

CHEMISTRY

FORM FOUR

FULLL NOTES

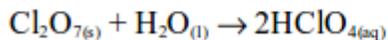
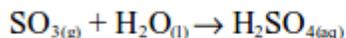
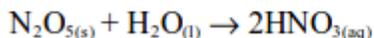
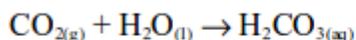
NON METALS AND THEIR COMPOUNDS

GENERAL CHEMICAL PROPERTIES OF NON METALS

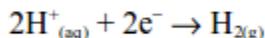
The non-metals are very reactive and most of them react with other elements to form different compounds.

The following are important chemical properties of non-metals which are connected with their tendency towards electron gain in the course of formation of compounds:

1. The oxide of a non-metal is either acidic or neutral but never basic. The oxide of a non-metal is a covalent compound. Being acidic, it combines with water to form an acid, e.g.

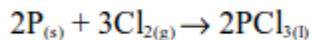


2. A non-metal never replaces hydrogen in an acid to form a salt. This is because replacement of hydrogen in an acid is due to the fact that H^+ accepts electrons supplied by a metallic atom.

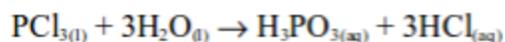


A non-metal is an electron acceptor and so cannot release electrons to hydrogen ions in solution.

3. Non-metals form covalent chlorides, for example, the behaviour of phosphorus forming its chlorides is well known.

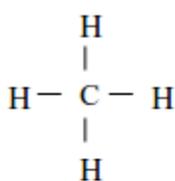


A covalent chloride like this is usually a volatile liquid, a non electrolyte, and rapidly hydrolysed by water.

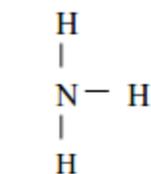


These properties are characteristic of non metallic chlorides (except CCl_4 which is not hydrolysed by water).

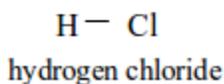
4. Non-metals combine with hydrogen to form many hydrides. A covalent compound is formed by equal sharing of electrons between or among the combining atoms. For example, methane ammonia, hydrogen chloride and hydrogen sulphide are the covalent compounds.



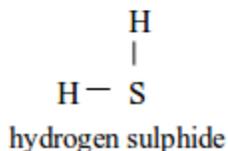
methane



ammonia



hydrogen chloride



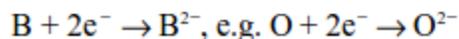
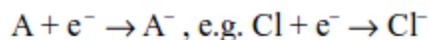
hydrogen sulphide

5. Non-metals are oxidizing agents As discussed early, non-metals accept electrons from other substances. Therefore, they are called oxidizing agents because, upon accepting the electrons, the substances donating these electrons are oxidized. So they act as the agents for oxidation of other substances.

The Oxidizing Properties of Non-metals

Explain the oxidizing properties of non-metals

Non-metals react by gaining electrons to become negative ions. A univalent non-metal accepts one electron while a divalent one accepts two electrons. The ion formed carries the corresponding number of negative charges, but they rarely exceed two and never exceed three.



When a substance loses electron(s), it becomes oxidized, i.e. its oxidation number increases. This is called **oxidation**. Due to the fact that non-metals accept the electrons(s) donated by other substances, particularly metals, they are, therefore, termed as **oxidizing agents**. This is because by accepting the electrons, they help oxidize the electron donors.

Those substances or metals which donated the electrons are called **reducing agents**. This is because the electrons they donate reduce the oxidation number of non-metals. This process is called **reduction**. In this respect, non-metals act as oxidizing agents while metals act as reducing agents.

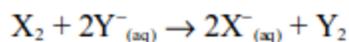
Strong and weak oxidants

As we have already seen, non-metals ionize by electron gain. In all cases, the extra electron(s) accepted lead to the formation of negative ions. The easiness of formation of negative ions depends on the ability of an element to accept the electrons. The ability of accepting electrons is called **electronegativity** of an element. Some elements are more electronegative than others.

The order of electronegativity of some non-metals is as follows: Fluorine < Chlorine > Bromine > Iodine > Nitrogen > Carbon

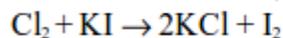
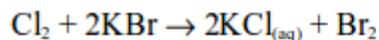
The degree of electronegativity indicates reactivity and hence oxidizing power of the element. Elements with higher electronegativity will displace those elements with lower electronegativity from their compounds.

Referring to the series above, fluorine will displace all the rest of the elements from their compounds as it is more electronegative than any other element in the series. Likewise, chlorine can displace bromine, iodine and nitrogen from their compounds. The displacement reaction occurs in the manner:



Where X is more electronegative than Y

Examples:



The higher the electronegativity the stronger the oxidant. For example, bromine is a stronger oxidant than iodine, nitrogen and carbon.

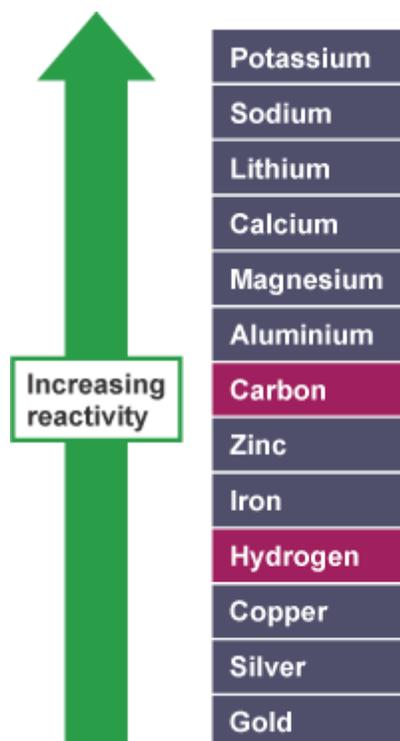
The Displacement of Non-metals by another Non-metal from a Compound

Describe the displacement of non-metals by another non-metal from a compound

Non-metals in the reactivity series

It is useful to place **carbon** and **hydrogen** into the reactivity series because these elements can be used to extract metals.

Here is the reactivity series including carbon and hydrogen:



Note that zinc and iron can be displaced from their oxides using carbon but not using hydrogen. However, copper can be extracted using carbon or hydrogen.

Chlorine

Chlorine is very reactive, so it is never found as the free element in nature. It occurs mainly as sodium chloride or rock salt. It also occurs in the combined state as chlorides of sodium, potassium and magnesium.

How is chlorine made?

In industry, chlorine is made by electrolysis of molten sodium chloride or brine. Brine is a concentrated solution of sodium chloride in water.

In the laboratory, chlorine is made by the oxidation of concentrated hydrochloric acid. The oxidation can be brought about by a number of oxidizing agents, for example, lead (IV) oxide, manganese (IV) oxide, trilead tetraoxide (Pb_3O_4) or potassium manganate (VII).

The reaction equation is:



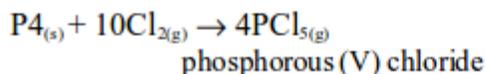
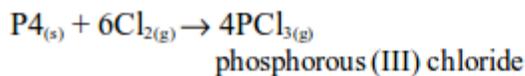
When potassium permanganate is used, reaction equation is:



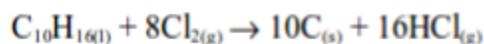
The poisonous nature of chlorine

Chlorine is a useful but dangerous gas. It is very poisonous if inhaled to even a small extent (1 part of chlorine in 50,000 parts of air causes death). Chlorine poisoning occurs when the gas is inhaled or swallowed. It reacts with water inside and outside of the body (such as water in the digestive tract and moisture on the lungs and eyes) to form hydrochloric acid and hydrochlorous acid. Both of these substances are extremely poisonous.

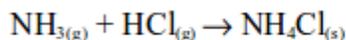
(i) Dry, yellow phosphorous burns spontaneously in the gas to produce white fumes of chlorides of phosphorous, mainly PCl_3 .



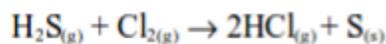
4. When a filter paper dipped into a little turpentine is dropped into a gas jar of chlorine, a violent reaction occurs and a black cloud of solid particles of carbon is formed.



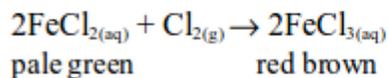
The reaction also takes place with other hydrocarbons as well and as with turpentine, hydrogen chloride gas is formed. The hydrogen chloride can be shown to be present by passing a little ammonia gas across the top of the jar whereby dense white fumes of ammonium chloride are observed.



5. Hydrogen chloride gas is oxidized to elemental sulphur by chlorine gas. When a gas jar of hydrogen sulphide is inverted over a gas jar of chlorine, a yellow precipitate of sulphur and hydrogen chloride gas will be formed.

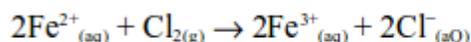


6. When a stream of chlorine gas is bubbled through a pale green iron (II) chloride solution, a red-brown precipitate of iron (III) chloride is formed, showing that the iron (II) chloride has been oxidized to iron (III) chloride.

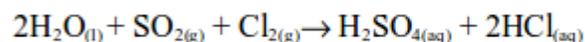


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Ionicly:

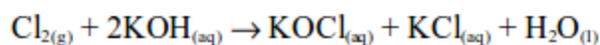
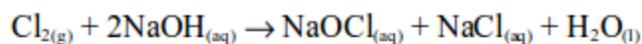


7. When chlorine is bubbled into the solution of sulphur dioxide in water for a few minutes, dilute sulphuric acid is obtained.

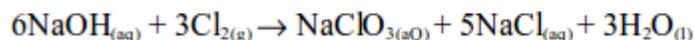
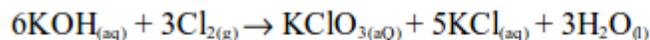


8. The reaction between chlorine and alkalis gives products which depend upon reaction conditions:

Chlorine reacts with cold dilute aqueous solution of sodium or potassium hydroxides, forming a pale yellow solution of the hypochlorite and chloride of the metal.



With the hot concentrated aqueous solution, a mixture of the chloride and chlorate is formed.



A similar reaction occurs if hot concentrated calcium hydroxide solution is used.

The Uses of Chlorine

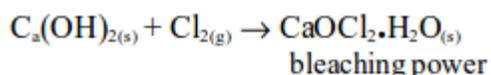
Explain the uses of chlorine

1. Chlorine is bleaching agent and is also used in the manufacture of other bleaches. When chlorine is added to sodium hydroxide solution, bleach is made.



The active chemical in bleach is sodium hypochlorite (sodium chlorate (I))

If chlorine is passed for a considerable time over solid calcium hydroxide the product formed is bleaching powder.



Bleaching power finds extensive use in dye works, and in laundries. It is used in industries where cloth, cotton, paper, etc. need to be bleached. Many textile industries use chlorine for bleaching purposes. Bleach is also used to kill bacteria for example in the toilet. It will also remove colour from the dyed materials.

2. Chlorine is added to water supplied to homes and industries to kill disease-causing germs like bacteria. If they were not killed, these pathogens might cause diseases such as cholera and typhoid. It is also used to sterilize the water in swimming pools.

3. Chlorine is used to make some important chemicals such as hydrochloric acid, chlorofluorocarbons (CFCs), tetrachloromethane (CCl_4), and chloroform (CHCl_3).

CFCs are carbon compounds containing both chlorine and fluorine. An example is trichlorofluoromethane (CCl_3F).

CFCs are very uncreative compounds. They were used in aerosol cans and refrigerators. However, CFCs damage the ozone layer. Consequently, their use is strongly discouraged.

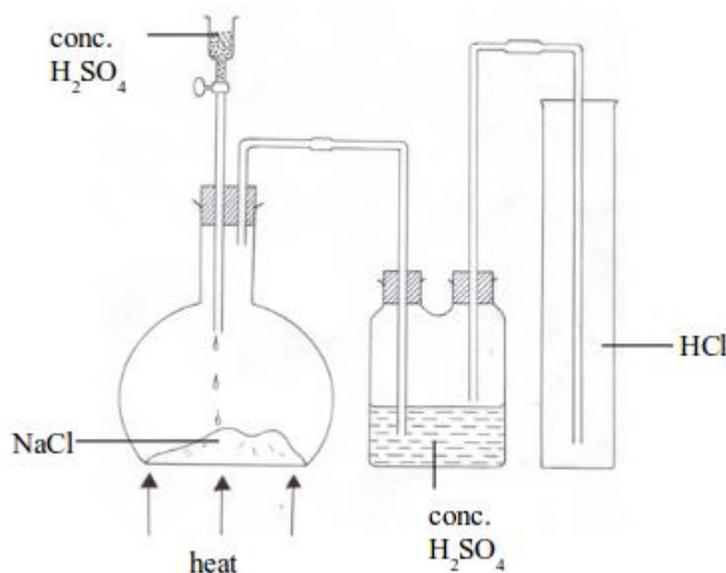
4. Chlorine is a reactant in the manufacture of organo-chloro compounds which are used to make pesticides, antiseptics (e.g. Dettol), herbicides (weed killers) and polyvinyl chloride (PVC) which is an intermediate compound in the production of plastics.

Hydrogen Chloride

A Dry Sample of Hydrogen Chloride Gas

Prepare a dry sample of hydrogen chloride gas

Hydrogen chloride is a gaseous compound at room temperature. It is usually prepared in the laboratory by the reaction between concentrated sulphuric acid and any chloride, e.g. sodium chloride. When a mixture of the two is gently warmed, hydrogen chloride gas is formed.



Preparation of hydrogen chloride gas

The Properties of Hydrogen Chloride Gas

Explain the properties of hydrogen chloride gas

(a) Physical properties

Includes

1. It is a colourless gas with a choking, irritating smell and an acid taste.
2. It is heavier (denser) than air.
3. It fumes in moist air due to the formation of tiny droplets of hydrochloric acid.

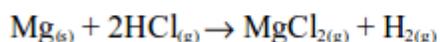
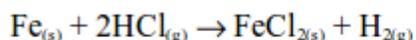
4. It is very soluble in water (450 cm³ of gas in 1 cm³ of water). The acidic properties and the solubility of hydrogen chloride gas can best be shown by the fountain experiment

b) Chemical properties

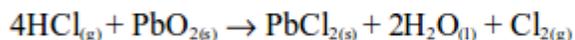
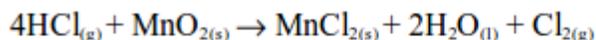
1. A dry sample of hydrogen chloride gas has no effect on dry, blue litmus paper but it turns moist, blue litmus paper to red. This is due to acidic properties of hydrogen chloride gas.

2. It does not burn and does not support combustion.

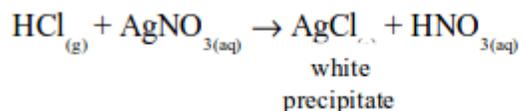
3. When a stream of hydrogen chloride gas is passed over some heated metals, the anhydrous chloride of these metals are formed:



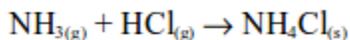
4. It is decomposed by strong oxidizing agents such as manganese dioxide, lead dioxide and red lead to give chlorine gas.



5. When the gas is passed through a solution of silver nitrate, acidified with dilute nitric acid, a white precipitate of silver chloride is formed. This is another test for hydrogen chloride gas and all soluble chlorides.



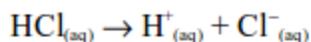
6. It gives clouds of white fumes when brought into contact with ammonia vapour. The fumes are solid ammonium chloride (NH₄Cl).



In qualitative analysis, this is the chemical test for hydrogen chloride gas as well as for ammonia gas.

Reactions of aqueous hydrogen chloride

Hydrogen chloride gas is very soluble in water (and in other polar solvents). In water, an acid solution is formed, which is hydrochloric acid. In aqueous solution, the hydrogen chloride molecule dissociates into hydrogen ions (H^+) and chloride ions (Cl^-):



The solution is called hydrochloric acid. Hydrochloric acid reacts with metals, metal oxides, hydroxides (soluble bases) and metal carbonates..

This suggests that when hydrogen chloride gas is dissolved in water an acidic solution is formed, for example:

- it turns damp blue litmus paper red;
- it reacts with various substances just like other acids (see table below); and
- it conducts electricity, yielding hydrogen gas at the cathode and chlorine gas at the anode.

Reactions of aqueous hydrogen chloride

<i>Acid reacting with</i>	<i>General equation</i>
oxide (base)	acid + metal oxide @ salt + water
alkali (soluble base)	acid+metal hydroxide(alkali)@salt+water
Metal	acid + metal @ salt + hydrogen
metal carbonate	acid + metal carbonate@salt+water+CO ₂

The Uses of Hydrogen Chloride

Explain the uses of hydrogen chloride

These are:

1. It is chiefly used in the production of hydrochloric acid. When the gas is dissolved in water in the appropriate proportions, hydrochloric acid is formed.
2. Aqueous hydrogen chloride is used in qualitative and quantitative analysis.
3. It is an important reagent in other industrial chemical transformations, e.g. hydrochlorination of rubber and production of vinyl and alkyl chlorides.
4. In the electronics industry, it is used to both rub semiconductor crystals and to purify silicon.
5. It is used in the textile industry, to separate cotton from wool and fluff.
6. In the laboratory, anhydrous forms of the gas are particularly useful for generating chloride-based Lewis acids.
7. It is used to remove rust from the oxidized metals.
8. It is extensively used in the manufacture of medicines and is a key substance utilized to turn maize and other agricultural products into artificial sweeteners.

Sulphur

Occurrence

Sulphur is a yellow, crystalline, non-metallic solid. Its symbol is S. It has an atomic number of 16. Sulphur exists in nature as a free element and in compounds.

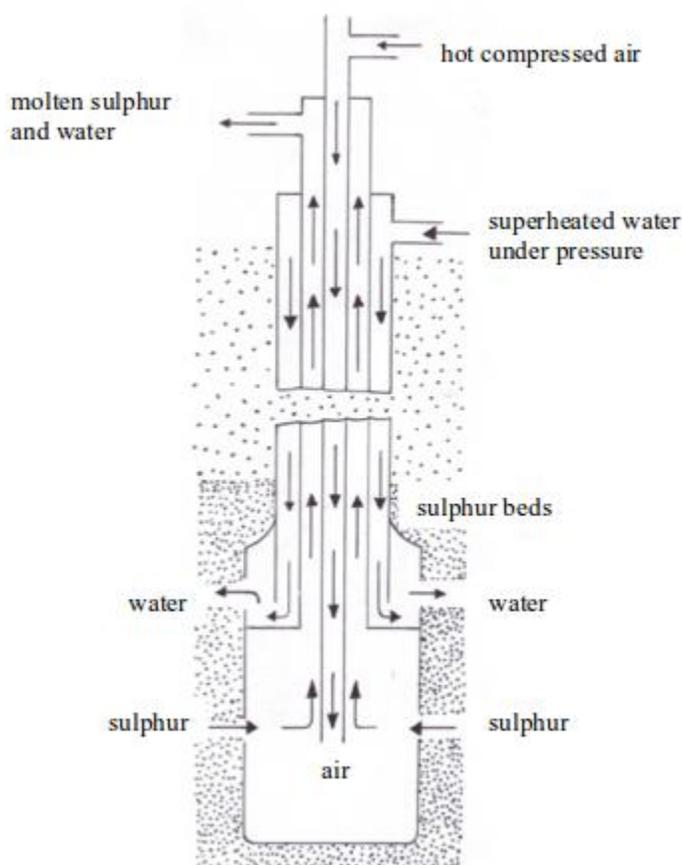
As a free element, sulphur is found in several countries such as Italy, Mexico, Japan, Poland, USA and Sicily. In its combined state, sulphur is found combined with metal ores such as galena (PbS), iron pyrites (FeS₂), Copper pyrites (CuFeS₂) and zinc blend (ZnS). It is also found in natural gas as hydrogen sulphide (H₂S) and in crude oil as organic sulphur compounds.

The Extraction of Sulphur from Natural Deposits

Describe the extraction of sulphur from natural deposits

Sulphur is extracted from its underground deposits by the Frasch process. The Frasch process makes use of the low melting point (119°C) of sulphur.

In this process, a hole about 30 cm in diameter is bored down through the clay, sand, and limestone to the sulphur beds. This boring is lined with an iron pipe and inside the pipe, is sunk a device called sulphur pump. The pump consists of three concentric pipes (cylindrical pipes with a common centre) which end in a reservoir of a large diameter (see figure bellow).



Extraction of sulphur

Down the outermost of the three pipes is forced a stream of water at about 170°C . This water must be kept at a pressure of about 10 atmospheres to maintain it in the liquid state, i.e. it is superheated water, and it is hot enough to melt the sulphur. The molten sulphur flows into the

reservoir at the base of the pump and is forced up to the surface. The sulphur obtained is 99.5% pure and can be used without any purification.

The stages involved in the entire extraction process can be summarized as follows:

1. Superheated water (170°C) is pumped through the outer pipe to melt the sulphur.
2. Hot compressed air (10 atm) is pumped down through the inner pipe. The combination of the hot water and the hot air melts the sulphur. The molten sulphur, hot air and hot water form a froth.
3. The froth is forced to the earth's surface through the middle pipe by the compressed air.
4. The molten sulphur is collected in large tanks (where the water drains off), cooled and solidified.

The Properties of Sulphur

Explain the properties of sulphur

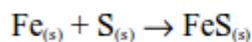
Sulphur is a relatively reactive element that readily reacts with other elements to form compounds such as oxides, chlorides and sulphides.

In chemical reactions, sulphur exhibits both oxidizing and reducing properties.

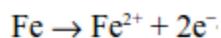
1. Oxidizing properties of sulphur

Heated sulphur reacts with metals such as iron, copper, zinc and tin to give metal sulphides.

When a mixture of iron filings and powdered sulphur, in the proportion of 56 to 32, that is 7:4 (the ratio of their relative atomic masses), is heated, the two react in a highly exothermic reaction. The heat given out makes the mixture to continue glowing even after the heating has stopped. A black or dark grey iron (II) sulphide is formed.



In this reaction, sulphur acts as an oxidizing agent which oxidizes iron metal to iron (II) ion.

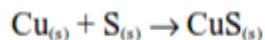


Sulphur is reduced to sulphur ion



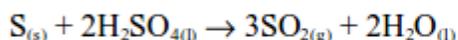
Iron (II) sulphide is not attracted by a magnet since it is not magnetic. The magnetic property of iron is lost when this compound is formed.

The copper powder reacts with sulphur in the same way to form copper (II) sulphide.



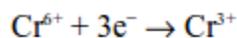
2. Reducing properties of sulphur

Dilute acids do not act upon sulphur. However, sulphur is oxidized by hot concentrated sulphuric acid with the formation of sulphur dioxide.

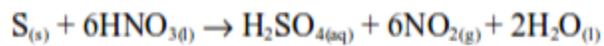


In this reaction, the sulphur is oxidized by the acid to sulphur dioxide and the acid is reduced to the same substance.

The filter paper soaked in potassium dichromate changes from *orange* to *green*. The sulphur dioxide reduces chromium from chromium (VI) to chromium (III).



When sulphur reacts with hot concentrated nitric acid, brown fumes of nitrogen dioxide are formed.



Sulphur is oxidized by hot concentrated nitric acid to sulphuric acid while nitric acid is reduced to nitrogen dioxide and water.

The Uses of Sulphur

Explain the uses of sulphur

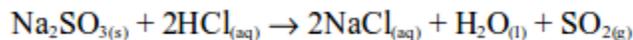
Includes

1. Most of the sulphur produced in the world (90%) is used to manufacture sulphuric acid. Sulphuric acid is an important reagent in many industrial processes.
2. Sulphur is used in the manufacture of sulphur dioxide (used in the Contact Process for the manufacture of sulphuric acid).
3. Manufacture of calcium hydrogensulphite, $\text{Ca}(\text{HSO}_3)_2$, and sodium sulphite which are used for bleaching wood straw and wood pulp in the paper industry.
4. It is also used for vulcanization of natural rubber. Rubber is usually sticky and soft. When heated with sulphur (vulcanization), it becomes hard and strong.
5. It is used for dusting vines to prevent growth of certain kinds of fungi and also as an insecticide.
6. Sulphur is used in smaller quantities for the manufacture of dyes, explosives, fireworks, gunpowder etc. For example gunpowder is a mixture of potassium nitrate, carbon and sulphur.
7. It is used in the manufacture of various organic compounds such as plastics and pharmaceuticals like sulphur ointments e.g. sulphadiazine, septrin e.tc.
8. Photographic chemicals such as carbon disulphide (CS_2) and sodium thiosulphate ($\text{Na}_2\text{S}_2\text{O}_3$) are made using sulphur as one of the raw materials.
9. Some is added to cement to make sulphur concrete. Unlike ordinary cement, this is not attacked by the acid. So it is used for walls and floors in plants where acid is used.

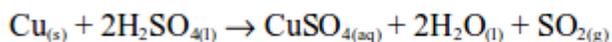
Sulphur Dioxide

Preparation of sulphur dioxide

In the laboratory, sulphur dioxide is prepared by heating a mixture of sodium sulphite and dilute hydrochloric acid. The reaction equation is:



Alternatively, sulphur dioxide can be prepared by heating a mixture of concentrated sulphuric acid and copper. In this case, there is no reaction until the mixture in the flask becomes hot. Then rapid effervescence occurs and the gas is usually collected as shown.



A dark brown mixture is left in the flask. It contains anhydrous copper (II) sulphate and certain impurities.

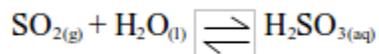
The Properties of Sulphur Dioxide

Describe the properties of sulphur dioxide

Physical properties

These are:

1. The gas is colourless with an irritating (pungent), choking smell.
2. It is denser than air. Its density is 2½ times that of air.
3. It is readily soluble in water and forms an acidic solution of sulphurous acid.



Acidic characteristics of sulphur dioxide

As indicated above, sulphur dioxide gas dissolves in water to form an acid solution of sulphurous acid, H₂SO₃. The solution turns *blue* litmus paper *red*. Sulphur dioxide is thus an acidic gas.

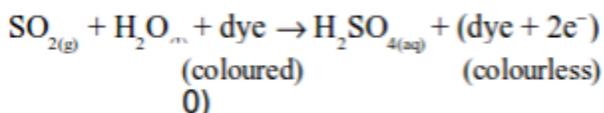
Chemical properties

The reaction characteristics described below explains the chemical properties of sulphur dioxide gas.

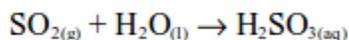
The reducing properties of sulphur dioxide

(i) Reduction of dyes in flower petals or colour in paper (bleaching)

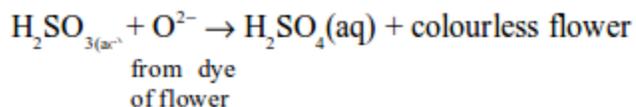
Sulphur dioxide bleaches the colours in dyes such as flower pigments. When the flower pigments or dyes contain oxygen, they are coloured. Sulphur dioxide reduces the dye (removes oxygen from it) and the dye, therefore, turns colourless. This process can be summarized as follows:



In this process, sulphur dioxide dissolves in water to form sulphurous acid:



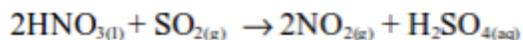
Then the acid takes up oxygen from the dye of the flowers or paper and forms sulphuric acid. The removal of oxygen from the dye converts it to a colourless compound:



However, the oxygen from the air may oxidize the reduced colourless compound back to the original coloured compound.

(ii) Reduction of nitric acid

If sulphur dioxide gas is bubbled through concentrated nitric acid, brown fumes of nitrogen dioxide gas are formed:

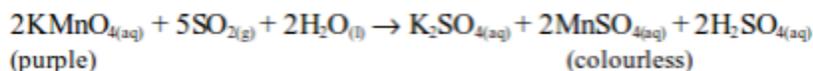


The nitric acid is reduced to nitrogen dioxide and the sulphur dioxide is oxidized to sulphuric acid.

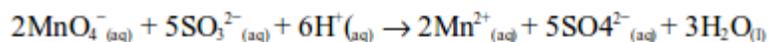
(iii) Reduction of acidified potassium permanganate solution

Sulphur dioxide decolourized purple potassium permanganate solution.

Sulphur dioxide is first converted to a sulphite (SO_3^{2-}), after reacting with water, and then oxidized to a sulphate (SO_4^{2-}) by the permanganate.



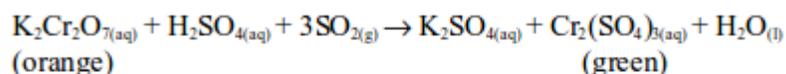
The ionic equation is:



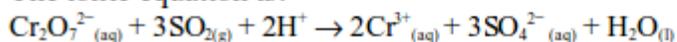
The oxidation state of manganese changes from +7 to +2. This is a reduction reaction.

(iv) Reduction of acidified potassium dichromate solution

When sulphur dioxide is mixed with potassium dichromate (VI) solution the **orange** colour of the solution changes to **green**. The dichromate (VI) is reduced to chromate (III) which is green in colour when in aqueous state:



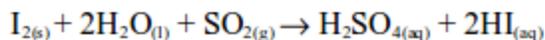
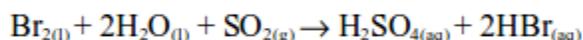
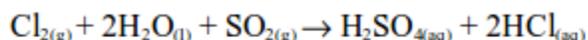
The ionic equation is:



The oxidation state of chromium changes from +6 in potassium dichromate (VI) to +3 in chromic sulphate. On the other hand, sulphur dioxide is oxidized by the dichromate (VI) to sulphate (SO_4^{2-}).

Other reduction reactions involving sulphur dioxide gas

Sulphur dioxide reduces chlorine, bromine and iodine to the hydrogen halides in the presence of water:

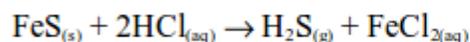


In all these cases, the solution changes from **brown** to **colourless**.

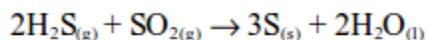
The oxidizing properties of sulphur dioxide

(i) Oxidation of hydrogen sulphide

Iron (II) sulphide reacts with dilute hydrochloric acid to produce hydrogen sulphide gas and iron (III) chloride:



Hydrogen sulphide gas has a smell similar to that of a rotten egg. The hydrogen sulphide gas is oxidized by sulphur dioxide in the gas jar to sulphur:

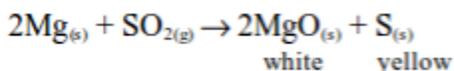


—

The sulphur produced is a yellow residue. The reaction takes place in the presence of moisture which acts as a catalyst. That is why water is added in the jar.

(ii) Oxidation of magnesium

When burning magnesium is lowered into a jar containing sulphur dioxide gas, a white solid, magnesium oxide, and yellow pieces of sulphur are formed:



Tests for sulphur dioxide gas

Includes

1. The gas can be identified by its characteristic pungent and choking smell.
2. It can also be detected by putting into it a filter paper that has been previously dipped into an acidified solution of potassium dichromate (VI). The colour of the filter paper changes from **orange** to **green** due to the reduction of dichromate (VI) to chromate (III).
3. Sulphur dioxide also decolourized acidified potassium permanganate solution.

The Uses and Hazards of Sulphur Dioxide

Explain the uses and hazards of sulphur dioxide

Sulphur dioxide has got a number of uses in daily life. However, there are also some hazards which can be caused by the gas if its production is not controlled.

Uses of sulphur dioxide

The following are some uses of sulphur dioxide gas:

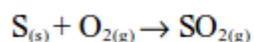
1. The gas is used in the industrial manufacture of sulphuric acid in the Contact Process.
2. It is used as a bleaching agent for wood pulp, silk, wool and straw.
3. Its poisonous nature makes it a useful fumigant. So it is used in fumigation. The gas is poisonous to all organisms, particularly bacteria.
4. It is used as a preservative and sterilizing agent in making soft drinks and jam, and in dried fruits. A very low concentration of the gas in food prevents fermentation as it stops the

growth of bacteria and moulds. Its reaction with oxygen prevents oxidation of juices and other liquids to which it is added for preservation.

Hazards of sulphur dioxide gas

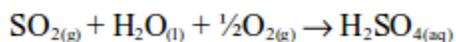
The hazards of sulphur dioxide gas are due to its effect in environmental pollution and the health problems accompanied with that pollution. Sulphur dioxide is a major air pollutant. The major sources of sulphur dioxide in the air are power plants that use fossil fuels such as coal, diesel and petrol; industrial boilers; and exhaust emissions from motor vehicles. The gas is also produced during metal smelting and other industrial processes.

Half of sulphur dioxide output comes from burning coal in coal-fired power stations. All coal contains small amounts of sulphur. So when the coal is burnt to produce energy, the sulphur in the coal reacts with oxygen in the air to produce sulphur dioxide



Sulphur dioxide is a very irritating gas and is thought to be the cause of bronchitis and other lung diseases. Exposure to higher concentrations of the gas can cause impairment of the respiratory function and heart diseases.

Sulphur dioxide also causes acid rain. This occurs when the gas comes in contact with moist air. The sulphur dioxide dissolves in water vapour from the clouds and combines with oxygen from the atmosphere to form an acid – **sulphuric acid**:



Acid rain damages the leaves and barks of plants making them more vulnerable to diseases, weather and insects. When acid rain reaches the lake, river or other water bodies it makes the whole water body acidic. Even a low concentration of acid in the water can kill fish and other marine organisms.

Sulphuric Acid

The Contact Process for the Manufacture of Sulphuric Acid

Describe the contact process for the manufacture of sulphuric acid

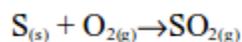
Sulphuric acid is an important laboratory and industrial reagent. It is produced in large scale through the Contact Process. The process involves four major stages. These are:

1. production of sulphur dioxide;
2. purification of sulphur dioxide;
3. catalytic conversion of sulphur dioxide (SO₂) to sulphur trioxide (SO₃); and
4. conversion of sulphur trioxide to sulphuric acid.

1. Production of sulphur dioxide

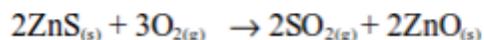
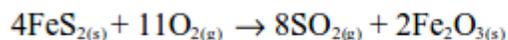
The sulphur dioxide used in the Contact Process can be obtained from different sources. These include:

(a) Burning sulphur in air:



This is the most convenient method of producing sulphur dioxide.

(b) Burning sulphide ores such as iron pyrite (FeS₂) and zinc blend (ZnS):



Sulphur dioxide gas is produced as a by-product.

2. Purification of sulphur dioxide

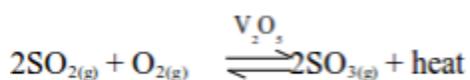
The sulphur dioxide produced in the first stage is mixed with air, ready for passing it over the catalyst. Before contact with the catalyst is allowed, the gas mixture has to be purified to remove impurities. This is achieved by passing the mixture through an electrostatic precipitator to remove any dust. It is then washed with water to remove impurities such as traces of arsenic (III) oxide (As_2O_3). The gas mixture is then passed through concentrated sulphuric acid to remove all moisture. The three impurities (As_2O_3 , dust and moisture), if not removed, will poison the catalyst thereby rendering it useless.

3. Catalytic conversion of sulphur dioxide to sulphur trioxide

The purified and dried mixture of sulphur dioxide and air is passed through a heat exchanger to acquire the necessary heat for the conversion to sulphur trioxide. The mixture is then taken to the conversion chamber, which contains a catalyst. The catalyst used is finely divided vanadium (V) oxide (vanadium pentoxide, V_2O_5) which is heated to 450°C .

Originally, platinized asbestos was used as a catalyst. But, compared to vanadium (V) oxide, platinum is very expensive and easily poisoned by impurities. So it has been replaced by vanadium (V) oxide as the usual catalyst used in the Contact Process.

Sulphur dioxide remains in contact with the catalyst during the conversion process, hence the name Contact Process. The reaction that takes place during the conversion is:



The conversion takes place at a temperature of 450°C and normal atmospheric pressure (1 atm).

The reaction is exothermic, which means that, as sulphur trioxide is formed, heat energy is released. If the temperature rises above 450°C the yield of sulphur trioxide decreases.

Once the reaction has started, no external heating is required. Thus, the heat exchanger maintains the temperature at 450°C . According to Le Chatelier's principle, a lower temperature should be used to shift the equilibrium to the right, hence increasing the percentage yield. However, too low temperature will lower the formation rate to an economical level. Hence, to increase the rate,

high temperature (450°C), medium pressure (1-2 atm) and a catalyst (V₂O₅) are used to ensure maximum yield. The catalyst only serves to increase the rate of reaction as it does not change the position of the dynamic equilibrium.

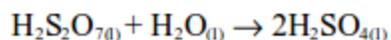
About 98% of the possible yield of sulphur trioxide is obtained.

