to region of low concentration.

## Exercise

1. Matter is made up of tiny particles as it can be evidenced from the process by diffusion
  - (a) Explain what is meant by diffusion
  - (b) In which state(s) of matter does diffusion occur?
  - (c) A gas jar of oxygen gas was inverted and placed on top of a gas jar containing nitrogen dioxide as shown below.



Draw a similar diagram to show the arrangement of the molecules of the two gases after being in contact for 30 minutes.

- (d) When the stopper is taken out of a bottle of perfume, the smell can soon be noticed. Explain from your knowledge of particles why this happens.

### **Name and use of apparatus**

#### **Stop watch**

It is an instrument used for measuring time.

The SI unit for time is the second, s.

#### **Thermometer**

It is an instrument used for measuring temperature.

The SI unit for temperature is the kelvin, K.

#### **Beam balance**

It is an instrument used to measure mass

The SI unit for mass is the kilogram, Kg

### **Apparatus for measuring volume**

#### **Measuring cylinder**

It is used for making approximate measurements of volumes of liquids

Measuring cylinders are in different sizes

#### **Burettes**

Burettes are used for accurate measurements of different volumes of liquids

They can measure small amounts of volume. For example, a burette can be used to measure **exactly**  $22.5\text{ cm}^3$  of the liquid.

They have a scale which starts from  $0\text{ cm}^3$  at the top up to  $50\text{ cm}^3$  at the bottom

The scale is more sensitive than the measuring cylinder

Burettes have a long narrow shape which ensures a 'long movement' for a small volume of liquid delivered out of the jet.

### **Pipette**

A pipette is used for delivering accurately a fixed volume of liquid

A pipette has to be filled carefully by sucking up the liquid or by using a special adaptor.

The volume of the liquid delivered is marked on the bulb and it is usually  $25\text{ cm}^3$ . Most of the liquid is held in the bulb.

### **Flasks**

There are three main types of flasks; each type is usually for holding liquids.

#### **Flat bottomed flask**

The flat bottomed flask can stand on the table.

It is mainly used in carrying out reactions involving a solid and a liquid.

#### **Round bottomed flask**

Its shape enables uniform heating of the liquid it contains

It is used for heating liquids for longer periods

#### **Conical flask**

The conical flask is used for mixing liquids while shaking.

### **Beakers**

Beakers are in different sizes

They are used on tripod stand and gauzes for heating liquids

They are used for mixing liquids while using volumes which are too big for the test tube.

### **Test tube**

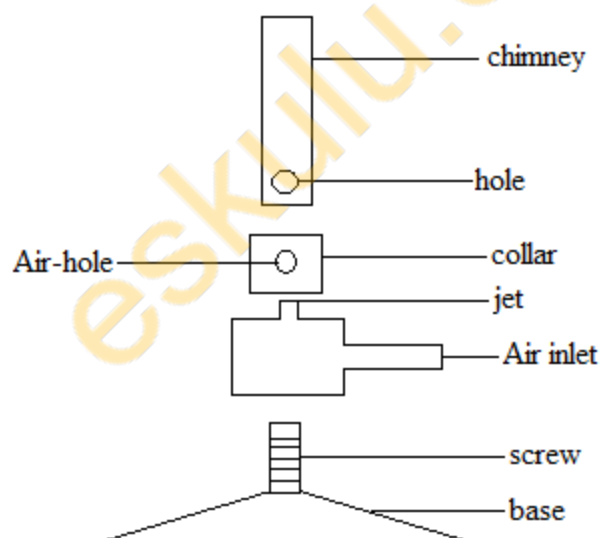
The tube is used for heating and mixing liquids or solids.

### **The Bunsen burner**

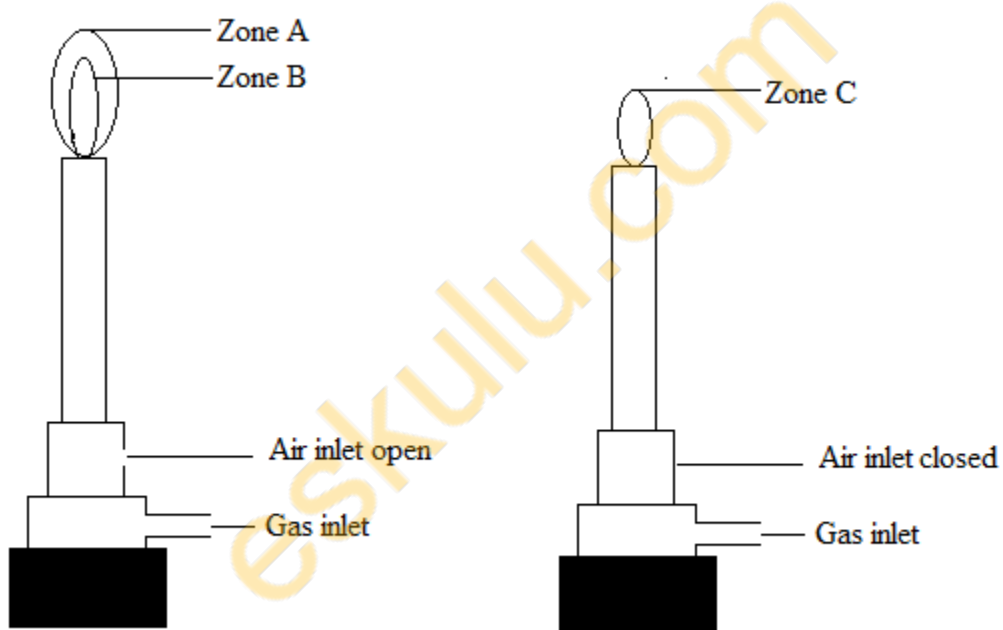
The Bunsen burner is the most common tool for heating

It is connected to the cylinder or gas tap and lighted

### **Component parts of a Bunsen burner**



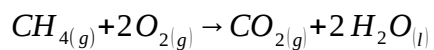
## Flames produced by the Bunsen burner



### Zone A

It is a blue flame

It produces the greatest amount of heat because methane gas is completely burnt. It is the hottest part of the flame and it used for heating.

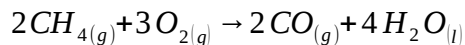


### Zone B

It is a blue green flame

It contains unburnt hydrocarbons

It appears blue green because of the incomplete combustion of methane.



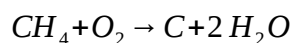
It has the lowest temperature and it is called non luminous

### **Zone C**

It is a yellow flame

It is luminous because it gives out light

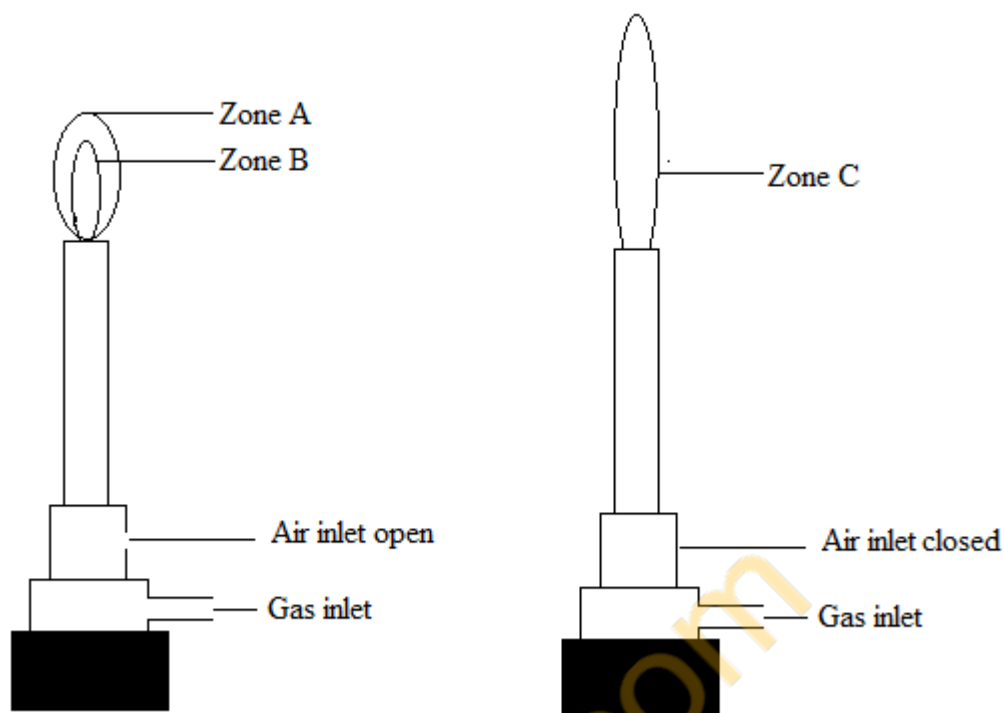
The yellow flame is called a 'dirty flame' because it coats things held inside it with a black deposit. This black substance is carbon.



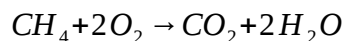
The cause of the colour in zone C is carbon charring due to incomplete combustion of methane

### **Exercise**

1. The diagram below represent the flames on a burner using methane as the fuel



The equation for the complete combustion of methane in zone A is:



- (a) What colour would you expect the flame to be in
  - (I) Zone B
  - (II) Zone C
- (b) Explain what causes the colour in zone C
- (c) Give an equation for the combustion of methane in zone C.

### Criteria of purity

Definition: This refers to all those physical properties which are characteristic of a pure substance.

The purity of a substance can be tested by determining:

- (a) the boiling point
- (b) the freezing point
- (c) the melting point
- (d) the density

Impure substances show variations in physical properties

### Importance of purity of substances



Purity of substances like food, drugs and water is important because very small amounts of impurities may cause serious illness or death.

The companies processing food and manufacturing drugs check regularly to ensure that their products are pure.

### **Separation techniques**

Separation techniques are methods used to obtain pure substances from their mixtures.

Substances usually exist as mixtures and special ways are used to separate them.

### **Terms used in separation techniques**

**Mixture:** A mixture is a substance which consists of two or elements which are physically combined but not chemically combined.

**Solution:** A solution is a mixture made up of a solvent and a solute.

**Solvent:** A solvent is a liquid in which a solute dissolves.

**Solute:** A solute is a substance that dissolves in a solvent. A solute can either be a solid, liquid or gas.

**Miscible liquids:** Miscible liquids are liquids that can mix completely.

**Immiscible liquids:** Immiscible liquids are liquids that do not mix completely.

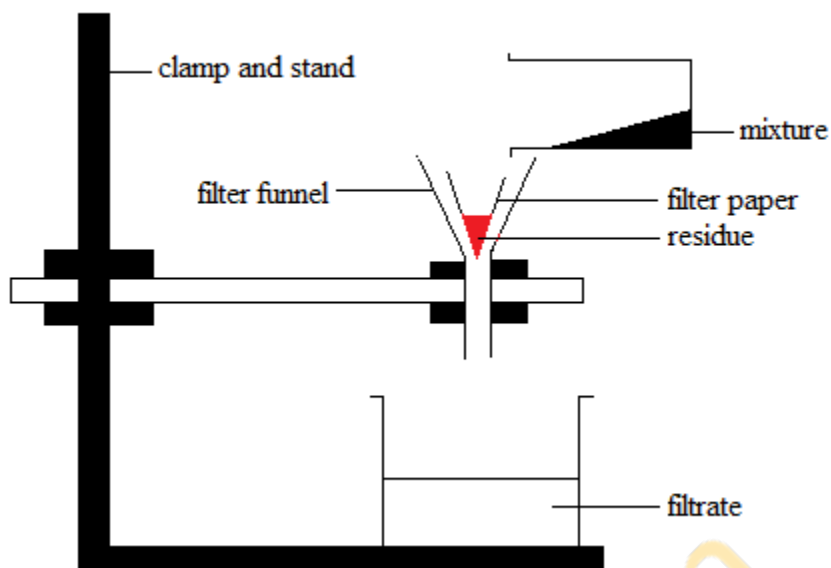
**Residue:** A residue is a solid that is trapped on the filter paper during filtration.

**Filtrate:** A filtrate is a clear liquid collected after filtration.

### **Methods of purification**

#### **1. Filtration**

This is a method of separating an insoluble solid from a liquid using a filter.



### Application of filtration

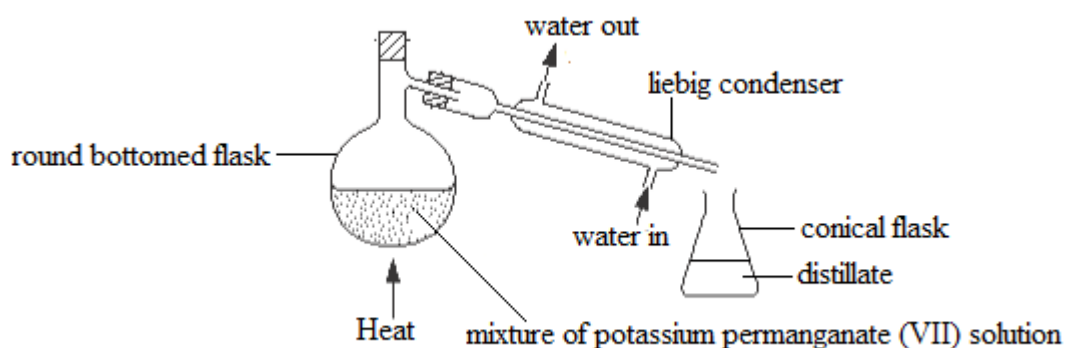
- (a) It is used at the water works to filter water using a filter bed made from gravel and sand
- (b) It is used in car engines where oil and petrol are passed through filters to remove impurities

## 2. Distillation

It is a process of vapourizing a liquid and then condensing the vapour

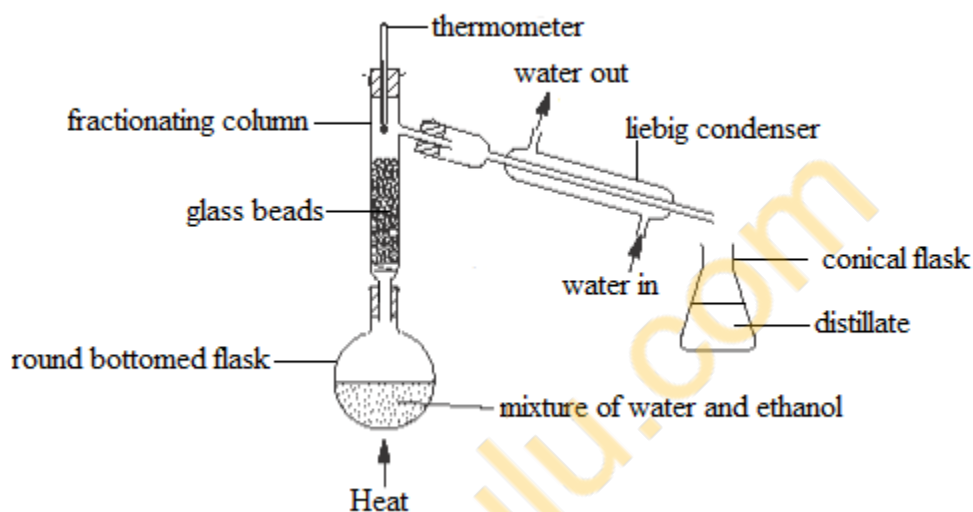
### (a) Simple distillation

It is a process used to separate a pure liquid from a solution containing dissolved solids. For example, simple distillation can be used to separate pure water from potassium permanganate (VII) solution



### (b) Fractional distillation

It is process of separating a mixture of liquids by distillation using a fractionating column



#### Properties upon which the mixture depends to allow separation

1. The liquids must be miscible
2. Liquids must have difference boiling points

Fractional distillation can be used to separate ethanol from a mixture of ethanol and water. Ethanol and water have different boiling points. Ethanol boils at  $78^{\circ}\text{C}$  and water boils at  $100^{\circ}\text{C}$ . When temperature reaches  $78^{\circ}\text{C}$ , ethanol, which is more volatile than water, boils off first. As the vapour passes through the glass beads in the fractionating column, water vapour condenses and returns back to the flask. Only ethanol vapour reaches the fractionating column and enters the liebig condenser where it condenses. The liquid ethanol finally collects in the conical flask.

#### Note

- The fractionating column is a long tube filled with glass beads. The glass beads provide a large surface area for condensation and allow efficient separation of the components in the mixture.

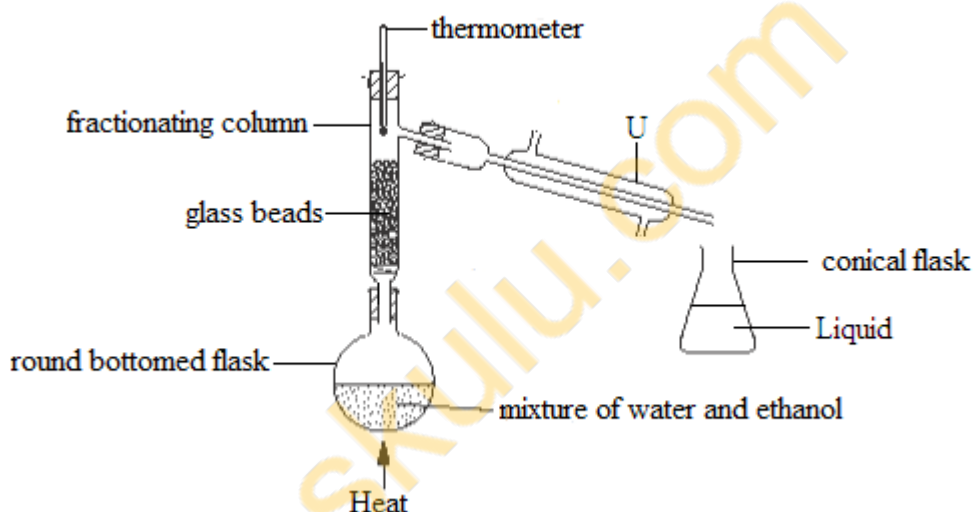
- The liebig condenser is kept in the slanting position to avoid the distillate formed by condensation from running back into the fractionating column; and also to ensure that cold water completely surrounds the inner glass tube where the vapour passes in order to provide maximum cooling and avoid loss of vapour.
- The thermometer is placed at the top of the fractionating column so that it registers the temperature of the vapour.

### Distillate

It is a pure and condensed liquid obtained by distillation

### Example

1. The diagram below shows the experiment on separation of a mixture



- (a) What is the name of the separation process shown in the diagram?
- (b) State two properties of the mixture that allows the separation to take place
- (c) What is the function of the apparatus labeled U?
- (d) Name the first part of the mixture that will be collected in the conical flask
- (e) Suggest one industrial use of the separation technique shown in the diagram

### Solution

- (a) Fractional distillation
- (b) Liquids must be miscible/mix completely (but not react)  
Liquids must have different boiling points
- (c) Cools the vapour causing it to condense into liquid
- (d) Ethanol
- (e) Separation of crude oil (at oil refinery plant)

### Exercise

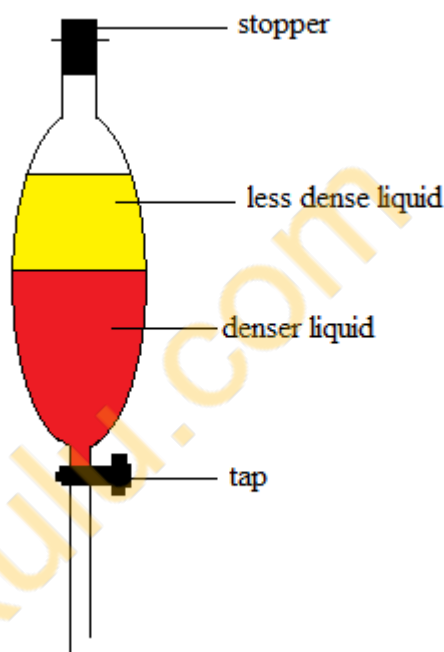
1. Two miscible liquids with boiling points  $78^{\circ}\text{C}$  and  $100^{\circ}\text{C}$  were mixed accidentally.
- (a) Name the process which can be used to separate the mixture
- (b) Draw a labeled diagram showing the arrangement of the apparatus used to separate the mixture.

**3. Separating funnel**

The separating funnel is used to separate two or more immiscible liquids

The method depends on the differences in densities of liquids to be separated.

The less dense liquid floats on the surface while the denser liquid sinks to the bottom.



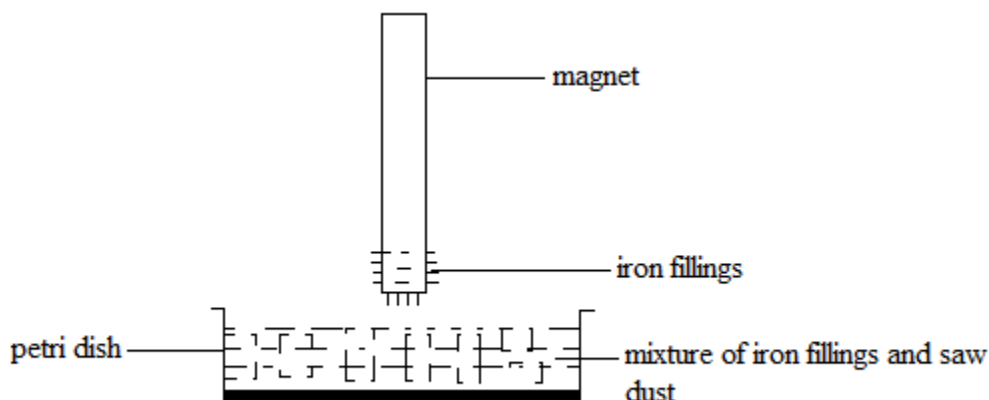
**Exercise**

2. Water and oil are immiscible. How would you separate a mixture of the two?

**4. Magnetism**

It is used to separate a mixture when one component is magnetic and other one is non-magnetic.

For example magnetism can be used to separate a mixture of saw dust and iron fillings. The magnet attracts iron fillings, only leaving particles of saw dust in the petri dish.



### 5. Decantation

It is used to separate solid impurities by allowing them to settle down and the liquid is poured out leaving the solid at the bottom of the container. For example it can be used to separate a mixture of sand and water

### 6. Crystallization

This is a process of separating pure solid from an impure solution.

For example it can be used to obtain copper (II) sulphate crystals from an impure copper (II) sulphate solution

### Steps to follow

- Add an impure solid in a solvent to dissolve the solid
- Filter off the solution into an evaporating dish
- Heat the solution using a Bunsen burner to evaporate most of the solvent
- Cool the concentrated solution. Some solids appear as pure crystals
- Pour off the solution to obtain the crystals. Dry the crystals on the filter paper

### 7. Chromatography

Chromatography is a technique for separating mixtures of solutes using a solvent and a separating medium.

In the case of paper chromatography, the separating medium is paper and the solvent is ethanol.

Substances in a mixture are separated according to their solubilities in the same solvent. The more soluble component will tend to remain in the solution and travel further up the chromatogram while the less soluble component will separate out on to paper.

### Experiment

**Aim:** To separate out components of black ink by paper chromatography.

### Procedure

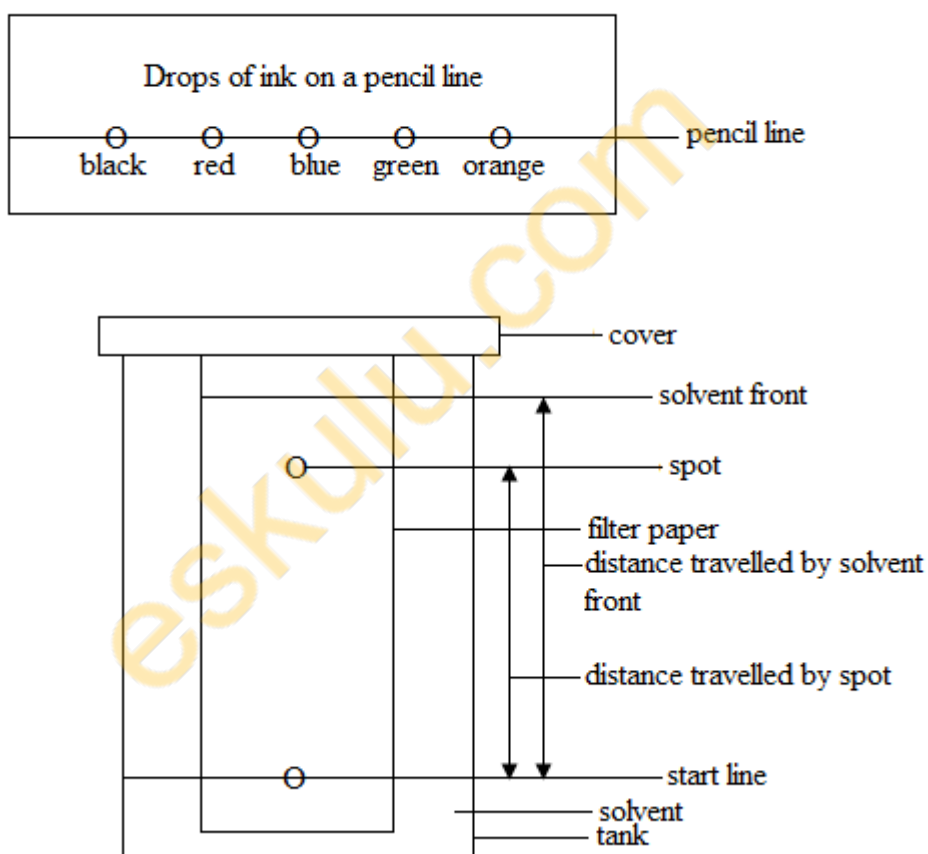
Use a pencil to draw the start line because ink contains dyes which contaminates the solvents

Use the black ink sample to make a small dot on the start line, together with other coloured ink to use as reference. The dots should be small to prevent the spreading of dyes sideways and thereby getting mixed up with other spots next to them.

Fold the paper into a cylinder and place it into a beaker containing the solvent, ensuring that the start line is above the solvent level.

Cover the beaker while the chromatogram develops

Remove the chromatogram from the beaker just as the solvent reaches the top of the paper.



### Retardation factor

Alternative term: Reference factor

Symbol:  $R_f$

Definition: Retardation factor,  $R_f$ , is the ratio of the distance travelled by the spot, compared with the distance travelled by the solvent front, both measured from the start line

$$\text{Formula: } R_f = \frac{\text{Distance travelled by spot}}{\text{Distance travelled by the solvent front}}$$

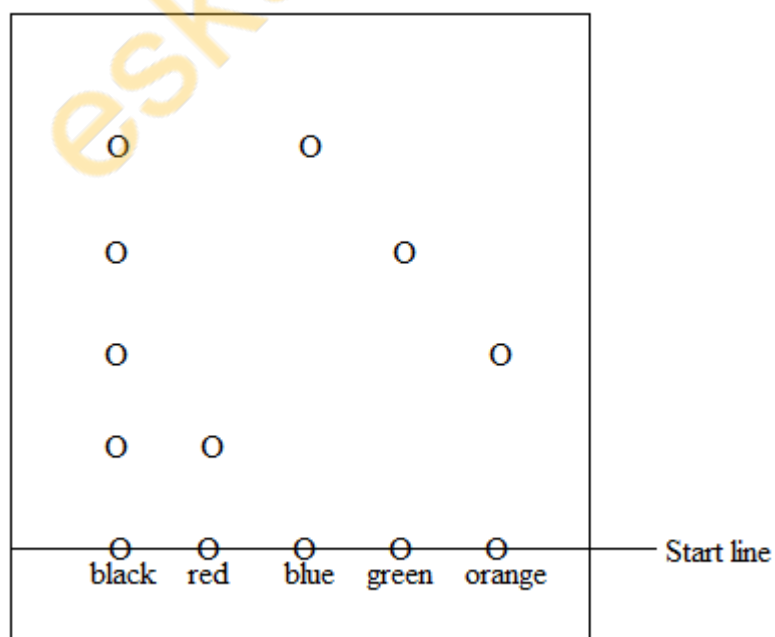
↕ start line    ↕ start line ↕

### Note

If the start line is below the solvent level, the sample dots will dissolve into the solvent instead of moving up the paper.

In descending paper chromatography, a longer sheet of paper can be used because the solvent moves faster and longer distance

### Interpretation of results





Dots that have travelled the same distance from the start line in the same solvent belong to same substance.

## Conclusion

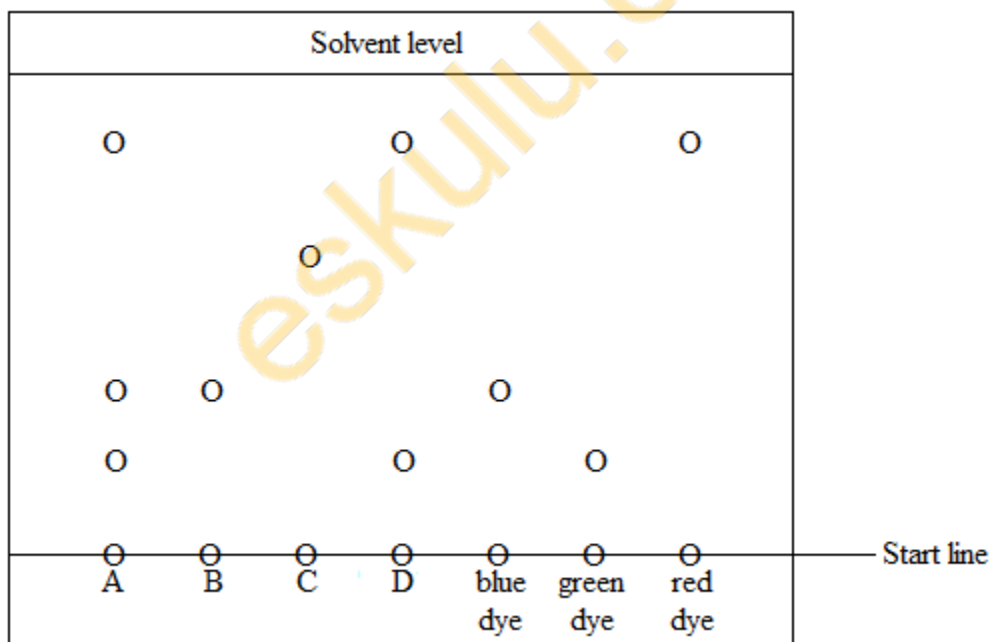
Black ink contains four coloured components; red, blue, green and orange.

## Application of chromatography

1. Separating pigments from plants
2. Identifying flavouring components in food stuffs
3. Separating amino acids from proteins
4. Separating antibiotic drugs from their growing media

## Example

1. The diagram below shows a chromatogram obtained using solutions of three single dyes (blue, green and red) and four other solutions (A, B, C and D).



- (a) Which of the solutions A, B, C and D contain the following:
- (I) One dye only
  - (II) Three of the dyes
  - (III) Green and red only
  - (IV) A dye rather than blue, green and green

(b) In preparing the chromatogram, the following instructions were given. Suggest a reason for each instruction;

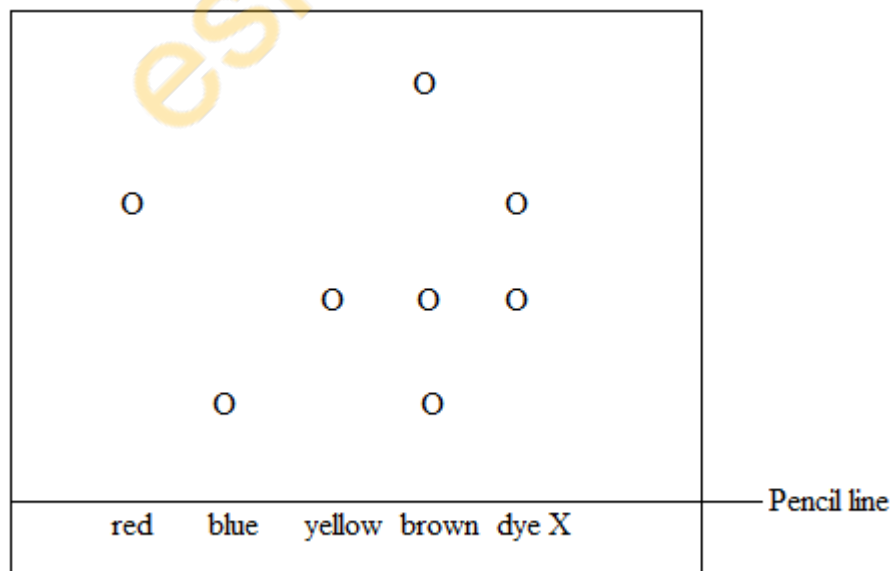
- (I) The start line should be drawn with pencil rather than ink
- (II) At the end of the experiment, the solvent front should be near the top of the paper
- (III) The spots of solutions and dyes on the starting line should be small.

### Solution

- (a) (I) Solution B
- (II) Solution A
- (III) Solution D
- (IV) Solution C
- (b) (I) Ink contains dyes, it thus contaminates the solvent and gives a wrong result
- (II) This is to ensure that the separation of the dyes is complete
- (IV) To prevent spreading of the dyes sideways thereby getting mixed up with other spots next to them.

### Exercise

1. Naosa Jane wants to find out which coloured dyes have been mixed together to make dye X. she separates a sample of dye X and samples of coloured dyes using paper chromatography. Her results are shown below.



- (a) Explain why the line is drawn in pencil and not in ink?

- (b) Which colours are present in dye X?  
(c) Which coloured dye contains a substance not present in any of the other coloured dyes?

## Elements, mixtures and compounds

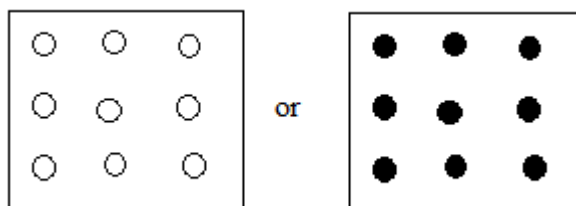
### Elements

Definition: An element is a pure substance which cannot be split into two or more other simpler substances by chemical means.

### Examples of elements

- Iron
- Sulphur
- Magnesium
- Oxygen
- Copper

### Diagrammatic representation of elements



### Mixture

**Definition:** A mixture is a substance which consists of two or more elements not chemically combined.

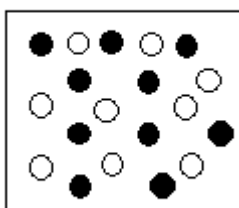
It is easy to separate a mixture into its components because each component keeps its own properties.

In a mixture, the particles of each substance remain separate and the number of each can vary.

### **Examples of mixtures**

- Air: Air is a mixture of oxygen, carbon dioxide, nitrogen and other gases.
- Sugar solution: Sugar solution is a mixture of sugar and water.
- Brass: Brass is a mixture of zinc and copper.

### **Diagrammatical representation of a mixture**



### **Compound**

**Definition:** A compound is a substance which consists of two or more elements chemically combined.

The properties of a compound are different from those of individual elements. This is because a chemical change has taken place.

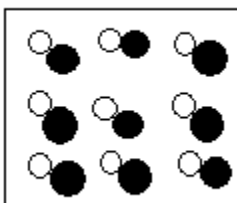
In a compound, the particles of elements are combined chemically in a fixed ratio. It is difficult to separate a compound into its constituent elements.

### **Examples of compounds**

- Water: Water consists of the elements hydrogen and oxygen.
- Common salt: Common salt consists of the elements sodium and chlorine.
- Carbon dioxide: Carbon dioxide consists of the elements carbon and oxygen.
- Sugar: Sugar consists of the elements carbon, hydrogen and oxygen.

- Iron sulphide: Iron sulphide consists of the elements iron and sulphur.

### Diagrammatical representation of a compound



### Differences between mixtures and compounds

Mixture	Compound
The substances in a mixture can be separated by physical means	The elements in a compound cannot be separated by physical means
Energy is not usually given out or absorbed when mixing occurs	Energy (heat, light or sound) is usually given when a compound is formed
The properties of a mixture (density, colour) are an average of those of the substances in it	The properties of a compound are quite different from those of the elements in it
The composition of a mixture is variable. The substances can be present in any proportions by mass	The composition a compound is fixed. The elements are combined in definite proportions by mass

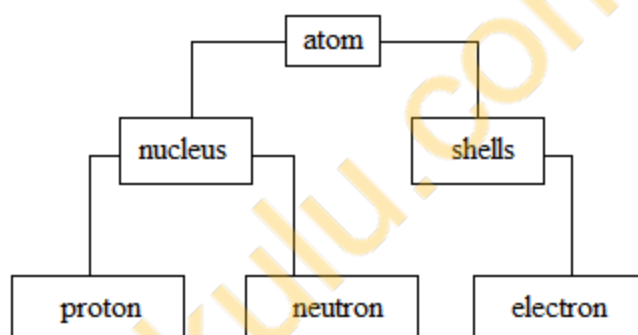
### Exercise

1. Consider the following list of common substances  
Air, salt, brass, sugar, glass, water, limestone  
Choose from the list a substance which:
  - (a) is a mixture containing both elements and compounds
  - (b) is a mixture of compounds
  - (c) is a mixture of elements
  - (d) is a compound containing only two elements

(e) is a compound which contains carbon

## Structure of an atom

Definition: An atom is the smallest particle of an element that can take part in a chemical reaction.



Atoms are electrically neutral. They have no overall charge. This is because number of protons is equal to number of electrons.

## Fundamental particles of an atom

### 1. Electron

It is a negatively charged particle.

It has a charge of -1

It is found in shells of around the nucleus of an atom

It has a mass of  $\frac{1}{1840}$  atomic mass units (a.m.u)

### 2. Proton

It is a positively charged particle

It has a charge of +1

It is found in the nucleus of an atom

It has a mass of 1 atomic mass units (a.m.u)

### 3. Neutron

It is a neutral particle

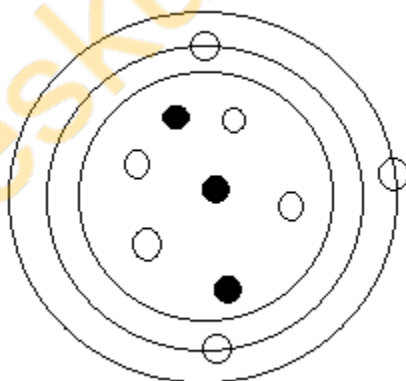
It has no charge

It is found in the nucleus of an atom

It has a mass of 1 atomic mass units (a.m.u)

### Example




1. The diagram below represents an atom of lithium.



What do the symbols represents?



## Solution

	electrons
	protons
	neutrons

## Exercise

1. Complete the table below

Particle	Relative charge	Position in the atom	Relative mass
	-1		Shells around the nucleus
Proton		Nucleus	
			1

## Proton number

Alternative term: Atomic number

Symbol: Z

Definition: It is the number of protons in the nucleus of an atom

## Mass number

Alternative term: Nucleon number

Symbol: A

Definition: It the sum of protons and neutrons in the nucleus of an atom

Formula:  $A = Z + N$

A = mass number

Z = proton (atomic number)

N = number of neutrons



### Example

1. An atom of sodium has 11 protons and 12 neutrons. Calculate its mass number.

Data	Solution
A = ?	$A = Z + N$
Z = 11	$A = 11 + 12$
N = 12	$A = 23$

### Exercise

1. An atom of aluminium has a mass number of 27 and has 13 protons. Work out the number of neutrons.
2. An atom has the notation  $^{32}_{15}\text{X}$ . State the number of protons, electrons and neutrons in one atom of X.

### Atomic numbers and mass numbers for the first 20 elements

Element	Symbol	Atomic number	Mass number
Hydrogen	H	1	1
Helium	He	2	4
Lithium	Li	3	7
Beryllium	Be	4	9
Boron	B	5	11
Carbon	C	6	12
Nitrogen	N	7	14
Oxygen	O	8	16
Fluorine	F	9	19
Neon	Ne	10	20
Sodium	Na	11	23
Magnesium	Mg	12	24
Aluminium	Al	13	27
Silicon	Si	14	28
Phosphorous	P	15	31
Sulphur	S	16	32
Chlorine	Cl	17	35.5
Argon	Ar	18	40
Potassium	K	19	39
Calcium	Ca	20	40

## Nuclides

A nuclide consists of a symbol with the atomic number in front of the symbol and just below it and the mass number also in front and just above the symbol.

Nuclide notation:  ${}^A_ZX$

A = mass number

X = symbol of an atom

Z = proton (atomic number)

## Isotopes

Definition: Isotopes are atoms of the same element having the same number of protons but different number of neutrons (and mass numbers)

Carbon has three isotopes

Carbon-12, $^{12}_6\text{C}$	p = 6 n = 6
Carbon-13, $^{13}_6\text{C}$	p = 6 n = 7
Carbon-14, $^{14}_6\text{C}$	p = 6 n = 8

Hydrogen has three isotopes

Hydrogen-1, $^1_1\text{H}$ (Ordinary hydrogen)	p = 1 n = 0
Hydrogen-2, $^2_1\text{H}$ (Deuterium)	p = 1 n = 1
Hydrogen-3, $^3_1\text{H}$ (Tritium)	p = 1 n = 2

Chlorine has two isotopes

Chlorine-35, $^{35}_{17}\text{Cl}$	p = 17 n = 18
Chlorine-37, $^{37}_{17}\text{Cl}$	p = 17 n = 20

**Some uses of isotopes**

1. Hydrogen isotopes are used in the study of nuclear energy
2. Radio cobalt,  $^{60}_{27}\text{Co}$  is used in the treatment of cancer.

### Mass spectrometer

The mass spectrometer is used for the separation of isotopes of an element and determination of their respective masses.

### Relative atomic mass

Symbol:  $A_r$

Definition: Definition: Relative atomic mass of an element is the mass of one atom of an element compared to  $\frac{1}{12}$  the mass of carbon – 12 isotope .

$$\text{Formula: } A_r = \frac{A_r \text{ of isotope A} \times \text{percentage abundance}}{100} + \frac{A_r \text{ isotope B} \times \text{percentage abundance}}{100}$$

### Example

1. Chlorine has two main isotopes,  $^{35}_{17}\text{Cl}$  and  $^{37}_{17}\text{Cl}$  with abundances of 75% and 25% respectively. Calculate the relative atomic mass for chlorine.

$$\begin{aligned} A_{r(\text{Cl})} &= \frac{A_r \text{ } ^{35}\text{Cl} \times \text{percentage abundance}}{100} + \frac{A_r \text{ } ^{37}\text{Cl} \times \text{percentage abundance}}{100} \\ &= \frac{35 \times 75}{100} + \frac{37 \times 25}{100} \\ &= \frac{2625}{100} + \frac{925}{100} \\ &= 26.25 + 9.25 \\ &= 35.5 \end{aligned}$$

### Note

The relative atomic mass of chlorine is 35.5 (not a whole number) because it is the average of two isotopes i.e. chlorine-35 and chlorine -37.

## Exercise

- Chlorine has two isotopes,  $^{35}_{17}\text{Cl}$  and  $^{37}_{17}\text{Cl}$ 
  - Define the term isotopes
  - State the number of neutrons in each of the following isotopes of chlorine
    - Chlorine – 35
    - Chlorine – 37
  - Explain why the relative atomic mass of chlorine on the periodic table is not a whole number?
  - What is the difference in the nuclei of the isotope with nucleon number 7 and its isotope whose nucleon number is 6?
- The table below shows the three isotopes of the element hydrogen and their nucleon (mass) numbers.
  - Complete the table to show the number of particles in the three nuclides.

Symbol	Name	Nucleon (mass) number	Protons	Neutrons
H	Hydrogen	1		
D	Deuterium	2		
T	Tritium	3		

- The boiling point of  $\text{D}_2\text{O}$  is  $101.6^\circ\text{C}$  but that of  $\text{H}_2\text{O}$  is  $100.0^\circ\text{C}$ . Suggest a reason for this difference

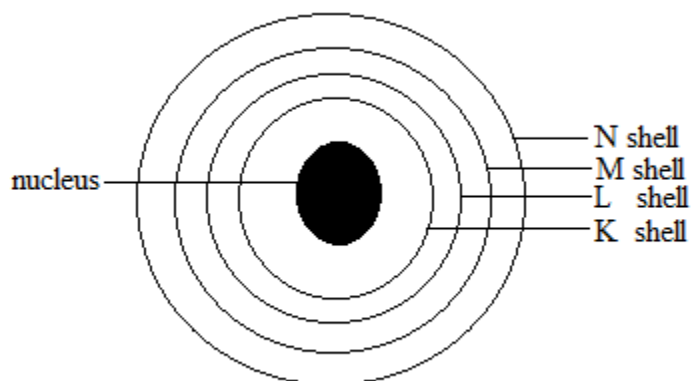
## Electron shells

Alternative term: Energy levels.

Definition: A shell is a concentric ring around the nucleus

The nucleus is also called the core of an atom.

The shells, in order of their increasing distance from the nucleus, are assigned by letters K, L, M, N etc.



## Electron configuration

Alternative term: Electronic structure

Definition: Electron configuration is the arrangement of electrons in shells of atoms

The maximum number of electrons each shell can accommodate is given by the formula:  $2n^2$ , where  $n$  is the number of shells.

K shell, $n = 1$	$= 2n^2$ $= 2 \times 1^2$ $= 2 \times 1 \times 1$ $= 2 \text{ electrons}$
L shell, $n = 2$	$= 2n^2$ $= 2 \times 2^2$ $= 2 \times 2 \times 2$ $= 8 \text{ electrons}$
	$= 2n^2$

M shell, n = 3	$= 2 \times 3^2$ $= 2 \times 3 \times 3$ $= 18 \text{ electrons}$
N shell, n = 4	$= 2n^2$ $= 2 \times 4^2$ $= 2 \times 4 \times 4$ $= 32 \text{ electrons}$

Metals have 1 or 2 or 3 electrons in the outer most shells

Non-metals have 4 or 5 or 6 or 7 electrons in the outer most shell

The outer most shell is the last shell

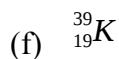
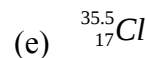
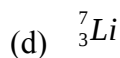
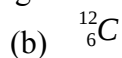
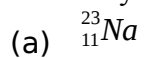
### Ways of showing the electron configuration

#### [A] By writing

The symbol of an element is written first followed by the number of electrons in each shell separated by a dot.

#### Example

1. Show by writing the electron configuration in each of the following nuclides:



#### Solution

(a) Na 2. 8. 1

(b) C 2.4

(c) Ne 2.8

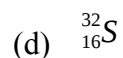
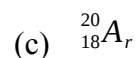
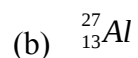
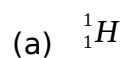
(d) Li 2.1

(e) Cl 2.8.7

(f) K 2.8.8.1

#### Exercise

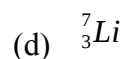
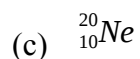
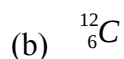
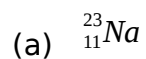
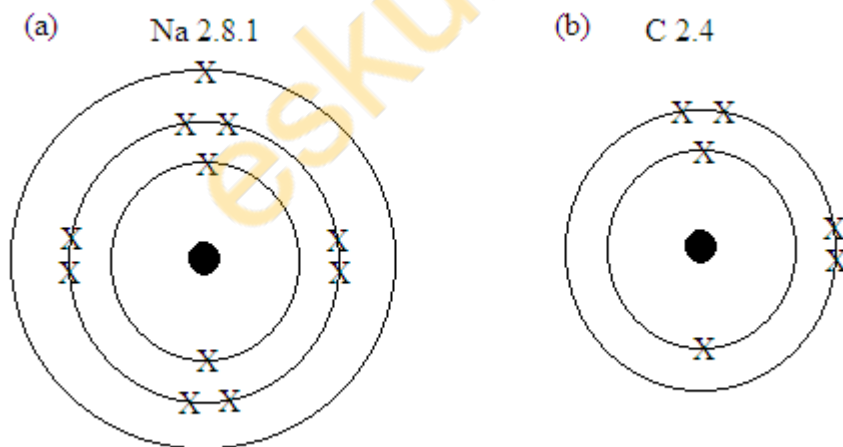
1. Show by writing the electron configuration for each of the following nuclides:

**[B] By drawing**

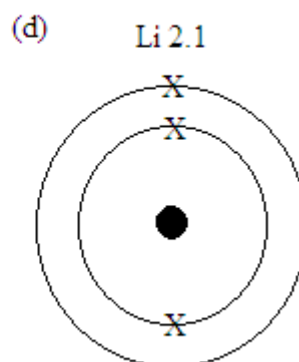
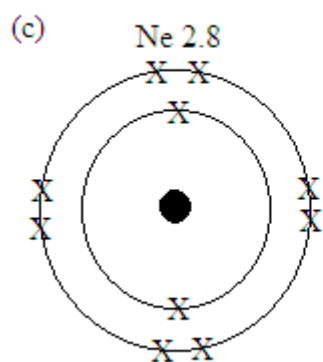
First show the electron configuration by writing, then draw the shells in form of rings or circles and indicate the number of electrons in each shell as crosses (x) or dots (·)

**Examples**

1. Show by drawing the electron configuration for each of the following nuclides:

**Solution**





### Electron configuration for the first 20 elements

Element	Symbol	Atomic number	Electrons in shells K . L . M . N
Hydrogen	H	1	1
Helium	He	2	2
Lithium	Li	3	2 . 1
Beryllium	Be	4	2 . 2
Boron	B	5	2 . 3
Carbon	C	6	2 . 4
Nitrogen	N	7	2 . 5
Oxygen	O	8	2 . 6
Fluorine	F	9	2 . 7
Neon	Ne	10	2 . 8
Sodium	Na	11	2 . 8 . 1
Magnesium	Mg	12	2 . 8 . 2
Aluminium	Al	13	2 . 8 . 3
Silicon	Si	14	2 . 8 . 4
Phosphorous	P	15	2 . 8 . 5
Sulphur	S	16	2 . 8 . 6
Chlorine	Cl	17	2 . 8 . 7
Argon	Ar	18	2 . 8 . 8

Potassium	K	19	2 . 8 . 8 . 1
Calcium	Ca	20	2 . 8 . 8 . 2

## Ions

Definition: An ion is a charged particle

### Types of ions

There are two types of ions; cations and anions

#### A. Cations

A cation is a positively charged particle

It has more protons than electrons

#### Formation of cations

Metals lose their outer most shell electrons to form cations

Cations can be divided into three categories

#### 1. Monovalent cations

These are formed when a metal loses a single electron

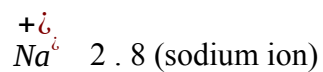
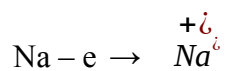
Na 2. 8. 1 (sodium atom)



$$p = 11$$

$$e = 11$$

Sodium atom loses a single electron to form sodium ion



$$e = 10$$

## 2. Divalent cations

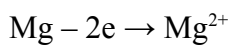
These are formed when a metal loses two electrons

Mg 2. 8. 2 (magnesium atom)



$$e = 12$$

Magnesium atom loses two electrons to form magnesium ion



$\text{Mg}^{2+}$  2. 8 (magnesium ion)

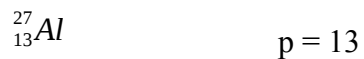


$$e = 10$$

## 3. Trivalent cations

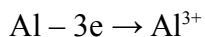
These are formed when a metal loses three electrons

Al 2. 8. 3 (aluminium atom)



$$e = 13$$

Aluminium loses three electrons to form aluminium ion



$\text{Al}^{3+}$  2. 8 (aluminium ion)



$$e = 10$$

## B. Anions

An anion is a negatively charged particle

An anion has more electrons than protons

### Formation of anions

Non-metals gain electrons to form anions

Anions can be divided into three categories

#### 1. Monovalent anions

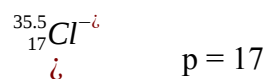
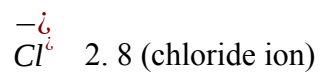
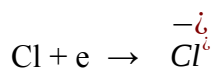
These are formed when a non-metal gains a single electron

Cl 2. 8. 7 (chlorine atom)



$$e = 17$$

Chlorine gains a single electron to form chloride ion



$$e = 18$$

## 2. Divalent anions

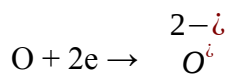
These are formed when a non-metal gains two electrons

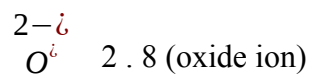
O 2 . 6 (oxygen atom)



$$e = 8$$

Oxygen atom gains two electrons to form oxide ion



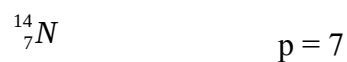


$$e = 10$$

### 3. Trivalent anions

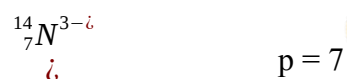
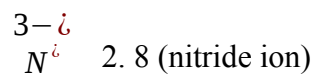
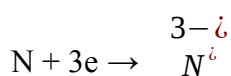
These are formed when a non-metal gain three electrons

N 2 . 5 (nitrogen atom)



$$e = 7$$

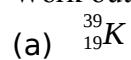
Nitrogen atom gains three electrons to form nitride ion

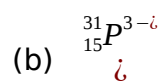


$$e = 10$$

### Example

1. Work out the number of protons, electrons and neutrons in each of the following:





### Solution

	Proton s	Electrons	Neutron s
${}_{19}^{39}\text{K}$	19	19	20
${}_{15}^{31}\text{P}^{3-}$	15	18	16
${}_{20}^{40}\text{Ca}^{2+}$	20	18	20

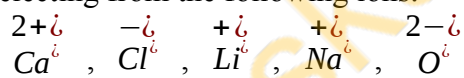
### Exercise

1. A lithium atom has a mass number of 7 and has 3 protons

(a) Write the formula for the ion formed by lithium.

(b) Explain how the lithium ion is formed

(c) Selecting from the following ions:



Choose the ion that;

(I) has the same arrangement of electrons as  ${}_{13}^{27}\text{Al}^{3+}$

(II) has only two electrons

(III) has the same arrangement of electrons as neon

2. Complete the table below

Ion	Number of protons	Number of electrons
${}_{9}^{19}\text{F}^{-}$	9	
	11	10

$2 + \overset{+}{\underset{\cdot}{\text{Li}}}$ $\text{Mg}^{\overset{+}{\underset{\cdot}{\text{Li}}}}$		10
--	--	----

## Bonding of atoms

Definition: Bonding is chemical combination of two or more atoms.

Compounds and molecules result from chemical bonding

Only outer most shell electrons take part in bonding.

Atoms are held together by the forces of attraction or bonds.

A bond is a force of attraction between atoms

## Why do atoms form bonds?

Atoms form bonds in order to be stable

Atoms react with one another in order to acquire full outer most shells like those of noble gases

## Structure of noble gases

Noble gases are atoms that have eight electrons in the outer most shells except helium which has only two electrons.

Helium which has only two electrons obeys a duplex rule.

Other noble gases which have eight electrons in their outer most shells obey an octet rule.

## Examples of noble gases

Noble gas	Symbol	Electron configuration
Helium	He	2
Neon	Ne	2. 8
Argon	Ar	2. 8. 8

## Types of bonding

There are three types bonding

- Ionic bonding
- Covalent bonding
- Metallic bonding

## Ionic bonding



Alternative term: Electrovalent bonding.

Ionic bonding involves the transfer of electrons from a metal to a non-metal

A metal loses electrons while a non-metal gains electrons.

### Electrovalency

Electrovalency is the number of electrons lost or gained by an atom.

### Ionic bond

Alternative term: Electrovalent bond

An ionic bond is the force of attraction between oppositely charged ions.

### Ionic compounds

Ionic compounds consist of cations and anions.