4. Conversion of sulphur trioxide to sulphuric acid

The sulphur trioxide from the conversion chamber is passed through a heat exchanger to remove excess heat. It is then taken to an absorption tower where it is dissolved in concentrated sulphuric acid to form **oleum** or fuming sulphuric acid:

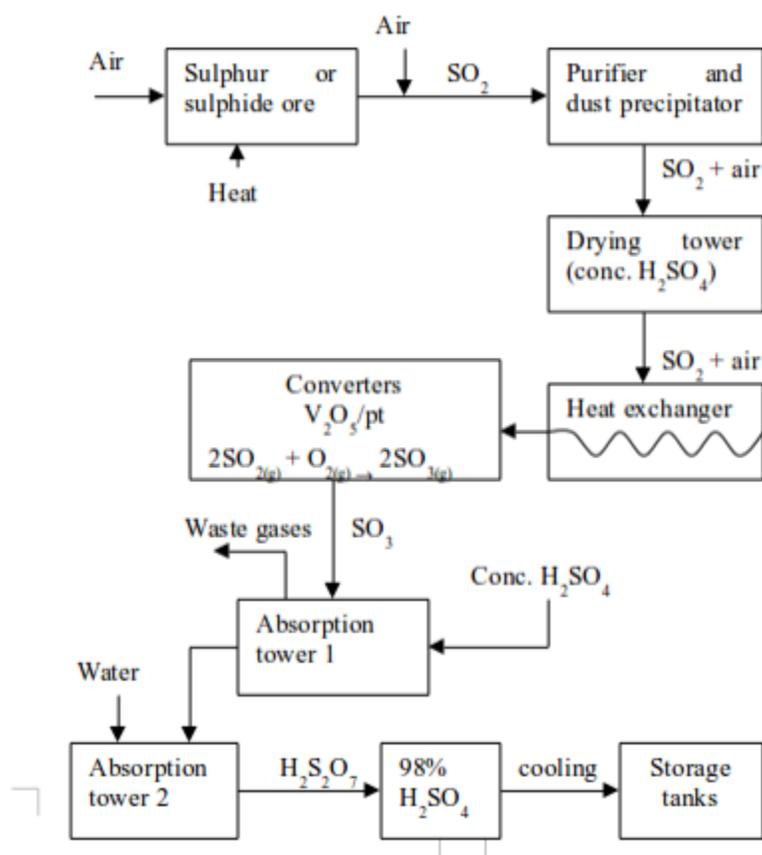


Oleum is then carefully diluted with the correct amount of water to give ordinary concentrated sulphuric acid:



Sulphur dioxide cannot be dissolved directly in water to form sulphuric acid. The reaction is so highly exothermic that the heat produced vapourizes the sulphuric acid formed. This makes it difficult to collect the gas because the acid vapour (mist) produced is very stable and cannot be condensed.

The flow diagram for the manufacture of sulphuric acid is show in the figure below



A flow diagram of the Contact Process

The Properties of Sulphuric Acid

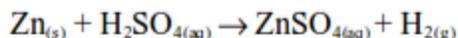
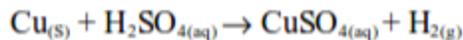
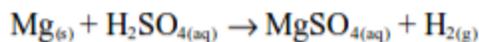
Explain the properties of sulphuric acid

Chemical properties of dilute sulphuric acid

Dilute sulphuric acid reacts with metals, metal oxides, metal hydroxides and metal carbonates and hydrogencarbonates to produce salts.

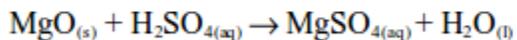
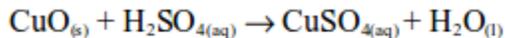
Reaction with metals

Dilute sulphuric acid reacts with many metals above hydrogen in the activity series to form sulphates and hydrogen gas, e.g.



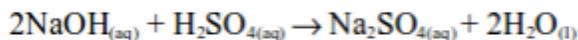
Reaction with metal oxides

Reactions of metal oxides with dilute sulphuric acid are neutralization reactions. Metal oxides react with dilute sulphuric acid to form a salt (sulphate) and water, e.g.



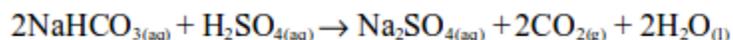
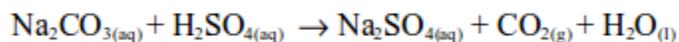
Reaction with metals hydroxides

The reaction between dilute sulphuric and a metal hydroxide is a neutralization reaction. Metal hydroxides react with dilute sulphuric acid to form a sulphate and water, e.g



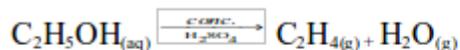
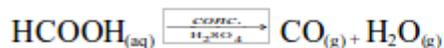
Reaction with metal carbonates and hydrogencarbonates

Dilute sulphuric acid reacts with metal carbonates and hydrogencarbonates to give metal sulphates, carbon dioxide and water, e.g.



Chemical properties of concentrated sulphuric acid

Concentrated sulphuric acid as a dehydrating agent



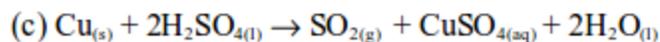
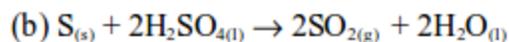
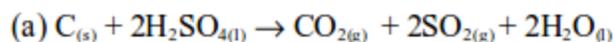
Concentrated sulphuric acid as a drying agent

As a drying agent, concentrated sulphuric acid absorbs traces of water from substances. Because of its ability to absorb water, it is used for drying most gases prepared in the laboratory that it would not react with. It cannot be used for drying ammonia, carbon dioxide, hydrogen sulphide or any gas with which it reacts.

Sulphuric acid as an oxidizing agent

Hot concentrated sulphuric acid is a strong oxidizing agent. It oxidizes both metals and non-metals while it is reduced to sulphur dioxide.

Concentrated sulphuric acid oxidizes charcoal (carbon) to carbon dioxide, sulphur to sulphur dioxide and copper to copper (II) sulphate.



With sulphur and copper, the **orange** colour of the dichromate (VI) paper changes to **green**. This confirms the presence of sulphur dioxide gas.

With carbon, a white precipitate is formed on the glass rod when the rod dipped in lime water (calcium hydroxide) is placed in the mouth of the test tube. This confirms the presence of carbon dioxide gas which reacts with the calcium hydroxide on the glass rod to produce a white precipitate of calcium carbonate.



The Uses of Sulphuric Acid

Explain the uses of sulphuric acid

Sulphuric acid is one of the most important industrial chemicals. It has widely varied uses and plays some part in the production of nearly all manufactured goods. The following are some of the uses of sulphuric acid:

1. **Manufacture of fertilizers** The major use of sulphuric acid is the production of fertilizers such as ammonium sulphate and superphosphates (phosphate fertilizers).
2. **Manufacture of chemicals** It is widely used in the manufacture of chemicals e.g. in making hydrochloric acid, nitric acid, phosphoric acid, sulphate salts, synthetic detergents, soap, paints and pigments, explosives, plastics and drugs.
3. **Refining of crude oil** A large quantity of sulphuric acid is used in refining crude oil.
4. **Extraction and manufacturing of metals** Sulphuric acid is used in the iron and steel-making industry to remove rust and scale from the surface of the rolled iron sheets. It is also used in processing metals e.g. in pickling (cleaning) iron and steel before plating them with tin or zinc to produce galvanized iron.
5. **Manufacture of alum** Sulphuric acid is used in the manufacture of aluminium sulphate, which is used in water treatment plants to filter impurities and to improve the taste of water. Aluminium sulphate is made by reacting bauxite with sulphuric acid.
6. **Manufacture of natural and man-made fibres** Sulphuric acid is used for making natural and synthetic (artificial) fibres. For example, the textile called rayon is made from cellulose fibres derived from wood. These fibres are dissolved in a solution of tetraamminecopper (II) sulphate to produce a thick liquid which is then injected into sulphuric acid to form rayon fibres.
7. **Other uses:** Sulphuric acid is used as (i) an electrolyte in lead-acid batteries, which are used in cars, to allow the flow of electrons between the plates in the battery. The sulphuric acid used in this way is called battery acid; (ii) as a general dehydrating agent in its concentrated form in tanning leather; and (iii) in waste water treatment.

Nitrogen

Occurrence

Nitrogen makes about 78% of the air by volume. The element also occurs combined with other compounds in the form of sodium nitrate, Chile saltpetre, NaNO_3 (as a mineral deposit in Chile), and in the soil as ammonium sulphate, sodium nitrate, potassium nitrate and calcium nitrate.

Combined nitrogen also occurs as a constituent of all living matter of plants and animals in the form of proteins, enzymes, alkaloids.

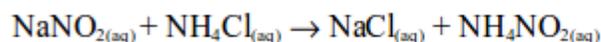
Preparation of a sample of Nitrogen in the Laboratory

Prepare a sample of nitrogen in the laboratory

Nitrogen can be prepared in the laboratory by either separating the gas from the air or by heating ammonium nitrite.

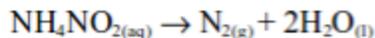
(i) Preparation of nitrogen by the action of heat on ammonium nitrite

The reaction between sodium nitrite and ammonium chloride gives sodium chloride and ammonium nitrite.



A solution of ammonium nitrite readily decomposes, on slight warming, to give nitrogen gas.

As the solution becomes warm, rapid effervescence occurs as more nitrogen is given off.



The nitrogen evolved may be collected over water because the gas is only slightly soluble in water, at ordinary temperature, and slightly denser than air.

Tests for nitrogen gas

Aim: To test for the presence of nitrogen.

Procedure

Using the four gas jars of nitrogen gas collected in the previous experiment (Experiment 1.16), carry out the following tests for nitrogen gas and write down your observations:

1. Remove the cover from the first jar and smell the gas. Observe the colour of the gas and identify its smell.
2. Remove the cover from the second jar and put in it a piece of damp universal indicator.
3. Place a lighted splint into the third gas jar.
4. To the fourth jar, add some calcium hydroxide solution (lime water) and shake.

Observations and inferences

1. The gas is colourless and odourless. This distinguishes it from gases such as sulphur dioxide, ammonia, hydrogen chloride, etc.
2. The colour of the indicator does not change. This shows that nitrogen is a neutral gas.
3. The lighted splint is extinguished and the gas does not burn. It can not, therefore, be any gas which supports combustion, e.g. oxygen, dinitrogen oxide, or any combustible gas, e.g. hydrogen sulphide, carbon monoxide, hydrogen, etc.
4. After the above tests, the only gas with which nitrogen may be confused is carbon dioxide. To distinguish it from carbon dioxide, the gas is dissolved in calcium hydroxide solution. Nitrogen leaves the calcium hydroxide unchanged while carbon dioxide turns the solution milky (due to formation of a precipitate of CaCO_3).

Properties of nitrogen

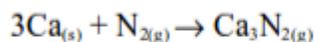
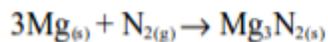
Physical properties

Nitrogen is colourless and odourless. It is slightly less dense than air and sparingly insoluble in water. The gas is neutral to litmus.

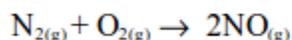
Chemical properties

Under ordinary conditions, nitrogen gas is inert. However, the gas only takes part in reactions at very high temperature as follows:

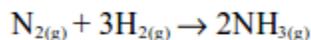
1. It reacts with red hot metals, like magnesium and calcium to form nitrides



2. Nitrogen does not burn nor does it support combustion. When heated, the gas combines with oxygen to form nitrogen monoxide gas:



3. At ordinary pressure and moderately high temperatures, nitrogen reacts with hydrogen in the Haber Process to produce ammonia:



The Uses of Nitrogen

Explain the uses of nitrogen

Here are some uses of Nitrogen:

1. **Manufacture of fertilizers:** Nitrogen is used to manufacture nitrogenous fertilizers. These include diammonium phosphate (DAP), calcium ammonium nitrate (CAN), ammonium superphosphate (ASP), ammonium nitrate (AN), ammonium phosphate sulphate (APS), ammonium sulphate nitrate (ASN), ammonium sulphate (AS) and urea.
2. **Refrigeration:** Because of its low boiling point (-196°C), liquid nitrogen is used as a refrigerant for storing organs in research laboratories, bull semen for artificial insemination, eggs and other cells for medical research and reproductive technology, etc. It is also used for preservation of food products and for their transportation.

3. **Processing reactive substances:** Some reactions require an inert atmosphere in order to proceed as desired. Because of its low reactivity, nitrogen is used to provide an inert atmosphere for storing and processing reactive substances.
4. **Manufacture of nylon:** Nitrogen is used in the manufacture of synthetic fibres such as polyamides. Polyamides are commonly known as nylons. Nylons are chemically inert and are stronger than natural fibres. They are used in making fishing nets, clothes, ropes, and many other items.
5. **Manufacture of ammonia:** Nitrogen is used in the manufacture of ammonia through the Haber Process. In the Haber Process, ammonia is manufactured by direct combination of nitrogen and hydrogen. Nitrogen and hydrogen are mixed in the ratio of 1:3. The gases are then reacted together at a temperature of about 450°C and a pressure of 250 atmospheres in the presence of finely divided iron as a catalyst. $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) + \text{heat}$ The gases are cooled while still under pressure and ammonia is removed as a liquid.
6. **Manufacture of nitric acid:** The ammonia gas manufactured using nitrogen in the Haber Process is used in the manufacture of nitric acid by catalytic oxidation.
7. **Plant nutrition:** When atmospheric nitrogen is fixed into the soil by bacterial actions, it becomes a nutrient to plants. Nitrogen fixation refers to the conversion of atmospheric nitrogen, by certain species of bacteria, into **nitrites**.

Ammonia

Preparation of a Dry Sample of Ammonia Gas in the Laboratory

Prepare a dry sample of ammonia gas in the laboratory

Ammonia is a binary compound of nitrogen and hydrogen. Ammonia gas is colourless and has a strong pungent and choking smell. It does not occur free in air, but exists in nitrogenous organic materials such as hoofs and horns of animals. The gas can be released by heating or burning these materials.

Laboratory preparation of ammonia

Ammonia is prepared in the laboratory by heating any ammonium salt with an alkali. In most cases, ammonium chloride and calcium hydroxide (the cheaper alkali) are used. Both are solid so

they must be thoroughly ground first to give a very fine mixture so that the reaction can occur efficiently.



Calcium hydroxide reacts with ammonium chloride to produce ammonia gas, calcium chloride and water. The flask is tilted to prevent any condensed water formed from running back into the hot flask, which might break it.

Ammonia gas is dried by passing it over quicklime because it reacts with all the usual drying agents. Concentrated sulphuric acid is acidic and would absorb the gas forming a salt e.g.



It reacts with calcium chloride, forming solid complex compounds, e.g. $8\text{NH}_{3(g)} + \text{CaCl}_{2(s)} \rightarrow \text{CaCl}_2 \cdot 8\text{NH}_{3(s)}$

Ammonia is less dense than air and very soluble in water, so it is collected as shown by upward delivery (or downward displacement of air).

Ammonia is an alkaline gas and it turns wet, red litmus paper blue.

The Properties of Ammonia

Describe the properties of ammonia

Physical Properties of Ammonia

1. It is a colourless poisonous gas with a strong choking smell.
2. It is less dense than air.
3. It is easily liquefied by cooling to -33°C or by compressing it.
4. It turns wet, red litmus paper blue as it is the only common alkaline gas
5. It is very soluble in water forming alkaline solution. Ammonia has the highest solubility of all known gases. About 800 volumes of the gas dissolve in 1 volume of water at 15°C . The fountain experiment below demonstrates this solubility.

Chemical properties of ammonia

Reaction with air and oxygen

Ammonia will not normally burn in air but can be made to do so in two ways:

- Burning ammonia in an oxygen-rich atmosphere; and
- Use of a catalyst.

Burning ammonia in oxygen-rich air

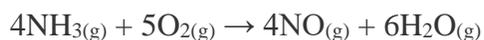
When ammonia is burned in air enriched with oxygen, the products formed are nitrogen and water. $4\text{NH}_3(\text{g}) + 3\text{O}_2(\text{g}) \rightarrow 2\text{N}_2(\text{g}) + 6\text{H}_2\text{O}(\text{l})$

Using a catalyst

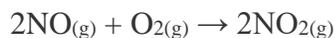
The source of ammonia gas in this experiment is concentrated ammonia solution which gives off fumes of ammonia gas. If some concentrated ammonia solution is left in a stoppered flask for a few minutes, the flask will quickly become full of ammonia gas by diffusion.

The catalyst used is the metal platinum. The platinum coil is heated in a bunsen flame until it is red hot. It is then lowered into a flask containing ammonia. The coil continues to glow even though it is not being heated. This indicates that a chemical reaction is taking place. Near the top of the flask brown fumes can be seen.

The products of this reaction are nitrogen monoxide (nitrogen (II) oxide), which is a colourless gas, and water.



However, as the nitrogen monoxide gas moves towards the neck of the flask and comes into contact with the air, it reacts with the oxygen in the air to form nitrogen dioxide gas which is brown in colour. Hence, the brown fumes are seen at the neck of the flask.



Reaction with copper

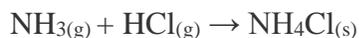
When ammonia gas is passed over heated copper (II) oxide, the gas is oxidized to nitrogen and water by the hot copper (II) oxide while the oxide is reduced to copper.



Copper (II) oxide is black. During the reaction it is oxidized to copper which is reddish brown in colour.

Reaction with hydrogen chloride gas

When ammonia and hydrogen chloride are mixed, dense white fumes of ammonium chloride are formed.



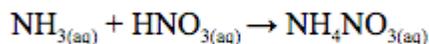
This test is simply performed by dipping a glass rod into concentrated hydrochloric acid then holding the glass rod at the mouth of a gas jar containing ammonia gas.

The Uses of Ammonia

Explain the Uses of Ammonia

Manufacture of fertilizer

Since ammonia solution is alkaline, it reacts with acids to form ammonium salts which are used as fertilizers.



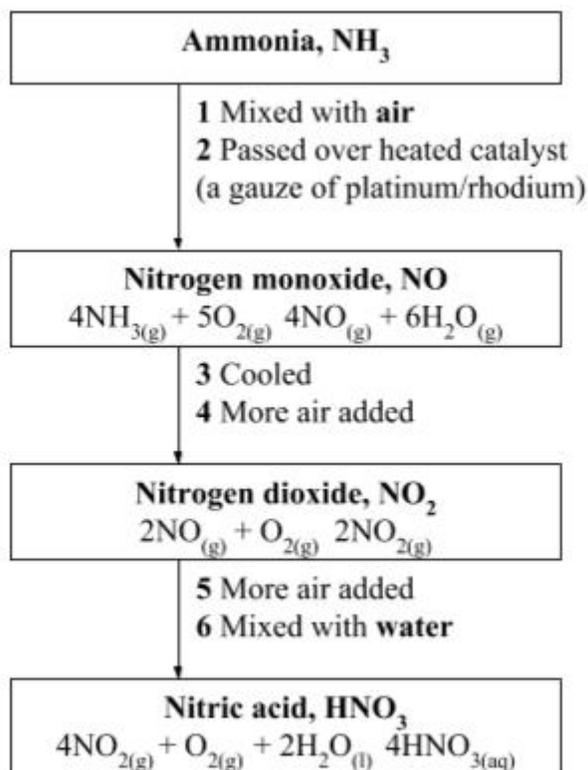
Other nitrogenous fertilizers manufactured using ammonia include ammonium sulphate nitrate (ASN), diammonium phosphate (DAP) and calcium ammonium nitrate (CAN)

Ammonia itself can be used directly as a fertilizer but has three disadvantages:

- Ammonia comes as a gas or a concentrated solution which is less easy to store; it is easier to store the solid ammonium salts.
- Ammonia is alkaline and can affect the natural pH of the soil.
- Ammonia easily evaporates if directly applied to the soil.

Manufacture of nitric acid

A lot of the ammonia from the Haber Process is used to make nitric acid. The raw materials for manufacture of nitric acid are ammonia, air and water.



The overall result is that ammonia is oxidized to nitric acid.

Cleaning

Ammonia solution is very useful in cleaning. This is because it softens water in homes and laundries and neutralizes acid stains caused by perspiration, hence making washing easier. It is also used as a grease solvent.

Refrigeration

Liquid ammonia is used in large-scale refrigerating plants such as in ships and warehouses. It used to be used in domestic refrigerators, but has now been replaced by non-toxic, non-corrosive chlorofluorohydrocarbons (CFHs).

Manufacture of synthetic fibres

In the textile industry, ammonia is used in the manufacture of synthetic fibres such as nylon and rayon.

Carbon

The Forms in which Carbon Exists

Name the forms in which carbon exists

Although carbon forms less than one percent of the earth's crust by weight, it is the most interesting of all elements. This is because of the following reasons:

1. All living things are made of carbon and its compounds.
2. Over $\frac{3}{4}$ of the world's power is obtained from carbon and its compounds.
3. Over $\frac{3}{4}$ of all substances in the world are made of carbon.

Carbon is not commonly found in a free state. The free element is mainly found as graphite and diamond. Carbon occurs in a number of other forms, e.g. wood charcoal, animal charcoal, coke, soot (lampblack).

Carbon compounds are found in many naturally occurring substances such as coal, petroleum, wood, coal gas, natural gas, carbonates, shells, organic matter of all kinds, all living things, and occurs in the air to a small, but very important extent (0.03 – 0.04% by volume) as carbon dioxide. The carbohydrates, proteins and lipids in all living things contain carbon.

Pure carbon is found in the form of diamond in Tanzania (Mwadui), Sierra Leone, India, South Africa, Russia and South America; and impure carbon, as graphite, is found in Sri Lanka.

Allotropic Forms of Carbon

Describe allotropic forms of carbon

An element that exists in more than one form is said to exhibit allotropy. Allotropy is the existence of an element in more than one form (without change of state). The various forms are known as allotropes.

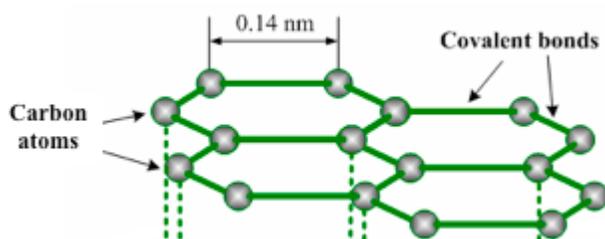
Allotropes of a given element differ in their physical properties and may differ in some chemical properties as well. The allotropic forms of carbon are:

- graphite;
- diamond; and
- amorphous carbon.

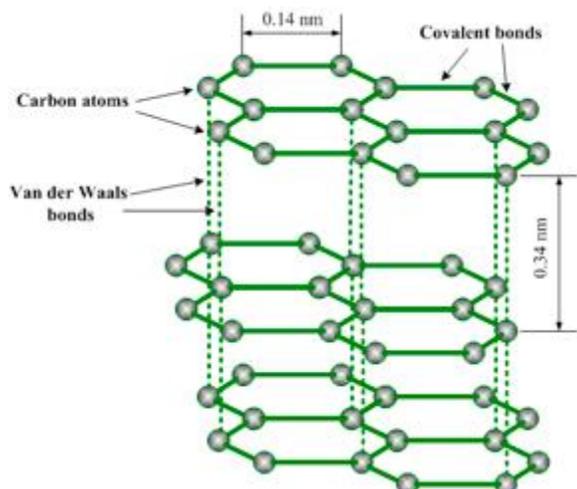
These allotropes have got different molecular structures. The structural differences are mainly due to the way their atoms are packed.

Graphite

Graphite has a layer structure. Figure 1.18 illustrates one layer of the structure of graphite. Each layer consists of carbon atoms covalently bonded together into hexagonal rings. These rings form flat parallel layers, one over the other. The force that hold the carbon atoms together are very strong. Adjacent layers are held together by weak van der Waals' forces as shown in figure 1.19. The layers readily slide over one another, accounting for the soft and greasy texture of graphite.



Carbon atoms in one graphite layer



Graphite structure

Carbon atom has got four electrons in its outer shell. Each carbon atom forms three covalent bonds to other carbon atoms. Thus, three of its four outermost electrons are paired up to form covalent bonds. The fourth electron is not attached to any particular atom (delocalized) and is free to move anywhere along the layers. Graphite conducts electricity in the plane of the layers but not at right angles to them.

Because conduction of electricity involves movement of unshared electrons from one atom to another atom, graphite is a good conductor of electricity since the hexagonal layers permit this movement. It is also a good conductor of heat for a similar reason.

Physical properties of graphite

1. It is a black, soft and slippery substance. It feels soapy and greasy. It has a metallic lustre and is opaque to light.
2. It has low relative density (2.3) as compared to diamond (3.5)
3. Graphite is a good conductor of heat and electricity due to the delocalized electrons.
4. It has a very high melting point (3730°C) and boiling point (4830°C). The melting and boiling points are high because of strong covalent bonds between the carbon atoms which require more energy (heat) to break in order to melt graphite.

Uses of graphite

1. It is used as an electrode in electrolysis and as a positive terminal in dry cells. The use of graphite as electrode in electrolysis has an advantage because it does not react readily with most substances (it is an inert electrode).
2. It is used as a lubricant, particularly when high temperatures are involved, where the usual lubricating oils easily decompose due to extreme heat. It is a lubricant for dynamos, electric motors and fast-moving parts of machinery.
3. The major use of graphite is in making lead pencils of different hardness, by mixing it with different proportions of clay. The weakly held layers of carbon atoms in graphite easily slide over each other and are left behind on paper as black marks.
4. Being resistant to chemicals and having a high melting point and also because it is a good conductor of heat, graphite is used to make crucibles.
5. Graphite has the ability to absorb fast-moving neutrons, thus, it is used in nuclear reactors to control the speed of the nuclear fission reaction.

Diamond

The basic unit of the diamond structure is shown in figure 1.20. Each carbon atom is covalently bonded to four other carbon atoms. This basic unit is repeated in three dimensions as shown in figure 1.21 to form a giant tetrahedral structure of millions of carbon atoms, all forming four covalent bonds to each other. The melting point of diamond is high. This is because of the strong covalent bonds between carbon atoms, which require a large amount of heat energy to break up.

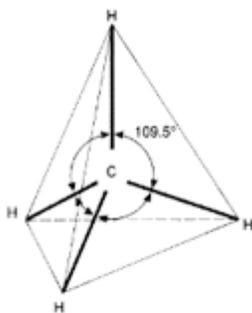
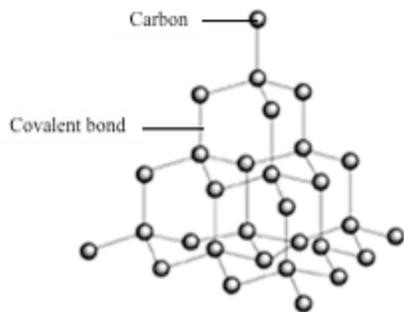


Figure 1.20 Tetrahedral



Structure of diamond

Physical properties of diamond

1. It is the hardest natural substance known. This due to the strong covalent bonds between the carbon atoms in diamond. Again the compact tetrahedral arrangement of carbon atoms contributes to its hardness.
2. It has the highest melting point (3550°C) and boiling point (4289°C).
3. It has a high relative density (3.5) compared to graphite (2.3)
4. It is a poor conductor of heat and electricity. This is because there are no free electrons to conduct electricity. All electrons are firmly held in covalent bonds.
5. It is colourless, transparent and has a dazzling (amazing) brilliant lustre and radiance.
6. It has a high refractive index of 2.5. The high refractive index results in high dispersion of light, making it suitable for use in jewellery.

Uses of diamond

1. It is used in making jewellery.
2. Due to its extreme hardness, it is used to make glass cutters, drilling devices, rock borers, and as an abrasive for smoothing very hard materials.

Comparison of the properties of diamond and graphite

Diamond	Graphite
1. Colourless, transparent and glittering	Black, opaque with metallic lustre

2. Hardest natural substance known, used to cut glass and in drills	Soft to touch, greasy or soapy, can be used as a lubricant and in making lead pencils
3. High relative density (3.5)	Low relative density (2.3)
4. Non-conductor	Good conductor of heat and electricity
5. Burns in air least readily (at about 900°C)	Burns in air readily (at 700°C)
6. Have strong C-C covalent bonds arranged octahedrally to form a giant molecular crystal	Have strong C-C bonds within the hexagonal rings in the sheets but weak Van der Waal's forces in between layers.
7. Its cleavage is difficult and it occurs along the boundaries of the octahedral crystal unit	Cleavage easy, and occurs along the sheets or the layers.
8. Prepared from graphite at very high pressure and temperature	Prepared from coke and silica mixture at high temperature
9. Not attacked by potassium chlorate and nitric acid together	Attacked by these reagents

A proof that diamond and graphite are both allotropic forms of carbon can be shown experimentally by burning equal masses of each allotrope in a stream of oxygen. It is found that equal masses of each allotrope produce equal masses of carbon dioxide. $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$

The weight of carbon dioxide produced can be determined by allowing it to be absorbed in a weighed amount of potassium hydroxide solution. $2KOH_{(aq)} + CO_{2(g)} \rightarrow K_2CO_{3(aq)} + H_2O_{(l)}$. Then, the weight of carbon dioxide is obtained by calculations based on the equation above.

Amorphous carbon

Amorphous carbon is carbon that does not have any clear shape, form or crystalline structure. Amorphous carbon is made of tiny bits of graphite with varying amounts of other elements considered as impurities. It is formed when a material containing carbon is burned in a limited supply of oxygen, resulting in incomplete combustion.

Amorphous carbon exists in many forms. The following are the major forms in which it occurs:

- a. Charcoal
- b. Lampblack (soot) or carbon black
- c. Coke

Charcoal

Charcoal is made by heating organic material (animal or plant parts) to a high temperature in the absence of air or in the presence of limited amounts of oxygen or other reagents, catalysts, or solvents. This process is called destructive distillation. There are three categories of charcoal, namely, wood charcoal, animal charcoal and sugar charcoal.

Wood charcoal

Wood charcoal is made by heating wood or other vegetable matter (for example coconut shells) in the almost complete absence of air. Wood charcoal is light, porous and is a remarkably good absorbent for liquid or gases (1 cm³ of wood charcoal will absorb 100 cm³ of ammonia gas at 0°C).

Uses of wood charcoal

1. Because of its ability to absorb large amounts of gas or liquid, it is used in gas masks to absorb poisonous gases in air in industrial process to recover volatile materials from waste gases.
2. Wood charcoal can be used in metal refining instead of coke.
3. Wood charcoal is a good source of energy. Thus, it is used as fuel for cooking and heating in homes.

Animal charcoal

Animal charcoal is made by heating animal bones in the absence of air. Its main component is calcium phosphate, Ca₃(PO₄)₂, and carbon constitutes about 10% of the components.

Uses of animal charcoal: It is used in sugar industries to remove the colouring matter from brown sugar to make it white

Sugar charcoal

Sugar charcoal is a very pure form of carbon, and is made by removing the elements of water (oxygen and hydrogen) from sugar. This is achieved by using strong dehydrating agents such as concentrated sulphuric acid or concentrated nitric acid, which removes water from sugar.

Uses of sugar charcoal: Sugar charcoal is chiefly used in the manufacture of artificial diamonds.

Lampblack/soot/carbon black

This is produced by burning petroleum or any hydrocarbon in a limited supply of air (or in chlorine). It can also be produced from the burning of organic material at home. It is commonly found in the kitchen chimneys, lamps and on bases of cooking pans and pots.

Uses of lampblack/soot/carbon

1. It is used in making printers' ink, shoe polish and carbon papers.
2. It is an important industrial material in the manufacture of tyres. It is used as a filler material in tyres.

Coke

Coke is made by destructive distillation of coal. During the process, coal is obtained as the major product. The other products formed when coal is destructively distilled are coal gas, coal tar, coal oil, gas carbon and ammonia liquor.

Uses of coke

1. Coke is used as a fuel and as a reducing agent in the extraction of iron, lead and zinc. It is also used as a fuel in boilers.
2. It is used in the manufacture of producer gas and water gas.

Chemical properties of carbon

1. Carbon burns in excess oxygen to form carbon dioxide $C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}$. In insufficient oxygen, carbon monoxide is formed. $2C_{(s)} + O_{2(g)} \rightarrow 2CO_{(g)}$
2. Carbon has got reducing properties and thus acts as a reducing agent. Carbon reduces oxides of metals below it in the electrochemical and activity series to their respective metals. This occurs on strong heating, and this reaction is used industrially for extraction of metals from

their ores: $\text{PbO}_{(s)} + \text{C}_{(s)} \rightarrow \text{Pb}_{(s)} + \text{CO}_{(g)}$; $\text{Fe}_2\text{O}_3_{(s)} + 3\text{C}_{(s)} \rightarrow 2\text{Fe}_{(s)} + 3\text{CO}_{(g)}$; $\text{ZnO}_{(s)} + \text{C}_{(s)} \rightarrow \text{Zn}_{(s)} + \text{CO}_{(g)}$.

3. Sulphur vapours react with red hot carbon to give carbon disulphide. $\text{C}_{(s)} + 2\text{S}_{(g)} \rightarrow \text{CS}_{2(l)}$

4. Carbon dioxide is reduced by red hot carbon to carbon monoxide $\text{C}_{(s)} + \text{CO}_{2(g)} \rightarrow 2\text{CO}_{(g)}$; This reaction is used in the industrial manufacture of producer gas.

Carbon Dioxide

Preparation of a Dry Sample of Carbon Dioxide Gas in the Laboratory

Prepare a dry sample of carbon dioxide gas in the laboratory

Carbon dioxide is one of the oxides of carbon. The gas is present in the air at a level of approximately 0.03% by volume. It is also found dissolved in water. The gas is one of the by-products of all decaying organic matter. Without carbon dioxide there is no life on earth. It is used by all plants in the process of photosynthesis and both plants and animals evolve carbon dioxide in respiration.

Laboratory preparation of carbon dioxide

Carbon dioxide is prepared in the laboratory by the action of dilute hydrochloric acid on marble (calcium carbonate).

When dilute hydrochloric acid is poured on marble chips, effervescence occurs. Dilute hydrochloric acid reacts with the marble chips to give calcium chloride, water and carbon dioxide.



The Properties of Carbon Dioxide

Analyse the properties of carbon dioxide

Physical properties

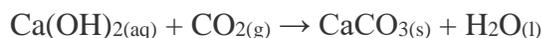
1. Carbon dioxide is a colourless and odourless gas.
2. It is denser than air.

3. When the gas is cooled to -78°C , it turns straight into the solid (it sublimates). Sublimation is the change of a gas straight into a solid or change of a solid straight into a gas. Solid carbon dioxide is called dry ice. It sublimates when it is heated or exposed to air.
4. It has a melting point of -199°C and boiling point of -91.5°C .
5. Carbon dioxide does not support combustion. This is why it is used in fire extinguishers.

Chemical properties

Reaction of carbon dioxide with lime water (Test for carbon dioxide)

When a little carbon dioxide gas is bubbled into lime water (calcium hydroxide solution), the solution turns milky. This is due to the formation of a white precipitate of insoluble calcium carbonate.



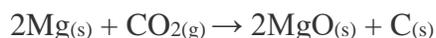
This is a confirmatory test for the presence of carbon dioxide. The test serves to distinguish carbon dioxide from any other gas.

When excess carbon dioxide is bubbled into the lime water, the white precipitate dissolves to form a clear solution of soluble calcium hydrogen carbonate: $\text{CaCO}_{3(\text{s})} + \text{H}_2\text{O}_{(\text{l})} + \text{CO}_{2(\text{g})} \rightarrow \text{Ca(HCO}_3)_2(\text{aq})$

Barium hydroxide can also be used to test for carbon dioxide as it forms a precipitate of barium carbonate: $\text{Ba(OH)}_{2(\text{aq})} + \text{CO}_{2(\text{g})} \rightarrow \text{BaCO}_{3(\text{s})} + \text{H}_2\text{O}_{(\text{l})}$

Reaction of carbon dioxide with magnesium

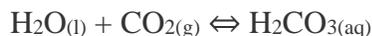
When a burning magnesium ribbon is lowered into a gas jar containing carbon dioxide gas, it continues to burn for a short time with a spluttering flame. A white ash of magnesium oxide and black specks of carbon are formed. The black specks of carbon can be seen on the sides of the gas jar.



This clearly shows that carbon dioxide contains carbon and oxygen.

Reaction of carbon dioxide with water

Carbon dioxide reacts with water to form a weak carbonic acid. When carbon dioxide is bubbled into water, it dissolves to form a weakly acidic solution of carbonic acid:



The solution turns a blue litmus paper pink. This indicates that the solution is slightly acidic and hence too weak to turn the blue litmus paper to red (as strong acids do). The solution has no effect on red litmus paper.

The Uses of Carbon Dioxide

Explain the uses of carbon dioxide

Uses of Carbon Dioxide include:

1. **Fire extinguisher:** Carbon dioxide is inert (i.e. it does not burn). It is denser than air and does not support combustion. Hence, it is a very useful fire-fighting chemical. When applied to fire, it forms a blanket over the burning material. Thus, it prevents air (oxygen) from reaching the burning material and therefore, extinguishing the flames.
2. **Manufacture of aerated (fizzy) drinks:** Soda water and mineral water contain carbon dioxide dissolved under pressure. Because the gas is only slightly soluble, it is bubbled into these drinks under pressure to make more of it dissolve. When the bottles are opened, the gas escapes and it causes the “fizzy”. Dissolved carbon dioxide is responsible for the pleasant taste of soft drinks such as lemonade, Coca cola, Pepsi cola and other aerated drinks and mineral waters. Other beverages like beers are also bottled together with carbon dioxide.
3. **Refrigeration:** Carbon dioxide is used for refrigeration purposes (i.e. in the deep-freezing of foods). The gas liquefies at ordinary pressure to form dry ice which sublimates at -78°C . Dry ice is a good refrigerant because it leaves no liquid after sublimation as is the case with ordinary ice.
4. **Manufacture of sodium carbonate by the Solvay Process:** Carbon dioxide is used in the manufacture of anhydrous sodium carbonate in the Solvay Process. The sodium carbonate produced is used in the manufacture of glass.
5. **Manufacture of baking soda:** Carbon dioxide is used in making baking soda (sodium bicarbonate). Baking soda is prepared by passing carbon dioxide into cold concentrated sodium hydroxide solution: $\text{CO}_2(\text{g}) + 2\text{NaOH}(\text{aq}) \rightarrow \text{Na}_2\text{CO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$. Further addition of carbon

dioxide produces sodium bicarbonate which, at sufficiently high concentration, will precipitate out of the solution as a solid: $\text{Na}_2\text{CO}_{3(\text{aq})} + \text{CO}_{2(\text{g})} + \text{H}_2\text{O}_{(\text{l})} \rightarrow 2\text{NaHCO}_{3(\text{s})}$ Yeast and sodium bicarbonate (hydrogencarbonate) are important in the baking industry. Thus in baking of bread, yeast is added to flour, sugar and water (forming the dough). In the making of cakes, baking powder (a mixture of bicarbonate and an acid) is used instead of yeast.