### Examples of ionic compounds

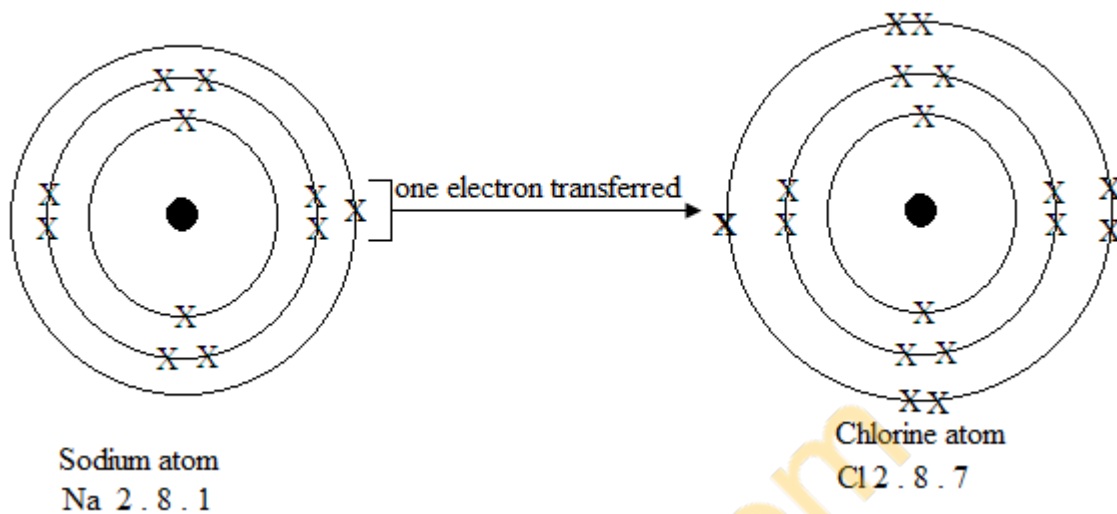
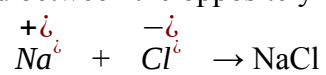
- Sodium chloride, NaCl
- Magnesium oxide, MgO
- Calcium chloride, CaCl<sub>2</sub>

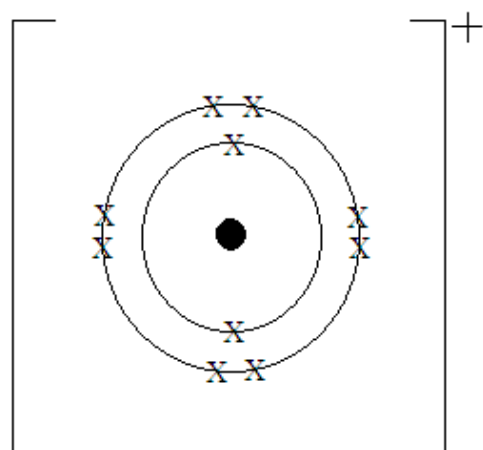
### Formation of an ionic bond

#### Formation of sodium chloride

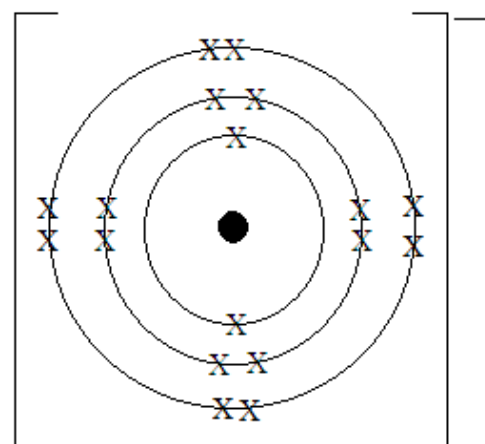
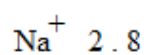
Electron configuration for sodium atom: Na 2.8.1	Electron configuration for chlorine atom: Cl 2.8.7
Sodium atom loses a single outer most shell electron to form sodium ion with a positive charge. $\text{Na} - e \rightarrow \overset{+1}{\text{Na}}$ $\overset{+1}{\text{Na}} \quad 2.8$	Chlorine atom gains a single electron lost by sodium to form chloride ion with a negative charge. $\text{Cl} + e \rightarrow \overset{-1}{\text{Cl}}$ $\overset{-1}{\text{Cl}} \quad 2.8.8$
The sodium and chloride ions attract each other to form a neutral compound called sodium	

chloride and the ionic bond is formed between the oppositely charged ions.

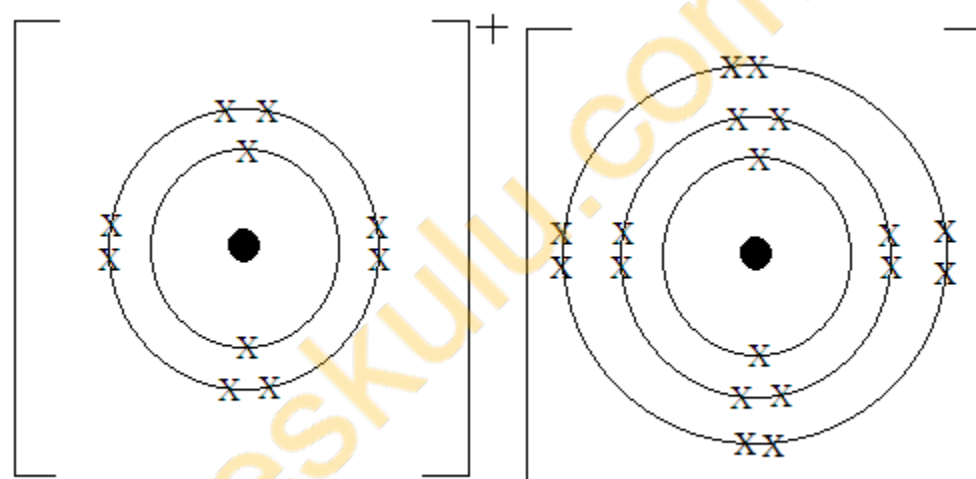
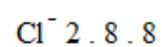




Sodium ion



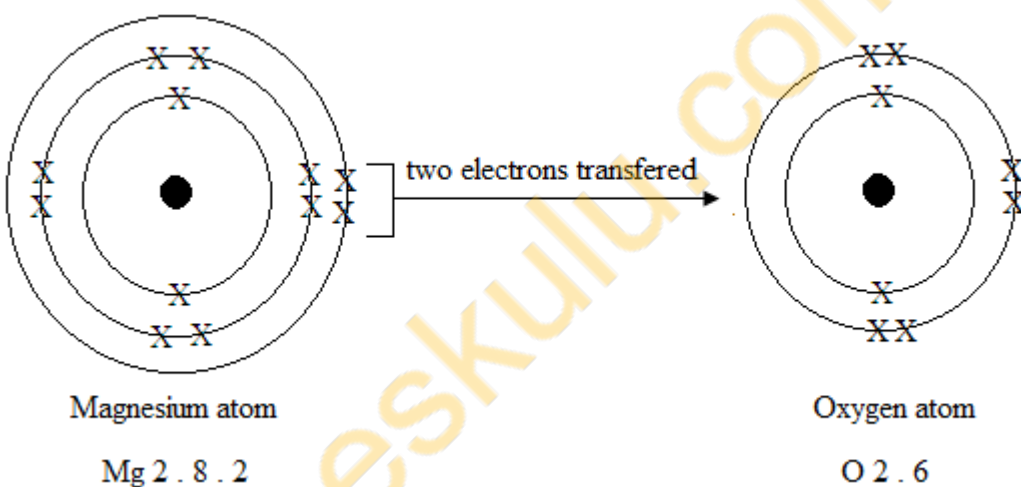
Chloride ion

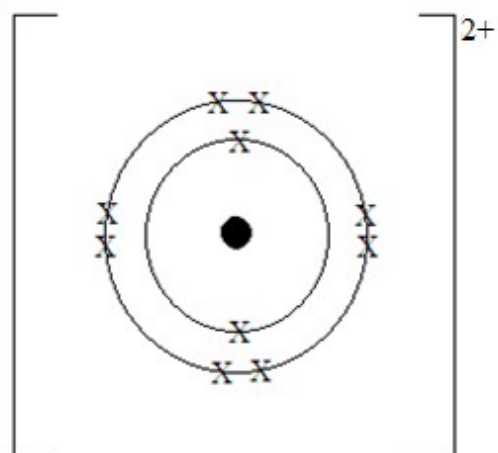


Sodium chloride, NaCl

## Formation of magnesium oxide

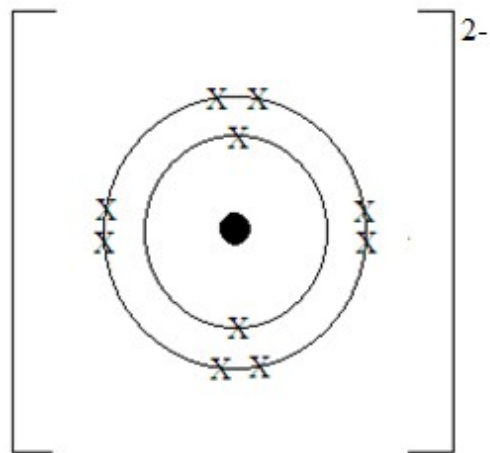
<p>Electron configuration for magnesium atom: Mg 2.8.2</p> <p>Magnesium atom loses its two outer most shell electrons to form magnesium ion with a charge of +2.</p> $\text{Mg} - 2e \rightarrow \overset{2+}{\underset{\cdot\cdot}{\text{Mg}}}$ $\overset{2+}{\underset{\cdot\cdot}{\text{Mg}}} \quad 2.8$	<p>Electron configuration for oxygen atom: O 2.6</p> <p>Oxygen atom gains two electron lost by magnesium to form oxide ion with a charge of -2.</p> $\text{O} + 2e \rightarrow \overset{2-}{\underset{\cdot\cdot}{\text{O}}}$ $\overset{2-}{\underset{\cdot\cdot}{\text{O}}} \quad 2.8$
<p>The magnesium and oxide ions attract each other to form a neutral compound called magnesium oxide and the ionic bond is formed between the oppositely charged ions.</p> $\overset{2+}{\underset{\cdot\cdot}{\text{Mg}}} + \overset{2-}{\underset{\cdot\cdot}{\text{O}}} \rightarrow \text{MgO}$	





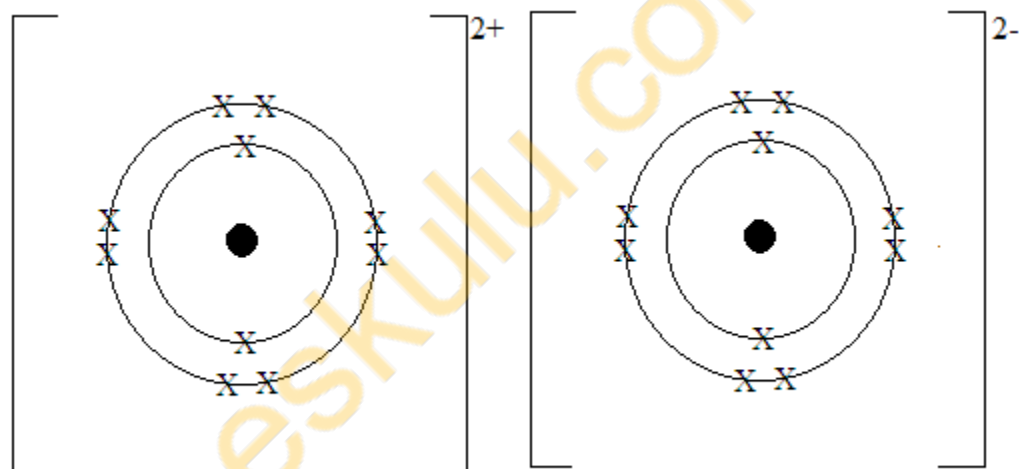
Magnesium ion,  $\text{Mg}^{2+}$

$\text{Mg}^{2+}$  2 . 8



Oxide ion,  $\text{O}^{2-}$

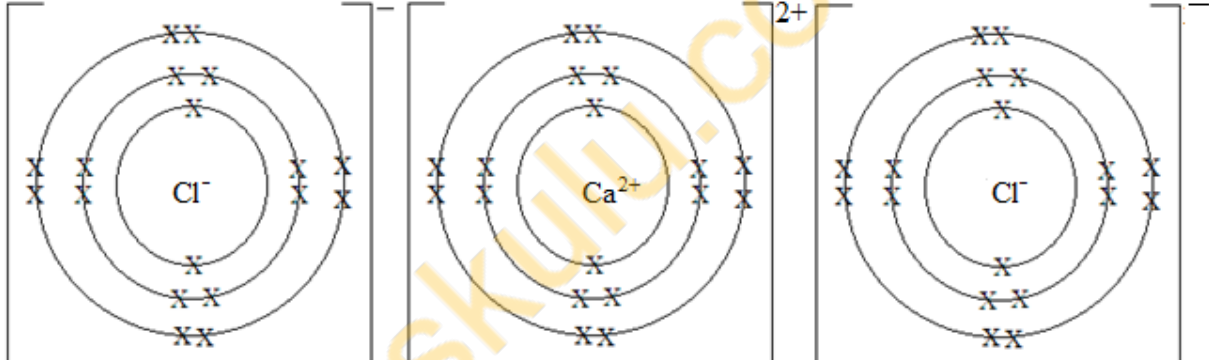
$\text{O}^{2-}$  2 . 8



Magnesium oxide,  $\text{MgO}$

### Formation of calcium chloride

Electron configuration for calcium atom:	Electron configuration for chlorine atom:
--	---

Ca 2.8.8.2	Cl 2.8.7
<p>Calcium atom loses its two outer most shell electrons to form calcium ion with a charge of +2.</p> $\text{Ca} - 2e \rightarrow \overset{2+}{\underset{\cdot\cdot}{\text{Ca}}}$ $\overset{2+}{\underset{\cdot\cdot}{\text{Ca}}} \quad 2.8.8$	<p>The two electrons lost by calcium atom are gained by two atoms chlorine atom. Each chlorine atom gains only one electron to form a chloride ion.</p> $\text{Cl} + e \rightarrow \overset{-}{\underset{\cdot\cdot}{\text{Cl}}}$ $\overset{-}{\underset{\cdot\cdot}{\text{Cl}}} \quad 2.8.8$ $2\text{Cl} + 2e \rightarrow 2\overset{-}{\underset{\cdot\cdot}{\text{Cl}}}$
<p>The calcium and chloride ions attract each other to form a neutral compound called calcium chloride and the ionic bond is formed between the oppositely charged ions.</p> $\overset{2+}{\underset{\cdot\cdot}{\text{Ca}}} + 2\overset{-}{\underset{\cdot\cdot}{\text{Cl}}} \rightarrow \text{CaCl}_2$ <div style="text-align: center;">  <p>Calcium chloride, <math>\text{CaCl}_2</math></p> </div>	

### Characteristics of ionic compounds

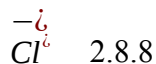
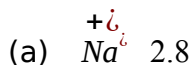
1. They are made up of positively and negatively charged ions.
2. They have high melting and boiling points because of strong electrostatic forces of attraction between ions.
3. They are soluble in water but insoluble in organic solvents such as ethanol and petrol.
4. In aqueous solution or molten state, they conduct electricity because the ions are free to move.
5. They are non-volatile and generally solids at room temperature.

### Example

1. Sodium chloride is an ionic solid.

- (a) Show by writing the electronic structure of both a sodium ion and a chloride ion.
- (b) Sodium chloride has a melting point of about 800 °C.
  - (I) Explain why sodium chloride has a high melting point.
  - (II) Magnesium oxide, MgO, has a similar structure to sodium chloride. Suggest why the melting point of magnesium oxide is higher than that of sodium chloride.
- (c) Explain why solid sodium chloride will not conduct electricity but molten sodium chloride will.

#### Solution



- (b) (I) Because of the strong attraction between oppositely charged ions
- (II) Because of the higher charges on the ions hence stronger attraction
- (c) Ions cannot move in the solid but can move in the melt

#### Exercise

1. A metal X (atomic number 11) reacts with chlorine to form a white solid chloride Y.
  - (a) Write down a balanced chemical equation for the reaction
  - (b) Show by drawing, the arrangement of electrons in X:
    - (I) before the reaction
    - (II) after the reaction
  - (c) State three characteristics of Y.

#### Covalent bonding

Alternative term: Molecular bonding

Covalent bonding involves the sharing of the outer most electrons between non-metal atoms.

#### Covalency

Covalency is the number of electrons an atom shares with another atom.

#### Covalent bond

Alternative term: Molecular bond

A covalent bond consists of a shared pair of electrons and it is formed between non-metals which share one or pairs of electrons.

Atoms are held by the attraction between their positive nuclei and the shared electrons.

### Covalent compounds

Alternative term: Molecular compounds

Covalent compounds are usually molecules. A molecule the smallest particle of an element or compound which exists independently, that is in a free state.

They are formed when non-metals combine by sharing electrons.

As a result of sharing electrons, each non-metal acquires a completely filled outer most shell.

### Examples of covalent compounds

- Hydrogen molecule,  $H_2$
- Water,  $H_2O$
- Carbon dioxide,  $CO_2$
- Ammonia,  $NH_3$

### Formation of hydrogen molecule

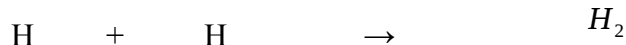
Formula:  $H_2$



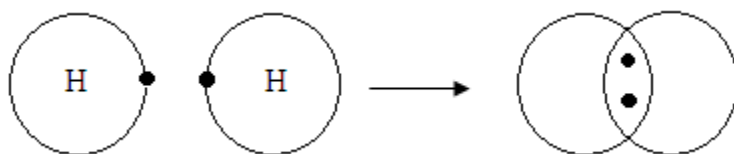
Each hydrogen atom has one electron.

When the two hydrogen atoms combine, they share electrons.

**Note:** only outer most shell electrons are shown.

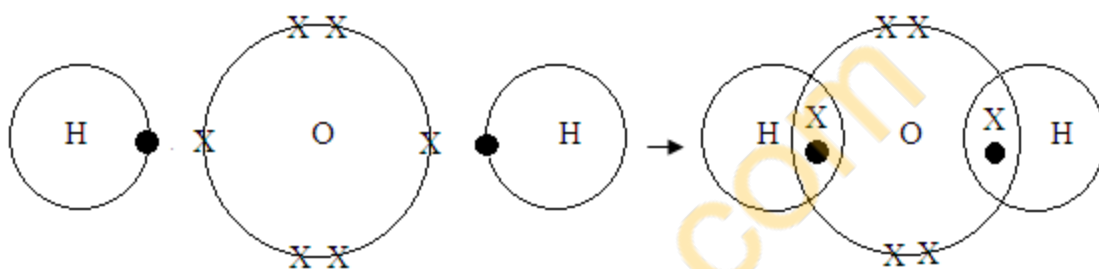
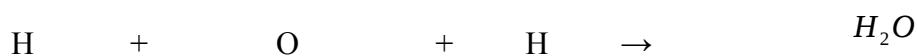
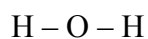






### Formation of water molecule

Formula:  $H_2O$

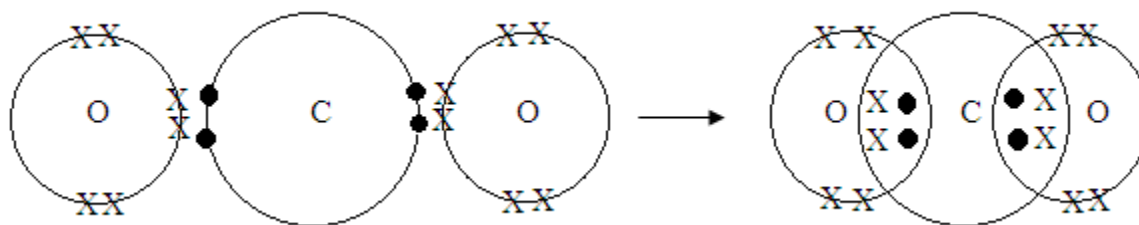


### Formation of carbon dioxide

Formula:  $CO_2$



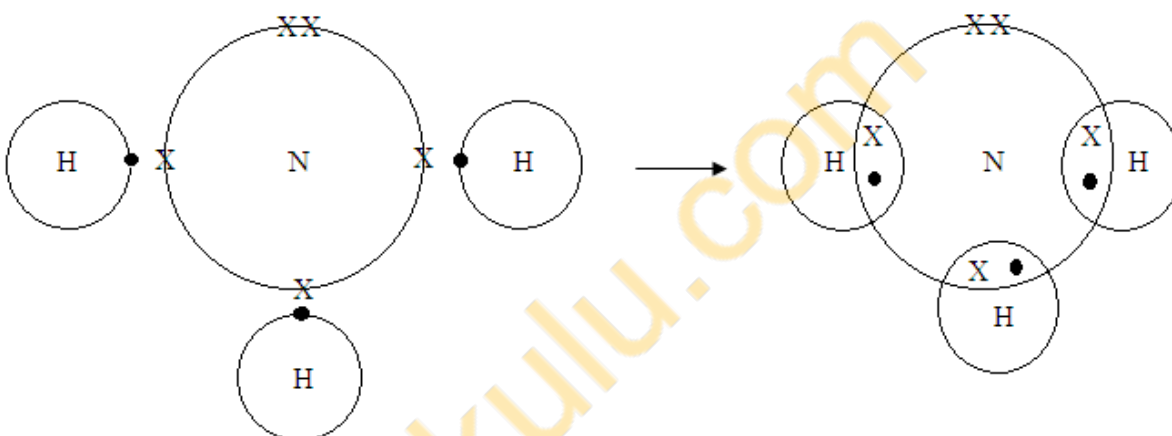
The two pairs of electrons are shared between a carbon atom and each oxygen atom and a double covalent bond is formed.



### Formation of ammonia

Formula:  $NH_3$

Ammonia is formed from bonding between one nitrogen atom and three hydrogen atoms.



### Characteristics of covalent compounds

1. They are made up of molecules
2. They have low melting and boiling points because of the weak forces of attraction which hold the molecules.
3. They are insoluble in water but soluble in organic solvents such as ethanol and petrol.
4. They do not conduct electricity in solid or solution form because they are made up of molecules.
5. They are generally volatile

### Exercise

1. With the aid of diagrams, show how covalent bonds are formed in the following molecules:
  - (a) Oxygen,  $O_2$
  - (b) Ethane,  $CH_4$
  - (c) Hydrogen chloride, HCl

(d) Chlorine,  $Cl_2$

### Metallic bonding

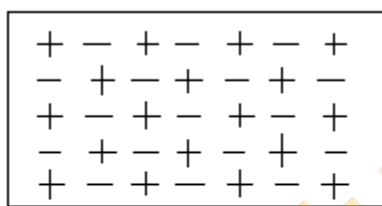
Metallic bonding is the attraction between the positively charged metal ions and the free electrons in a metallic lattice.

It involves the sea of electrons around positively charged particles inside a metal structure.

The electrons are free to move anywhere in the metallic lattice. The electrons are said to be delocalized.

Sodium atoms, for example, lose a single electron from the outer most shell. When a large number of sodium atoms lose these electrons, the result is many free electrons.

### Sodium metal lattice



key

+ sodium ions  
- electrons

### Valency – Combining power

Valency is the number of electrons lost or gained or shared by an atom of the element to attain a stable structure

### Valencies of some elements

Valency	Metals		Non metals	
	Name	Symbol	Name	Symbol
1	Potassium	K	Chlorine	Cl
	Silver	Ag	Hydrogen	H
	Sodium	Na		
	Copper (I)	Cu		

2	Barium	Ba	Oxygen	O
	Calcium	Ca	Sulphur	S
	Copper (II)	Cu		
	Iron (II)	Fe		
	Lead (II)	Pb		
	Magnesium	Mg		
	Mercury	Hg		
	Zinc	Zn		
3	Aluminium	Al	Nitrogen	N
	Iron (III)	Fe	Phosphorus (III)	P
4	Lead (IV)	Pb		
5			Phosphorus (V)	P

## Radical

A radical is a group of atoms which is present in several compounds but incapable of independent existence.

## Radicals and their Valencies

Radical	Formula	Valency
Ammonium	NH <sub>4</sub>	1
Chlorate	ClO <sub>3</sub>	
Chloride	Cl	
Hydrogen carbonate	HCO <sub>3</sub>	
Hydrogen sulphate	HSO <sub>4</sub>	
Hydroxide	OH	
Nitrate	NO <sub>3</sub>	
Nitrite	NO <sub>2</sub>	

Carbonate	CO <sub>3</sub>	2
Oxide	O	
Sulphate	SO <sub>4</sub>	
Sulphide	S	
Sulphite	SO <sub>3</sub>	
Phosphate	PO <sub>4</sub>	3

### Chemical formula

A chemical formula consist of a symbol or symbols showing the number of atoms in one molecule of an element or a compound

### Writing chemical formula

#### Steps to consider when writing the chemical formula

1. Write the symbol for the combining elements and radicals
2. Write the Valency of each element or radical at the top at its top right hand side
3. Exchange the Valencies of the combining elements and radicals by writing them at the bottom right hand side of the element or radical. If the number is 1, do not write it.

In some formulae, radicals are written in brackets followed by a small sub script digit.

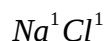
### Examples

1. Write the formula for each of the following compounds

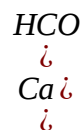
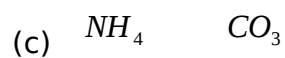
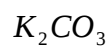
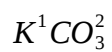
- (a) Sodium chloride
- (b) Potassium carbonate
- (c) Ammonium carbonate
- (d) Aluminium phosphate
- (e) Calcium hydrogen carbonate

### Solution

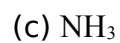
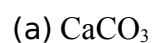
- (a) Na                  Cl



- (b) K                  CO<sub>3</sub>



2. Write the Valency for the elements and radical for each of the following:



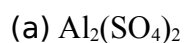
### Solution

	Element /radical	Valency
(a)	Ca	2
	$CO_3$	2

(b)	Fe	3
	O	2
(c)	N	3
	H	1

### Exercise

1. Write the Valency for the elements and radicals in each of the following:



2. Calcium nitrate has the ions  $2\text{Ca}^{+2}$  and  $\text{NO}_3^{-1}$ . Write the formula of the compound formed when the two ions combine.

### State symbols

State symbols are letters that are used to show the physical state of substances in the equation

State symbols are placed in brackets after the name or formula of each substance in the equation

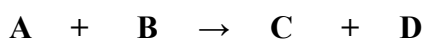
### Examples

Physical state	State symbol
Gas	(g)
Liquid	(l)
Solid	(s)
Aqueous solution	(aq)

### Equations

An equation is a chemical sentence which describes what is happening in a chemical reaction

An equation can be represented in the form:



(Reactants)                      (Products)

The plus (+) sign on the left hand side means “react with”

The plus (+) sign on the right hand side means “and”

The arrow (→) between the reactants and products means “to form”

### Word equations

Word equations are chemical equations written in words

### Examples

1. Write down the word equation for each of the following reactions including state symbols
  - (a) Magnesium metal reacts with oxygen gas to form magnesium oxide
  - (b) Hydrogen sulphide gas reacts with oxygen gas to form sulphur and water
  - (c) Iron (II) chloride solution and hydrogen gas are produced when iron reacts with dilute hydrochloric acid
  - (d) Iron reacts with chlorine gas to form iron (II) chloride

### Solution

- (a) Magnesium<sub>(s)</sub> + Oxygen<sub>(g)</sub> → Magnesium oxide<sub>(s)</sub>
- (b) Hydrogen sulphide<sub>(s)</sub> + Oxygen<sub>(g)</sub> → Sulphur<sub>(s)</sub> + Water<sub>(l)</sub>
- (c) Iron<sub>(s)</sub> + Hydrochloric acid<sub>(aq)</sub> → Iron (II) chloride<sub>(aq)</sub> + Hydrogen<sub>(g)</sub>
- (d) Iron<sub>(s)</sub> + Chlorine<sub>(g)</sub> → Iron (II) chloride<sub>(s)</sub>

### Exercise

1. Write down word equations including state symbols for each of the reactions:
  - (a) Mercury oxide decomposes into mercury and oxygen
  - (b) Hydrogen gas reacts with oxygen to form water
  - (c) Sodium metal reacts with water to produce a solution of sodium hydroxide and hydrogen gas
  - (d) Calcium oxide dissolves in water to produce calcium hydroxide solution.

### Equations with symbols

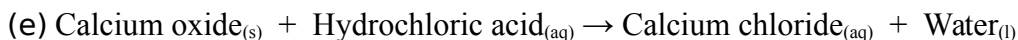
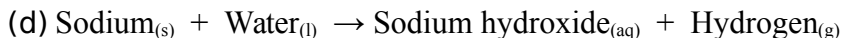
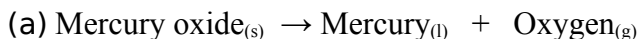
### Writing balanced chemical equations

Balancing the equation is the process of making the number of each type atom equal on both sides of the equation

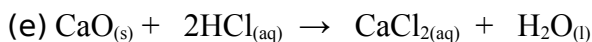
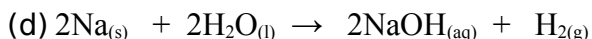
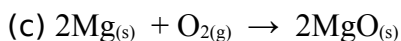
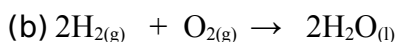
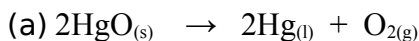
### Examples



1. Write down balanced chemical equations including state symbols for each of the following word equations

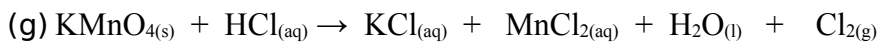
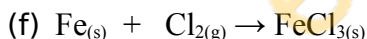
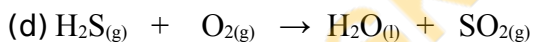
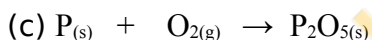
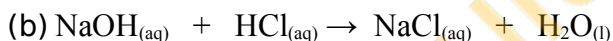
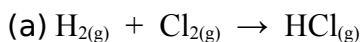


### Solution



### Exercise

1. Balance the following equations



### Ionic equations

Ionic equations show only the ions involved in a chemical reaction

Ions not taking part in the reaction (spectator ions) are cancelled out in the construction of ionic equations

### Steps to consider when writing the ionic equation

1. Construct a balanced chemical equation

- Split only soluble ionic compounds into ions. Insoluble ionic compounds, elements and covalent compounds remain unchanged.
- Cancel out spectator ions. These are ions that appear on both the left and right hand side of the equation.
- Rewrite the equation without the spectator ions

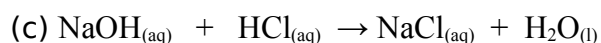
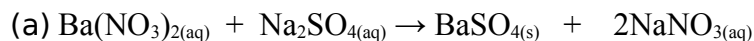
#### Note

Ion	Formula of ion	Valency
Ammonium ion	$\overset{+}{\underset{\cdot\cdot}{N}}\overset{\cdot\cdot}{H}_4$	1
Chloride ion	$\overset{-}{\underset{\cdot\cdot}{Cl}}$	1
Hydrogen ion	$\overset{+}{\underset{\cdot\cdot}{H}}$	1
Hydroxide ion	$\overset{-}{\underset{\cdot\cdot}{O}}\overset{\cdot\cdot}{H}$	1
Nitrate ion	$\overset{-}{\underset{\cdot\cdot}{N}}\overset{\cdot\cdot}{O}_3$	1
Potassium ion	$\overset{+}{\underset{\cdot\cdot}{K}}$	1
Silver ion	$\overset{+}{\underset{\cdot\cdot}{Ag}}$	1
Sodium ion	$\overset{+}{\underset{\cdot\cdot}{Na}}$	1

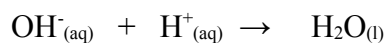
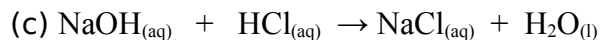
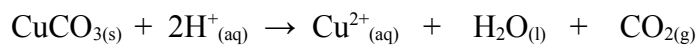
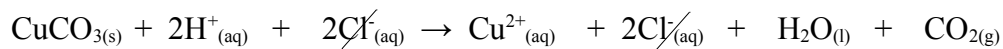
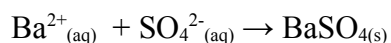
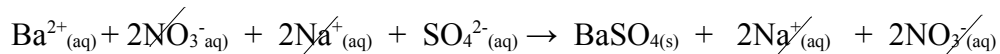
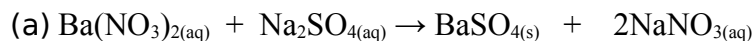
Ion	Formula of ion	Valency
Aluminium ion	$\overset{3+}{\underset{\cdot\cdot}{Al}}$	3
Carbonate ion	$\overset{2-}{\underset{\cdot\cdot}{C}}\overset{\cdot\cdot}{O}_3$	2
Lead (II) ion	$\overset{2+}{\underset{\cdot\cdot}{Pb}}$	2
Phosphate ion	$\overset{3-}{\underset{\cdot\cdot}{P}}\overset{\cdot\cdot}{O}_4$	3
Sulphate ion	$\overset{2-}{\underset{\cdot\cdot}{S}}\overset{\cdot\cdot}{O}_4$	2
Barium ion	$\overset{2+}{\underset{\cdot\cdot}{Ba}}$	2
Copper (II) ion	$\overset{2+}{\underset{\cdot\cdot}{Cu}}$	2
Calcium ion	$\overset{2+}{\underset{\cdot\cdot}{Ca}}$	2

#### Example

- Write the ionic equations for the reactions below

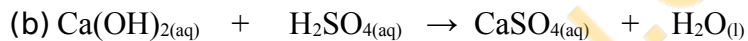
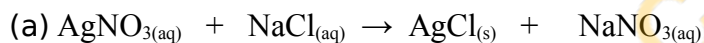


### Solution



### Exercise

1. Write the ionic equations for the following reactions



## Stoichiometric calculations

### Relative atomic mass

Symbol:  $A_r$

Units: It has no units

Definition: Relative atomic mass of an element is the mass of one atom of an element compared to

$\frac{1}{12}$  the mass of carbon – 12 isotope .

### Relative atomic masses of some elements

Element	Symbol	$A_r$	Element	Symbol	$A_r$
Hydrogen	H	1	Aluminium	Al	27
Carbon	C	12	Sulphur	S	32
Nitrogen	N	14	Chlorine	Cl	35.5
Oxygen	O	16	Calcium	Ca	40
Sodium	Na	23	Iron	Fe	56
Magnesium	Mg	24	Copper	Cu	64

### Relative molecular mass

Symbol:  $M_r$

Units: It has no units

Definition: Relative molecular mass of a compound is the mass of one molecule of the compound

or element compared with  $\frac{1}{12}$  the mass of carbon – 12 isotope .

Relative molecular mass can also be defined as the sum of relative atomic masses

### Examples

1. Find the relative molecular,  $M_r$ , of the following:

(a) Hydrogen chloride, HCl

(b) Carbon dioxide, CO<sub>2</sub>

(c) Sodium sulphate, Na<sub>2</sub>SO<sub>4</sub>

(d) Copper (II) sulphate -5-water, CuSO<sub>4</sub>.5H<sub>2</sub>O

(e) Three moles of ammonium carbonate,  $3(\text{NH}_4)_2\text{CO}_3$

### Solution

$$(a) M_r \text{ of HCl} = (1 \times 1) + (1 \times 35.5)$$

$$= 1 + 35.5$$

$$= 36.5$$

$$(b) M_r \text{ of CO}_2 = (1 \times 12) + (2 \times 16)$$

$$= 12 + 32$$

$$= 44$$

$$(c) M_r \text{ of Na}_2\text{SO}_4 = (2 \times 23) + (1 \times 32) + (4 \times 16)$$

$$= 46 + 32 + 64$$

$$= 142$$

$$(d) M_r \text{ of CuSO}_4 \cdot 5\text{H}_2\text{O} = (1 \times 64) + (1 \times 32) + (4 \times 16) + (10 \times 1) + (5 \times 16)$$

$$= 64 + 32 + 64 + 10 + 80$$

$$= 250$$

$$(e) M_r \text{ of } 3(\text{NH}_4)_2\text{CO}_3 = (6 \times 14) + (24 \times 1) + (3 \times 12) + (9 \times 16)$$

$$= 84 + 24 + 36 + 144$$

$$= 288$$

2. It is known that one form of carbon has the molecules of formula  $\text{C}_{60}$ . What is the relative molecular mass,  $M_r$ , of these molecules?

### Solution

The formula  $\text{C}_{60}$  means that the molecule contains 60 carbon atoms bonded together.

$$M_r \text{ of } \text{C}_{60} = 60 \times 12$$

$$= 720$$

### Exercise

1. Work out the relative molecular mass of the following:

(a)  $2\text{H}_2$

- (b)  $O_2$
- (c)  $2H_2O$
- (d)  $\begin{array}{c} HCO \\ \textcolor{red}{\downarrow} \\ Ca\textcolor{red}{\downarrow} \\ \textcolor{red}{\downarrow} \end{array}$

## Molar mass

Symbol: MM

SI unit: gram per mole, g/mol

Definition: Molar mass is the mass of one mole of a substance

Molar mass can also be defined as relative molecular mass expressed in grams per mole

## Examples

1 mole of potassium (K),  $MM = (1 \times 39) = 39 \text{ g/mol}$

1 mole of sodium (Na),  $MM = (1 \times 23) = 23 \text{ g/mol}$

1 mole of ammonia  $\begin{array}{c} NH \\ \textcolor{red}{\downarrow} \end{array} (3) \textcolor{red}{\downarrow}$ ,  $MM = [(1 \times 14) + (3 \times 1)] = 17 \text{ g/mol}$

1 mole of carbon dioxide  $\begin{array}{c} CO \\ \textcolor{red}{\downarrow} \end{array} (2) \textcolor{red}{\downarrow}$ ,  $MM = [(1 \times 12) + (2 \times 16)] = 44 \text{ g/mol}$

## Mole

Symbol:  $n$

Unit: mole, mol

Definition: The mole is the amount of substance which contains as many elementary entities as they are in 12.00g of carbon-12 isotope

## Calculating number of moles

$$\text{Number of moles} = \frac{\text{mass}}{\text{molar mass}}$$

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

$n$  = mole [mol]

$m$  = mass [g]

$MM$  = molar mass [g/mol]

### Examples

- 1 How many moles of potassium are there in 3.9g of potassium?

Data	Solution
$n = ?$	$n = \frac{m}{MM}$
$m = 3.9\text{g}$	
$MM = 39\text{g/mol}$	$n = \frac{3.9\text{ g}}{39\text{ g/mol}}$
	$n = 0.1\text{mol}$

- 2 Find the mass of 0.2moles of ammonia molecules,  $\text{NH}_3$ .

Data	Solution
$m = ?$	$m = n \times MM$
$n = 0.2\text{mol}$	$m = 0.2\text{mol} \times 17\text{g/mol}$
$MM = 17\text{g/mol}$	$m = 3.4\text{g}$

- 3 Calculate the molar mass of 2.5moles of a substance X weighing 100g.

Data	Solution

MM =?	$MM = \frac{m}{n}$
$n = 2.5\text{mol}$	
$m = 100\text{g}$	$MM = \frac{100\text{ g}}{2.5\text{ mol}}$
	$MM = 40\text{g/mol}$

4 How many moles of hydrogen atoms does 3.2g of methane,  $\text{CH}_4$ , contain?

### Solution

$$\text{MM for } \text{CH}_4 = (1 \times 12) + (4 \times 1) = 16\text{g/mol}$$

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

$$n = \frac{3.2\text{ g}}{16\text{ g/mol}}$$

$$n = 0.2\text{mol}$$

$$\begin{aligned} \text{Number of moles of hydrogen in } \text{CH}_4 &= \text{number of hydrogen atoms in } \text{CH}_4 \times n \\ &= 4 \times 0.2\text{mol} \\ &= 0.8\text{mol} \end{aligned}$$

### Exercise

1. Calculate the number of moles in 20g of calcium carbonate,  $\text{CaCO}_3$
2. If you need 2.5 moles of sodium hydroxide,  $\text{NaOH}$ , what mass of sodium hydroxide do have to weigh?
3. Calculate the molar mass of 0.5 moles of substance X weighing 28g.
4. How many moles of oxygen molecules are there in 64g of oxygen,  $\text{O}_2$ ?

### Avogadro's number

Alternative term: Avogadro's constant



Symbol:  $N_A$

$$N_A = 6.02 \times 10^{23} \text{ moles}$$

Definition: Avogadro's number is the number of particles in exactly one mole of a pure substance

12.00g of carbon contains as many as  $6.02 \times 10^{23}$  atoms

1 mole of any element has mass equivalent to its mass number and contains  $6.02 \times 10^{23}$  particles.

**Example:** 1 mole of Ca = 40g =  $6.02 \times 10^{23}$  particles

1 mole of Fe = 56g =  $6.02 \times 10^{23}$  particles

1 mole of C = 12g =  $6.02 \times 10^{23}$  particles

1 mole of Mg = 24g =  $6.02 \times 10^{23}$  particles

1 mole of N = 14g =  $6.02 \times 10^{23}$  particles

1 mole of  $N_2$  = 28g =  $6.02 \times 10^{23}$  particles

1 mole of H = 1g =  $6.02 \times 10^{23}$  particles

1 mole of  $H_2$  = 2g =  $6.02 \times 10^{23}$  particles

1 mole of Na = 23g =  $6.02 \times 10^{23}$  particles

Elementary entities include atoms, molecules, ions, electrons, protons and neutrons

1 mole of atoms =  $6.02 \times 10^{23}$  atoms

1 mole of molecules =  $6.02 \times 10^{23}$  molecules

1 mole of ions =  $6.02 \times 10^{23}$  ions

1 mole of electrons =  $6.02 \times 10^{23}$  electrons

1 mole of protons =  $6.02 \times 10^{23}$  protons

1 mole of neutrons =  $6.02 \times 10^{23}$  neutrons

### Examples

1. How many atoms of iron (Fe) are there in 25g of iron?

#### Solution

56g  $\rightarrow 6.02 \times 10^{23}$  atoms

25g  $\rightarrow x$

$$x = \frac{25 \text{ g} \times 6.02 \times 10^{23} \text{ atoms}}{56 \text{ g}}$$

$$x = 2.89 \times 10^{23} \text{ atoms}$$

2. If 1 mole of carbon is 12g, calculate the mass of 1 atom of carbon 12

#### Solution

$6.02 \times 10^{23}$  atoms  $\rightarrow 12\text{g}$

1 atom  $\rightarrow x$

$$x = \frac{12 \text{ g} \times 1 \text{ atom}}{6.02 \times 10^{23} \text{ atoms}}$$

$$x = 1.99 \times 10^{-23} \text{ g}$$

3. What is the mass of  $1.2 \times 10^{23}$  atoms of calcium?

**Solution**

$$6.02 \times 10^{23} \text{ atoms} \rightarrow 40\text{g}$$

$$1.2 \times 10^{23} \text{ atoms} \rightarrow x$$

$$x = \frac{1.2 \times 10^{23} \text{ atoms} \times 40 \text{ g}}{6.02 \times 10^{23} \text{ atoms}}$$

$$x = 7.97\text{g}$$

4. How many hydrogen atoms are there in 1 mole of hydrogen molecules,  $\text{H}_2$ ?

**Solution**

$$1 \text{ mole of atoms} \rightarrow 6.02 \times 10^{23} \text{ atoms}$$

$$1 \text{ mole of } \text{H}_2 \text{ molecules} \rightarrow x$$

**But**

$$1 \text{ mole of } \text{H}_2 \text{ molecules} \rightarrow 2 \text{ atoms}$$

$$6.02 \times 10^{23} \text{ molecules} \rightarrow x$$

$$x = \frac{6.02 \times 10^{23} \text{ molecules} \times 2 \text{ atoms}}{1 \text{ mol of } \text{H}_2 \text{ molecules}}$$

$$x = 1.204 \times 10^{24} \text{ atoms}$$

5. How many oxygen atoms are in 1.6g of sulphur trioxide,  $\text{SO}_3$  ?

**Solution**

$$M_r \text{ of oxygen} = 3 \times 16 = 48$$

$$M_r \text{ of } \text{SO}_3 = (1 \times 32) + (3 \times 16) = 80$$

$$n(\text{SO}_3) = \frac{m}{MM}$$

$$n = \frac{1.6 \text{ g}}{80 \text{ g/mol}}$$

$$n = 0.02 \text{ mol}$$

$$\text{Number of oxygen atoms in } 1.6 \text{ g of } \text{SO}_3 = \text{number of oxygen atoms in } \text{SO}_3 \times n \times N_A$$

$$= 3 \times 0.02 \text{ mol} \times 6.02 \times 10^{23} \text{ atoms}$$

$$= 3.612 \times 10^{22} \text{ atoms}$$

### Exercise

1. How many atoms of magnesium are there in 5g of magnesium?
2. What is the mass of  $3.01 \times 10^{23}$  atoms of carbon?
3. How many nitrogen atoms are there in 7g of nitrogen molecules,  $\text{N}_2$ ?

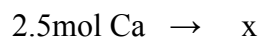
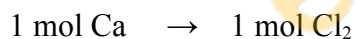
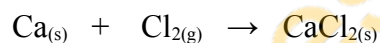
### Calculations from equations

#### Mole to mole calculations

#### Examples

1. How many moles of chlorine are required to react 2.5 moles of calcium to produce calcium chloride?

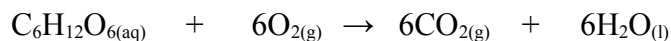
#### Solution



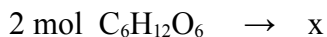
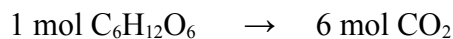
$$x = \frac{2.5 \text{ mol Ca} \times 1 \text{ mol Cl}_2}{1 \text{ mol Ca}}$$

$$x = 2.5 \text{ mol}$$

2. How many moles of carbon dioxide ( $\text{CO}_2$ ) will be produced by complete combustion of 2 moles of glucose ( $\text{C}_6\text{H}_{12}\text{O}_6$ ) according to the equation?



#### Solution

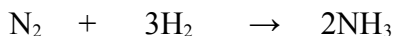


$$x = \frac{2 \text{ mol C}_6\text{H}_{12}\text{O}_6 \times 6 \text{ mol CO}_2}{1 \text{ mol C}_6\text{H}_{12}\text{O}_6}$$

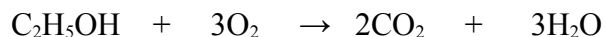
$$x = 12 \text{ mol CO}_2$$

### Exercise

1. How many moles of ammonia can be produced from 8 moles of nitrogen gas?



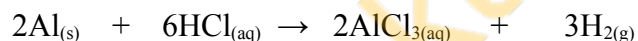
2. How many moles of oxygen are needed to burn 1.8 moles of ethanol, C<sub>2</sub>H<sub>5</sub>OH?



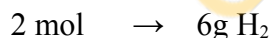
### Mole to mass calculations

#### Examples

1. What mass of hydrogen can be produced by reacting 6 moles of aluminium with hydrochloric acid?



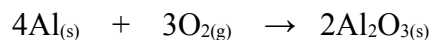
#### Solution



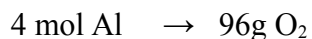
$$x = \frac{6 \text{ mol Al} \times 6 \text{ g H}_2}{2 \text{ mol Al}}$$

$$x = 18 \text{ g H}_2$$

2. How many grams of oxygen are required to react with 0.3 moles of aluminium to produce aluminium oxide?



#### Solution





$$x = \frac{0.3 \text{ mol Al} \times 96 \text{ g O}_2}{4 \text{ mol Al}}$$

$$x = 7.2 \text{ g O}_2$$

### Exercise

1. What mass of magnesium oxide will be produced when 0.5 moles of magnesium burns in oxygen

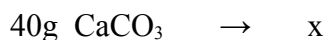
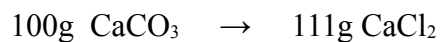
### Mass to mass calculation

#### Examples

1. Calculate the mass of calcium chloride produced when 40g of calcium carbonate reacts with hydrochloric acid



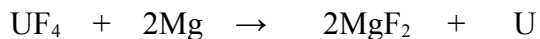
#### Solution



$$x = \frac{40 \text{ g CaCO}_3 \times 111 \text{ g CaCl}_2}{100 \text{ g CaCO}_3}$$

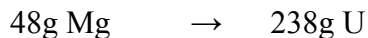
$$x = 44.4 \text{ g CaCl}_2$$

2. Consider the reaction below.



How many tonnes of uranium can be produced in the above reaction using 24 tonnes of magnesium?

#### Solution

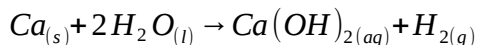


$$x = \frac{24 \text{ tonnes Mg} \times 238 \text{ g U}}{48 \text{ g Mg}}$$

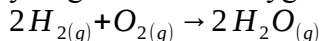
$$x = 119 \text{ tonnes U}$$

## Exercise

1. What mass of calcium metal reacts with 9.0g of water according to the equation below?



2. Hydrogen burns in oxygen to form water. The equation for the reaction is:



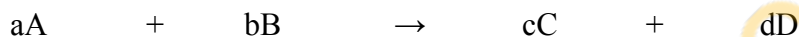
How much oxygen is needed to burn 1g of hydrogen?

## Limiting reagent

Definition: A limiting reagent is a reactant that is in short supply by the mole ratio and hence it finishes before the other reactants are completely reacted.

A limiting reagent is always smaller or in less quantity compared to the other reactant

A limiting reagent is found by dividing the number of moles of each reactant by its stoichiometric coefficient in balanced chemical equation.



$$R_A = \frac{n_{(A)}}{a}, \quad R_B = \frac{n_{(B)}}{b}$$

$$R_A = \text{Reagent } A, \quad R_B = \text{Reagent } B$$

The ratio that is smaller is that of a limiting reagent. A limiting reactant has less number of moles compared to the other reactant

A limiting reagent determines the extent to which the chemical reaction can proceed and the amount of products that would be formed. Once the limiting reagent is finished, the reaction stops even if the other reactants are still available in the reaction vessel

For this reason, it is important to identify the limiting reagent before calculating the theoretical yield

In the identification of the limiting reagent,

- The balanced chemical equation and the mole ratio of reactants are used
- You cannot use volumes, concentrations or masses of the reactants since these will easily mislead you.

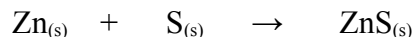
## Note

### Excess reagent

An excess reagent is a reactant that remains unreacted at the end of the reaction.

### Example

1. 19.5g of zinc and 9.40g of sulphur were heated together



- (a) Which of the two is the limiting reactant?
- (b) How many moles of zinc remain unreacted?
- (c) How many grams of zinc element remain unreacted?
- (d) Calculate the mass of zinc sulphide formed

### Solution

$$\begin{aligned} \text{(a) } n(\text{Zn}) &= \frac{m}{MM} & n(\text{S}) &= \frac{m}{MM} \\ &= \frac{19.5 \text{ g}}{65 \text{ g/mol}} & &= \frac{9.40 \text{ g}}{32 \text{ g/mol}} \\ &= 0.3 \text{ mol} & &= 0.29 \text{ mol} \end{aligned}$$

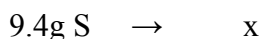
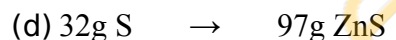
The limiting reagent is sulphur because it has a smaller number of moles compared to zinc.

$$\begin{aligned} \text{(b) Number of moles of Zn unreacted} &= 0.3 \text{ mol} - 0.29 \text{ mol} \\ &= 0.01 \text{ mol} \end{aligned}$$

$$\text{(c) } m = n \times MM$$

$$m = 0.01 \text{ mol} \times 65 \text{ g/mol}$$

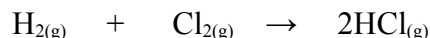
$$m = 0.65 \text{ g of Zn remained unreacted}$$



$$x = \frac{9.40 \text{ g S} \times 97 \text{ g ZnS}}{32 \text{ g S}}$$

$$x = 28.5 \text{ g ZnS}$$

2. How many grams of hydrogen chloride would be produced from 0.49g of hydrogen and 50g of chlorine?



### Solution



$$n(\text{H}_2) = \frac{m}{MM}$$

$$= \frac{0.49 \text{ g}}{2.0 \text{ g/mol}}$$

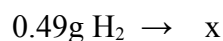
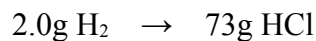
$$= 0.245 \text{ mol}$$

$$n(\text{Cl}_2) = \frac{m}{MM}$$

$$= \frac{50 \text{ g}}{71 \text{ g/mol}}$$

$$= 0.704 \text{ mol}$$

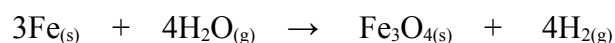
The limiting reagent is hydrogen because it has a smaller number of moles compared to chlorine.



$$x = \frac{0.49 \text{ g H}_2 \times 73 \text{ g HCl}}{2.0 \text{ g H}_2}$$

$$x = 17.885 \text{ g HCl}$$

3. How many moles of iron trioxide ( $\text{Fe}_3\text{O}_4$ ) can be obtained by reacting 16.8g of iron with 10g of steam?



#### Solution

$$n(\text{Fe}) = \frac{m}{MM}$$

$$n = \frac{16.8 \text{ g}}{56 \text{ g/mol}}$$

$$n = 0.3 \text{ mol}$$

$$R = \frac{n(\text{Fe})}{3}$$

$$n = \frac{0.3 \text{ mol}}{3}$$

$$n = 0.1 \text{ mol}$$

$$n(\text{H}_2\text{O}) = \frac{m}{MM}$$

$$n = \frac{10 \text{ g}}{18 \text{ g/mol}}$$

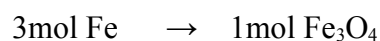
$$n = 0.56 \text{ mol}$$

$$R = \frac{n(\text{H}_2\text{O})}{4}$$

$$n = \frac{0.56 \text{ mol}}{4}$$

$$n = 0.14 \text{ mol}$$

Limiting reagent is iron (Fe)

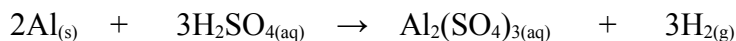


$$x = \frac{0.3 \text{ mol Fe} \times 1 \text{ mol Fe}_3\text{O}_4}{3 \text{ mol Fe}}$$

$$x = 0.1 \text{ mol Fe}_3\text{O}_4$$

### Exercise

1. Aluminium reacts with Sulphuric acid, which is the acid in automobile battery, according to the equation below



If 20.0g of aluminium are put in a solution containing 115g of Sulphuric acid;

- (a) Which is the limiting reagent
  - (b) How many moles of hydrogen gas will be produced
  - (c) How many moles and grams of the reactant in excess will remain after the reaction has stopped?
2. A mixture of 8.0g of hydrogen with 8.0g of oxygen is ignited  

$$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$$
 What is the mass of water formed?

### Gas volume (Molecular volume of gases)

#### Avogadro's law

The law states that: the volume of a gas is directly proportional to the number of moles of the gas molecules present if the pressure and temperature are constant

$$\text{Number of moles} = \frac{\text{Volume}}{\text{Molar volume}}$$

$$n = \frac{V}{V_m}$$

$$V = n \times V_m$$

$n$  = number of moles [mol]

$V$  = volume [ $\text{cm}^3$ ] or [ $\text{dm}^3$ ]

$V_m$  = molar volume [ $\text{cm}^3/\text{mol}$ ] or [ $\text{dm}^3/\text{mol}$ ]

**Room temperature and pressure (r.t.p):** The volume of one mole of any gas is  $24\text{dm}^3$  or  $24000\text{cm}^3$  at r.t.p

**Standard temperature and pressure (s.t.p):** The volume of one mole of any gas is  $22.4\text{dm}^3$  or  $22400\text{cm}^3$  at s.t.p

**Example**

1. Calculate the number of moles of carbon dioxide molecules present in  $240\text{cm}^3$  of gas at r.t.p

**Solution**

$$n = \frac{V}{V_m}$$

$$n = \frac{240\text{cm}^3}{24000\text{cm}^3/\text{mol}}$$

$$n = 0.01\text{ mol}$$

2. What is the volume of the following gases at s.t.p?

(a)  $2.8 \times 10^{-3}$  mol of Nitrogen,  $\text{N}_2$

(b) 3.2g of oxygen,  $\text{O}_2$

**Solution**

(a)  $V = n \times V_m$

$$V = 2.8 \times 10^{-3}\text{mol} \times 22.4\text{dm}^3/\text{mol}$$

$$V = 0.0627\text{dm}^3$$

(b)  $n = \frac{m}{MM}$

$$n = \frac{3.2\text{g}}{32\text{g/mol}}$$

$$n = 0.1\text{mol}$$

$$V = n \times V_m$$

$$V = 0.1\text{mol} \times 22.4\text{dm}^3/\text{mol}$$

$$V = 2.24\text{dm}^3$$

**Exercise**

1. How many moles of molecules of each of the following gases would contain

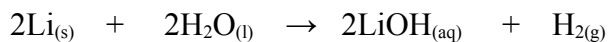
(a)  $12\text{dm}^3$  of hydrogen at r.t.p

(b) 100cm<sup>3</sup> of carbon dioxide at s.t.p

### Calculations from equations

#### Examples

1. What volume of hydrogen measured at s.t.p is produced when 0.35g of Lithium reacts with water?

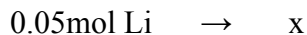
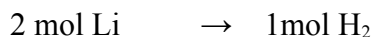


#### Solution

$$n(\text{Li}) = \frac{m}{MM}$$

$$n = \frac{0.35 \text{ g}}{7 \text{ g/mol}}$$

$$n = 0.05 \text{ mol}$$



$$x = \frac{0.05 \text{ mol Li} \times 1 \text{ mol H}_2}{2 \text{ mol Li}}$$

$$x = 0.025 \text{ mol H}_2$$

$$V = n \times V_m$$

$$V = 0.025 \text{ mol} \times 22.4 \text{ dm}^3/\text{mol}$$

$$V = 0.56 \text{ dm}^3$$

2. What mass of ammonium sulphate is required to produce 5.6dm<sup>3</sup> of ammonia at s.t.p by the reaction shown below

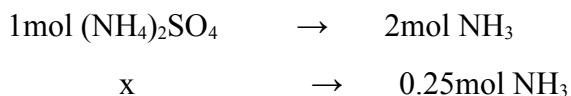


#### Solution

$$n(\text{NH}_3) = \frac{V}{V_m}$$

$$n = \frac{5.6 \text{ dm}^3}{22.4 \text{ dm}^3/\text{mol}}$$

$$n = 0.25 \text{ mol NH}_3$$



$$x = 1 \text{ mol} \frac{0.25 \text{ mol NH}_3}{2 \text{ mol NH}_3} \times 1 \text{ mol (NH}_4\text{)}_2\text{SO}_4$$

$$x = 0.125 \text{ mol (NH}_4\text{)}_2\text{SO}_4$$

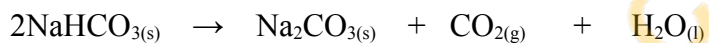
$$m = n \times \text{MM}$$

$$m = 0.125 \text{ mol} \times 132 \text{ g/mol}$$

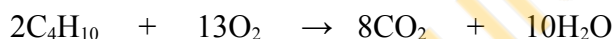
$$m = 16.5 \text{ g (NH}_4\text{)}_2\text{SO}_4$$

### Exercise

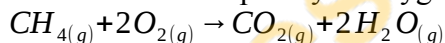
1. What volume of carbon dioxide measured at s.t.p will be produced when 21.0g of sodium hydrogen carbonate (NaHCO<sub>3</sub>) is completely decomposed according to the equation?



2. What volume of oxygen at s.t.p is required for complete combustion of 40cm<sup>3</sup> of butane (C<sub>4</sub>H<sub>10</sub>) according to the equation?

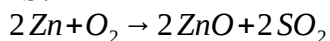


3. Methane burns completely in oxygen according to the equation below.



If 0.2mol of methane is burned completely, what volume of carbon dioxide measured at r.t.p is formed?

4. What volume of sulphur dioxide (at r.t.p) is given off on heating 9.7g of zinc sulphide, ZnS?



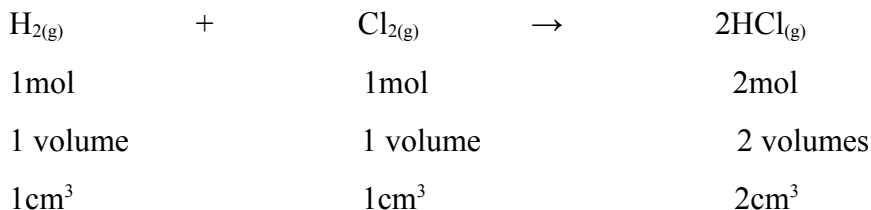
### Volume ration

Gas volume calculations are easy especially when the reactants and products are all gases.

### Avogadro's law

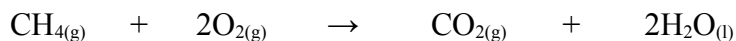
The law states that: equal number of volumes of gases at the same temperature and pressure contain the same number of moles.

The significance of Avogadro's law is that the ratio of gas volumes in a reaction is the same as the number of moles in the equation: e.g.



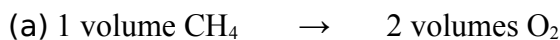
### Example

1. Consider the reaction below



- (a) What volume of oxygen is needed to react with  $40\text{cm}^3$  of methane,  $\text{CH}_4$ ?
- (b) What volume of carbon dioxide would be produced?

### Solution

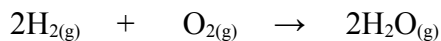


$$x = \frac{40 \text{ cm}^3 \text{ CH}_4 \times 2 \text{ volumes } \text{O}_2}{1 \text{ volume } \text{CH}_4}$$

$$x = 80\text{cm}^3 \text{ O}_2$$

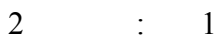
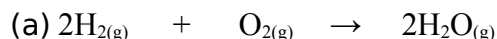


2. When  $100\text{cm}^3$  of hydrogen is sparked with  $100\text{cm}^3$  of oxygen at  $110^\circ\text{C}$ , steam is produced.



- (a) Which reactant is in excess?
- (b) What volume of steam would be produced

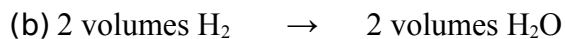
### Solution



$$\frac{100 \text{ cm}^3}{2} : \frac{100 \text{ cm}^3}{1}$$

$$50 \text{ mol} \quad 100 \text{ mol}$$

Oxygen is in excess because it has a bigger number of moles

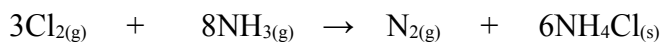


(c)  $x = \frac{100 \text{ cm}^3 \text{ H}_2 \times 2 \text{ volumes H}_2\text{O}}{2 \text{ volumes H}_2}$

$$x = 100 \text{ cm}^3 \text{ H}_2\text{O}$$

### Exercise

1. The following reaction takes place when chlorine is bubbled into excess ammonia solution.



- (a) What volume of nitrogen is formed when  $72 \text{ cm}^3$  of chlorine is bubbled in ammonia solution?
- (b) How many moles of nitrogen are there in this volume at r.t.p?
- (c) How many grams of nitrogen are in these number of moles
2. What volume of oxygen at r.t.p is required for the complete combustion of  $25.0 \text{ cm}^3$  of hexane according to the equation?



### Relative molecular mass of gases

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

$$\text{Mass} = \text{Density} \times \text{volume}$$

### Example

1. The density of a gas is  $0.71\text{g/dm}^3$  at r.t.p. What is the mass of the gas?

**Solution**

Mass = Density x volume

$$= 0.71\text{g/dm}^3 \times 24\text{dm}^3$$

$$= 17.04\text{g}$$

**Exercise**

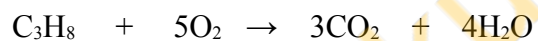
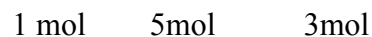
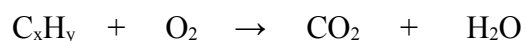
1. The mass of  $1\text{ dm}^3$  of a gas at s.t.p is  $12.37\text{g}$ . What is the mass of the gas?
2. The density of a gaseous oxide of carbon is  $1.15\text{g/dm}^3$  at r.t.p. What is the mass of 1 mole of the gas?

**Hydrocarbon analysis**

**Example**

1.  $20\text{cm}^3$  of a hydrocarbon requires  $100\text{cm}^3$  of oxygen for complete combustion and produces  $60\text{cm}^3$  of carbon dioxide. What is the formula of the hydrocarbon?

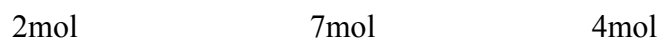
**Solution**



Formula:  $\text{C}_3\text{H}_8$

2.  $20\text{cm}^3$  of hydrocarbon gas requires  $100\text{cm}^3$  of oxygen for complete combustion.  $40\text{cm}^3$  of carbon dioxide was formed and  $30\text{cm}^3$  of excess oxygen remained. What is the formula of the hydrocarbon?

**Solution**



Formula:  $\text{C}_4\text{H}_{12}$



### Exercise

1. 10cm<sup>3</sup> of a hydrocarbon gas reacts with 90cm<sup>3</sup> of oxygen to form 60cm<sup>3</sup> carbon dioxide. What is the formula of the hydrocarbon?

### Concentration

Definition: Concentration is the amount of solute dissolved in a unit volume of the solution.

Units:  $g/dm^3$

$mol/dm^3$

$$\text{Formula: Concentration (g/dm}^3\text{)} = \frac{\text{mass of solute (g)}}{\text{volume of solution (dm}^3\text{)}}$$

$$\text{Concentration (mol/dm}^3\text{)} = \frac{\text{number of moles of solute (mol)}}{\text{volume of solution (dm}^3\text{)}}$$

The concentration expressed in  $mol/dm^3$  is called molarity.

$$M = \frac{n}{V}$$

### Note

M = Molarity [mol/dm<sup>3</sup>]

Molarity is the number of moles of solute in one liter of solution

n = moles [mol]

V = volume [dm<sup>3</sup>]

### Example

1. A solution of glucose contains 0.45g of glucose in 0.075dm<sup>3</sup> of solution. Calculate the concentration of glucose solution in g/dm<sup>3</sup>.

**Solution**

$$\begin{aligned}\text{Concentration (g/dm}^3\text{)} &= \frac{\text{mass of solute (g)}}{\text{volume of solution (dm}^3\text{)}} \\ &= \frac{0.45 \text{ g}}{0.075 \text{ dm}^3} \\ &= 6.0 \text{ g/dm}^3\end{aligned}$$

2. Find the concentration in mol/dm<sup>3</sup> of a solution of sodium hydroxide if it contains 3.5g of NaOH in 100cm<sup>3</sup> of solution.

**Solution**

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

$$n = \frac{3.5 \text{ g}}{40 \text{ g/mol}}$$

$$n = 0.0875 \text{ mol}$$

$$\text{Concentration (mol/dm}^3\text{)} = \frac{\text{number of moles of solute (mol)}}{\text{volume of solution (dm}^3\text{)}}$$

$$\text{Concentration} = \frac{0.0875 \text{ mol}}{0.1 \text{ dm}^3}$$

$$\text{Concentration} = 0.875 \text{ mol/dm}^3$$

**Exercise**

1. What is the concentration of 0.5g of sodium hydroxide contained in 250 cm<sup>3</sup> of solution in:  
(a) g/dm<sup>3</sup>  
(b) mol/dm<sup>3</sup>

**Converting Molarity (concentration in mol/dm<sup>3</sup>) into g/dm<sup>3</sup>**

$$\text{Concentration (mol/dm}^3\text{)} = \frac{\text{concentration (g/dm}^3\text{)}}{\text{molar mass (g/mol)}}$$

$$\text{Concentration (g/dm}^3\text{)} = \text{Concentration (mol/dm}^3\text{)} \times \text{Molar mass (g/mol)}$$

### Example

1. 4.5g of anhydrous sodium carbonate ( $\text{Na}_2\text{CO}_3$ ) was dissolved in distilled water and made up to  $500\text{cm}^3$ . Express the concentration of the solution in terms of :

(a)  $\text{g/dm}^3$

(b)  $\text{mol/dm}^3$

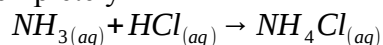
### Solution

$$\begin{aligned} \text{(a) Concentration (g/dm}^3\text{)} &= \frac{\text{mass of solute (g)}}{\text{volume of solution (dm}^3\text{)}} \\ &= \frac{4.5\text{ g}}{0.5\text{ dm}^3} \\ &= 9.0\text{ g/dm}^3 \end{aligned}$$

$$\begin{aligned} \text{(b) Concentration (mol/dm}^3\text{)} &= \frac{\text{concentration (g/dm}^3\text{)}}{\text{molar mass (g/mol)}} \\ &= \frac{9.0\text{ g/dm}^3}{106\text{ g/mol}} \\ &= 0.085\text{ mol/dm}^3 \end{aligned}$$

### Exercise

1.  $1.5\text{ dm}^3$  of hydrogen chloride gas measured at room temperature and pressure was absorbed in aqueous ammonia solution and  $50\text{ cm}^3$  of ammonia solution was neutralized completely



Calculate;

- (a) The molarity of the ammonia solution
- (b) The mass of ammonium chloride expected to be produced in the reaction
- (c) The percentage yield of the ammonium chloride if 2.68g of ammonium chloride was obtained after evaporating the solution

### Calculations from equations

#### Example

1. Calculate the mass of calcium hydroxide required to neutralize 2.5dm<sup>3</sup> of 0.5M HCl acid.



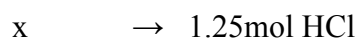
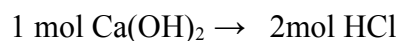
#### Solution

$$M_{(HCl)} = \frac{n}{V}$$

$$n = M \times V$$

$$n = 0.5\text{mol/dm}^3 \times 2.5\text{dm}^3$$

$$n = 1.25\text{mol HCl}$$



$$x = \frac{1 \text{ mol Ca(OH)}_2 \times 1.25 \text{ mol HCl}}{2 \text{ mol HCl}}$$

$$x = 0.625 \text{ mol Ca(OH)}_2$$

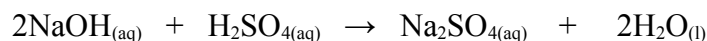
$$m(\text{Ca(OH)}_2) = n \times \text{MM}$$

$$m = 0.625 \text{ mol} \times 74 \text{ g/mol}$$

$$m = 46.25 \text{ g Ca(OH)}_2$$

2. 0.4M of sodium hydroxide was made to react completely with 50cm<sup>3</sup> of 0.1M Sulphuric acid. What was the volume of sodium hydroxide used?

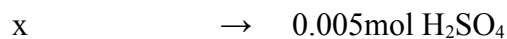
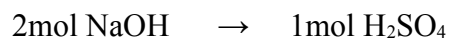
### Solution



$$n(\text{H}_2\text{SO}_4) = M \times V$$

$$n = 0.1 \text{ mol/dm}^3 \times 0.05 \text{ dm}^3$$

$$n = 0.005 \text{ mol H}_2\text{SO}_4$$



$$x = \frac{2 \text{ mol NaOH} \times 0.005 \text{ mol H}_2\text{SO}_4}{1 \text{ mol H}_2\text{SO}_4}$$

$$x = 0.01 \text{ mol NaOH}$$

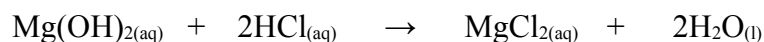
$$V(\text{NaOH}) = \frac{n}{M}$$

$$V = \frac{0.01 \text{ mol}}{0.4 \text{ mol/dm}^3}$$

$$V = 0.025 \text{ dm}^3 = 25.0 \text{ cm}^3$$

### Exercise

1. Calculate the volume of 1M HCl which can be neutralized by 0.29g of magnesium hydroxide, Mg(OH)<sub>2</sub>



2. What volume of  $0.1 \text{ mol/dm}^3$  of sulphuric acid would completely neutralize  $20 \text{ cm}^3$  of  $0.2 \text{ mol/dm}^3$  of sodium hydroxide?

### Percentage by mass of an element in a compound

$$\text{Formula: \% by mass} = \frac{\text{number of atoms} \times A_r \text{ of element}}{M_r \text{ of compound}} \times 100\%$$

### Example

1. Calculate the % by mass of each element present in sodium carbonate,  $\text{Na}_2\text{CO}_3$

### Solution

$$\text{(a) \% by mass of Na} = \frac{2 \times 23}{(2 \times 23) + (1 \times 12) + (3 \times 16)} \times 100\%$$

$$= \frac{46}{106} \times 100\%$$

$$= 43.3\%$$

$$\text{(b) \% by mass of C} = \frac{1 \times 12}{106} \times 100\%$$

$$= 11.3\%$$

$$\text{(c) \% by mass of O} = \frac{3 \times 16}{106} \times 100\%$$

$$= 45.3\%$$

$$\text{Percentage by mass of H}_2\text{O in a compound} = \frac{\text{number of moles of H}_2\text{O} \times M_r \text{ of H}_2\text{O}}{M_r \text{ of compound}} \times$$

100%

### Example

1. Calculate the percentage by mass of water in sodium carbonate crystals,  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

**Solution**

$$\begin{aligned}\% \text{ by mass of } \text{H}_2\text{O} \text{ in } \text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O} &= \frac{10 \times 18}{286} \times 100\% \\ &= 62.9\%\end{aligned}$$

**Exercise**

1. Calculate the percentage by mass of water in copper (II) sulphate crystals,  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

**Mass of element in sample**

$$\text{Formula: Mass of element in sample} = \frac{\text{Mass of element in compound}}{M_r \text{ of compound}} \times \text{sample mass}$$

**Example**

1. Calculate the mass of copper (Cu) in 32g of copper (II) sulphate

**Solution**

$$\begin{aligned}\text{Mass of Cu in } \text{CuSO}_4 &= \frac{64 \times 32 \text{ g}}{160} \\ &= 12.8 \text{ g}\end{aligned}$$

**Exercise**

1. Calculate the mass of iron in 10.0g of sample of rust,  $\text{Fe}_2\text{O}_3$

**Empirical formula**

Symbol: E.F

Definition: Empirical formula is a formula which shows the lowest ratio of the different atoms in a compound

**Example**

1. Find the empirical formula of a compound with the composition of 80% copper and 20% sulphur

**Solution**

-

Symbols of elements	Cu	S
Percentage by mass	$\frac{80}{64}$	$\frac{20}{32}$
Molar mass		
Number of moles	1.25	0.625
Divide by smallest number	$\frac{1.25}{0.625}$	$\frac{0.625}{0.625}$
Mole ratio	2	1
E.F = Cu <sub>2</sub> S		

2. 30g of silicon oxide contains 14g of silicon. Find the empirical formula of the compound

**Solution**

$$\begin{aligned}\text{Mass of O} &= 30\text{g} - 14 \\ &= 16\text{g}\end{aligned}$$

Symbols of elements	
Percentage by mass	
Molar mass	
Number of moles	
Multiply both sides by 2	
Mole ratio	

3. A compound was found to contain 29.4% calcium, 23.5% sulphur and 47.1% oxygen. What is the empirical formula of the compound?



### Solution

Symbols of elements	
Percentage by mass	
Molar mass	
Number of moles	
Divide by smallest number	
Mole ratio	

### Exercise

1. A hydrocarbon contains 85.7% carbon and 14.3% hydrogen. Work out the empirical formula.
2. A compound X contains 50% sulphur and 50% oxygen, by mass. What is the empirical formula of the compound?

### Molecular formula

Symbol: M.F

Definition: Molecular formula is a formula which shows the actual number of each kind of atom in a compound

Formula: Molecular formula = (empirical formula)<sub>n</sub>

$$\text{M.F} = (\text{EF})_n$$

Relative molecular mass = n x relative empirical formula mass

$$n = \frac{\text{Relative molecular mass}}{\text{Relative empirical formula mass}}$$

### Example

1. The empirical formula of a compound is C<sub>2</sub>H<sub>4</sub>O. Its relative molecular mass is 88. Find the molecular formula

### Solution

$$n = \frac{\text{Relative molecular mass}}{\text{Relative empirical formula mass}}$$

$$n = \frac{88}{44}$$

$$n = 2$$

$$\text{M.F} = (\text{E.F})_n$$

$$\text{M.F} = (\text{C}_2\text{H}_4\text{O})_2$$

$$\text{M.F} = \text{C}_4\text{H}_8\text{O}_2$$

2. A compound of carbon has a composition of 15.8% carbon and 84.2% sulphur. Find the empirical formula. If the relative molecular mass of the compound is 76, find its molecular formula

Symbols of elements	C	S
Percentage by mass	<u>15.8</u>	<u>84.2</u>
Molar mass	12	32
Number of moles	1.317	2.631
	<u>1.317</u> 1.317	<u>2.631</u> 1.317
Divide by smallest number		
Mole ratio	1	2
E.F = CS <sub>2</sub>		

### Exercise

1. 4.04g  
of

$$n = \frac{\text{Relative molecular mass}}{\text{Relative empirical formula mass}}$$

$$n = \frac{76}{76}$$

$$n = 1$$

$$\text{M.F} = (\text{E.F})_n$$

$$\text{M.F} = (\text{CS}_2)_1$$

$$\text{M.F} = \text{CS}_2$$

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nitrogen combines with 11.46g of oxygen to produce a compound with relative molecular mass of 92. What is the molecular formula of the compound?

2. A compound contains 40% carbon, 6.7% hydrogen and 53.3% oxygen.

(a) Find the empirical formula of the compound

(b) If the relative molecular mass of the compound is 180, work out its molecular formula.

### Percentage yield

Definition: Percentage yield is the ratio of the actual yield to the theoretical yield multiplied by 100%

$$\text{Formula: Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

### Yield

Definition: Yield is the amount of product produced when substances react.

### Actual yield

Definition: Actual yield is the amount of product obtained at the end of the reaction

Actual yield is also called experimental yield

### Theoretical yield

Definition: Theoretical yield is the maximum amount of the product calculated from the measured amounts of a given reactant using the balanced chemical equation and the mole concept.

Theoretical yield is also called expected yield

### Note

The actual yield is usually less than the theoretical yield due to the following factors:

- the reactants may fail to react completely due to the presence of impurities in them
- the reaction may be reversible such that some of the products formed are converted back into the reactants preventing the reaction from going to completion
- there may be evaporation of both reactants and products for the reaction involving volatile chemicals
- there may be loss of samples of reactants or products as they are being transferred from one vessel to another during measurements
- for large scale industrial processes, there may be leakages in pipes carrying the reactants or products of the reaction

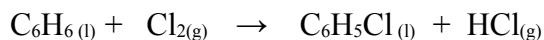
### Percentage purity

Definition: Percentage purity is the ratio of the amount of a pure substance in the sample to the total amount of the sample multiplied by 100%

$$\text{Formula: Percentage purity} = \frac{\text{Amount of pure substance in sample}}{\text{Total amount of sample}} \times 100\%$$

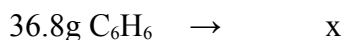
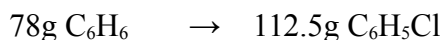
### Example

1. Consider the reaction below



When 36.8g of benzene ( $\text{C}_6\text{H}_6$ ) reacts with an excess of chlorine ( $\text{Cl}_2$ ), the actual yield of chlorobenzene ( $\text{C}_6\text{H}_5\text{Cl}$ ) is 38.8g. Find the percentage yield of chlorobenzene ( $\text{C}_6\text{H}_5\text{Cl}$ )

### Solution



$$x = \frac{36.8\text{ g C}_6\text{H}_6 \times 112.5\text{ g C}_6\text{H}_5\text{Cl}}{78\text{ g C}_6\text{H}_6}$$

$$x = 53.08\text{g C}_6\text{H}_5\text{Cl (Theoretical yield)}$$

$$\text{Percentage yield} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

$$= \frac{38.8\text{ g}}{53.08\text{ g}} \times 100$$

$$= 73.1\%$$

2. Marble occurs naturally as rock and contains a lot of calcium carbonate



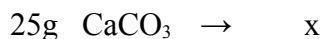
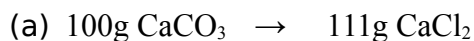
(a) If you started with 25g of marble, what would be the expected mass of calcium chloride?

(b) If the actual yield of calcium chloride obtained is 13.8g, what is the percentage purity of calcium chloride, given that;

$$\text{Percentage purity} = \frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$$

(c) What is the likely impurity in the sample product?

### Solution



$$x = \frac{25\text{ g CaCO}_3 \times 111\text{ g CaCl}_2}{100\text{ g CaCO}_3}$$

$$x = 27.75\text{g CaCl}_2$$

(b) Percentage purity =  $\frac{\text{Actual yield}}{\text{Theoretical yield}} \times 100$

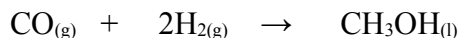
$$= \frac{13.8\text{ g}}{27.75\text{ g}} \times 100\%$$

$$= 41.73\%$$

(c) Silicon dioxide, SiO<sub>2</sub>

### Exercise

1. Methanol can be produced through the reaction of carbon monoxide (CO) and hydrogen (H<sub>2</sub>) in the presence of a catalyst.



If 75.0g of carbon monoxide (CO) reacts to produce 68.4g of methanol (CH<sub>3</sub>OH), what is the percentage yield of methanol, CH<sub>3</sub>OH?

2. Aluminium(Al) reacts with excess copper (II) sulphate (CuSO<sub>4</sub>) according to the equation given below:



If 1.85g of aluminium (Al) reacts and the percentage yield of copper (Cu) is 56.6%, what mass of copper (Cu) is produced?

## The periodic table

The periodic table is a chart of elements placed according to the order of increasing atomic numbers.

Atomic number is the property of elements used to place them in order on the periodic table.

### Important features of the periodic table

	GROUP																	
	I	II											III	IV	V	VI	VI I	O
P E R I O D I C S Y S T E M	H																	He
	Li	Be	TRANSITION ELEMENTS										B	C	N	O	F	Ne
	Na	Mg											Al	Si	P	S	Cl	Ar
	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Ti	Pb	Bi	Po	At	Rn
	5	Fr	Ra	Ac														
6																		
7																		
			Lanthanoids series															
			Actionoid series															

	Metals
	Non- metals

Key:  ${}^A_ZX$

A = Relative atomic mass

X = Atomic symbol

Z = Proton (atomic) number

In the periodic table,

1. Elements are arranged in the order of increasing atomic numbers
2. Elements with similar electronic configuration are placed in the same group.
3. Elements with similar chemical properties are placed in the same group

### Period

A period is a horizontal row of elements in the periodic table

The periodic table has 7 periods.

Period 1 contains two elements; hydrogen and helium

Periods 2 and 3 contain eight elements each and are called short periods.

Periods 4, 5 and 6 contain eighteen elements each and are called long periods.

Period 7 contains three elements

### Progression of properties across the period

As we move across the period (from left to right)

1. The metallic nature of elements decreases. They change from metals to non-metals and inert gases.
2. Electro-negativity increases. Electronegativity is the relative ability of an atom to attract the pair of electrons in a covalent bond.
3. The atomic number increases by one between successive elements.
4. The number of shells remains the same while the number of valence electrons increases steadily. The valence of each element is equal to;  
(a) The valence electrons for metals.

### Examples

(i) Na 2. 8.1, valence = 1

(ii) Mg 2.8.2, valence = 2

(iii) Al 2.8.3, valence = 3

(b) Eight (8) minus the valence electrons for non-metals

### Examples

(i) Cl 2.8.7  
Valency =  $8 - 7$   
= 1



- (ii) O 2.6  
Valency = 8 - 6  
= 2
- (iii) N 2.5  
Valency = 8 - 5  
= 3

## Groups

A group is a vertical column of elements in the periodic table

The position of an element in the periodic table is determined by the number of electrons in the outer most shell.

There are eight groups on the periodic table

Groups are labeled with roman numerals i.e. groups I, II, III, IV, V, VI, VII with the final group labeled O

Some groups have special names

## Examples

Group	Special name
I	Alkali metals
II	Alkaline earth metals
VII	Halogens
O	Noble gases/ Inert gases/ rare gases

## Progression of properties down the group

As we move from top to bottom (down the group)

1. The metallic nature of elements increases
2. The atomic number increases
3. Elements in the same group have similar chemical properties
4. Elements in the same group have the same number of electrons in the outer most shell.
5. For non-metals, the group number is equal to eight minus the valence.
6. For metals, the group number is equal to the valence.

## Position of hydrogen in the periodic table

Hydrogen is placed between group I and group VII because it behaves like group I and group VII elements i.e. it can lose or gain a single electron.

Hydrogen can lose one electron to form hydrogen ion,  $H^{+}$  with 1+ charge and can gain one electron to form hydride ion,  $H^{-}$  with 1- charge.

### **Zig-zag diagonal line**

The zig-zag diagonal line in the periodic table divides metallic elements from non-metallic elements.

Elements near the line are called metalloids

Metalloids have the characteristics of both metals and non – metals

Metalloids are also called semi-metals

### **Group properties**

#### **Group I elements**

Alternative term: Alkali metals

They are called alkali metals because they react with water to form alkaline solutions. (Alkalis)

#### **Examples of group I elements**

Element	Symbol	Atomic number
Lithium	Li	3
Sodium	Na	11
Potassium	K	19
Rubidium	Rb	37
Caesium	Cs	55
Francium	Fr	87

### **Occurrence of group I elements**

Group I elements do not occur naturally as free elements because they are very reactive.

They are found in compounds e.g. rock salt (impure sodium chloride) which is a good source of sodium.

### Identification of group I elements

Group I elements and their compounds give characteristic colours in a flame.

#### Examples

Element	Characteristic colour
Lithium	Red flame
Sodium	Yellow / orange flame
Potassium	Lilac / Pinkish flame

### Storage of group I elements

Group I element are stored under oil to prevent them from reacting with atmospheric air or water.

### Physical properties of group I elements

1. They are soft metals which can be cut with a knife.
2. They are good conductors of heat and electricity
3. They have low densities and hence float on water as they react with it. Their densities increase as you go down the group.
4. They have low melting and boiling points. Their melting points decreases as you go down the group.

Name	Symbol	Density, g/cm <sup>3</sup>	Melting point, °C
Lithium	Li	0.53	180
Sodium	Na	0.78	98
Potassium	K	0.86	64
Rubidium	Rb	1.5	39
Caesium	Cs	1.9	29

### Trend in chemical reactivity of group I elements

The reactivity of group I elements increases as you go down the group.

Lithium is the least reactive and francium is the most reactive element in group I.

### Chemical properties of group I elements

1. They have a single electron in their outer most shells.

#### Example

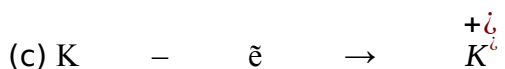
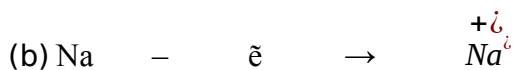
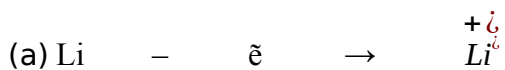
(a) Li 2.1

(b) Na 2.8.1

(c) K 2.8.8.1

2. They lose their single electrons in their outer most shells to form ions with 1+ charge.

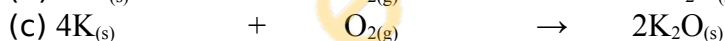
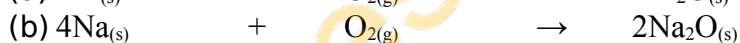
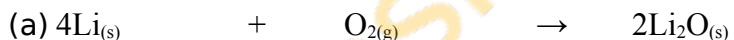
#### Examples



3. They are powerful reducing agents because they lose electrons.

4. They react with oxygen to form basic oxides

#### Examples



5. They react with water to form metal hydroxides and hydrogen gas.

#### Examples

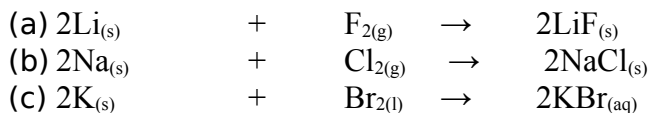


#### Note

- The metal hydroxide solutions formed are all strong alkalis with PH values of around 14
- Lithium reacts violently with water
- Sodium reacts very violently with water, sometimes with an explosion
- Potassium reacts explosively with water

6. They react with group VII elements to form salts

### Examples



### Group VII elements

Alternative term: Halogens

They are called Halogens because they react with group I elements to form salts

The term halogen means salt former

### Examples of group VII elements

Element	Symbol	Atomic number
Fluorine	F	9
Chlorine	Cl	17
Bromine	Br	35
Iodine	I	53
Astatine	At	85

### Occurrence of group VII elements

Group VII elements do not occur naturally in a free state, instead they exist as diatomic molecules meaning two atoms chemically combined.

### Physical Properties of Group VII Elements

1. They exist as **diatomic** covalent molecules (meaning two atoms chemically combined)

#### Examples

Element	Molecular formula
Fluorine	F <sub>2</sub>
Chlorine	Cl <sub>2</sub>
Bromine	Br <sub>2</sub>
Iodine	I <sub>2</sub>

2. They exist as coloured, non-metallic elements

#### Examples

Element	Colour
Fluorine	Pale yellow
Chlorine	Yellowish – green
Bromine	Reddish-brown
Iodine	Black

3. They show a gradual change in their physical states at room temperature and pressure.

#### Examples

Element	Physical state at room temperature and pressure
Fluorine	Gas
Chlorine	Gas
Bromine	Liquid
Iodine	Solid

4. Their melting and boiling points increases as you go down the group.

Element	Melting point/°C	Boiling point /°C
Fluorine	-220	-188
Chlorine	-101	-35
Bromine	-7	59
Iodine	114	184

5. Their densities increases as you go down the group.

6. Their compounds can either be ionic or covalent. If they combine with a metal the compound is ionic and if they combine with another nonmetal the compound is covalent.

### Trend in Chemical reactivity of Group VII Elements

The reactivity of group VII elements increases as you go up the group.

Astatine is the least reactive halogen while fluorine is the most reactive halogen

### Chemical properties of group VII elements

1. They all have seven electrons in their outer shells and hence have similar chemical properties.

#### Examples

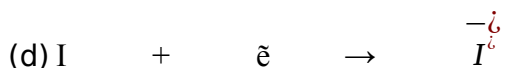
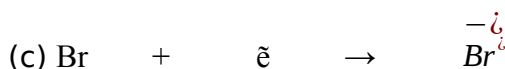
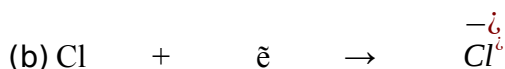
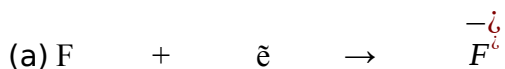
(a) F 2.7

(b) Cl 2.8.7

(c) Br 2.8.18.7

2. They gain a single electron to form ions with 1- charge

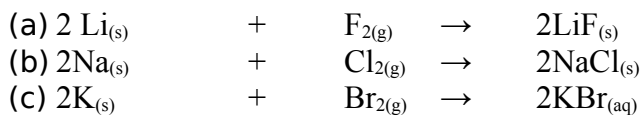
#### Examples



3. They are oxidizing agents because they accept /gain electrons.

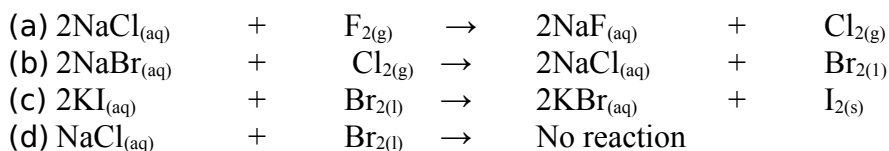
4. They react with group I elements to form salts

#### Examples



5. They displace each other in chemical reactions involving their halide ions i.e. the group VII Ions. The more reactive halogen will displace the less reactive halogen from its aqueous salt solution.

### Examples



### Uses of group VII elements

1. Fluorine is used in fluoride tooth paste to help prevent tooth decay.
2. Chlorine is used to sterilize drinking water because it kills harmful micro-organisms.
3. Iodine is used as an additive in table salt to prevent goiter in human beings.

### Harmful Effects of Group VII Elements

Compounds of group VII elements are known to be responsible for the depletion of the Ozone layer.

#### Note.

Ozone is an allotrope of oxygen made up of three oxygen atoms ( $\text{O}_3$ )

### Group O elements

Alternative term: Noble gases / Inert gases / Rare gases

They are called noble gases or inert gases or rare gases because they are chemically unreactive and therefore do not form compounds.

Group O elements are chemically unreactive because they have full outer most electron shells. Their outer most shells are completely filled.

Group O elements are gases at room temperature and pressure.

Group O elements exist as unreactive monatomic elements with very low melting and boiling points.

They consist of single atoms.



### Examples of Group O elements.

Element	Symbol	Atomic number
Helium	He	2
Neon	Ne	10
Argon	Ar	18
Krypton	Kr	36
Xenon	Xe	54
Radon	Rn	86

Group O elements have eight electrons in the outer most shell except for helium which has only two electrons.

### Examples

- (a) He 2
- (b) Ne 2.8
- (c) Ar 2.8.8
- (d) Kr 2.8.18.8
- (e) Xe 2.8.18.18.8

### Uses of group O elements

1. Helium is used to fill weather balloons because of low density.
2. Neon is used to fill coloured glowing tubes used in advertisements because it glows red hot in an electric current.
3. Argon is used to fill light bulbs to provide an inert atmosphere to prevent the oxidation of the filament.

### Transition elements

Transition elements are found in the centre block of the periodic table. They are found between group II and III of the periodic table and through periods 4 and 6

They are all metals.

### Examples of transition elements

Element	Symbol	Atomic number
Copper	Cu	29
Iron	Fe	26
Zinc	Zn	30
Silver	Ag	47
Gold	Au	79
Mercury	Hg	80
Manganese	Mn	25

### Physical properties of transition elements

1. They have high densities
2. They have high melting and boiling points
3. They are good conductors of heat and electricity
4. They are solids at room temperature and pressure except mercury which is a liquid
5. They are ductile i.e. they can be drawn into wires
6. They are malleable i.e. they can be hammered into thin sheets.

### Chemical properties of transition elements

1. They are catalysts
2. They have variable Valencies and form positively charged ions.

### Examples

(a) Copper has a valency of 1 or 2 and forms the ions  $Cu^{+1}$  and  $Cu^{2+}$  respectively.

(b) Iron has a valence of 2 or 3 and forms the ions  $Fe^{2+}$  and  $Fe^{3+}$  respectively.

3. They form coloured compounds depending on the valence used.

### Examples

- (a) Copper (II) compounds are blue
  - (b) Iron (II) compounds are pale green
  - (c) Iron (III) compounds are reddish brown
4. They are reducing agents because they lose electrons.

### Uses of transition elements

1. They are used to make electric cables because they are good conductors of electricity.
2. They are used to make pots and pans because they are good conductors of heat.
3. They are used to make alloys

### Examples

- (a) Brass is an alloy of copper and Zinc
- (b) Bronze is an alloy of copper and tin
4. They are used as catalysts in the industry to speed up reactions.

### Examples

- (a) Iron is used as a catalyst in Haber process.
- (b) Nickel is used as a catalyst in the hydrogenation of oil to make margarine
- (c) Platinum is used as a catalyst in contact process.

### Example

1. Using the following evidence, state the group numbers for the elements A, B, C, D and E on the periodic table:
  - (I) An oxide  $A_2O$  exists and is strongly basic
  - (II) B form a liquid covalent chloride,  $BCl_3$
  - (III) The oxide of C is  $C_2O_3$
  - (IV) D produces an ion  $D^{6-}$
  - (V) E exists as an unreactive monoatomic element.
  - (a) Using the given letters, write the formula for the compound formed between C and D

### Solution

- (I) Group I
  - (II) Group V
  - (III) Group III
  - (IV) Group VII
  - (V) Group O
- (a)  $CD_3$

## Exercise

1. The diagram below shows part of the periodic table.

				He
C	N	O	F	Ne
		S	Cl	Ar
			Br	Kr

- (a) Answer these questions using only the elements shown in the diagram.

Write down the symbol for an element which

- (i) Has five electrons in the outer most shell
  - (ii) Has diatomic molecules
  - (iii) Reacts with sodium to form sodium bromide
  - (iv) Is a noble gas.
  - (v) Has a lower proton than fluorine
- (b) Why is argon very unreactive

2. Use the periodic table to answer this question.

- (a) Name the element in group II and Period 3 on the periodic table.
- (b) State whether the element named in (a) is a metal or non-metal.
- (c) Suggest the formula of the compound formed between the element named in (a) and sulphur, S.
- (d) Group VII of the periodic table contains fluorine and chlorine. Explain why these elements have similar chemical properties.

3. An element has atomic number of 16.

- (a) Use the periodic table to name the element and give the symbol.

- (b) Explains why

- (i) The element is placed in group VI of the periodic table
- (ii) The element has a valence of two in its compound with magnesium.
- (iii) An ion of this element has two negative charges.

4. An element is in group I of the periodic table. Another element is in group VII.

- (a) Suggest two ways in which the properties of these elements must be different.
- (b) Two elements are in group I of the periodic table one is placed in period 2 and the other is in period 3. State two ways in which these elements must be chemically similar.

5. Use the periodic table to help you answer this question.

- (a) Name the element in group V which is in the same period as Lithium.
- (b) Calculate the number of protons and neutrons in one atom of the element you have named in (a)
- (c) (i) Name the element with a relative atomic mass of 31
- (ii) Suggest one property, physical or chemical of this element.

6. Some elements have only seven electrons in their outer most shells.

- (a) (i) Name three of these elements
- (ii) In which of the group of the periodic table are they placed?
- (b) Use your knowledge of physical and chemical properties of these elements to justify placing them in the same group of the periodic table.

7. Caesium, Lithium, Potassium and sodium are all in group I of the periodic table

- (a) Place these metals in order of reactivity with water, most reactive metal first.
- (b) Name the chemical products of the reactions between lithium and water and between sodium and water.
- (c) (i) What would you expect to see if small pieces of Caesium were dropped onto water? How would the PH of the resulting solution be different from the PH of water?
- (ii) Write the full chemical equation for the reaction between Caesium and water. Include state symbols.

8. Chlorine, bromine and iodine are placed in this order in group VII of the periodic table.

- (a) State four ways in which the physical or chemical properties of chlorine, bromine and iodine are similar.
- (b) (i) Describe the trends in physical properties of chlorine, bromine and iodine.
- (ii) How is the trend in chemical reactivity of chlorine, bromine and iodine shown by the displacement reactions? Give an equation for a reaction in which one element displaces another from its compound.

9. The diagram below shows a table of elements taken from a larger classification of elements given on the periodic table.

I	II		III	IV	V	VI	VII	O
		hydroge						helium

		n						
Lithium	beryllium		boron	carbon	Nitrogen	oxygen	fluorine	neon
Sodium	magnesium		aluminum	silicon	phosphorous	sulphur	chlorine	argon

(a) Which group contains

- (i) Halogens
- (ii) Alkali metals

(b) From the diagram above, choose

- (i) A metal from period 2
- (ii) A non-metal with a valence of 2

(c) Hydrogen is difficult to classify into a group as it can be compared with both chlorine and sodium.

- (i) How many electrons are there in an atom of hydrogen?
- (ii) What is the valence of a hydrogen atom?
- (iii) State one way in which hydrogen is similar to chlorine
- (iv) State one way in which hydrogen is similar to sodium.

10. Use the periodic table to answer this question

(a) Give the symbol of:

- (i) A non-metal used to sterilize water
- (ii) An element which forms diatomic molecules
- (iii) An element which reacts with water to give an alkaline solution
- (iv) An element which forms an ion of the type  $x^{2-}$

(b) Oxygen, sulphur and selenium are in group VI of the periodic table. At room temperature, oxygen is a gas and sulphur is a solid.

- (i) Predict whether selenium is a liquid, a solid or a gas at room temperature
- (ii) The trend in reactivity of group VI is similar to that in group VII. Suggest the most reactive element in group VII.

## Acids

Definition: An acid is a chemical substance which when dissolved in water produces hydrogen

ions,  $H^{+}$ , as the only positively charged ions.

An acid can also be defined as a proton donor.

**Note**

The hydrogen ions give an acid its characteristic properties.

**Types of acids**

Acids can be classified into two categories

**1. Mineral acids**

Mineral acids are also called inorganic acids

They are acids that are prepared from the minerals obtained from the earth

Generally all mineral acids are strong acids

Examples of mineral acids	Formula
Hydrochloric acid	HCl
Nitric acid	HNO <sub>3</sub>
Sulphuric acid	H <sub>2</sub> SO <sub>4</sub>
Phosphoric acid	H <sub>3</sub> PO <sub>4</sub>

**2. Organic acids**

Organic acids are naturally occurring acids

They are found in organic matter of living things

They are prepared from organic sources such as plants

Generally organic acids are weak acids

Examples of organic acids	Formula
Methanoic acid	HCOOH
Ethanoic acid	CH <sub>3</sub> COOH
Propanoic acid	C <sub>2</sub> H <sub>5</sub> COOH

Butanoic acid	$C_3H_7COOH$
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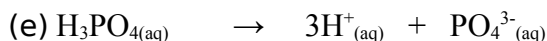
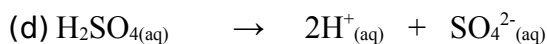
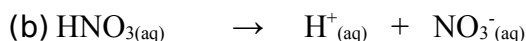
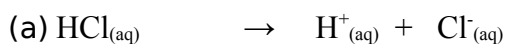
## Ionization of acids

Ionization is the process of forming ions

An ion is a charged particle

When acids dissolve in water, they produce hydrogen ions,  $H^+$ , as the only positively charged ions

## Examples of ionization of acids



## Strength of acids

Strength of an acid is the measure of its ability to produce hydrogen ions

It can also be defined as the ability to donate protons

Acids can be grouped into two classes

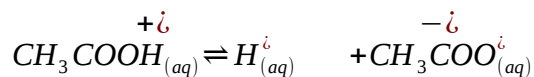
### 1. Weak acids

A weak acid is an acid that partially ionizes when dissolved in water

Weak acids have reversible ionization  $\rightleftharpoons$

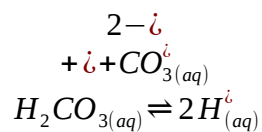
## Examples of weak acids

(a) Ethanoic acid



(b) Carbonic acid



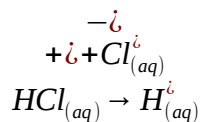


## 2. Strong acids

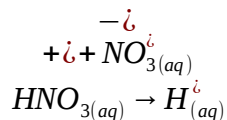
A strong is an acid that completely ionizes when dissolved in water

### Examples of strong acids

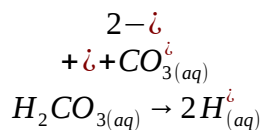
(a) Hydrochloric acid



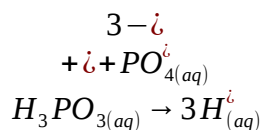
(b) Nitric acid



(c) Sulphuric acid



(d) Phosphoric acid



### Basicity of an acid

Alternative term: Protocity of an acid.

Definition: Basicity of an acid is the number of moles of hydrogen ions,  $\text{H}^+$ , produced from one mole of an acid

### 1. Monobasic acid

A monobasic acid is an acid that produces one hydrogen ion,  $1H^{+}$

Example of monobasic acids	Formula	Equation	Basicity
Hydrochloric acid	HCl	$HCl_{(aq)} \rightarrow H^{+}_{(aq)} + Cl^{-}_{(aq)}$	1
Nitric acid	$HNO_3$	$HNO_{3(aq)} \rightarrow H^{+}_{(aq)} + NO_3^{-}_{(aq)}$	1
Ethanoic acid	$CH_3COOH$	$CH_3COOH_{(aq)} \rightarrow H^{+}_{(aq)} + CH_3COO^{-}_{(aq)}$	1

### 2. Dibasic acid

A dibasic acid is an acid that produces two hydrogen ions,  $2H^{+}$

Examples of dibasic acid	Formula	Equation	Basicity
Carbonic acid	$H_2CO_3$	$H_2CO_{3(aq)} \rightarrow 2H^{+}_{(aq)} + CO_3^{2-}_{(aq)}$	2
Sulphuric acid	$H_2SO_4$	$H_2SO_{4(aq)} \rightarrow 2H^{+}_{(aq)} + SO_4^{2-}_{(aq)}$	2

### 3. Tribasic acid

A tribasic acid is an acid that produces three hydrogen ions,  $3H^{+}$

Example of tribasic acid	Formula	Equation	Basicity
Phosphoric acid	$H_3PO_4$	$  \begin{array}{c}  3 - \overset{+}{\underset{\cdot}{H}} \\  + \overset{+}{\underset{\cdot}{H}} + PO_4^{\overset{-}{\underset{\cdot}{\cdot}}}(aq) \\  H_3PO_4(aq) \rightarrow 3H^+(aq)  \end{array}  $	3

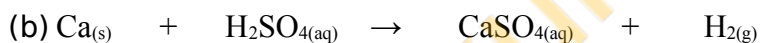
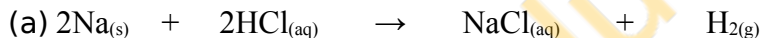
### Physical properties of acids

1. Acids have PH numbers less than 7
2. Acids turn blue litmus paper red
3. Acids have a sour taste

### Chemical properties of acids

1. Acids react with **reactive metals** to form a salt and hydrogen gas,  $H_2$

#### Examples

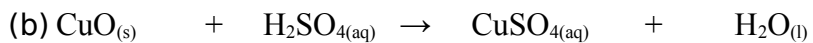
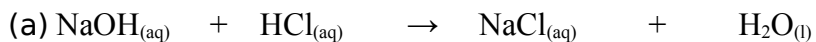


#### Note

Metals below hydrogen in the reactivity series cannot react with acids

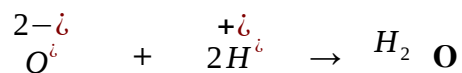
2. Acids react with bases and alkalis to form a salt and water only. The reaction between an acid and a base is called **neutralization**.

#### Examples



### Ionic equations for neutralization reactions





3. Acids react with carbonates or hydrogen carbonates to form a salt, water and carbon dioxide gas

### Examples



### Bases

Definition: A base is a substance which reacts with an acid to form a salt and water

A base can also be defined as an oxide or hydroxide of a metal or a proton acceptor

A base neutralizes an acid

A soluble base is called an **alkali**

An alkali is a substance which when dissolved in water produces the hydroxide ions, OH<sup>-</sup>, as the only negatively charged ions

### Examples of alkalis

Name	Formula	Special name
------	---------	--------------

Sodium hydroxide	NaOH	Caustic soda
Potassium hydroxide	KOH	Caustic potash
Ammonium hydroxide	NH <sub>4</sub> OH	Aqueous ammonia
Calcium hydroxide	Ca(OH) <sub>2</sub>	Lime water

### Examples of insoluble bases

Name	Formula
Copper (II) oxide	CuO
Zinc oxide	ZnO
Iron (III) oxide	Fe <sub>2</sub> O <sub>3</sub>
Lead (II) hydroxide	Pb(OH) <sub>2</sub>

### Ionization of alkalis

When alkalis dissolve in water, they produce hydroxide ions, OH<sup>-</sup>, as the only negatively charged ions.

### Examples of ionization of alkalis



### Strength of alkalis

Strength of an alkali is the measure of its ability to produce hydroxide ions

Alkalis can be classified into two categories

#### 1. Weak alkalis

A weak alkali is an alkali that partially ionizes when dissolved in water

Weak alkalis have reversible ionization  $\rightleftharpoons$

### Example of a weak alkali

(a) Ammonium hydroxide



## 2. Strong alkalis

A strong alkali is an alkali that ionizes completely when dissolved in water

### Examples of strong acids

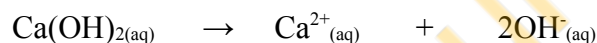
(a) Sodium hydroxide



(b) Potassium hydroxide



(c) Calcium hydroxide



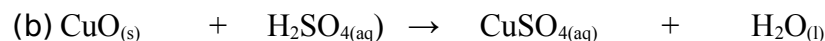
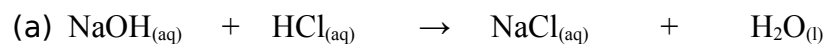
### Physical properties of alkalis

1. Alkalis have PH numbers greater than 7
2. Alkalis turn red litmus paper blue
3. Alkalis have a bitter taste and feel soapy or slippery between fingers

### Chemical properties of bases and alkalis

1. Alkalis and bases react with acids to form a salt and water only

### Examples



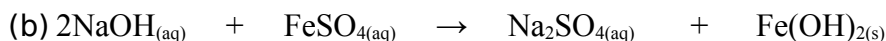
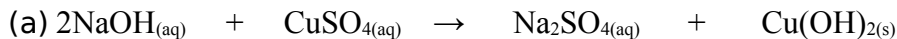
2. Alkalis reacts with ammonium compounds to form a salt, water and ammonia gas

### Examples



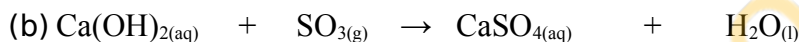
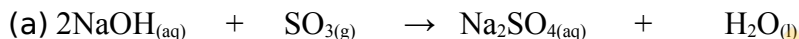
3. Alkalis react with solutions of soluble salts to form precipitates of insoluble hydroxides

### Examples



4. Alkalis react with acidic oxides to form a salt and water only

### Examples



### The PH scale

Definition: PH is the degree of acidity or alkalinity of a substance

PH stands for Potenz Hydrogen

Potenz is a German term which means potential

The PH scale ranges from 0 to 14

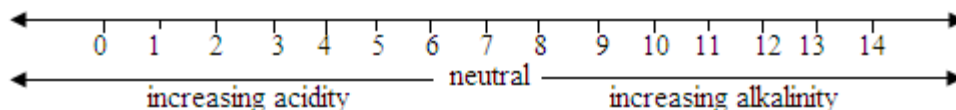
PH values from 0 to 7 implies acidic medium.

PH values 7 imply a neutral medium e.g. water,  $\text{H}_2\text{O}$  and sodium chloride,  $\text{NaCl}$

PH values from 7 to 14 implies alkaline medium

The lower the PH value, the stronger the acidity e.g. hydrochloric acid ( $\text{HCl}$ ), sulphuric acid ( $\text{H}_2\text{SO}_4$ ) and nitric acid ( $\text{HNO}_3$ )

The greater the PH value, the stronger the alkalinity e.g. Potassium hydroxide ( $\text{KOH}$ ) and sodium hydroxide ( $\text{NaOH}$ )



The ion responsible for acidity is the hydrogen ion,  $H^+$  and the ion responsible for alkalinity is the hydroxide ion,  $OH^-$

PH is a numerical value and has no units

PH is related to the concentration of acids and alkalis.