6. **Rain making:** When pieces of dry ice (solid carbon dioxide) are dropped into clouds, the temperature of the clouds is lowered to such an extent that rain precipitates out.

7. **Photosynthesis:** Plants use carbon dioxide from the air to manufacture their own food through the process of photosynthesis

ORGANIC CHEMISTRY

INTRODUCTION TO ORGANIC CHEMISTRY

Organic chemistry is the chemistry of carbon compounds. Due to the ability of carbon to form chains of atoms, and for other atoms or groups of atoms to be attached to these chains, there are a huge number of carbon compounds. All organic compounds contain carbon together with one or more other elements such as hydrogen, oxygen, nitrogen, sulphur and the halogens.

Normally every compound of carbon is an organic compound. Even after discovering that these compounds could be synthesized in the laboratory, the definition that they are *organic* (of organic nature, that is, they originate from living things) has been retained. However, for conventional and historic reasons, some of the simpler compounds such as carbon dioxide (CO₂) carbonates, carbon monoxide (CO) are usually studied with other non-carbon compounds in Inorganic Chemistry.

Difference between Organic from Inorganic Chemistry

Distinguish organic from inorganic chemistry

Organic chemistry is the chemistry of carbon compounds. All organic compounds contain carbon and other elements such as H, O, N, S and the halogens. Normally every compound of carbon is an organic compound. Examples of organic compounds/substances are plastics, milk, carbohydrates, lipids, proteins, sugar and hydrocarbons. Inorganic substances includes table salt, CO₂, diamond, iron and water.

The Importance of Organic Chemistry in Life

Explain the importance of organic chemistry in life

Carbon is the most unusual atom. It has the ability to join up to itself and form very long chains of atoms. Without this ability, life on Earth would not exist because the molecules that make our bodies contain mostly long chains of carbon atoms.

All living things contain carbon compounds. Raw materials such as oil and coal, derived from living things, are also based on carbon. Our modern society is very much dependent on organic

chemistry to make the fuels and materials that we use in every day of our lives. In particular, polymers, large molecules obtained from alkanes, have very widespread use. Without alkanes from crude oil our transport system would be impossible.

We also need various fractions obtained from crude oil (petrol, diesel, kerosene, oil, natural gas, etc.) to run motor vehicles and other machines to simplify our work and life.

In brief, the compounds obtained from crude oil have thousands of different uses, for example:

- some are used as fuel or converted into fuels;
- some are used for making detergents, dyes, drugs, paints, and cosmetics; and yet some are used for making polyethene, polyvinyl chloride (PVC) and other plastics.

The Origin of Organic Compounds

Explain the origin of organic compounds

Fossil fuels were formed in the Earth's crust from material that was once living. Coal comes from fossils of plant material. Crude oil and natural gas are formed from bodies of marine microorganisms. The formation of these fuels took place over geological periods of time (many millions of years).

Crude oil is one of the world's major natural resources. The oil is the result of a process that began up to 400 million years ago. Prehistoric marine organisms died and sunk to the sea bed and were covered by mud and sand. The change into crude oil and natural gas was brought about by high pressure, high temperature and bacteria acting over millions of years. The original organic material broke down into hydrocarbons. Compression of the mud above the hydrocarbon mixture transformed it into shale. Then geological movements and pressure changed this shale into harder rocks, squeezing out the oil and gas. The oil and gas moved upwards through the porous rocks, moving from high- pressure to low-pressure conditions. Sometimes they reached the surface, but often they became trapped by a layer of non porous rock. Reservoirs of oil and gas were created. These reservoirs are not lakes of oil or pockets of gas. Instead, the oil or gas is spreadthroughout the pores in coarse rocks such as sandstone or limestone the same as water is held in a sponge.

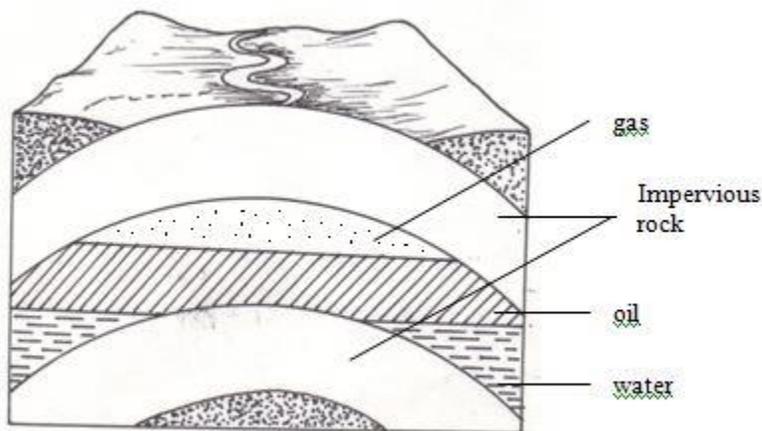


Figure 2.1 Formation of crude oil

The Fractional Distillation of Crude Oil

Describe the fractional distillation of crude oil

Crude oil from an oilfield is separated from impurities such as sand and water and is pumped through pipelines to the refinery. At the refinery, fractional distillation is used to separate the crude oil into several fractions, each fraction containing several hydrocarbons which boil within a certain range of temperatures. These different boiling points are roughly related to the number of carbon atoms in the hydrocarbon (Table 2.1)

Separation of the hydrocarbons takes place in a fractionating column (fractionating tower). At the start of the refinery process, crude oil is preheated to a temperature of 350–400°C and pumped in at the base of the tower. As it boils, the vapour passes up the tower. It passes through a series of bubble caps and cools as it rises further up the column. The different fractions cool and condense at different temperatures, and therefore at different heights in the column. The fractions condensing at the different levels are collected on trays.

Thus, vapour is rising and liquid falling at each level in the tower. As a result very efficient fractionation occurs. Liquid is taken off at several different levels, the higher the level, the lower the boiling point of the fraction removed. Figure 2.2 shows the process of separation of crude oil into different fractions.

After fractional distillation, impurities are removed. The commonest impurity is sulphur, which is removed and used to manufacture sulphuric acid. If petrol (gasoline) containing sulphur is not

purified before it is used in an internal combustion engine, the exhaust fumes will contain oxides of sulphur (SO_2 and SO_3). These are poisonous gases and will pollute the environment.

Table 2.1 Various crude oil fractions

Name of fraction	Number of carbon atoms per molecule	Boiling point range ($^{\circ}\text{C}$)	
Natural gas	C1–C4	Below 40	Boiling points and viscosity increase ↓
Petrol (gasoline)	C5–C6	40 – 100	
Naphtha	C6–C10	90 – 150	
Kerosene (paraffin)	C10–C16	150 – 240	
Diesel oil	C16–C20	220 – 250	
Lubricating oil	C20–C30	255 – 350	
Fuel oil	C30–C40	Above 350	
Paraffin waxes	C40–C50	-	
Bitumen, Asphalt	C50 upwards	-	

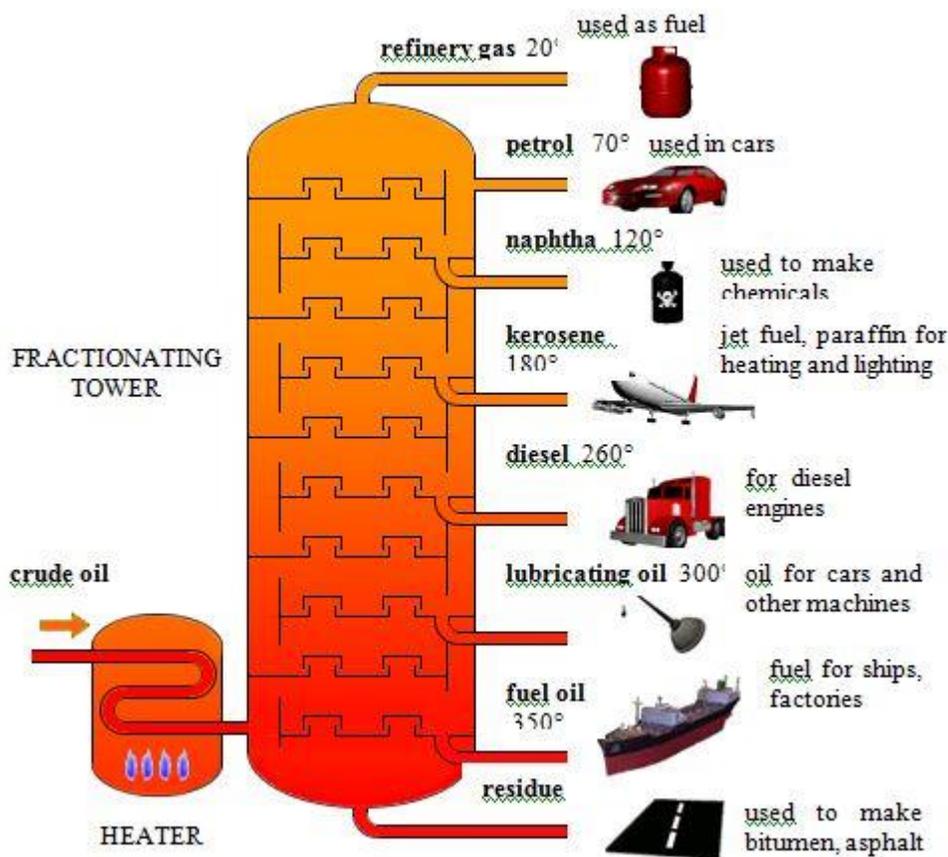


Figure 2.2 Fractional distillation of crude oil in a refinery

Uses of different petroleum fractions

1. Natural gas (refinery gas). The gas fractions consist of mainly methane, ethane, propane, and butane. The methane and ethane are usually burnt as fuel. The propane and butane are liquefied and are distributed in high pressure gas cylinders and tanks to be used for lighting and heating purposes.
2. Petrol (motor gasoline). It is mainly used as a fuel in internal combustion engines in motor vehicles. It is also used as a solvent for grease stains and paints.
3. Naphtha. It is used as a raw material for making many chemicals and plastics.

4. Kerosene (paraffin). It is used in homes as a fuel in paraffin lamps and stoves for heating, lighting and cooking food. However, in addition to its domestic use, it is used as a fuel for jet engines in aeroplanes. It is also used as a detergent.
5. Diesel oil. It is used as a fuel in diesel engines (e.g. in diesel train engines, tractors, lorries, diesel car engines).
6. Lubricating oil. It is used to make petroleum jelly (e.g. Vaseline). It is also used as oil for lubricating moving parts of cars and other machines.
7. Fuel oil. It is used as a fuel for power stations, ships and factories.
8. Paraffin waxes. They are used to make candles, polishes and waxed papers. They are also used in water proofing and as grease.
9. Asphalt, bitumen. They are used to make protective coatings for road surfaces and concrete roof tops, and also as binding agents for roofing sheets.

Hydrocarbons

Hydrocarbons are compounds containing hydrogen and carbon and no other element. That is, a hydrocarbon has the molecular formula C_xH_y , x and y being whole numbers. For example, methane (CH_4) ethane (C_2H_6) and benzene (C_6H_6) are hydrocarbons.

The three Families of Hydrocarbons

Classify the three families of hydrocarbons

In order to simplify the study of these compounds, chemists have grouped them into families. The members of each family have characteristic chemical properties and graded physical properties, such as boiling point, etc. The main family members of hydrocarbons that we shall study at this level are the alkanes, the alkenes and the alkynes.

Alkanes

The members of this group of hydrocarbons are distinguished by possessing the general molecular formula C_nH_{2n+2} , where n is 1, 2, 3, etc., for successive members of the group. The first member of the series ($n = 1$) is methane (CH_4) and the second ($n = 2$) is ethane (C_2H_6).

Both are gases at room temperature and pressure. This general formula can be used to work out the formula of any other alkane if we know the number of carbon atoms it consists of. The following table gives the molecular formula and name of the first few alkanes, plus an indication of some of their physical properties.

Table 2.2 Formulae and physical properties of some alkanes

name	Molecular formula	Melting point (oC)	Boiling point (oC)	Density (gcm ⁻³)
Methane	CH ₄	-183	-162	gas
Ethane	C ₂ H ₆	-172	-89	gas
Propane	C ₃ H ₈	-188	-42	gas
Butane	C ₄ H ₁₀	-135	-1	gas
Pentane	C ₅ H ₁₂	-130	36	0.626
Hexane	C ₆ H ₁₄	-95	69	0.659
Heptane	C ₇ H ₁₆	-91	98	0.684
Octane	C ₈ H ₁₈	-57	126	0.703
Nonane	C ₉ H ₂₀	-54	151	0.718
Decane	C ₁₀ H ₂₂	-30	174	0.730

Structure of alkanes

In the alkanes, all carbon atoms show a covalency of four. Table 2.3 shows the structures of the first five members of the alkanes.

Table 2.3 Structure of alkanes

Molecular formula	Open structural formula	Condensed structural formula
CH ₄	$ \begin{array}{c} \text{H} \\ \\ \text{H}-\text{C}-\text{H} \\ \\ \text{H} \end{array} $	CH ₄
C ₂ H ₆	$ \begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H}-\text{C}-\text{C}-\text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array} $	CH ₃ CH ₃
C ₃ H ₈	$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array} $	CH ₃ CH ₂ CH ₃
C ₄ H ₁₀	$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} $	CH ₃ CH ₂ CH ₂ CH ₃
C ₅ H ₁₂	$ \begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \quad \\ \text{H}-\text{C}-\text{C}-\text{C}-\text{C}-\text{C}-\text{H} \\ \quad \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array} $	CH ₃ CH ₂ CH ₂ CH ₂ CH ₃

The Homologous Series of the Three Families of Hydrocarbons

Write the homologous series of the three families of hydrocarbons

A homologous series is a series of compounds with similar chemical properties which differ by CH_2 . Such series has the following characteristics:

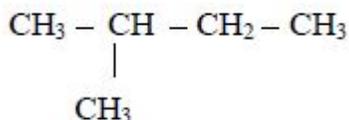
1. All members obey the general molecular formula, e.g. for alkanes $\text{C}_n \text{H}_{2n+2}$, alkenes $\text{C}_n \text{H}_{2n}$ and alkynes, $\text{C}_n \text{H}_{2n-2}$.
2. Each member differs, in molecular formula, from the next by CH_2 , e.g. alkanes are CH_4 , C_2H_6 , C_3H_8 , and so on.
3. All members show similar chemical properties.
4. The general properties of members change gradually in the same direction along the series, e.g. in alkanes, boiling points and freezing points rise with increase in the number of carbon atoms (CH_4 – a gas; C_5H_{12} – a liquid; $\text{C}_{20}\text{H}_{42}$ – a solid at ordinary temperatures and pressure).
5. General methods of preparation are known which can be applied to any member of the series. Other homologous series are alcohols, $\text{C}_n\text{H}_{2n+1}$ and carboxylic acids, $\text{C}_n\text{H}_{2n+1}\text{COOH}$.

Nomenclature of alkanes

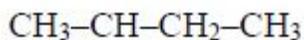
The term nomenclature means naming. Organic compounds are named using IUPAC system of nomenclature. IUPAC stands for International Union of Pure and Applied Chemistry.

Rules of Nomenclature

1. Name the longest unbranched carbon chain. For example, consider the following compound:



In this compound, the longest unbranched chain is



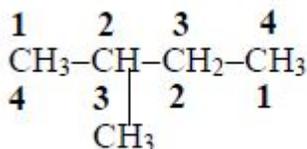
The longest chain is, therefore, butane.

2. Name the functional groups. Functional groups are branches of the main carbon chain. These are sometimes called alkyl groups.

Examples of alkyl groups are as follows:

- CH₃ – methyl
- CH₃CH₂ – ethyl
- CH₃CH₂CH₂ – propyl
- Cl – chloro
- Br – bromo
- I – iodo
- F – fluoro

3. Give the position(s) of the functional group(s) using lower numbers when possible. Consider the following example:



There are two possibilities of naming the above compound but only one is correct.

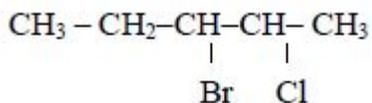
1. 2 – methylbutane
2. 3 – methylbutane

The first name is correct because it bears the lowest number (2). The second name is wrong because it bears a large number (3).

4. Names of the functional groups are named in alphabetical order in the final name.

Example

Consider the following compound:

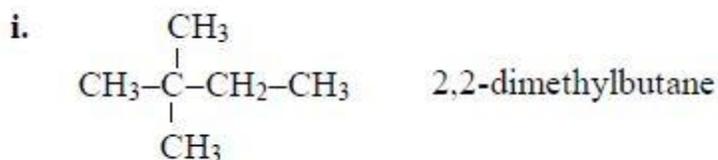


The name of the compound is: 3-bromo-2-choloropentane

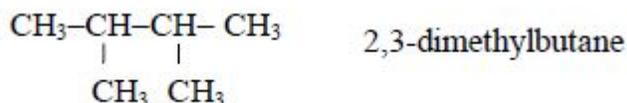
Note: We start with bromo and not chloro because b comes before c in alphabet (a, b, c, d ...)

5. If there are identical functional groups, use the prefixes di (2), tri (3), tetra (4), penta (5), etc. These prefixes do not account for alphabetical order.

Examples:



ii.



6. Commas separate numbers and hyphens separate numbers from words.

The Concept of Isomerism

Explain the concept of isomerism

Isomers are organic compounds with the same molecular formula but different structural formulae.

Isomerism is the occurrence of two or more compounds with the same molecular formula but different molecular structures (structural formulae).

Isomers of the same molecular formula have different physical and chemical properties because of structural differences.

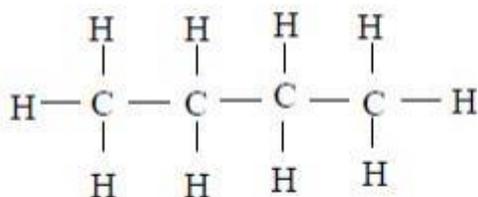
Structural Formulae of all Isomers of Hydrocarbons up to Five Carbon Atoms

Write structural formulae of all isomers of hydrocarbons up to five carbon atoms

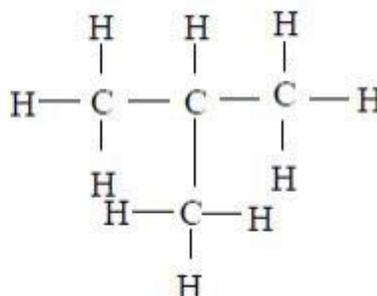
Example 1

1. Butane The two isomers of butane, with molecular formula C_4H_{10} , are as shown below. Isomers can be presented either in an open formula (structure) as follows.

Open formula



butane



2-methylpropane

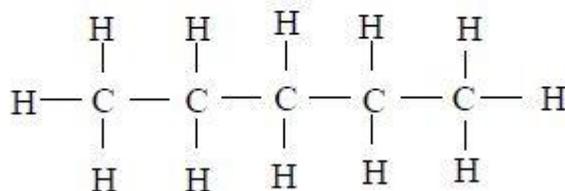
Example 2

Pentane

The three isomers of pentane show a open formula as follows:

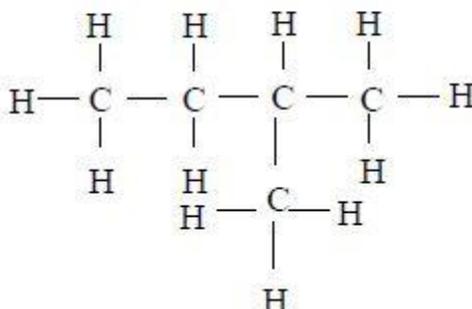
1. Pentane

Open structure



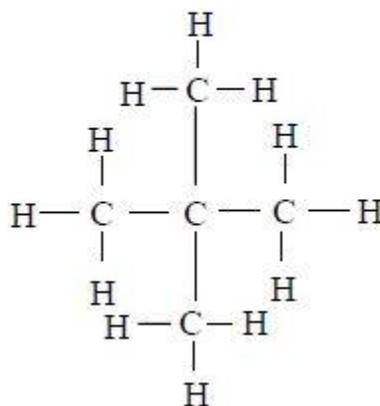
2. 2 – methylbutane

Open structure



3. 2,2 – dimethylpropane

Open structure



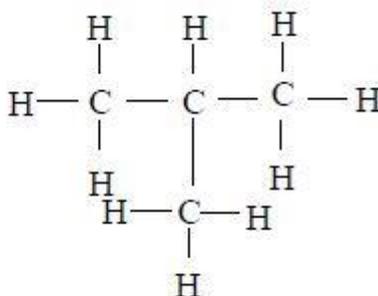
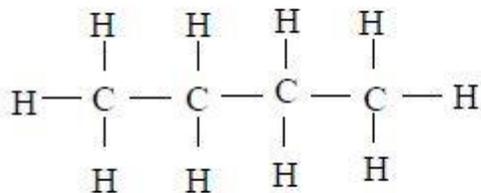
Isomers of Hydrocarbons up to Five Carbon Atoms

Name the isomers of hydrocarbons up to five carbon atoms

Example 3

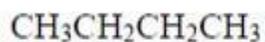
alkanes showing isomerism

1. Butane The two isomers of butane, with molecular formula C_4H_{10} , are as shown below. Isomers can be presented either in an open or condensed formula (structure).

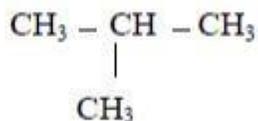
Open formula

butane

2-methylpropane

Condensed formula

butane



2-methylpropane

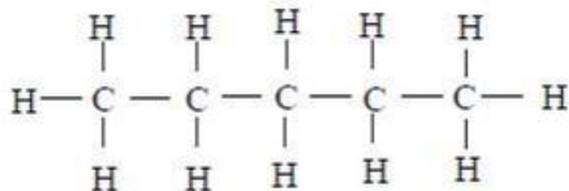
Note: Remember that CH₄, C₂H₆ and C₃H₈ have no isomers because they cannot form alkyl groups, that is, they cannot be branched. Isomerism in alkanes starts from an alkane with four carbon atoms (butane) in its structure (C₄H₁₀).

2. Pentane

The three isomers of pentane are shown as follows:

1. Pentane

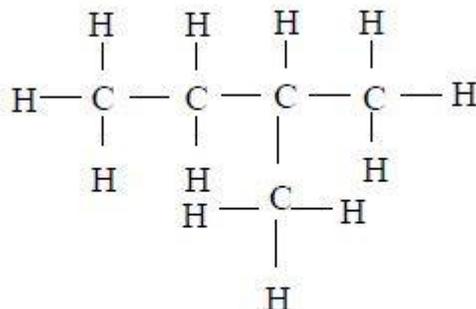
Open structure



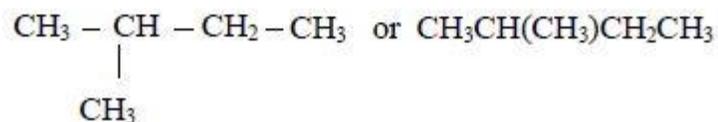
Closed structure
 $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$

2. 2 - methylbutane

Open structure

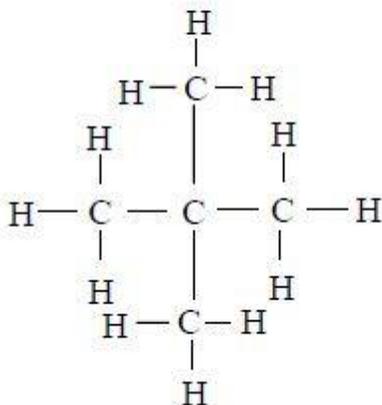


Closed structure

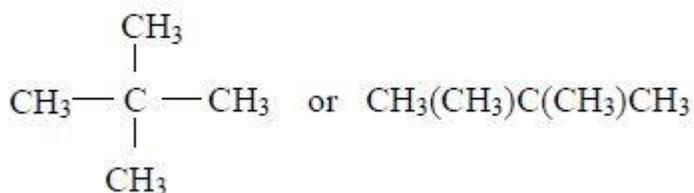


3. 2.2 – dimethylpropane

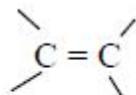
Open structure



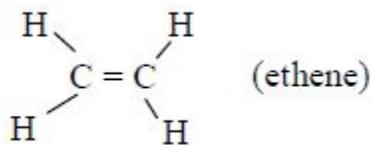
Closed structure

**Alkenes**

Alkenes are members of a homologous series of hydrocarbons with general molecular formula $\text{C}_n \text{H}_{2n}$ where $n = 2, 3, 4, \text{etc.}$ The common structural feature is the presence of a carbon-carbon double bond:



For example:



There is no member of this series for $n = 1$ since there needs to be at least two carbon atoms present to have a double bond. Table 2.3 shows the first five members of alkenes.

Table 2.3 formulae and physical properties of some alkenes

Number of carbons (n)	Name	Molecular formula	Boiling point ($^{\circ}\text{C}$)	Physical state at room temperature	
2	Ethene	C_2H_4	-104	gas	Boiling point and viscosity increasing
3	Propene	C_3H_6	-47	gas	
4	Butene	C_4H_8	-6	gas	
5	Pentene	C_5H_{10}	+30	liquid	
6	Hexene	C_6H_{12}	above 30	liquid	

Structure of alkenes

Alkanes are characterized by possessing one or more carbon to carbon double bond(s) ($\text{C}=\text{C}$) in the carbon chain. Alkenes are unsaturated hydrocarbons because it is possible to break the double bond and add extra atoms to the parent molecule.

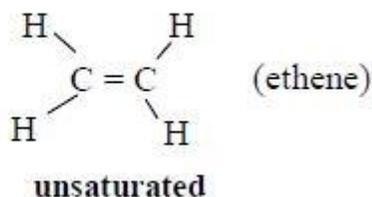
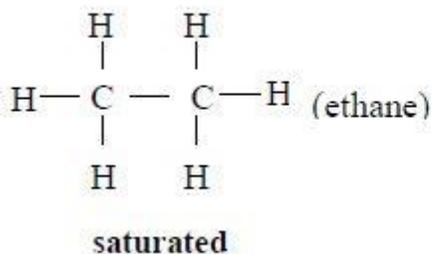


Table 2.4 shows the structures of the first five members of the homologous series of alkenes.

Table 2.4 Structure of alkenes

Name	Open structure	Condensed structure
Ethene	$\begin{array}{c} \text{C} & & \text{H} \\ & \diagdown & / \\ & \text{C} = \text{C} & \\ & / & \diagdown \\ \text{H} & & \text{H} \end{array}$	$\text{CH}_2 = \text{CH}_2$
Propene	$\begin{array}{c} & \text{H} & \text{H} \\ & & \\ \text{H} & \diagdown & / \\ & \text{C} = \text{C} - \text{C} - \text{H} \\ & / & \\ \text{H} & & \text{H} \end{array}$	$\text{CH}_2 = \text{CH}-\text{CH}_3$
Butene	$\begin{array}{c} & \text{H} & \text{H} & \text{H} \\ & & & \\ \text{H} & \diagdown & / & \\ & \text{C} = \text{C} - \text{C} - \text{C} - \text{H} \\ & / & & \\ \text{H} & & \text{H} & \text{H} \end{array}$	$\text{CH}_2 = \text{CH}-\text{CH}_2-\text{CH}_3$
Pentene	$\begin{array}{c} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & \\ \text{H} & \diagdown & / & & \\ & \text{C} = \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ & / & & & \\ \text{H} & & \text{H} & \text{H} & \text{H} \end{array}$	$\text{CH}_2 = \text{CH}-\text{CH}_2-\text{CH}_2-\text{CH}_3$
Hexene	$\begin{array}{c} & \text{H} & \text{H} & \text{H} & \text{H} & \text{H} \\ & & & & & \\ \text{H} & \diagdown & / & & & \\ & \text{C} = \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ & / & & & & \\ \text{H} & & \text{H} & \text{H} & \text{H} & \text{H} \end{array}$	$\text{CH}_2 = \text{CH}-\text{CH}_2-\text{CH}_2-\text{CH}_2-\text{CH}_3$

Nomenclature of alkenes

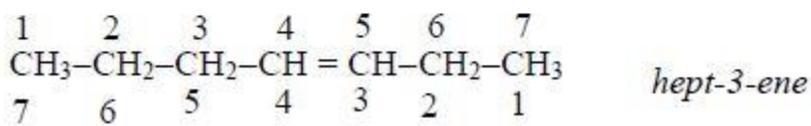
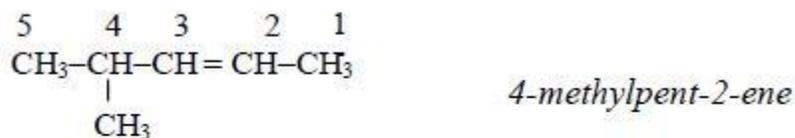
Rules for naming alkenes

- Names of alkenes have the ending -ene.
- The double bond is given the number of the carbon atom where it begins.

3. In addition to the rules discussed earlier, the position of the double bond must be included in the name. Examples: $\text{CH}_3\text{-CH=CH}_3$ prop-1-ene, $\text{CH}_3\text{-CH=CH-CH}_3$ but-2-ene

4. Double bonds are given the lowest number possible, usually lower than the functional groups.

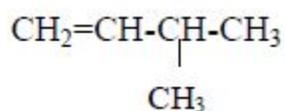
Examples:



Counting from the left to right, the double bond (=) is on carbon number 4 and from the right to left, it is on carbon number 3. Because the double bonds should be given the lowest number possible, the name of the compound is, therefore, hept-3-ene instead of hept-4-ene.

Isomerism

Alkenes, like alkanes show branching isomerism, for example $\text{CH}_3\text{-CH=CH-CH}_3$ (pent-1-ene) can be branched into (3-methylbut-1-ene) as follows:



They also show positional isomerism due to different positions of the double bond in the molecule, for example, pent-1-ene and pent-2-ene are both the isomers of pentene (C_5H_{10}):

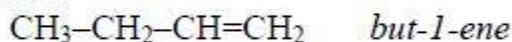


Other examples include:

Hexene:



Butene:



Alkynes

These are homologous series of hydrocarbons with the general formula $\text{C}_n\text{H}_{2n-2}$. The common structural feature is the presence of a carbon-carbon triple bond ($\text{C}\equiv\text{C}$). There is no member for $n = 1$ because, as for the alkenes, there needs to be at least two carbon atoms present to have a triple bond. Table 2.5 shows the first five members of the alkynes.

Table 2.5 First five members of alkynes

Number of carbons(n)	Name	Molecular formula
2	Ethyne	$\text{CH}\equiv\text{CH}$
3	Propyne	$\text{CH}\equiv\text{C-CH}_3$
4	Butyne	$\text{CH}\equiv\text{C-CH}_2\text{-CH}_3$
5	Pentyne	$\text{CH}\equiv\text{C-CH}_2\text{-CH}_2\text{-CH}_3$
6	Hexyne	$\text{CH}\equiv\text{C-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_3$

Table 2.6 Structure of alkynes

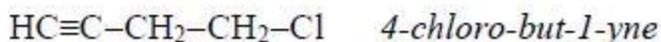
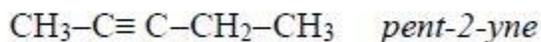
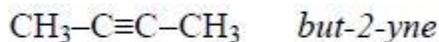
Name	Open structure	Condensed structure
Ethyne	$\text{H} - \text{C} \equiv \text{C} - \text{H}$	$\text{CH} \equiv \text{CH}$
Propyne	$\begin{array}{c} \text{H} \\ \\ \text{H} - \text{C} \equiv \text{C} - \text{C} - \text{H} \\ \\ \text{H} \end{array}$	$\text{CH} \equiv \text{C} - \text{CH}_3$
Butyne	$\begin{array}{c} \text{H} \quad \text{H} \\ \quad \\ \text{H} - \text{C} \equiv \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \\ \text{H} \quad \text{H} \end{array}$	$\text{CH} \equiv \text{C} - \text{CH}_2 - \text{CH}_3$
Pentyne	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \\ \text{H} - \text{C} \equiv \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\text{CH} \equiv \text{C} - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$
Hexyne	$\begin{array}{c} \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \\ \quad \quad \quad \\ \text{H} - \text{C} \equiv \text{C} - \text{C} - \text{C} - \text{C} - \text{C} - \text{H} \\ \quad \quad \quad \\ \text{H} \quad \text{H} \quad \text{H} \quad \text{H} \end{array}$	$\text{CH} \equiv \text{C} - \text{CH}_2 - \text{CH}_2 - \text{CH}_2 - \text{CH}_3$

Nomenclature of alkynes

Rules for naming alkynes

1. Alkynes have the ending -yne
2. Triple bond is given the lowest number possible, usually lower than the functional groups.
3. As for the alkenes the position of the triple bond must be included in the name.

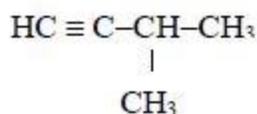
Examples:



Isomerism

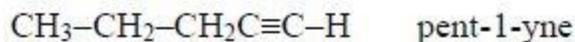
Alkynes show branching isomerism and positional isomerism. The alkyne with the molecular formula, C₅H₈, shows chain branching isomerism, for instance,

HC≡C-CH₂-CH₂-CH₃ (pent-1-yne) can branch into 3-methylbut-1-yne:



3-methylbut-1-yne

Positional isomerism



A General Formula to Identify the Families of Hydrocarbons

Apply a general formula to identify the families of hydrocarbons

Activity 1

Apply a general formula to identify the families of hydrocarbons

Properties of Hydrocarbons

The Physical Properties of Lower Hydrocarbons; Alkanes, Alkenes and Alkynes

Explain the physical properties of lower hydrocarbons; alkanes, alkenes and alkynes

Alkanes

1. The first four alkanes are gases at room temperature, the next twelve (C₅–C₁₇) are liquids, and the rest are solids.
2. The boiling and melting points of unbranched alkanes increase as the molar masses increase. The larger the molecule, the higher the boiling point or melting point.
3. Branched alkanes have lower boiling points than the unbranched alkanes,
4. Alkanes are very sparingly soluble in water but they easily dissolve in organic solvents.
5. In an alkane molecule, each carbon atom forms four single covalent bonds. This means that alkanes are saturated hydrocarbons.

Alkenes

Here again we find that alkenes possess physical properties that are the same as those of alkanes, i.e.

1. They are insoluble in water but soluble in organic solvents such as benzene, ether and chloroform.
2. They are less dense than water.
3. The boiling point increases with increase in molecular weight i.e., increase in the number of carbon atoms.

Alkynes

The physical properties of the alkynes are essentially the same as those of the alkanes and alkenes.

The Concept of Saturated and Unsaturated Hydrocarbons

Explain the concept of saturated and unsaturated hydrocarbons

Hydrocarbons are classified into two distinct categories: saturated and unsaturated. Saturated hydrocarbons contain only one carbon-carbon single bond. Unsaturated hydrocarbons contain at

least one carbon-carbon double or triple bond. The unsaturated hydrocarbons are more reactive and they contain fewer hydrogen atoms bonded to the carbon atoms than saturated hydrocarbons.

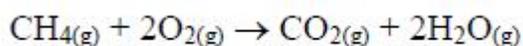
The Chemical Properties of Alkanes, Alkenes and Alkynes

Compare the chemical properties of alkanes, alkenes and alkynes

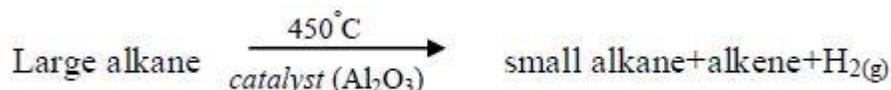
Alkanes

Alkanes are not as reactive as other hydrocarbons. However, they exhibit the following chemical properties:

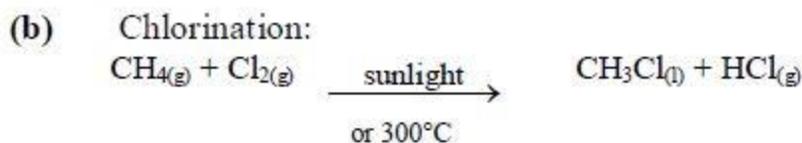
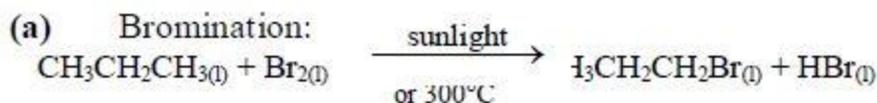
Combustion: alkanes burn in a sufficient amount of air to form carbon dioxide and steam.



Cracking: this is a process in which large alkanes are broken down into smaller hydrocarbons.



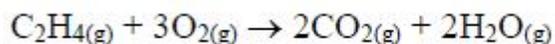
Halogenation: under special conditions (sunlight or 300°C), halogens react with alkanes in a substitution reaction. A substitution reaction is a reaction in which one atom or group of atoms replaces another.