## Indicators

Definition: An indicator is a chemical substance which has different colours with different substances or solutions

Indicator	Colour in acid	Colour in alkali
Litmus	Red	Blue
Methyl orange	Red	Yellow
Bromothymol	Yellow	Blue
Phenolphthalein	Colourless	Red / pink

## Universal indicator

A universal indicator is a solution or paper which shows different colors in acidic or alkaline conditions

PH scale	1,2,3	4,5	6	7	8	9,10	11,12,13,14
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							4
<b>Colour</b>	Red	Orange	Yellow	Green	Blue	Indigo	Purple

### **Soil acidity**

#### **Formation of acid rain**

Acid rain is formed when gaseous acidic oxides dissolve in rain water in the atmosphere

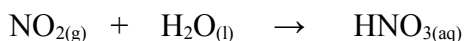
#### **What is destroyed by acid rain?**

1. Soil – the soil becomes acidic
2. Crops and vegetation

#### **Examples of acidic rain fall**

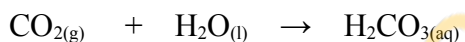
##### **1. Nitric acid**

Nitric acid is formed when nitrogen dioxide gas dissolve in rain water in the atmosphere



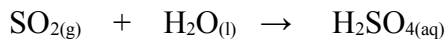
##### **2. Carbonic acid**

Carbonic acid is formed when carbon dioxide gas dissolve in rain water in the atmosphere



##### **3. Sulphuric acid**

Sulphuric acid is formed when sulphur dioxide gas dissolve in rain water in the atmosphere



All these acids come down as acid rainfall

Acid rain causes pollution

Acidic soils on the farm can be neutralized or avoided by adding lime (Calcium oxide)

#### **Exercise**

1. Acid rain is partially caused by Sulphur dioxide
  - (a) What is damaged by acid rain

(b) How is acid rain formed?

(c) Suggest how this pollution can be avoided

2. The PH of a solution depends upon the ions present in it

(a) State the PH of a neutral solution

(b) Complete the table below

Solution in water	PH range
Acids	
Alkalis	

(c) What gas is formed when;

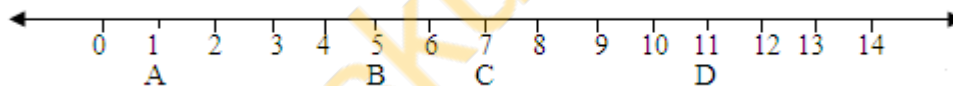
(i) Dilute Sulphuric acid is added to sodium carbonate

(ii) Sodium hydroxide is warmed with ammonium chloride

(iii) Write a balanced chemical equation for either of the reactions in (c)

(d) Explain why sulphuric acid is said to be a strong acid.

3. The figure below shows a PH scale and the PH values of four solutions A, B, C and D.



(a) Which of the solutions is likely to be:

(I) Sodium chloride

(II) Hydrochloric acid

(b) State the ion which is responsible for:

(I) Acidity

(II) Alkalinity

(c) What type of reaction occurs when solution A is mixed with solution D? Write an ionic equation for the reaction that occurs.

4. Analysis of cigarette smoke and cigar smoke were carried out. The results showed that cigarette smoke is acidic and cigar smoke is alkaline with the following PH values:

Smoke_	PH
Cigarette	5.2
Cigar	8.3

- (a) State the ion which is formed when:
- Cigarette smoke is absorbed in water and is responsible for the PH value given
  - Cigar smoke is absorbed in water and is responsible for the PH value given
- (b) When cigar smoke is mixed with cigarette smoke, neutralization occurs. What is the meaning of neutralization?
- (c) If cigarette smoke is absorbed in universal indicator solution, what colour change would be observed?
- (d) Name an alkali that would neutralize cigarette smoke.
- (e) Smoking cigarette can be a danger to health. This fact is well known in Zambia. The main danger of cigarette smoking is that it can cause lung cancer. Carbon monoxide is present in cigarette smoke. It does not cause lung cancer, yet is toxic. Describe and explain the poisonous or toxic nature of carbon monoxide.
- (f) How would you use blue litmus paper to show that cigarette smoke is acidic?

## Oxides

Definition: An oxide is a compound formed when oxygen combines with any other element

### Classification of oxides

#### [A] Acidic oxides

Acidic oxides are oxides of non-metals

They are formed when a non – metal reacts with oxygen

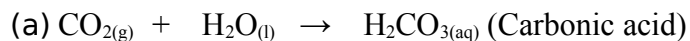
Acidic oxide	Formula	Reaction
Carbon dioxide	$\text{CO}_2$	$\text{C} + \text{O}_2 \rightarrow \text{CO}_2$
Nitrogen dioxide	$\text{NO}_2$	$\text{N}_2 + 2\text{O}_2 \rightarrow 2\text{NO}_2$
Sulphur dioxide	$\text{SO}_2$	$\text{S} + \text{O}_2 \rightarrow \text{SO}_2$
Sulphur trioxide	$\text{SO}_3$	$2\text{SO}_2 + \text{O}_2 \rightarrow 2\text{SO}_3$

Silicon dioxide	SiO <sub>2</sub>	$Si + O_2 \rightarrow SiO_2$
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### Characteristics of acidic oxides

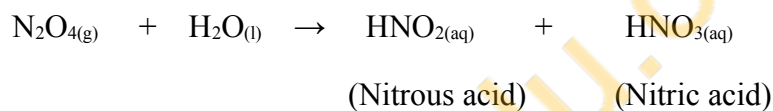
1. Acidic oxides dissolve in water to form acids

#### Examples



#### Note

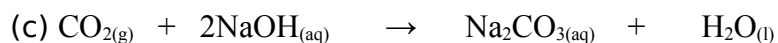
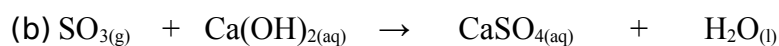
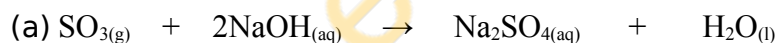
- Dinitrogen tetra oxide forms two acids when dissolved in water



- They are called acidic oxides because they react with water to form acids

2. Acidic oxides react with alkalis to form a salt and water only

#### Examples



### [B] Basic oxides

Basic oxides are oxides of metals

They are formed when a metal reacts with oxygen

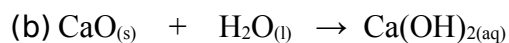
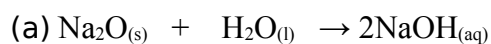
Basic oxide	Formula	Reaction
Sodium oxide	Na <sub>2</sub> O	$4Na + O_2 \rightarrow 2Na_2O$

Copper (II) oxide	CuO	$Cu + O_2 \rightarrow CuO$
Iron (III) oxide	Fe <sub>2</sub> O <sub>3</sub>	$4 Fe + 3 O_2 \rightarrow 2 Fe_2 O_3$
Calcium oxide	CaO	$Ca + O_2 \rightarrow CaO$
Magnesium oxide	MgO	$Mg + O_2 \rightarrow MgO$
Potassium oxide	K <sub>2</sub> O	$4 K + O_2 \rightarrow 2 K_2 O$

### Characteristics of basic oxides

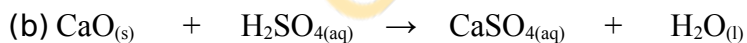
1. Some soluble basic oxides dissolve in water to form alkalis

#### Examples



2. Basic oxides react with acids to form a salt and water only

#### Examples



### [C] Amphoteric oxides

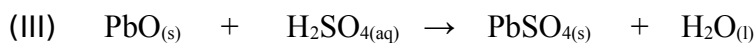
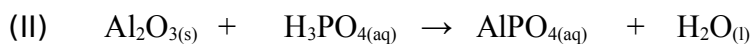
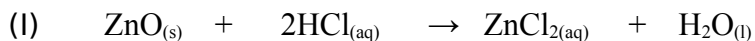
Amphoteric oxides are oxides of metals

Amphoteric oxide	Formula	Reaction
Zinc oxide	ZnO	$Zn + O_2 \rightarrow ZnO$
Aluminium oxide	Al <sub>2</sub> O <sub>3</sub>	$4 Al + 3 O_2 \rightarrow 2 Al_2 O_3$
Lead (II) oxide	PbO	$Pb + O_2 \rightarrow PbO$

Amphoteric oxides show both basic and acidic properties i.e. they react with both acids and alkalis to form a salt and water

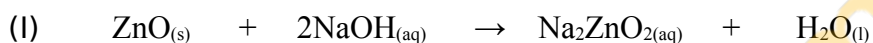
**(a) Reaction with acids**

**Examples**

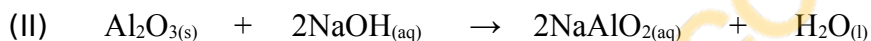


**(b) Reaction with alkalis**

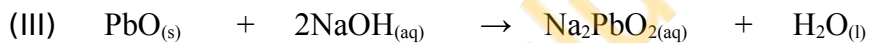
**Examples**



(Sodium zincate)



(Sodium aluminate)



(Sodium plumbite)

**[D] Neutral oxides**

Neutral oxides are oxides of **non** – metals

Neutral oxides do not show either basic or acidic properties i.e. they do not react with either bases or acids

Neutral oxide	Formula
Carbon monoxide	CO
Nitrogen monoxide	NO
Water (Hydrogen oxide)	H <sub>2</sub> O
Dinitrogen oxide	N <sub>2</sub> O

## Salts

Definition: A salt is a chemical substance formed when the hydrogen ions in an acid are replaced

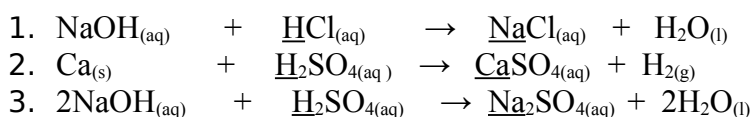
by a metal or ammonium ions,  $NH_4^+$

### Types of salts

#### 1. Normal salt

This is a salt formed when all the hydrogen ions in an acid are replaced by a metal or ammonium ions.

#### Examples

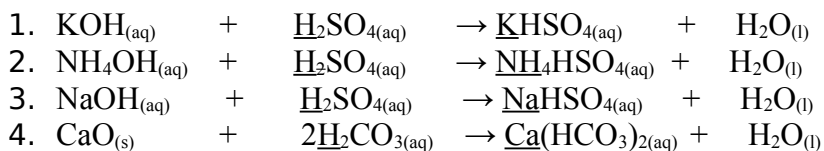


Normal salt	Formula	Common name
Sodium chloride	NaCl	Common salt/Table salt
Calcium sulphate	CaSO <sub>4</sub>	
Sodium sulphate	Na <sub>2</sub> SO <sub>4</sub>	Glauber's salt
Copper (II) sulphate	CuSO <sub>4</sub>	
Calcium carbonate	CaCO <sub>3</sub>	Limestone/Marble
Magnesium sulphate	MgSO <sub>4</sub>	Epsom salt

#### 2. Acid salt

This is a salt formed when part of the hydrogen ions in an acid are replaced by a metal or ammonium ions.

#### Examples



Acid salt	Formula	Common name
-----------	---------	-------------

Potassium hydrogen sulphate	KHSO <sub>4</sub>	
Sodium hydrogen sulphate	NaHSO <sub>4</sub>	
Calcium hydrogen carbonate	Ca(HCO <sub>3</sub> ) <sub>2</sub>	
Sodium hydrogen carbonate	NaHCO <sub>3</sub>	Baking/Bicarbonate salt

### Solubility of salts

Solubility is the ability of a salt to dissolve in water.

### Facts about solubility of salts in water

Salt	Solubility
Nitrates	All nitrates are soluble
Chlorides	All chlorides are soluble except silver chloride and lead (II) chloride which are insoluble
Sulphates	All Sulphates are soluble except barium sulphate and lead (II) sulphate which are insoluble. Calcium sulphate is slightly soluble.
Carbonates	All carbonates are insoluble except potassium carbonate, sodium carbonate and ammonium carbonate which are soluble.

### Preparation of salts

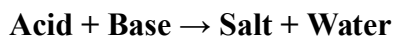
The method chosen to prepare a given salt depends on its solubility and how it can be separated from the mixture of other products.

### Methods of preparing salts

1. Neutralization
2. Replacement (Displacement)
3. Synthesis
4. Precipitation (Double Decomposition)

#### 1. Neutralization

It is a reaction between an acid and a base to form a salt and water only.



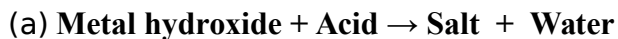
Neutralization includes the preparation of a salt by reacting:

- (a) a metal hydroxide with a dilute acid.



- (b) an insoluble metal oxide with a dilute acid.
- (c) a metal carbonate with a dilute acid.

### **Preparation of soluble salts by neutralization**



#### **Example: Preparation of sodium chloride**

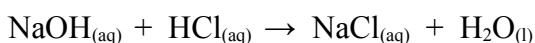
##### **Reagents**

- Sodium hydroxide, NaOH
- Hydrochloric acid, HCl

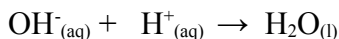
##### **Products**

- Sodium chloride, NaCl
- Water, H<sub>2</sub>O

##### **Reaction equation**



##### **Ionic equation**



##### **Method of preparation**

**A preliminary titration is carried out to find the end point with the help of an indicator.**

- Using a pipette, measure 25.0cm<sup>3</sup> of Sodium hydroxide and put it into a conical flask.
- Add two or three drops of indicator to sodium hydroxide using a teat pipette.
- Fill the burette to the zero reading with dilute hydrochloric acid
- Place the conical flask on a white tile below the burette.
- Add dilute hydrochloric acid from the burette to sodium hydroxide in the conical flask, while swirling, until the solution just changes colour.
- From the titration result, we can know the exact volume of hydrochloric acid needed to react with 25.0cm<sup>3</sup> of sodium hydroxide.

Volume of hydrochloric acid used:  $V_a = V_2 - V_1$

**A second titration is carried out without the indicator. The exact volume obtained from the preliminary titration is used.**

- Using a pipette, measure  $25.0\text{ cm}^3$  of sodium hydroxide and put it into a conical flask. This time no indicator is added.
- Add  $V_a\text{ cm}^3$  of dilute hydrochloric acid from the burette to sodium hydroxide.
- Evaporate the mixture to obtain a saturated solution.
- Cool the saturated solution to obtain sodium chloride crystals.
- Filter the mixture to obtain pure sodium chloride crystals.

### Note

- The point at which the colour changes is called **end point**.
- At the end point, the volume of acid used is measured at the bottom of the meniscus in the burette. This volume is called **titre**.

(b) **Insoluble metal oxide + Acid  $\rightarrow$  Salt + Water**

### Example: Preparation of copper (II) sulphate

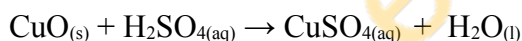
#### Reagents

- Copper (II) oxide,  $\text{CuO}$
- Dilute sulphuric acid,  $\text{H}_2\text{SO}_4$

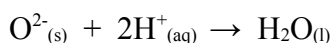
#### Products

- Copper (II) sulphate,  $\text{CuSO}_4$
- Water,  $\text{H}_2\text{O}$

#### Reaction equation



#### Ionic equation



#### Method of preparation

**Copper (II) sulphate crystals  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  are prepared from copper (II) oxide and sulphuric acid.**

- Put dilute sulphuric acid in a beaker, warm the acid but don't boil.

- Add an excess of copper (II) oxide to the acid in the beaker and stir until the reaction is over. Excess copper (II) oxide is added to ensure that all the sulphuric acid is converted to copper (II) sulphate.
- Filter off excess copper (II) oxide to have a blue solution of copper (II) sulphate.
- Evaporate the filtrate to obtain a saturated solution.
- Cool the filtrate in an ice bath to allow crystals of copper (II) sulphate to form.

(c) **Metal carbonate + Acid → Salt + Water + Carbon dioxide**

### Example: Preparation of Magnesium sulphate

#### Reagents

- Magnesium carbonate,  $\text{MgCO}_3$
- Dilute sulphuric acid,  $\text{H}_2\text{SO}_4$

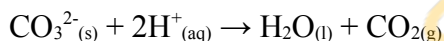
#### Products

- Magnesium sulphate,  $\text{MgSO}_4$
- Water,  $\text{H}_2\text{O}$
- Carbon dioxide,  $\text{CO}_2$

#### Reaction equation



#### Ionic equation



#### Method of preparation

- Put dilute sulphuric acid in a beaker, warm the acid but don't boil.
- Add an excess of magnesium carbonate to the acid to ensure that all the sulphuric acid is converted to magnesium sulphate.
- Stir the mixture and filter to have a clear solution of magnesium sulphate.
- Evaporate the mixture to obtain a saturated solution.
- Cool the filtrate (saturated solution) in an ice bath to allow crystals of magnesium sulphate to form.

#### Hydrated salt

This is a salt that contains water of crystallization. They contain a fixed amount of water in their crystal lattice. This is called water of crystallization. The water of crystallization is part of the structure. If this water is removed, by heating for example, the colour and shapes of the crystals may change.

## Examples of hydrated salts

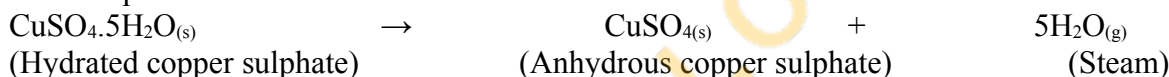
Name of crystallized salt	Formula
Copper (II) sulphate -5 water	$CuSO_4.5 H_2 O$
Sodium carbonate -10 water	$Na_2 CO_3.10 H_2 O$
Cobalt (II) chloride - 6 water	$CoCl_2.6 H_2 O$
Iron (II) sulphate - 7 water	$FeSO_4.7 H_2 O$

## Anhydrous salts

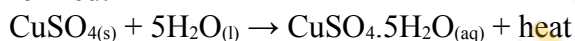
A salt which has lost its water of crystallization is called an **anhydrous salt**.

When water is added to an anhydrous salt, the salt becomes **hydrated**.

For example, when blue copper (II) sulphate crystals are heated, steam is produced and a pale- blue or white powder.



When water is added to anhydrous copper (II) sulphate heat is produced and a blue solution is formed:



This process is called **hydration**.

## Efflorescence

This is the loss of water of crystallization to the atmosphere.

### Example

Crystals of sodium carbonate - 10- water become Powderly when exposed to air.



## Deliquescence

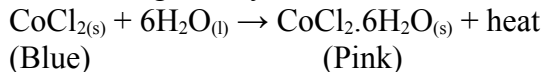
This is the absorption of water from the atmosphere to form a solution. Calcium chloride is a deliquescent salt. It is used as a drying agent in desiccators. A desiccator is a piece of equipment used to dry substances.

## Hygroscopic

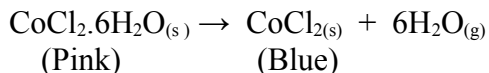
A hygroscopic substance absorbs water from the air but does not the change its state.

Anhydrous cobalt chloride is a hygroscopic salt.

Water changes anhydrous cobalt chloride from blue to pink.



This reaction is often used as a test for the presence of water. The process can be reversed by heating the pink hydrated salt:



Concentrated sulphuric acid is also hygroscopic. It can be used to dehydrate blue crystals of hydrated copper (II) sulphate forming the pale blue anhydrous salt.

## 2. Replacement (Displacement)

This is a method where the hydrogen ions in an acid are replaced by a metal. It can also be defined as a reaction in which one element displaces another from a compound



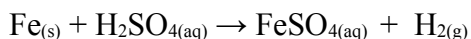
**Example: Preparation of iron (II) sulphate**

### Method

- Add iron fillings to warm dilute sulphuric acid in a beaker until no more hydrogen gas is evolved.
- Filter off the solution when the reaction is complete to remove excess iron.

-

### Reaction equation



### Note

- Iron should be in excess so that all the acid is used up.
- Air must be excluded to prevent oxidation of iron (II) sulphate.

## 3. Synthesis

This method involves the direct combination of elements for binary salts.

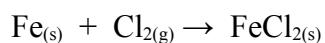
In this method, a salt is prepared directly from its elements i.e. a metal and a halogen.



**Example: Preparation of iron (II) chloride**

Iron (II) chloride can be prepared by passing chlorine gas over heated iron.

### Reaction equation



#### 4. Precipitation

Precipitation is the formation of an insoluble product and may occur on mixing two solutions.

Precipitation is an example of double decomposition. In double decomposition, two solutions are mixed to form an insoluble salt and a soluble solution.

**Soluble salt + soluble salt → insoluble salt + soluble salt**

**Soluble solution + soluble solution → insoluble solid + soluble solution**

In double decomposition reactions, cations and anions are exchanged.

Precipitation is also an example of ionic association which is the attraction of oppositely charged ions to one another to form a solid called **precipitate** abbreviated as **ppt.**

#### Preparation of insoluble salts by precipitation (Double decomposition)

##### Example 1: Preparation of silver chloride

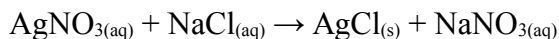
##### Reagents

- Silver nitrate,  $\text{AgNO}_3$
- Sodium chloride,  $\text{NaCl}$  (Alternatively hydrochloric acid,  $\text{HCl}$ )

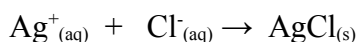
##### Products

- Silver chloride,  $\text{AgCl}$
- Sodium nitrate,  $\text{NaNO}_3$

##### Reaction equation



##### Ionic equation



##### Method of preparation

- Mix silver nitrate solution with sodium chloride solution in a beaker.

- A white precipitate of silver chloride forms.
- Allow the precipitate to settle.
- Filter off the precipitate and wash it with distilled water to remove any amount of sodium nitrate left.
- Dry the precipitate on the filter paper.
- A pure dry sample of silver chloride forms.

### Example 2: Preparation of lead (II) chloride

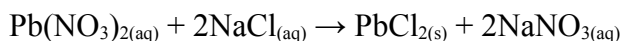
#### Reagents

- Lead (II) nitrate,  $\text{Pb}(\text{NO}_3)_2$
- Sodium chloride,  $\text{NaCl}$  (Alternatively, hydrochloric acid,  $\text{HCl}$ )

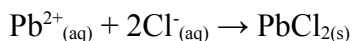
#### Products

- Lead (II) chloride,  $\text{PbCl}_2$
- Sodium nitrate,  $\text{NaNO}_3$

#### Reaction equation



#### Ionic equation



#### Method of preparation

- Mix lead (II) nitrate solution with sodium chloride solution in a beaker.
- A white precipitate of lead (II) chloride forms.
- Allow the precipitate to settle.
- Filter off the precipitate and wash it with distilled water to remove any amount sodium nitrate left.
- Dry the precipitate on the filter paper.
- A pure dry sample of lead (II) chloride forms.

### Example 3: Preparation of lead (II) iodide

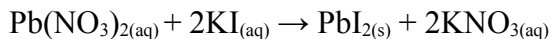
#### Reagents

- Lead (II) nitrate,  $\text{Pb}(\text{NO}_3)_2$
- Potassium iodide,  $\text{KI}$

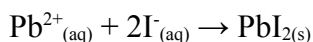
#### Products

- Lead (II) iodide,  $\text{PbI}_2$
- Potassium nitrate,  $\text{KNO}_3$

### Reaction equation



### Ionic equation



### Method of preparation

- Mix lead (II) nitrate solution with potassium iodide solution in a beaker.
- A yellow precipitate of lead (II) iodide forms.
- Allow the precipitate to settle.
- Filter off the precipitate and wash it in distilled water to remove any amount of potassium nitrate left.
- Dry the precipitate on the filter paper.
- A pure dry sample of lead (II) iodide forms.

### Example 4: Preparation of lead (II) sulphate

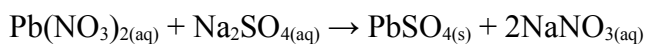
#### Reagents

- Lead (II) nitrate,  $\text{Pb}(\text{NO}_3)_2$
- Sodium sulphate,  $\text{Na}_2\text{SO}_4$  (Alternatively, sulphuric acid,  $\text{H}_2\text{SO}_4$ )

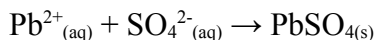
#### Products

- Lead (II) sulphate,  $\text{PbSO}_4$
- Sodium nitrate,  $\text{NaNO}_3$

### Reaction equation



### Ionic equation





### Method of preparation

- Mix lead (II) nitrate solution with sodium sulphate solution in a beaker
- A white precipitate of lead (II) sulphate forms.
- Allow the precipitate to settle.
- Filter off the precipitate and wash it with distilled water to remove any amount sodium nitrate left.
- Dry the precipitate on the filter paper.
- A pure dry sample of lead (II) sulphate forms.

### Example 5: Preparation of barium sulphate

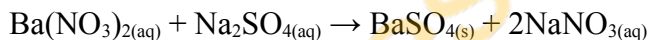
#### Reagents

- Barium nitrate,  $\text{Ba}(\text{NO}_3)_2$
- Sodium sulphate,  $\text{Na}_2\text{SO}_4$  (Alternatively, sulphuric acid,  $\text{H}_2\text{SO}_4$ )

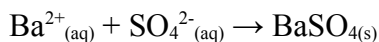
#### Products

- Barium sulphate,  $\text{BaSO}_4$
- Sodium nitrate,  $\text{NaNO}_3$

#### Reaction equation



#### Ionic equation



### Method of preparation

- Mix barium nitrate solution with sodium sulphate solution in a beaker.
- A white precipitate of barium sulphate forms.
- Allow the precipitate to settle.
- Filter off the precipitate and wash it with distilled water to remove any amount of sodium nitrate left.
- Dry the precipitate on the filter paper.
- A pure dry sample of barium sulphate forms.

### Note

Silver chloride, lead (II) chloride, lead (II) iodide, lead (II) sulphate and barium sulphate do not form crystals and therefore cannot be crystallized.

## Qualitative analysis tests

### Identification of ions.

#### Test for anions in solution

Anion in solution	Test method	Positive test result
Carbonate ion, $2-\overset{-2}{\underset{\cdot\cdot}{\text{C}}}\text{O}_3$	Add any dilute acid	Effervescence occurs and bubbles of carbon dioxide gas are produced. $\text{CO}_3^{2-}(\text{aq}) + 2\text{H}^+(\text{aq}) \rightarrow \text{CO}_2(\text{g}) + \text{H}_2\text{O}(\text{l})$
Chloride ion, $\overset{-1}{\underset{\cdot\cdot}{\text{Cl}}}$	Add a few drops of dilute nitric acid to make the solution acidified. Then add a few drops of silver nitrate.	A white precipitate of silver chloride forms. $\text{Ag}^+(\text{aq}) + \text{Cl}^-(\text{aq}) \rightarrow \text{AgCl}(\text{s})$
Iodide ion, $\overset{-1}{\underset{\cdot\cdot}{\text{I}}}$	Add a few drops of dilute nitric acid to make the solution acidified. Then add a few drops of aqueous lead (II) nitrate	A yellow precipitate of lead (II) iodide forms $\text{Pb}^{2+}(\text{aq}) + 2\text{I}^-(\text{aq}) \rightarrow \text{PbI}_2(\text{s})$
Sulphate ion, $2-\overset{-2}{\underset{\cdot\cdot}{\text{S}}}\text{O}_4$	Add a few drops of dilute nitric acid to make the solution acidified. Then add a few drops of barium nitrate.	A white precipitate of barium sulphate forms. $\text{Ba}^{2+}(\text{aq}) + \text{SO}_4^{2-}(\text{aq}) \rightarrow \text{BaSO}_4(\text{s})$
Nitrate ion, $\overset{-1}{\underset{\cdot\cdot}{\text{N}}}\text{O}_3$	Add a few drops aqueous sodium hydroxide then aluminium foil; warm carefully. Introduce red litmus paper into the test	Moist red litmus paper turns blue. Ammonia gas is produced.

	tube.	
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### Test for cations in solution

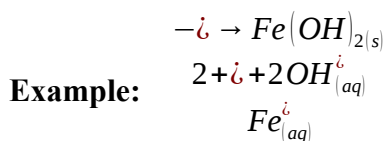
When testing for a cation using either aqueous sodium hydroxide or aqueous ammonia, two observations will help identify the cation present:

- The colour of the precipitate formed on adding a few drops of chemical reagent;
- The solubility of the precipitate in excess chemical reagent

Cation in solution	Effect of aqueous sodium hydroxide	Effect of aqueous ammonia
Aluminum, $3+\overset{+}{\underset{i}{Al}}$	White ppt, soluble in excess giving a colourless solution	White ppt, insoluble in excess
Ammonium, $+\overset{+}{\underset{i}{NH_4}}$	Ammonia gas produced on warming.	
Calcium, $2+\overset{+}{\underset{i}{Ca}}$	White ppt insoluble in excess	No ppt or very slight white ppt
Copper (II), $2+\overset{+}{\underset{i}{Cu}}$	Light blue ppt, insoluble in excess	Light blue ppt, soluble in excess giving a dark blue solution
Iron (II), $2+\overset{+}{\underset{i}{Fe}}$	Green ppt, insoluble in excess	Green ppt, insoluble in excess

Iron (III), $Fe^{3+}$	Red-brown ppt, insoluble in excess	Red-brown ppt insoluble in excess
Zinc, $Zn^{2+}$	White ppt, soluble in excess giving a colourless solution	White ppt, soluble in excess giving a colourless solution

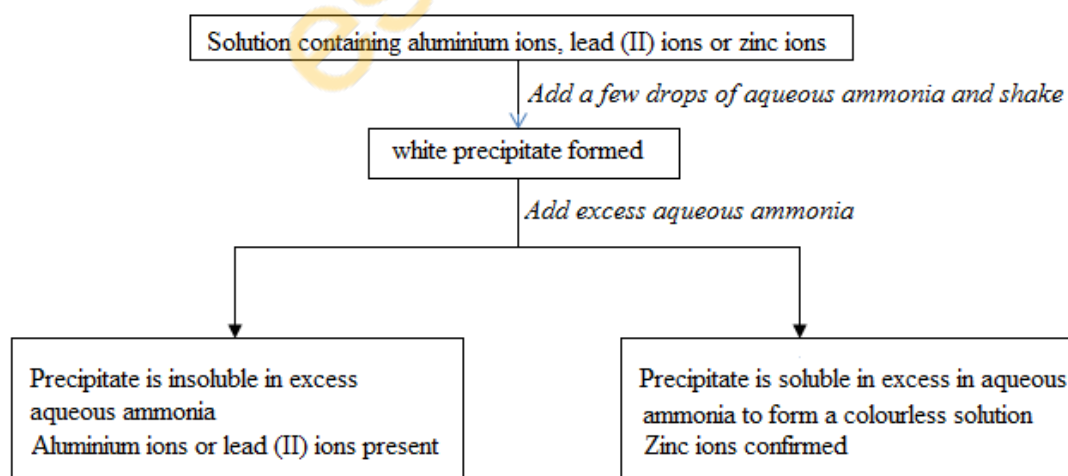
The cations react with hydroxide ions present in aqueous sodium hydroxide or ammonia to form insoluble hydroxides. These hydroxides appear as precipitates.



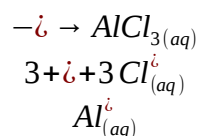
Some of these precipitates dissolve in excess aqueous sodium hydroxide or aqueous ammonia to form soluble complex salts. These appear as colourless solutions, or in the case of copper (II) ions in excess aqueous ammonia, a dark blue solution.

Copper (II), iron (II) and iron (III) ions are easily identified by the characteristic colour of their precipitates.

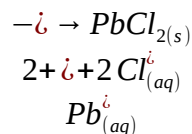
Aluminium, lead (II) and zinc ions all give the same observations when aqueous sodium hydroxide is used. However, only zinc ions will give a white precipitate soluble in excess aqueous ammonia; aluminium and lead ions do not.



To distinguish between aluminium and lead (II) ions, dilute hydrochloric acid (HCl) or aqueous potassium iodide can be used:



(from HCl) (colourless solution)



(from HCl) (white precipitate)

Similar results will be obtained if potassium iodide is used. Aluminium ions will give a colourless solution of aluminium iodide while lead (II) ions will give a yellow precipitate of lead (II) iodide.

### Test for gases

When recording observations for gases, it is important to record

- Presence of effervescences, if any
- Colour and smell of the gas
- Chemical test for the gas and test result
- Name of the gas

Gas	Colour and smell of gas	Test method	Positive test result
Oxygen, $\text{O}_2$	Colourless Odourless	Introduce a glowing splint in the test tube containing oxygen.	Relights a glowing splint
Hydrogen, $\text{H}_2$	Colourless Odourless	Introduce a burning splint in the test tube containing hydrogen.	Burns with a pop sound.
Carbon dioxide, $\text{CO}_2$	Colourless Odourless	Bubble carbon dioxide into lime water (Calcium hydroxide)	Turns lime water milky
Ammonia, $\text{NH}_3$	Colourless Pungent smell	-	Turns damp red litmus paper blue.
Chlorine, $\text{Cl}_2$	Yellow green Pungent smell	-	Turns moist blue litmus paper red, then bleached. Bleaches the moist blue litmus paper.

Sulphur dioxide, SO <sub>2</sub>	Colourless Pungent smell	-	Turns moist blue litmus red Turns orange acidified potassium dichromate (VI) green
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### Exercise

- Copper (II) sulphate crystals, CuSO<sub>4</sub>.5H<sub>2</sub>O, are soluble in water. Describe how these crystals could be prepared from a named acid and a suitable compound of copper.
- Will the method in 1 above be suitable to prepare a sample of potassium chloride? Give a reason for answer.
- Barium sulphate (BaSO<sub>4</sub>) is an insoluble salt which is prepared by precipitation.
  - Using sodium sulphate as one of the reactants:
    - Name the other reactant you would use to prepare barium sulphate
    - Write a balanced chemical equation for the reaction. Include state symbols.
    - Write an ionic equation for the reaction.
  - Briefly explain how you would obtain a fairly pure dry sample of the salt.
  - Name one salt that can be prepared by the reaction of a metal with a dilute acid.
- Silver chloride is an insoluble salt where as magnesium sulphate is a soluble salt.
  - Describe how you would prepare a pure dry sample of silver chloride naming the reagents used.
  - Write an ionic equation for the reaction involved.
  - The following procedure was used by Darlington Naosa junior to prepare magnesium sulphate crystals: "Dilute sulphuric acid was put in a beaker and an excess of magnesium carbonate was added to the acid. The mixture stirred and filtered. The filtrate obtained was evaporated to half its original volume. The filtrate was then cooled in an ice bath". State why :-
    - An excess of magnesium carbonate was added to dilute sulphuric acid.
    - The reaction mixture was filtered.
    - The filtrate was evaporated to half its original volume.
    - The filtrate was cooled.

5. Sodium phosphate,  $\text{Na}_3\text{PO}_4$ , is a soluble salt, used as water softener in washing powders.

It is made by reacting dilute phosphoric acid,  $\text{H}_3\text{PO}_4$ , with an alkali.

(a) Give the formula of the ions present in sodium phosphate.

(b) (i) Name the alkali which reacts with phosphoric acid to make sodium phosphate.

(ii) Write an equation for this reaction.

(c) Given solutions of phosphoric acid and an alkali, a suitable indicator and standard laboratory apparatus, explain how you would obtain crystals of sodium phosphate.

(d) Sodium carbonate also reacts with phosphoric acid to make sodium phosphate.

(i) Name the gas formed during this reaction.

(ii) Describe the test for this gas.

(e) Calcium sulphate is used to make fertilizers.

(i) Deduce the formula of calcium phosphate.

(ii) What essential plant element does calcium phosphate provide?

## Reduction and oxidation

Reduction and oxidation can be defined in terms of oxygen, hydrogen, electrons and oxidation number.

### Oxidation

#### Oxidation in terms of oxygen

Oxidation is the addition of oxygen to a chemical substance.

#### Examples



Magnesium has been oxidized to magnesium oxide since oxygen has been added

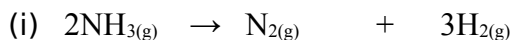


Iron (II) oxide ( $\text{FeO}$ ) has been oxidized to iron (III) oxide ( $\text{Fe}_2\text{O}_3$ ) since oxygen has been added.

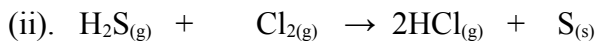
#### Oxidation in terms of hydrogen

Oxidation is the removal of hydrogen from a chemical substance.

#### Examples



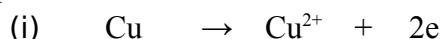
Ammonia ( $\text{NH}_3$ ) has been oxidized to nitrogen ( $\text{N}_2$ ) since hydrogen has been removed.



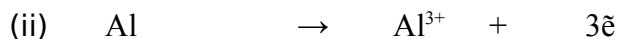
Hydrogen sulphide ( $\text{H}_2\text{S}$ ) has been oxidized to sulphur ( $\text{S}$ ) since hydrogen has been removed.

**Oxidation in terms of electrons.**

Oxidation is the loss of electrons from a chemical substance.

**Examples**

Copper atoms (Cu) have been oxidized to copper (II) ions ( $\text{Cu}^{2+}$ ) since two electrons have been lost.



Aluminum atoms (Al) have been oxidized to aluminum ions ( $\text{Al}^{3+}$ ) since three electrons have been lost.



Chloride ions ( $\text{Cl}^-$ ) have been oxidized to chlorine molecules ( $\text{Cl}_2$ ) since electrons have been lost.

**Oxidation number.****Rules to consider when assigning the oxidation number**

1. The oxidation number of neutral particles like atoms and molecules is equal to Zero.

**Examples**

$\text{Cu}^0$	Oxidation number = 0	$\text{Al}^0$	Oxidation number = 0	$\text{Cl}_2^0$	Oxidation number = 0
$\text{Na}^0$	Oxidation number = 0	$\text{Fe}^0$	Oxidation number = 0	$\text{H}_2^0$	Oxidation number = 0
$\text{Mg}^0$	Oxidation number = 0	$\text{Zn}^0$	Oxidation number = 0	$\text{O}_2^0$	Oxidation number = 0

2. The oxidation number of hydrogen in all compounds except metallic halides is +1
3. The oxidation number of oxygen in all compounds except in peroxides and in  $\text{OF}_2$  is -2.
4. For some metals the oxidation number is equal to the group number on the periodic table or the valence.
5. The oxidation number of a simple ion is equal to the charge it carries.

**Examples**

Ion	Formula	oxidation number
Aluminium ion	$3+\overset{+}{\underset{i}{\text{Al}}}$	+3
Calcium ion	$2+\overset{+}{\underset{i}{\text{Ca}}}$	+2
Chloride ion	$\overset{-}{\underset{i}{\text{Cl}}}$	-1



Nitride ion	$3-\overset{+}{\underset{\cdot\cdot}{\text{N}}}$	-3
Oxide ion	$2-\overset{+}{\underset{\cdot\cdot}{\text{O}}}$	-2
Sodium ion	$+\overset{+}{\underset{\cdot\cdot}{\text{Na}}}$	+1

6. In neutral compounds, the sum of individual elements present is equal to zero.

### Examples

a) Find the oxidation number of

(i) Sulphur in  $\text{SO}_2$

(ii) Sulphur in  $\text{H}_2\text{SO}_4$

### Solution\_

$$(i) \quad x + (-2) 2 = 0$$

$$x + (-4) = 0$$

$$x - 4 = 0$$

$$x = +4$$

$$(ii) \quad (1 \times 2) + x + (-2) 4 = 0$$

$$2 + x - 8 = 0$$

$$x - 6 = 0$$

$$x = +6$$

7. The sum of all oxidation numbers of all elements in a complex ion is equal to the charge on the ion.

### Examples

a) Find the oxidation number of

(i) Carbon in  $\text{HCO}_3^-$

(ii) Sulphur in  $\text{SO}_4^{2-}$

### Solution\_

$$(i) \quad 1 + x + (-2)3 = -1$$

$$x + 1 - 6 = -1$$

$$x - 5 = -1$$

$$x = +5 - 1$$

$$x = +4$$

$$(ii) \quad x + (-2)4 = -2$$

$$x - 8 = -2$$

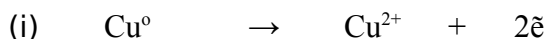
$$x = +8 - 2$$

$$x = +6$$

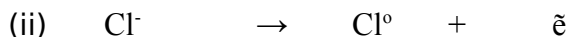
### Oxidation in terms of oxidation number

Oxidation is the increase in the oxidation number of a substance.

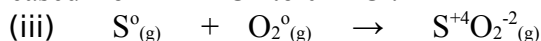
### Examples



Copper atoms (Cu) have been oxidized to copper (II) ions ( $\text{Cu}^{2+}$ ) because the oxidation number has increased from 0 in Cu to +2 in  $\text{Cu}^{2+}$ .



A Chloride ion ( $\text{Cl}^-$ ) has been oxidized to chlorine atom (Cl) since the oxidation number has increased from -1 in  $\text{Cl}^-$  to 0 in Cl.



Sulphur (S) has been oxidized to sulphur dioxide ( $\text{SO}_2$ ) since the oxidation number has increased from 0 in S to +4 in  $\text{SO}_4$ .

### **Oxidizing agents (oxidants)**

An oxidizing agent is a chemical substance which brings about oxidation of another substance but end up being reduced.

#### **Examples of oxidizing agents.**

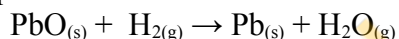
- Oxygen,  $\text{O}_2$
- Chlorine,  $\text{Cl}_2$
- Hydrogen peroxide,  $\text{H}_2\text{O}_2$
- Potassium permanganate,  $\text{KMnO}_4$
- Manganese dioxide (manganese (IV) oxide),  $\text{MnO}_2$
- Concentrated Sulphuric acid,  $\text{H}_2\text{SO}_4$

### **Characteristics of an oxidizing agent.**

#### **An oxidizing agent: -**

(a) Supplies or donates oxygen to another substance

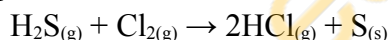
#### **Example**



Lead (II) oxide ( $\text{PbO}$ ) is an oxidizing agent because it has donated oxygen to hydrogen

(b) Removes hydrogen from another substance

#### **Example**

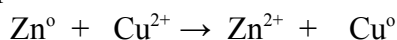


Chlorine ( $\text{Cl}_2$ ) is an oxidizing agent because it has removed hydrogen from hydrogen sulphide ( $\text{H}_2\text{S}$ )

(c) Accept electrons from another substance.

(d) Increases the oxidation number of another substance.

#### **Example**



Copper (II) ion ( $\text{Cu}^{2+}$ ) is an oxidizing agent because it has caused the increase in the oxidation number of Zinc from 0 in Zn to +2 in  $\text{Zn}^{2+}$ .

### **Test for oxidizing agents.**

An oxidizing agent can be tested by using acidified potassium iodide, KI or concentrated hydrochloric acid.

Oxidizing agents liberate iodine from a solution of acidified potassium iodide.

They turn moist starch iodide paper from white to blue. Starch iodide paper contains starch and potassium iodide. The iodide ion is oxidized to form iodine.



The iodine reacts with starch to produce a blue colour.

## Reduction

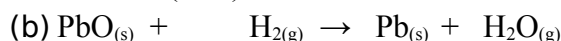
### Reduction in terms of oxygen

Reduction is the removal of oxygen from a chemical substance.

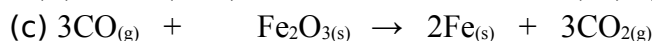
#### Examples



Carbon dioxide ( $\text{CO}_2$ ) has been reduced to carbon monoxide (CO) since oxygen has been removed.



Lead (II) oxide ( $\text{PbO}$ ) has been reduced to lead (Pb) by the removal of oxygen.



Iron (III) oxide ( $\text{Fe}_2\text{O}_3$ ) has been reduced to iron (Fe) by the removal of oxygen.

### Reduction in terms of hydrogen.

Reduction is the addition of hydrogen to a chemical substance.

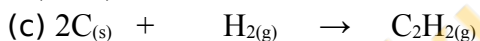
#### Examples



Nitrogen ( $\text{N}_2$ ) has been reduced to ammonia ( $\text{NH}_3$ ) since hydrogen has been added.



Ethene ( $\text{C}_2\text{H}_4$ ) has been reduced to ethane ( $\text{C}_2\text{H}_6$ ) by the addition of hydrogen

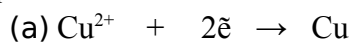


Carbon (C) has been reduced to ethyne ( $\text{C}_2\text{H}_2$ ) by the addition of hydrogen.

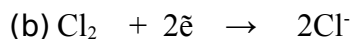
### Reduction in terms of electrons

Reduction is the gain of electrons.

#### Examples



Copper (II) ions ( $\text{Cu}^{2+}$ ) have been reduced to copper atoms (Cu) by gaining two electrons.

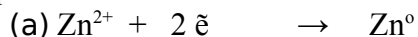


Chlorine molecules ( $\text{Cl}_2$ ) have been reduced to chloride ions ( $\text{Cl}^{-}$ ) by gaining two electrons.

### Reduction in terms of oxidation number

Reduction is the decrease in the oxidation number of a chemical substance.

#### Examples



Zinc ions ( $\text{Zn}^{2+}$ ) have been reduced to Zinc atoms (Zn) since the oxidation number has decreased from +2 in  $\text{Zn}^{2+}$  to 0 in Zn.

### Reducing agents (Reductants)

A reducing agent is a chemical substance which brings about reduction but end up being oxidized.

**Examples of reducing agents.**

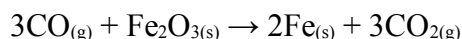
- Hydrogen,  $H_2$
- Carbon monoxide,  $CO$
- Carbon,  $C$
- Ammonia,  $NH_3$
- Hydrogen sulphide,  $H_2S$
- Sulphur dioxide,  $SO_2$

**Characteristics of a reducing agent.**

**A reducing agent: -**

- (a) Removes oxygen from another substance

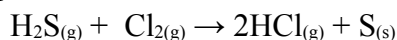
**Example**



Carbon monoxide ( $CO$ ) is a reducing agent because it has removed oxygen from iron (III) oxide ( $Fe_2O_3$ )

- (b) Donates or supplies hydrogen to another sustenance

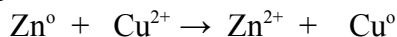
**Example**



Hydrogen sulphide ( $H_2S$ ) is a reducing agent because it has donated hydrogen to chlorine.

- (c) Donates electrons to another substance  
(d) Decreases the oxidation number of another substance

**Example**

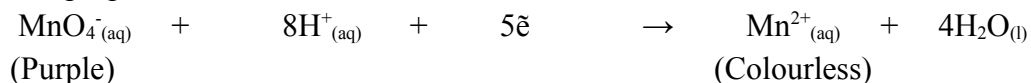


Zinc atom ( $Zn$ ) is a reducing agent because it has caused the decrease in the oxidation number of copper (II) ions from +2 in  $Cu^{2+}$  to 0 in  $Cu$ .

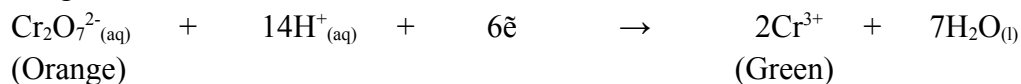
**Test for reducing agents.**

Reducing agents can be tested by using acidified potassium permanganate or acidified potassium dichromate (VI)

1. Reducing agents change the colour of the solution of potassium permanganate (VII) from purple to colourless.



2. Reducing agents change a solution of acidified potassium dichromate (VI) from orange to green.

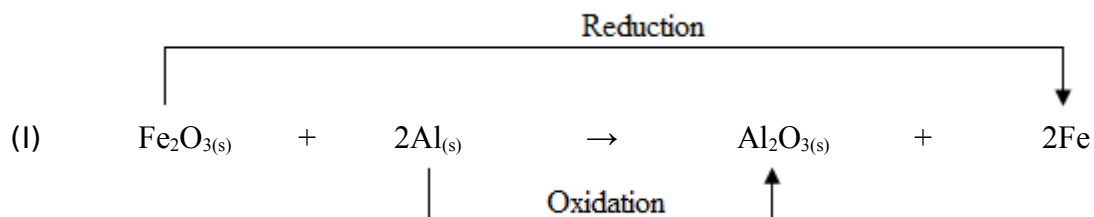


In both tests, the electrons come from the reducing agent.

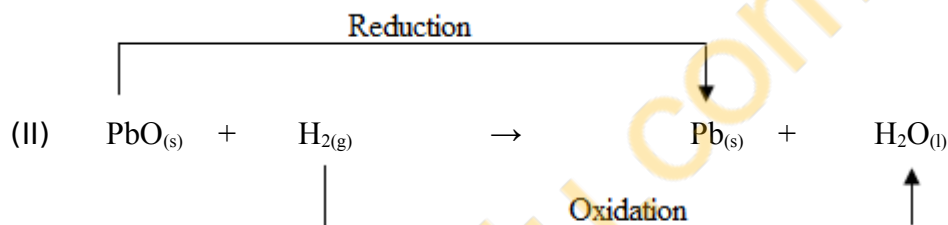
## Redox reactions

Reduction and oxidation reactions are called redox reactions because they occur simultaneously. When one substance is reduced, the other one is oxidized.

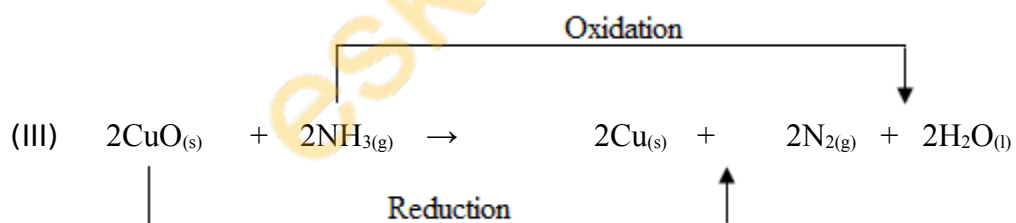
### Examples of redox reactions



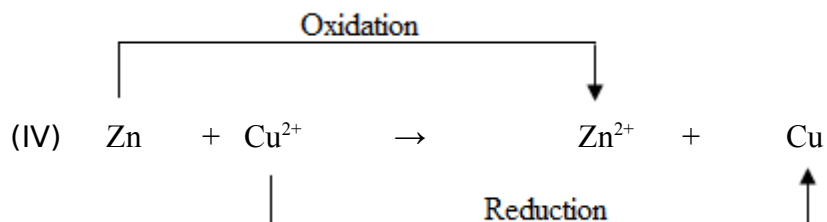
Iron (III) oxide ( $\text{Fe}_2\text{O}_3$ ) has been reduced to iron ( $\text{Fe}$ ) while aluminium ( $\text{Al}$ ) has been oxidized to aluminium oxide,  $\text{Al}_2\text{O}_3$ .



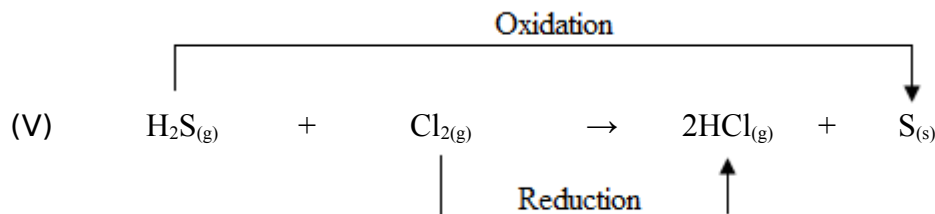
Lead (II) oxide ( $\text{PbO}$ ) has been reduced to lead ( $\text{Pb}$ ) while hydrogen ( $\text{H}_2$ ) has been oxidized to water ( $\text{H}_2\text{O}$ ).



Copper (II) oxide ( $\text{CuO}$ ) has been reduced to copper ( $\text{Cu}$ ) while ammonia ( $\text{NH}_3$ ) has been oxidized to nitrogen ( $\text{N}_2$ ).



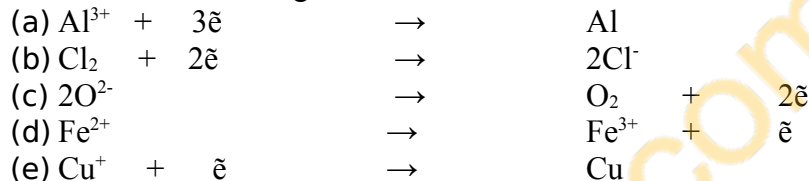
Zinc (Zn) has been oxidized to zinc ion ( $\text{Zn}^{2+}$ ) while copper (II) ion ( $\text{Cu}^{2+}$ ) has been reduced to copper (Cu).



Hydrogen sulphide ( $\text{H}_2\text{S}$ ) has been oxidized to sulphur (S) while chlorine molecules ( $\text{Cl}_2$ ) have been reduced to hydrogen chloride (HCl)

### Exercise

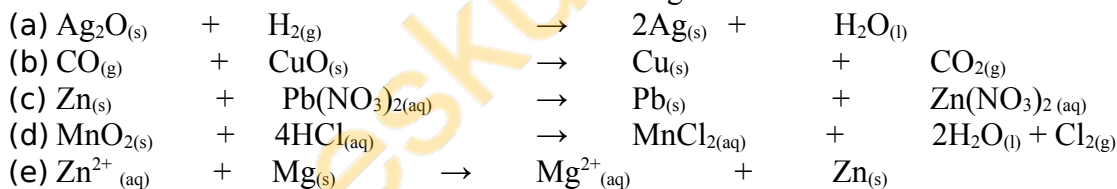
1. Which of the following reactions is oxidation and which is reduction?



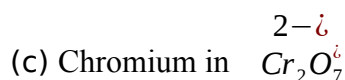
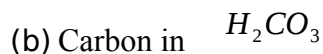
2. State whether the underlined substance has been oxidized or reduced.