Alkenes

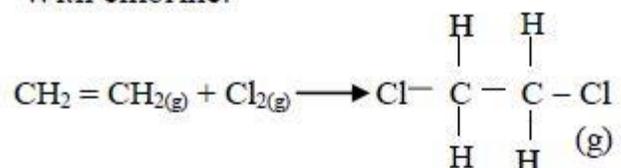
Alkenes are much more reactive than alkanes. This is because the double bond can break to form single bonds and add on other atoms. Because the double bond allows them to add on more atoms, alkenes are said to be unsaturated. The alkanes don't have double bonds and can't add on more atoms, so they are saturated.

Combustion: alkenes burn in sufficient supply of air (explodes) to form carbon dioxide and steam.

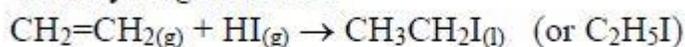


Addition reactions: Alkenes give a number of addition reactions in which two hydrogen atoms (or their equivalent) are taken into combination per molecule to form a single product. The following are some of the addition reactions shown by alkenes:

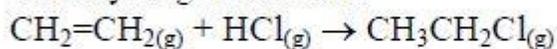
(a) With chlorine:



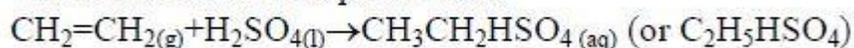
(b) With hydrogen iodide:



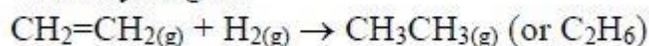
(c) With hydrogen chloride:



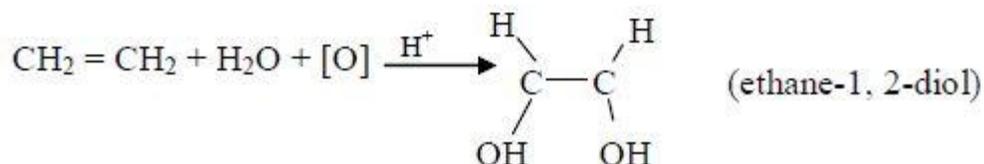
(d) With concentrated sulphuric acid:



(e) With hydrogen:



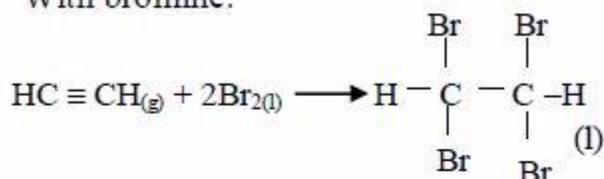
(f) With acidified potassium manganate(VII) (KMnO_4):



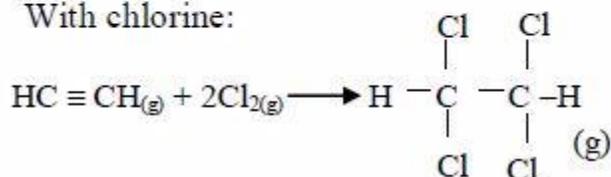
Alkynes

Addition: having carbon-carbon triple bonds, alkynes are unsaturated compounds. They give a number of addition reactions:

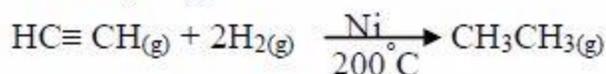
With bromine:



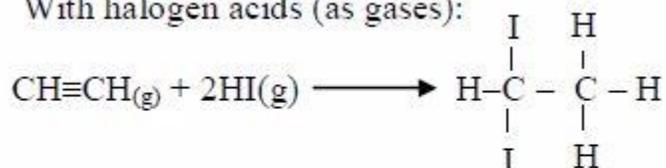
With chlorine:



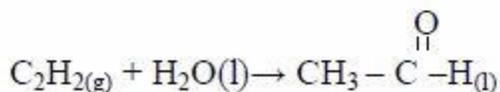
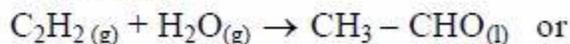
With hydrogen:



With halogen acids (as gases):

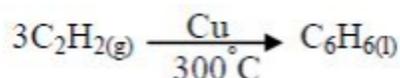


With water:

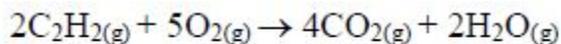


With acidified potassium manganate (VII) solution: At room temperature, with shaking, ethyne quickly decolorizes this solution (i.e. reduces it) with formation of ethanedioic acid

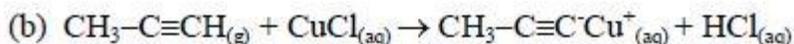
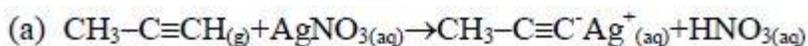
Polymerization



Combustion:



Salt formation:



This is a test for terminal alkynes, i.e. those with $\text{C}\equiv\text{C}$ at the end. For those with $\text{C}\equiv\text{C}$ at the centre, no reactions take place e.g. $\text{CH}_3\text{-CH}_2\text{-C}\equiv\text{C-CH}_2\text{-CH}_3 + \text{AgNO}_3 \rightarrow \text{No reaction!}$

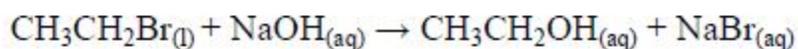
Alcohols

Alcohols form a homologous series of general molecular formula, $\text{C}_n\text{H}_{2n+2}$, where $n = 1, 2, 3$, etc. for successive members of the group. The hydroxyl group, $-\text{OH}$, is the characteristic functional group of the alcohols.

Preparation of Ethanol in the Laboratory

Prepare ethanol in the laboratory

Laboratory preparation of an alcohol involves heating a haloalkane with an aqueous alkali. Ethanol is prepared by heating a mixture of bromoethane and sodium hydroxide solution. The reaction proceeds as follows:

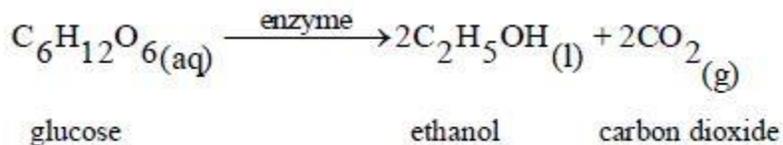


The ethanol, as indicated in the equation will be in solution. It can be isolated by distillation.

Ethanol can also be prepared by fermentation of glucose whereby yeast produces an enzyme called zymase which acts as an organic catalyst to catalyse the degradation of glucose.

For substantial fermentation to take place, a mixture of glucose and yeast is left in a warm place for a considerable length of time.

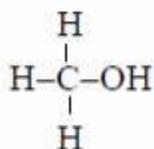
The equation for the reaction taking place is:



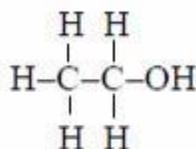
The Homology of Alcohols up to Five Carbon Atoms

Write the homology of alcohols up to five carbon atoms

Alcohols are named as if they are derived from alkanes by the replacement of hydrogen atom by the hydroxyl group (–OH). The lowest two members containing one and two carbon atoms in the molecule, are, respectively, methanol and ethanol. Their structural formulae are shown below:



Methanol



Ethanol

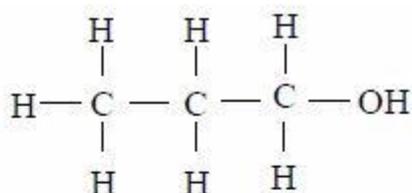
Other members of the series are as shown below:

Number of carbons per molecule (n)	Name	Formula
1	Methanol	CH ₃ OH
2	Ethanol	C ₂ H ₅ OH
3	Propanol	C ₃ H ₇ OH
4	Butanol	C ₄ H ₉ OH
5	Pentanol	C ₅ H ₁₁ OH
6	Hexanol	C ₆ H ₁₃ OH
7	Heptanol	C ₇ H ₁₅ OH

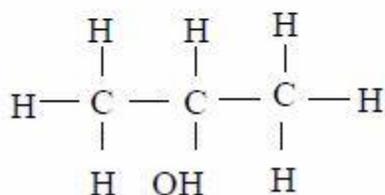
8	Octanol	C ₈ H ₁₇ OH
9	Nonanol	C ₉ H ₁₉ OH
10	Decanol	C ₁₀ H ₂₁ OH

The successive members of the series have molecular formulae which differ by CH₂.

Like other series, alcohols exhibit isomerism. For instance, propanol (C₃H₇OH) can have two different structural formulae as exemplified below:



Propan-1-ol



Propan-2-ol

The first is called propan-1-ol because the –OH group is on the first carbon atom.

The second is called propan-2-ol because the –OH group is on the second carbon atom.

Structure of all Isomers of Saturated Alcohols up to Five Carbon Atoms

Write structure of all isomers of saturated alcohols up to five carbon atoms

Nomenclature of branched alcohols

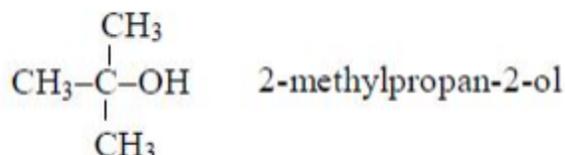
Rules:

1. For branched alcohols, the –OH group is given the lowest number than the alkyl group.

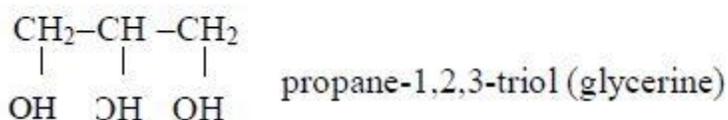
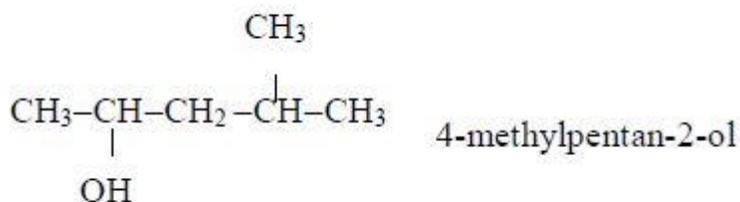
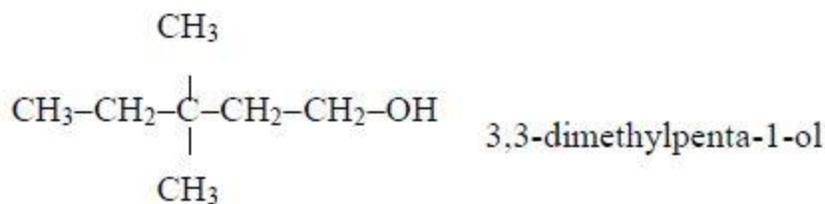
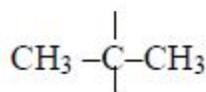
2. The alcohol group ($-\text{OH}$) or the alkyl groups can be attached to different positions of the carbon chain. It is the different positions of these groups that result to the different names of the alcohol.

3. The carbon chain may have several branches of different alkyl groups.

Examples:



Note: Both the methyl ($-\text{CH}_3$) and hydroxyl ($-\text{OH}$) groups are on carbon number 2. The longest unbranched carbon chain is



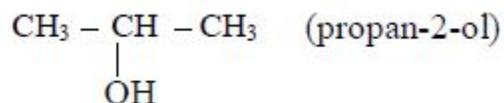
Isomers of Alcohols up to Five Carbon Atoms

Name all isomers of alcohols up to five carbon atoms

Alcohols exhibit chain branching isomerism as with all the other homologous series. In addition, they show an isomerism based on the position of the hydroxyl group (–OH) in the molecule.

Alcohols that have the formula CH_3OH and $\text{CH}_3\text{CH}_2\text{OH}$ have only one possible structure. They do not have isomers. The –OH group in ethanol, $\text{CH}_3\text{CH}_2\text{OH}$, is always on the last carbon atom.

With the formula $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$, however, the –OH group can either be attached to the first or second carbon of the carbon chain to give two isomers namely, $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ (propan-1-ol) and



Isomers of other members in the series are as follows:

Butanol: $\text{C}_4\text{H}_9\text{OH}$ or $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

Isomers:

$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$, butan-1-ol

$\text{CH}_3 - \text{CH}_2 - \underset{\text{OH}}{\text{CH}} - \text{CH}_3$ butan-2-ol

$\underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \text{CH}_2 - \text{OH}$ 2-methylpropan-1-ol

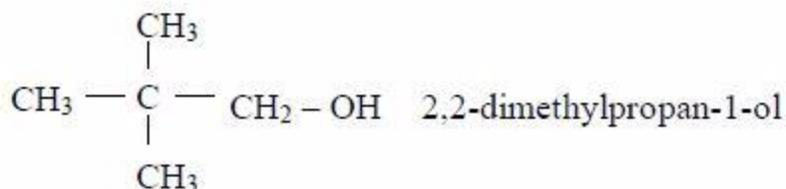
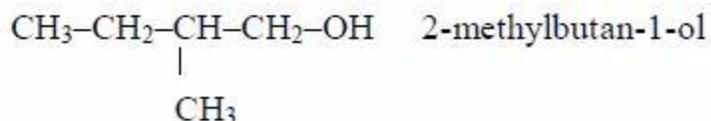
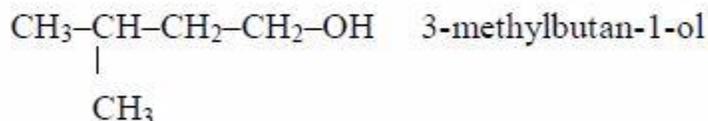
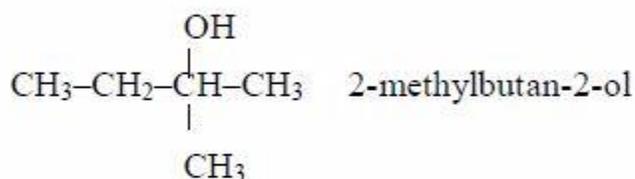
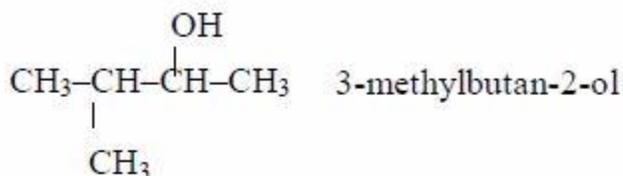
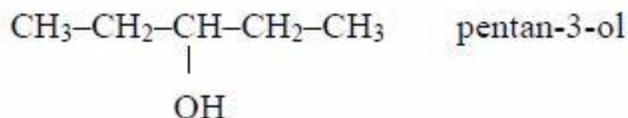
$\begin{array}{c} \text{OH} \\ | \\ \text{CH}_3 - \text{C} - \text{CH}_3 \\ | \\ \text{CH}_3 \end{array}$ 2-methylpropan-2-ol

Pentanol: $\text{C}_5\text{H}_{11}\text{OH}$ or $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$

Its Isomers:

$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ pentan-1-ol

$\text{CH}_3 - \text{CH}_2 - \text{CH}_2 - \underset{\text{OH}}{\text{CH}} - \text{CH}_3$ pentan-2-ol



The Properties of Alcohol

Describe the properties of alcohol

Ethanol is the best known and most important of all alcohols. It has several different uses. Due to its diverse use, its name is used interchangeably with that of “alcohol” as if it represents all other classes of alcohols.

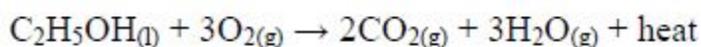
Physical properties of ethanol (alcohol)

1. It is a clear, colourless liquid with a boiling point of 78°C.
2. It is readily soluble in water and it mixes completely with it (miscible).
3. It evaporates very easily when exposed to air (it is a very volatile liquid).

Chemical properties of ethanol

Reaction with oxygen (combustion)

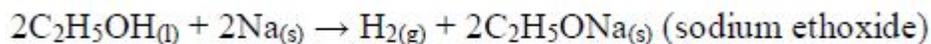
It burns well in oxygen giving carbon dioxide and water, and plenty of heat.



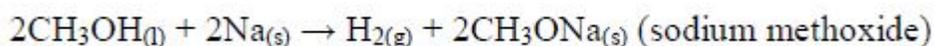
This reaction is the basis of its use as a fuel.

Reaction with sodium metal

Ethanol reacts vigorously with sodium to produce sodium ethoxide and hydrogen. However, the reaction is not as vigorous as the reaction between sodium and water.

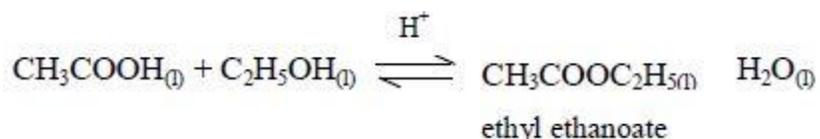


Methanol reacts similarly to produce sodium methoxide and hydrogen:



Reaction with ethanoic acid (esterification)

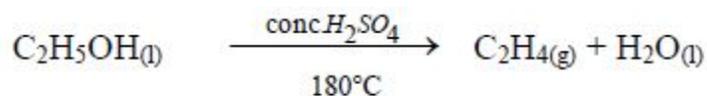
Alcohols react with organic acids to form sweet-smelling oily liquids known as esters.



The symbol, H⁺, indicates that the reaction takes place in acidified conditions. Normally dilute sulphuric acid is added as a catalyst for this esterification reaction.

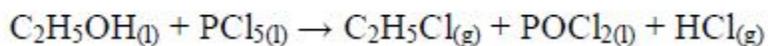
Reaction with concentrated sulphuric acid

Concentrated sulphuric acid dehydrates ethanol to give ethene. The reaction takes place at 180°C.



Reaction with phosphorus pentachloride

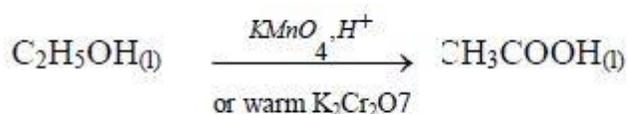
Ethanol reacts vigorously with phosphorus pentachloride to give chloroethane, phosphorus oxychloride and hydrogen chloride.



Hydrogen chloride is evolved as white fumes, and this reaction is used to test for alcohols and other hydroxyl compounds.

Oxidation

Ethanol is oxidized by strong oxidizing agents such as warm acidified potassium dichromate or acidified potassium permanganate to ethanoic acid.



The Uses of Alcohol

Explain the uses of alcohol

Alcohol is used as an alcoholic beverage. Different alcohol drinks contain different amounts of ethanol. Beer and wines contain 8–13% of ethanol. Spirits such as whisky, gin, brandy, rum, etc. contain about 35–40% of ethanol. However, these beverages must only be drunk with moderation as too much consumption of alcohol can lead to health problems.

Ethanol as fuel.

- Ethanol burns with a clear flame, giving out quite a lot of heat. $C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g) + \text{heat}$ On a small scale, ethanol can be used as methylated spirit (ethanol mixed with methanol or other compounds) in spirit lamps and stoves.
- Ethanol produced by fermentation of sugar from sugar cane has been used as an alternative fuel to gasoline (petrol), or mixed with gasoline to produce “gasohol”.

Ethanol as a solvent.

Alcohol is a good solvent, dissolving many compounds that are insoluble in water. The fact that it evaporates easily makes it a good solvent in products like glues, paints, varnishes, deodorants (perfumes), and aftershaves.

It is used in the manufacture of many chemicals

For example, it is used in making sweet-smelling liquids called esters which are used as solvents, in food flavourings, and as fragrance in beauty products (cosmetics).

Ethanol is also used as an ingredient in iodine tincture (a mixture of alcohol and iodine) which is largely used in hospitals for treatment of wounds.

The Harmful Effects of Alcohol

Explain the harmful effects of alcohols

In spite of its widest use as a useful product, ethanol, taken as an alcoholic beverage, has a lot of detrimental health effects. Some of the effects of alcohol are as follows:

1. Even just one drink impairs coordination and judgement. It is a factor among the many causes of road accident as it leads to blurred vision.
2. It leads to lack of muscular control (e.g. drunken stagger) and ultimately to coma, the state in which a person is said to be dead-drunk.
3. Prolonged consumption of too much alcohol causes liver deterioration (cirrhosis of the liver) which can cause liver failure and death. Also heavy drinking eventually damages the muscle tissue of the heart. There may well be some long-term damage to the brain. All these health effects accelerate death.

- Alcohol is a depressive drug and can be addictive. Occasional drinking may lead to alcohol addiction, a condition during which a person is said to be alcoholic. When a drunkard finds him/herself in such a condition it is very difficult to go without drinking. This can eventually lead to poverty as a drunkard spends most of his/her time and money drinking (buzzing).
- Alcohol can make someone aggressive. This accounts for many arrests, conviction and jail sentences.
- Excessive drinking causes depression and other mental disorders.
- It can lead to gastric ulcers, high blood pressure and cancer of the mouth, throat, and gullet. People who smoke as well are at greater risk from these cancers.

Women are at greater risk than men from the harmful effects of alcohol. One reason is that men's bodies have higher water content. So alcohol in their body fluids is more diluted.

Drinking during pregnancy can damage the baby's brain and heart, and slow down its growth so that it is born underweight.

Carboxylic Acids

Carboxylic acids form a homologous series of the general formula $C_nH_{2n+1}COOH$ (or $C_nH_{2n+1}CO_2H$), where $n = 1, 2, 4$, etc. for successive members of the group. All these acids have the characteristic functional (carboxyl) group, $-COOH$, attached to a hydrocarbon chain.

Natural Sources of Organic Acids

Identify natural sources of organic acids

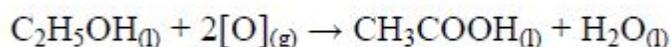
There are various natural sources of organic acids. Some of these sources are:

- milk (lactic acid)
- citrus fruits (citric acid);
- tobacco (nicotinic acid); and
- tea (tartaric acid).

The Oxidation of Ethanol to Ethanoic Acid

Explain the oxidation of ethanol to ethanoic acid

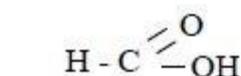
When exposed to open air, ethanol is oxidized (by oxygen of the air) to ethanoic acid. The reaction for the process occurs thus:



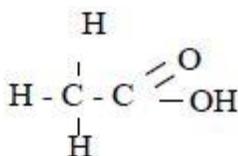
The Structures of the Homologues of Carboxylic Acids up to Five Carbon Atoms

Write the structures of the homologues of carboxylic acids up to five carbon atoms

Carboxylic acids are named as if they are derived from alkanes by the replacement of one hydrogen atom by the $-\text{COOH}$ group. The two lowest members, containing one atom and two carbon atoms respectively, are:



methanoic (formic) acid



ethanoic (acetic) acid

The other members of the homologous series are as shown below:

n	Number of carbon atoms in chain	Formula	Name
0	1	HCOOH	Methanoic acid
1	2	CH_3COOH	Ethanoic acid
2	3	$\text{C}_2\text{H}_5\text{COOH}$	Propanoic acid
3	4	$\text{C}_3\text{H}_7\text{COOH}$	Butanoic acid
4	5	$\text{C}_4\text{H}_9\text{COOH}$	Pentanoic acid
5	6	$\text{C}_5\text{H}_{11}\text{COOH}$	Hexanoic acid
6	7	$\text{C}_6\text{H}_{13}\text{COOH}$	Heptanoic acid
7	8	$\text{C}_7\text{H}_{15}\text{COOH}$	Octanoic acid
8	9	$\text{C}_8\text{H}_{17}\text{COOH}$	Nonanoic acid
9	10	$\text{C}_9\text{H}_{19}\text{COOH}$	Decanoic acid

The successive members of the series have molecular formulae which differ by $-\text{CH}_2$. It is important to remember that every carboxylic acid molecule contains the functional group $-\text{COOH}$ which is called the carboxyl group.

The Isomers of Carboxylic Acids up to Five Carbon Atoms

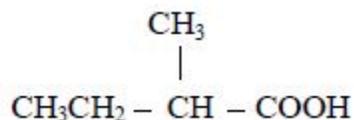
Name the isomers of carboxylic acids up to five carbon atoms

Like other organic compounds, carboxylic acids also exhibit isomerism. Isomers of carboxylic acid are a result of branching of the hydrocarbon end (R) rather than the position of the carboxyl group in a molecule of the carboxylic acid. More isomers of the carboxylic acids can be created by branching the hydrocarbon end in as many different ways as possible.

Rules

The carbon of the carboxyl group ($-\text{COOH}$) is considered as carbon atom number 1.

Identify the positions of the alkyl group(s) attached to the (longest) acid chain. For example, in a molecule,



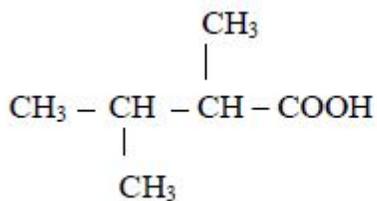
the alkyl group is methyl ($-\text{CH}_3$) and it is attached to carbon number 2.

Name the branched alkyl group, followed by the name of the acid to which the alkyl group is attached. For example, in the case above (rule no.2):

- the alkyl group is methyl;
- it is attached to carbon number and
- the acid to which it is attached is butanoic acid, $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$

Therefore, the name of the compound is 2-methylbutanoic acid.

In case there occurs more than one alkyl groups in the compound the prefixes di(2), tri(3), tetra(4) etc (as it was the case in alkanes) may be used. For, example in the compound



- there are two methyl groups, one attached to carbon number 2 and the other to carbon number 3; and
- they are both attached to butanoic acid chain.

Therefore, the name of the compound is 2,3-dimethylbutanoic acid.

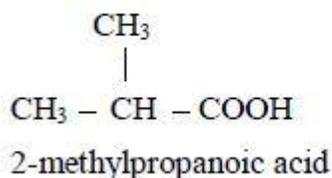
Isomerism and nomenclature

Branching isomerism is found in this homologous series. Isomerism in carboxylic acids begins from butanoic acid, $\text{C}_3\text{H}_7\text{COOH}$. The first three members of the series do not show isomerism because their hydrocarbon ends do not form branches. The following are the structures and names of the isomers of carboxylic acids up to five carbon atoms:

- Butanoic acid, $\text{C}_3\text{H}_7\text{COOH}$ or $\text{C}_3\text{H}_7\text{CO}_2\text{H}$ or $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$

Isomers:

$\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$ butanoic acid



- Pentanoic acid, $\text{C}_4\text{H}_9\text{COOH}$

Isomers

$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{COOH}$ pentanoic acid

$\text{CH}_3 - \text{CH}_2 - \underset{\text{CH}_3}{\text{CH}} - \text{COOH}$ 2-methylbutanoic acid

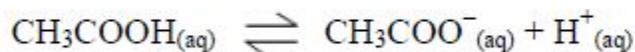
$\text{CH}_3 - \underset{\text{CH}_3}{\text{CH}} - \text{CH}_2 - \text{COOH}$ 3-methylbutanoic acid

$\begin{array}{c} \text{CH}_3 \\ | \\ \text{CH}_3 - \text{C} - \text{COOH} \\ | \\ \text{CH}_3 \end{array}$ 2,2-dimethylpropanoic acid

The Properties of Carboxylic Acids

Explain the properties of carboxylic acids

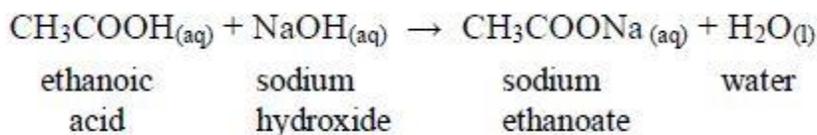
Carboxylic acids are weak acids. They are slightly ionized in dilute solutions.



Like inorganic acids, their solutions contain H^+ ions. The presence of H^+ ions give the solutions acidic behaviour, that is, their solutions affect indicators, just like the inorganic acids do.

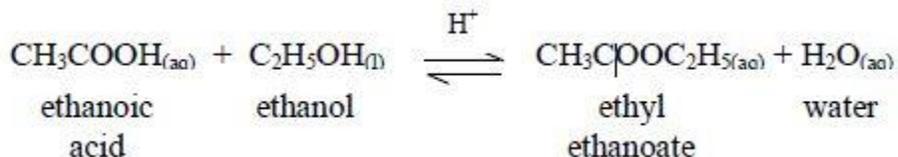
Neutralization

Like inorganic acids, carboxylic acids react with metals, alkalis, carbonates, and hydrogen carbonates to form salts. For example:



Esterification

The reaction between carboxylic acids and alcohols is called esterification. The acids will react reversibly with alcohols to form sweet-smelling esters. Concentrated sulphuric acid is a catalyst for the reaction.

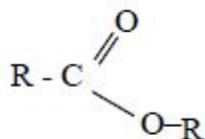


The reaction can be reversed to recover an acid and alcohol again by boiling the products (an ester + water) with a mineral acid (HCl or H₂SO₄) or with an aqueous alkali (KOH or NaOH) as a catalyst.

Esters are manufactured for use as solvents, food flavourings, and fragrance for perfumes and beauty products. Ethyl ethanoate is just one example of many esters. The esters usually have strong and pleasant smells. Many of these compounds occur naturally. They are responsible for the flavours in fruits and for the scents of flowers. Fats and oils are naturally occurring esters used for energy storage in plants and animals. Some of the naturally occurring esters include:

1. vegetable oils e.g. palm oil, groundnut oil, cashewnut oil, olive oil, sunflower oil, etc; and
2. animal fats.

All esters contain the functional group,

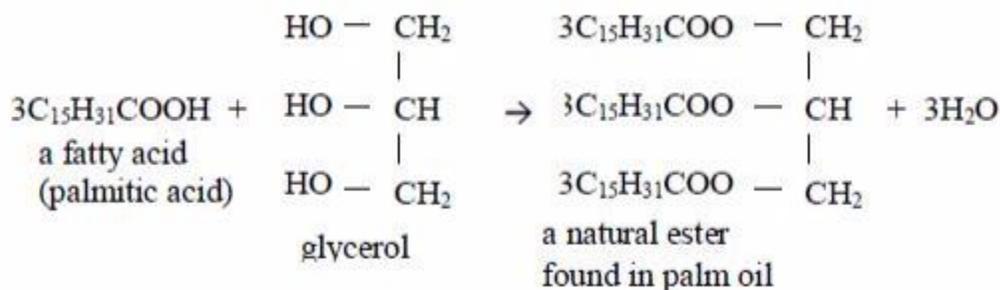


, where R is any alkyl group.

Preparation of Soap from Animal Fats or Vegetable Oil

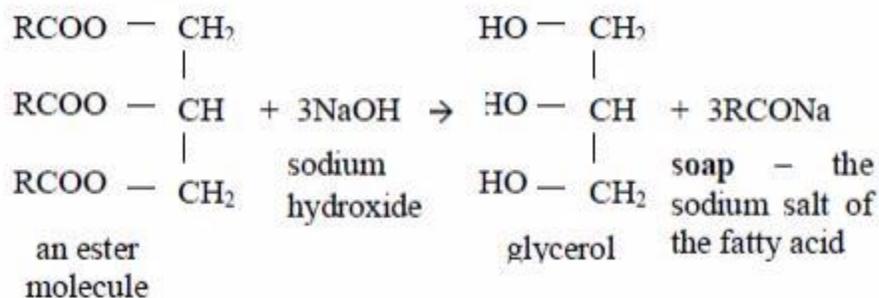
Prepare soap from animal fats or vegetable oil

Vegetable oils are formed from fatty acids and an alcohol called glycerol (also called glycerine). Fatty acids are carboxylic acids with long chains of carbon atoms. They are called “fatty” because the long chains repel water, making them immiscible with water. Glycerol or glycerine (or propane-1,2,3-triol) has three –OH groups. This is how fatty acids and glycerol react:



Preparation of soap from oils

Soap is made by heating animal fats or vegetable oils with sodium hydroxide solution. The oils react with the solution of sodium hydroxide and break down to form glycerol and the sodium salts of their fatty acids. These salts are used as soap. The reaction equation is:



This process is known as saponification. The soap you buy is made from a blend of different oils. When soap dissolves in water it ionizes thus:



The cleansing agent in soap is the ion, RCOO⁻

SOIL CHEMISTRY

SOIL FORMATION

Soil is formed by the process of weathering. All types of weathering (physical, chemical or biological) result to disintegration of rocks into smaller particles. Air and water enter the space between these particles and chemical changes take place, which lead to the production of chemical substances. Bacteria and plant life soon appear. When plants and animals die, they decay and produce humus. Bacteria and other decomposers play a vital role in the decomposition of plant and animal substrata. The end product of these mechanical, chemical and biological processes is soil.

Therefore, soil can be defined as unconsolidated mineral (inorganic) and organic material on the immediate surface of the earth's crust that serves as the medium for plant growth.

All soils contain mineral matter, organic matter, water, air and living organisms, especially bacteria. If any one of these is substantially reduced in amount or is removed from the soil, then the soil deteriorates. There are many types of soil and each has specific characteristics related to the climate, the vegetation and the rock of the region in which it forms. The weathering processes of a region also play an important part in determining soil characteristics. The relationship of these factors is as shown in figure 3.1.

THE FACTORS INFLUENCING SOIL FORMATION

Describe the factors influencing soil formation

Information about soil formation can lead to better soil classification and more accurate interpretation of soil properties. There are several factors responsible for soil formation. The factors include climate, living organisms, relief (topography), parent material and temperature. All the factors, except time, depend to a greater or lesser extent upon each other, upon the soil itself or upon some other factor. None of the factors can be considered more

important than any other, but locally one factor may exert a particular strong influence. These factors are explained in details below.

Parent material

Parent materials are made up of mineral material or organic matter or a mixture of both. The organic matter is usually composed predominantly of unconsolidated, dead and decaying plant remains. The mineral material, which is the most widespread type of parent material, contains a large number of different rock- to form Climate which decays to form results in weathering of influences the type of climate rocks vegetation humus Climate Soil mineral soil Climate forming minerals and can be in either consolidated or unconsolidated state.

Some rocks are more easily weathered than others. Acidic rocks are more resistant to weathering than basic rocks. The parent rock affects soil texture and water permeability.

Parent rock with fine particles is more resistant to chemical weathering than mechanical weathering. Very compact parent rocks like sandstone are very much resistant to weathering. Porous rocks weather easily by chemical processes. This is because they have large surface areas for weathering agents to act upon.

Climate

Climate is the principal factor governing the rate and type of soil formation as well as being the main agent determining the distribution of vegetation. The dead vegetations decay to form humus as one of the components of the soil.

To understand well the influence of climate on soil formation let us have a look at its components and how each of these components affects soil formation.

Temperature

The main effect of temperature on soil is to influence the rate of reactions; for every 10°C rise in temperature, the speed of a chemical reaction increases by a factor of 2 or 3 (twice or thrice). Temperature, therefore, influences the speed of disintegration and decomposition of the parent materials and its consolidation to form the soil.

Rainfall (water)

The water in soils includes all forms of water that enter the soil system and is derived mainly from precipitation as rain. The water entering soils contains appreciable amounts of dissolved carbodioxide, forming a weak carbonic acid. This dilute, weak acid solution is more reactive than pure water. It thus reacts with unconsolidated minerals and organic matter, breaking them down into mineral (clay, sand) and organic debris (humus) respectively.

Organisms

The organisms influencing the development of soils range from microscopic bacteria to large mammals including man. In fact, nearly every organism which lives on the surface of the earth or in the soil affects the development of soils in one way or another. More important soil organisms of interest to soil formation are as follows:

Higher plants.

Higher plants (particularly grasses) extend their roots into the soil and act as binders. So they prevent soil erosion. The roots also assist in binding together small groups of particles hence developing a crumby or granular structure. Large roots are agents of physical weathering as they open and widen cracks in rocks and stones. When plants die they contribute organic matter to the soil, which acts as a binder of the soil particles. Higher plants intercept rain and they shelter the soil from the impact of raindrops. They also shade the soil and hence reduce evaporation.

Vertebrates

Mammals such as moles, ground squirrels and mice burrow deeply into the soil and cause considerable mixing up of the soil, often by bringing up subsoil to the surface, and creating burrows through which the top soil can fall and accumulate within the subsoil.

Microogarnisms

These include bacteria, fungi, actinomycetes, algae and protozoa. These organisms act as decomposers of organic and even mineral matter.

Mesofauna

These include earthworms, nematodes, millipedes, centipedes and many insects, particularly termites and ants. Activities of mesofauna include:

ingesting organic mineral materials e.g. earthworms and millipedes;

transportation of materials e.g. earthworms, millipedes, termites, beetles, etc; and

improvement of soil structure and aeration.

Man

Activities of man are too many and too diverse. Man's roles include:

Cultivation of soils for production of food and tree crops, which in many cases has negative effects causing impoverishment of the soil and erosion.

Indiscriminate grazing, casual burning, cutting of trees, manure and fertilizer use, all of which alter the soil characteristics.

Relief (Topography)

This refers to the outline of the earth's surface. All land surfaces are constantly changing through weathering and erosion. It may take millions of years, in the case of Himalayas and the Andes, to be worn down to flat undulating surfaces. The soils on steep mountain slopes are shallow and often stony and contain many primary minerals. In areas where the difference in elevation between the highest and the lowest point is great, then climatic changes are introduced. These differences in elevation, slope, slope direction, moisture and soil characteristics lead to the formation of a number of interesting soil sequences.

Time

Soil formation is a very slow process requiring thousands and even millions of years. Hence, it is impossible to make definite statements about the various stages in the development of soils. This is because it takes a considerable period of time for a particular soil type to be formed and categorized.

SOIL REACTION

Soil reaction refers to how acidic or alkaline a soil is. It is expressed as a pH value. The soil can be acidic, neutral or alkaline. Extremely acidic soils can have pH values below 4.5 and on the other hand, very alkaline soils can have pH values up to, and even higher than 9.0.

Nearly all soils have pH values between 4 and 8. Soils with $\text{pH} < 4$ generally contain sulphuric (IV) acid, while those with $\text{pH} < 8$ contain a high percentage of Na^+ ions and thus they are alkaline.

pH is defined as the negative logarithm (to base 10) of the hydrogen ion activity (concentration):

$\text{pH} = -\log_{10}[\text{H}^+]$ where $[\text{H}^+]$ denotes the concentration of H^+ ions in grams/litre. This is the same as saying that pH is the logarithm of the reciprocal of $[\text{H}^+]$:

The greater the $[\text{H}^+]$, the lower the pH and the more acidic the soil is. Acidic soils are common in humid regions, particularly the tropics, where rainfall is sufficiently high to leach the exchangeable bases from the top soil. Alkaline soils, on the other hand, are characteristic of the arid regions of the world where, because of low rainfall, there is a high concentration of basic cations (Ca^{2+} , Mg^{2+} , Na^+ , etc) in the surface soil layer. Generally, acidic soils occupy a large area of arable land than alkaline soils do. Because of this, acidic soils are considered to be more important, at the practical level, as compared to alkaline soils.

Causes of soil acidity

Having known that the soil can be acidic and that the acidity is a result of great concentration of H^+ ions in the soil, let us now look at the causes of soil acidity. The causes of soil acidity include the following:

Leaching: Heavy rains may leach bases like Ca^{2+} , Mg^{2+} , K^+ and Na^+ from the soil to the ground water table, leaving a surplus of $\text{H}^+(\text{aq})$ in the soil.

Soil Microorganisms and root respiration produce carbon dioxide which forms weak carbonic acid with the soil solution.

Near industrial regions, acid rain (often pH 2–4) may bring sulphuric (IV) acid and nitric (V) acid to the soil.

Acid mineral fertilizers, like ammonium sulphate (VI) and ammonium chloride make the soil solution more acidic due to oxidation and hydrolysis:

Oxidation:

Hydrolysis:

Also the NH_4OH produced by oxidation and hydrolysis dissociates further to give NH_4^+ and OH^- ions. The NH_4^+ ions produced undergoes microbial and enzymatic oxidation (as show above) to release more H^+ ions to the soil.

5. Nitrification of ammonium ions by bacteria produces $\text{H}^+(\text{aq})$:

6. Organic acids produced during the decomposition of organic matter also contribute to soil acidity. Due to such reasons, most soils in the humid tropics are acidic.

7. The Al^{3+} ions present in soil solution contribute to soil acidity indirectly when they are hydrolysed:

For simplicity and easy understanding, the equation for hydrolysis of Al^{3+} ions is sometimes represented in a single equation as:

8. Small amounts of ions such as NO_3^- , NO_2^- , H_2PO_4^- , SO_4^{2-} and Cl^- present in the soil solution also contribute to soil acidity.

The above causes to soil acidity can be categorized as either natural or artificial. The artificial causes are acid rain and acid mineral fertilizers which are a result of deliberate human actions. The rest of the causes are classified natural because they occur naturally.

The pH of a Given Soil Sample

Measure the pH of a given soil sample

The pH of a soil can be tested by using Soil pH Kit. The kit comprises of equipment and dyes (pigments) that are employed in soil pH determination.

Soil pH kit is simple to use and can be used many times. Colour indicator dye and chart easily helps to find out pH. Knowledge of soil pH is very important to a farmer. Most plants grow well in soils with pH ranging between 5.5 and 7.5.

The following is a quick and accurate way to find soil pH using a soil pH kit:

1. Getting prepared

First collect your equipment

You will need a clean trowel and a clean container for each sample you take. You can use clean boxes, plastic bags, or any convenient container to collect your sample. For powder-based kits you will need distilled water for the test itself.

Decide where to take the samples

Soil pH can vary in different parts of your garden either naturally or through different types and levels of cultivation. You may be able to see clear differences in colour, texture and humus content. Therefore, aim to take a number of samples from different areas and test each one separately.

2. Collecting the soil samples

For each area you are sampling, scrape away the top soil to a depth of about 5 cm. This prevents the reading being affected by any top dressings or mulches you have applied or any accumulation of leaf litter or pine needles.

Now break up the soil to a depth of about 12 cm and take the sample from the bottom level. Collect more than you think you will need as you will be picking out all the lumps, stones, twigs etc. Make sure you label each sample so that you know where they have come from.

3. Sample preparation

- Pick out any stones, roots and twigs and leave the sample to dry.

- Break up the dry sample with the back of a clean teaspoon or the tip of a clean trowel, and place the specified amount in the test tube or test chamber provided.

4. Carry out the pH test

This stage will vary depending on the type of kit you have purchased. Before going any further, it is important to note that soil pH test is purely a qualitative test. In this test, barium sulphate is often used as a reagent.

USE OF BARIUM SULPHATE

Barium sulphate is used in soil testing as a flocculant. It causes the fine soil particles to clump together and sink, leaving a clear test solution. This enables you to make an accurate colour comparison. If you have a clay soil with lots of fine particles you may need to add extra barium sulphate to clear the liquid. This is another advantage of liquid-based tests where the barium sulphate powder is provided separately.

Liquid-based kits

If your kit contains a liquid test solution, you will usually have to add a scoop of the provided barium sulphate powder to the sample followed by the specified amount of test solution. If you

have a clay-based soil it is useful to add extra barium sulphate right at the start. Put the cap on the test tube and shake it well. Leave it to settle for the required time, normally 10 minutes.

Powder-based kits

For kits containing the reagent in powder form you will have to add the specified quantity of powder (this usually contains the appropriate amount of barium sulphate as well as the reagent) followed by the required amount of distilled water. Put the cap on the test tube and shake well to mix. Allow to settle for the specified time, usually around 10 minutes.

5. Read the results

Compare the resulting colour of the solution against the supplied colour chart. Don't leave the solution for much longer than the stated time because the colour may start to change and you won't get an accurate result. Try to do this in good natural light but away from bright sunlight to make an accurate comparison. The following are the results obtained from two soil samples tested: The sample from the West Border (above) is neutral (it is neither acidic nor basic).

The soil sample from the North-east border, however, was found to be acidic, with pH 6.0. The soil contains a lot of organic matter, such as garden compost and rotten manure, which tends to lower soil pH, making it more acidic.

However, both soils fall well within the pH range (5.5 to 7.5) acceptable to most plants so the farmer can just carry on with farming as before. There is no need for soil pH amelioration.

Determination of the soil pH is important because it helps to identify the pH of different soils and hence making the correct decision on different kinds of crops that can be grown on a soil with a particular pH.

Plant growth is affected by the acidity or alkalinity (pH) of the soil. Soils with high peat content, or with minerals such as iron compounds, or with rotting vegetation and lack of oxygen, tend to be acidic. Their pH can reach as low as pH 4. Soils in limestone or chalky areas are alkaline (up

to pH 8.3). Different plants prefer different pH conditions. Farmers and gardeners can test the soil pH to see whether it suits the needs of particular plants. An example of preferred soil pH conditions for different crops is given below:

Crop Preferred pH

Irish potato 4.5 – 6.0

Chicory, parsley 5.0 – 6.5

Carrot, sweet potato 5.5 – 6.5

Cauliflower, garlic, tomato 5.5 – 7.5

Broad bean, onion, cabbage and many others 6.0 – 7.5

Managing the Soil pH by Using Different Liming Materials

Manage the soil pH by using different liming materials

If the soil is strongly acidic ($\text{pH} < 5$), most crops will give only very poor yields if any. In such a soil, the acidic $\text{H}^+(\text{aq})$ and $\text{Al}^{3+}(\text{aq})$ ions prevail while the basic nutrient ions such as Na^+ , Mg^{2+} , Ca^{2+} , etc are not sufficiently available.

In order to raise the pH of such a soil, basic compounds of calcium and magnesium are added and mixed well with the top soil; e.g. the oxides, hydroxides, carbonates and silicates of calcium and magnesium, commonly called agricultural limes. All these compounds have the effect of neutralizing the acidity of the soil. If the soil is too alkaline, it helps to dig

When lime is added to an acidic soil, the liming material usually reacts with the water and/or with the carbonic acid in the soil and dissolves e.g:

All liming materials, directly or after dissolution, react with hydrogen ions (H^+) adsorbed on the soil colloids e.g:

Thus, by liming an acid soil, the percentage base saturation and the pH of the soil is raised and carbon dioxide is produced. The amount of lime needed depends on the pH of the soil, its texture, structure and its content of organic matter.

Overliming, that is, raising the soil pH to above 7.5, is a danger especially in soils of low cation exchange capacity and hence low reserve acidity. It reduces the availability of P, K, Fe, Mn, B and Zn often so much that crops suffer from the deficiencies of these nutrients. Often, crops become stunted and turn yellow. Therefore, overliming must be avoided by all means.

Plant Nutrients in The Soil

The Essential Plant Nutrients

Categorize the essential plant nutrients

MACRO AND MICRONUTRIENTS

Macronutrients are those mineral nutrients that are required by plants in greater amounts. They constitute about 99% of plants' requirements.

Macronutrients, also referred to as major nutrients are further divided into primary and secondary macronutrients. Primary macronutrients are the elements that are required by plants in relatively large quantities (60% of the plant's requirements). They are nitrogen, phosphorus and potassium. The secondary macronutrients are calcium, magnesium and sulphur. These elements contribute the remaining 39% of the plant's needs

Micronutrients, also referred to as trace elements, are those mineral nutrients that are required by plants in smaller amounts. They constitute about 1% of plants' requirements.

Plants use the sugars for energy supply and to produce cellulose (for the cell walls) and starch (for storage). Proteins are made from sugar and nitrogen. They are used to synthesize protoplasm which is vital for the plant cells.

INTAKE OF NUTRIENTS BY PLANTS

Except for some gaseous carbon dioxide, oxygen and sulphur dioxide, all nutrients enter the plants in the form of ions usually from the soil solution through the roots.

The metals are absorbed by the plant roots in the form of their cations. Nitrogen is taken in as ammonium or nitrate (V) ions; phosphorus as dihydrogenphosphate (V) ions; sulphur as sulphate (VI) ions and chlorine as chloride ions.

The nutrient ions move towards the plant roots either with the flow of the soil solution (since the roots also take in water) or by diffusion. The ions diffuse from areas of high concentration to those of low concentration caused by the intake by the roots.

Plant roots either absorb equal numbers of positive and negative charges in the form of ions from the soil solution or they exchange one ion against another one with the same charge, usually H^+ or OH^- . Thus, roots possess electrical charges on their surfaces which can hold and exchange ions.

The Functions of Each of the Primary Macronutrients in Plant Growth

Explain the functions of each of the primary macronutrients in plant growth

AVAILABILITY, FUNCTION AND DEFICIENCY OF PLANT NUTRIENTS

All essential plant nutrients perform specific functions to aid plant growth or reproduction. They must all be available in the right proportion to facilitate optimum plant growth.

Carbon, Hydrogen and Oxygen

Availability: carbon and oxygen are taken in by plants through the stomata in the form of carbon dioxide from the air. Thus, they are never in scarce supply. Hydrogen (and oxygen) is supplied by water

Use in the plant: in the presence of sunlight, the green parts of the plant synthesize carbohydrates (sugars) from carbon dioxide and water.

Deficiency symptoms: plants wilt and die if they do not obtain sufficient water.

Nitrogen

Availability: only ammonium and nitrate (V) ions are available to plants. Usually about 98% of a soil's nitrogen is available (in organic matter). Organic matter decomposes by microbial action to form NH_4^+ . This process is called ammonification. Almost any microbe can carry out ammonification.

There is another process called nitrification, which is carried out only by a few specific bacteria e.g. nitrosomonas. Nitrosomonas bacteria oxidize ammonium ions to nitrate (V) ions:

A few living organisms can fix nitrogen from the air. The best known are rhizobia (legume bacteria) and the free living bacteria such as azotobacter and clostridium, also the blue-green algae.

Plant needs: plants need more nitrogen than any other nutrient. However, their needs vary greatly: plants with high vegetative growth (stems, leaves, etc) have high N needs (maize, sorghum, rice, sugar cane, pasture grasses, most vegetables). Root crops (cassava, sweet potatoes, taro) have lower N needs. Legumes (alfalfa, desmodium, kudzu, all types of beans and peas, ground nuts, etc) may not need N fertilization if the proper strain of rhizobia is fixing N for them.

Use in the plant

It is used to build amino acids, nucleic acids, many enzymes, chlorophyll, generally speaking: all proteins.

It promotes the vegetative growth in plants. It is therefore important in the growth of plants in which leaves are harvested, such tobacco and vegetables.

It is an essential element in cell division. It is therefore needed for plant growth.

It increases grain size and protein content in cereals.

It promotes root growth.

Deficiency symptoms: leaves turn yellow and finally die, because chlorophyll can not be build up. Then due to lack of chlorophyll the plant grows slowly, because the chlorophyll is needed for carbohydrate production. The shortage of chlorophyll is called chlorosis.

Excess nitrogen: excess nitrogen causes dark green succulent vegetation with weak stems, often at the expense of seed or fruit production, e.g. in grain crops, in tomatoes and beans.

It causes the potatoes to be watery. It delays crop maturity, and makes plants more vulnerable to attack by diseases and pests. Thus, fertilizers must be carefully dosed.

Available N is easily leached since NH_4^+ is rapidly nitrified in a warm climate, and NO_3^- is not adsorbed by soil colloids. Thus, it is important to apply fertilizer at the right time in order to avoid leaching.

Phosphorus

Availability: only H_2PO_4^- and to a lesser extent HPO_4^{2-} are available to plants.

Plant needs: plants need less phosphorus than nitrogen or potassium.

Use in plant

Phosphorus is an essential component of the genetic material of the cell nucleus (RNA, DNA); also in ADP and ATP, which play a vital role in photosynthesis, amino acid and fat metabolism, etc.

It increases the grain yield e.g. of millet, sorghum and rice because it promotes the formation of tillers.

It promotes root growth.

It strengthens the resistance of plants to diseases.

Also rhizobia bacteria need it in order to fix nitrogen from the air.

It hastens plant maturity.

Deficiency symptoms

Dark green colouration

Purple spots or streaks.

Stunting, delayed maturity.

Fertilizers: superphosphates, triple phosphates, ammonium phosphates.

Potassium

Availability: only the K^+ ions of the soil solution are available to plants. Hydrated potassium ions attached to soil colloids are readily available because they are not bonded strongly to the surface of the colloids.

After nitrogen, potassium is the second-most element needed by plants. Starch and sugar crops (cassava, sweet potatoes, banana, sugarcane) have relatively high needs of K.

Use in plants. Potassium is present in plants in the form of its ions only. It does not form any integral part of the structure of any known organic compounds in plants.

Potassium is an activator of a number of enzymes involved in amino acid synthesis and several enzymes concerned with carbohydrate and nucleic acid metabolism.

Potassium aids in the uptake of other nutrients and in their movements within the plant e.g. potassium ions and nitrate (NO_3^-) ions may move together.

Potassium is also important in the metabolism of carbohydrates and translocation of food. Thus, it promotes starch and sugar formation.

It regulates osmosis in cells, improves tissue formation and assists in protein synthesis.

It strengthens plant stalk, hence preventing lodging and microbial attack.

Deficiency symptoms.

Stunting: First the edges of the older leaves and then areas between veins turn yellow and finally brown. Small, brown necrotic spots develop while the veins are still green.

Leaf curling and premature leaf fall.

Fertilizers: potassium chloride, potassium sulphate, potassium nitrate. Wood ashes and their aqueous extract (potash) contain potassium carbonate. Tobacco stems contain about 5% potassium, and cocoa shell meal about 3%.

Calcium

Availability: only Ca^{2+} ions in the soil solution are available to plants. Calcium comes from CaCO_3 (calcite), gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$), apatite and other minerals.

Use in plants.

Calcium is a constituent of cell walls and hence makes the straw stiff and resistant to lodging.

It is essential for cell division.

It promotes early root and seed development.

It regulates the intake of potassium by plants.

It neutralizes harmful organic acids like ethanedioic (oxalic) acid in plants, thus detoxifying them:

Magnesium

Availability: plants take in $\text{Mg}^{2+}(\text{aq})$ through roots and leaves.

Use in plant;

Magnesium is vital to the production of chlorophyll, because every molecule of chlorophyll contains a magnesium ion at the core of its complex structure. Most of the magnesium in plants is found in either chlorophyll or seeds. A lesser part is distributed in other parts.

Aids in the translocation of carbohydrates.

Regulates the uptake of other nutrients.

Part of the distributed magnesium functions in the enzyme system involved in carbohydrate metabolism.

Fertilizers: Mostly dolomitic limestone ($\text{CaCO}_3 \cdot \text{MgCO}_3$). The principal magnesium fertilizer is magnesium sulphate (VI), sometimes known as epsom salt. It is soluble in water and can be sprayed onto the leaves.

Sulphur

Availability: Plants take in sulphate (VI) ions (SO_4^{2-}) from the soil solution and sulphur dioxide from the air.

Its Use in plants.

Sulphur is a vital part of plant proteins since cystine and methionine are sulphur-containing amino acids.

Sulphur is also essential for the action of enzymes involved in nitrate (V) production.

The Deficiency symptoms,

Sulphur deficiency symptoms resemble nitrogen deficiency symptoms because both are related to protein and chlorophyll deficiency.

Fertilizers: gypsum and elemental sulphur, both of which are also used to lower soil pH; ammonium sulphate, superphosphate potassium sulphate (VI).

Iron

Occurrence: In igneous rocks, iron occurs in the Fe^{2+} form. The iron in water-logged soils tends to remain in this form and contributes to the bluish-grey colours that indicate wetness. Much of the iron in well drained soils is in the Fe^{3+} form and is associated with humus and mineral particles.

Availability: Plants absorb iron in the form of Fe^{2+} and Fe^{3+} .

Use in plants;

Iron is an essential catalyst in the formation of chlorophyll and functions in some of the enzymes of the respiratory system. Iron is needed in larger quantity than all other micronutrients.

Its Deficiency symptoms,

An iron deficiency results in the young leaves being small and pale green or yellow in colour.

Fertilizers: Iron (II) sulphate (FeSO_4) which is soluble in water. Application of iron is generally ineffective to calcareous soils.

THE OTHER MICRONUTRIENTS

Availability: Micronutrients are taken in by plants as Bo_2^- , Co_2^+ , Cu_2^+ , Mn_2^+ , MoO_2^- and Zn_2^+ . The micronutrients in the soil usually originate from the parent material of the soil. Plant needs of these micronutrients are very small.

Use in plants: Most micronutrients are used as catalysts in plant metabolism:

Manganese is a catalyst in the formation of chlorophyll and in many redox reactions, e.g. metabolism of nitrogen, iron, copper, zinc and in vitamin C synthesis.

Boron aids protein synthesis, regulates the K:Ca ratio in plant tissues and is required for the formation of roots and fruits.

Copper is involved in respiration and in the nitrogen and iron metabolism.

Molybdenum is essential in the protein synthesis and for the nitrogen fixation by rhizobia on the roots of legumes.

Zinc catalyses the formation of growth hormones and promotes the synthesis of RNA and chloroplasts. Thus it is essential for normal growth.

Chlorine seems to be essential in photosynthesis and is required for plant growth.

Cobalt is essential for nitrogen fixation by rhizobia and hence aids growth of legumes. However, it is not clear whether it is essential for growth of higher plants.

Fertilization: Large amounts of micronutrients are usually toxic to plants. The best method of application is usually foliar spraying.

PREPARATION OF PLANT NUTRIENT CULTURES IN THE LABORATORY

Prepare plant nutrient cultures in the laboratory

Nutrient cultures are prepared in the laboratory by using chemicals such as CaSO_4 , $\text{Ca}_3(\text{PO}_4)_2$, MgSO_4 and KNO_3 . These salts are dissolved in water to make cultures containing ions of plant mineral elements. Different cultures lacking some mineral nutrients are made and used to grow plants. The health of plants in various cultures is compared with those grown in a culture with all elements.

MANAGING THE LOSS OF PLANT NUTRIENTS FROM THE SOIL

Manage the loss of plant nutrients from the soil

Crop plants take up nutrients from the soil continuously. To maintain the soil fertility, the nutrients taken by plants must be replenished (replaced). There are several methods that when combined at least in some aspects can help raise or maintain soil fertility. These are:

ADDITION OF INORGANIC FERTILIZERS AND MANURE

Inorganic (industrial) fertilizers

Fertilizers are mostly inorganic compounds which contain one or more plant nutrients in a concentrated form. They help to increase or maintain fertility if used carefully with a good background of knowledge. However, if used without proper knowledge or advice by agricultural officers they can be harmful to the soil, crops, animals and humans.

It should also be noted that without reasonable humus content, the soil may have such a low cation exchange capacity that most of the applied fertilizer is leached from the soil instead of being available to plants.

Thus, just adding fertilizer on a field without good cropping system and, advisably, with addition of manure is often a waste of money, time and energy.

ORGANIC FERTILIZERS (MANURES)

There are different kinds of manures that can be applied to the soil. These include:

biogas manure - from biogas plants-

farm yard manure - from wastes of farm animals such as cattle, sheep, goats, poultry, pigs, donkeys, etc;-

compost manure – from decomposed organic matter; and-

leguminous green manures, like sunhemp, beans, cowpeas, groundnuts, peas, etc. These young plant materials when ploughed and incorporated into the soil provide organic matter and nitrogen.

PREVENTION OF SOIL EROSION

Most plant nutrients are concentrated on the top soil. If this soil is eroded the nutrients are lost too. This can be stopped by taking soil conservation measures which include mulching terracing/ridging, deep tillage, contour ploughing, strip cropping, planting shelter belts or windbreaks, reforestation, avoiding overgrazing and overstocking, etc.

Crop rotation

This refers to the practice of planting different crops in a field in successive growing seasons. A good crop rotation is that which include leguminous crops (which fix nitrogen in the soil) followed by non-leguminous crops and vice-versa.

Intercropping

Intercropping refers to the act of planting two different crops (preferably legumes with non-legumes) on the same field. Legumes provide nitrogen to non-legumes and the non-legumes help to cover the soil to prevent erosion.

Agroforestry

This refers to mixed cropping of e.g. cereals and usually leguminous trees like *Leucaena leucocephala*, which provide nitrogen to the field. The trees take up nutrients from the deeper

layers of the soil while the cereals take up their nutrients from the top layers. Leguminous trees provide the cereals with the humus when their leaves fall and rot on the soil. They also provide forage for animals, and firewood. Agroforestry is also one of the protections against soil erosion.

Good harvesting practices

Crop remnants harvest should not be burnt down but they must be ploughed and incorporated into the soil. This will help to maintain adequate levels of organic matter in the soil and hence reduce soil erosion. Also by burning crop residues, valuable plant nutrients (N, P and S) are lost and the chance to increase humus level of the soil is reduced.

Prevention of leaching

Leaching refers to loss of plant nutrients from the top to the bottom soil layers, following heavy rains or overirrigation. This can partly be stopped or reduced by maintaining adequate levels of soil organic matter to trap the nutrients and also by avoiding too much irrigation. It can also be stopped by avoiding overcultivation, a fact which makes the soil too loose that the nutrients are easily percolated with the soil solution to the bottom soil layers making these nutrients unavailable to plants.

Following /bush fallow

This refers to leaving the land idle to rest, a fact which allows the land time to regain its lost fertility. However this practice is only possible for farmers with plenty of land. It was an equally good practice in the past when human population was low as compared to vastness of the land at that time. It is not widely practiced today except in areas with low population density and abundant arable land.

Soil conservation

Taking soil conservation measures such as terracing, contour ploughing, mulching, deep tillage, etc. will help maintain soil fertility.

Cultivation of the appropriate crops for the soil

Different crops are suited to different soil types. If you plant crops in a wrong soil you are likely to weaken that soil and destroy its fertility status. But if appropriate crops are planted in the right soil type, chances of maintaining or sustaining the fertility of that soil is also very high.

Good farming practices

Adoption of appropriate soil amendment practice such as liming, acidification, conversion, etc helps to maintain soil fertility. For example, liming is good as it corrects soil acidity but if too much lime (overliming) is applied it results to another problem of setting on soil alkalinity. Likewise, an acid soil, no matter how much beneficial nutrients it contains, is of no use unless its acidity is corrected

Avoidance and/or control of soil pollution

Avoid dependence and overuse of agrochemicals such as pesticides, herbicides and inorganic fertilizers unnecessarily. These chemicals must be used with care and only where agricultural production is impossible without their application. This is because they contribute a great deal to soil pollution and toxification of beneficial soil organisms.

Nutrient balance maintenance

The balance of nutrients in the soil must always be maintained. Plants usually require specific quantities of different nutrient elements. These nutrients must be maintained in the soil by good cropping systems, application of appropriate fertilizers and manure and adopting good soil management practices.

Manures and Fertilizers

Fertilizer refers to any natural/manufactured/synthetic materials that contain at least 5% or more of one or more of the primary plant nutrients/element (N, P or K). Examples of fertilizers include ammonium nitrate, sulphate of ammonia, CAN, NPK, etc.

Manure refers to any fertilizer material, from plant or animal bodies or wastes. Examples of manures include farm yard manure (from domesticated animal wastes), green manure (from young green leguminous plants), and heap and compost manure (from decomposed plants).

Manures are sometimes called organic fertilizers.

PREPARATION OF HEAP AND PIT COMPOST MANURE

Prepare heap and pit compost manure

Steps:

Dig compost pit;

Place dry plant materials. Sprinkle enough water;

The next layer will be composed of green plant materials or any refuse

Top this with a mixture of animal manure, soil, and ash;

Repeat steps 2-4 until the pile reaches a height of 1 m;

Cover the pit with broad-leaved plants;

Turn the pile every two weeks. The compost is ready after 3-4 months.

THE ADVANTAGES AND DISADVANTAGES OF NATURAL MANURES

Explain the advantages and disadvantages of natural manures

Manures have got several advantages and disadvantages. Some of these are explained below:

ADVANTAGES

They add nutrients to the soil and at the same time improve soil physical properties such as soil colour, soil structure and water holding capacity of the soil. A soil with good content of organic matter (supplied by manure) holds water and dissolved nutrients efficiently making them available to crop plants.

Manures supply humus to soil which, in turn, increases the cation exchange capacity of the soil. Humus accounts for 30–90% of the cation exchange capacity of mineral soils. And because of its high cation exchange capacity, humus helps to store nutrient cations, especially ammonium ions, thus reducing the leaching of these nutrients from the soil.

Manures improve the proliferation of the soil macro- and microorganisms by supplying the nutrients and conducive conditions needed by these organisms for survival. These organisms play a vital role in soil fertility and plant nutrition by decomposing organic matter which releases nutrients to the

Manures provide organic matter which acts as the binding materials for soil particles, making them more compact and hence resistant to the impact of rain drops and surface run off of water. Thus, it reduces soil erosion.

Manures can remain in the soil for a long time and they can provide the nutrients to crops for several growing seasons. Its nutrients are released slowly over a long period of time

They do not change the soil pH greatly as the inorganic fertilizers do.

Humus from organic matter is dark in colour and imparts this black colouration to the soil. Black colour absorbs more heat and hence helps to regulate soil temperature.

DISADVANTAGES

Manures contain and provide little nutrients per unit volume and weight. One has to apply tremendous amounts of manure to meet the requirements of plants.

Their bulkiness and volume makes it difficult to store, handle or apply in the field. It requires more space to store or transport and more labour to apply manures in the field.

Some kinds of manures e.g. sludge or industrial and municipal wastes may contain toxic chemicals which can harm humans, animals or soils to which it is applied.

Manures act very slowly in that they release nutrients to the soil at a very slow rate.

If the plant materials used to make manure is infested with plant pests or weed seeds; or infected with diseases, there is a risk of spreading them to the farm.

Manures easily lose nutrients if stored improperly. Under hot conditions, manures produce a lot of heat that leads to loss of nitrogen through vapourization. Soluble nutrients are easily leached

TYPES OF SYNTHETIC FERTILISERS USED IN TANZANIA

Mention types of synthetic fertilisers used in Tanzania

Farmers in different parts of the country use different fertilizers (depending on soil conditions) to improve soil fertility. Examples of fertilizers used by farmers in Tanzania include:

Sulphate of ammonia, $(\text{NH}_4)\text{SO}_4$;

Calcium Ammonium Nitrate, CAN;

NPK;

Superphosphates;

Ammonium chloride, NH_4Cl ;

Urea, $\text{CO}(\text{NH}_2)_2$

Ammonium nitrate, NH_4NO_3 ;

Potassium sulphate, K_2SO_4

Potassium chloride, KCl; etc.

THE CONCEPT OF FERTILISER GRADES AND ANALYSIS

Explain the concept of fertiliser grades and analysis

A fertilizer is any substance containing plant nutrients that is usually added to soil to supplement the required plant nutrients. Chemical fertilizers may be natural or synthetic. Natural inorganic fertilizers would include materials such as Chile saltpetre (NaNO_3), rock phosphate, potassium chloride (KCl), etc. Synthetic fertilizers are manufactured products, such as urea, ammonium sulphate, ammonium phosphate, single superphosphate, etc.

Synthetic fertilizers are available in various grades and analyses. A complete fertilizer has all three primary fertilizer ingredients (N, P and K) as part of its formulation. For example, 14 – 15 – 14 is a complete fertilizer. This fertilizer has 14%N, 15%P and 14%K.

Fertilizers may be classified according to the nutrient elements present. Fertilizers may be:

Single nutrient fertilizer or straight fertilizers: These are fertilizers containing only one of the primary nutrient elements.

Double nutrient fertilizer: These contain two primary nutrient elements.

Complete fertilizers or complex fertilizers: These are materials that contain all three primary elements, N, P and K.

TYPES OF FERTILIZERS

Now let us look at few common fertilizer materials and their grades.

In most of the commercial fertilizers P is expressed as P_2O_5 and K as K_2O . To convert P_2O_5 to P, multiply the value by 0.437 and to convert K_2O to K, multiply the value by 0.830. However, in table 3.1 the nutrient contents are given in elemental form, N, P and K.

The nutrient fertilizer grade indicates that everything in a bag of fertilizer is not plant nutrient. Much of the material in the bag is made up of filler materials. For example, ammonium sulphate contains 20%N. That means, 100 Kg of ammonium sulphate will contain 20 Kg of N and the remaining 80 Kg is sulphate and filler material.

With this background about fertilizer material, we need to calculate the amounts of each nutrient source to meet the fertilizer recommendations. Fertilizer recommendations are expressed in kilograms of nitrogen (N), phosphorus (P) and potassium (K) per hectare. Fertilizers available in the market also contain carrier and filler materials in addition to N, P, or K. Hence, there is need to compute the amount of fertilizer required to supply the recommended rate of nutrients. For example, if 90 Kg of N is recommended for sorghum, we must convert this recommendation to Kg of urea or some other N fertilizer to be applied.

Example 1

A certain soil requires 80 Kg of N per hectare so as to fulfil plant requirements of nitrogen. Calculate, in kilograms, the quantity of ammonium sulphate fertilizer required to meet this demand.

METHODS OF FERTILIZER APPLICATION

Identify methods of fertilizer application

Fertilizers can be applied in several ways. The most important point to remember is to apply them at the proper rate, as overapplication can result in plant damage or death. Follow soil recommendations or manufacturer's directions. Some of the common fertilizer application methods are as follows:

Broadcasting

Broadcasting refers to spreading the fertilizer uniformly over the entire area before planting and then incorporating it into the soil. Application of high rates of the major nutrients namely, nitrogen, potassium and phosphorus is usually carried out by broadcasting with a tractor-mounted fertilizer spreader. This allows a specific amount of fertilizer to be spread over the entire under-tree area or in band along the row.

Monitoring of the application rate for the various fertilizers which are used is important. If calibration is not done properly, the quantity applied may be considerably different to the desired rate.

Soon after spreading, the fertilizer should be covered with the surface soil to a depth of 4 to 6 inches or alternatively watered in. On alkaline soils, prompt incorporation into the soil profile is vital for nitrogenous fertilizers as they are readily lost into the atmosphere (volatilized) in the form of ammonia if left exposed on the soil surface.

Broadcasting is particularly good:

In soils whose fertility status is extremely low;

In closely spaced crops such as rice, wheat, pasture, millet, etc;

If the fertilizer used is in fine particles (granules or powdered); and

If the field is properly prepared and is in good tilth.

Fertigation

Fertigation refers to the application of nutrients through an irrigation system. In this method, liquid fertilizers such as liquid ammonia, nitrogen solutions, phosphoric acids and even complete fertilizers are applied to the soil via irrigation water. The nutrients are spread onto the soil in solution and then carried down with the infiltrating water. It provides a simple and effective way to supply nutrients, particularly nitrogen and potassium. Most trickle, jet, spray and sprinkler systems can be used. Do not attempt fertigation using flood or furrow irrigation as the distribution of nutrients will be uneven and leaching will occur.

Fertigation has the advantage of supplying nutrients to the area of greatest root activity that is, the irrigated part of the root zone. Depending on the irrigation system used, applications of fertilizer may need to be split over several irrigations. This also improves the percentage taken up and utilized by the plant. Frequent applications are easy to apply and there is no soil compaction problem as would be the case with broadcasting with a tractor.

Before injecting a nutrient into an irrigation system ensure that the form being used is suitable. Some nutrients are readily soluble in irrigation water while other nutrients must be specially formulated for fertigation. For example, most forms of phosphorus are not suited to fertigation as they tend to precipitate out and block the small orifices of irrigation emitters.

Foliar sprays/applications

This refers to spraying a dilute nutrient solution directly to the plant leaves. Foliar application is used for the correction of trace element deficiencies. It should not be relied upon to supply the total nitrogen, phosphorus, and potassium needs of plants. Commonly required foliar sprays are zinc and manganese. Foliar application has the benefit of rapid response as the nutrients are taken into the plant quickly. Foliar applications of micronutrients, especially iron, may be beneficial when high soil pH conditions make the iron unavailable to plant roots.

Generally, uptake is enhanced by low pH, thus there is benefit in adjusting the pH of the spray solution to slightly acidic.

Often foliar applications are more effective in correcting trace element deficiencies than soil applications. Trace elements are frequently tied up by unfavourable soil condition so that nutrients applied to the soil are bound before the plant can utilize them while foliar application bypasses this problem. Foliar spray can also be used to alleviate deficiency of major elements. This will provide only temporary relief and should be used only as a quick fix to minimize yield or quality loss due to a sudden deficiency. It is not possible to apply the quantity of the major nutrients that growing plants require by foliar applications. Soil applications should provide over 90% of the quantity of each major nutrient.

Banding

Banding refers to placement of fertilizer 2 to 3 inches to each side and below the seed at planting. This technique is risky as placement too close to the seed or at high rate can cause fertilizer burn and inhibit germination.

This method is ideal:

where the amount of fertilizer to apply is limited;

for widely-spaced crops;

when small labour is required ; and

in seedbed preparation.

Side-dressing

Side-dressing refers to placing the fertilizer beside the row during the growing season. This technique is usually used to apply additional nitrogen during the growing season and is particularly useful for applying nitrogen on sandy soils.

Top-dressing

Top-dressing is similar to side-dressing except that the fertilizer is applied around the plant. Care must be taken not to apply the fertilizer too close to the plant as this can cause fertilizer burn.

Starter Solution Application

Starter solution fertilizers are soluble in water and they are usually high in phosphorus. They are applied as liquid around the plant roots at the time of planting. They are primarily used for vegetable transplants to hasten root development and establishment. Follow manufacturer's directions for application rates.

The Advantages and Disadvantages of Artificial Fertilizers as Compared to Natural Manures

Explain the advantages and disadvantages of artificial fertilizers as compared to natural manures

Advantages

They contain more nutrients per unit volume and weight.

They are compact and hence easy to transport, store and apply to the field as compared to manures which are bulky in nature.

They contain specific quantities of plant nutrients per unit volume and weight. So the quantity of a particular nutrient to be applied to the soil can easily be estimated to avoid overapplication. For example the weight of nitrogen in a kilogram of NH_4NO_3 can easily be established and quantified.

They dissolve quickly and hence provide nutrients to plants instantly as they are added to the soil.

DISADVANTAGES

They are used only for one growing season as they are short-lived. Because the uptake of the nutrients in the fertilizer is very high, no or few nutrients would have remained in the soil in the next growing season.

Some acidic mineral fertilizers such as NH_4Cl and $(\text{NH}_4)_2\text{SO}_4$ contribute to soil acidity. When these fertilizers are applied to the soil repeatedly, they can make the soil acidic and hence not fit for plant growth.

Prolonged use of artificial fertilisers may lead to deterioration of the soil structure and poisoning of soil and soil microbes.

Extensive use of fertilizers may cause contamination of drinking water resources, by especially nitrate fertilizers. Nitrates dissolved in water are not removed by normal purification processes. In the body nitrates may be converted into nitrosamines. These are carcinogenic (cancer-causing) compounds

If too much nitrogenous fertilizer is used, serious pollution can occur. One kind of pollution is called eutrophication. Excess of the fertilizer applied finally finds its way to water. This encourages fast growth and huge increase in the number of microscopic, aquatic plants called algae, a phenomenon called algal bloom. Proliferation of algae on the water surface blocks sunlight from reaching the plants beneath the water. These plants can not carry out photosynthesis and, therefore, they die. Bacteria and other decomposers feed on these dead plants and increase in number. These decomposers use up all the oxygen dissolved in the water. Without ample supply of oxygen fish and other organisms living in the water die.