3. Indicate reduction and oxidation in the following redox reactions.



4. Find the oxidation number of



### Rates of chemical reactions

Definition: Rate of chemical reaction is the speed at which the reaction takes place

Formula: Rate of reaction = 
$$\frac{\text{change in amount of reactants/ products}}{\text{time taken}}$$

### Measuring the rate of reaction

The rate of reaction can be measured by measuring:

- how quickly a product is obtained
- how quickly a reactant is used up

### Example

Consider the reaction below;

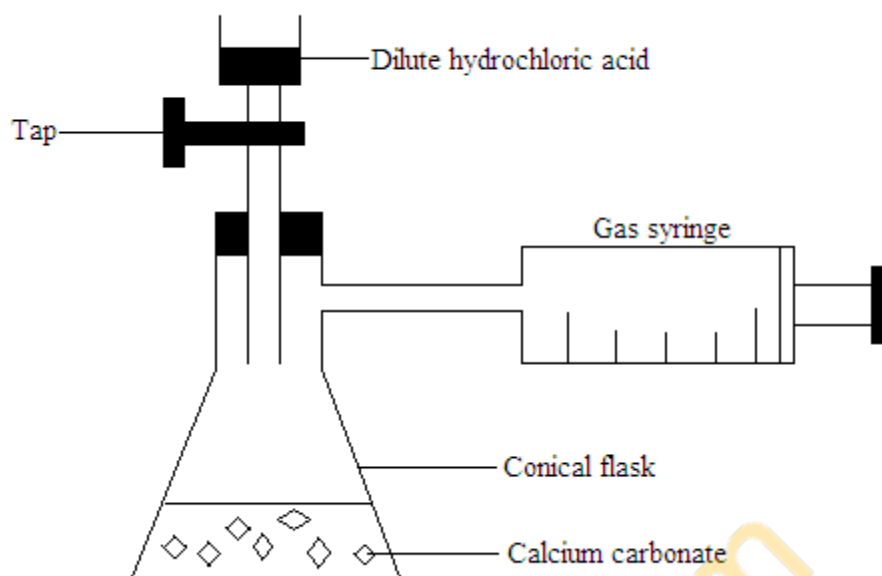


In the reaction above, the rate of reaction can be measured by measuring:

- The volume of carbon dioxide over time
- The decrease in mass of the system due loss of carbon dioxide

### [A] Measuring the rate of reaction by measuring the volume of the gas produced

A graduated syringe is used to measure the volume of carbon dioxide gas formed over time



The total volume of carbon dioxide given off at one minute interval is recorded

The graph of total volume of carbon dioxide against time is plotted

The gradient of the graph is calculated

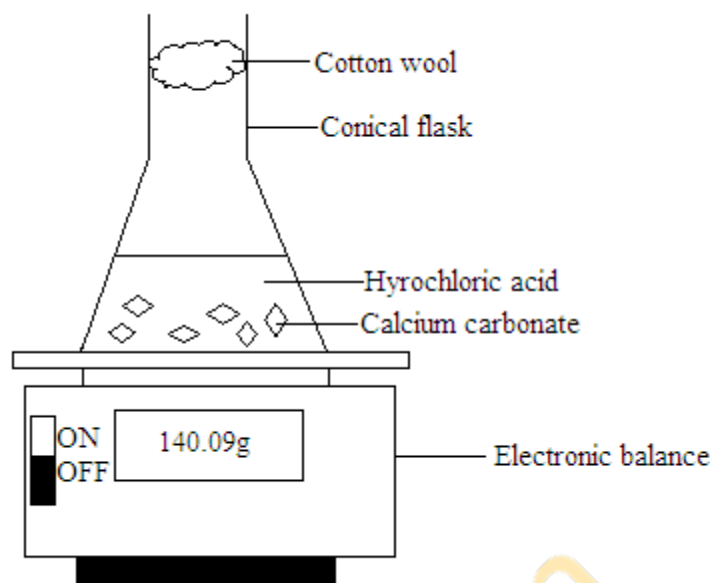
The gradient of the graph is equal to the rate of reaction

$$\text{Rate of reaction} = \frac{\text{volume of carbon dioxide}}{\text{time taken}}$$

### **[B] Measuring the rate of reaction by measuring the decrease in mass of a system due to loss of product**

A mass balance is used to follow the loss in mass of a system





The mass readings will drop over time as the carbon dioxide gas formed escapes. The mass readings are taken at one minute intervals and plotted against time

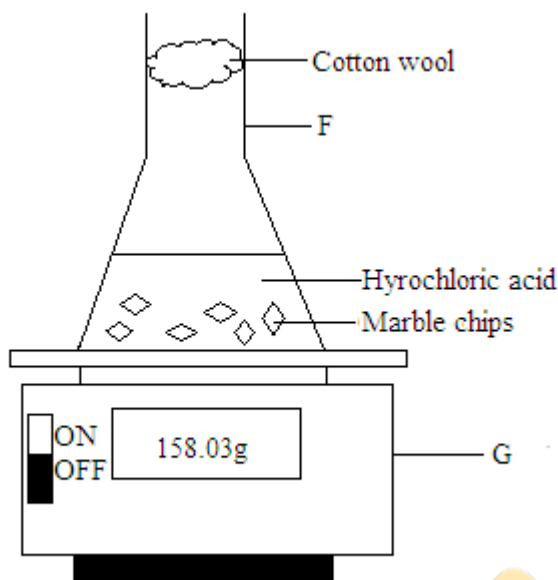
The gradient of the graph at various points of the curve will give the rate of reaction. The reaction is fastest at the start because the gradient of the graph is the highest. The value of the gradient decreases with time and finally becomes zero. This means that as the reaction proceeds, the reaction slows down and finally comes to a stop.

#### Note

- The cotton wool is used as a stopper. It will allow the escape of carbon dioxide into the atmosphere and prevent the solution inside the conical flask from splashing out.
- The mass decreases as the reaction proceeds because of the loss and escape of carbon dioxide into the atmosphere
- When the curve levels off, it means the reaction has stopped

#### Exercise

1. The rate of reaction between dilute hydrochloric acid and marble chips (calcium carbonate) was investigated using the following apparatus



- Name the piece of apparatus labeled F and G
- Why was the cotton wool placed in the neck of the apparatus F?
- Name two compounds left in the solution at the end of the experiment
- Why did the mass decrease as the reaction proceeds?

### The collision theory

The collision theory states that: For a reaction to take place, the particles of the reacting substances must move and collide with each other with a certain amount of kinetic energy.

The number of collisions taking place per unit time depends on the number of particles

If the particles are increased, the number of collisions also increases

### Factors affecting the rate of reaction

- Concentration
- Temperature
- Pressure
- Surface area (size of particles)
- Catalyst

### Effects of concentration on the rate of reaction

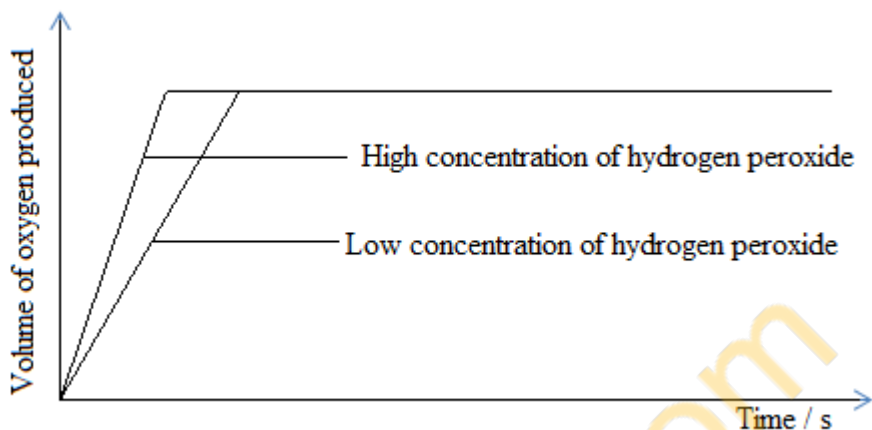
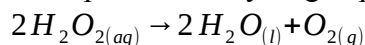
Concentration refers to the reactants in solution

When concentration is increased, the rate of reaction also increases. This is because the number of particles in the solution increases and collides with each other effectively.

On the other hand, when concentration is reduced, the rate of reaction also reduces. This is because the number of particles in the solution reduces and do not collide effectively.

### Graphical representation of concentration

**Example:** Decomposition of hydrogen peroxide



### Effects of temperature on the rate of reaction

Temperature is the measure of the average kinetic energy of the particles

When temperature is increased, the rate of reaction also increases. This is because the particles gain kinetic energy and move faster and collide effectively

On the other, when temperature is reduced, the rate of reaction also reduces. This is because the particles lose kinetic energy and move slower and do not collide effectively

#### Note

Temperature increases the rate of reactions for endothermic reactions

### Effects of pressure on the rate of reaction

Pressure becomes a dominant factor in reactions involving gases

When pressure is increased, the rate of reaction also increases. This is because the volume reduces forcing the gas particles closer together and collides effectively

On the other hand, when pressure is reduced, the rate of reaction also reduces. This is because the volume increases and the gas particles are further apart and do not collide effectively

### Effects of surface area (particle size) on the rate of reaction

Particle size usually refers to particles of a solid reactant

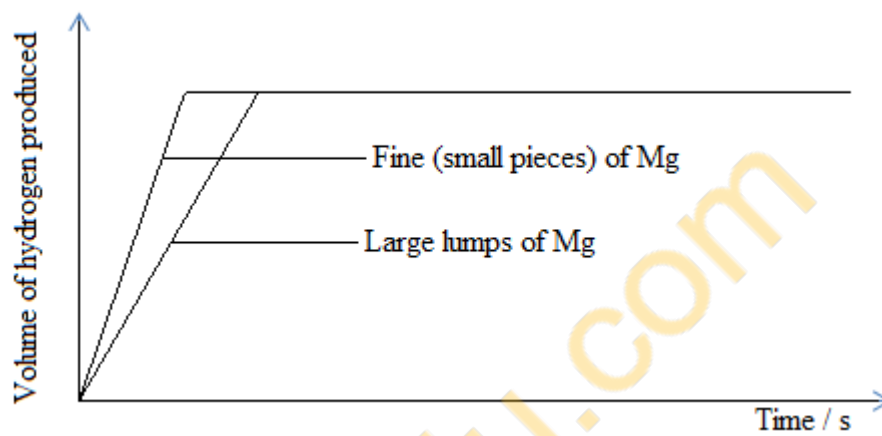
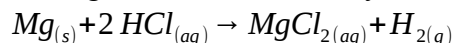
The rate of reaction is faster when the size of particles is small. This is because a small sized particle has a large surface area.

#### Note

- When a reactant is in solid state, the reaction takes place on the surface of the solid. By breaking up the solid into smaller pieces, the surface area is increased giving a greater area for collisions to occur. This results in an increase of the rate of reaction.
- This explains why mixtures of saw dust, fine products of flour mills and combustion of gases can cause an explosion due to the large surface area.

### Graphical representation of surface area

**Example:** Reaction of magnesium with dilute hydrochloric acid



### Effects of a catalyst on the rate of reaction

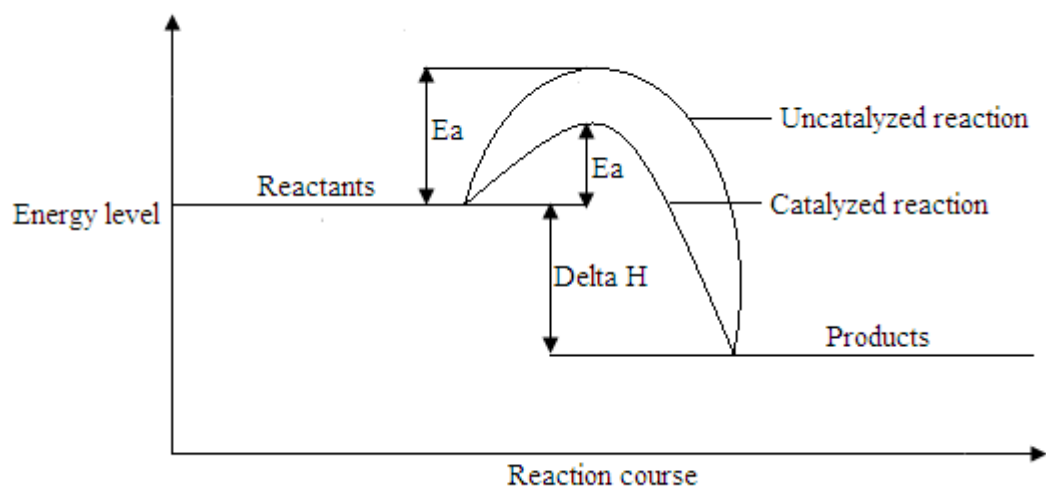
A catalyst is a chemical substance which alters the rate of reaction but remains chemically unchanged at the end of the reaction.

A catalyst usually speeds up the reaction by lowering the activation energy of the reaction.

### Activation energy

Symbol:  $E_a$

Definition: Activation energy is the minimum energy required to start a reaction. As a result, a catalyst allows a reaction to go by a different pathway with lower activation energy allowing more collisions for a successful reaction.



Activation energy is usually the energy barrier because if any collision is not energetic enough, the reaction will be futile

Some catalysts slow down the reactions; these are called inhibitors (negative catalysts)

#### Characteristics of a catalyst

1. It catalyzes both the forward and reverse reaction
2. It undergoes physical change
3. It remains chemically unchanged at the end of the reaction
4. It is only needed in very small amounts
5. It is poisoned or rendered useless in the presence of impurities

#### Examples of some catalysts used for important reactions

Catalyst	Reaction catalyzed
Aluminium oxide	Cracking of alkanes
Iron	Haber process: Production of ammonia
Manganese (IV) oxide	Decomposition of hydrogen peroxide
Vanadium pentoxide	Contact process: Manufacture of sulphuric acid
Nickel	Hydrogenation of vegetable oils

#### Chemical equilibrium

Equilibrium is the point where the rate of forward reaction is equal to the rate of reverse reaction.

#### Reversible reactions

Symbol for reversible reactions:  $\rightleftharpoons$

Definition: A reversible reaction is a reaction that proceeds in the forward and backward directions. It follows that if the reaction is exothermic, then the reverse reaction will be endothermic and vice versa

**Example:**  $A + B \rightleftharpoons C + D$

The double headed arrow shows that the reaction is a reversible reaction

## Characteristics of equilibrium reactions

1. Rate of forward reaction is equal to rate of backward reaction
2. Concentration of reactants and products remain constant at equilibrium
3. An equilibrium can only be established in a closed system
4. There is no loss or gain of external materials by the reacting system

## Le Chatelier's Principle

The principle states that: If an equilibrium is disturbed by a changing the conditions the reaction moves to counteract the change

### Factors that affect the position of equilibrium

#### Temperature changes

Temperature variations changes the position of the equilibrium of either endothermic or exothermic reactions

An increase in temperature favors the forward reaction of endothermic reaction while a decrease in temperature will shift the equilibrium backwards

#### Example



In thermal decomposition of ammonium chloride, temperature increase cause equilibrium to shift to the right producing ammonia and hydrogen chloride. On the other hand, when temperature is reduced, equilibrium shifts to the left and the backward reaction is favored producing ammonium chloride

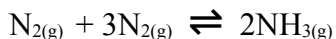
#### Concentration changes

Generally, an increase in concentration of the reactants of an equilibrium reaction favors the forward reaction. This is because the equilibrium will adjust itself so as to offset the effect of adding more reactants. On the other hand, if the concentration of products is increased, the backward reaction will be favored so that the reactants are produced to restore the balance

#### Pressure changes

In gaseous systems, an equilibrium reaction is followed by volume change. Therefore, the equilibrium is affected by change in pressure.

#### Example



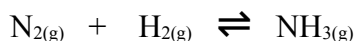
In the production of ammonia, there is a general decrease in volume and a consequent increase in pressure. Therefore, an increase in pressure will make the equilibrium shift towards the reduction of volume. This means the forward reaction is favored and more ammonia is produced.

Consequently, a decrease in pressure leads to the production of nitrogen and hydrogen; it favors the backward reaction

Generally, gaseous reactions that lead to reduction in volume are favored by high pressure.

#### Exercise

1. The gas ammonia is made industrially by Haber process. In process nitrogen and hydrogen gases are reacted together, as in the equation



- (a) Balance the equation
- (b) What does the notation  $\leftrightarrow$  show about the reaction?
- (c) Ammonia is removed from the reaction mixture by cooling until it condenses. How does this affect the formation of ammonia
- (d) How does an increase in pressure affect the position of equilibrium?
- (e) State Le Chatelier's principle
- (f) Mention any two characteristics of an equilibrium reaction

### Energy changes

Alternative term: Energetics

Energetics refers to the energy changes that characterize chemical reactions

### Terms related to energy changes

#### Enthalpy

Symbol: H

Definition: This is the total energy in one mole of a substance

It is also the heat content of a reacting system

It depends on the physical state of the compound and varies from compound to compound

#### Enthalpy change of reaction

Symbol:  $\Delta H$  (delta H)

Formula:  $\Delta H = H_{\text{products}} - H_{\text{reactants}}$

Units: Kilojoules per mole, KJ/mol

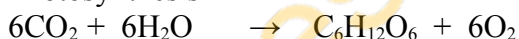
Definition: This is the difference between the enthalpy of the products and the enthalpy of the reactants

#### Endothermic reaction

This is a reaction which absorbs heat energy from the surroundings

#### Examples of endothermic reactions

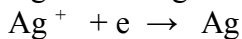
- (a) Photosynthesis



- (b) Photography

The essential reaction in photography is the reduction of silver ions to metallic silver

With exposure to light energy, the silver salts decompose into ions as follows:



Light is usually absorbed to dissociate silver salts

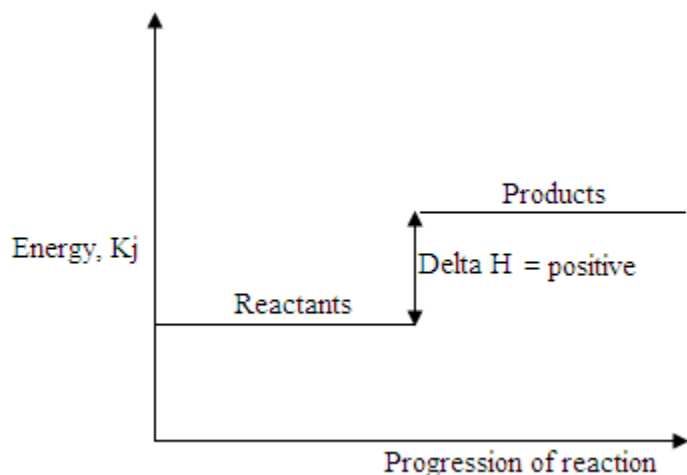
- (c) Dissolving processes such as dissolving ammonium nitrate or potassium nitrate in water.

Endothermic reaction is a bond breaking process

In endothermic reaction;

- Energy is absorbed from the surroundings
- Reactants have less energy than products
- $\Delta H$  is positive
- Temperature of the system falls

### Energy level diagram for endothermic reactions



### Exothermic reaction

This is a reaction in which energy is released to the surroundings

#### Examples of exothermic reactions

(a) Combustion

(b) Tissue respiration



(c) Dissolving sodium hydroxide crystals in water

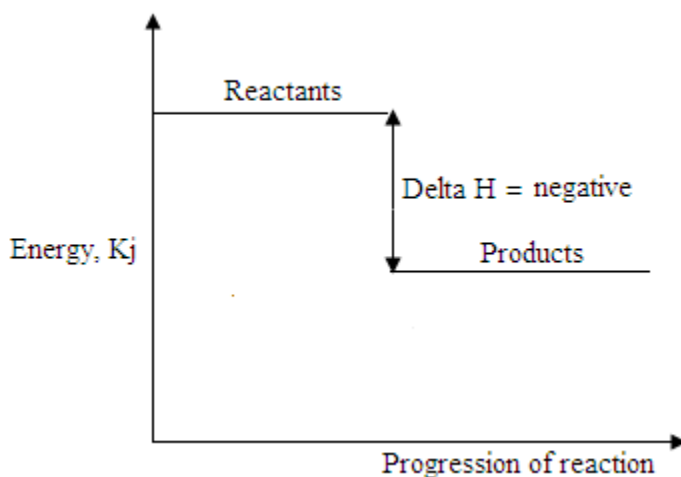
Exothermic reaction is a bond forming process

In exothermic reactions;

- Energy is released to the surroundings
- Reactants have more energy than products
- $\Delta H$  is negative
- Temperature of the system increases
- Bonds formed are relatively stronger than bonds broken

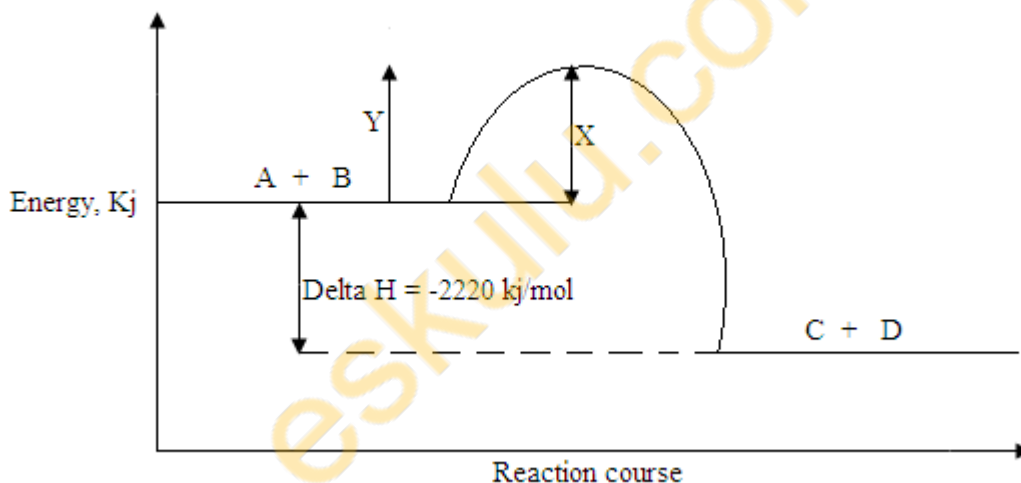
### Energy level diagram for exothermic reactions





### Example

- The diagram below is an energy level diagram for the combustion of propane in plentiful supply of air



Use the information above to answer the following questions

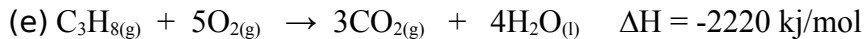
- Given that A = propane, B = oxygen, C = carbon dioxide and D = water, write down a balanced chemical equation including state symbols for the reaction between propane and oxygen
- State the molar enthalpy change of combustion of propane
- What is X?
- What is the purpose of Y?
- How much heat is energy is released to the surroundings when 2.2g of propane is burnt completely in oxygen?

### Solution

- $\text{C}_3\text{H}_{8(g)} + 5\text{O}_{2(g)} \rightarrow 3\text{CO}_{2(g)} + 4\text{H}_2\text{O}_{(l)}$
- $\Delta H = -2220 \text{ kJ/mol}$

(c) Activation energy

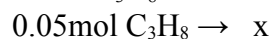
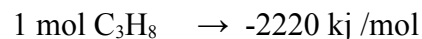
(d) To start a chemical reaction



$$n(\text{C}_3\text{H}_8) = \frac{m}{MM}$$

$$n = \frac{2.2 \text{ g}}{44 \text{ g/mol}}$$

$$n = 0.05 \text{ mol}$$



$$x = \frac{0.05 \text{ mol} \times (-2220 \text{ kJ/mol})}{1 \text{ mol}}$$

$$x = -1110 \text{ KJ/mol}$$

2. When carbon is burnt in air, heat is released to the surroundings

(a) State with reason, whether the reaction is an endothermic or exothermic process.

(b) When 1.2g of carbon is completely burned in air, 39KJ of heat is liberated

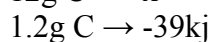
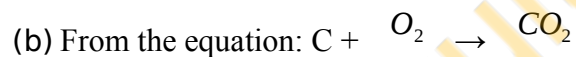
Calculate the enthalpy of combustion of carbon

(c) Draw the energy level diagram for the burning of carbon

### Solution

(a) Exothermic process

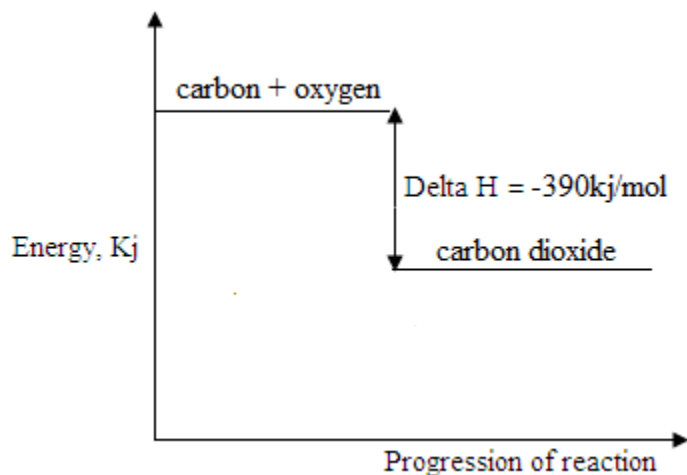
Reason: Heat is released to the surroundings



$$x = \frac{12 \text{ g} \times (-39 \text{ KJ/mol})}{1.2 \text{ g}}$$

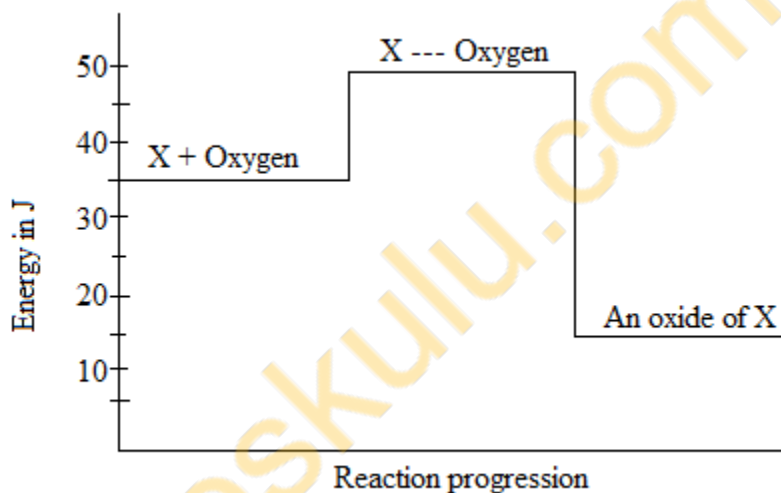
$$x = -390 \text{ kJ/mol}$$

(c)

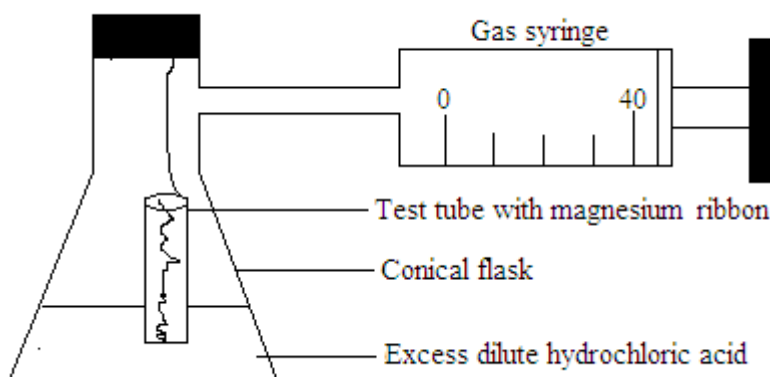


### Exercise

- Below is the energy level diagram for the combustion of one mole of an unknown fuel X



- State the type of reaction represented by the diagram
  - State the energy levels for:
    - reactants
    - products
  - Calculate the energy change for this reaction
  - State one example of an endothermic reaction in every day experiences
  - What scientific term is used to describe the amount of energy required for the reaction to occur?
- The rate of reaction between magnesium ribbon and an excess of dilute hydrochloric acid could be measured using the apparatus shown below

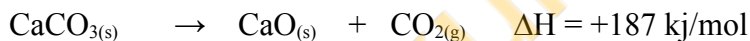


- (a) What was the purpose of the test tube?  
 (b) How do you get the reaction to start?  
 (c) The volume of hydrogen produced was recorded every minute as shown in the table below

Time / minutes	0	1	2	3	4	5	6	7
Volume of hydrogen gas / cm <sup>3</sup>	0	1	2	3	38	4	4	4
		4	3	1		0	0	0

- (I) Plot the results on the graph and draw the graph  
 (II) What was the total volume of hydrogen produced when the reaction was over  
 (III) Why did the reaction stop?  
 (IV) How do you make the reaction go faster?

3. Consider the reaction below



- (a) State whether the reaction is exothermic or endothermic. Give a reason  
 (b) Draw the energy level diagram for this reaction  
 (c) When calcium oxide reacts with carbon dioxide, will heat be given out or taken in?  
 (d) Calculate the energy change when 88g of carbon dioxide reacts with excess of calcium oxide

### Bond energy

Alternative term: Bond enthalpy

Definition: This is the amount of energy required to either break the bond or energy released when one mole of bond is formed

### Calculating enthalpy change using bond energies

Formula:  $\Delta H = \sum \text{bond energies of reactants} - \sum \text{bond energies of products}$

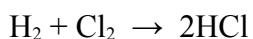
#### Example

1. Calculate the enthalpy change for the reaction between hydrogen and chlorine gas given the following bond energies

Bond	Bond energy, KJ/mol
Cl – Cl	243

H – H	436
H – Cl	431

### Solution



$$\Delta H = \sum \text{bond energies of reactants} - \sum \text{bond energies of products}$$

$$= (436 + 243) - (2 \times 431)$$

$$= 679 - 862$$

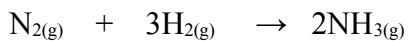
$$= -183\text{Kj/mol}$$

### Exercise

1. Some bond enthalpy terms in kj/mol are shown in the table below

H – H	C – Cl	H – Cl	N $\equiv$ N	N – H
+436	+242	+431	+945	+389

Calculate the enthalpy change for the reaction:



## Electrochemistry

### Electrolysis

Electrolysis is the decomposition of an electrolyte by using an electric current

### Electrolyte

An electrolyte is a substance which conduct electricity in fused (molten) or in solution and is thereby decomposed

**Examples of electrolytes**

- Aqueous sulphuric acid
- Aqueous hydrochloric acid
- Nitric acid
- Aqueous sodium chloride
- Aqueous sodium hydroxide
- Aqueous carbonic acid
- Aqueous ethanoic acid

**Strong electrolyte**

It is a substance which ionizes completely and produces a lot of ions in solution which are able to carry out an electric current rapidly.

**Examples of strong electrolytes**

- Aqueous sodium hydroxide
- Aqueous sodium chloride
- Aqueous copper (II) sulphate
- Aqueous hydrochloric acid
- Aqueous sulphuric acid
- Aqueous nitric acid

**Weak electrolyte**

It is a substance which ionizes partially and it conducts electric current only slightly and therefore undergoes slight decomposition

**Examples of weak electrolytes**

- Carbonic acid
- Organic acids e.g. ethanoic acid

**Non electrolyte**

It is a substance which does not conduct electricity I fused or in solution state

**Examples of non-electrolytes**

- Sugar solution
- Ethanol
- Petrol
- Benzene

- Tetra chloromethane

They do not conduct electricity because they exist only in form of molecules and not capable of ionization

### **Conductor**

It is a solid substance that allows electricity to pass through without decomposing e.g. all metals

### **Non conductor**

Alternative term: Insulator

It is a solid that does not conduct electricity e.g. plastics, wood and glass

### **Electrodes**

They are conductors that allows electricity in and out of an electrolyte

#### **Anode**

It is a positively charged electrode

It is an electrode connected to the positive terminal of the power supply

#### **Cathode**

It is a negatively charged electrode

It is an electrode connected to the negative terminal of the power supply

### **Cations**

They are positively charged ions

#### **Examples of cations**

- $Na^{+}$
- $Ca^{2+}$
- $Al^{3+}$
- $Mg^{2+}$
- $H^{+}$

### **Anions**

They are negatively charged ions

### Examples of anions

- $\overset{-1}{\text{Cl}}$
- $\overset{-1}{\text{OH}}$
- $\overset{-1}{\text{Br}}$
- $\overset{2-}{\text{SO}_4}$
- $\overset{-1}{\text{I}}$

### The ionic theory

The ionic theory states that: The electrolytes contain ions and when no current is passing, the ions wander about randomly in the solution. If the electric circuit is closed, the cathode immediately becomes negatively charged and the anode becomes positively charged. The anode attracts negatively charged ions while the cathode attracts the positively charged ions.

### The selective order of discharge of ions

The discharge of ions varies from one electrolyte set up to another. When two or more ions of

similar charge are present under similar conditions in a solution e.g.  $\overset{+1}{\text{H}}$  and  $\overset{+1}{\text{Na}}$  or  $\overset{-1}{\text{OH}}$

and  $\overset{2-}{\text{SO}_4}$ , one is preferentially selected for discharge. The ion selected for discharge of


competing ions depends on the following factors:

- The position of ions in the electrochemical series
- The concentration of ions in solution
- The nature of electrodes

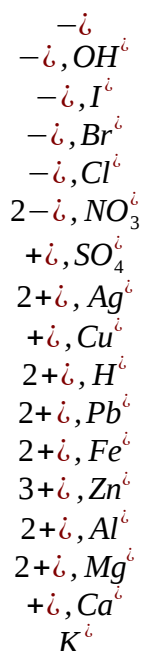
#### 1. Position of ions or radicals in the electrochemical series

Ions are arranged in the order of decreasing order of stability and amount of energy they require for them to get discharged from an aqueous solution when an electric current is made to flow through the solution. The arrangement is called electrochemical series. Note that the electrochemical series is slightly different from the reactivity series of metals.

Most stable ions      Increase in stability and require energy      least stable ions







The ions of very reactive metals such as potassium, sodium, calcium, magnesium and aluminium are more stable in solution and hence require more energy to be liberated as compared to the ions of less reactive metals such as copper, silver, mercury and gold.

Therefore, when the ion of a more reactive metal is competing for discharge against the ion of a less reactive metal, the less stable ion requiring lower energy for discharge is liberated in preference to the more stable ion. Positive ions will be discharged at the cathode and negative ions at the anode. For example,  $\text{H}^+$  will be discharged at the cathode in preference to  $\text{Na}^+$  since  $\text{H}^+$  are less stable and require lower energy for discharge. Equally, the  $\text{OH}^-$  will be discharged at the anode in preference to  $\text{SO}_4^{2-}$  since the  $\text{OH}^-$  are less stable and require lower energy for discharge.

## 2. Concentration of ions in aqueous solution

Concentration has no effect on the selective discharge of metal cations. However, the concentration of anions is the principle factor that determines which anions will be liberated regardless of their position in the electrochemical series. The anion with the highest concentration is selectively discharged from the solution in preference to the one whose concentration is lower regardless of their position in the electrochemical series. For example, in the electrolysis of concentrated sodium chloride, both  $\text{OH}^-$  and  $\text{Cl}^-$  are present. The  $\text{Cl}^-$  are discharged in preference to  $\text{OH}^-$  owing to the high concentration of  $\text{Cl}^-$  in solution despite  $\text{Cl}^-$  requiring more energy than  $\text{OH}^-$ . This is the only case in which the order of discharge as stated by the electrochemical series is reversed.

## 3. Nature of electrodes

Inert or unreactive electrodes such as platinum and graphite (Carbon) have no effect on the selective discharge of competing ions on their surfaces. However, active electrodes such as copper, mercury and most metals have an effect on the preferential discharge of competing ions. An active

electrode selectively discharges more stable ions in preference to less stable ions. For example, in the electrolysis of sodium chloride solution using inert electrodes,  $\text{H}^+$  are discharged at the cathode in preference to  $\text{Na}^+$ . However, when the mercury cathode has been used,  $\text{Na}^+$  are selectively discharged to form sodium Amalgam ( $\text{NaHg}$ ) in preference to the  $\text{H}^+$ .

### **Electrolysis of lead (II) bromide**

#### **Ions present in lead (II) bromide**

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

#### **At the cathode**

Lead (II) ions,  $\text{Pb}^{2+}$ , move to the cathode where they gain electrons to become lead atoms



Lead is given off as a liquid

#### **At the anode**

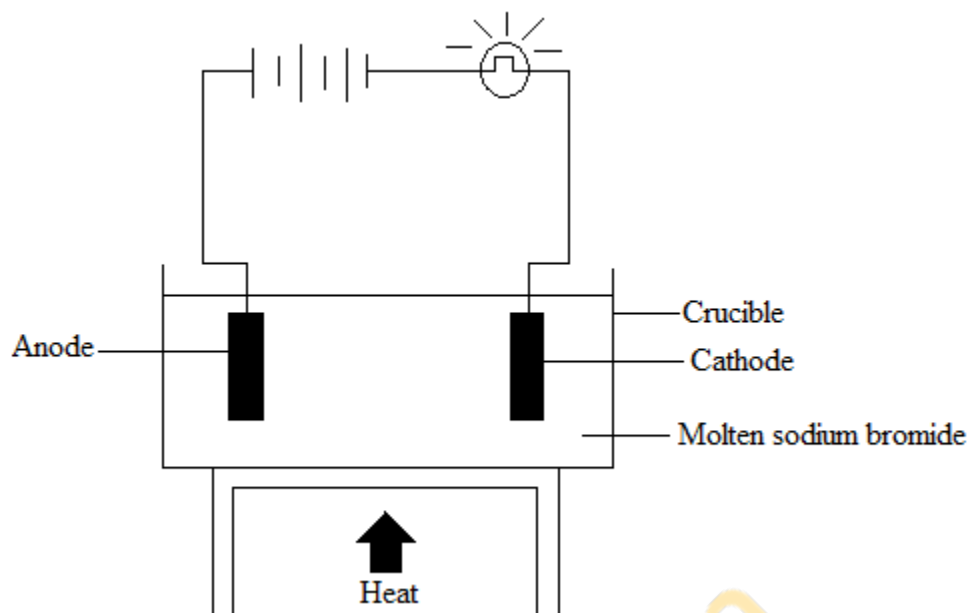
The bromide ions,  $\text{Br}^-$ , each lose one electron to form bromine atoms. They pair as molecules



Bromine is given off as a gas.

### **Exercise**

1. The diagram below shows apparatus which were used by Jane Naosa to electrolyte molten sodium bromide using inert electrodes.

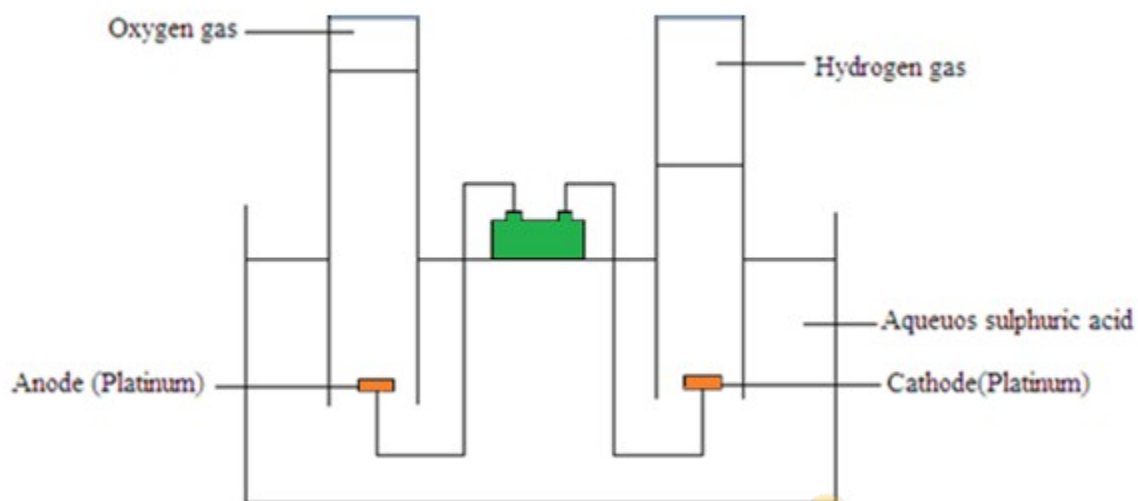


- State the ions present in molten sodium bromide
- State two suitable materials for the electrodes
- Name the product formed at each electrode. Write the equation for the reaction occurring at each electrode
- A silvery coloured liquid was seen floating on the electrolyte around the cathode. Name this liquid and explain why it floats on molten sodium bromide.
- State what was seen at the anode
- Why was molten sodium bromide being heated?
- Jane Naosa repeated the electrolysis but using aqueous sodium bromide. Write the;
  - Equation for the anode and cathode reactions
  - Overall equation for this electrolysis

### Electrolysis of acidified water

Pure water is a weak electrolyte. It only partially ionizes. Therefore, it is a poor conductor of electricity. The addition of hydrochloric acid or sulphuric acid makes it a strong electrolyte.

### Hoffman apparatus



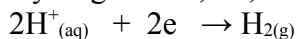
### Ions present in aqueous sulphuric acid

$H^{+}$  and  $SO_4^{2-}$  : from sulphuric acid

$H^{+}$  and  $OH^{-}$  : from water

### At the cathode

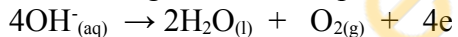
Hydrogen ions,  $H^{+}$ , are attracted to the cathode where they are discharged as hydrogen gas



2 volumes of hydrogen gas are produced

### At the anode

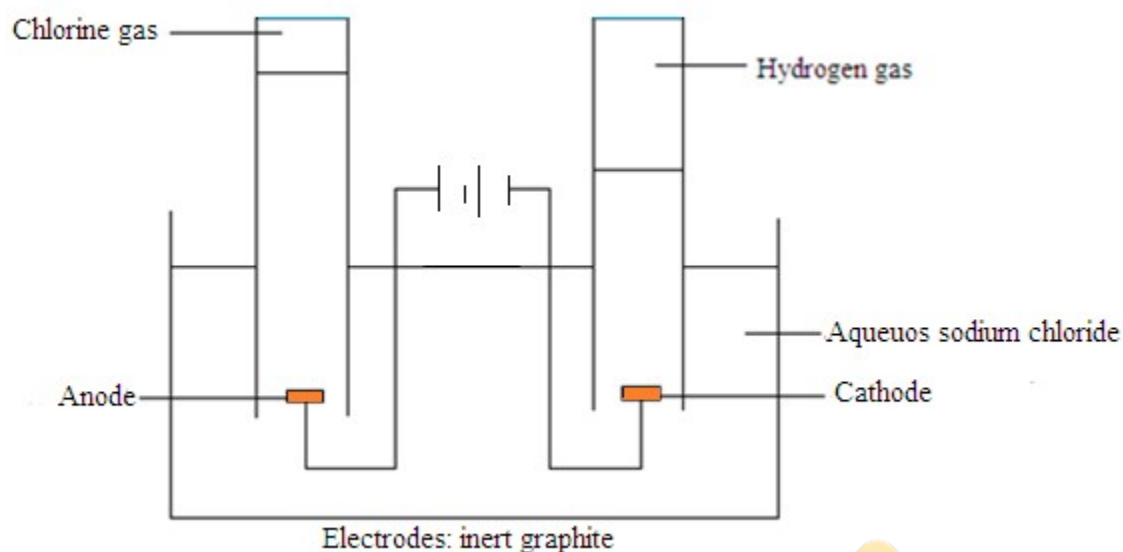
Hydroxide ions,  $OH^{-}$ , and sulphate ions,  $SO_4^{2-}$  are attracted to the anode. But the  $OH^{-}$  are preferred for discharge due to their position in the electrochemical series.



1 volume of oxygen is produced

### Electrolysis of sodium chloride

Concentrated sodium chloride is called brine.



### Ions present in aqueous sodium chloride

$\overset{+1}{Na}$  and  $\overset{-1}{Cl}$  : from sodium chloride

$\overset{+1}{H}$  and  $\overset{-1}{OH}$  : from water

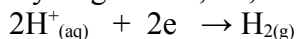
### At the anode

Chloride ions,  $Cl^-$ , are discharged in preference to hydroxide ions,  $OH^-$  due to the concentration factor.



### At the cathode

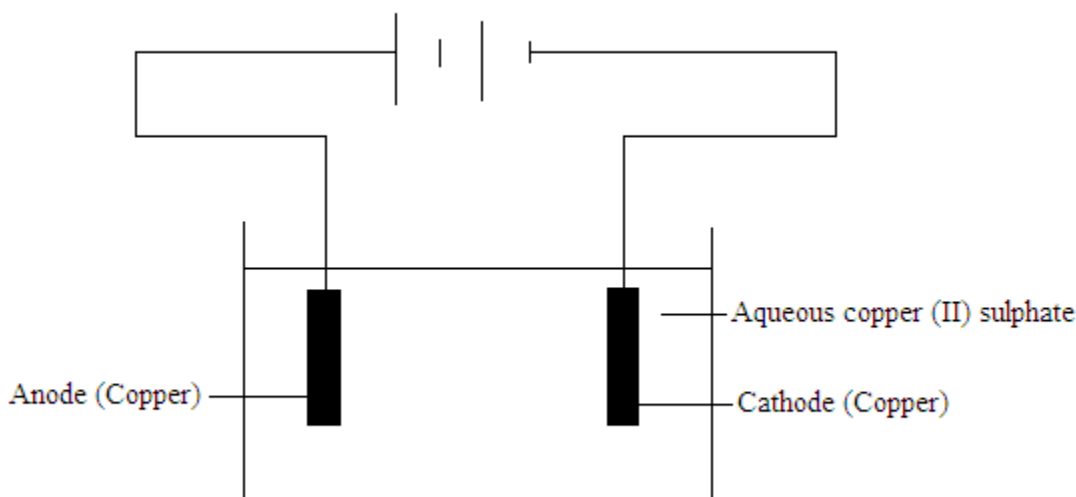
Hydrogen ions,  $H^+$ , are discharged in preference to sodium ions,  $Na^+$ .



Sodium ions,  $Na^+$ , and hydroxide ions,  $OH^-$ , remain in solution and the electrolyte gradually becomes alkaline due to the presence of sodium hydroxide,  $NaOH$ .

### Electrolysis of aqueous copper (II) sulphate

#### (a) Using copper electrodes



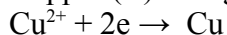
### Ions present in aqueous copper (II) sulphate

$2+ \overset{+}{\underset{+}{\text{Cu}}}$  and  $2- \overset{-}{\underset{-}{\text{SO}_4}}$  : from copper (II) sulphate

$+ \overset{+}{\underset{+}{\text{H}}}$  and  $- \overset{-}{\underset{-}{\text{OH}}}$  : from water

### At the cathode

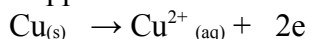
Copper (II) ions gain two electrons and deposited as copper atoms on the cathode.



The copper cathode grows as copper atoms are deposited

### At the anode

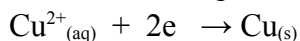
Copper atoms lose two electrons and enter the solution as copper (II) ions



### (b) Using an inert electrode e.g. carbon (graphite)

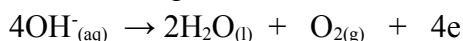
#### At the cathode

Copper (II) ions,  $\text{Cu}^{2+}$  are liberated in preference to hydrogen ions,  $\text{H}^+$ , to form copper metal because  $\text{Cu}^{2+}$  require less energy for discharge than  $\text{H}^+$ . Hydrogen ions remain in solution



#### At the anode

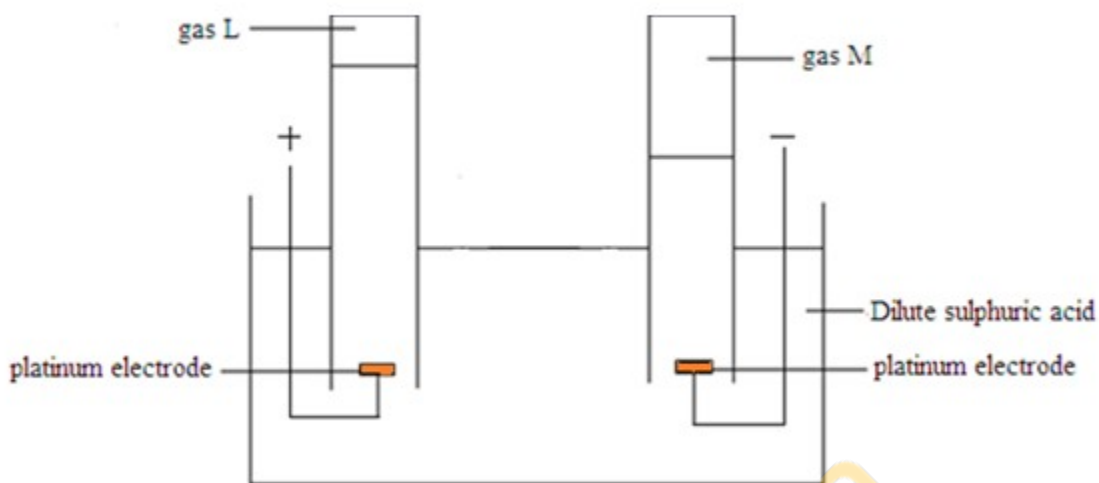
Hydroxide ions,  $\text{OH}^-$ , from water are discharged in preference to sulphate ions,  $\text{SO}_4^{2-}$ , to produce oxygen gas because they require less energy for discharge and are more concentrated than sulphate ions. The sulphate ions remain in solution



The hydrogen ions and sulphate ions that remain solution combine to form sulphuric acid. As aqueous copper (II) sulphate solution is electrolyzed using inert electrode, its blue colour disappears due to the removal of copper (II) ions and the solution becomes acidic.

### Example

1. The diagram below shows the electrolysis of dilute sulphuric acid



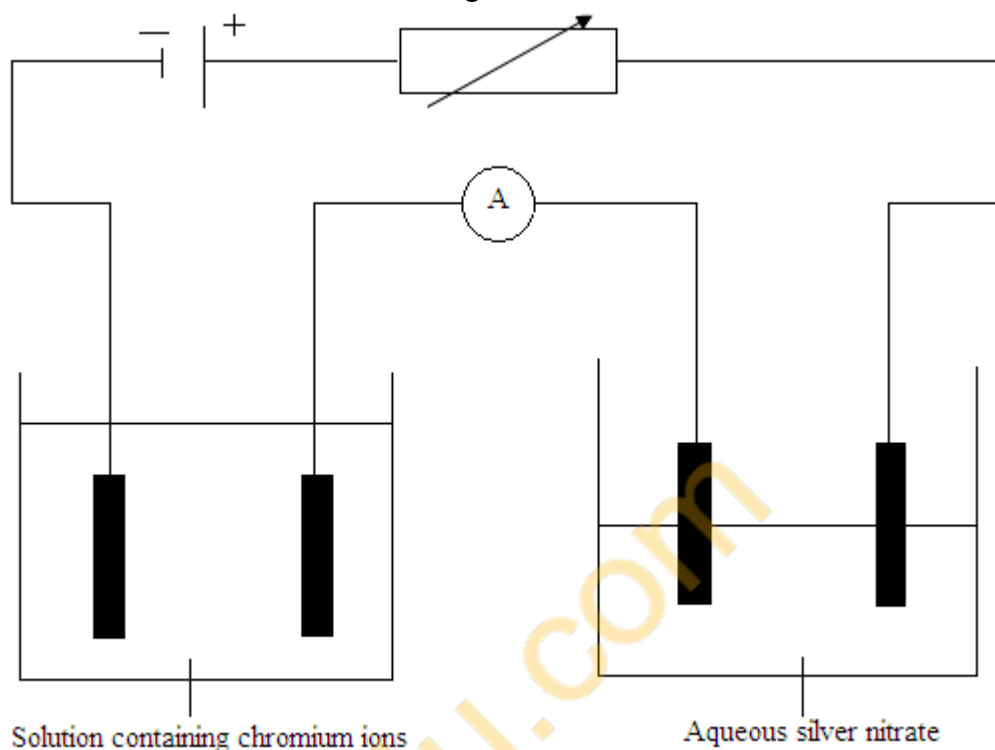
- (a) Give the names of the gases labeled
- (I) L
  - (II) M
- (b) During the electrolysis of dilute sulphuric acid, which ions move;
- (I) Positive electrodes
  - (II) Negative electrodes
- (c) Give the equations for the reactions occurring at:
- (I) The positive electrode
  - (II) Negative electrode

**Solution**

- (a) (I) L = Oxygen
- (II) M = Hydrogen
- (b) (I) Hydroxide ions,  $\text{OH}^-$
- (II) Hydrogen ions,  $\text{H}^+$
- (c) (I)  $4\text{OH}^-_{(\text{aq})} \rightarrow 2\text{H}_2\text{O}_{(\text{l})} + \text{O}_{2(\text{g})} + 4\text{e}^-$
- (II)  $2\text{H}^+_{(\text{aq})} + 2\text{e}^- \rightarrow \text{H}_{2(\text{g})}$

**Exercise**

1. In order to determine the charge on chromium ion, two electrolytic cells were connected in series, one containing an aqueous solution of chromium ions and the other an aqueous solution of silver nitrate as shown in the diagram below.



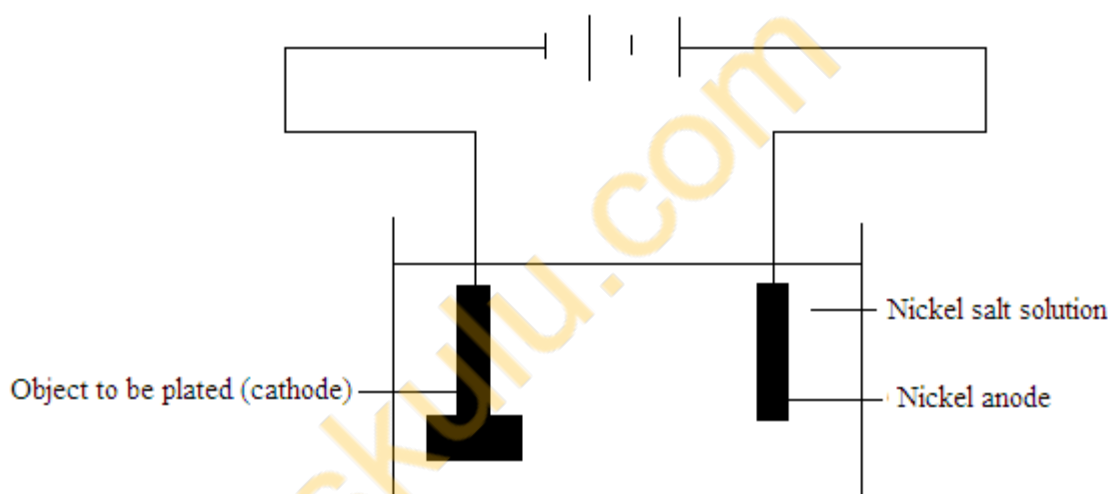
- What name is given to the electrode where chromium and silver are deposited?
- Write down the half reaction showing the discharge of silver ions
- The two aqueous solutions in the diagram above conduct electricity. What name is given to compounds which conduct electricity and are decomposed?
- At the end of the experiment, it was found that 2.02g of silver and 0.324g of chromium had been deposited. Calculate the charge on a chromium ion. Show your working.
- Suggest the formula of the compound, chromium, in solution.
- Chromium is a metal. Explain how the structure of metals enables them to conduct electricity and beaten into thin sheets.

### Industrial application of electrolysis

- Electrolysis is used in extraction of very reactive metals such as potassium, sodium, magnesium, calcium and aluminium

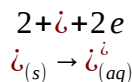


- Electrolysis is used in the refinery and purification of metals such as copper and zinc.
- Electrolysis is used in the electroplating metals. Electroplating is the art of covering the surface of a metal with a thin adherent metal coating by means of electrolysis. Electroplating is done to protect the surface of the base metal against corrosion or for a purely decorated effect. Metals that may be used for electroplating include nickel, silver, gold, chromium, zinc, tin etc. The object to be electroplated is used as the cathode and is immersed in a solution containing ions of the metal to be plated. When an electric current passes through the solution, metal ions that migrated to the cathode are reduced, depositing on the object as free metal. The metal deposited on the object is replaced in the solution by using an anode of the same metal.



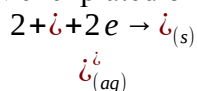
#### Anode reaction

Nickel dissolves at the anode and replenishes the solution



#### Cathode reaction

Nickel plated on the object



- Sodium hydroxide, chlorine gas and hydrogen gas are manufactured on a large scale by electrolysis of brine in the mercury cathode cell.

#### Exercise

- Electrolysis is also used to purify copper.
  - Draw a labeled diagram which could be used to purify a block of impure copper

- (I) Describe what happens at each electrode during electrolysis
- (II) Write equations to show the reactions at each electrode

### Faraday's laws of electrolysis

#### Faraday's first law of electrolysis

The law states that: The mass of a substance produced at the electrode during electrolysis is directly proportional to the quantity of electricity passing through the electrolyte.

$$m \propto Q$$

$$m \propto It$$

$$Q = It$$

$$m = \text{mass [g]}$$

$$I = \text{current [A]}$$

$$t = \text{time [s]}$$

$$Q = \text{charge (quantity of electricity) [Coulombs, C]}$$

#### Example

1. A current of 0.4A flows for about 1500 seconds. Calculate the quantity of electricity.

#### Solution

$$Q = It$$

$$Q = 0.4\text{A} \times 1500\text{s}$$

$$Q = 675\text{C}$$

#### Faraday's second law of electrolysis

The law states that: When the same quantity of electricity is passed through different electrolytes the number of moles of the element deposited is inversely proportional to the charges on the ions of the element.