They can scorch (burn) and kill crop plants if not applied under manufacture's directions or even harm humans if not properly handled.

Fertilizers are expensive to purchase and hence not affordable.

SOIL FERTILITY AND PRODUCTIVITY

The Concept of Soil Fertility and Soil Productivity

Explain the concept of soil fertility and soil productivity

Soil fertility

Soil fertility is the ability of the soil to supply the essential nutrient elements in adequate amounts, forms, and proportions for maximum plant growth.

There are three types of soil fertility. These are:

Chemical soil fertility: this is the fertility due to chemical processes that contribute to soil fertility. The chemical soil fertility falls under two categories namely, (i) potential chemical fertility, due to cations in soil solution; and (ii) active chemical fertility, which is due to exchangeable cations adsorbed to the soil colloidal surface or negatively charged plant roots.

Physical soil fertility: the fertility contributed by soil moisture, texture, structure, temperature, etc.

Biological soil fertility: this is due to organic matter content, and soil microorganisms.

SOIL PRODUCTIVITY

Soil productivity is the capacity or ability of a particular soil to sustain plant growth and development. It is measured in terms of yield of a particular crop which is a reflection or consequence of nutrients taken up by plants from the soil. Soil productivity is an interaction of three main factors.

Soil fertility. This refers to the ability of the soil to supply the essential plant nutrients required for maximum plant growth.

Plant factors. These include yield potential, root growth characteristic and genetic make up of a particular crop plant. This means that some crop plants are high-yielding than other plants of the same species and are thus likely to give more crop yields. Also plants with good root development are likely to absorb more nutrients from the soil, grow better and give good yield as compared to plants with poor root development. Genetic make up of a plant also plays a vital role in this respect. For example hybrid maize will always survive harsh soil and environment conditions than local varieties of maize and, therefore, will give high yields.

Environment factors. These factors include climatic factors and agronomic practices. Climatic factors – These are factors such as temperature, precipitation (rainfall), radiation, humidity, altitude, etc. Agronomic practices include weed control, pest and disease control, good soil

preparation, plant population, etc. Yield can be measured in terms of grain yield, tubers yield, dry matter, height of plants, number of leaves, number and size of fruits, berries, etc.

A soil is considered to productive if:

It has adequate water retention capacity;

It is well aerated; and

It is able to supply adequate amounts of the nutrients to plant.

Water retention capacity is influenced by soil organic matter, soil texture (loam, clay, sand, etc), soil structure, and proportions of macro and micro pores in the soil. Aeration is influenced by soil structure and texture.

DIFFERENCE BETWEEN SOIL FERTILITY AND SOIL PRODUCTIVITY

Differentiate soil fertility form soil productivity

We have learned that soil productivity depends on soil fertility in one way or another. However, plant and climatic factors have their roles play too.

From this point of view, therefore, it is correct to assert that a fertile soil is not necessarily productive simply because soil productivity does not rely singly on the fertility of the soil. It depends on several other factors such as soil moisture, which is determined by climate and even altitude, which influences plant development a great deal. In concise, it should be understood that there are several other factors apart from soil fertility which affects the productivity of the soil. Even soil management practices can affect soil productivity to a large extent. Soil fertility is accounted for by the type and quantity of the nutrient elements present in a particular soil which are available to crop plants.

Soil productivity is a measure of the amount of harvest or yield that can be obtained from a given piece of land under certain agronomic conditions and practices. For example, suppose a farmer grows maize on one acre of plot A and manages to harvest 20 bags of maize. On another one-acre plot, plot B, he harvests only 10 bags of maize. Of the two plots, A is said to be more productive than B. This is one among many means for determining soil productivity.

THE FACTORS WHICH DETERMINE FERTILITY AND PRODUCTIVITY OF THE SOIL

Explain the factors which determine fertility and productivity of the soil

A fertile soil provides all essential plant nutrients in amounts and proportions which are suitable for growth of most plants. Soil fertility depends on a number of factors, namely:

THE TEXTURE AND STRUCTURE OF THE SOIL

This affects water and nutrient storage, and aeration. The soil with a fine texture such as clay contains small airspaces. The movement of air in and out of such a soil is thus minimal. However, these soils have a great capability of holding water and nutrients. Its structure can be corrected by addition of organic matter, such as farm yard manure and compost, and heap manure.

On the other hand, soils having a coarse texture such as sand are quite porous. Sand allows water to pass through it very quickly. It is poor at water retention and nutrient storage. It has wide air spaces and thus well aerated. It can also be improved by adding organic manures.

THE DEPTH OF THE SOIL PROFILE

The deeper the soil the better the plant root development and the greater the water and nutrient supply potential it has. Shallow soils do not normally allow roots to penetrate deep through the soil. This leads to poor root development and poor plant growth.

THE MINERAL AND ORGANIC MATTER CONTENT

The chemical composition of the parent material of the soil provides the natural inorganic nutrient supply due to minerals present. A soil formed from the decomposition of limestone will probably contain reasonably high concentrations of Ca^{2+} ions in their exchangeable sites due to inherent Ca^{2+} ions derived from limestone. The same case can apply to high contents of nitrogen and phosphorus in humid soils due to high decomposition of organic matter. The soil organic matter helps to cement the soil particles therefore aiding to create a crumbly structure which is ideal for most agronomic practices.

Cation Exchange Capacity (CEC)

This depends very much on the content of the soil and soil pH. A soil well supplied with organic matter has an optimum cation exchange capacity. The cations adsorbed to the soil colloids are easily exchanged with those in the soil solution. Also humus contains humic (organic) acids which can donate protons if the pH is low.

SOIL PH

This affects nutrient storage and availability. The availability of N, P, K, S, Ca, Mg, and Mo decreases with increase in soil acidity. Below pH 5 and above pH 7, Al^{3+} and Fe^{3+} ions form complexes with soluble phosphates so that the phosphates are no longer available to plants. This is called phosphorus fixation. Below pH 4.8, Al^{3+} becomes so soluble that it appears in high concentrations in the soil solution which are detrimental to most plants. This aluminium toxicity is a problem in some tropical soils.

CLIMATE

The climate affects water availability, temperature, weathering as well as the physical and chemical properties of the soil. In humid tropical climates the rate of weathering and organic matter decomposition is very high. Soils in wet tropical and equatorial regions are well supplied with water because these regions normally receive sufficient rainfall.

The position of the ground water table

Water table position affects drainage. Normally, the lower the water table the wet is the soil. Such soils have a good content of moisture and soil microorganisms. Usually water rises from the bottom to the upper parts of the soil profile by capillarity action. The presence of a water table can be detected by vegetations growing directly above it, which always remain greenish even during the dry spell.

THE CAUSES OF LOSS IN SOIL FERTILITY

Explain the causes of loss in soil fertility

All factors that contribute to loss of nutrients from the soil cause loss in soil fertility. These factors include:

Soil erosion: Most plant nutrients are contained in top and sub soil. It is these nutrients that are available to plants for growth and development. When the top layer of the soil is removed by erosion, the nutrients in it are lost too. Erosion agents tend to clear and transport the soil from its original site to another site far away. By so doing, the nutrient elements that are contained in this soil are also carried together with the soil. This process then leads to loss of nutrients from the soil and hence loss in soil fertility.

Leaching: This refers to the flushing of plant nutrients from the top to the lower layers of the soil and beyond the reach of plant roots. This is caused by heavy rainfall or flood irrigation. The process makes the nutrients unavailable to plants as it washes them far beyond the root zone.

Monoculture: The cultivation of the same type of crop on a piece of land year after year, leads to soil depletion if manures or fertilizers are not added. Different plants have specific needs for particular mineral compounds. If the same type of crop is grown on a similar field continuously over a number of years, then the soil will become deficient of the minerals taken up by that crop.

Denitrification: Denitrifying bacteria convert nitrates of the soil to gaseous nitrogen which escapes to the atmosphere, thus depriving the soil of nitrogen. However, this process is counteracted by another type of beneficial bacteria called nitrifying bacteria, which again convert nitrogen of the air back to soil nitrates by a process called nitrification.

Nutrient uptake by plants: Growing plants absorb nutrients from the soil for growth and development. If the nutrients taken up by plants are not replaced through adding manure or inorganic fertilizers, the soil becomes deficient of these minerals.

Volatilization: This refers to the conversion of ammonium compounds into ammonia gas. Nitrogenous compounds in the soil are decomposed by heat into ammonia gas. Also when nitrogenous fertilizers are added to highly basic soils, they react with sodium hydroxide in the soil to release ammonia gas which simply escapes to the atmosphere.

$$\text{NH}_4^+(\text{aq}) + \text{OH}^-(\text{aq}) \rightarrow \text{NH}_3(\text{g}) + \text{H}_2\text{O}(\text{l})$$

Accumulation of salts: Under normal conditions, rain water washes the mineral salts away, thereby keeping their concentrations in the soil low. However in arid and semi arid regions the salts accumulate in the soil as the rain falling there is irregular and is insufficient to wash

away the salts. This, together with the high evaporation rate and poor drainage, leads to excessive accumulation of salts on or below the soil surface.

Change in soil pH: Use of acidic fertilizers over a long period of time can make the soil acidic. Change in soil pH affects the activity of soil microorganisms and availability of some plant nutrients. This, in turn, affects the fertility of the soil.

Burning of vegetation: Burning crop residues and vegetation deprives the soil microorganisms of the organic matter they require for survival and proliferation. This affects microbial activities such as nitrogen fixation and decomposition of organic matter

The act of burning vegetation also exposes the soil to erosion agents such water and wind. The resulting ash also may cause imbalance of nutrients in the soil or make the soil alkaline.

POLLUTION

Pollution can be defined as the introduction by human (or animal) activities, directly or indirectly, of substances or energy into the environment resulting in harmful effects which may endanger human health and harm living resources and ecosystems.

Concept of Pollution

The Concept of Pollution

Explain the concept of pollution

Pollution can also be defined as the introduction of contaminants or pollutants into the natural environment. The environment comprises of living (biotic) and non-living (abiotic) things such as plants, animals, air, land and water.

Contaminants or pollutants are harmful substances introduced into the environment that disturb the balance of nature. Pollution can be in the form of chemical substances or energy such as noise, heat or light.

Human activities play a major role in the pollution of the environment. Humans engage in a myriad of activities such as agriculture, manufacturing, transport, waste disposal, mining etc. All of these activities contribute to environmental pollution in one way or another.

There are three main types of pollution:

- Terrestrial (land) pollution
- Aquatic (water) pollution
- Aerial (air) pollution

Terrestrial Pollution

The Concept of Terrestrial Pollution

Explain the concept of terrestrial pollution

Terrestrial pollution is the degradation or destruction of the earth's surface and soil, directly or indirectly, as a result of human activities. The human activities refer to any activities performed by man that lessens the quality and or productivity of the land as an ideal resource for agriculture, forestation, construction, etc.

Human Activities which Cause Terrestrial Pollution

Identify human activities which cause terrestrial pollution

The human activities responsible for this kind of pollution include poor agricultural practices, mining, waste dumping and urban waste disposal. Below are some causes of terrestrial pollution.

Agricultural activities

Because of the ever-increasing human population, demand for food has increased rapidly. Farmers often use fertilizers to increase crop production and pesticides to get rid of pests, fungi and bacteria that destroy the crops or harm animals. The overuse of such agrochemicals results in the contamination and poisoning of the soil. Other causes of soil pollution from agricultural activities include:

- poor methods of irrigation which causes the leaching of cations down the soil surface;
- manure heaped on land, which may leach down the soil; and
- oil spillages that seep into the soil.

Mining activities

During mineral extraction, several land spaces are created beneath the soil surface. The underground holes dug during mining causes the land to sag or subside (caving in). This is nothing but the nature's way of filling the spaces left out after mining or extraction activities. This destroys the land and makes it unfit for use.

Mining involves the use of toxic chemicals used for mineral separation. When these chemicals drain into the soil, it gets polluted.

Rain water often leaches harmful substances from the exposed mining waste into the ground. These harmful substances are like heavy metals (e.g. arsenic) and sulphuric acid or chemicals

used in processing the ores (e.g. cyanide. These chemicals are another cause of soil contamination.

Deforestation and soil erosion

Deforestation refers to indiscriminate cutting of trees in search of land for agriculture, settlement, mining, industrialization etc. Trees have got a number of advantages which include attracting rainfall, checking soil erosion and breaking strong winds. The act of cutting down trees carelessly leaves the land bare and hence exposes it to agents of erosion.

Soil erosion causes land pollution. The eroded soil loses its nutrients and organic matter, as well as its ability to hold water. As such, soil erosion can render a fertile land as no longer suited for agriculture, or even turn originally fertile lands into barren deserts.

Other than causing soil erosion, deforestation has also been linked to floods which can, in turn, be seen as another cause of land and water pollution.

Sewage disposal

Sewage refers to a waste, in solution or suspension, carried off in sewers or drains with intention of removing it from the community.

In areas where there are no water bodies into which to dump urban sewage directly, it is dumped into sewage pools that are usually dug far away from residential areas to avoid bad smell emitted by the deposited sewage.

The toxins and poisonous chemicals in the sewage gradually seep down into the ground, thus polluting the land and killing beneficial soil microorganisms.



Figure 4.1 Sewage pools near Morogoro town

Garbage disposal

Tonnes of garbage are produced each year, especially in urban and industrial areas. Garbage is collected and moved to the dumping sites allocated for that purpose.

The garbage in dumping sites comprises of biodegradable and non-biodegradable wastes. The biodegradable wastes are those that can be broken down easily by the action of microorganisms, e.g. bacteria and fungi. The degradable waste matter may include materials such as rotten foods, kitchen wastes etc.

The non-biodegradable wastes are those that cannot be decomposed by microorganisms and thus remain on the ground for a long time. The non-biodegradable wastes are such as plastic, polythene bags, metal, some clothing and glass.

One of the common causes of land pollution in dumping sites is the contamination of the soil with toxic and even hazardous substances. Needless to say, the ability of this soil to support life is significantly affected.

Transfer of toxic wastes

Industries in developed countries produce much toxic wastes, including the deadly, reactive nuclear wastes. However, these countries have very strict laws which prohibit the dumping of such toxic wastes in their countries. The easiest and cheapest alternative is to dump them in the developing third-world countries. This is because of the greedy and selfish leaders in poor countries are easily that agree to sign contracts to allow the disposal of such dangerous wastes on their lands for their own economic gains.

Hazards Caused by Terrestrial Pollution

Identify hazards caused by terrestrial pollution

The extent of terrestrial pollution is often overlooked because its effects are not well evident to most people. However, land pollution has got a number of negative effects to soil, soil organisms, man, plants and animals. The following are some effects of terrestrial pollution:

1. Wastes dumped carelessly can endanger the health of man as well as other organisms. Broken glass, metal and other sharp objects may pierce one's skin and introduce disease germs into the body. Empty cans, glass and plastic containers are potential breeding grounds for mosquitoes which spread malaria and other diseases. Rotten organic matter may harbour many disease germs and they also produce noxious smell when they rot. The rotten wastes also attract flies which transmit a number of enteric diseases like dysentery, cholera, diarrhoea, etc.
2. Land pollution causes chemical contamination to the ecosystem. This occurs when the chemicals in the waste matter poison the soil. Then plants growing on the poisoned soil, animals that eat these plants and even humans are all affected by these chemicals. This process is called biomagnifications and is a serious threat to the ecology. It can lead to the loss of some types of plants and animal life as well as create long-term health problems such as cancer and other deformities in humans. Radiation from nuclear wastes causes healthy problems such as cancers and other deformities.
3. Piles of waste in urban areas keep growing due to increase in waste. When this waste is burned it produces a lot of smoke that leads to air pollution.

4. Soil erosion (as a form of land pollution) leads to loss of land for agriculture, settlement, forest cover, fodder patches for grazing, etc.
5. Land pollution leads to loss of ecosystem and hence directly or indirectly cause change in climatic patterns.
6. Deforestation causes imbalance in the rain cycle. A disturbed rain cycle affects a lot of factors such as reduction in the green cover. Plants help absorb excess carbon dioxide from the air and release oxygen to the atmosphere. This process helps to balance the atmosphere. Without vegetation cover, excessive accumulation of carbon dioxide in the atmosphere causes concerns like global warming, the greenhouse effect, irregular rainfall, and floods among other imbalances.
7. Land pollution damages terrestrial life, especially plants. This greatly affects wildlife and other animal species which are forced to move further away and adapt to new regions or die trying to adjust.
8. Heaps of different wastes from mining activities make the environment unsightly and ugly.
9. Terrestrial pollution is a big problem in urban areas where waste production outweighs waste disposal. In such areas you find poor and blocked sewage system, effluent from domestic toilets flowing on the streets and roads, and dirty water carelessly poured on the ground. This makes life in urban areas uncomfortable and a mere nuisance.

Different Methods of Preventing Terrestrial Pollution

Suggest different methods of preventing terrestrial pollution

The following are some measures that can be taken to prevent and control land pollution:

Recycling and reuse

Recycling is the processing of changing used materials into usable raw materials instead of discarding them as wastes altogether. Scrap metals, plastic bottles and glass should be recycled instead of being dumped into the environment. Packaging materials such as plastic bags, beverage and water bottles can be recycled or re-used for packaging or carrying goods.



Figure 4.2 Used water bottles for recycling or re-use

Using biodegradable materials

Emphasis should be put on manufacturing and using materials that can easily be broken down (biodegradable). For example, paper bags should be manufactured and used instead of plastic (polythene) bags, which are non-biodegradable. Biodegradable plastics have been developed and are used. Some biodegradable plastics include

- biopolymers such as those used in making surgical sutures;
- photodegradable plastics, which break down upon exposure to light; and
- soluble plastics which can be broken down by water

Proper disposal of wastes

Urban waste should only be dumped in allocated dumping sites. These sites must be far away from residential areas to avoid the risk of spreading diseases, pest infestation and a bad smell. The sewage should be properly treated before being drained into dumping pools. Some of the

methods that can be used to curb urban waste problem include incineration and recycling. Paraffin should be poured onto the sewage pools to suffocate and kill mosquito larvae and hence prevent the spread of malaria to residents living in the vicinity of the dumping pools.



Figure 4.3 Waste dumping site

Reducing the use of agrochemicals

Farmers should be advised and encouraged to avoid dependency on agricultural chemicals (fertilizers, herbicides pesticides, etc). All of these chemicals pollute the soil and affect soil microorganisms a great deal. Farmers should use organic manures and chemicals in their agricultural operations. These do not pollute the land or affect crops and animals as compared to artificial chemicals. They help to improve soil structure and hence prevent soil erosion.

Making and enacting environmental laws and policies

The government should make and implement laws and regulations to prevent and control terrestrial pollution. Likewise, local government authorities should make by-laws aiming at curbing the problem of environmental pollution. The laws must clearly state guidelines and procedures to be followed by everybody regarding environment sanitation. These may include:

- discharge and treatment of sewage;
- disposal of lethal nuclear wastes;
- use of agrochemicals in agricultural production;
- use of plastic and related materials;
- disposal of toxic chemicals and solid wastes from industries; and
- careless littering of the environment by irresponsible people.

Creating public awareness

The general public should be educated about the importance of keeping the environment clean and the benefit of living in a clean environment. This knowledge can be conveyed through meetings or via mass media such as television, radio and newspapers. It may also be conveyed via announcements, posters and other social media.

Aquatic Pollution

The Concept of Aquatic Pollution

Explain the concept of aquatic pollution

Aquatic pollution is the introduction of substances that lower the quality of water into water bodies such as oceans, rivers, lakes, aquifers and ground water. This makes the water unsafe for use in homes and industries. Water pollution also affects living organisms (plants and animals) living in water.

Human Activities which Cause Water Pollution

Identify human activities which cause water pollution

There are two broad categories of sources of water pollution namely, point and non-point sources.

A point source is one that delivers harmful substances directly into a water body. An example of a point source of water pollution is a pipe from an industrial facility discharging effluent (liquid waste) directly into a river, lake or sea.

A non-point source of water pollution is a source that delivers pollutants into the water body indirectly through transport or environmental change. An example of a non-point source of water pollution is when fertilizer from a farm field is carried into a stream by rain (surface run off).

The following are some of the major causes of water pollution:

Pesticides

Pesticides that are applied to crops and animals drip onto the soil and may eventually run off into the local streams and rivers. They can also seep down to reach ground water. This contaminates the water and makes it unwholesome for human use and can drastically affect the aquatic and other organisms whose lives depend on that water.

Fertilizer (nutrient pollution)

Many pollutants, including sewage, manure and chemical fertilizers, contain nutrients such as nitrates and phosphates. Nitrates are very soluble. Rain washes or leaches them out of the soil into rivers. In the rivers, excess levels of nutrients (the nitrates) stimulate the growth of aquatic plants and algae. These form a layer on the water surface. A layer of these algae and aquatic plants on the surface of water will prevent light and oxygen from reaching the organisms under the water. As a result, these organisms will begin to die. When the aquatic organisms and the algae die, bacteria feed on the remains. In the process, they use up the oxygen dissolved in the water. Thus, the amount of oxygen in water drops. As a result, fish and other river life die from oxygen starvation, and the river becomes choked and lifeless. This is called **eutrophication**. Water with limited dissolved oxygen supports only a few aquatic organisms. Such areas are called **dead zones**.

Oil spills

Oil spills in oceans and seas cause water pollution and big problems for local wildlife, fishermen and aquatic organisms. Oil spilled onto land is also carried into water bodies by surface run off. This includes drips of oil, fuel and fluid from motor vehicles, oil spilled onto the ground at filling stations; and drips of oil from industrial machinery. These sources and many more combine together to form continual petroleum pollution to all of the world's waters.

Oil spilled by ships, discharge of oily wastes, and drips from motor boats are all significant sources of marine pollution. Drilling and extraction operations for oil and gas can also contaminate coastal waters and ground water.

Mining

Mining causes pollution in a number of ways. They include the following:

1. The mining process exposes heavy metals and sulphur compounds that were previously locked deep in the earth. Rain water leaches these compounds out of the exposed earth, resulting in “acid mine drainage” and heavy metal pollution that can continue long after the mining operations have practically ceased.
2. The action of rain water on piles of mining waste (tailings) transfers pollution to freshwater supplies.
3. In gold mining, cyanide is intentionally poured on piles of mined rock (a leach heap) to chemically extract the gold from the ore. Some of the cyanide ultimately finds its way into nearby water.
4. Huge pools of mining waste slurry (semi-liquid mixture) are often stored behind containment dams. If a dam leaks or bursts, water pollution is likely to take place.
5. Mining companies in developing countries sometimes dump mining waste directly into rivers or other water bodies as a method of disposal.

Sediment

The act of clearing the forests to get ample land for agriculture, settlement or wood leaves the land bare and exposed to the agents of denudation. This accelerates soil erosion and the sediment is free to run into nearby streams, rivers and lakes. The increased amount of sediment running off the land into nearby water bodies seriously affects the fish and other aquatic life. Poor farming practices and cultivation along and close to the rivers, exposes the soil to erosion agents. Soil erosion causes water pollution.

Industrial processes

Most of the water that is used in the production process in industries is eventually discharged into water bodies. This waste water may contain harmful chemicals such as acids, alkalis, salts, toxic chemicals, oil, heavy metals and even harmful bacteria, and other reagents. These substances affect the quality of water and the lives of aquatic organisms.

In some cases, the waste water discharged into a water body may be hot enough to kill any organism living in that water.

Sewage

In developing countries about 90% of untreated sewage is discharged directly into rivers and streams. This renders the water unwholesome for domestic and other uses. Untreated sewage harbours a myriad of disease-causing organisms. This is the reason why diseases such as cholera, dysentery, typhoid and bilharzias are very common among African countries. Leaking septic tanks and other sources of sewage can contaminate ground and stream waters as well.

Marine debris (marine litter)

Marine debris is trash in the ocean. This is litter that ends up in ocean, seas or other large water bodies. The debris mainly comes from urban sewers and garbage thrown overboard from ships and boats.

Examples of marine debris include plastic bags, water bottles, balloons, shoes, lags etc. It can also include items that wash in from the ocean, such as fishing line, ropes, nets and traps, and items from ship such as lost cargo from container ships.



Figure 4.4 Marine debris at Msasani beach in Dar es Salaam

Air pollution

Air pollution contributes substantially to water pollution. Pollutants like mercury, sulphur dioxide, nitrogen oxides, and ammonia can get into the water bodies from the air. This can cause problems like mercury contamination in fish, acidification of lakes and eutrophication (nutrient pollution).

Most of the air pollution that affects water comes from coal-fired power plants, vehicle exhaust fumes, and industrial emissions.

According to a long-term study by the United Nations Environment Programme (UNEP), it has been observed that the earth's oceans have absorbed enough carbon dioxide from the air to cause a slight increase in ocean acidification. Most of the carbon dioxide gas that acidifies the ocean results from human activities (man-made carbon dioxide). It is feared that further carbon dioxide uptake will increase acidification even more and cause the carbonate structure of corals, algae and marine plankton to dissolve. This could have negative impacts on the biological systems of the oceans

Heat

Heat is a water pollutant. Increase in water temperature results in deaths of many aquatic organisms. This is because, as water temperature increases, the amount of oxygen that can dissolve in it also decreases. Therefore, warm and shallow water will contain very little oxygen to an extent that the dissolved gas will not sustain aquatic life.

These increase in temperature is most often caused by discharge of cooling water (which is always hot) by factories and power plants.

Global warming also contributes significantly to heating of the oceans.

Noise

Many marine organisms, including mammals, sea turtles and fish, use sound to communicate, navigate and hunt. Noise from ship engines and sonars has a negative effect on these organisms. Following noise pollution, some species may find it hard to hunt or detect predators. Others may not be able to navigate properly.

The Hazards which are Caused by Water Pollution

Identify the hazards which are caused by water pollution

The following are some of the effects of water pollution:

Waterborne diseases

Human infectious diseases are among the most serious effects of water pollution. Waterborne diseases occur when parasites or other disease-causing microorganisms are transmitted via contaminated water. Water may be contaminated by pathogens originating from excreta. Waterborne diseases include typhoid, diarrhoea, dysentery, cholera, bilharzia and many other diseases caused by bacteria, protozoa and viruses. Contaminated water also spread intestinal parasites such as hook worm, round worm, and ascaris.

Polluted beach water can cause skin rashes, ear aches, pink eye, respiratory infection, hepatitis, diarrhoea, vomiting and stomach ache.

Nutrient pollution

Nutrient pollution stimulates the overgrowths of algae and other aquatic plants. Algae can have direct toxic effects and finally result in oxygen deficiency in water.

Certain species of algae are toxic. Overgrowths of these algae result in harmful algal blooms. These are more colloquially referred to as red tides or brown tides. Zooplankton eat the toxic algae. When fish eat the zooplankton, the toxins are passed to fish. Ultimately, when fish is eaten by seabirds, marine mammals and man, the toxins pass to these organisms. In this way, the toxins pass to the food chain and become part of it.

Blooms of algae and seaweed also reduce water clarity. This makes it hard for marine animals to find food. Algal bloom also blocks the sunlight needed by sea plants, which serve as nurseries for many important fish species.

When the algal overgrowths finally die, bacteria do feed on the remains. In the process, bacteria use up the oxygen dissolved in the water. In some cases, the process takes enough oxygen from the water such that oxygen level in the water falls too low to support normal aquatic life. As a result, fish and other aquatic organisms die from suffocation. The region becomes a coastal dead zone.

Some algae are poisonous to fish and humans. People swimming through these algae or swallowing the water may get rashes, eye irritation, muscle pains, vomiting and diarrhoea.

Excess nitrate in the river may get into drinking water. It increases the risk of blue-baby syndrome. What happens is that bacteria in a feeding bottle or a baby's body convert the nitrate to nitrite. This gets taken up instead oxygen, by the haemoglobin in blood. The baby turns blue and can die.

Nutrient pollution can also trigger unusual outbreaks of fish diseases.

Chemical contamination

Every year many types of chemicals are draining into water. Severe chemical spills and leaks into water bodies kill fish and other aquatic life. Chemical pollution is caused by a number of

toxic chemicals. The following are some categories of water pollution effects due to chemical contamination:

Every year many types of chemicals are draining into water. Severe chemical spills and leaks into water bodies kill fish and other aquatic life. Chemical pollution is caused by a number of toxic chemicals.

The following are some categories of water pollution effects due to chemical contamination:

Pesticides

Pesticides are carried in rain water run off from sources such as farm fields, suburban lawns and home gardens into the nearest rivers and streams.

Pesticides contained in drinking water and in the food chain can result in damage to the nervous system, reproductive and endocrine systems and the liver. It can also damage the DNA and cause various cancers.

Oil spills

Exposure to oil or its constituent chemicals can alter the ecology of aquatic habitats and the physiology of marine organisms.

The oil (or chemical component of the oil) can seep into marsh and sub-tidal sediments and remain there for many years. This negatively affects marsh grasses, marine worms, and other aquatic life forms that live in, on or near the sediment.

Compounds of crude oil, called the polycyclic aromatic hydrocarbons (PAHs), can remain in the marine environment for many years and are toxic to marine life at even low concentrations. Prolonged exposure to PAHs can affect development of marine organisms, increase susceptibility to disease, and distort normal reproductive cycles in many marine species.

Mercury

Mercury gets into water from coal-fired power plants, gold mining and some other industrial processes. In the water, the elemental mercury is converted to methylmercury, $[CH_3Hg]^+$, by certain bacteria. Then this new form of mercury moves up the food chain of fish when small

fishes are eaten by a big fish. In the end, the big fish may be eaten by man and the mercury is passed on to him.

The effects of mercury on humans are many and are already pretty well understood:

- Young children and unborn babies are at a higher risk because their body systems are still developing. Exposure to mercury in unborn babies can cause neurological problems such as slower reflexes, learning deficit, delayed or incomplete mental development, autism, and brain damage.
- Mercury can also cause serious nervous system problems in adults. These problems include Parkinson's disease, multiple sclerosis, and Alzheimer's disease. It can also cause heart disease and damage to the brain.

Industrial chemicals

Chemicals used in industrial processes are being discharged into water bodies daily. Many chemicals can have direct toxic effects on aquatic life. Industrial spills into rivers kill fish for many kilometres downstream.



Figure 4.5 Dead fish killed by toxic chemicals in a river

A new threat from chemicals is the hormone-disturbing character of many chemicals. The effects of hormone-disturbing chemicals include interrupted sexual development, thyroid system disorders, inability to breed, reduced immune response, and abnormal and parenting behaviour.

In humans, endocrine disruptors lead to low immune function, mental impairment, decreased fertility and increase in some types of cancers.

Mining

There is a good number of negative water-pollution effects from mining operations. They include the following:

Acid Mine Drainage (AMD):

This refers to the out flow of acid water from metal mines or coal mines. This is how it is formed: Mining process exposes rocks and soil. When rain or surface water flows over exposed rock and soil, it combines with naturally-occurring sulphur to form sulphuric acid. The acidified water eventually finds its way to streams and ground water. This pollutes the water and affects

the local aquatic life. Some streams are so acidic that they destroy the aquatic ecosystem completely.



Figure 4.6 A stream receiving acid drainage from surface coal mining

Spills and leaks:

Leaks in containment system, cyanide leach heap or breakage in coal-slurry impoundment dam result in pollution of streams, rivers and ground water. This kills fish and poisons drinking water.

Mountaintop Removal Mining (MTR):

In this technique, the tops of coal-rich mountains are removed and the resulting rocks are dumped into nearby valleys. The rocks bury stream habitats altogether. This has catastrophic effect on whatever life forms that live in or around the stream.



Figure 4.7 Mountaintop Removal Mining

Marine debris

Marine debris, also known as marine litter refers to trash in the ocean. Though trash fouls inland waterways too, it seems to be a particular problem in seas and oceans.

The effects of marine debris are many. Marine animals can swallow the trash items mistaking them with food. For example, sea turtles will eat a plastic bag believing it to be a jelly fish. The bag cause intestinal blockage and sometimes death. In some cases, trash can get attached to food and consequently get ingested together with the food. This may harm or even kill the animal that ingests it.

Discarded or lost fishing gear (line, rope, nets) and certain trash items can get wrapped around marine animals' fins or flippers and cause them to drown or injure their fins.

Marine debris can also degrade coral reefs, sea grass beds, and other aquatic habitats. This can interfere with the normal sea life.



Figure 4.8 A turtle trapped in fishing net

Thermal pollution

Discharging the hot water from a power plant into a river could affect aquatic organisms greatly. In fact, industrial thermal pollution is a problem to water bodies.

Aquatic organisms are adapted to a particular temperature range. Even a small increase in temperature can kill the organisms from thermal shock. Also the extra heat may disrupt spawning or kill young fish.

A high temperature warms the water and lowers the amount of oxygen that can dissolve in that water. Insufficient dissolved oxygen forces the aquatic organisms to increase their respiration rates. This increases the aquatic organisms' susceptibility to disease, parasites and the effects of toxic chemicals.

Global warming also causes extra heat to the oceans, leading to similar effects explained above.

Noise pollution

Noise pollution from various ship engines and sonar systems make it difficult for marine organisms like whales, dolphins, and porpoises to communicate, mate, find food and avoid

hazards. Excessive noise pollution may cause damage to marine animals' sound-sensitive organs. This can result to internal bleeding and even death.

Ways of Preventing Water Pollution

Suggest ways of preventing water pollution

We have seen that water pollution poses a great threat to aquatic organisms, humans and the environment. Therefore, something must be done to prevent and control this from happening.

The following are some of the methods that can be employed to prevent and control aquatic pollution:

Reducing nutrient and pesticide pollution

This can be done by adopting good agricultural practices. These include practicing organic farming (farming which does not involve use of artificial chemicals), controlling soil erosion, and reducing or controlling the use of fertilizers and pesticides in agricultural production.

Treating sewage and industrial wastes

Sewage and industrial waste must be treated in order to kill harmful microorganisms and detoxify poisonous chemicals before being discharged into water bodies. This will reduce the hazards that the chemicals and microbes contained in wastes can cause to the environment in general. Sewage treatment plants should be upgraded so that they can filter out chemicals and toxins. Heated up water from industries should be cooled down and detoxified before being release into water bodies or effluent pools.



Figure 4.9 Sewage treatment plant

Stopping deforestation

Forests act as a soil cover which prevents soil erosion. They also help to absorb carbon dioxide from the air, the excess of which causes acid rains. Cutting down trees indiscriminately exposes the soil to erosion agents. Soil erosion produces sediments which pollute water. So the presence of trees prevents water pollution through cutting off deposition of sediments into water and preventing the formation of acid rain.

Controlling coastal development

Infrastructures such as buildings and industries destroy the natural shorelines which serve many purposes like fish nurseries, absorption of hurricane impacts, and filtration of the river water entering the estuary.

Furthermore, most of the waste from these establishments is directed into the nearby water body. So prevention of coastal establishment will prevent this kind of water pollution from taking place.

The government should make and enforce laws that prohibit the establishment of settlements and industries near water bodies. This will help control water pollution and its impacts to the environment.

Reducing pollution from oil spills

Listed below are some of the ways that can be used to control the occurrence and repercussions of oil spills:

- Enforcing the regulations and rules that govern maintenance and inspection of commercial ships and other marine vessels that leak oil and fuel into the water.
- Cleaning oil spills as promptly as they occur.
- Converting oil tankers into double-hull ships. A double-hull ship has two complete layers of watertight hull surface. The outer layer forms the normal hull of the ship. A second inner hull forms a protective barrier to sea water in case the outer hull is damaged and leaks.
- Educating the public how to keep oil out of the environment.

Controlling production of greenhouse gases

Greenhouse gases, particularly carbon dioxide and sulphur dioxide, contribute to water pollution through acid rain (acidification) and an increase in ocean temperature (thermal pollution). This can be reduced by a number of ways which include forestation, reducing emission of greenhouse gases from industries and motor vehicles, and employing good agricultural practices.

Reducing mercury emissions

The use of mercury in many industrial processes is being phased out. However, some industries continue to use mercury on a large scale. Such industries should apply the appropriate technology to prevent mercury from being released into the environment. Where other alternatives exist, the use of mercury should be stopped completely.

Cleaning up existing and abandoned mines

The following are some of the ways through which water pollution by mines can be controlled:

- Mining companies should clean up abandoned mines which continue to release pollutants to the environment.
- New mines should not be established in areas where they are likely to cause water pollution problems.
- Mining practices which cause water pollution should be banned.

Cleaning up chemical pollution

Chemical pollution on land should be stopped. This is because chemicals on land dissolve in surface run off and finally find their way into water bodies. So preventing chemical pollution on land will automatically help keep our water clean.

Aerial Pollution

The Concept of Aerial Pollution

Explain the concept of aerial pollution

Aerial pollution is the introduction of harmful substances into the earth's atmosphere.

Human Activities which Cause Aerial Pollution

Identify human activities which cause aerial pollution

Air pollution can result from both human and natural actions. Natural events that pollute the air include forest fires, volcanic eruptions, wind erosion, pollen dispersal, and evaporation of organic compounds, hot springs, and fumaroles. However, pollution from natural occurrences does not occur very often.

Human activities that cause air pollution include gaseous emissions from industries, burning of fossil fuel (e.g. gas, coal), household and agricultural chemicals, and deforestation.