#### Note

$$1 \text{ Faraday} = 1 \text{ mole of electrons} = 96500\text{C}$$

$$\frac{\text{Charge on ion of solution B}}{\text{Charge on ion of solution A}} = \frac{\text{Mass of substance A} \div \text{relative atomic mass of A}}{\text{Mass of substance B} \div \text{relative atomic mass of B}}$$

$$n = \frac{Q \times MM}{m \times F} = q$$

$$m = \frac{A_r \times It}{F \times q}$$

$$n = \text{number of moles [mol]}$$

$$m = \text{mass [g]}$$

$$MM = \text{molar mass}$$

$$F = \text{faraday's constant [96500C /mol]}$$

$$A_r = \text{relative atomic mass}$$

$$I = \text{current [A]}$$

$$q = \text{number of faradays} = \text{magnitude of charge on the ion}$$

#### Example

1. Calculate the charge on an ion X if 5.4g is deposited by a current of 5A passing for 3 hours 13 minutes. [  $A_r$  of X = 27]

**Solution**

$$q = \frac{Q \times MM}{m \times F}$$

$$q = \frac{It \times MM}{m \times F}$$

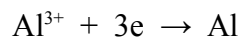
$$q = \frac{0.5 A \times [(60 \times 60 \times 3) + (60 \times 13)] s \times 27 g/mol}{5.4 g \times 96500 C/mol}$$

$$q = 3$$

$$\text{Charge on ion X} = X^{3+} \text{ or } X^{3-}$$

2. How many moles of electron are required to produce 2.7g of aluminium by electrolytic reduction?

**Solution**



$$3 \text{ mol of electron} \rightarrow 27g$$

$$x \rightarrow 2.7g$$

$$x = \frac{3 \text{ mol of electron} \times 2.7 g}{27 g}$$

$$x = 0.3 \text{ mol of electron}$$

**Exercise**

1. An element X has a relative atomic mass of 88. When a current of 0.5A was passed through the fused chloride of X for 32 minutes 10 seconds, 0.44g was deposited at the cathode. Calculate the number of faradays to liberate 1 mole of X.
2. In an electrolysis experiment, the same quantity of electricity deposited 16g of copper and 6g of titanium. What was the charge on the titanium ion? [Assume the charge on the copper ion is 2+]  
A 1+      B 2+      C 3+      D 4+

**Calculations involving molar volumes**

The volume of one mole of any gas is:

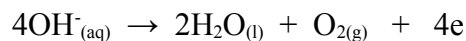
- $24 \text{ dm}^3$  ( $24000 \text{ cm}^3$ ) at r.t.p
- $22.4 \text{ dm}^3$  ( $22400 \text{ cm}^3$ ) at s.t.p

**Example**

1. 0.2 faradays of electricity were passed through a solution of dilute sulphuric acid. Calculate the volume of the gases produced or evolved measured at r.t.p at the anode and cathode.

**Solution**

At the anode oxygen gas is produced.



$$1\text{F} \rightarrow 1 \text{ mol of } \tilde{\text{e}}$$

$$x \rightarrow 4 \text{ mol of } \tilde{\text{e}}$$

$$x = \frac{1\text{F} \times 4\text{mol}}{1\text{mol}}$$

$$x = 4\text{F}$$

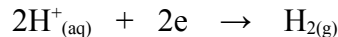
$$4\text{F} \rightarrow 24\text{dm}^3$$

$$0.2\text{F} \rightarrow x$$

$$x = \frac{0.2\text{F} \times 24\text{dm}^3}{4\text{F}}$$

$$x = 1.2\text{dm}^3$$

At the cathode hydrogen gas is produced



$$1\text{mol of } \tilde{\text{e}} \rightarrow 1\text{F}$$

$$2\text{mol of } \tilde{\text{e}} \rightarrow x$$

$$x = \frac{1\text{F} \times 2\text{mol}}{1\text{mol}}$$

$$x = 2\text{F}$$

$$2\text{F} \rightarrow 24\text{dm}^3$$

$$0.2\text{F} \rightarrow x$$

$$x = \frac{0.2\text{F} \times 24\text{dm}^3}{2\text{F}}$$

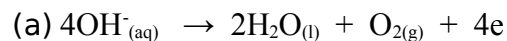
$$x = 2.4\text{dm}^3$$

2. What volume of oxygen and hydrogen is produced at r.t.p. when a current of 2A is passed for 6 minutes 26 seconds through a solution containing:

(a) Hydroxide ions

(b) Hydrogen ions

**Solution**



$$Q = It$$

$$Q = 2\text{A} \times [(6 \times 60) + 26]\text{s}$$

$$Q = 772\text{C}$$

$$1\text{mol of e}^- \rightarrow 96500\text{C}$$

$$4\text{mol of e}^- \rightarrow x$$

$$x = \frac{4\text{mol} \times 96500\text{C}}{1\text{mol}}$$

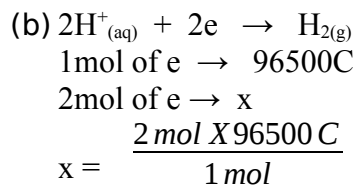
$$x = 386000\text{C}$$

$$386000\text{C} \rightarrow 24\text{dm}^3$$

$$772C \rightarrow x$$

$$x = \frac{772 C \times 24 \text{ dm}^3}{386000 C}$$

$$x = 0.048 \text{ dm}^3$$



$$x = 193000 C$$

$$193000 C \rightarrow 24 \text{ dm}^3$$

$$772 C \rightarrow x$$

$$x = \frac{772 C \times 24 \text{ dm}^3}{193000 C}$$

$$x = 0.096 \text{ dm}^3$$

### Exercise

- 0.2F of electricity were passed through a solution of copper (II) sulphate. Calculate the volume of oxygen produced at r.t.p.

### Alloys

Definition: An alloy is a mixture of two or more metals or a metal with a non-metal

The combination of alloys is physical

Alloys are harder than the metals from which they are made

Alloying a metal is one way of increasing its strength

### Preparation of alloys

The mixture is usually heated under controlled temperature

The molten mixture is then allowed to cool and solidify

### Advantages of alloys

- They are flexible in use
- They usually have improved appearance
- They are durable and reliable
- They have increased resistance to corrosion

### Examples of alloys

Alloy	Typical composition		Particular property	Typical use
Brass	Copper, Cu Zinc, Zn	70% 30%	Harder than pure copper, Resistant to corrosion	Used to make musical instruments
Bronze	Copper, Cu Tin, Sn	90% 10%	Harder than pure copper	Used to make trophies Used to make medallions
Mild steel	Iron, Fe Carbon, C	99.7% 0.3%	Stronger and harder than pure iron	Used to make bridges Used to make boring tools and crushing equipment Used to make automobile bodies and parts e.g. car bodies
Stainless steel	Iron, Fe Chromium, Cr Nickel, Ni	70% 20% 10%	Harder than pure iron Does not rust	Used in cutlery e.g. making razor blades, knives because it does not rust
Solder	Tin, Sn Lead, Pb	50% 50%	Has lower melting point than either tin or lead	Used for soldering and welding

### Exercise

- Alloying is one way of preventing rusting of iron
  - Name any two alloys containing iron and state one use for each
  - State two other methods of rust prevention

### Metals

#### General physical properties of metals

- Metals are good conductors of heat and electricity
- Metals are malleable i.e. they can be hammered into thin sheets
- Metals are ductile i.e. they can be drawn into long wires
- Metals are sonorous i.e. they produce sound when hammered
- Metals are lustrous i.e. they have a silver luster surface when freshly cut
- Metals are solids at room temperature and pressure except for mercury which is a liquid at room temperature and pressure
- Metals have high melting and boiling points

### The reactivity series

Alternative term: Activity series

Definition: Reactivity is a list of metals with the most reactive metal at the top and the least reactive metal at the bottom.

The order of reactivity can be determined by the reaction of the metal with water or steam and acids. In both types of reaction, if a reaction takes place, hydrogen gas is formed.

Metal	Symbol	
Potassium	K	<div style="display: flex; align-items: center; justify-content: center;"> <div style="margin-right: 10px;">Most reactive</div> <div style="flex-grow: 1; border-left: 1px solid black; position: relative;"> <div style="position: absolute; top: -10px; left: 50%; transform: translateX(-50%);">↑</div> <div style="position: absolute; bottom: -10px; left: 50%; transform: translateX(-50%);">↓</div> </div> </div>
Sodium	Na	
Calcium	Ca	
Magnesium	Mg	
Aluminium	Al	
Zinc	Zn	
Iron	Fe	
Lead	Pb	
Hydrogen	H	
Copper	Cu	
Mercury	Hg	
Silver	Ag	
Gold	Au	
		Least reactive

The reactivity series is related to the tendency of metals to form positive ions

Very reactive metals lose their valence electrons easily to form cations

Metals at the top of series lose the electrons more easily and form ions rapidly and are called electropositive.

Metals at the bottom of the series lose electrons with difficulty and do not readily form ions and are said to be less electropositive

The metal higher up in the series will displace the one below it from aqueous solution of its salts

Hydrogen is included in the series although it is a non-metal. It serves as a reference point in the series. Metals above hydrogen will react with dilute acids to give hydrogen gas, while metals below hydrogen will not react with dilute acids to give hydrogen gas.

### Reaction of metals with water or steam

Metal	Observation / Equation
Potassium	Reacts very violently with cold water to produce potassium hydroxide and hydrogen gas $2K_{(s)} + 2H_2O_{(l)} \rightarrow 2KOH_{(aq)} + H_{2(g)}$
Sodium	Reacts violently with cold water to produce sodium hydroxide and hydrogen gas $2Na_{(s)} + 2H_2O_{(l)} \rightarrow 2NaOH_{(aq)} + H_{2(g)}$

Calcium	Reacts less violently with cold water to produce calcium hydroxide and hydrogen gas $\text{Ca}_{(s)} + 2\text{H}_2\text{O}_{(l)} \rightarrow \text{Ca}(\text{OH})_{2(aq)} + \text{H}_{2(g)}$
Magnesium	Reacts very slowly with cold water but violently with steam to produce hydrogen gas $\text{Mg}_{(s)} + 2\text{H}_2\text{O}_{(l)} \rightarrow \text{Mg}(\text{OH})_{2(aq)} + \text{H}_{2(g)}$ $\text{Mg}_{(s)} + \text{H}_2\text{O}_{(g)} \rightarrow \text{MgO}_{(s)} + \text{H}_{2(g)}$
Aluminium	Does not react with cold water but react slowly with steam to form aluminium oxide and hydrogen gas. $2\text{Al}_{(s)} + 3\text{H}_2\text{O}_{(g)} \rightarrow \text{Al}_2\text{O}_{3(s)} + 3\text{H}_{2(g)}$
Zinc	Does not react with cold water but hot zinc burns in steam to form zinc oxide and hydrogen gas. $\text{Zn}_{(s)} + \text{H}_2\text{O}_{(g)} \rightarrow \text{ZnO}_{(s)} + \text{H}_{2(g)}$
Iron	Does not react with cold water but react slowly with steam to form iron oxide and hydrogen gas. $\text{Fe}_{(s)} + \text{H}_2\text{O}_{(g)} \rightarrow \text{FeO}_{(s)} + \text{H}_{2(g)}$
Lead Copper Silver Gold	They are below hydrogen in the reactivity series do not react with cold water not even steam

### Reaction of metals with dilute hydrochloric acid

All metals above hydrogen in the reactivity series react with dilute hydrochloric acid to form a salt and hydrogen gas

All metals below hydrogen in the reactivity series do not react with dilute acids

Metal	Observation / Equation
Potassium	Explosive reaction



Sodium	$\text{K}_{(\text{s})} + \text{HCl}_{(\text{aq})} \rightarrow \text{KCl}_{(\text{aq})} + \text{H}_{2(\text{g})}$ $\text{Na}_{(\text{s})} + \text{HCl}_{(\text{aq})} \rightarrow \text{NaCl}_{(\text{aq})} + \text{H}_{2(\text{g})}$
Calcium	Reacts vigorously to give calcium chloride and hydrogen gas $\text{Ca}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow \text{CaCl}_{2(\text{aq})} + \text{H}_{2(\text{g})}$
Magnesium	Reacts rapidly to give magnesium chloride and hydrogen gas $\text{Mg}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow \text{MgCl}_{2(\text{aq})} + \text{H}_{2(\text{g})}$
Zinc	Reacts quiet slow (moderately fast) to give zinc chloride and hydrogen gas $\text{Zn}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow \text{ZnCl}_{2(\text{aq})} + \text{H}_{2(\text{g})}$
Iron	Reacts slowly to give iron (II) chloride and hydrogen gas $\text{Fe}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow \text{FeCl}_{2(\text{aq})} + \text{H}_{2(\text{g})}$
Lead	Slow, and only if the acid is concentrated $\text{Pb}_{(\text{s})} + 2\text{HCl}_{(\text{aq})} \rightarrow \text{PbCl}_{2(\text{aq})} + \text{H}_{2(\text{g})}$
Copper Gold	No reaction, even with concentrated acid

### Reaction of metals with oxygen

Metal	Behavior / Equation
Sodium	Catches fire with only a little heating. Burns fiercely with a bright yellow flame $4\text{Na}_{(\text{s})} + 2\text{O}_{2(\text{g})} \rightarrow 2\text{Na}_2\text{O}_{(\text{s})}$
Magnesium	Catches fire easily. Burns with a blinding white flame $2\text{Mg}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{MgO}_{(\text{s})}$
Iron	Does not burn, but the hot metal glows brightly in oxygen, and gives off yellow sparks. $\text{Fe}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow \text{Fe}_3\text{O}_{4(\text{s})}$
Copper	Does not burn, but the hot metal becomes coated with a black substance. $2\text{Cu}_{(\text{s})} + \text{O}_{2(\text{g})} \rightarrow 2\text{CuO}_{(\text{s})}$
Gold	No reaction, no matter how much the metal is heated.

### Example

1. Iron, calcium and copper are metals. The table below describes the reactions of these metals with cold water and steam.

(a) Place a tick (✓) if the reaction will take place and a cross (x) if the reaction will not take place

Metal	Reaction of metal with cold water	Reaction of metal with steam
Copper		
Iron		
Calcium		

(b) place these metals in order of chemical activity, starting with the most reactive

### Solution

(a)

Metal	Reaction of metal with cold water	Reaction of metal with steam
Copper	x	x
Iron	x	✓
Calcium	✓	✓

(b) Calcium , iron, copper

### Exercise\_

2. The list below shows metals arranged in ascending order of reactivity.

Silver  
Zinc  
Aluminium  
Sodium

(a) Using metals from the list only, name:

- (I) A metal which can be displaced by copper
- (II) A metal which can react with cold water to produce an alkaline solution
- (III) A metal which forms an amphoteric oxide when burnt
- (IV) A metal whose carbonate does not decompose when heated
- (V) A metal which forms a stable oxide layer

(b) Write a balanced chemical equation for the reaction between sodium and water.

3. Place in order of chemical reactivity towards the metals calcium, iron, magnesium and zinc, with the most reactive first. Four other metals A, B, C and D are tested with dilute hydrochloric acid and with water

Metal A reacts with steam but not with cold water

Metal B does not reacts with steam or cold water but does react with dilute hydrochloric acid

Metal C reacts quickly with cold water

Metal D does not react with water or with dilute hydrochloric acid

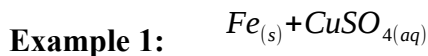
(a) Place metals A, B, C and D in order with the most reactive first

(b) State between which two letters (metals) hydrogen should be placed in the above series

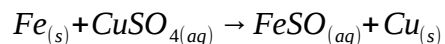
### Displacement of metals from their compounds

A metal high in the reactivity series will always displace a less reactive metal from solution of its compound

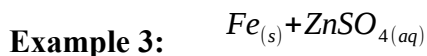
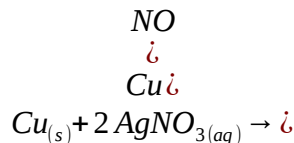
A metal lower in the reactivity series cannot displace the one above it from the solution of its compound.



Iron will displace copper from the blue copper (II) sulphate solution. Green iron (II) sulphate is formed.



Since copper is above silver in the reactivity series, copper will displace silver from silver nitrate solution. The solution will also turn from colourless to blue due to the formation of copper (II) ions.



Iron is lower than zinc in the reactivity series. Since it is less reactive than zinc, no displacement reaction will take place

### Exercise

1. What would you see when zinc is added to copper (II) sulphate solution? Write a balanced chemical equation for the reaction.
2. Will copper react with zinc sulphate? Explain why

### Recycling of metals

Metals are finite resources. It is essential that we recycle metals that are still useful to us.

#### Advantages or reasons of recycling metals

1. Better conservation of natural resources, so that reserves last longer. The demand for metal ores will decrease once scrap metal is identified as a viable source of raw material.
2. With recycling, less mining will take place. There will be less air and water pollution caused by mining process
3. More effective waste disposal as scrap metal is recovered. Less landfill space will be needed. This will also solve the problem of litter accumulation

Recycling is sometimes not feasible because of the costs involved. Transportation, sorting through waste and cleaning the scrap metal etc. may cost more than extracting the metal from ores. This is true for some cheaper metals.

### Extraction of metals

Most metals occur in the earth's crust as ores

An ore is a compound from which a metal can be extracted.

### Methods of extraction

The method of extraction of a metal from the ore depends on its position in the reactivity series

There are three main methods used to extract metals from their ores

1. Electrolysis
2. Reduction
3. Thermal decomposition

Metal	Symbol	Method of extraction
Potassium Sodium Calcium Magnesium Aluminium	K Na Ca Mg Al	Electrolysis of fused oxides or chlorides
Zinc Iron Lead	Zn Fe Pb	Reduction by coke
Copper Mercury Silver Gold	Cu Hg Ag Au	Thermal decomposition

### Stability of compounds

Compounds of very reactive metals like potassium, sodium, calcium, magnesium and aluminium cannot be decomposed by heating or reduction method using hydrogen, carbon or carbon monoxide as reducing agents

Compounds of these metals are very stable and can therefore be extracted by electrolysis

Mild reactive metals like iron, zinc and lead can easily be extracted from their ores by reduction with carbon or carbon monoxide because their compounds are less stable

Less reactive metals like copper and silver can be extracted from their ores by heating

Unreactive metals like gold exists in nature as pure and free metals and can be mined in pure form because their compounds are unstable

Gold always occur in native (Free State)

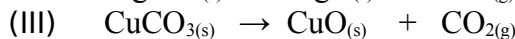
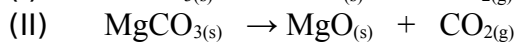
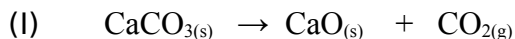
Silver occurs both in native and combined state

Metal extraction often produces sludge because they contain impurities

### Effect of heat on carbonates

- (a) Carbonates of group I elements like potassium, sodium, rubidium are extremely stable and hence cannot be decomposed by heat
- (b) Carbonates of group II elements like calcium, magnesium, barium and transition elements like zinc, iron, lead, copper etc. are only decomposed to oxides and carbon dioxide when heated. No further decomposition is possible after this. The oxides are extremely stable and can only be reduced by electrolysis.

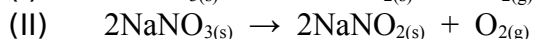
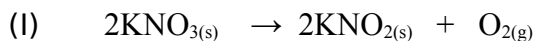
#### Examples



#### Effects of heat on nitrates

- (a) Nitrates of Group I elements like potassium and sodium decomposes into nitrites and oxygen when heated.

#### Examples



- (b) Nitrates of group II elements like calcium, magnesium, barium and transition elements like zinc, iron, lead, copper etc. are decomposed to metal oxides, nitrogen dioxide and oxygen when heated.

#### Examples



### Aluminium

Aluminium is the most abundant metal in the earth's crust

#### Ores of aluminium

##### Bauxite

Chemical name: Aluminium oxide

Formula:  $\text{Al}_2\text{O}_3$

The oxide is **very stable** and hence cannot be decomposed by heat or reduction with carbon

#### Extraction of aluminium

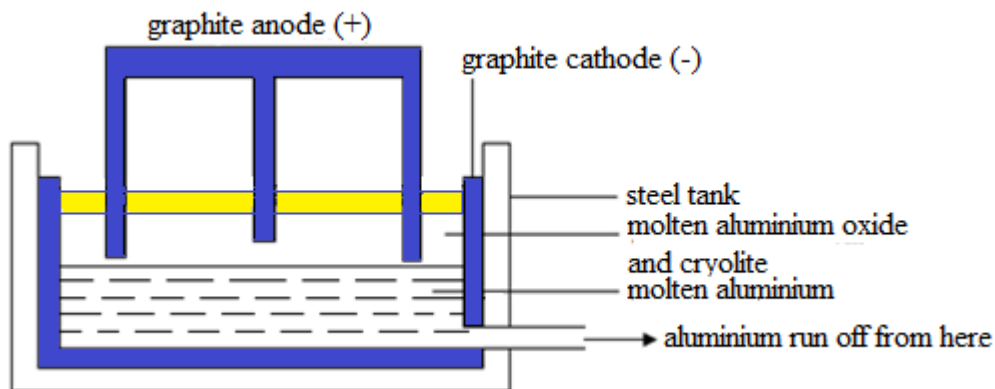
Aluminium is extracted by electrolysis of molten bauxite,  $\text{Al}_2\text{O}_3$  in the electrolytic cell.

Extraction of aluminium from bauxite is carried out in cell graphite (carbon) electrodes

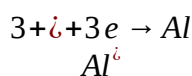
Bauxite is dissolved in cryolite ( $\text{Na}_3\text{AlF}_6$ ) to lower its lower melting point

Aluminium is formed at the cathode and settles at the bottom in molten form

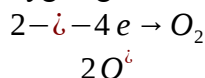
Aluminium is tapped out by opening an outlet when it has accumulated



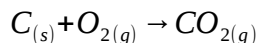
Aluminium is formed at the cathode



Oxygen gas is formed at the anode



The oxygen gas immediately reacts with the graphite electrodes to form carbon dioxide gas since they are made of carbon. For this reason, the anodes are eaten away and hence they are replaced at regular intervals



### Summary

#### Three main stages in the extraction of aluminium from bauxite

Bauxite is impure aluminium oxide,  $Al_2O_3$

1. Bauxite is purified
2. Pure aluminium oxide is dissolved in molten cryolite,  $Na_3AlF_6$
3. Electrolysis is performed in the cell

#### The apparent unreactivity of aluminium

Despite being high in the reactivity series, aluminium does not easily react with water and oxidizing acids like nitric acid and sulphuric acid.

Aluminium forms aluminium oxide in the presence of air. This is because shortly after being extracted out, a thin protective layer of aluminium oxide forms on its surface.

This oxide is insoluble and resistant to corrosion. So it forms a protective coating for aluminium.

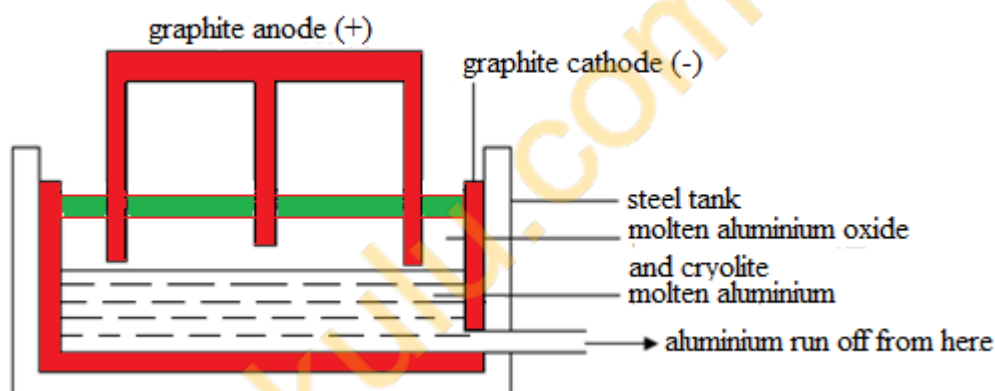
#### Uses of aluminium

1. It is used in overhead electrical cables because it is a good conductor of electricity
2. It is used in making cooking utensils like sauce pans and kettles because it is a good conductor of heat and it is resistant to heat

3. It is used in making food wrappers and drink cans due to its resistance to corrosion and is non-toxic
4. It is used in the manufacture of aeroplanes because it is lighter (low density) and has high strength. It is cheaper and therefore preferred than copper
5. It is used in making light aluminium roofing sheets
6. It is used in making alloys e.g. duralumin
7. It is used in making aluminium paints. The powdered metal is used with oil

### Example

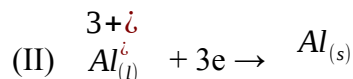
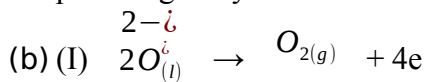
1. The diagram below represents the electrolytic cell used for the production of aluminium. The electrolyte contains aluminium oxide and cryolite (sodium aluminium fluoride) and is molten at about  $800^{\circ}\text{C}$ . The electrodes are made from graphite.



- (a) Why is a mixture of cryolite and aluminium oxide, and not pure aluminium oxide, is used as the electrolyte?
- (b) Write the equations for the reactions occurring at
  - (I) the positive electrode
  - (II) the negative electrode
- (c) Explain why the graphite anodes need to be replaced at regular intervals?
- (d) Calculate the maximum mass of aluminium that can be made from 408 tonnes of aluminium oxide.
- (e) Aluminium foil is used to make food containers because it does not corrode easily.
  - (I) Explain why aluminium does not corrode easily
  - (II) Give a use, other than for food containers, together with the physical property that makes aluminium suitable for that use
  - (III) Give a further use of aluminium, other than for food containers, together with a different physical property from that given in part (II) that makes aluminium suitable for that use

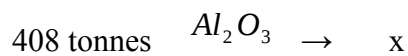
### Solution

(a) Aluminium oxide has a very high melting point. With the addition of cryolite, the melting point is greatly reduced. Hence it is economical



(c) The oxygen produced at the graphite anode oxidizes the graphite to carbon dioxide.

(d) From the equation:  $2Al_2O_3 \rightarrow 4Al + 3O_2$



$$x = \frac{408 \text{ tonnes} \times 108 g}{204 g}$$

$$x = 216 \text{ tonnes Al}$$

(e) (I) Aluminium forms aluminium oxide in the presence of air. This oxide is insoluble and resistant to corrosion. So it forms a protective coating for aluminium

(II) It is used in making cooking utensils since it has very good conductivity, in addition to its good appearance and resistance to corrosion use

(III) It is a component in several alloys used in air craft construction. Its favorable use is due to its low density and high tensile strength

### Exercise

1. Before experimenting with aluminium to place in the reactivity series, the surface of the aluminium must be scrapped. Why is this necessary?
2. Give two reasons why it is important to recycle metals

### Copper

#### Ores of copper

##### Malachite

Chemical name: Copper (II) carbonate

Formula:  $CuCO_3$

##### Copper pyrites

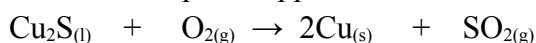
Chemical name: Copper (I) sulphide

Formula:  $Cu_2O$



### Extraction of copper

Copper is extracted from copper (I) sulphide by thermal decomposition. This is usually done in the presence of oxygen. The copper (I) sulphide is reduced to copper by heating in a controlled supply of air. The impure copper is called blister copper.

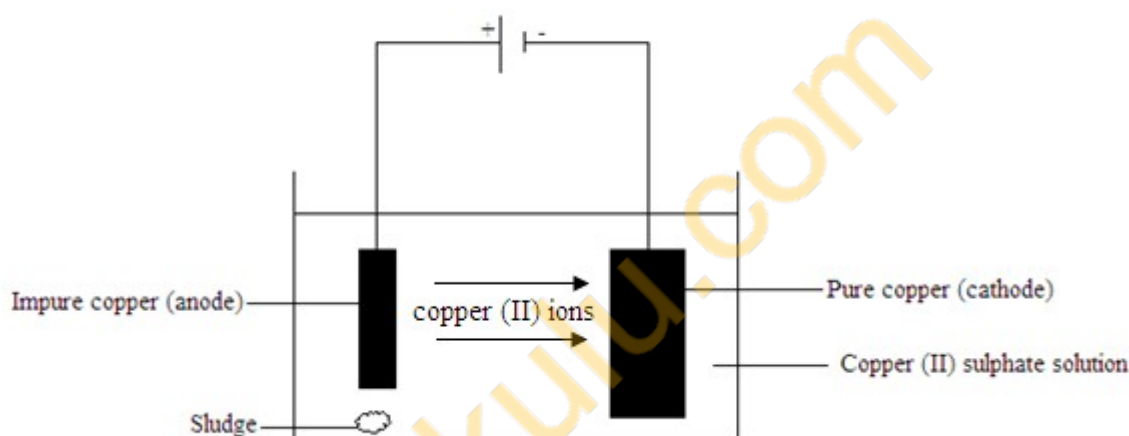


### Purification of copper

The copper formed is impure

Silver, gold and cobalt are usually present as impurities

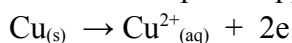
It is purified by electrolysis



The electrolyte is an acidified solution of an electrolyte containing the metal ion

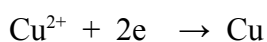
The impure copper anode loses mass as copper ions are formed.

At the anode pure copper from pure anode goes into solution, reducing the size of the anode



Impurities called anode sludge fall to the bottom of the cell. The anode sludge may contain valuable metals such as silver and gold

At the anode copper ions accept two electrons each and are deposited as pure copper metal on the electrode which increases in size.



### Uses of copper

1. it is used in making electric cables because it is a good conductor of electricity
2. it is used in making alloys e.g. bronze and brass
3. it is used in making coils
4. it is used in making ornaments in jewelry industries e.g. coins, necklaces and rings
5. it is used in making cooking utensils and boilers since it is a good conductor of heat

## **Zinc**

### **Ores of zinc**

#### **Zinc blend**

Chemical name: Zinc sulphide

Formula:  $\text{ZnS}$

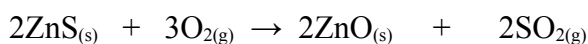
#### **Calamine**

Chemical name: Zinc carbonate

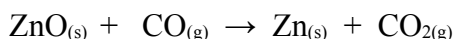
Formula:  $\text{ZnCO}_3$

### **Extraction of zinc**

Zinc blend is heated in air to form zinc oxide and sulphur dioxide



Zinc oxide is then reduced to zinc metal by carbon monoxide



### **Uses of Zinc**

1. It is used in making alloys e.g. brass which is an alloy of zinc and copper
2. It is used to galvanize iron to prevent rusting
3. It is used in making roofing sheets
4. It is used in the preparation of dry cell batteries

### **Exercise**

1. Zinc is extracted from its ore, zinc blend. The zinc blend is heated in air to form the oxide and an acidic gas. The oxide is then reduced to zinc.
  - (a) Name the acidic gas
  - (b) What is the chemical name of zinc blend
  - (c) Write down the chemical equations for the two processes involved in the extraction of zinc from zinc blend
  - (d) Why is not possible to reduce aluminium oxide to aluminium using carbon?
  - (e) Important uses of zinc are galvanizing steel, making alloys and manufacturing dry cells.
    - (i) Why is steel galvanized?
    - (ii) Name an alloy containing zinc metal. State one physical property of the alloy

## Iron

### Ores of iron

#### Haematite

Chemical name: Iron (III) oxide

Formula:  $\text{Fe}_2\text{O}_3$

#### Magnetite

Chemical name: Tri iron tetra oxide

Formula:  $\text{Fe}_3\text{O}_4$

#### Siderite

Chemical name: Iron (II) carbonate

Formula:  $\text{FeCO}_3$

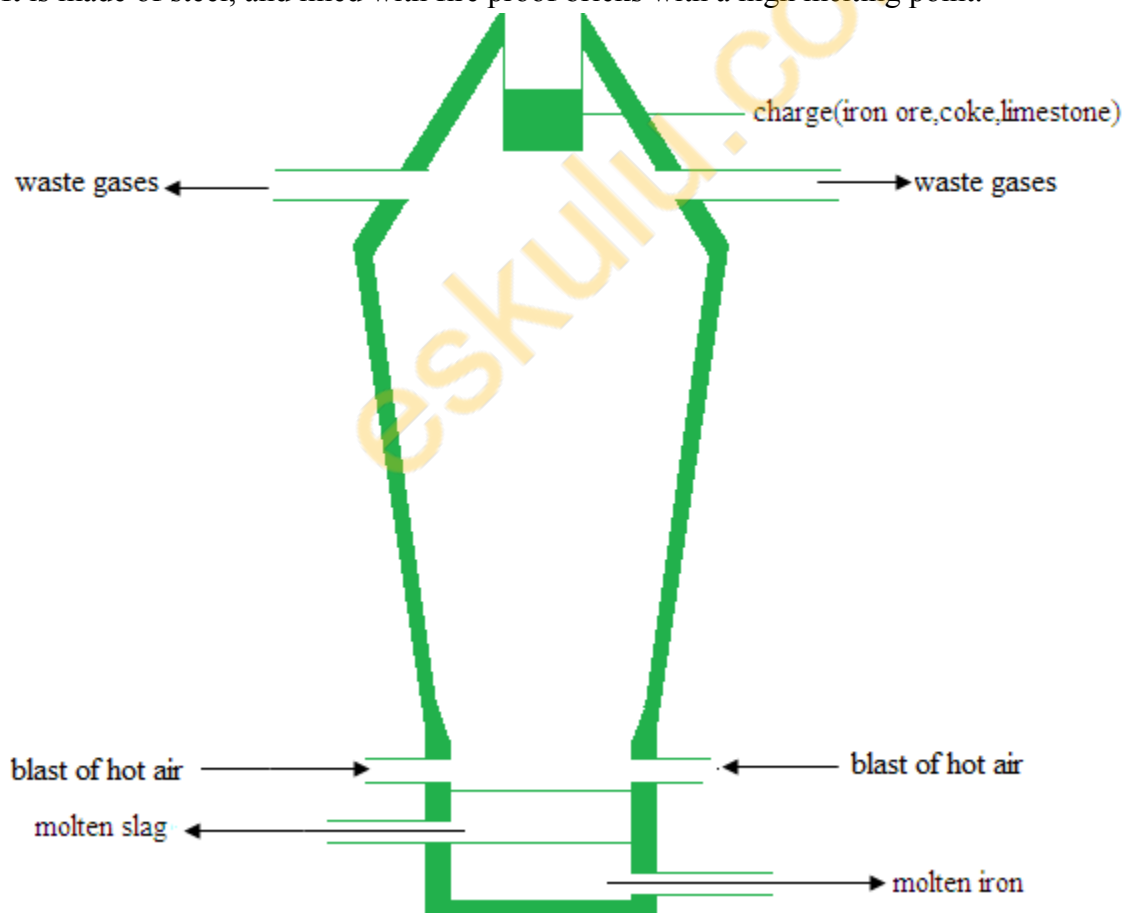
### Extraction of iron

Iron is extracted from Haematite by the reduction method in the blast furnace

#### The blast furnace

The blast furnace is tower of about 30 – 40 meters high

It is made of steel, and lined with fire proof bricks with a high melting point.



### Charge

To extract iron, three substances called charge (raw materials) are mixed together.

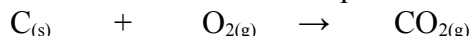
These are:

- **Iron ore:** The chief ore is hematite,  $\text{Fe}_2\text{O}_3$
- **Lime stone:** This is calcium carbonate,  $\text{CaCO}_3$
- **Coke:** This is pure carbon, C

The charged is crushed and placed into the top of the blast furnace. It is then roasted in air.

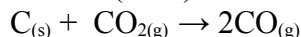
### Chemical reactions in the blast furnace

1. Coke reacts with oxygen in hot air to form carbon dioxide. This is an oxidation process. The reaction rises the temperature in the blast furnace.

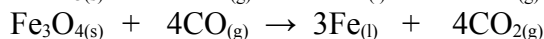
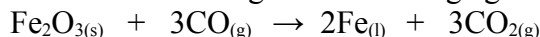


Hot air (oxygen) is forced into the bottom of the blast furnace

2. Carbon dioxide rising up reacts with more coke to form carbon monoxide  
Carbon (coke) is a reducing agent because it reduces carbon dioxide to carbon monoxide



3. Carbon monoxide react with iron oxide to form liquid iron and carbon dioxide  
Carbon monoxide gas is a reducing agent because it reduces the iron oxide to iron



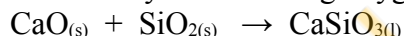
Iron trickles to the bottom of the furnace where it is tapped off.

4. Limestone decomposes to calcium oxide and carbon dioxide



The purpose of limestone is to act as a flux

5. Calcium oxide reacts with silicon dioxide (sand) to form calcium silicate or slag. The slag runs down the furnace and floats on the iron. This prevents the molten iron from being oxidized by the incoming oxygen. Slag is tapped off.



Calcium oxide is used to remove impurities such as silicon dioxide  $\text{SiO}_2$  )

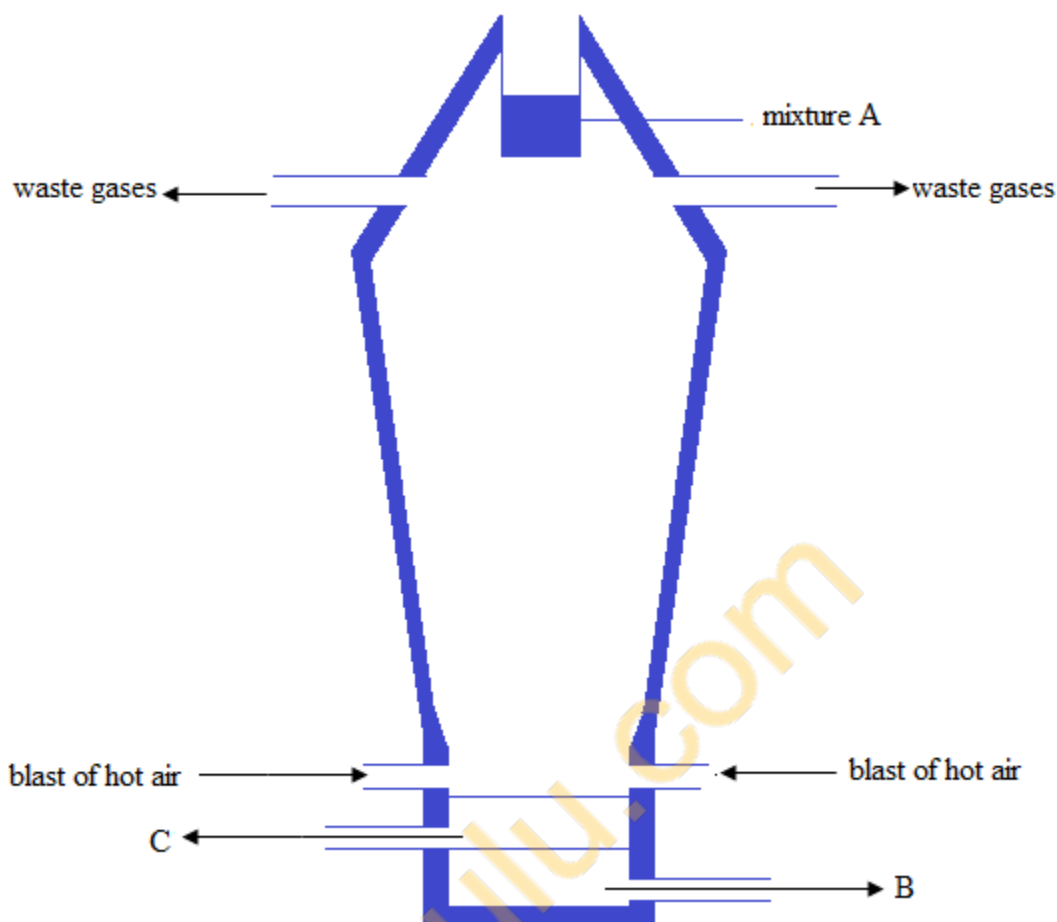
### Uses of slag

1. It is used in the manufacture of cement
2. It is used for making roads

**Note:** The raw iron obtained in this process is called cast iron or pig iron. It contains impurities. The purest form of iron is called wrought iron.

### Exercise

1. The diagram below shows the blast furnace



- Name the components of mixture A, B and C in the diagram above
- Explain how the furnace is heated to the high temperature needed for the reduction of the iron ore.
- Name two processes that lead to the production of carbon dioxide in the blast furnace
- Name the gaseous reducing agent in the furnace
- Which of the components of mixture A produces the gaseous reducing agent in (b).
- Construct an equation for a reaction in which the gaseous reducing is produced.
- Outline the changes that take place in a blast furnace during the manufacture of iron
- The iron produced by the blast furnace is converted into alloys. Explain what is meant by an alloy.
- How is mixture C removed from the furnace?
- What is the chemical name given to the change by which iron oxide becomes iron?

## Air

Clean, dry air is a mixture of gases

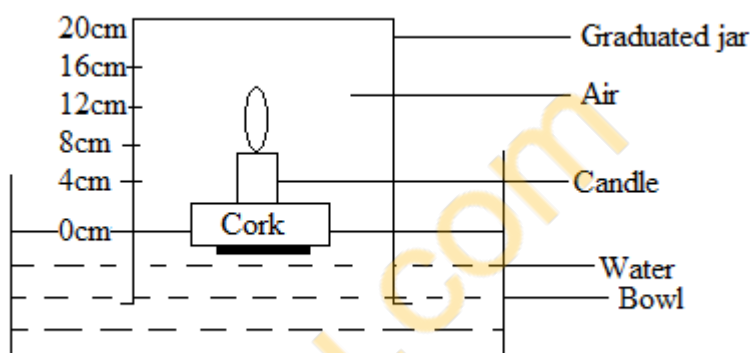
### Composition of clean dry air

Component	Percentage
-----------	------------

Nitrogen, $N_2$	79%
Oxygen, $O_2$	20%
Carbon dioxide, $CO_2$	0.04%
Noble gases (mainly argon)	0.93%

### Example

1. A student wanted to find the percentage of water in air. A candle wax was fixed to a weighed piece of cork. This was floated on water. The student then lit the candle and lowered a graduated gas jar over it, as shown below



The candle flame slowly went out and the water level rose in the jar

- (a) Why did the flame go out?
- (b) What two substances are produced when a wax (hydrocarbon) candle burns?
- (c) What did the water replace when it rose in the jar?
- (d) Why did the water not fill the jar?
- (e) The water rose to the 3.5cm mark on the jar. Calculate the percentage change of volume of the air.

### Solution

- (a) All the oxygen needed to support combustion in the jar is used up
- (b) Carbon dioxide and water
- (c) The water replaced the oxygen gas used up to burn the candle
- (d) Oxygen occupies only 20% by volume of air. The remaining gas is mainly nitrogen gas

$$(e) \text{ Percentage change} = \frac{3.5 \text{ cm}}{20 \text{ cm}} \times 100\%$$

$$= 17.5\%$$

### Non metals

#### Hydrogen gas

Formula:  $H_2$

At room temperature and pressure, hydrogen gas exists as a diatomic molecule,  $H_2$

## Occurrence

Hydrogen occurs in water, oils and natural gas

## Preparation of hydrogen gas

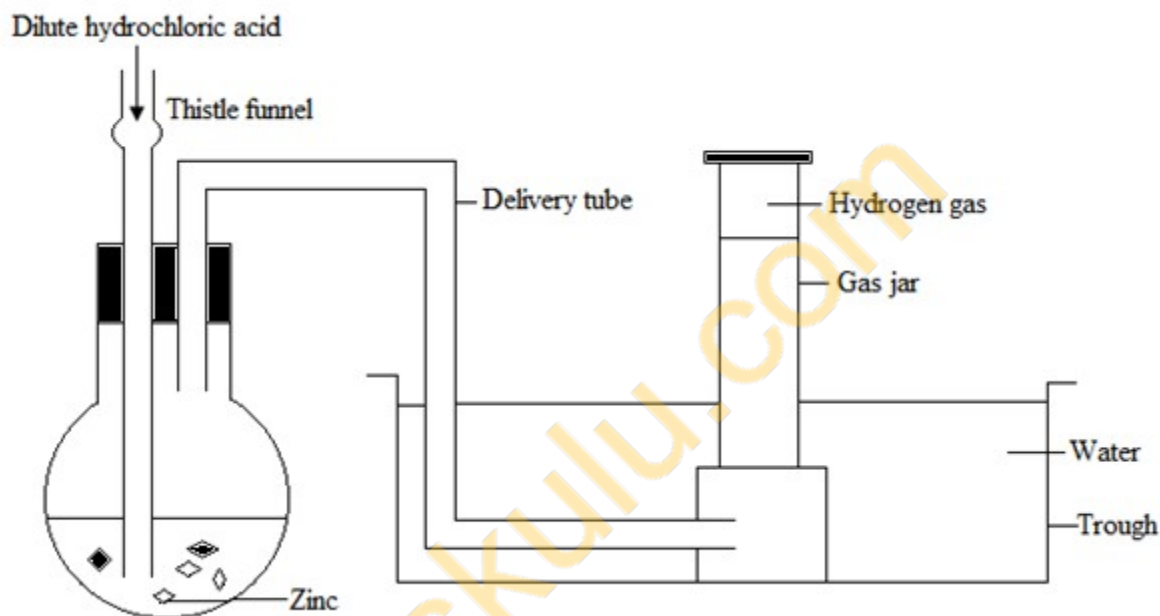
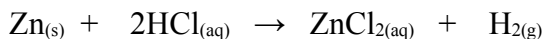
### 1. Laboratory preparation of hydrogen

In the laboratory, hydrogen gas can be prepared by reacting:

- a reactive metal with a dilute acid
- a reactive metal with water

#### [A] Reaction of reactive metal with a dilute acid

##### Example



The gas is collected over water

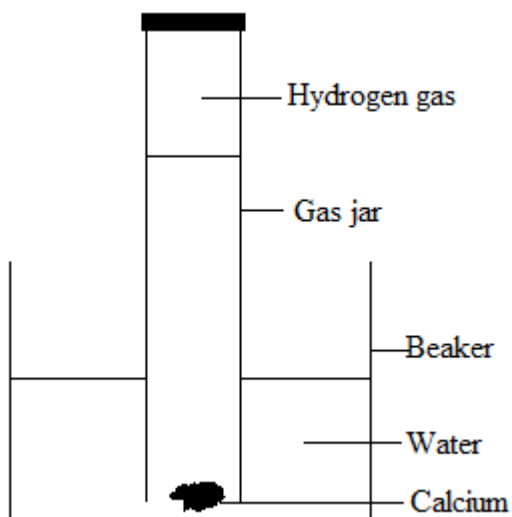
Drying agent: Concentrated Sulphuric acid

Method of collection: Down ward displacement of air or upward delivery since it is less dense

#### [B] Reaction of a reactive metal with water

##### Example



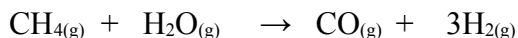


### Note

- Potassium and sodium float on water as they react with it, they must be wrapped in a wire mesh to make them sink.
- The reaction of potassium with water produces a lilac flame and the reaction of sodium with water produces a yellow flame

### 2. Industrial preparation of hydrogen

On the scale, hydrogen gas is manufactured by the reaction of methane and steam



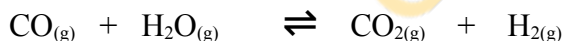
#### Conditions

Catalyst: Nickel metal

Temperature: 1000°C

Pressure: 50 atmosphere

More steam is then added and the gases are passed over a catalyst iron (III) oxide to remove the carbon monoxide



Carbon dioxide is removed by dissolving it in water under pressure

### 3. Hydrogen can also be produced by cracking of alkanes

#### Test for hydrogen

Hydrogen gas burns with a pop sound when a burning splint is introduced to it

### Physical properties of hydrogen

1. It is colourless
2. It is odorless
3. It is less dense than air



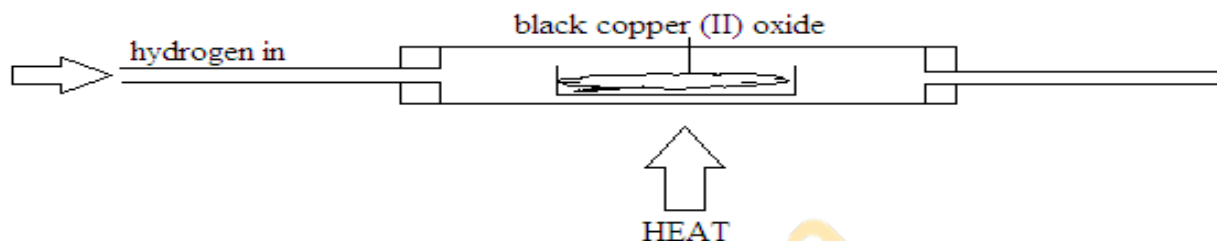
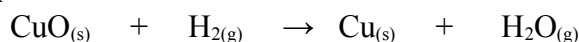
4. It has a boiling point of  $-253^{\circ}\text{C}$
5. It is not poisonous and does not support life

### Chemical properties of hydrogen

1. It has no effect on litmus paper
2. It burns in oxygen with a blue flame producing a pop sound  

$$2\text{H}_{2(\text{g})} + \text{O}_{2(\text{g})} \rightarrow 2\text{H}_2\text{O}_{(\text{g})}$$
3. It is a reducing agent. It reduces the oxides of metals below it in the reactivity series

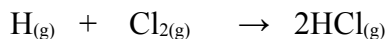
### Example



When hydrogen is passed over black copper (II) oxide in the apparatus above, the black powder turns pink

4. Hydrogen burns in chlorine with a white flame forming hydrogen chloride

### Example



A mixture of hydrogen and chlorine is explosive in sun light

### Uses of hydrogen gas

1. It is used in the manufacture of ammonia in haber process
2. It is used in the manufacture of margarine from vegetable oil in the process called catalytic hydrogenation
3. Liquid hydrogen is used as a fuel in rockets
4. It is used as a reducing agent

### Exercise

1. A small piece of potassium is dropped on to called water and mixed with a little universal indicator.
  - (a) When potassium reacts with water, hydrogen gas is produced
    - (I) What name is given to reactions that produce heat?
    - (II) What colour does the universal indicator become?
    - (III) Describe a test for hydrogen
  - (b) (I) How do the observations differ when sodium is used instead of potassium?
  - (II) Write a balanced chemical equation for the reaction between sodium with water.

### Oxygen gas

Formula:  $\text{O}_2$

Oxygen gas exists as a diatomic molecule,  $\text{O}_2$

It makes up about 21% of air by volume

## Preparation of oxygen

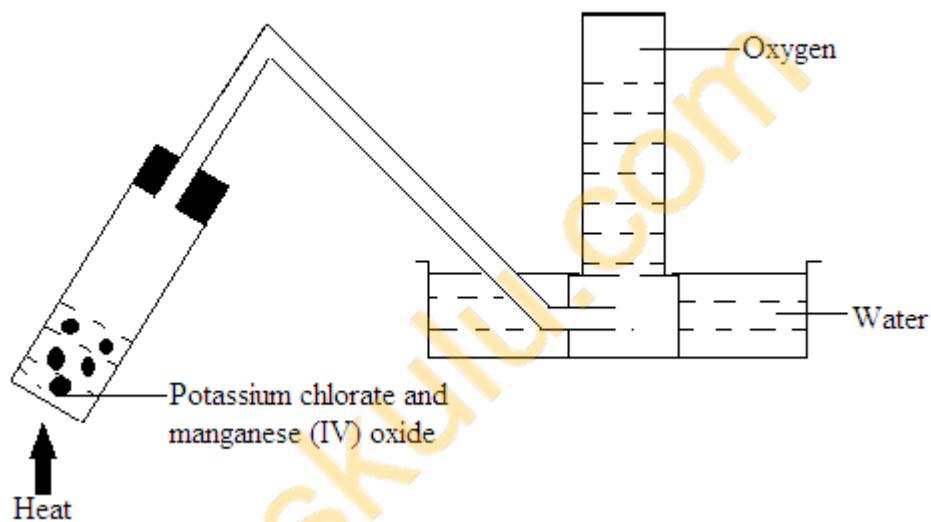
### 1. Laboratory preparation of oxygen

In the laboratory, oxygen gas can be prepared using the following chemicals:

- (a) Potassium chlorate,  $\text{KClO}_3$
- (b) Hydrogen peroxide,  $\text{H}_2\text{O}_2$
- (c) Sodium nitrate,  $\text{NaNO}_3$  and Potassium nitrate,  $\text{KNO}_3$

#### [A] Potassium chlorate

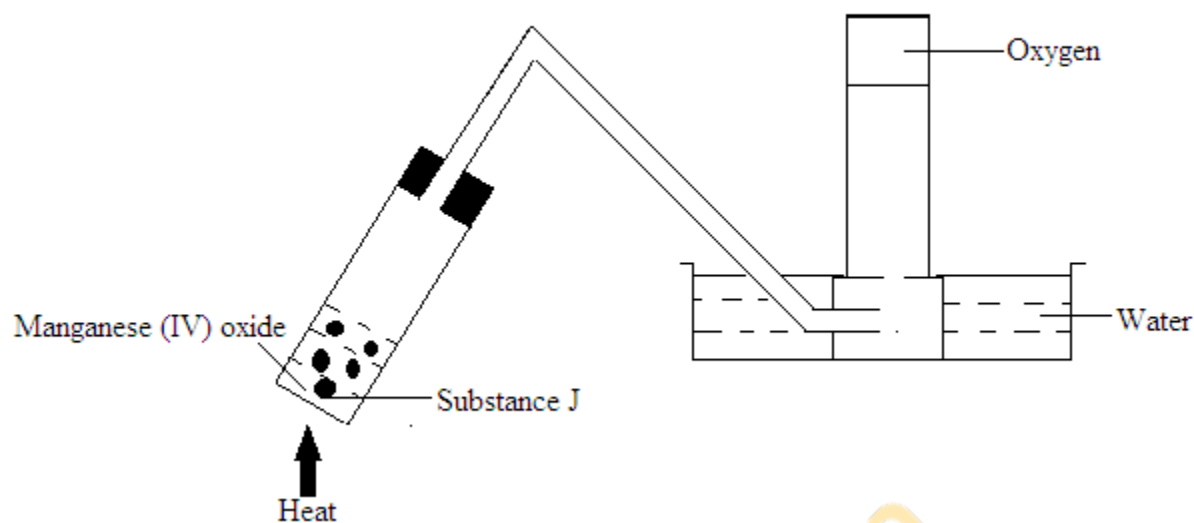
Potassium chlorate is mixed with a catalyst manganese (IV) oxide upon heating and decomposes into potassium chloride and oxygen gas



**Note:** This experiment is explosive

#### Exercise

1. Study the diagram below that shows preparation and collection of oxygen gas



- Name substance J
- Write a balanced chemical equation for the reaction in the experiment
- What is the method of collecting the gas used in the experiment?
- What is the function of the manganese (IV) oxide in the experiment?
- Explain why the first gas collected in the gas jar was not pure oxygen?
- State one industrial use of oxygen

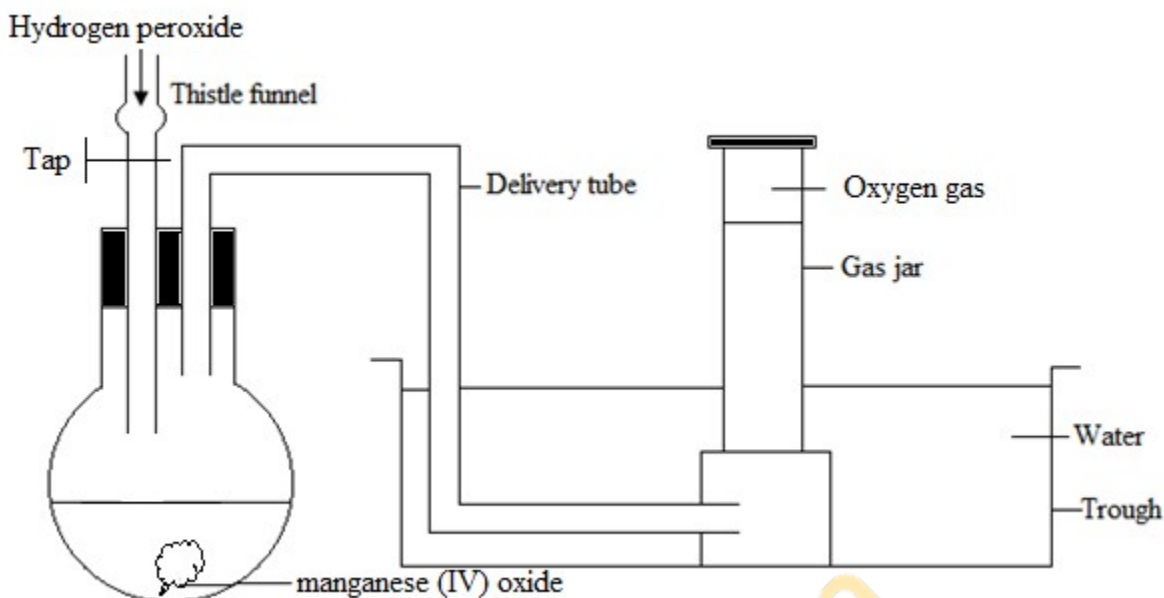
**Solution**

- Potassium chlorate
- $2\text{KClO}_{3(s)} \rightarrow 2\text{KCl}_{(s)} + 3\text{O}_{2(g)}$
- Down ward displacement of water
- Acts as a catalyst
- It is contaminated with air already in the apparatus
- Welding (as oxyacetylene flame) etc.

**[B] Hydrogen peroxide**

Oxygen gas is also prepared by the decomposition of hydrogen peroxide solution using manganese (IV) oxide as a catalyst. No heating is required





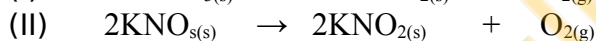
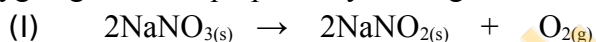
Oxygen gas is collected over water

Method of collection: Down ward displacement of water

Drying agent: Concentrated sulphuric acid

### [C] Sodium nitrate and potassium nitrate

Oxygen gas can be prepared by heating sodium nitrate or potassium nitrate



## 2. Industrial preparation of oxygen gas

On the large scale, oxygen gas is manufactured by fractional distillation of liquid air. Liquid oxygen boils at  $-183^{\circ}\text{C}$  while liquid nitrogen boils at  $-196^{\circ}\text{C}$

Nitrogen gas which has a the lower boiling point distils off first

### Test for oxygen gas

Oxygen gas relights a glowing splint introduced in its container

### Uses of oxygen

1. It is used in the manufacture of steel in the blast furnace
2. It is used in oxygen tents in hospitals for patients in the intensive care unit
3. It used for welding in the oxy-acetylene flame
4. It used by deep sea divers and mountain climbers
5. It is used as liquid oxygen in rockets when in outer space to support burning of hydrogen

### Physical properties of oxygen

1. It is colorless
2. It is odorless
3. It is slightly soluble in water
4. It is slightly denser than air
5. It supports burning

6. It boils at  $-183^{\circ}\text{C}$

7. It does not burn

### **Chemical properties of oxygen**

#### **1. Respiration**

Respiration is the process by living organisms oxidize glucose to produce carbon dioxide, water and energy



#### **2. Combustion**

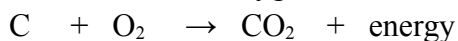
Alternative term: Burning

Combustion is the process by which a substance reacts with oxygen to produce an oxide and heat.

It is also defined as the burning of substances in oxygen.

#### **Example**

Carbon burns in oxygen to form carbon dioxide and heat energy.



#### **3. Rusting**

Rusting is the corrosion of iron.

It is an electrochemical process by which iron corrodes in the presence of oxygen, water and an electrolyte.

#### **Rust**

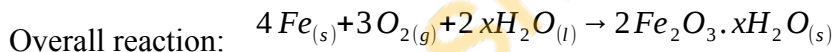
Chemical formula:  $\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$

Chemical name: Hydrated iron (III) oxide.

Colour: Reddish – brown

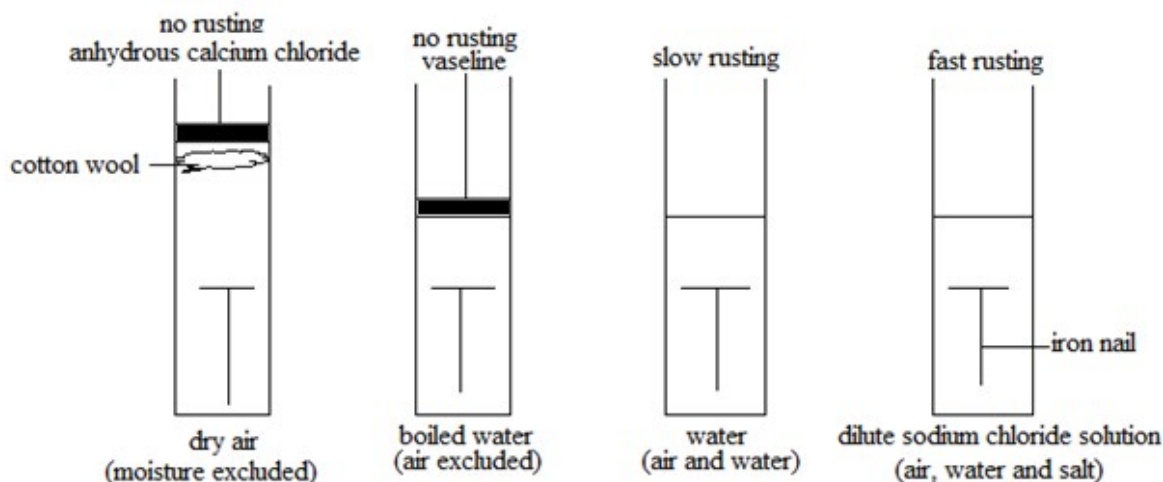
#### **Formation of rust**

Iron reacts with oxygen in air in the presence of water to form rust.



#### **Conditions necessary for iron to rust**

1. Presence of oxygen
2. Presence of water or moisture
3. Presence of a strong electrolyte such as sodium chloride or sulphuric acid



## Prevention of rusting

### 1. Painting

A paint coat excludes both air and water from contact with iron

### 2. Oiling

Oil or grease may be applied on the surface of iron metal to prevent water and oxygen from contact with iron

### 3. Galvanizing

Galvanizing is the coating of iron with zinc metal. Zinc is higher than iron in the reactivity series of metals; so if the surface is scratched, the zinc is oxidized in preference to iron. This is called sacrificial protection.

### 4. Electroplating or alloying

Iron can be electroplated or alloyed with non-corrosive elements like nickel, copper, chromium and carbon. The coating of iron with a metal which does not corrode easily protects iron from rusting. An electric current is used in electroplating.

## Exercise

- Burning and rusting are two chemical processes
  - Give four ways by which rusting of iron metal can be prevented
  - Give one in which rusting and burning :
    - resemble one another
    - differ from one another
  - Explain how you could show the presence of iron metal in a sample of rust
- Oxygen may be prepared by the decomposition of hydrogen peroxide
  - Explain the term decomposition
  - Name the catalyst used in this preparation
  - Draw the apparatus which could be used to prepare and collect the oxygen produced
  - On the industrial scale, oxygen is separated from nitrogen by fractional distillation. Explain what is meant by fractional distillation and name one other commercial process in which it is used.

## Sulphur dioxide

Formula:  $SO_2$

Sulphur burns in oxygen with a blue flame to form sulphur dioxide

### Properties of sulphur dioxide

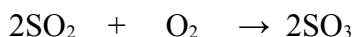
1. It has a smell
2. It does not burn or support burning
3. It is fairly soluble in water forming sulphurous acid
4. It decolourizes the solution of acidified potassium permanganate since it is a reducing agent
5. It turns aqueous potassium dichromate (VI) from orange to green
6. It is denser than air.

### Uses of sulphur dioxide

1. It is used as a bleaching agent in the manufacture of wood pulp for paper
2. It is used as a food preservative since it kills bacteria
3. It is used in the manufacture of sulphuric acid in contact process

### Manufacture of sulphuric acid

Sulphuric acid is manufactured on large scale by contact process. In this process, sulphur dioxide is reacted with oxygen at a very high temperature of about  $450^{\circ}\text{C}$  in the presence of the platinum or vanadium pentoxide catalyst to form sulphur trioxide



#### Conditions

Catalyst: Platinum or Vanadium pentoxide

Temperature:  $450^{\circ}\text{C}$

Sulphur trioxide is a white crystalline solid which is very soluble in water

Sulphur trioxide is dissolved in cold concentrated sulphuric acid to form an oily liquid called oleum,  $H_2S_2O_7$



Oleum is then converted to sulphuric acid by diluting it with water



### Diluting sulphuric acid

During dilution, sulphuric acid is added to water and not the other way round i.e. do not add water to acid because this results in an explosion since the specific heat capacity of sulphuric acid is small and hence the heat evolved will boil the solution.

### Properties of sulphuric acid

1. It is a strong electrolyte
2. It reacts with carbonates and hydrogen carbonates to produce a salt, water and carbon dioxide
3. It neutralizes bases and alkaline solutions
4. It reacts with metals above hydrogen in the reactivity series to form a salt and hydrogen gas
5. It displaces less volatile acids like hydrochloric acid and nitric acid from their salts
6. It is a strong dehydrating agent since it removes water from other compounds e.g.  
$$\text{H}_2\text{SO}_4 + \text{C}_{12}\text{H}_{22}\text{O}_{11} \rightarrow 12\text{C} + 11\text{H}_2\text{O}$$
7. It is a powerful oxidizing agent

### Uses of sulphuric acid

1. It is used in the manufacture of detergents and soap
2. It is used in the manufacture of fertilizers like ammonium sulphate
3. It is used as an electrolyte in car batteries
4. It is used in refining of petroleum
5. It is used as a drying agent when concentrated

### Chlorine gas

Formula:  $\text{Cl}_2$

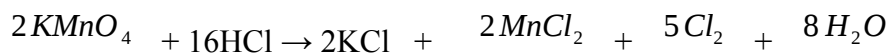
Chlorine exists as diatomic molecules,  $\text{Cl}_2$

### Properties of chlorine gas

1. It is a greenish yellow gas with a choking smell.
2. It is poisonous
3. It is sparingly soluble in water
4. It bleaches damp litmus paper

### Preparation of chlorine

Chlorine is prepared by the action of oxidizing agents on hot concentrated hydrochloric acid solution





## Manufacture of chlorine

Chlorine is manufactured by the electrolysis of concentrated sodium chloride or brine in the mercury cathode cell. Sodium hydroxide is obtained as a by product

Sources of sodium chloride include sea water and rock salt

## Uses of chlorine

1. It is used in the sterilization of drinking water and water in swimming pools
2. It is used in the manufacture of bleaching agents and pesticides
3. It is used to make polyvinylchloride (PVC)
4. It is used in the manufacture of hydrochloric acid

## Silicon

Formula: Si

Silicon is a non - metal in group IV of the periodic table. It is a common element in most rocks as it is found in combination with oxygen. It is commonly found as silicon dioxide or silica e.g. quartz and sand which is an impure form of silicates e.g. mica and calcium silicate

## Uses of silicon

1. It is used in the manufacture of semi – conductors dioxides for radios and televisions and other electronic devices
2. It is used in the manufacture of silicones. Silicones are macromolecules of polymers of silicon, oxygen and alkyl group of organic compounds

Different silicones are able to exist as oils, waxes or plastics. Silicone plastics are fire resistant since they have to form sand and carbon dioxide when burnt in oxygen

## Uses of sand

1. It is used in making glass
2. It is used in manufacture of silicon by reduction
3. It is used in the construction of buildings when mixed with cement and water

## Nitrogen gas

Formula:  $N_2$

Nitrogen exists as a diatomic molecule,  $N_2$

## Physical properties of nitrogen

1. It is colourless

2. It is odorless
3. It does not burn and does not support burning except magnesium which burns with it.

Chemically, nitrogen gas is very unreactive due to the strong bonds between the nitrogen atoms in the molecule. However, under forced conditions, nitrogen reacts with hydrogen gas to form ammonia in the presence of the iron catalyst.

### **Manufacture of nitrogen gas**

Nitrogen gas is manufactured by fractional distillation of liquid air.

### **Uses of nitrogen**

1. It is used in the manufacture of ammonia.
2. It is used to provide an inert atmosphere during the arc welding of aircraft parts and in electric bulbs.

### **The need for nitrogen, phosphorus and potassium compounds in plant life**

Nitrogen is essential in the manufacture of proteins while phosphorus is mainly needed for enzyme activity. Potassium is important in the controlling of rates of photosynthesis and respiration.

### **Ammonia**

Formula:  $\text{NH}_3$

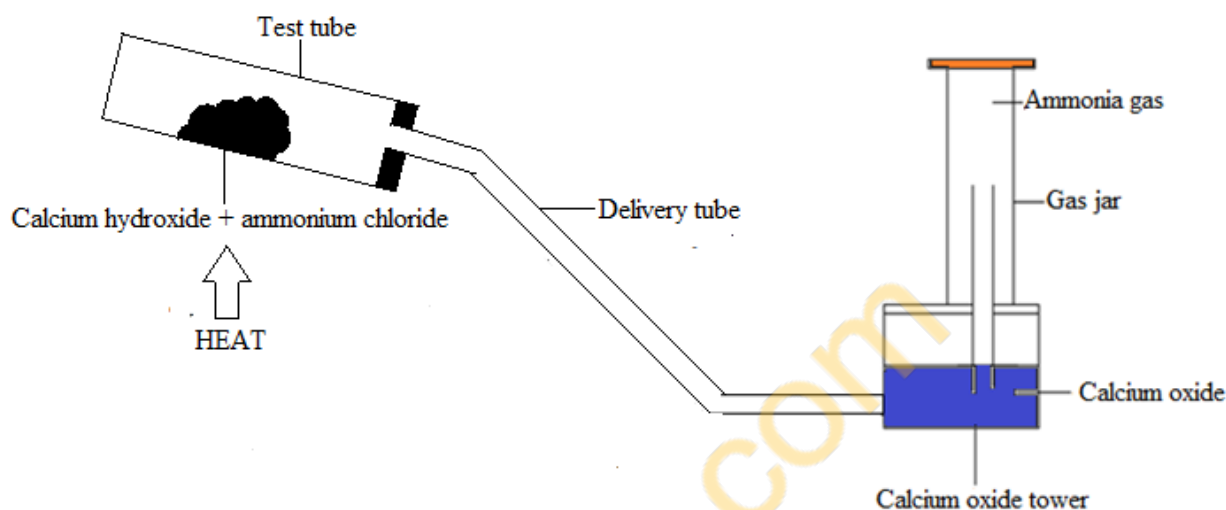
Physical state: Gas

### **Preparation of ammonia**

#### **[A] Laboratory preparation of ammonia**

In the laboratory, ammonia gas can be prepared by the action of heating an alkali with an ammonium compound.

### Example



The test tube must be tilted downwards to prevent the water formed from running back into the reaction mixture which may boil and cause an explosion.

Method of collection: Ammonia gas is collected by down ward displacement of air because it is less dense than air.

Drying agent used: Calcium oxide

Drying agents like calcium chloride and concentrated sulphuric acid should not be used because they easily react with ammonia.

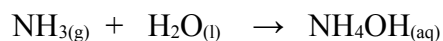
### Physical properties of ammonia

1. It is a colourless gas with a pungent choking smell
2. It is less dense than air
3. It is very soluble in water
4. It is easily liquefied, either by cooling to  $-33^{\circ}\text{C}$  or by compressing. This makes it easy to transport in tanks and cylinders.

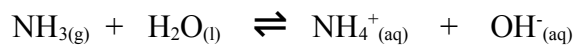
### Chemical properties of ammonia

1. It turns damp red litmus paper blue
2. It burns in pure oxygen with a yellow - brown flame

3. It dissolves in water to form ammonium hydroxide

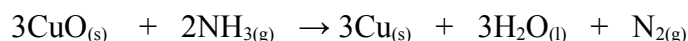


**Note**

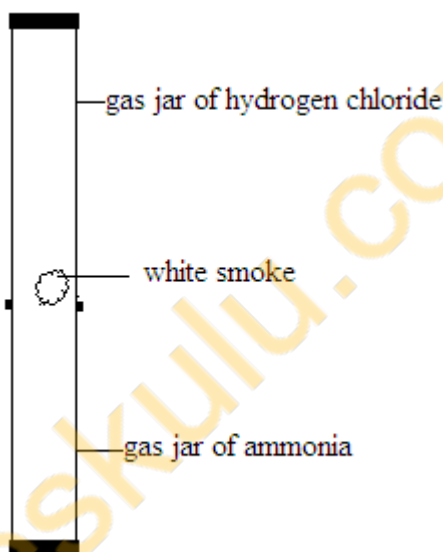


4. It is a reducing agent because it reduces oxides to metals low in the reactivity series of metals.

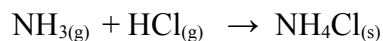
**Example**



5. It reacts with hydrogen chloride gas to form a white smoke.



The white smoke is made of tiny particles of solid ammonium chloride:



**Test for ammonia gas**

Ammonia gas turns damp red litmus paper blue. It is alkaline in nature

**[B] Industrial preparation of ammonia**

The industrial preparation of ammonia is called Haber process

Ammonia gas produced industrially from nitrogen and hydrogen

**Importance of Haber process**

Haber process is important because it produces ammonia on a large scale

### Raw materials for Haber process

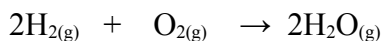
- Nitrogen
- Hydrogen

### Sources of raw materials for nitrogen and hydrogen

#### 1. Nitrogen

**Source:** Liquid air (obtained by fractional distillation)

Nitrogen is obtained by burning hydrogen in air. Air is mostly nitrogen and oxygen, with small amounts of other gases. Only the oxygen reacts with hydrogen, forming steam:

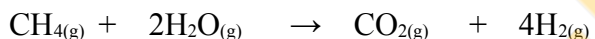


When the steam condenses, the gas that remains is mainly nitrogen.

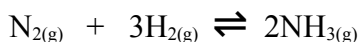
#### 2. Hydrogen

**Source:** Methane (natural gas)  
Steam

Hydrogen is made from methane and steam.



### Reaction between nitrogen and hydrogen



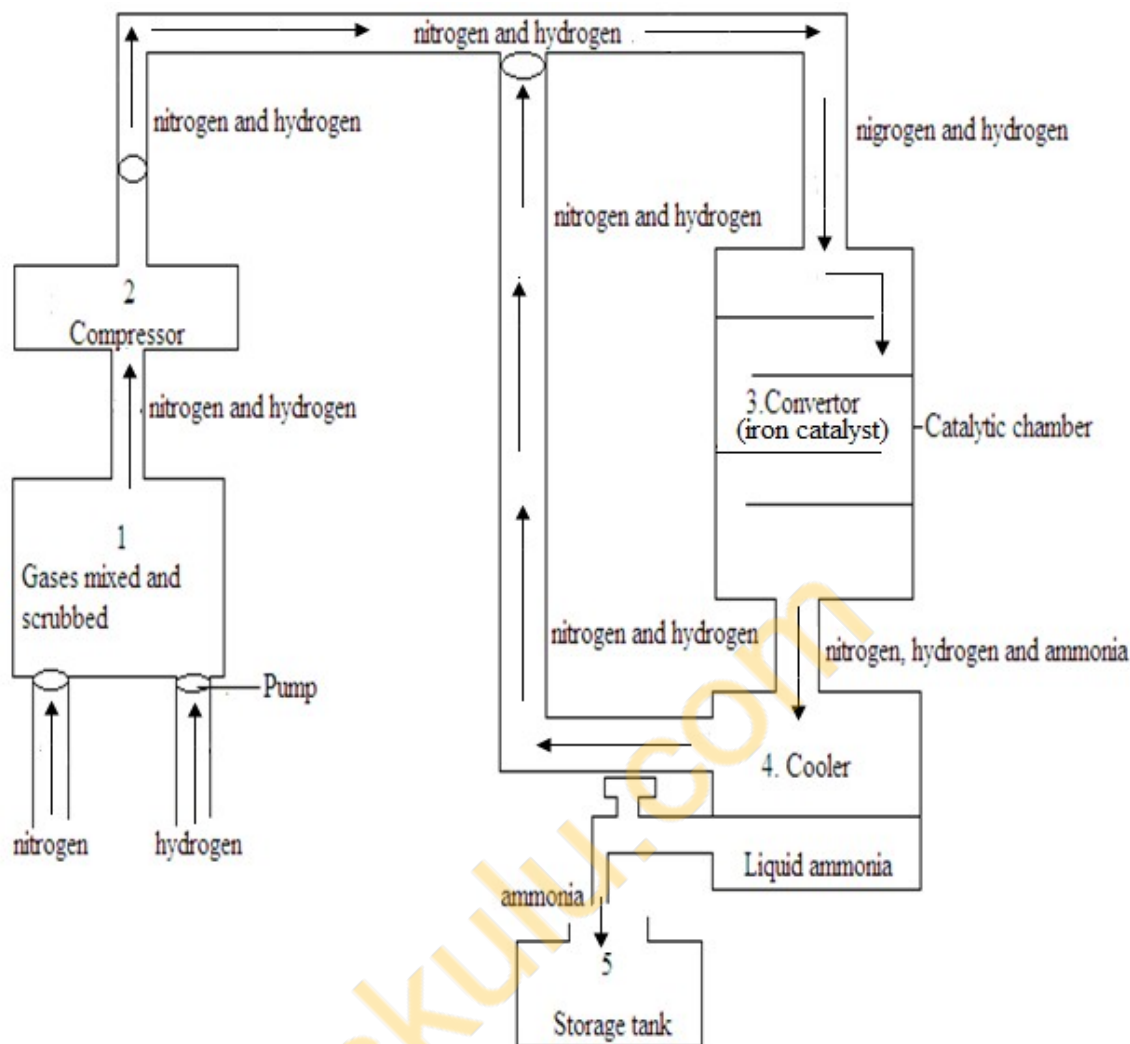
### Essential conditions needed for the manufacture of ammonia in Haber process

Catalyst: Iron

Temperature: 350°C to 450°C

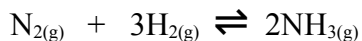
Pressure: 350 atmospheres

### The reaction scheme



Nitrogen is unreactive. To make it react with hydrogen, a process called Haber process is used:

1. The two gases are mixed. The mixture is cleaned or scrubbed, to get rid of any impurities
2. Next the mixture is compressed. This pushes the gas molecules closer together
3. Then the mixture goes to the converter. This is a round tank containing beds of hot iron. The iron is a catalyst for this reaction:



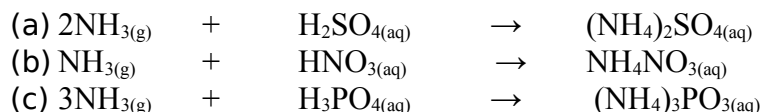
The double headed arrow in the equation means the reaction is reversible. So it does not go to completion. A mixture of nitrogen, hydrogen and ammonia leaves the converter.

4. The mixture is cooled until the ammonia condenses. At the end of the reaction, about 10% of ammonia is produced. The unreacted gases of nitrogen and hydrogen are pumped back to the converter for another chance to react.
5. The ammonia is run into tanks and stored as a liquid, under pressure.

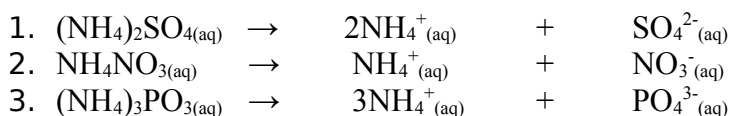
### Uses of ammonia

1. It is used in the refrigerating plants as a refrigerant
2. It is used in the manufacture of explosives
3. It is used in the manufacture of plastics and glue
4. It is used in the manufacture of nitric acid
5. It is used as a cleaning agent
6. It is used in the manufacture of fertilizers such as ammonium sulphate, ammonium nitrate and ammonium phosphate.

### Examples



### Ionic equations



### Note

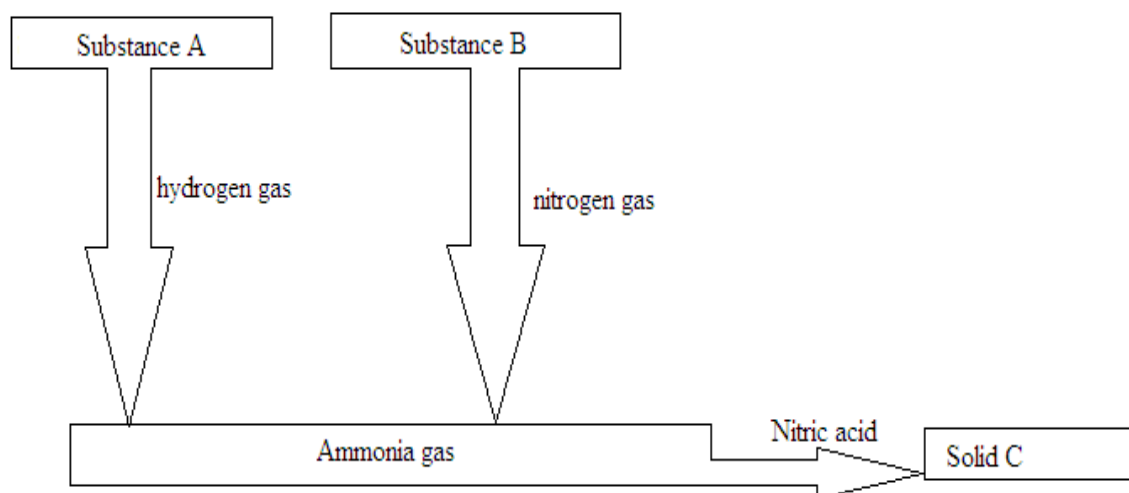
1. Ammonium sulphate is used as a fertilizer because it contains nitrogen and sulphur needed by plants
2. Ammonium nitrate is used as a fertilizer because it contains nitrogen needed by plants
3. Ammonium phosphate is used as a fertilizer because it contains nitrogen and phosphorous needed by plants
4. The three essential elements present in many fertilizers are nitrogen, phosphorous and potassium (N.P.K)

### Problems with chemical fertilizers

- Chemical fertilizers tend to make the soil acidic if they are used for long periods of time
- Chemical fertilizers are easily leached away e.g. nitrates ( $\text{NO}_3^-$ ), sulphate ( $\text{SO}_4^{2-}$ ) and chlorides ( $\text{Cl}^-$ ). They are leached because they easily dissolve in water and move with it. This is wasteful. Besides, when the rainwater drains into rivers, the nitrates cause pollution

### Example

1. Study the reaction scheme below

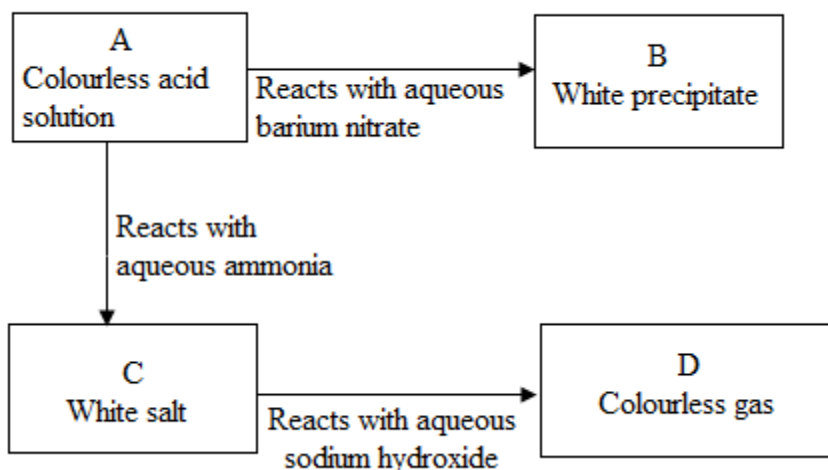


- Identify substances A, B and C
- Ammonia is manufactured by direct synthesis in the Haber process. The reaction is reversible and releases 46 kJ of heat energy per mole of ammonia. Write a balanced chemical equation including all the information given.
- State three essential conditions which are needed for the manufacture of ammonia in Haber process
- What is the use for solid C
- Write down the chemical equation for the reaction between ammonia and nitric acid
- Write any two uses of ammonia besides the one shown above.

### Solution

- A – Nitrogen  
B – Hydrogen  
C – Ammonium nitrate
  - $$\text{N}_{2(\text{g})} + 3\text{H}_{2(\text{g})} \rightleftharpoons 2\text{NH}_{3(\text{g})}$$
  - Catalyst: Iron  
Temperature: 350°C to 450°C  
Pressure: 350 atmospheres
  - It is used as a fertilizer because it contains nitrogen needed by plants
  - $$\text{NH}_{3(\text{g})} + \text{HNO}_{3(\text{aq})} \rightarrow \text{NH}_4\text{NO}_{3(\text{aq})}$$
  - It is used in the refrigerating plants as a refrigerant  
It is used in the manufacture of explosives  
It is used in the manufacture of plastics and glue  
It is used as a cleaning agent
2. The diagram below shows some of the properties and reactions of aqueous ammonia and some other substances





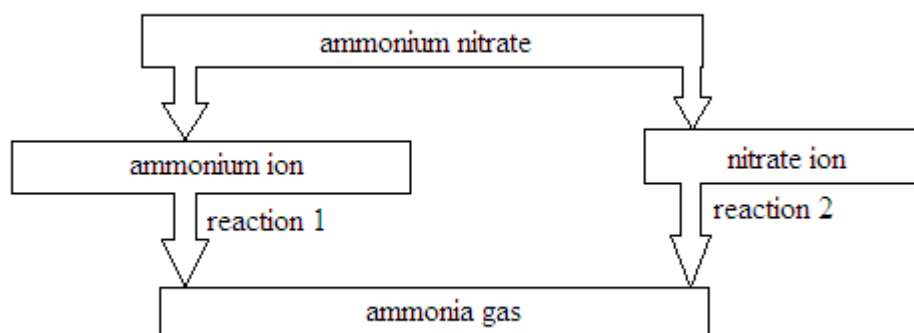
- (a) Identify, by name, the substances A, B, C and D
- (b) Write an ionic equation including symbols for the reaction of:
  - (I) A with aqueous barium nitrate to form B
  - (II) A with aqueous ammonia to form C
  - (III) C with aqueous sodium hydroxide
- (c) Name a method you would use to collect gas D

### Solution

- (a) A – Sulphuric acid  
 B – Barium sulphate  
 C – Ammonium sulphate  
 D – Ammonia
- (b) (I)  $\text{Ba}^{2+}_{(\text{aq})} + \text{SO}_4^{2-}_{(\text{aq})} \rightarrow \text{BaSO}_{4(\text{s})}$   
 (II)  $\text{H}^{+}_{(\text{aq})} + \text{OH}^{-}_{(\text{aq})} \rightarrow \text{H}_2\text{O}_{(\text{l})}$   
 (III)  $\text{NH}_4^{+}_{(\text{aq})} + \text{OH}^{-}_{(\text{aq})} \rightarrow \text{H}_2\text{O}_{(\text{l})} + \text{NH}_{3(\text{g})}$
- (c) Down ward displacement of air.

### Exercise

1. Ammonium nitrate contains ammonium ions ( $\text{NH}_4^{+}$ ) and nitrate ions ( $\text{NO}_3^{-}$ )
  - (a) Name two substance which are used to manufacture ammonium nitrate
  - (b) Explain why ammonium nitrate can act as a fertilizer
  - (c) The diagram below shows ammonium ions ( $\text{NH}_4^{+}$ ) and nitrate ions ( $\text{NO}_3^{-}$ ) can be changed into ammonia.



- (i) Describe how you would carry out reaction 1 and reaction 2
- (ii) Write an ionic equation for reaction 1 including state symbols
2. In the industry, nitrogen is combined with hydrogen to form ammonia
  - (a) From what raw materials is the hydrogen extracted?
  - (b) Explain why haber process is important?
3. Name three essential elements present in many fertilizers
  - (a) Name two compounds which can be used as fertilizers
  - (b) Explain why after fertilizers have been added to the soil heavy rains can be a disadvantage.

## Pollution

pollution is the contamination of the environmet with harmful substances. The harmful substances are called pollutants.

### Types of pollution

There are three main types of pollution.

- Land pollution

- Air pollution
- Water pollution

### **Land pollution**

Land pollution occurs when pollutants are added to the land. The major causes of land pollution are materials which do not rot or decay. These materials resist bacterial action and are said to be non biodegradable.

### **Examples of land pollutants**

- Plastics
- Glass

### **water pollution**

Water pollution occurs when pollutants are added to water.

### **Examples of water pollutants**

**Oil spillage:** Oil spillage by oil tankers and leaking engines of speed boats pollutes the water the water. It disturbs marine life since oxygen supply is cut off.

**Solution:** You can scoop the oil from the surface of the water

**Weeds:** Weeds usually prevent smooth transport and make H.E.P generation very difficult.

**Solution:** You can cut and remove all the weeds from the water

**Industrial wastes:** Acidic industrial effluents make the water slightly acidic. This disturbs the balance of living things .

**Solution:** Industrial wastes should be treated with slaked lime to neutralize them. You can also set up dumping sites

**Acid rain:** Acid rain reduces the PH of the water

**Debris:** Debris include solid particles and plant parts

### **Air pollution**

Air pollution occurs when pollutants are added to the atmosphere

### **Examples of air pollutants**

- Carbon monoxide
- Sulphur dioxide
- Oxides of nitrogen

- Soot
- Lead compounds

### Carbon monoxide

Formula: CO

**Source:** Incomplete combustion of fuel in car exhausts.

Carbon monoxide is produced by the incomplete combustion of carbon containing compounds in limited supply of air such as in engines of vehicles and blast furnace

**Effects:** When carbon monoxide is inhaled in the body, it enters the blood stream; it combines with haemoglobin making it difficult for red blood cells to transport oxygen. This may lead to suffocation, unconsciousness or death.

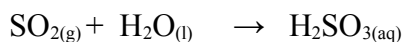
**Solution:** Use alternative source of fuel like hydrogen which does not pollute the air. Avoid incomplete combustion of fuels

### Sulphur dioxide

Formula:  $SO_2$

**Source:** Combustion of fossil fuels.

Sulphur dioxide is produced as a result of the combination of fossil fuels containing sulphur compounds. Sulphur dissolve in rain water which come down as acid rain



### Adverse effects of acid rain

Acid rain has a lot of adverse effects on buildings, roofing sheets, monuments, vegetation and on the lungs

1. Acid rain make the soil to become acidic and hence destroy vegetation
2. Acid rain dissolve monuments (statues) made of calcium carbonate
3. Acid rain erodes buildings and iron roofing sheets. Iron roofing sheets rust rapidly because of the presence of an electrolyte

4. Sulphur dioxide combines with water vapour in the lungs to form an acid. The acid can cause temporary or permanently damaged to the lungs

### **Carbon dioxide**

Formula:  $CO_2$

**Source:** Complete combustion of fuels like petrol and charcoal

**Effects:** Depletes the ozone layer leading to global warming. It also causes acid rain.

**Solution:** Massive afforestation

### **Oxides of nitrogen**

**Source:** Combustion of fuels in car exhaust.

Oxides of nitrogen are found in car exhaust gases.

**Effects:** Compounds of nitrogen form cumulative poison in tissues of living things. Nitrogen combines with oxygen at high temperature in the cylinder of car engines to form nitrogen monoxide which is very poisonous. Nitrogen monoxide damage lungs and irritate eyes.

### **Lead compounds**

**Source:** Combustion of fuels in car exhausts.

Lead compounds are found in car exhaust gases.

**Effects:** When lead is taken into the body, it may settle and be stored in the bones or membranes of the brain. This leads to damaging of the bones, brain and the nervous system.

Quantities of lead in the blood as low as 100 micrograms per cubic decimeter can cause children to have low intelligence, poorer memories and less muscular coordination than children who do not carry that burden of lead.

Petrol contains about  $0.5\text{g/dm}^3$  to  $1\text{g/dm}^3$  of lead. Lead poisoning is an example of global poisoning.

**Solution:** Lead tetraethyl is added to petrol as an inhibitor to prevent knocking

### **Ozone**

Formula:  $O_3$

**Source:** Photochemical smog

**Effects:** At ground level, ozone is an eye irritant, causes breathing problems and damages plants.

### Example

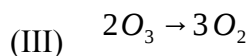
1. Ozone,  $O_3$ , is an atmospheric pollutant in the lower atmosphere but is beneficial higher up in the atmosphere.
  - (a) How is ozone formed in the lower atmosphere?
  - (b) Ozone in the upper atmosphere is being depleted. Describe briefly how this is happening and some of the health problems caused by ozone depletion.
  - (c) At room temperature ozone decomposes slowly to form oxygen,  $O_2$ .

The decomposition can be represented by the equation below. The reaction is exothermic. One mole of ozone will release 143 kJ when it is fully decomposed.

$$2O_3 \rightarrow 3O_2$$
    - (I) In terms of the energy changes that take place during bond breaking and bond making, explain why this reaction is exothermic.
    - (II) Explain why the **rate** of this decomposition increases as the **temperature** increases.
    - (III) Calculate the energy released when 16 g of ozone is decomposed.

### Solution

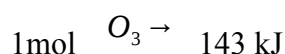
- (a) Ozone is formed by photochemical reactions (or sparks in air, ultraviolet on  $O_2$ )
- (b) Ozone removed by reaction with chlorine (atoms) and is derived from CFC's  
Ozone loss causes skin cancers or cataracts or crop damage or skin diseases or eye damage
- (c) (I) Bond breaking is endothermic/absorbs energy and bond forming is exothermic/releases energy more energy released than absorbed  
(II) As temperature increases molecules move faster or increased K.E hence more frequent collisions or more molecules energy exceeds the activation energy.

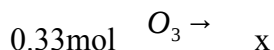


$$n = \frac{m}{MM}$$

$$n = \frac{16g}{48g/mol}$$

$$n = 0.33mol$$





$$\frac{0.33O_3 \times 143\text{ kJ}}{1\text{ mol } O_3}$$

$$x = 47.7\text{ kJ}$$

### General solutions to the problems of pollution

1. Recycling of waste products
2. Setting up protection standards. This involves limiting or banning of the manufacture and handling of certain products that are a source of pollution
3. Developing engines that use fuels which pollutes less and using catalytic convertors.
4. Setting up advisory boards to monitor pollution. Such boards would advise and give assistance on the disposal of pollutants

**Note:** Fossil fuels must be conserved because they are limited and non-renewable energy sources.

### Exercise

1. The increase in industrial activity in Zambia has resulted in high level of air pollution.
  - (a) What is meant by air pollution?
  - (b) Name two common air pollutants in Zambia and state what effect each pollutant has on either plant or animal life
  - (c) State one way in which the emission of one of the pollutants you have named can be minimised.
  - (d) When limestone is heated strongly, quicklime, CaO, is formed according to the following chemical equation:  

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

What would be observed if the gas produced above was passed through lime water until there was no further change?
  - (e) Name two gases, other than sulphur dioxide, that pollute the atmosphere. Give one source of each of each pollutant. Sulphur dioxide is shown as an example of a pollutant  
 Pollutant: Sulphur  
 Source: Burning coal
  - (f) Give one reason for conserving fossil fuels
  - (g) What is damaged by the sulphur dioxide released when some fossil fuels are burnt. .  
 Give two examples

### Water

Chemical formula: H<sub>2</sub>O

## Test for water

If a liquid is water, it will:

- (a) turn blue cobalt chloride paper pink
- (b) turn white anhydrous copper (II) sulphate blue
- (c) boils at  $100^{\circ}\text{C}$  and freezes at  $0^{\circ}\text{C}$  at natural pressure if it is pure water

## Uses of water

- (a) It is essential for all living things
- (b) In homes, water is used for cooking, washing and flushing
- (c) It is used as a solvent
- (d) It is used for making beer, cement

Water from the source (rivers and underground) is never completely pure because it contains the following impurities:

**Bacteria and tiny organisms:** Most bacteria are harmless but some can cause diseases

**Dissolved substances:** Nitrates and sulphates from the soil, gases from air and some calcium and magnesium compounds from the rocks

**Solid particles:** Solid particles include particles of mud, sand, grit, twigs, dead plants, dead animals and perhaps tins and rags that people have dumped.

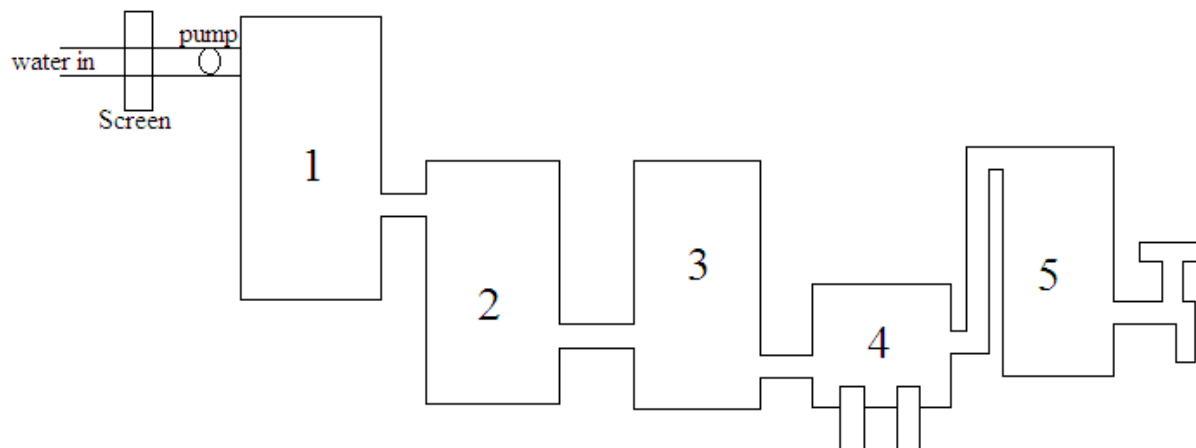
Before the water is safe to drink, the bacteria and solid substances must be removed. This is done at the water works.

## The water works

### Purification of water at the water works

The diagram below shows what happens at the water works





The water is pumped through the screen which gets rid of large bits of rubbish. Then the water gets through following stages:

1. **Course sand filter**  
The course sand filter tank traps the larger particles of solid
2. **Sedimentation tank**  
Here chemicals are added to it, to make the smaller particles stick together. These particles then settle to the bottom of the tank.
3. **Fine sand filter**  
The fine sand filter traps any remaining particles.
4. **Chlorination tank**  
In this tank, a little chlorine gas is added. Chlorine gas dissolves, and kills any remaining bacteria. This is called disinfecting or sterilising the water. In some places, a fouride compound is also added to the water, to help prevent tooth decay. Water is now fit to drink.
5. **Storage tank**  
Water is now pumped into high storage tanks and from there piped to homes and facories. The water that flows from the taps is clean but not quite pure. It still contains dissolved substances which were not removed at the water works. Pure water can be made by distillation of tap or rain water

#### **Two main stages in the purification of water**

- (a) **Filtration**: Solid paticles are removed from the water
- (b) **Chlorination**: Chlorine is added to water to kill the bacteria

#### **Exercise**

1. Water is life and it is an important raw material in the home and industry
  - (a) Describe the identty test of pure water
  - (b) Outline the two main stages in the purification of water
  - (c) State two uses of water in the industry

#### **Types of water**

- Soft water
- Hard water

### Soft water

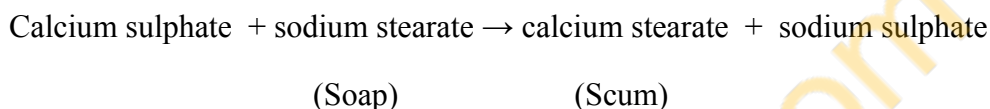
Soft water forms lather easily with soap

### Hard water

Hard water does not form lather easily with soap. Soap gives a scum with hard water.

Hardness in water is caused by dissolved calcium and magnesium compounds e.g calcium hydrogen carbonate, magnesium hydrogen carbonate, calcium sulphate and magnesium sulphate

The scum form because the compounds react with soap and give an insoluble product that floats on water



### Temporory hardness

Temporory hardness is caused by the presence of calcium hydrogen carbonate in water. It occurs in limestone areas when rain water containing a small amount of dissolved carbon dioxide from the air passes over the limestone.



Temporory hardness can be removed by boiling the water. The white diposite (fur) which is produced by boiling hard water is calcium carbonate



### Permanent hardness

Permanent hardness is caused by small amounts of dissolved calcium and magnesium compounds.

Permanent hardness cannot be removed by boiling

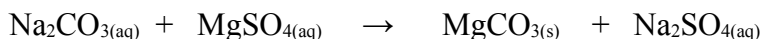
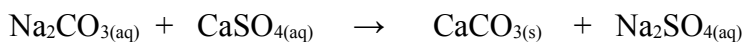
### Removal of permanent hardness

#### [A] Distillation

This method is too expensive to produce large quatities of soft water

### [B] Addition of sodium carbonate ( washing soda)

Sodium carbonate precipitates the calcium and magnesium ions which cause hardness



This method removes both temporary and permanent hardness but it can damage woolen materials since water becomes alkaline

### Advantages of hard water

1. It has a better or pleasant taste due to dissolved compounds
2. It contains calcium compounds which are good for bones and teeth
3. Doctors think it helps to prevent heart disease

### Disadvantages of hard water

1. Leads to wastage of soap and production of scum
2. Leaves fur in kettles, pipes, boilers and radiators. This makes them less effective and also cause blockage.

## Carbon

### Allotropes of carbon

Definition: Allotropes are elements in different physical forms but in the same state

Allotropy is the existence of an element in different physical forms but in the same state

Carbon exists in the form of graphite, diamond and amorphous

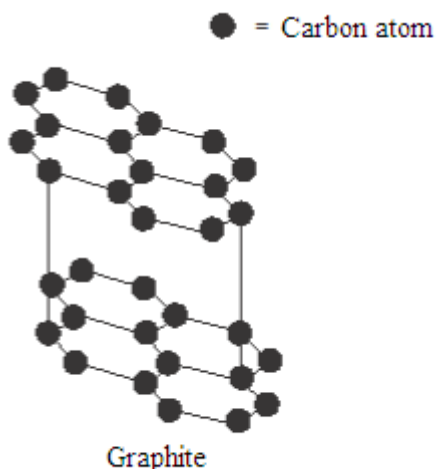
Graphite and diamond are allotropes of carbon.

### [A] Graphite

#### Structure of graphite

Graphite is a soft, black, crystalline form of carbon that is a fair conductor of electricity.

It is made up of flat sheets of carbon atoms



Each carbon atom is bonded to three others while the fourth electron is delocalised. Since each carbon atom forms covalent bonds to three others, this gives rings of six atoms that join to make flat sheets

The sheets of atoms lie on top of each other, held together by weak forces

### Physical properties of graphite

1. It is a good conductor of electricity because of free moving electrons in between the layers of carbon atoms
2. It is soft and slippery. This is because the sheets of atoms can slide over each other easily.
3. It writes well on paper
4. It has a density of  $2.22\text{g/cm}^3$
5. It has a high melting point. This is because the strong bonds between the carbon atoms within a layer make graphite difficult to pull apart in the direction of the layer.

### Uses of graphite

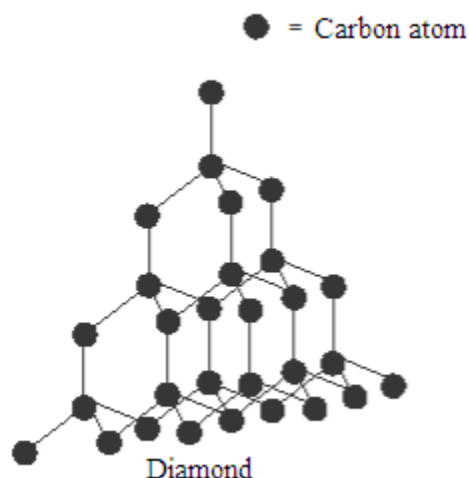
1. It is used as a lubricant because the layer of carbon atoms slide over each other easily
2. It is used as an electrode in electrolysis
3. It is used in making the “lead” for pencils. This is because it leaves a grey streak or when it is drawn across a sheet of paper

### [B] Diamond

#### Structure of diamond

Diamond is a colourless, crystalline solid with an extremely high density

It is a giant structure of carbon atoms



Each carbon atom shares electrons with each of its four nearest neighbours, thus forming four covalent bonds

In addition, each carbon atom is imagined to be at the centre of the tetrahedron surrounded by four other carbon atoms whose centres are at the corners of the tetrahedron

### Physical properties of diamond

1. It is very hard - the hardest substance known. It has a very high melting point of about 3700°C because each atom is held in place by four strong bonds.
2. It is colourless and transparent with a dazzling brilliant lustre
3. It has a density of 3.5g/cm<sup>3</sup>
4. It does not conduct electricity because there are no ions or free electrons in it to carry charge

### Uses of diamond

1. It is used for cutting tools and drilling devices
2. It is used for cutting glass

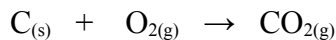
### [C] Amorphous carbon

Amorphous carbon such as coal and charcoal is porous and easily absorbs pigments from solutions e.g in the refining of white spoon sugar

Charcoal is used to absorb the brown colour from brown sugar which is then turned white

### Chemical properties of carbon

1. All the forms of carbon react with oxygen to form carbon dioxide



### Example

1. Diamond and graphite are allotropes of carbon. Diamond has a melting point of about 3700°C where as graphite has a melting point of about 3300°C.

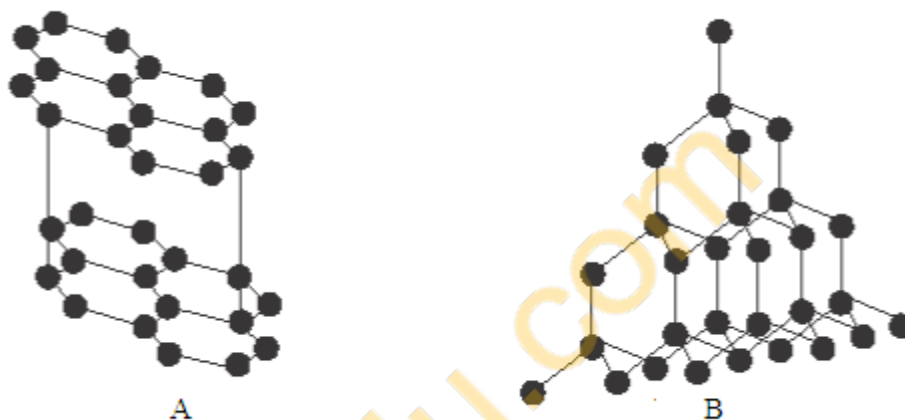
- (a) Explain what is meant by the term allotropes?
- (b) Explain why diamond does not conduct electricity whereas graphite does

**Solution**

1. (a) Allotropes are elements in different physical forms but in the same state.
- (b) Diamond does not conduct electricity because there are no ions or free electrons in it to carry charge whereas graphite conducts electricity because of free moving electrons in between the layers of carbon atoms.

**Exercise**

1. Carbon exists in two different forms. They have the following structures



- (a) Name the form of carbon having:
  - (I) Structure A
  - (II) Structure B
- (b) Give the use of the form of carbon having:
  - (I) Structure A
  - (II) Structure B
- (c) Explain why both diamond and graphite have very high melting points
- (d) Why is graphite used in pencils?

**Carbonates, oxides and hydroxides**

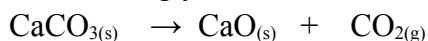
**[A] Calcium carbonate\_**

Chemical formula:  $\text{CaCO}_3$

Calcium carbonate is a white solid which is insoluble in water

In nature, calcium carbonate exists as limestone, marble, chalk and calcite

When strongly heated, calcium carbonate decomposes to form calcium oxide and carbon dioxide



**Uses of calcium carbonate**

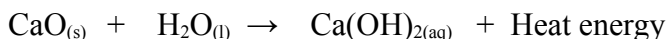
1. It is used in the manufacture of cement
2. It is used for making glass
3. It is used to remove impurities like silica as slag in the blast furnace

### [B] Calcium oxide

Chemical formula: CaO

Special name: Quick lime

Calcium oxide reacts vigorously with water to form calcium hydroxide and a lot of heat energy



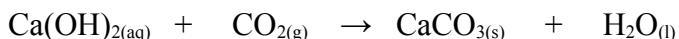
### [C] Calcium hydroxide

Chemical formula: Ca(OH)<sub>2</sub>

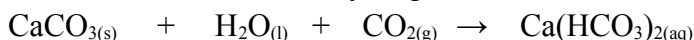
Special name: Slaked lime or lime water

Calcium hydroxide glows brightly at high temperatures

Calcium hydroxide turns milky or cloudy when carbon dioxide is passed through it and a white precipitate (suspension) of calcium carbonate is formed



When excess carbon dioxide gas is passed through for some time, the precipitate disappears and a clear solution of calcium hydrogen carbonate is formed



### Uses of calcium oxide and calcium hydroxide

1. They are used in treating acidic soils on the farm
2. They are used in the neutralization of acidic industrial waste products before discharging them into rivers and lakes
3. Calcium hydroxide is used as plaster of paris for broken arms and legs
4. Calcium oxide is used as lining in the blast furnace.
5. Calcium oxide is used to remove silica impurities in the extraction of iron.
6. Calcium oxide is used as a drying agent especially for ammonia gas.

### Example

1. A white solid V is heated strongly. At a high temperature, V gives off carbon dioxide and changes to solid W which begins to glow. When water is added to W, it begins to fizz, produces heat and crumbles to a powder X. X dissolves in water to form an alkaline solution Y. When carbon dioxide is passed into solution Y, the solution turns cloudy. The

cloudiness is caused by a white suspension Z and its formation is used as a test for carbon dioxide.

(a) Deduce the identity of V, W, X, Y and Z giving either their chemical or common names.

(b) Write chemical equations for:

(I) the action of heat on V

(II) the action of carbon dioxide on solution Y

(c) State the use for either W or X

### Solution

(a) V - Calcium carbonate,  $\text{CaCO}_3$

W - Calcium oxide,  $\text{CaO}$

X - Calcium hydroxide,  $\text{Ca(OH)}_2$

Y - Calcium carbonate,  $\text{CaCO}_3$

Z - Calcium hydrogen carbonate,  $\text{Ca(HCO}_3)_2$

(b) (I)  $\text{CaCO}_{3(s)} \rightarrow \text{CaO}_{(s)} + \text{CO}_{2(g)}$

(II)  $\text{CaCO}_{3(s)} + \text{H}_2\text{O}_{(l)} + \text{CO}_{2(g)} \rightarrow \text{Ca(HCO}_3)_2_{(aq)}$

(c) W and X are used in treatment of acidic soils on the farms and also in the neutralization of acidic waste products before discharging them into rivers and lakes

X is used as plaster of Paris for broken arms or legs.

## Organic chemistry

Definition: Organic chemistry is the study of carbon compounds except carbonates carbon monoxide, carbon dioxide, carbon disulphide etc.

### Common terms used

#### 1. Organic compounds

Organic compounds are compounds which contain carbon except carbonates, carbon monoxide, carbon dioxide, carbon disulphide etc.