Figure 4.10 Emission of harmful gases into the atmosphere

The following are the chief causes of air pollution:

Carbon dioxide

Carbon dioxide (CO_2) is one of the main air pollutants. The major man-made sources of carbon dioxide are burning of fossil fuels and deforestation. The act of deforestation removes trees that absorb carbon dioxide and help to reduce the level of carbon dioxide gas in the atmosphere. The natural sources of carbon dioxide include respiration, decay, volcanic eruptions and diffusion out of the oceans.

Carbon monoxide

Carbon monoxide (CO) is formed when fossil fuels burn in too little air (oxygen). However, when the fuels are burnt in a plentiful supply of oxygen, carbon dioxide (CO_2) is produced. Other sources of carbon monoxide include metal processing and chemical manufacturing activities, forest fires, wood burning for heat or cooking and combustion of natural gas.

Ground level ozone (smog)

This is a product of burning fossil fuels. Smog is formed when oxides of nitrogen (NO_x) react with volatile organic compounds (VOCs) in the presence of sunlight. It is formed in heavy traffic in hot weather, when sunlight causes the nitrogen oxides and hydrocarbons from car exhausts to react together.

Sunlight and hot weather are catalysts in the NO_x /VOCs reactions that cause ground-level ozone (smog) to form. Areas with the highest concentration of motor vehicles and industrial emissions tend to have the worst ground-level ozone problems.



Figure 4.11 Smog

Nitrogen oxides

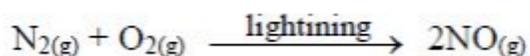
Nitrogen oxides, nicknamed NO_x , are highly reactive gases that contain nitrogen and oxygen in varying molecular combinations. The oxides of nitrogen include nitrogen monoxide (NO), nitrogen dioxide (NO_2) and dinitrogen oxide (N_2O).

Nitrogen oxides form when fuel is burned at high temperatures, such as in automobile engines, coal-fired power plant, or any process that burns fuel. Inside car engines and power station furnaces, the air gets so hot that nitrogen and oxygen react together to form oxides of nitrogen.



Figure 4.12 Exhaust fumes contain oxides of nitrogen

Nitrogen monoxide (NO) is also formed in the atmosphere by lightning where nitrogen and oxygen combine together to form the oxide:



NO_x and the pollutants formed from it can be transported by wind over long distances. Thus, these types of pollution are not confined to areas where they are produced, and controlling them is best done using regional and national plans.

Sulphur compounds

Compounds of sulphur that pollute the air include sulphur dioxide (SO₂), sulphur trioxide (SO₃) and hydrogen sulphide (H₂S). Sulphur dioxide is the most important air pollutant among the compounds of sulphur.

Coal, oil and gas all contain sulphur and sulphur compounds as impurities. When these sulphur-containing fuels are burned sulphur dioxide gas is formed. The gas is also formed during petroleum refinery.

Particulate matter (PM)

Particulate matter comprises of extremely small solid particles and liquid droplets. These are mainly particles of carbon (soot) from burning coal in power stations and petrol in motor engines. The other particles include smoke, nitrates, sulphates, dust particles, and organic chemicals. Exhaust fumes from leaded petrol also contain particles of lead.

Lead

Lead can pollute the air. Lead in air comes mainly from industrial activities like lead smelting, metal processing, lead-acid battery manufacturing, waste incineration and power generation. Lead is also produced from combustion of airplane fuel. Leaded petrol is still used in some developing countries. Wind-blown soil and road dust can also contain naturally-occurring lead as well as lead from other sources.

Chlorofluorocarbons (CFCs)

Chlorofluorocarbons are organic compounds made up of carbon, chlorine and fluorine atoms. CFCs are widely used as refrigerants in refrigerators and air condition systems, solvents in cleaners, blowing agents in the production of foam propellants in aerosol cans, and as fire extinguisher chemicals.

Hazards Caused by Aerial Pollution

Identify hazards caused by aerial pollution

The following are some effects of air pollution.

Health problems

Exposure to air pollutants can cause serious health problems. The level of effects usually depends on the length of time of exposure as well as the kind and concentration of the pollutants.

Short term air pollution can aggravate or complicate medical conditions of individuals with asthma, emphysema, bronchitis, lung and heart diseases, and respiratory allergies. Long-term

health effects can include chronic respiratory diseases, lung cancer, heart diseases, and even damage to the brain, nerves, liver or kidneys.

Inhaling or ingesting lead can damage the brain and peripheral nerves resulting to retardation, behaviour disorders and memory loss. It can also cause high blood pressure, heart diseases, anaemia and reproductive disorders.

Carbon monoxide is poisonous even in small concentrations. It combines with haemoglobin in the blood and stops it from transporting oxygen to the body cells. This can cause harmful health effects by reducing oxygen delivery to the body tissues and vital organs (most notably the heart and the brain). Inhaling high levels of carbon monoxide can cause vision problems, physical or mental impairment, and even death.

Global warming

Global warming is the increase in the average temperature of the earth's atmosphere as a result of the greenhouse effect. Greenhouse gases in the atmosphere allow ultraviolet radiations to pass through them and reach the earth. As the earth's surface gets heated up, some of the heat is radiated back to the atmosphere. A layer of the greenhouse gases in the atmosphere, acting as a blanket, prevents the heat from escaping to the upper atmosphere. This causes excess heat in the air around the earth (atmosphere), a phenomenon called global warming.

Global warming is mainly caused by human activities such as fossil fuel burning and deforestation, which produce green house gases such as carbon dioxide and some oxides of nitrogen (NO_x). Carbon dioxide is one of the greenhouse gases that contribute to global warming. Indeed, carbon dioxide is responsible for over 50% of the global warming.

One member of the NO_x family, nitrogen oxide (N₂O), is also a potent greenhouse gas. The gas contributes to the greenhouse effect.

Global warming may result in melting of the polar ice caps, causing an increase in levels of the ocean water. This may lead to flooding of the coastlands and islands. Other effects include increase in the average temperature of the earth, change in weather patterns, and increased desertification, which would in turn cause reduction of the arable land.

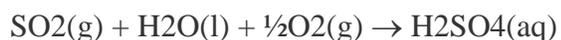
Depletion of the ozone layer

The production and emission of chlorofluorocarbons (CFCs), is the leading cause of ozone layer depletion. CFCs accounts for almost 80% of the total depletion of ozone. Ozone is a triatomic form of oxygen (O₃), found in the earth's atmosphere. When the CFCs reach the stratosphere (a layer of the atmosphere with high concentrations of ozone), they are broken down by the intense sun rays to release chlorine radicals (•Cl). These radicals then react with the ozone molecules splitting them into oxygen atoms and free oxygen molecules. This is how the ozone layer is getting depleted.

Acid rain

Human activities produce harmful gases such as oxides of nitrogen and sulphur which are released into the atmosphere. These gases are responsible for the formation of acid rain.

Sulphur dioxide gas in air dissolves in rain water to form acid rain and other sulphur compounds. Acid rain is formed when the sulphur dioxide dissolves in water vapour from the clouds and combines with oxygen from the atmosphere to form an acid rain.



Sulphur dioxide attacks the lungs, and can affect people with asthma and heart diseases very badly.

Nitrogen monoxide and nitrogen dioxide also play a great part in the formation of acid rain and photochemical smog. Acid rain is formed by the reaction of NO_x, oxygen of the air and water vapour. $4\text{NO}_2(\text{g}) + 2\text{H}_2\text{O}(\text{l}) + \text{O}_2(\text{g}) \rightarrow 4\text{HNO}_3(\text{aq})$

These acidic solutions then fall on the ground in the form of acid rain. Acid rain damages plants and corrodes many ancient buildings, monuments and sculptures made of marble. It greatly affects the aquatic life due to the acidification of lakes and streams.

Eutrophication

Even though most of the nutrient pollution comes from fertilizers and animals wastes that run off from farm fields, deposition of nitrogen from fossil fuel air pollution adds significantly to the problem.

Eutrophication causes algal bloom which prevents the penetration of air and light into a water body. This deprives aquatic life of oxygen and light. When algae die, bacteria act on them. The bacteria use dissolved oxygen in the water, depleting the gas from the water. The depletion of oxygen in the water (hypoxia) causes a reduction and even death of certain fish and other aquatic organisms.



Figure 4.13 Algal bloom

Effect on wildlife

Just like humans, animals also face some devastating effects of air pollution. Toxic chemicals present in air can force wildlife species to move to new places and change their habitat. The toxic pollutants deposited in the water can also affect sea animals.

Reduced visibility (haze)

Smog reduces visibility, making activities such as driving, surveying and flying difficult.

Different Methods of Preventing Air Pollution

Suggest different methods of preventing air pollution

The following are some remedial measures that can be taken to control air pollution:

Emphasis on clean energy sources

Clean energy sources are those which do not produce harmful substances during production and use. They include wind energy, solar energy, hydro electric power, and geothermal energy.

Installation of solar panels for home will help curb air pollution. This will help reduce dependency on fossil fuels, wood and charcoal which produce and emit harmful substance into the atmosphere during use. Also the use of wind energy, hydro electricity and geothermal sources of energy will greatly reduce the generation of air pollutants.



Figure 4.14 Wind mills

Using energy-efficient devices

Use devices that consume less electricity not only help lower electricity bills but also reduce the pollution. The domestic appliances which serve energy include energy-serving bulbs, which can be purchased from local shops.



Figure 4.15 Energy-server bulbs

Using public transport

Use of public mode of transport will reduce the number of motor vehicles on the road, and consequently, the emission of harmful gases by car exhaust system.



Figure 4.16 Public transport

Reducing pollution from fossil fuels

Several steps are being taken to help cut down pollution from fossil fuel, for example:

- the exhaust of new cars are fitted with catalytic converters in which harmful gases are converted to harmless ones;
- manufacturers are looking at ways to make car engines more efficient so that they can use less petrol, and other alternative fuels;
- coal is turned into smokeless fuel for use in homes; and
- scientists are looking at ways to make homes and factories more energy efficient, so that we can burn less fuel, not more.

Use of air pollution control devices

Air pollution control devices should be installed in industrial plants and any other places where air pollutants are produced in tremendous quantities. Most plants include areas for treating effluent (waste liquid) and waste gases before they are released, for example:

limestone: This will neutralize acidic liquids, or the sulphur dioxide in waste gases from burning coal. Gases leaving the power station are passed through limestone, which reacts with the sulphur dioxide to form calcium sulphate. Calcium sulphate is used to make plaster for building industry.

charcoal: This is porous and has a large surface area. It is excellent at absorbing impurities. So it is used for filtering both air and liquids.

scrubbers: The waste gas is sprayed with water to dissolve harmful compound before they reach the chimneys. **incinerators:** Harmful waste gases such as solvent fumes are burned in an incinerator to give harmless products.

ion exchangers: when waste liquid flows through an ion exchanger, harmful ions (such as mercury or cadmium ions) are replaced by harmless ones. Ion exchangers can be designed to remove any ions you wish.

electrostatic precipitators: In these, an electric current is passed through smoke on its way to the chimneys. The dust particles get charged and cling to electrodes. This method is used at cement factories to stop cement dust escaping from kilns. The trapped dust is returned to the cement store.

Law enforcement

Environmental pollution laws which ensure safe disposal of wastes should be enacted and implemented. Policies should be put in place to prohibit any kind of pollution by vehicles and industries. Vehicles which emit a lot of exhaust gases should not be allowed to operate. The owners of a plant which pollutes the environment should be fined or the plant should even be closed down.

The National Environment Management Council (NEMC) has put in place laws and regulations that control careless pollution of the environment. Violators of the environment sanitation laws are fined, sentenced and even stopped from operating.

Safety Measures to Protect Industrial Workers from Gaseous Pollution

Identify safety measures to protect industrial workers from gaseous pollution

People working in industries face serious health risks from harmful gases and chemicals used in industrial processes. These gaseous pollutants cause various health problems to workers, including illness and disorders upon contacting the skin or getting inhaled into the body.

Harmful gases get into the worker's bodies through breathing contaminated air, eating food contaminated with gaseous fumes or via skin contact.

Safety measures should be ensured in order to protect the workers from being affected by the hazardous fumes or other chemicals. The following are some safety measures that should be taken to protect industrial workers from gaseous pollution.

Eliminate or substitute hazardous chemicals

The most effective way of controlling hazards caused by chemicals is to stop using or substitute the hazardous chemicals with the harmless ones. Many industries are now using harmless

chemicals in place of the usual hazardous chemicals in industrial processes and operations so as to safeguard the health of workers.

Examples of substituting for toxic substances are:

- using water-based paints or glues instead of those that are organic solvent based (figure 4.17);
- using water-detergent solutions instead of solvents; and
- using trichloromethane as a degreasing agent instead of trichloroethylene.

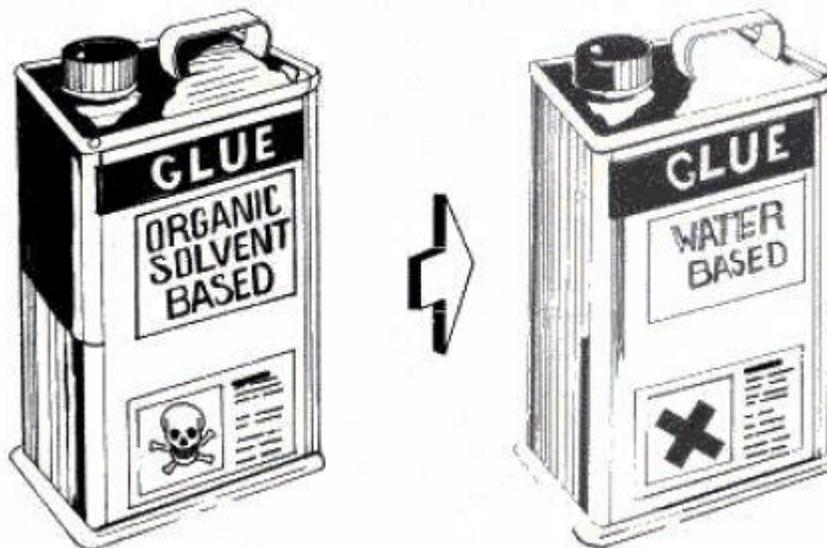


Figure 4.17 Chemical substitution

Shield processes that release harmful substances

The processes that involve the use of hazardous chemicals or release harmful products should be performed in chambers. This will prevent the harmful substances from being released into the environment.

Use of protective gears

Workers should be provided with the necessary protective equipment and be trained on the correct use of each gear. Each worker should put on protective equipment to ensure personal safety at work place. The protective equipment include safety glasses, goggles, earmuffs and plugs, gloves, safety shoes, helmets, aprons, overalls and respirator (which covers the mouth and nose of the worker to prevent the entry of chemicals into the body by inhalation). If possible, workers must take showers at workplace before leaving work to avoid bringing chemicals at home. Dirty clothes should be left at work. If they must be washed at home, washing should be done separately, never with the family wash!



Figure 4.18 An industrial worker

Ventilation

Ventilation means trapping the contaminants (fumes, gases, vapours or mists) released into the air from the process or operation and preventing them from entering the breathing zone of the workers. The trapped contaminants are conveyed by ducts to a collector (cyclone, filter house, scrubbers or electrostatic precipitators) where they are removed before the air is discharged into

the outside environment. This is accomplished by a special exhaust system or by increasing the general ventilation.

Environmental Conservation

The Meaning of Environmental Conservation

Explain the meaning of environmental conservation

Environmental conservation is the protection and preservation of natural resources from destruction, wastage or loss. Thus, conservation of the environment involves the conservation of the natural resources. The natural resources include soil, minerals, water, air, animals and plants.

Importance of conserving the environment

We depend on the environment for our livelihood. It is, therefore, important to conserve the environment for our survival and sustainable development. The following are some of the reasons why environmental conservation is crucial.

Sustenance of life

The environment contains all the resources that sustain human life. These include soil, water, air, animal and plants. Environmental conservation ensures the protection of these resources for the continued sustenance of life on earth.

Protection of animal and plant species

Plants and animals maintain the ecological balance in the ecosystem. Man has been exploiting these resources for quite a long time, to the extent that some plant and animals species are in danger of disappearing from the earth's surface. Human activities which lead to destruction of wildlife include hunting, agriculture, settlement, mining and trade. Environmental conservation aims at protecting plants and animals from destruction.



Figure 4.18 Wildlife

Economic value

Economic activities such as fishing, agriculture, mining and navigation depend on the natural resources. For sustainable economic development, these resources need to be conserved so as make them available in sufficient amounts.

Wildlife conservation makes game and plant resources available for attracting tourists. Tourism earns the country foreign exchange. It also creates employment opportunities to local people who are employed to conserve wildlife resources.

Future generations

Environmental conservation aims at preserving the resources so as to make them available for the upcoming generations.

Beauty/austhecy

The natural resources give the environment beautiful scenery for example, flower are attractive to look at. Forests provide shade and the air around forest is also cold. Thus, environmental conservation initiative helps to preserve this natural beauty.



Figure 4.19 A planted forest

Right Attitudes, Values, and Behaviours towards Environmental Conservation

Demonstrate right attitudes, values, and behaviours towards environmental conservation

The following are some of the measures taken to conserve the environment.

Setting up organizations and institutions

Many organizations have been set up for the purpose of conserving the environment. These organizations include international organizations, government ministries and agencies, and non-government organizations. Examples of government ministries and agencies include the Ministry of Natural Resource and Tourism and the National Environment Management Council (NEMC) respectively. An example of international agencies concerned with environmental conservation issues is the United Nations Environment Programme (UNEP).

Legislation

The laws that govern environmental conservation are being made and enacted. The laws aim at curbing environmental destruction by punishing or fining those individuals who destroy our environment.

Education

People are being educated about the importance of conserving the environment for their benefits. Environment education is being continually offered in schools, colleges, universities and other organizations. Academic institutions now offer courses such as environmental studies, environmental management, and environmental engineering that teach the history and methods of environmental protection.

Research

Research is being carried out on the best ways to protect and conserve the natural resources. Some of the areas of research include

- alternative sources of energy;
- methods of preventing and controlling pollution;
- sustainable use of natural resources;
- recycling and reuse of material;
- environmental impact assessment.

Pollution prevention and control

Much effort is being directed towards prevention and control of pollution. This is being done by setting up recycling factories, rehabilitating polluted areas and enacting laws and policies to control pollution, among others.

International agreement

International organizations such as the United Nations (UN) and regional blocks such as the European Union (EU) have drafted agreements which provide guidelines on the conservation of

the environment. Member nations commit themselves by signing and implementing these agreements. Most of the agreements are legally binding for countries that have formally ratified them. Such agreements include the Kyoto Protocol which was agreed upon in Kyoto, Japan on December 11, 1997.

Personal involvement

It is crucial that everyone gets involved in the conservation of the environment at individual level. Each citizen should feel obliged to take part in conserving the environment. We cannot let the task be done by the government, agencies and the international organizations alone. This is because we are all involved in environmental destruction, and the effect of this destruction affects all of us.

The following are some of the ways in which you can participate in environmental conservation:

1. Plant more trees at home and farm fields, school and village forest. Do not cut down trees indiscriminately because doing so leaves the soil bare and vulnerable to soil erosion.
2. Always dump litter in areas designated for waste disposal and in litter bins. Do not just throw dirt anywhere and carelessly.
3. Do not start fires near forests. Farmers should not prepare their farm fields by burning the vegetation because the fire can spread and destroy trees and nearby forests. Fire also kills important soil microorganisms, thus curtailing soil fertility and productivity.
4. Do not harm domestic and wild animals by any means. Be kind to animals and treat them humbly.
5. Convey environmental conservation education to all people. Let them know the importance of conserving and living in a clean environment.
6. Participate in environmental conservation programs and tasks. These include World environment Day (June 5, every year) and clear-up exercises in the local area or town.

Global Warming

Global warming refers to an equivocal and continuing rise in the average temperature of the air and sea at the earth's surface. Since the early 20th century, the global air and sea surface temperature has increased by about 0.8°C , with about two-thirds of the increase occurring since 1980. Each of the last three decades has been successively warmer at the earth's surface than preceding decades since 1850.

The recent rapid warming was caused by human activities which contribute to the production of greenhouse gases, such as carbon dioxide, that trap heat in the earth's atmosphere. It is predicted that the continuation of these activities will result in $1.8\text{--}4^{\circ}\text{C}$ average temperature increase over the next century.

The Global Warming in Terms of 'Green House' Effect

Explain the global warming in terms of 'green house' effect

The greenhouse effect is a phenomenon in which the greenhouse gases in the earth's atmosphere form a layer that shields the heat emitted by the earth and prevents it from escaping out into space.

The sun's light (also called solar radiation) passes through the atmosphere and hits the earth's surface. Energy from the sunlight is absorbed by the earth's surface in form of heat, making it warmer. Some of this heat energy (also called infrared radiation) is released back into the atmosphere. Certain gases, called greenhouse gases, form a layer in the earth's upper atmosphere that prevents much of this heat from leaving the atmosphere and going out into space. These gases act like the glass of a greenhouse or window: they let light in, but keep some of the heat from passing back out.

How the Major "Greenhouse" Gases are Produced

Describe how the major "greenhouse" gases are produced

Scientific understanding of the cause of global warming has been increasing. Global warming is mostly caused by increasing concentrations of greenhouse gases in the atmosphere. The greenhouse gases include water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), dinitrogen oxide or nitrous oxide (N_2O), ozone (O_3) and chlorofluorocarbons (CFCs). The following greenhouse gases are the main contributors to global warming. They are the main causes of global warming.

Carbon dioxide

Carbon dioxide is the main greenhouse gas. The gas contributes over 50% of the greenhouse effect. It is because of this reasons that man is struggling to reduce carbon dioxide emissions. The following are some of the man-made sources of carbon dioxide in the atmosphere.

Deforestation

Green plants absorb carbon dioxide gas from the atmosphere and use it to manufacture their food through the process of photosynthesis. Cutting down trees means that a few trees are left to absorb carbon dioxide gas from the air. This has led to the increase in the amount of carbon dioxide in the atmosphere.



Figure 4.20 Deforestation

Combustion of fuel

Burning of fossil fuel such as wood, coal, petroleum and natural gas, releases carbon dioxide into the atmosphere. The gas is produced during combustion of these fuels in car engines, power stations, industries, etc.

Methane

The main source of methane is from agricultural activities. It is released from wetlands such as rice fields and from animals, particularly cud-chewing animals, like cattle. The emission of methane gas into the atmosphere, therefore, increases with increase in agricultural activities. Since 1960s the amount of methane in the air has increased by 1% per year, twice as fast as the build-up of carbon dioxide.

Methane is also produced by the decomposition of waste materials by bacteria. It is the major component of natural gas. The gas is also produced during the mining of coal and oil (as natural gas) and when vegetation is burnt.

Nitrous oxide (dinitrogen oxide, N₂O)

Dinitrogen oxide is produced from both man-made and natural processes. Human activities which produce dinitrogen oxide include combustion of fossil fuels in vehicles and power stations, use of nitrogenous fertilizers and burning of vegetation and animal waste. During combustion of fuel in automobile engines, the air gets so hot that nitrogen reacts with oxygen to form dinitrogen oxide.

The gas is also produced by digesting bacteria, and is part of the nitrogen cycle, one of the most important natural processes on earth.

Chlorofluorocarbons (CFCs)

The sources of CFCs in the atmosphere include refrigerators, air conditioners and aerosols. CFCs are extremely effective greenhouse gases. One CFC molecule is about 10,000 times more effective in trapping heat than a carbon dioxide molecule. Some of them are up to 14,000 times effective than carbon dioxide, the main greenhouse gas.

Climatic Conditions caused by Global Warming

Describe climatic conditions caused by global warming

Global warming is expected to have far-reaching, long-lasting and, in many cases, devastating consequences for planet earth. The following are some effects of global warming:

Increase in average temperatures

One of the most immediate and obvious impacts of global warming is the increase in temperatures on the world. The average global temperature has increased by about 0.8°C over the past 100 years. Scientists predict that the earth's average temperature will increase by between 1.4 and 5.8°C by the year 2100. Increase in global temperature will affect both the land and the ocean environments. The average temperature of the oceans has increased significantly in the past few decades, causing negative effects on marine life.

When the ocean water gets warm, the algae in the ocean tends to produce toxic oxygen compounds called superoxides which are damaging for the corals. Global warming is threatening the coral reefs to a great extent, and the fact is that if coral reefs are wiped off the planet, it will affect one third of planet's marine biodiversity, as well as other ecosystems related to the coral reefs directly or indirectly.

Extreme weather events

Extreme weather events include record-breaking high or low temperatures, floods or intense storms, droughts, heat waves, hurricanes and tornadoes, etc. These are effective measures of climate change and global warming.



Figure 4.21 Floods

Scientists project that extreme weather events, such as heat waves, droughts, blizzards and rainstorms will continue to occur more often and with greater intensity due to global warming.

Other effects of extreme weather events include:

- higher or lower agricultural yields;
- melting of arctic ice and snowcaps. This causes landslides, flash floods and glacial lake overflow;
- extinction of some animal and plant species; and
- increase in the range of disease vectors, that is, organisms that cause diseases.

Change in world's climate patterns

It is forecasted that global warming will cause climate patterns worldwide to experience significant changes. Climate change resulting from increasing temperatures will likely include changes in wind patterns, annual precipitation and seasonal temperature variations.

Climatic patterns in most parts of the world have already changed. Rains fall when least expected and at irregular intervals. This has greatly affected the timing of planting and harvesting activities. Sometimes the rains fall so heavily to cause floods, or too little leading to drought.

Most of the arable land that once used to be productive is slowly turning arid. With time, farmers will run short of the land for cultivation, a fact that will result in famine.

Because high levels of greenhouse gases in the atmosphere are likely to remain high for many years, these changes are expected to last for several decades or longer.

Rise in sea levels

Continued increase in the global temperature will cause the melting of ice caps in the poles and mountain glaciers. Melting polar ice and glaciers are expected to raise sea levels significantly. Global sea levels have risen about 8 inches since 1870 and the rate of increase is expected to accelerate in the coming years. If current trends continue, many coastal areas will eventually be flooded.

Scientists predict that by the year 2100 the sea level will raise by at least 25m, leading to coastal flooding that will displace millions of people. Small islands in the Caribbean, South Pacific, Mediterranean and Indian Ocean will be totally covered by ocean waters.

Ocean acidification

As levels of atmospheric carbon dioxide increase, the oceans absorb some of it. This increases the acidity of seawater. Since the Industrial Revolution began in the early 1700s, the acidity of the oceans has increased about 25%.

Because acids dissolve calcium carbonate, seawater that is more acidic has a drastic effect on organisms with shells made of calcium carbonate, such as corals, mollusks, shellfish and plankton. The acid water is likely to dissolve the carbonaceous shells, thus endangering the lives of these sea creatures. Change in ocean acidity will also affect fish and other aquatic animals and plants.

If current ocean acidification trends continue, coral reefs are expected to become increasingly rare in areas where they are now common.

Effects on plants and animals

The effects of global warming on the earth's ecosystems are expected to be profound and widespread. Many species of plants and animals are already moving their range northward or to higher altitudes as a result of warming temperatures.

Additionally, migratory birds and insects are now arriving in their summer feeding and nesting grounds several days or weeks earlier than they did in the 20th century.

Warmer temperatures will also expand the range of many disease-causing pathogens that were once confined to tropical and subtropical areas, killing off plant and animal species that formerly were protected from disease.

These and other impacts of global warming, if left unchecked, will likely contribute to the disappearance of up to one-half of the earth's plants and one-third of animals from their current range by 2050.

Effects on humans

As dramatic as the effects of climate change are expected to be on the natural world, the projected changes to human society may be even more devastating.

Agricultural systems will likely be affected badly. Though growing seasons in some areas will expand, the combined impacts of drought, severe weather, lack of snowmelt, greater number and diversity of pests, lower groundwater tables and a loss of arable land could cause severe crop failures and livestock shortages worldwide.

This loss of food security might, in turn, create havoc in international food markets and could spark famines, food riots, political instability and civil unrest worldwide.

The effect of global warming on human health is also expected to be serious. An increase in mosquito-borne diseases like malaria and dengue fever, as well as a rise in cases of chronic conditions like asthma, are already occurring, most likely as a direct result of global warming.

Ways of Preventing Global Warming

Suggest ways of preventing global warming

The effects of greenhouse gases in the atmosphere will continue to be felt for many years. This is because greenhouse gases remain in the atmosphere for a very long period of time. For example, carbon dioxide molecules can remain in the atmosphere for a period ranging between 50 and 100 years while that of a CFC molecule is approximately 110 years. This means that global warming will continue even if the emission of greenhouse gases is reduced to very low levels.

A growing number of business leaders, government officials and private citizens are increasingly concerned about global warming and its implications. Thus they are proposing steps to reverse the trend. The following are some steps that can be taken to reduce the emission of greenhouse gases into the atmosphere:

1. Conserving the energy so as to reduce the use of fossil fuels which produce greenhouse gases. Such measures can be taken by using public transport to reduce the number of motor vehicles on the road and using cars that consume a little fuel.

2. Minimize the use of deodorants, as they contain CFCs (chlorofluorocarbons) that contributes to the ozone depletion, which in turn gives rise to most destructive effects.
3. Planting more trees (afforestation) and avoiding cutting down trees (deforestation) carelessly. This is because forests play an important role in absorbing carbon dioxide, thus reducing the amount of carbon dioxide in the atmosphere.
4. Encourage the use of renewable sources of energy like wind, biomass, solar, and geothermal energy. The use of solar power and biomass should be installed widely. But there are a few obstacles that are delaying the use of these technologies.
5. Raise awareness! Educate people about global warming and its disastrous effects. Share various solutions to stop global warming. Make sure you take initiatives to help conserve the environment and encourage others to do the same.
6. Countries, including Tanzania, have ratified the international agreements aiming at minimizing the emission of greenhouse gases. One of those agreements is the Kyoto Protocol.

Ozone Layer Destruction

The Meaning of Ozone Layer and its Importance of to Life on Earth

Explain the meaning of ozone layer and its importance of to life on earth

The atmosphere is divided into five layers. From the closest and thickest to the farthest and thinnest, the layers are: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

The majority of the atmosphere's ozone is in the stratosphere, which extends from 10 kilometres to 50 kilometres above the earth's surface.

The ozone layer is a layer of gaseous ozone (O₃) in the stratospheric atmosphere. The earth's stratospheric ozone plays an important role in absorbing ultraviolet radiations. Ultraviolet radiations (UVR), are high energy electromagnetic waves emitted from the sun. UV radiations include UV-A, the least dangerous form of UV radiations, UV-B, and UV-C, which is the most dangerous. UV-C is unable to reach the earth's surface due to stratospheric ozone's great ability to absorb it. The real threat comes from UV-B, which can enter the earth's atmosphere, and has adverse effects.

UV-B radiation (the higher-energy UV) causes skin cancer, eye cataracts, and can lead to genetic damage. Although natural phenomena can cause temporary ozone loss, chlorine and bromine released from man-made compounds such as CFCs are the main cause of ozone layer depletion (destruction). They are also greenhouse gases and contribute to global warming.

CFCs are made up of chlorine, fluorine and carbon atoms and are more extremely stable. This extreme stability allows the CFCs to slowly make their way into the stratosphere. They can remain in the atmosphere for 20 to 120 years or more.

In the stratosphere, CFCs are broken down by UV rays from the sun, releasing free chlorine radicals ($\bullet\text{Cl}$). Chlorine atom (radical) reacts with an ozone molecule (O_3) to form chlorine monoxide, ClO , and one molecule of oxygen (O_2). Then chlorine monoxide reacts with a second molecule of ozone to yield the original chlorine atom and two molecules of oxygen.

- $\text{CCl}_3\text{F} \rightarrow \bullet\text{CCl}_2\text{F} + \bullet\text{Cl}$.
- $\bullet\text{Cl} + \text{O}_3 \rightarrow \bullet\text{ClO} + \text{O}_2$.
- $\bullet\text{ClO} + \text{O}_3 \rightarrow \bullet\text{Cl} + 2\text{O}_2$

After each reaction, the freed chlorine atom (radical) is able to begin destructive cycle again with another ozone molecule. It is estimated that one chlorine radical can destroy up to 100,000 molecules of ozone.

Chemical Substances which Destroy the Ozone Layer

Identify chemical substances which destroy the ozone layer

The main ODS are chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), carbon tetrachloride and methyl chloroform. Halons (brominated fluorocarbons) also play a big role. Their application is quite limited: they're used in specialized fire extinguishers. But the problem with halons is they can destroy up to 10 times as much ozone as CFCs can.

Hydrofluorocarbons (HFCs) are being developed to replace CFCs and HCFCs, for uses such as vehicle air conditioning. HFCs do not deplete ozone, but they are strong greenhouse gases. CFCs are even more powerful contributors to global climate change, though, so HFCs are still the

better option until even safer substitutes are discovered. The following are the main ozone-depleting substances:

Chlorofluorocarbons (CFCs)

- The most widely used ODS, accounting for over 80% of total stratospheric ozone depletion.
- Used as coolants in refrigerators, freezers and air conditioners in buildings and cars manufactured before 1995.
- Found in industrial solvents, dry-cleaning agents and hospital sterilizers.
- Also used in foam products such as soft-foam padding (e.g. cushions and mattresses) and rigid foam (e.g. home insulation)

Halons

- Used in some fire extinguishers, in cases where materials and equipment would be destroyed by water or other fire extinguisher chemicals.

Trichloroethane (CH₃CCl₃)

- Used mainly in industry as a solvent in many products and for metal cleaning.

Carbon tetrachloride (CCl₄)

- Used in solvents and some fire extinguishers.

Hydrochlorofluorocarbons (HCFCs)

- HCFCs have become major, “transitional” substitutes for CFCs. They are much less harmful to stratospheric ozone than CFCs are. However, HCFCs still cause some ozone destruction and are potent greenhouse gases.

Possible effects of ozone depletion

As ozone depletes in the stratosphere, it forms a 'hole' in the layer. This hole enables harmful ultraviolet rays to enter the earth's atmosphere. Ultraviolet rays of the sun are associated with a

number of health-related and environmental issues. Let us take a look at how ozone depletion affects different life forms.

Impact on humans

Skin cancer: Exposure to ultraviolet rays poses an increased risk of developing several types of skin cancers, including malignant melanoma, basal and squamous cell carcinoma.

Eye damage: Direct exposure to UV radiations can result in photokeratitis (snow blindness), and cataracts.

Immune system damage: Increased exposure to UV rays may lead to impairment of the immune system.

Accelerated aging of skin: Constant exposure to UV radiation can cause photo allergy, which results in the outbreak of rash in thin-skinned people.

Other effects: Ozone chemicals can cause difficulty in breathing, chest pain, throat irritation, and can hamper lung functioning.

Effects on amphibians

Ozone depletion is listed as one of the causes of the declining numbers of amphibian species. Ozone depletion affects many species of amphibians at every stage of their life cycle. Some of the effects are mentioned below:

- Hinders growth and development in larvae.
- Changes behaviour and habits.
- Causes deformities in some species.
- Decreases immunity: Some species have become more vulnerable to diseases and death.
- Retinal damage and blindness in some species.

Effects on marine ecosystems

In particular, plankton (phytoplankton and bacterioplankton) are threatened by increased UV radiation. Marine phytoplankton play a fundamental role in both the food chain as well as the oceanic carbon cycle. Plankton play an important role in converting atmospheric carbon dioxide

into oxygen. Ultraviolet rays can influence the survival rates of these microscopic organisms, by affecting their orientation and mobility. This eventually disturbs and affects the entire ecosystem.

Impact on plants

In some species of plants, UV radiation can alter the time of flowering, as well as the number of flowers. Plant growth can be directly affected by UV-B radiation. Despite mechanisms to reduce or repair these effects, physiological and developmental processes of plants are affected.

Methods of Protecting the Ozone Layer

Suggest methods of protecting the ozone layer

The most effective way of controlling the depletion of ozone layer is to ban the production and use of ozone depleting substances (ODS). The most dangerous of these substances are chlorofluorocarbons (CFCs). Since their introduction, CFCs have been used as:

- refrigerants in refrigerator and air conditioning units;
- propellants in aerosol cans;
- solvents and blowing agents for insulation foams;
- cleaners in electronic industry;
- fire extinguisher chemicals.

Eliminating the use of CFCs will prevent the depletion of ozone layer. New refrigerants have been developed and new aerosols use other propellants such as methane in place of CFCs.

QUALITATIVE ANALYSIS

The Meaning of Qualitative Analysis

Explain the meaning of qualitative analysis

Qualitative analysis involves determining metals and non metals (or metallic and non-metallic elements) present in a given sample. It is a process used to determine what elements (or radicals) are present in the sample.

Whereas quantitative analysis involves determining how much (quantity) of a substance is present in a sample, qualitative analysis involves identifying what (quality) substances are present in a sample.

Qualitative analysis may be divided into examination of:

- acidic or non-metallic radicals or negative ions;
- basic or metallic radicals, including ammonium ion.

The Importance of Qualitative Analysis in Real Life

State the importance of qualitative analysis in real life

Qualitative analysis has numerous applications. The following are some applications (importance) of qualitative analysis in real life.

Detection of poisonous substances in the environment

Sometimes it may be necessary to find out the chemical composition of contaminants in the environment. This may require the application of qualitative analysis procedures to identify the chemical composition of a given contaminant. Qualitative analysis methods are highly employed by environmental scientists to detect and identify different contaminants in the environment.