#### 2. Hydrocarbon

A hydrocarbon is a compound which consists of the elements carbon and hydrogen only,

### Examples of hydrocarbons

- Methane,  $\text{CH}_4$
- Ethene,  $\text{C}_2\text{H}_4$
- Ethyne,  $\text{C}_2\text{H}_2$

#### 3. Homologous series



A homologous series is a family of similar organic compounds  
Each member in a family is called homologue

### Characteristics of the homologous series

- (a) Members in the family show a gradual change in physical properties i.e. change from gas to liquid and solid as the carbon chain increases.
- (b) Members in the family have similar methods of preparation
- (c) Members in the family have similar chemical properties because they have the same functional group.
- (d) Members in the family can be represented by the general molecular formula:

### Examples

- Alkanes,  $C_n H_{2n+2}$
  - Alkenes,  $C_n H_{2n}$
  - Alkynes,  $C_n H_{2n-2}$
  - Alkanols (alcohols),  $C_n H_{2n+1} OH$
  - Alkanoics ( carboxylic acids),  $C_n H_{2n+1} COH$
- (e) Each member in the family differs to the next by  $CH_2$  or by 14.

## 4. Functional group

A functional group is a group which determines the chemical properties of organic compounds

Organic family	Functional group	Name of functional group
Alkanes	$-C-C-$	Single carbon – carbon covalent bond
Alkenes	$C=C$	Double carbon – carbon covalent bond
Alkynes	$C\equiv C$	Triple carbon – carbon covalent bond
Alkanols ( alcohols)	$-OH$	Hydroxyl group

Alkanoics (carboxylic acids)	$\text{— COOH}$ or $\begin{array}{c} \text{O} \\ \parallel \\ \text{C-O-H} \end{array}$	Carboxyl group
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### Nomenclature of organic compounds

Nomenclature is a standardized way of naming organic compounds.

Nomenclature takes into account the following:

- Prefix
- Suffix

The prefix shows the number of carbon atoms in an organic compound.

Prefix	Number of carbon atoms
Meth	1
Eth	2
Prop	3
But	4
Pent	5
Hex	6
Hept	7
Oct	8
Non	9
Dec	10

The suffix shows the organic family of the organic compound.

Organic family	Suffix
Alkanes	ane
Alkenes	ene
Alkynes	yne
Alcohols	anol
Carboxylic acids	anoic
Esters	anoate

### Alkanes

Alternative term: Saturated hydrocarbons

General molecular formula:  $C_nH_{2n+2}$  where  $n = 1, 2, 3, 4, \dots$

Alkanes have single carbon – carbon covalent bonds between carbon atoms.

They are called saturated hydrocarbons because they have the required (maximum) number of hydrogen atoms.

They end with ane

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#### Examples of alkanes

Name	Molecular formula	Structural formula	Condensed formula	$M_r$
Methane	CH <sub>4</sub>	$\begin{array}{c} \text{H} \\   \\ \text{H}-\text{C}-\text{H} \\   \\ \text{H} \end{array}$	CH <sub>4</sub>	16

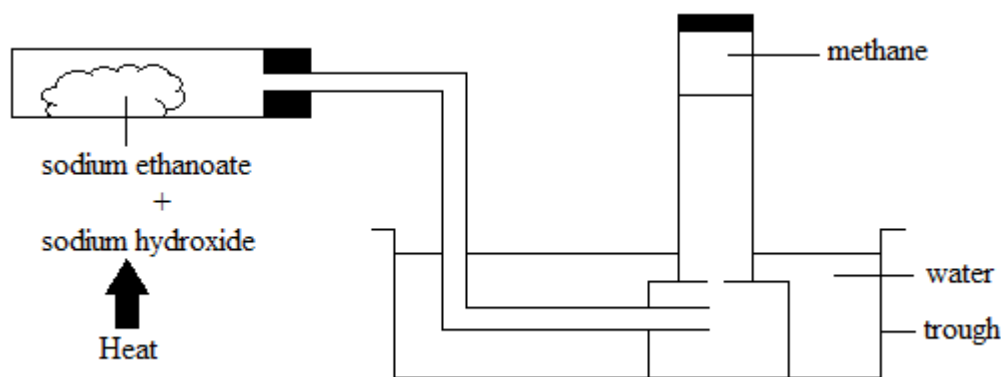
Ethane	$C_2H_6$	$  \begin{array}{c}  H & H \\    &   \\  H-C & -C-H \\    &   \\  H & H  \end{array}  $	$CH_3CH_3$	30
Propane	$C_3H_8$	$  \begin{array}{c}  H & H & H \\    &   &   \\  H-C & -C & -C-H \\    &   &   \\  H & H & H  \end{array}  $	$CH_3CH_2CH_3$	44
Butane	$C_4H_{10}$	$  \begin{array}{c}  H & H & H & H \\    &   &   &   \\  H-C & -C & -C & -C-H \\    &   &   &   \\  H & H & H & H  \end{array}  $	$CH_3(CH_2)_2CH_3$	58
Pentane	$C_5H_{12}$	$  \begin{array}{c}  H & H & H & H & H \\    &   &   &   &   \\  H-C & -C & -C & -C & -C-H \\    &   &   &   &   \\  H & H & H & H & H  \end{array}  $	$CH_3(CH_2)_3CH_3$	72

### Preparation of methane

Methane can be prepared by heating a mixture of anhydrous sodium ethanoate,  $CH_3COONa$ , and soda lime (sodium hydroxide),  $NaOH$ .

Reaction:  $CH_3COONa_{(s)} + NaOH_{(s)} \rightarrow CH_{4(g)} + Na_2CO_{3(s)}$

Diagram:



### Physical properties of alkanes

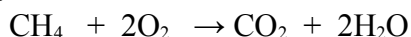
1. Their physical states vary at room temperature and pressure. Lower members are gases; others are liquids while higher members are solids.
2. Their melting and boiling points increases as the carbon chain (relative molecular masses) increases.
3. Their densities increases as the carbon chain increases.

### Chemical properties of alkanes

#### 1. Combustion

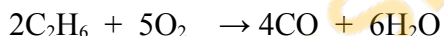
- (a) In a plentiful supply of air (complete combustion), alkanes react with oxygen to form carbon dioxide and water.

#### Example



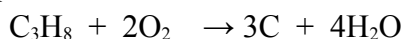
- (b) In a limited supply of air (incomplete combustion), alkanes react with oxygen to form carbon monoxide and water

#### Example



- (c) In a very limited supply of air (incomplete combustion), alkanes react with oxygen to form carbon and water

#### Example



#### 2. Substitution reaction

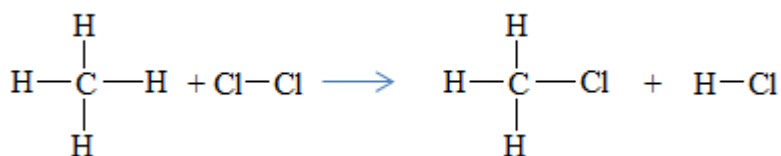
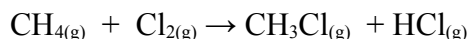
A substitution reaction is a reaction in which one atom or group of atoms in a molecule is replaced by another.

Alkanes undergo substitution reactions with halogens in the presence of ultraviolet light.

#### Example

##### Halogenation of methane

Methane can react with chlorine gas in the presence of sunlight to form chloromethane and hydrogen chloride.



### Condition

Temperature: 200°C

Catalyst: Sunlight (ultraviolet light)

### Isomerism of alkanes

Isomerism is the existence of compounds with the same molecular formula but different structural formula

### Isomers

Isomers are compounds which have the same molecular formula but different structural formula.

Alkanes with more than three carbon atoms exhibit isomerism

### Nomenclature of alkane isomers

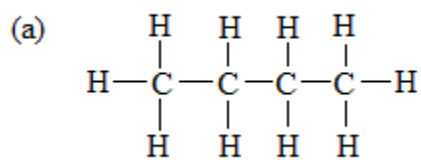
#### The International Union for Pure and Applied Chemistry (IUPAC) rules for naming alkanes

- Choose the longest continuous carbon chain in the molecule.
- Number the carbon atoms in the longest chain chosen starting from the end that gives the

smaller set of numbers nearer the branched methyl group  $\begin{array}{c} \text{CH} \\ | \\ (2,2,3) \\ | \end{array}$

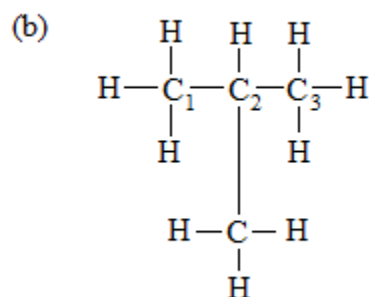
- Write the number of carbon atom at which the branched methyl group is attached to the main chain in alphabetical order.
- Put a comma after each group number and a hyphen between the group number and the methyl group.
- Name the compound as a derivative of the normal alkane having the same number of carbon atoms as in the longest chain chosen.

**Examples 1:** Butane has two isomers



Molecular formula:  $\text{C}_4\text{H}_{10}$

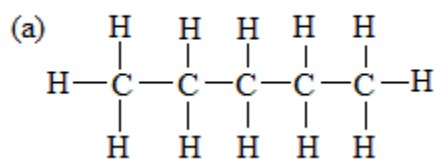
IUPAC name: Normal butane



Molecular formula:  $\text{C}_4\text{H}_{10}$

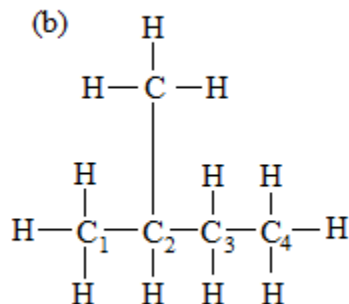
IUPAC name: 2 – methyl propane

**Example 2:** Pentane has three isomers



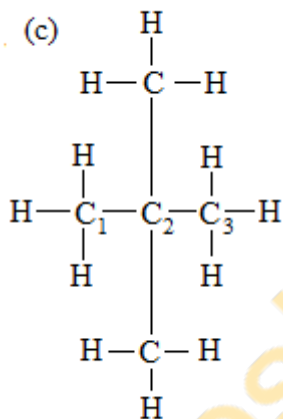
Molecular formula:  $C_5H_{12}$

IUPAC name: Normal pentane



Molecular formula:  $C_5H_{12}$

IUPAC name: 2 – methyl butane



Molecular formula:  $C_5H_{12}$

IUPAC name: 2, 2 – dimethyl propane

### Exercise

1. Draw the structure of the compound with the IUPAC name; 2, 3, 4, 4 – tetra methylpentane

### Cracking of alkanes

Cracking is the breaking down of large hydrocarbon molecules into simpler and smaller molecules.



Alkanes break down to produce alkenes, short chain alkanes and in some cases hydrogen gas.

### Types of cracking

#### 1. Thermal cracking

This is where heat is used to break down large molecules into smaller ones.

#### Example

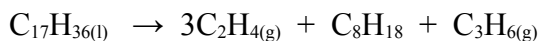


#### 2. Catalytic cracking

This is where both heat and a catalyst are used to break down large molecules into smaller ones.

Common catalysts used include aluminium oxide ( $\text{Al}_2\text{O}_3$ ) and silica ( $\text{SiO}_2$ ).

#### Example



### Conditions

Catalyst: Aluminium oxide,  $\text{Al}_2\text{O}_3$

Temperature:  $600^\circ\text{C}$

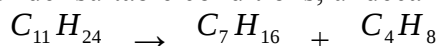
### Importance of cracking

1. It is used in the production of raw materials for petrol chemicals like ethene and hydrogen. Hydrogen is used in making plastics and margarine.
2. It is used in the production of petrol.

### Exercise

1. One of the hydrocarbons found in crude oil is undecane,  $\text{C}_{11}\text{H}_{24}$

Under suitable conditions, undecane undergoes the reaction below



- (a) What term is used to describe this type of reaction in the petrochemical industry?
- (b) State two conditions necessary for this reaction to take place

### Fuels

A fuel is a substance which burns in air to produce useful energy.

### Sources of fuels

(a) **Natural gas**

The main component of natural gas is methane.

Natural gas is usually mined and purified before use.

(b) **Petroleum (crude oil)**

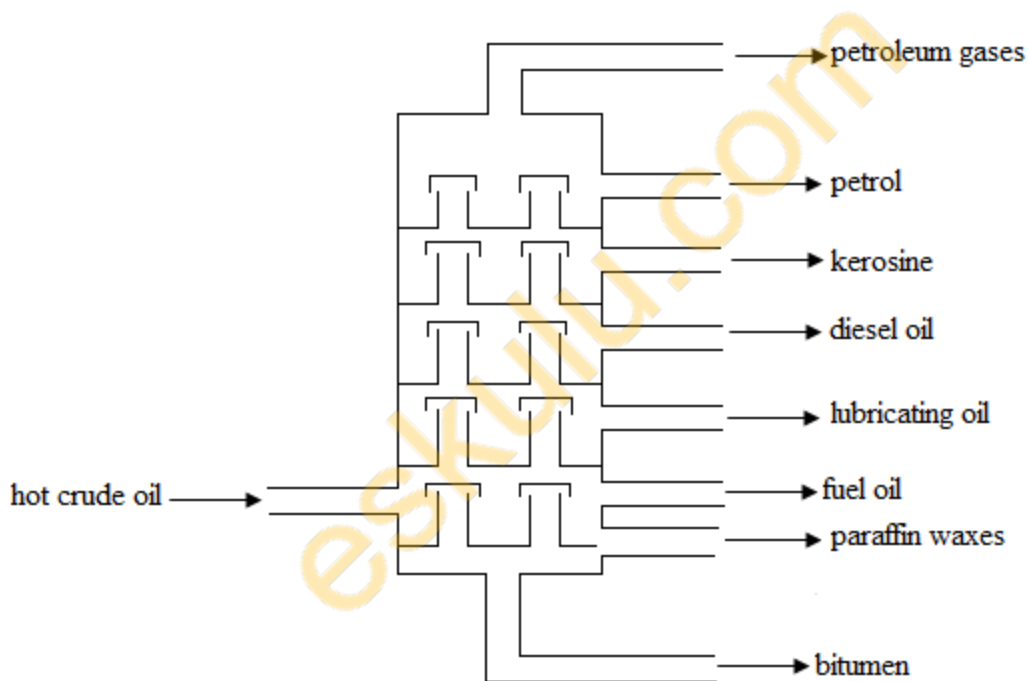
Crude oil is a mixture of long chain hydrocarbons and some elements like sulphur and nitrogen

Crude oil was formed millions of years ago by the decomposition of animals and plants under pressure.

Crude oil can be refined by fractional distillation.

Fractional distillation is a process of separating components of a mixture based on their boiling points.

The diagram below shows a fractionating tower and different fractions obtained from crude oil.



**Fractions of crude oil and their uses**

Fraction	Number of carbon atoms	Use
Petroleum gases	$C_1 - C_4$	Used in camping stoves and cookers as bottled gas
Petrol (gasoline)	$C_4 - C_{10}$	Used as a fuel in internal combustion engines in vehicles
Kerosine ( paraffin)	$C_{10} - C_{17}$	Used as a fuel in jets Used in paraffin lamps for lighting Used in paraffin lamps for cooking

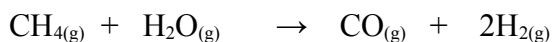
Diesel oil (gas oil)	$C_{17} - C_{20}$	Used as a fuel in diesel engines like trains, hammer mills, tractors, lorries
Lubricating oil	$C_{20} - C_{30}$	Used as a lubricant in machines to reduce friction
Fuel oil	$C_{30} - C_{40}$	Used as a fuel in ships, power stations and industrial machinery
Paraffin waxes	$C_{40} - C_{50}$	Used in making waxes, polishes and wax papers
Bitumen (residue)	$C_{50}$ upwards	Used to tar roads Used as a roofing material

#### Note

1. Petroleum gases have the smallest boiling point and have the smallest relative molecular mass.
2. Bitumen has the highest boiling point and have the largest relative molecular mass. In addition, bitumen has the longest chain.
3. Octane is the main component of petrol

#### Production of hydrogen from methane

Methane reacts with steam to form carbon monoxide and hydrogen gas.



#### Conditions

Temperature: 200°C

Catalyst: Nickel metal

#### Alkenes

Alternative term: Unsaturated hydrocarbons

General molecular formula:  $C_nH_{2n}$  where  $n = 2, 3, 4, 5$

Functional group: Double carbon – carbon covalent bond,  $C = C$

They have one or more double bonds between carbon atoms.

They end with ene.

They are called unsaturated hydrocarbons because they have a double bond between carbon atoms.

They have two hydrogen atoms less than their corresponding alkanes

### Examples of alkenes

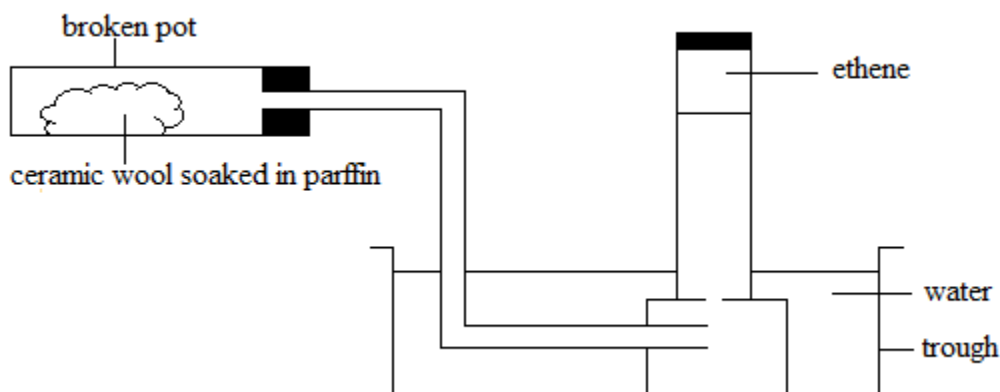
Name	Molecular formula	Structural formula	Condensed formula	M <sub>r</sub>
Ethene	C <sub>2</sub> H <sub>4</sub>	$\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{C} & = \text{C} \\   &   \\ \text{H} & \text{H} \end{array}$	CH <sub>2</sub> =CH <sub>2</sub>	28
Propene	C <sub>3</sub> H <sub>6</sub>	$\begin{array}{ccccc} \text{H} & & \text{H} & & \text{H} \\   & &   & &   \\ \text{C} & = & \text{C} & - & \text{C} - \text{H} \\   & & & &   \\ \text{H} & & & & \text{H} \end{array}$	CH <sub>2</sub> =CHCH <sub>3</sub>	42
Butene	C <sub>4</sub> H <sub>8</sub>	$\begin{array}{ccccccc} \text{H} & & \text{H} & & \text{H} & & \text{H} \\   & &   & &   & &   \\ \text{C} & = & \text{C} & - & \text{C} & - & \text{C} - \text{H} \\   & & & &   & &   \\ \text{H} & & & & \text{H} & & \text{H} \end{array}$	CH <sub>2</sub> =CHCH <sub>2</sub> CH <sub>3</sub>	56
Pentene	C <sub>5</sub> H <sub>10</sub>	$\begin{array}{ccccccc} \text{H} & & \text{H} & & \text{H} & & \text{H} & & \text{H} \\   & &   & &   & &   & &   \\ \text{C} & = & \text{C} & - & \text{C} & - & \text{C} & - & \text{C} - \text{H} \\   & & & &   & &   & &   \\ \text{H} & & & & \text{H} & & \text{H} & & \text{H} \end{array}$	CH <sub>2</sub> =CH(CH <sub>2</sub> ) <sub>2</sub> CH <sub>3</sub>	70

### Preparation of ethene gas

There are two methods used to prepare ethene.

#### 1. Catalytic cracking of alkanes

This is where a catalyst is used to break down large hydrocarbon molecules into smaller ones.



### Conditions

Temperature:  $600^{\circ}\text{C}$

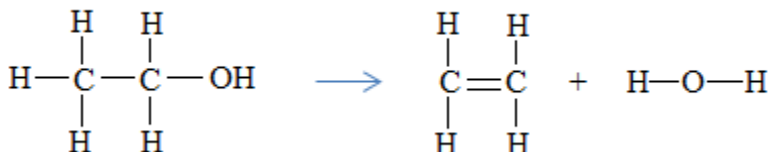
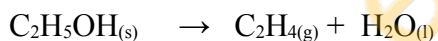
Catalyst: Aluminium oxide,  $\text{Al}_2\text{O}_3$

**Note:** The broken pot can act as a catalyst.

## 2. Dehydration of ethanol

Ethene can be prepared by the dehydration of ethanol using concentrated sulphuric acid as a dehydrating agent.

Sulphuric acid removes water.



### Conditions

Temperature:  $180^{\circ}\text{C}$

Dehydrating agent: Concentrated sulphuric acid.

### Test for unsaturation

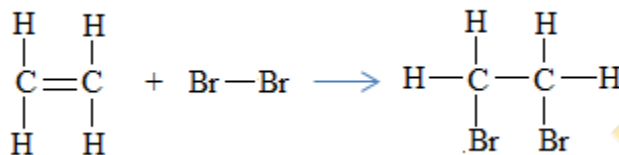
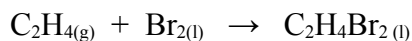
Alternative term: Test for alkenes

There are two ways you could test a hydrocarbon, to see whether it is an alkane or alkene

**Test 1:** Shake an alkene with bromine water.

**Result:** The brown colour of bromine disappears immediately. In other words alkenes decolorize bromine water.

**Explanation:** When ethene react with bromine water, a colourless compound (liquid) called 1, 2 – dibromoethane is formed.



### Note

When an alkane is shaken with bromine water, there is no reaction. Alkenes do not undergo addition reactions because they are saturated.

**Test 2:** Add acidified potassium per manganate (VII) solution to the hydrocarbon.

**Result:** The purple colour of potassium per manganate (VII) turns colourless if an alkene is present.

## Chemical properties of alkenes e.g. ethene

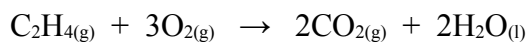
Alkenes are more reactive than alkanes because the double bond opens up to allow chemical reactions.

Alkenes undergo two notable chemical reactions.

### 1. Combustion

Alkenes react with oxygen to form carbon dioxide and water.

### Example



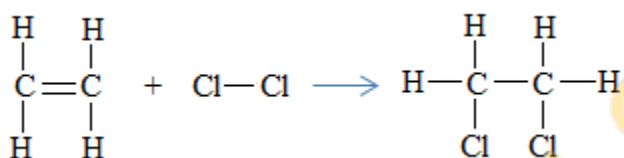
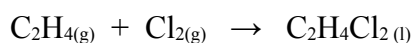
## 2. Addition reactions

An addition reaction is a reaction where a molecule is added to an unsaturated molecule by breaking a double bond.

### Examples of addition reaction involving ethene

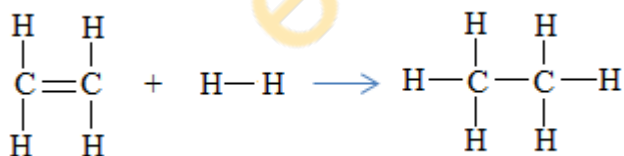
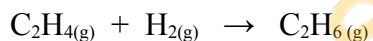
#### (a) Halogenation – reaction with halogens

Ethene reacts with chlorine to form 1, 2 – dichloroethane.



#### Hydrogenation – reaction with hydrogen

Alkenes react with hydrogen to form corresponding alkanes. Hydrogen makes the unsaturated compounds to become saturated. Ethene reacts with hydrogen to form ethane



### Conditions

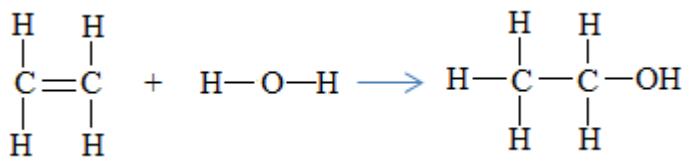
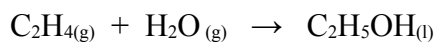
Temperature:  $200^\circ \text{C}$

Catalyst: Nickel metal

The reaction is important in the industry because it is used in the production of margarine from unsaturated vegetable oil. Vegetable oils are changed into fats which are saturated by hydrogenation.

### (b) Hydration

Ethene reacts with steam to in the presence of phosphoric acid to form ethanol.



### Conditions

Temperature:  $300^\circ \text{C}$

Catalyst: Phosphoric acid,  $\text{H}_3\text{PO}_4$

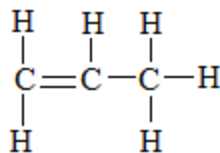
Pressure: 65 atmospheres

### Uses of ethene

1. Used in the manufacture of plastics
2. Used in the manufacture of ethanol
3. Used in the process of ripening fruits

### Exercise

1. Ethene,  $\text{C}_2\text{H}_4$ , is an unsaturated compound. It reacts with bromine to form 1, 2 – dibromoethane.  
Ethane,  $\text{C}_2\text{H}_6$ , is a saturated compound. It does not readily react with bromine
  - (a) Draw the full structural formula for ethene and 1, 2 – dibromoethane
  - (b) Write the equation for the reaction between ethene and bromine and name the type of reaction taking place
  - (c) Ethene like many other unsaturated compounds can be polymerized. Polyethene is formed when ethene is polymerized.



Name the compound which has the above structure



- (d) Margarine is manufactured using the addition reaction between hydrogen and a vegetable oil
- State the conditions used for this reaction
  - What type of bond must be present in the vegetable oil for this reaction to take place.

## Alcohols

Alternative term: Alkanols

General molecular formula:  $C_n H_{2n+1} OH$  where  $n = 1, 2, 3, 4 \dots$

Functional group: hydroxyl group,  $-OH$

They end with anol

They are not hydrocarbons because they contain oxygen

## Examples of alcohols

Name	Molecular formula	Structural formula	Condensed formula	$M_r$
Methanol	$CH_3OH$	$  \begin{array}{c}  H \\    \\  H - C - OH \\    \\  H  \end{array}  $	$CH_3OH$	32

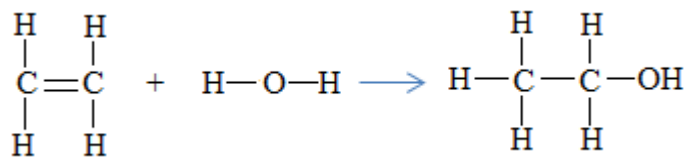
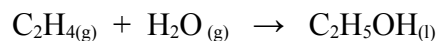
Ethanol	$C_2H_5OH$	$  \begin{array}{c}  H & H \\    &   \\  H-C & -C-OH \\    &   \\  H & H  \end{array}  $	$CH_3CH_2OH$	46
Propanol	$C_3H_7OH$	$  \begin{array}{c}  H & H & H \\    &   &   \\  H-C & -C & -C-OH \\    &   &   \\  H & H & H  \end{array}  $	$CH_3(CH_2)_2OH$	60
Butanol	$C_4H_9OH$	$  \begin{array}{c}  H & H & H & H \\    &   &   &   \\  H-C & -C & -C & -C-OH \\    &   &   &   \\  H & H & H & H  \end{array}  $	$CH_3(CH_2)_3OH$	74
Pentanol	$C_5H_{11}OH$	$  \begin{array}{c}  H & H & H & H & H \\    &   &   &   &   \\  H-C & -C & -C & -C & -C-OH \\    &   &   &   &   \\  H & H & H & H & H  \end{array}  $	$CH_3(CH_2)_4OH$	88

### Preparation of ethanol

There are two methods of preparing ethanol.

#### 1. Hydration of ethene

Ethanol can be prepared when ethene reacts with steam



Ethene

Steam

Ethanol

### Conditions

Temperature:  $300^\circ \text{C}$

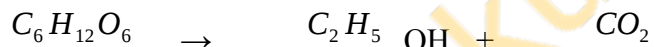
Catalyst: Phosphoric acid,  $\text{H}_3\text{PO}_4$

Pressure: 65 atmospheres

### 2. Fermentation of sugars

Fermentation is the decomposition of sugars using enzymes in yeast to produce ethanol and carbon dioxide. Sugars (glucose) is mixed with water and yeast and allowed to react for a few days in the absence of air.

Glucose  $\rightarrow$  ethanol + carbon dioxide



### Conditions for fermentation

Optimum temperature:  $37^\circ \text{C}$

Catalyst (enzyme): Zymase

### Note

Fermentation should take place in the absence of air (oxygen) to prevent oxidation of ethanol to ethanoic acid.

If the temperature goes above  $40^{\circ}\text{C}$ , the enzymes in yeast which catalyze the reaction becomes denatured.

### Physical properties of alcohols

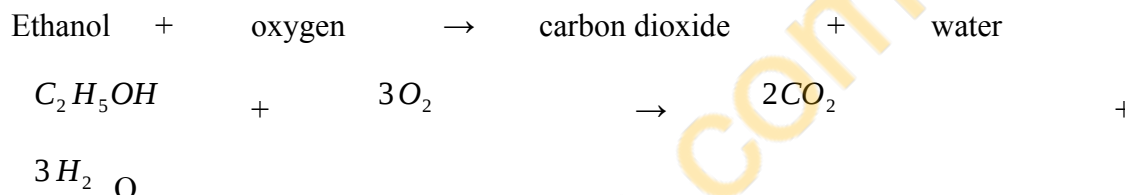
1. They are colourless inflammable liquids
2. Their boiling points increases as the carbon chain increases
3. Their solubilities in water decreases as the number of carbon chain increases

### Chemical properties of alcohols

#### 1. Combustion

Alcohols burn in air (react with oxygen) to form carbon dioxide and water.

#### Example



The reaction is exothermic. It gives out a lot of heat energy

#### 2. Oxidation

Oxidation is the addition of oxygen to a substance

(a) Ethanol can be oxidized to ethanoic acid by bacteria in the air



(b) Ethanoic acid can also be formed by using an oxidizing agent such as acidified potassium

per manganate [  $KMnO_4$  ] and potassium dichromate (VI) [  $K_2Cr_2O_7$  ]



The oxygen is from the oxidizing agent.

When ethanol reduces potassium permanganate, the reaction is indicated by the colour change from purple to colourless on mixing.

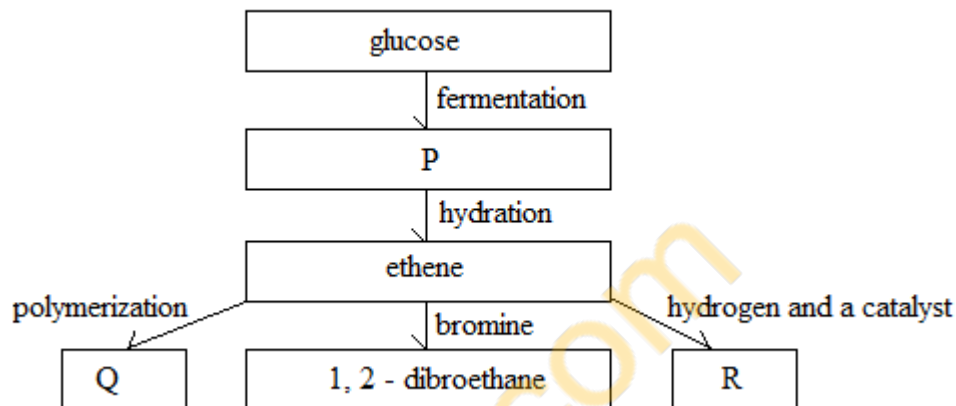
When ethanol reduces potassium dichromate, the reaction is indicated by the colour change from orange to green on mixing.

### Uses of ethanol

1. Used as a component in beer and wines
2. Used as a solvent
3. Used in making methylated spirit
4. Used as a fuel
5. Used in the preservation and sterilization of food

### Exercise

1. Carefully study the reaction below and use it to answer the questions that follow



- (a) Give the names of the substances and the conditions needed to ferment glucose
- (b) Give the name of the gas that is also produced during fermentation of glucose. Describe the simple test for this gas
- (c) Give the name and molecular formula for substances P
- (d) Give the names of substance Q and R
- (e) Write an equation for the addition reaction between ethene and bromine.

### Carboxylic acids

Alternative term: Alkanoic

General molecular formula:  $C_n H_{2n+1} COOH$  where  $n = 0, 1, 2, 3, \dots$

Functional group: Carboxyl group,  $-COOH$ .

They end with anoic acid

### Examples of carboxylic acids

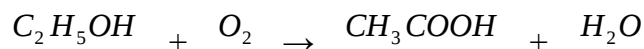
Chemical name	Molecular formula	Structural formula	Condensed formula
---------------	-------------------	--------------------	-------------------

Methanoic acid	HCOOH	$\begin{array}{c} \text{O} \\    \\ \text{H}-\text{C}-\text{OH} \end{array}$	HCOOH
Ethanoic acid	CH <sub>3</sub> CO OH	$\begin{array}{c} \text{H} \quad \text{O} \\   \quad    \\ \text{H}-\text{C}-\text{C}-\text{OH} \\   \\ \text{H} \end{array}$	CH <sub>3</sub> COOH
Propanoic acid	C <sub>2</sub> H <sub>5</sub> COOH	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{O} \\   \quad   \quad    \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{OH} \\   \quad   \\ \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> CH <sub>2</sub> COOH
Butanoic acid	C <sub>3</sub> H <sub>7</sub> CO OH	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{O} \\   \quad   \quad   \quad    \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>2</sub> COOH
Pentanoic acid	C <sub>4</sub> H <sub>9</sub> CO OH	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{O} \\   \quad   \quad   \quad   \quad    \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{OH} \\   \quad   \quad   \quad   \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	CH <sub>3</sub> (CH <sub>2</sub> ) <sub>3</sub> COOH

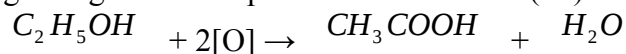
### Preparation of ethanoic acid

(a) Oxidation of ethanol

- (I) Ethanoic acid can be prepared by the oxidation of ethanol by bacteria in atmospheric air.



- (II) Ethanoic acid can also be prepared by the oxidation of ethanol using an oxidizing agent e.g. Acidified potassium dichromate(VI)



The oxygen is from the oxidizing agent.

The orange acidified potassium dichromate (VI) solution turns green in this reaction.

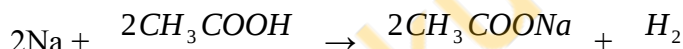
**Physical properties of carboxylic acids**

1. They turn blue litmus paper red
2. They have PH values less than 7
3. They have a sour taste

**Chemical properties of carboxylic acids**

1. They react with reactive metals to form a salt and hydrogen gas

**Example**



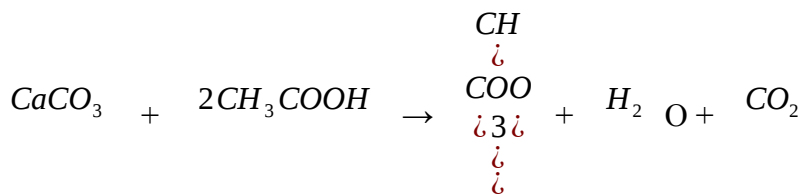
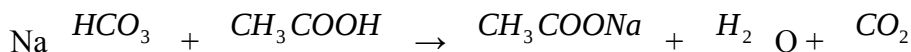
2. They react with bases to form a salt and water only

**Example**



3. They react with carbonates and hydrogen carbonates to form a salt, water and carbon dioxide

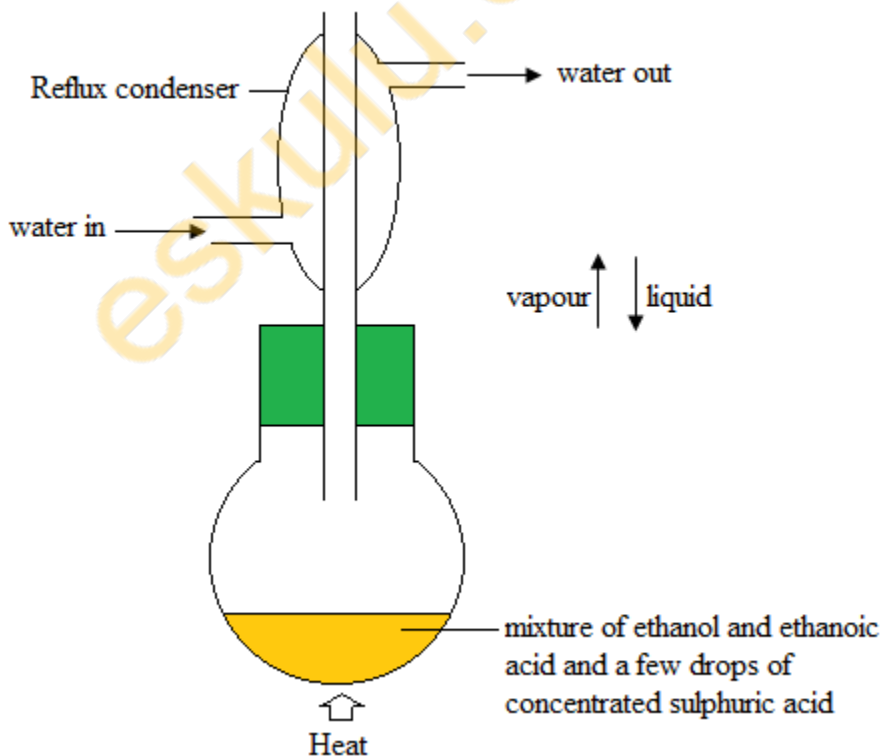
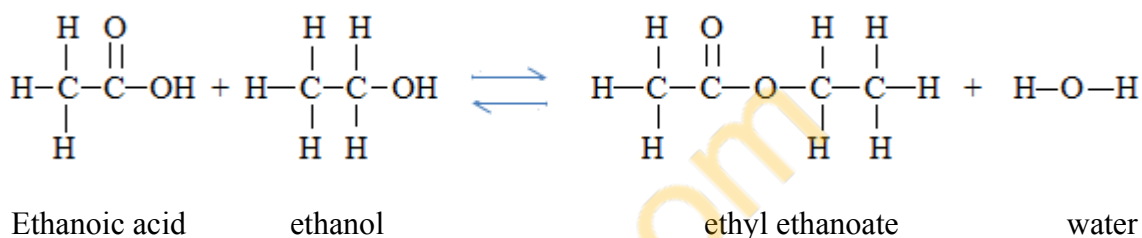
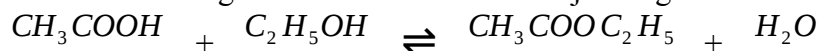
**Example**



4. They react with alcohols to form esters and the process is called esterification. Esterification is a reaction between a carboxylic acid and an alcohol to form an ester in the presence of sulphuric acid. Esters are sweet smelling compounds.

### Example

Ethanoic acid can react with ethanol to form an ester called ethyl ethanoate and water. In this reaction, ethanoic acid loses the  $\text{-OH}$  group while ethanol loses the  $\text{-H}$  group to form water. The remaining sections of the molecules join together to form the ester.



### Conditions for esterification



Temperature:  $180^{\circ}\text{C}$

Catalyst: Sulphuric acid

### Note

The name of the ester follows the order: alcohol, then acid. For example, if methanol reacts with propanoic acid, the ester formed will be called methyl propanoate.

**Reflux condenser:** It is held vertically to prevent the escape of any unchanged ethanol. Ethanol has a low boiling point and vaporizes easily. When the ethanol vapour comes into contact with the cold surface of the condenser, it will liquefy and return to the flask.

Esterification is reversible  $\rightleftharpoons$

The back ward reaction is called hydrolysis

Water can react with ethyl ethanoate to form ethanoic acid and ethanol. To prevent hydrolysis, sulphuric acid is added to remove (absorb) water.

### Special property of esters

1. Esters have sweet smells

### Uses of esters

1. They are used in perfumes due to sweet fruit smells
2. They are used in food and drink flavouring and preservation

### Similarities between esterification and neutralization

1. Both reactions produce water
2. Both reactions are exothermic

### Differences between esterification and neutralization

1. Esterification is reversible while neutralization is not reversible
2. Esterification produces an ester while neutralization produces a salt
3. Esterification is slower while neutralization is faster
4. Esterification involves a carboxylic acid (organic acid) and an alcohol while neutralization involves any acid (organic acid or mineral acid) and a base.

### Exercise

1. Substance A is an organic compound which contains an – OH group. On boiling A with acidified potassium dichromate (VII), substance B is formed. An aqueous solution of B has PH 4 and reacts with sodium carbonate to give carbon dioxide.
  - (a) Analysis of A gave the following results  
C 52.17%, H 13.04%, O 34.78%  
The relative molecular mass of A is 46. Use the information to identify A and B and draw the full structural formula of A
  - (b) Describe what would be seen when the acidified solution of potassium dichromate (VII) was added to A and name the type of reaction in which A is converted to B
  - (c) What type of reaction occurs when concentrated sulphuric acid reacts with an alcohol?
  - (d) Suggest the full structural formula for the substance produced when concentrated sulphuric acid reacts with the compound of the formula,  $C_3H_7OH$ .

## Macromolecules

Alternative term: Polymers

Definition: Macromolecules are giant molecules formed by joining smaller units called monomers.

Macromolecules are produced by the process called polymerization.

## Polymerization

Definition: Polymerization is the joining up of smaller units called monomers to form larger molecules called polymers.

## Types of macromolecules

There are two types of macromolecules.

- Synthetic macromolecules
  - Natural macromolecules
1. **Synthetic macromolecules**

Alternative term: Synthetic or artificial polymers

Synthetic polymers are man-made structures

They are divided into two categories:

- Addition polymers
- Condensation polymers

### (a) Addition polymers

Addition polymers are polymers formed from smaller identical unsaturated monomers

No other product is formed apart from the polymer

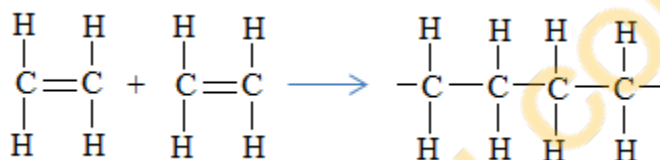
Addition polymers are formed by the process called addition polymerization.

Addition polymerization is polymerization where the polymer has the empirical formula as the monomer.

#### Examples of addition polymers

##### (I) Polyethene

Polyethene is formed when ethene molecules combine



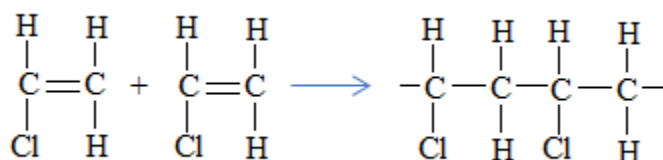
Polyethene

#### Uses of Polyethene

1. Used in making plastics bags
2. Used in making squeezing bottles

##### (II) Polyvinyl chloride

Polyvinyl chloride is formed when vinyl chloride molecules combine



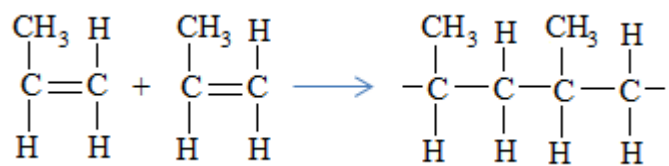
Polyvinyl chloride

#### Uses of polyvinylchloride

1. Used in making PVC paints
2. Used in making electrical insulators, records, seat covers, rain coats

(III) Polypropene

Polypropene is formed when propene molecules combine



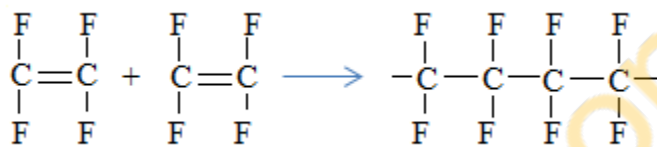
Ethane

Ethene

Polypropene

(IV) Polytetrafluoroethene

Polytetrafluoroethene is formed when tetrafluoroethene molecules combine



Polytetrafluoroethene

## Summary

Monomer	Polymer
Ethene $\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{C} & = \text{C} \\   &   \\ \text{H} & \text{H} \end{array}$	Poly(ethene) $\left[ \begin{array}{cc} \text{H} & \text{H} \\   &   \\ -\text{C} & - \text{C}- \\   &   \\ \text{H} & \text{H} \end{array} \right]_n$
Vinyl chloride $\begin{array}{cc} \text{H} & \text{H} \\   &   \\ \text{C} & = \text{C} \\   &   \\ \text{Cl} & \text{H} \end{array}$	Poly(vinyl chloride) $\left[ \begin{array}{cc} \text{H} & \text{H} \\   &   \\ -\text{C} & - \text{C}- \\   &   \\ \text{Cl} & \text{H} \end{array} \right]_n$
Tetrafluoroethene $\begin{array}{cc} \text{F} & \text{F} \\   &   \\ \text{C} & = \text{C} \\   &   \\ \text{F} & \text{F} \end{array}$	Poly(tetrafluoroethene) $\left[ \begin{array}{cc} \text{F} & \text{F} \\   &   \\ -\text{C} & - \text{C}- \\   &   \\ \text{F} & \text{F} \end{array} \right]_n$
Propene $\begin{array}{cc} \text{CH}_3 & \text{H} \\   &   \\ \text{C} & = \text{C} \\   &   \\ \text{H} & \text{H} \end{array}$	Poly(propene) $\left[ \begin{array}{cc} \text{CH}_3 & \text{H} \\   &   \\ -\text{C} & - \text{C}- \\   &   \\ \text{H} & \text{H} \end{array} \right]_n$

### (b) Condensation polymers

Some man-made polymers are formed by condensation polymerization.

Condensation polymerization involves two smaller units which combine to form a larger molecule with the elimination of the water molecule.

Condensation polymers do not have the same empirical formula as the monomers.

### Examples of condensation polymers

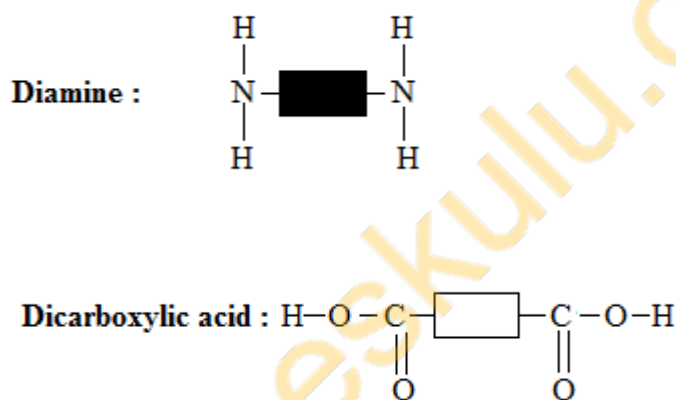
- Nylon
- Terylene

#### (I) Nylon

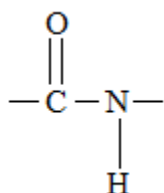
Nylon is a typical polyamide with amide linkages.

A polyamide is a polymer containing many amide linkages.

Monomers: Diamine and Dicarboxylic acid

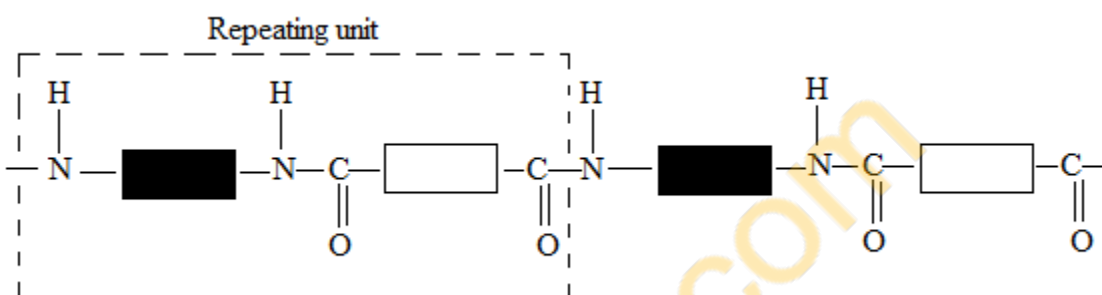
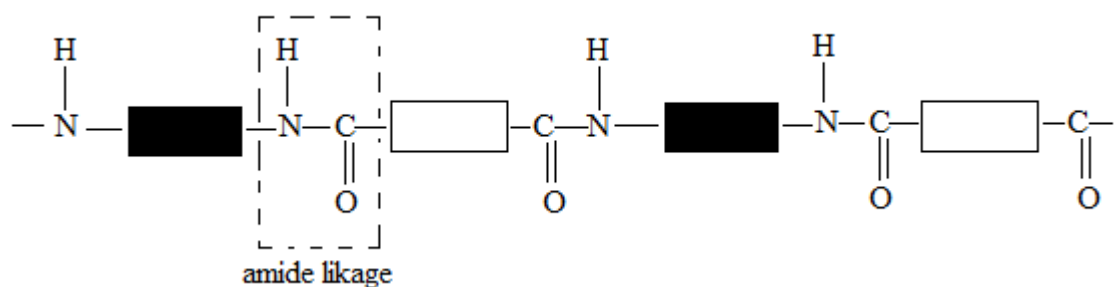


The amide linkage



The structure of nylon is similar to that of protein

Part of the structure of nylon



### Uses of nylon

1. Making tough bearing
2. Making clothing
3. Making ropes
4. Making bristle for brushes

### Exercise

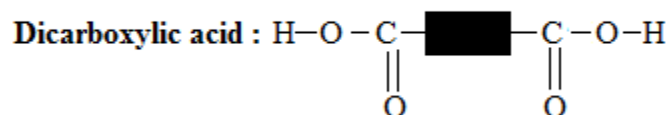
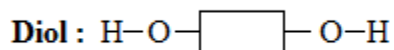
1. Nylon is a synthetic polymer which has an amide linkage similar to that of proteins
  - (a) What is meant by the term synthetic polymer?
  - (b) Draw the structure of nylon, showing at least three monomer units.  
Circle the amide linkage in the structure drawn
  - (c) Draw the structures of the two monomers from which nylon is made
  - (d) By what type of polymerization is nylon formed from its monomers?
  - (e) What other product is formed?

### (II) Terylene

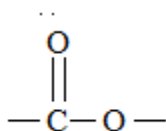
Terylene is typical polyester with ester linkages.

A Polyester is a polymer containing many ester linkages

Monomers: Diol and Dicarboxylic acid

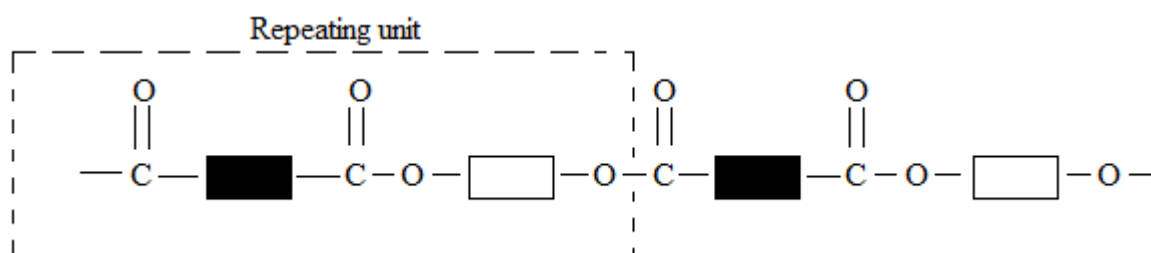
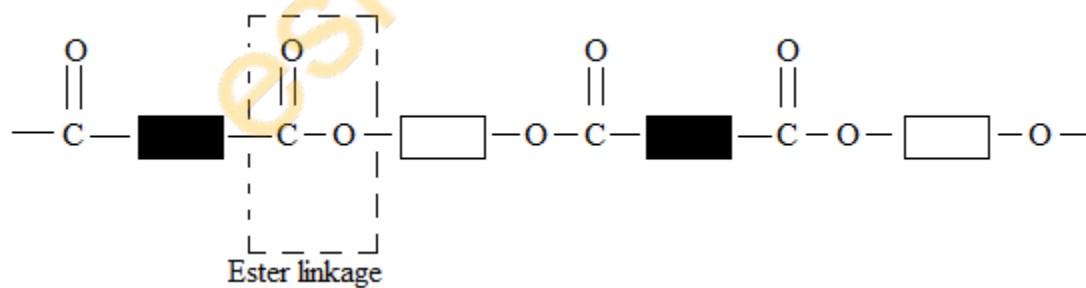


The ester linkage



The structure of Terylene is similar to that of fats.

Part of the structure of Terylene



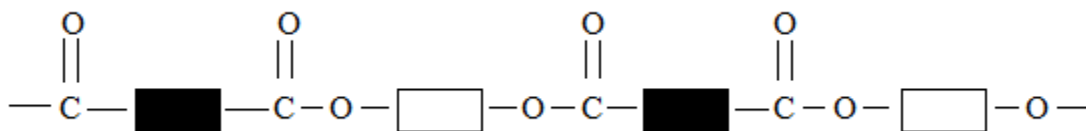
**Uses of Terylene**



1. Making tents and sails.
2. Making clothing

### Exercise

1. Terylene is synthetic polyester which has an ester linkage similar to fats. The structure of a Terylene molecule is shown below



- (a) What is a polyester?
- (b) Name the elements that make up an ester link
- (c) State one use of Terylene
- (d) Draw a box around a repeating unit in this Terylene structure
- (e) Name the plastic commonly used for making plastic bag
- (f) State two reasons why there is need to recycle plastics

### Advantages of synthetic polymers

- (a) They are durable. They do not rust, corrode or decay
- (b) They are lighter than steel, wood or stone
- (c) They are thermal and electrical insulators
- (d) They are not expensive. They are produced as by-products of oil refining
- (e) They are flexible in use

### Disadvantages of synthetic polymers

- (a) They are non-biodegradable. This means they cannot be decomposed by bacteria.
- (b) Non-biodegradability makes the disposal of plastics difficult and this result in pollution problems.
- (c) Plastics burn easily and may produce poisonous gases on combustion. They need to be coated with fire retardants to reduce the risk of fire.

### Reasons for recycling plastics

- They are difficult to dispose of: Plastic bags do not rot when they are thrown away, so they pollute the environment
- When some plastics burn, they produce harmful gases: For example polyvinylchloride (PVC) gives off fumes of hydrogen chloride when it burns. This would form hydrochloric acid in the eyes and throat.

### 2. Natural macromolecules

Alternative term: Natural polymers

Natural macromolecules occur in living organisms

## Examples of natural macromolecules

- Proteins
- Fats
- Carbohydrates

### (a) Proteins

Proteins are made by condensation polymerization

They are condensation polymers

They are poly amides like nylon because they contain the amide linkages

Protein hydrolysis results in amino acids

### (b) Fats

Fats are complex esters formed from fatty acids and glycerol

Fats have the structure similar to Terylene and poly carbonates

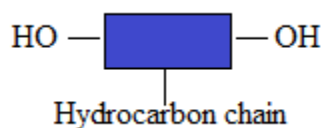
Fat hydrolysis results in fatty acids and glycerol

### (c) Carbohydrates

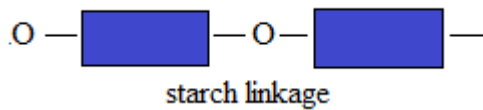
Carbohydrates are sugars which include starch and cellulose

Carbohydrates are formed from simple sugars like glucose

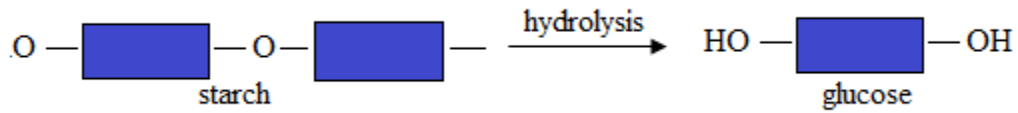
Part of a simple sugar (glucose)



Part of the structure of starch



Starch hydrolysis results in glucose



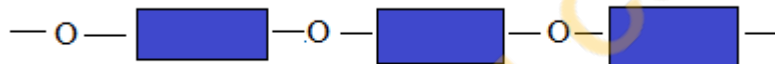
### Exercise

1. Some large molecules may be broken down to smaller molecules by hydrolysis.

(a) What is formed in the hydrolysis of?

- (I) Protein
- (II) Fat
- (III) Starch

(b) If starch is represented as



Complete the following to represent its hydrolysis