Determination of ions present in a chemical substance

This is achieved through dissolution of a substance in distilled water. Then the characteristics of the solution formed serve as a clue to establish the type of elements present in a tested sample. The mixture formed following dissolution of a solid sample may be a clear solution, an emulsion or a precipitate. The solution or emulsion is further analysed to detect the ions present in it. The

precipitate is then separated from the filtrate and both are subjected to further tests to identify the kind of elements present.

Determination of the type of gases produced in a chemical reaction

Many chemical reactions are accompanied with evolution of gases, as one of the products of the reaction. In some cases, the smell of the gas may not suffice to detect the gas, especially if the gas is colourless and odourless. In such cases, the gas is subjected to various qualitative analysis tests in order to establish its identify.

Finding the nature and identity of chemical substances

The nature of a chemical substance such as its solubility in water, characteristic smell, flame colour, and the characteristics of its reaction products can be used to identify the chemical substance under test. In this way, the nature and identity of unknown substance can ultimately be known.

Soil analysis

Determination of soil pH

Soils of given pH give specific colours when their solutions are added to certain types of indicators. This procedure is purely qualitative because it involves observation of the change in colour of indicators to determine the pH of the soil. For further details on the measurement of soil pH, read a topic on Soil Chemistry (Chapter Three) in this book.

Determination of soil composition

Qualitative tests are performed to determine the type of minerals contained in a particular soil. Such tests include test for nitrate, sulphate, chloride and phosphate ions. Determination of soil composition gives soil scientists information necessary for conservation.

Application in medical and criminology fields

Qualitative analysis techniques are applied in medical field, for example in carrying out various tests such as testing blood and urine samples, determining the level of blood sugar, pregnancy diagnose and blood grouping. Most of these analytical tests are done to diagnose a wide range of diseases and medical conditions.

For example:

- in detecting the causative agents for typhoid (*salmonella typhi*), the blood is left to clot, or it is centrifuged in order to separate blood corpuscles from plasma. The plasma is then subjected to various qualitative tests to detect the presence of *salmonella typhi*.
- in pregnancy diagnosis, a certain chemical is added to urine, where a specific change in colour of the urine confirms whether one is pregnant or not.

Qualitative analysis is also applied in blood grouping, whereby antibodies are added to the blood to determine the blood group. Agglutination of the blood corpuscles when antibodies are added help detect the group of the blood.

Forensic scientists may use qualitative chemical analysis to identify substances left at crime scenes, which can be vital in convicting criminals.

Application in industries

Many industries use qualitative analysis in their efforts to perform better and make quality products. In chemical industries, the products often get contaminated by unknown contaminants. Qualitative tests are done to detect the contaminants. This may be followed by quantitative analysis aiming at finding out the quantity (amount) of the contaminant present.

Qualitative analysis techniques

It is very important to be very keen when performing qualitative analysis tests. Just a small error can cause misinterpretation of the contents of a tested sample. The following are few but important measures that should be observed when carrying out qualitative analysis experiments.

Adding the reagent

After adding the test reagent, make sure the solution is stirred thoroughly. Before making any inference, wait until the solution has completely settled down. Often, additional quantities of the reagent must then be added so that an excess is present.

Avoid contamination

Contamination of the sample or reagent should strictly be avoided. For instance, if the contaminant contains a cation, the test can give misleading positive results. To avoid contamination of the sample and apparatus, the following precautions should be observed:

1. All the apparatus should be cleaned and dried thoroughly and must remain clean throughout the experiment.
2. Do not lay a glass rod on a dirt laboratory bench as it can get contaminated easily.
3. Avoid touching the side of a test-tube with the tip of a dropper. The contaminant can be picked up and transferred to another solution, a fact that would contaminate the solution, thus producing false results.
4. Only distilled water from the wash bottle should be used to dissolve the solids. Spring, rain or tap water contains chemicals that can lead to wrong results and conclusions.

Warming up the solution

The solution is warmed by dipping the test-tube containing the solution in a beaker of warm or boiling water (water bath). The test-tube is kept in a water bath for some time, with constant stirring. Then, the solution is tested for the presence of anions or cations contained in it.

Testing the pH of a solution

This is conducted by placing a litmus paper on a clean, dry surface and then pouring a drop of the solution to be tested on it. The colour of the paper is observed and noted while the paper is wet. Once dry, the colour may change or disappear, resulting in wrong interpretation.

Qualitative Analysis Procedures

The procedures of qualitative analysis involve carrying out analytical tests in the appropriate sequence of steps. The common procedures for testing an unknown sample is to make its solution and then test this solution for different ions present. The steps involved in the systemic analysis of a given sample are as follows:

Preliminary tests

- Colour and smell
- Flame test
- Solubility in water
- Dry heating
- Action on litmus (for gases evolved)

Tests for acid radicals (anions)

- Dilute acid test (dilute H₂SO₄)
- Concentrated acid test (concentrated H₂SO₄)
- Wet test for acid radicals

Wet tests for basic radicals (cations)

Using Special Apparatus for Qualitative Analysis

Use special apparatus for qualitative analysis

Activity 1

Use special apparatus for qualitative analysis

Preliminary Test on an Unknown Sample

Carry out preliminary test on an unknown sample

Preliminary tests include noting the appearance (colour, texture, feel, etc) of the sample, detecting the smell of the gas liberated, observing the action of a substance on litmus, and even the taste of the substance under investigation. The preliminary tests give a clue about the type of the elements present in a sample.)

Table 5.1 Colour and smell of some solid substances

Observation	Inference
Black	Oxide or sulphide
Green	Iron (II) or copper salt
Yellow	Lead (II) oxide or iron (III) salt
Blue	Copper salt
Ammoniacal smell	Ammonium salt
Smell of rotten eggs	Sulphide salt
Sulphur dioxide smell	Sulphite
Vinegar-like smell	Acetate salt
Deliquescent	Chloride or nitrate

Table 5.2 Identification of gases

Gas	Colour	Smell	Action on litmus	Test
CH ₃ COOH	Colourless	Vinegar-like	Acidic	Liberated as dense white fumes
N ₂	Colourless	Odourless	Neutral	No chemical test
Water vapour	Colourless	Odourless	Neutral	Turns white CuSO ₄ blue
NO ₂	Reddish-brown	Pungent	Acidic	Not as red as Br ₂ vapour and does not condense on the sides of the test tube
NH ₃	Colourless	Pungent	Alkaline	Forms thick white fumes when in contact with HCl gas
HCl	White fumes	Irritating	Acidic	Forms thick white fumes when in contact with NH ₃ gas
HBr & Br ₂	White fumes &	Choking	Acidic &	HBr resembles HCl, & Br ₂

	reddish- brown gas		bleaches	condenses to a red liquid on the side of the test tube
Cl ₂	Pale green	Bleaches	Choking	Gives white fumes with NH ₄ OH
I ₂	Violet	Choking	Bleaches	Turns starch iodide paper blue/black
CO ₂	Colourless	Odourless	Slightly acidic	Turns lime water milky
CO	Colourless	Odourless	Neutral	Burns with pale blue flame
H ₂	Colourless	Odourless	Neutral	Burns with a „pop“ sound
H ₂ S	Colourless	Rotten eggs	Acidic	Burns with blue flame to SO ₂ blackens lead acetate paper.
O ₂	Colourless	Odourless	Neutral	Re-ignites a glowing splint
SO ₂	Colourless	Irritating smell of burning sulphur	Acidic	Decolourizes KMnO ₄ solution K ₂ Cr ₂ O ₇ from orange to green
SO ₃	Colourless	Pungent	Acidic	Fumes in moist air forming dense white fumes

Colours of some ions in solution

The appearance of a substance in solid or solution form can help in its identification:

- If a compound and its solution in water are colourless, it is probable that a transition metal is absent.
- If its colour is black, it is probably an oxide or a sulphide.
- If the solid and its solution in water are coloured, probably a transition metal is present.

The following are the colours of some transition element ions

Table 5.3 Colours of some ions

<i>Ion</i>	<i>Hydrated salt (solid)</i>	<i>Dilute solution</i>
Cr^{3+}	Deep green or violet	Dark green
Co^{2+}	Red or pink	Pink
Cu^{2+}	Blue or green	Blue
Fe^{2+}	Pale green	Very pale green
Fe^{3+}	Dark brown	Yellowish brown
Mn^{2+}	Very pale pink	Colourless
Ni^{2+}	Bright green	Green
CrO_4^{2-}	Yellow	Yellow
CrO_7^{3-}	Orange	Orange

Table 5.4 colours of some common insoluble substances

Substance	Colour
<i>Carbonates</i>	
Ag_2CO_3	yellow
CuCO_3	green
BaCO_3	white
CaCO_3	white
<i>Chlorides</i>	
AgCl	white
PbCl_2	white
CuCl_2	green

<i>Hydroxides</i>	
AgOH	grey-brown
$\text{Cu}(\text{OH})_2$	pale blue
$\text{Fe}(\text{OH})_2$	dirty green
$\text{Fe}(\text{OH})_3$	reddish-brown
$\text{Pb}(\text{OH})_2$	white
$\text{Zn}(\text{OH})_2$	white
<i>Sulphates</i>	
BaCl_2	white
BaSO_4	white

Preparation of Stock Solutions from Soluble and Insoluble Salts

Prepare stock solutions from soluble and insoluble salts

The solubilities of different compounds in water can be used in their identification. It is therefore important to know the solubilities of different compounds

To test the solubility of a compound, put one spatula of the compound in 1 cm³ of distilled water and stir. If the compound is soluble, this amount will dissolve. If the compound is moderately soluble, some of this amount will dissolve. If the compound is insoluble, not even a small amount will dissolve.

The following are some general rules on the solubility of different compounds in water:

- All common nitrates of metals are soluble.
- All common sodium, potassium and ammonium salts are soluble.
- All common chlorides are soluble except those of silver, mercury (I) and lead (II).
- All common sulphates are soluble except those of lead and barium. The sulphates of calcium and silver are sparingly soluble.
- All carbonates, sulphites and phosphates of sodium, potassium, and ammonium are soluble but other common carbonates are insoluble.
- Sodium, potassium and ammonium hydroxides [(ammonia solution, NH₃(aq))* are soluble but other common hydroxides are insoluble.
- All sulphides are insoluble except those of the alkali metals, the alkaline earth metals and ammonium.

* It is important to note that ammonium hydroxide does not exist. The solution of ammonia in water (ammonia solution) is always wrongly termed as ammonium hydroxide. Although the name ammonium hydroxide suggests an alkali with the formula [NH₄⁺][OH⁻], it is actually impossible to isolate samples of NH₄⁺ and OH⁻ ions from a solution of ammonia in water since the ions are negligibly very few in solution except in extremely dilute solutions.

Action of heat on the original substance

Different substances decompose on heating to give different products. Many compounds decompose on heating and leave solid residues. In performing this test, the compound is heated

in an ignition tube or dry test tube. Heating is continued until no further change occurs. The gas evolved, residue left or sublimate formed on heating may help to identify the acid radical present in a compound.

Table 5.5 Action of heat on the test substance

Observation (sublimates, residues, gases)	Inference
A white sublimate formed and ammonia gas detected	An ammonium salt (NH_4^+)
A white sublimate but no ammonia gas evolved	Mercury, arsenic or antimony oxide
A grey sublimate	Mercury (Hg) or Arsenic

	(As)
A yellow sublimate	Compound of sulphur e.g. thiosulphate or sulphide
Evolution of water vapour	Hydrated salt. The substance may be a bicarbonate, copper (II) sulphate or a hydroxide
A solid residue which is: (i) yellow when hot and white when cold (ii) reddish brown when hot and yellow when cold	Zinc oxide Lead (II) oxide
A solid residue which liquefies and turns yellow on cooling	Lead
Ammonia gas, NH_3 , evolved	Ammonium salt
Hydrogen chloride gas, HCl , evolved	Hydrated chloride (not group I or Ba)
Bromine, Br_2 , evolved and HBr formed	Bromide
Sulphur dioxide, SO_2 , and/or hydrogen sulphide, H_2S , evolved	Sulphite (not of group I, Ba or Ca)
Nitrogen dioxide, NO_2 , evolved	Nitrate or nitrite
Oxygen, O_2 , evolved	Chlorate, nitrate, peroxide, or M(IV) oxide (where M is a metal)
Carbon dioxide, CO_2 , evolved	Carbonate or bicarbonate
Carbon monoxide, CO , evolved	Oxalate ($\text{C}_2\text{O}_4^{2-}$)
Sulphur dioxide, SO_2 , evolved	Thiosulphate, sulphide or certain sulphates
Hydrogen, H_2 , evolved	Formate (methanoate), HCOO^-
Acetic acid, CH_3COOH , evolved	Acetate (CH_3COO^-)
Iodine, I_2 , evolved	Iodide (I^-)

Action of dilute sulphuric acid or dilute hydrochloric acid

Treat the solid with cold dilute sulphuric or hydrochloric acid. Identify the gas evolved. If there is no reaction with the cold acid, heat the mixture gently. Heat carefully and ensure the mixture does not boil. The gas evolved can be identified as follows:

Table 5.6 Detection of acidic radicals

<i>Observation (gas evolved)</i>	<i>Inference (ion indicated)</i>
Reddish-brown gas with pungent smell, which turns iron (II) sulphate solution black (NO_2)	NO_2^- (nitrite)
Colourless, odourless gas which turns lime water milky (CO_2)	CO_3^{2-} or HCO_3^- (carbonate or bicarbonate)
Colourless gas with pungent smell, which turns acidified potassium dichromate paper green (SO_3)	SO_3^{2-} (sulphite)
Colourless gas with smell like that of rotten eggs, turns lead acetate paper black (H_2S)	S^{2-} (sulphide)
Greenish-yellow gas with pungent, choking smell and which bleaches damp litmus paper (Cl_2)	OCl^- (hypochloride)
Colourless, acidic gas with irritating, choking smell	$\text{S}_2\text{O}_3^{2-}$
Sulphur dioxide, and yellow residue of sulphur on heating	$\text{S}_2\text{O}_3^{2-}$ (thiosulphate)

Action of concentrated sulphuric acid

As in the above test, the acid is added to the solid substance and if no reaction occurs, the mixture is warmed gently, but the mixture should not be boiled. Then, the gas given off is identified. In addition, observe any product, other than the gas, which results from the reaction.

Table 5.7 Action of conc. H_2SO_4

Observation	Inference (ion indicated)
Acidic, white fumes (vapours) with pungent smell, forms dense white fumes with NH_4OH , and a white precipitate with AgNO_3 solution (HCl)	Cl^- may be present
Acidic, reddish-brown vapours with pungent smell, and which condenses to a red liquid on the sides of a test tube (HBr , Br^-)	Br^- may be present
Neutral, deep violet vapours with pungent & choking smell, turns starch paper blue	I^- may be present
Acidic, reddish-brown gas with pungent smell, turns FeSO_4 solution black (NO_3^-)	NO_3^- or NO_2^- may be present
Acidic, white fumes with vinegar smell (CH_3COOH)	CH_3COO^- (acetate) may be present
Alkaline, pungent, colourless gas which forms thick white fumes when in contact with HCl gas (NH_3)	NH_4^+ may be present
Slightly acidic, colourless gas which turns lime water milky, together with a colourless gas which burns with a pale blue flame (CO_2 together with CO gas)	$\text{C}_2\text{O}_4^{2-}$ may be present
Neutral, colourless gas, which burns with a blue flame (CO)	HCOO^- (formate) may be present
Neutral, colourless gas which re-ignites a glowing splint, leaving a dark-red solid [chromic (IV) oxide,	CrO_4^{2-} may be present

Cr_2O_7	
Acidic, corrosive, greenish-yellow gas which bleaches damp litmus paper (Cl_2)	ClO_3^- may be present

Note:

- Oxalates give CO_2 with concentrated H_2SO_4 but not with HCl .
- Nitrates do not give NO_2 when treated with HCl but nitrites give NO_2 gas.
- If no result is obtained in the above tests, the salt is probably a sulphate, chromate or phosphate.

Precipitation of Insoluble Salts from their Solutions

Precipitate insoluble salts from their solutions

Activity 2

Precipitate insoluble salts from their solutions

Cations and Anions Identify

Confirm cations and anions identified

The detection of acidic radicals is important in that, in addition to other information, it enables a clear-cut identification of the substance being analysed. The substances are first dissolved in distilled water to make solutions. Then, the resulting solutions are tested for radicals. Table 5.8 shows a list of test/experiments, each of which confirms the presence of a given ion. Depending on the availability of reagents, students can do any of the listed tests to confirm the ions present in test solutions.

Table 5.8 confirmatory tests for anions

<i>Ion</i>	<i>Test/experiment</i>	<i>Observation/inference</i>
CO_3^{2-} and HCO_3^-	<ol style="list-style-type: none"> 1. Boil the solution. 2. Add MgSO_4 solution to a cold solution. 3. Add dilute HCl to the cold solution. 4. Add BaCl_2 or $\text{Ba}(\text{NO}_3)_2$ or CaCl_2 to the solution and boil. 	<ol style="list-style-type: none"> 1. Bicarbonate solution evolves CO_2 gas while the carbonate solution does not since it is not decomposed by heat. 2. A precipitate (ppt) forms immediately with the carbonate. With the bicarbonate, a ppt of MgCO_3 is formed. 3. A white ppt is formed

		and a colourless gas which forms a white ppt with lime water is evolved. With the bicarbonate, no ppt is formed though CO_2 is given off. 4. After boiling, a white ppt of CaCO_3 or BaCO_3 is formed.
Sulphide (S^{2-})	1. Add lead acetate solution to the test solution. 2. Add AgNO_3 solution. 3. Add cadmium carbonate.	1. Black ppt of PbS . 2. Black ppt soluble in hot dilute HNO_3 . 3. Yellow ppt of cadmium sulphide (CdS)
Sulphite (SO_3^{2-})	1. To salt solution, add BaCl_2 solution. 2. To salt solution, add KMnO_4 solution. 3. Add acidified solution of $\text{K}_2\text{Cr}_2\text{O}_7$. 4. Add iodine/bromine water.	1. A white ppt of BaSO_3 which is soluble in dilute HCl . 2. The purple colour of KMnO_4 is decolorized. 3. Green solution of Cr_3^+ is formed. 4. Iodine/bromine water is decolorized.
Nitrite (NO_2^-)	1. Add KMnO_4 solution with few drops of dilute H_2SO_4 . 2. Add a mixture of conc. HCl or H_2SO_4 and KI solution. 3. Add cold dilute acetic acid and a drop of cobalt nitrate. 4. Brown ring test. 5. Add dilute H_2SO_4 followed by FeSO_4 solution.	1. The solution becomes colourless. 2. Brown colouration or black ppt due to oxidation of KI to iodine (I_2). 3. Yellow ppt. 4. The whole solution turns brown, no brown ring formed. 5. Dark brown colouration.

Nitrate (NO ₃ ⁻)	<p>1. <i>Brown ring test:</i> To a solution, add FeSO₄ solution. Then slowly add conc. H₂SO₄ down the side of the test tube so that it sinks below the mixture.</p> <p>2. To a solid in a test tube, add NaOH solution followed by Devarda's alloy, and warm gently.</p> <p>3. Add conc. H₂SO₄ to a solution followed by copper turnings. Then shake thoroughly and let the mixture settle.</p> <p>4. Add acetic (oxalic) acid to a test solution.</p>	<p>1. A brown ring of FeSO₄.NO is formed at the junction of conc. H₂SO₄ layer and the test solution.</p> <p>2. Ammonia gas is liberated (Devarda's alloy is a reducing agent. When reacted with nitrate in sodium hydroxide solution, ammonia is liberated).</p> <p>3. Reddish-brown colouration due to formation of NO₂ gas.</p> <p>4. Vinegar-like smell is detected.</p>
Chloride (Cl ⁻)	<p>1. Add MnO₂ and conc. H₂SO₄ and warm.</p> <p>2. <i>Chromyl chloride test:</i> To a solid salt in a test tube, add potassium dichromate solution and excess conc. H₂SO₄. Heat gently.</p> <p>3. Add lead (II) ions e.g. lead ethanoate solution.</p> <p>4. Add dilute HNO₃ followed by AgNO₃ solution.</p>	<p>1. A pale-green gas (Cl₂) is given off (chlorine is toxic).</p> <p>2. A dense blood-red colouration of CrO₂Cl₂ is formed.</p> <p>3. A white ppt of PbCl₂. This dissolves on heating and precipitates on cooling.</p> <p>4. A white ppt of PbCl₂, soluble in ammonia.</p>
Bromide (Br ⁻)	<p>1. To a solid salt, add MnO₂ & conc. H₂SO₄ and warm.</p> <p>2. To a solution, add chlorine water dropwise, followed by CCl₄ (carbon tetrachloride).</p> <p>3. Add AgNO₃ solution to the test solution.</p>	<p>1. Bromine is evolved and it condenses on the side of a test tube as a red liquid.</p> <p>2. An orange/red solution</p> <p>3. A pale yellow ppt of AgBr.</p>

Iodide (I ⁻)	<ol style="list-style-type: none"> 1. Add HgCl₂ solution to a solution. 2. Add chlorine water dropwise & CCl₄ to a solution. 3. Add lead (II) ions e.g. lead ethanoate solution. 4. Add AgNO₃ solution 5. Add MnO₂ & conc. H₂SO₄ 	<ol style="list-style-type: none"> 1. A brilliant orange/red ppt. 2. Intense violet colouration. 3. Yellow ppt of PbI₂, soluble in excess iodine solution. 4. Yellow ppt of AgI. 5. Brown colouration due to formation of I₂.
Acetate/ ethanoate (CH ₃ COO ⁻)	<ol style="list-style-type: none"> 1. To a test solution, add ferric chloride solution. 2. To a solid salt, add a little ethanol & conc. H₂SO₄. 	<ol style="list-style-type: none"> 1. Blood-red colouration which is bleached by hydrogen chloride gas but not by HgCl₂. 2. Fruity smell or sweet smell of ethyl ethanoate.
Sulphate (SO ₄ ²⁻)	<ol style="list-style-type: none"> 1. Add dilute HCl followed by BaCl₂ solution or dilute HNO₃ followed by Ba(NO₃)₂ solution. 2. Add lead (II) acetate solution. 	<ol style="list-style-type: none"> 1. A white ppt of BaSO₄ which is insoluble in dilute HCl and acetic acid. 2. A white ppt of PbSO₄ which is insoluble in hot conc. H₂SO₄.
Chromate (CrO ₄ ²⁻)	<ol style="list-style-type: none"> 1. Add ammonia solution followed by AgNO₃ solution. 2. Add BaCl₂ solution. 3. Add dilute H₂SO₄ + H₂O₂ + ether, then shake. 	<ol style="list-style-type: none"> 1. Crimson-red ppt soluble in dilute HNO₃. 2. Yellow ppt soluble in dilute HCl. 3. A deep blue solution of perchromic acid is formed in ether layer.
Formate/ methanoate (HCOO ⁻)	<ol style="list-style-type: none"> 1. Add ferric chloride solution. 2. Add a solution of AgNO₃ and warm. 	<ol style="list-style-type: none"> 1. Red colouration. A brown ppt is formed on boiling. 2. Black ppt of metallic silver is deposited.
Phosphate (PO ₄ ³⁻)	<ol style="list-style-type: none"> 1. Add conc. HNO₃ and excess of ammonium 	<ol style="list-style-type: none"> 1. A yellow crystalline ppt.

	molybdate and heat. 2. Add a mixture of NH_4Cl , $\text{NH}_3(\text{aq})$ and MgSO_4 solutions. 3. To a slightly acid solution, add zirconium nitrate solution. 4. Add FeCl_3 solution.	2. White ppt. 3. Yellow ppt. 4. Yellow-white ppt soluble in acids.
Thiosulphate ($\text{S}_2\text{O}_3^{2-}$)	1. To a salt solution, add a solution of any lead (II) salt. 2. Heat the solution. 3. To a salt solution, add a solution of iodine in aqueous KI. 4. Add silver nitrate solution 5. Add FeCl_3 solution. 6. Add ammonium molybdate solution and gently pour H_2SO_4 into the mixture.	1. White ppt soluble in excess lead ethanoate and on boiling a black ppt of PbS is formed. 2. A yellow deposit of sulphur, and evolution of SO_2 and H_2S gases. 3. Immediate decolouration of the iodine solution. 4. White ppt insoluble in excess thiosulphate. On standing, the ppt turns yellow, then brown and finally black. 5. A dark violet colour which later turns colourless. 6. A blue ring forms at the junction of two liquids after some time.

TESTS FOR METALLIC RADICALS

Flame test

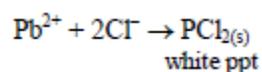
Some metal ions can be identified by the colour of their flame during a flame test. Flame test involves mixing solutions of ions with conc. HCl and then heating them on a platinum or nichrome wire over a non luminous flame. Alternatively, a dry solid can be used instead of the solution. To perform this experiment, dip a platinum or nichrome wire into concentrated hydrochloric acid and hold it just above the blue part of the flame. Repeat the process until the wire is clean. After that dip the clean wire into the acid and the dip it into the solution of the test substance (or its solid particles). Heat the substance strongly and observe the colour of the flame formed.

The flame changes to a colour characteristics of the element. The following are characteristic flame colours of some metal ions.

Observation	Inference
Bright yellow/orange	Sodium
Brick red	Calcium
Pale blue	Lead
Bluish green	Copper
Grassy green/light green	Barium
Lilac (pale violet)	Potassium
Crimson red	Strontium
Bluish green	Zinc
Yellow sparks	Transition metal such as Fe, Ni, Cr
Red/crimson	Lithium
Bright green	Boron
Yellowish green	Manganese

Action of hydrochloric acid

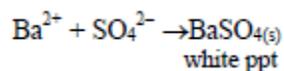
Add dilute hydrochloric acid dropwise to the test solution until the solution tests acidic to litmus paper. Observe for any reaction. A precipitate will form with any cation that forms an insoluble chloride. For example:



This can then be subjected to further tests to confirm the specific cation present in the solution.

Action of sulphuric acid

Add dilute sulphuric acid dropwise to the test solution until the solution is acidic. Observe for any reaction. A precipitate will form with any cation that forms an insoluble sulphate. For example:



Action of sodium hydroxide

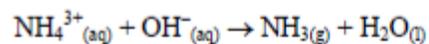
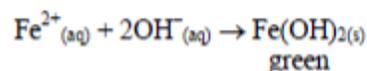
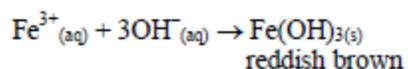
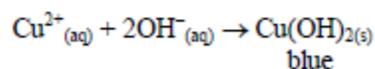
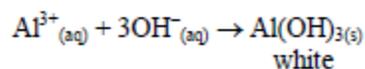
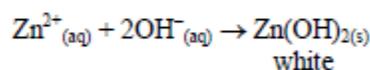
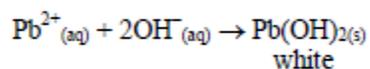
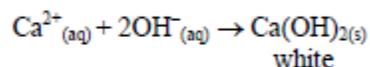
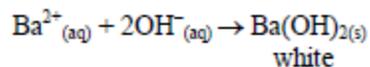
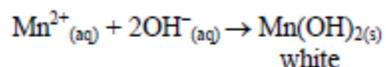
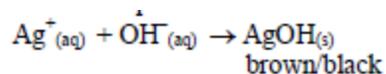
Add sodium hydroxide solution, a little at a time, to the test solution until there is an excess of it. Stir or shake the mixture and observe for any reaction. If no precipitate is formed, warm the mixture gently and test for ammonia. If a precipitate forms, continue adding the sodium hydroxide solution.

Table 5.9 Reaction of cations with dilute NaOH

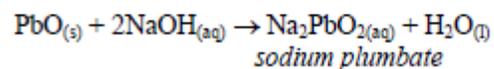
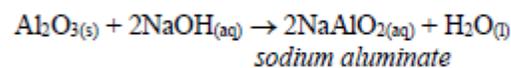
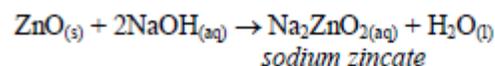
<i>Observation</i>	<i>Inference</i>
No ppt formed, even on warming.	Na^+ , K^+ or NH_4^+ present. Ammonia is liberated on warming if NH_4^+ is present.
White ppt insoluble in excess.	Ca^{2+} present
White ppt soluble in excess.	Pb^{2+} , Zn^{2+} , Al^{3+} present
Blue ppt insoluble in excess. The ppt turns black on warming.	Cu^{2+} present
Green ppt insoluble in excess. The ppt slowly oxidizes to brown.	Fe^{2+} present
Reddish-brown (rust brown) ppt insoluble in excess.	Fe^{3+} present
Off-white ppt slowly turning light brown.	Mn^{2+} present
Dark brown or black ppt.	Ag^+ present
No ppt formed, but on warming, a	NH_4^+ present

colourless gas with a pungent smell (ammonia) is evolved. The gas turns red litmus paper blue.	
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Reaction equations:



The oxides of zinc, aluminium and lead are soluble in excess sodium hydroxide. This is due to the amphoteric nature of the hydroxides of these metals.



Action of aqueous ammonia

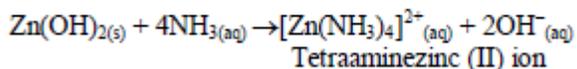
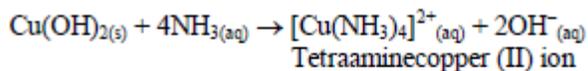
Add dilute aqueous ammonia to the test solution, drop by drop. Stir or shake the mixture and observe for any reaction. If a ppt forms, continue adding aqueous ammonia.

Table 5.10 Reaction of cations with aqueous ammonia

Observation	Inference
White gelatinous ppt soluble in excess.	Zn ²⁺ present
No ppt formed.	Na ⁺ , K ⁺ , NH ₄ ⁺ , Ca ²⁺ or Ba ²⁺ present
White ppt, insoluble in excess.	Pb ²⁺ , Al ³⁺ or Mg present
Pale blue ppt, soluble in excess forming a dark blue solution.	Cu ²⁺ present
Dirty green ppt, insoluble in excess, slowly oxidizing to brown.	Fe ²⁺ present
Reddish-brown ppt, insoluble in excess.	Fe ³⁺ present

Off-white ppt turning brown	Mn ²⁺ present
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An excess of aqueous ammonia dissolves the hydroxides of copper and zinc forming complex compounds of the metals:



Confirmatory tests for cations

After the preliminary tests have been performed, there is always a need to carry out confirmatory tests to confirm the presence of cations in substances.

Table 5.11 Confirmatory tests for cations

Cation	Test/Experiment	Observation/Inference
Na^+	1. To a test solution, add zinc uranyl ethanoate solution. 2. Add magnesium uranyl ethanoate solution. 3. Flame test.	1. Yellow ppt. 2. Yellow ppt. 3. Bright yellow flame.
NH_4^+	1. To a test solution, add Nessler's reagent. 2. Add copper (II) sulphate solution in excess. 3. Add NaOH solution and heat.	1. Yellow or brown colouration. 2. Dark blue solution. 3. Ammonia gas evolved.
Zn^{2+}	1. Add potassium ferrocyanide solution (potassium hexacyanoferrate (II)), $\text{K}_4[\text{Fe}(\text{CN})_6]$ 2. Add potassium	1. White yellow ppt soluble in aqueous ammonia. 2. White yellow ppt insoluble

	ferricyanide solution (potassium hexacyanoferrate (III)), $\text{K}_3[\text{Fe}(\text{CN})_6]$ 3. Pass H_2 gas, NH_3 gas and add NH_4Cl solution.	in aqueous ammonia. 3. Dirty white ppt.
Ca^{2+}	1. Add ammonium oxalate solution and warm on a water bath. 2. Flame test. 3. Add potassium chromate solution.	1. White ppt insoluble in water and acetic acid, but soluble in mineral acid. 2. Brick-red flame. 3. Yellow ppt.
Fe^{2+}	1. Add potassium ferrocyanide solution. 2. Add potassium ferricyanide solution. 3. Add ammonia solution 4. Add potassium or ammonium thiocyanate.	1. Light blue or nearly white ppt 2. Dark blue ppt. 3. Dirty greenish ppt, turning brown. 4. No reaction.
Fe^{3+}	1. Add potassium ferrocyanide solution 2. Add potassium ferricyanide solution 3. Add potassium or ammonium thiocyanate solution. 4. Add ammonium hydroxide solution.	1. Dark blue ppt (Prussian blue). 2. Dark solution but no ppt formed. 3. Deep red solution (no ppt formed) 4. Reddish-brown ppt.
Al^{3+}	1. Add sodium acetate solution. 2. Add aluminon reagent. 3. Add Arizarin and ammonia solutions. 4. Add sodium carbonate solution.	1. White ppt when solution is boiled. 2. Red ppt or solution. 3. Pink colour or ppt. 4. White ppt soluble in excess carbonate solution.
Pb^{2+}	1. Add potassium chromate (K_2CrO_4) solution.	1. Bright yellow ppt of lead chromate (PbCrO_4), soluble

	<ol style="list-style-type: none"> 2. Add dilute H_2SO_4. 3. Add dilute HCl. 4. Add few drops of KI solution. 	<p>in HNO_3.</p> <ol style="list-style-type: none"> 2. White ppt of $PbSO_4$, soluble in ammonium acetate solution on warming. 3. A white ppt soluble in hot water. 4. A yellow ppt of PbI_2, soluble in boiling water to form a colourless, soluble solution which deposits brilliant yellow crystals upon cooling. The ppt dissolves on heating.
Ag^+	<ol style="list-style-type: none"> 1. Add dilute HCl. 2. Add few drops of KI solution. 3. Add potassium chromate solution. 	<ol style="list-style-type: none"> 1. White ppt of $AgCl$, soluble in ammonia solution. 2. Pale yellow ppt of AgI. 3. Brick-red ppt of Ag_2CrO_4.
Hg^{2+}	<ol style="list-style-type: none"> 1. Add KI solution dropwise. 2. Add 1 ml of stannous chloride. 3. Action of heat. 	<ol style="list-style-type: none"> 1. Reddish-orange ppt of HgI_2 which dissolves in excess KI. 2. White ppt of $HgCl_2$, turning black with excess $SnCl_2$. 3. Black ppt insoluble in excess alkali.
Cu^{2+}	<ol style="list-style-type: none"> 1. Add ammonium hydroxide solution. 2. Add dilute acetic acid, then add a drop of potassium ferrocyanide solution. 3. Add KI solution. 	<ol style="list-style-type: none"> 1. Dark or bright blue solution. 2. Red-brown ppt, soluble in ammonia solution to give a blue solution which is insoluble in dilute acid. 3. White ppt of CuI and I_2 (brown solution).
Cr^{3+}	<ol style="list-style-type: none"> 1. Add dilute acetic acid solution followed by a drop of lead acetate solution. 2. Add NaOH solution, then 	<ol style="list-style-type: none"> 1. Yellow ppt of $PbCrO_4$. 2. Greenish ppt, then yellow colour (ppt or solution) when

	H ₂ O ₂ solution.	H ₂ O ₂ is added.
Ni ²⁺	1. Add ammonium solution and dimethylgloxine reagent. 2. Add potassium ferrocyanide solution. 3. Add potassium ferricyanide solution.	1. Pink or red ppt. 2. Greenish ppt, soluble in ammonia solution. 3. Brown ppt, soluble in ammonia solution.
Mn ²⁺	1. Add potassium ferrocyanide solution. 2. Add dilute HCl followed by lead (II) oxide or red lead, then shake. 3. Add conc. HNO ₃ followed by sodium bismuthate and shake. 4. Add potassium ferricyanide solution.	1. Brown ppt, insoluble in acid and ammonia solution. 2. Dark brown solution of MnO ₂ . 3. Purple solution. 4. Whitish ppt, insoluble in ammonia solution.
Ba ²⁺	1. Add potassium chromate solution. 2. Flame test. 3. Add ammonium oxalate solution.	1. Yellow ppt of BaCrO ₄ , insoluble in dilute HCl and acetic acid. 2. Green or greenish-yellow flame. 3. White ppt, soluble in dilute acids.
Mg ²⁺	1. Add magneson followed by NaOH solution. 2. Add titan yellow. 3. Add NH ₄ Cl and a little ammonia solution until alkaline and then add 5-6 drops of disodium phosphate (Na ₂ HPO ₄) solution. Shake well and allow to settle. 4. Add sodium phosphate solution.	1. Sky-blue solution. 2. Red colouration. 3. White crystalline ppt. 4. White ppt, soluble in acids in the presence of ammonia gas or NH ₄ Cl.
K ⁺	1. Add sodium hexanitrocobaltate (III) solution.	1. Yellow ppt.
	2. Add sodium perchlorate solution. 3. Flame test.	2. White ppt. 3. Lilac flame.

Confirmatory tests for iron salts

The original test solution has to be divided into three portions. Then the solutions should be treated with the following reagents and the results recorded as shown in table 5.12.

1. Potassium hexacyanoferrate (II) solution
2. Potassium hexacyanoferrate (III) solution
3. Potassium thiocyanate solution

Table 5.12 Tests for iron salts

<i>Reagent used</i>	<i>Iron (II) salt</i>	<i>Iron (III) salt</i>
1. Potassium hexacyanoferrate (II)	Light blue or nearly white ppt	Dark blue ppt
2. Potassium hexacyanoferrate (III)	Dark blue ppt	Dark solution but no ppt
3. Potassium thiocyanate	No reaction	Deep red solution

Table 5.13 Tests for bromides and iodides

<i>Test</i>	<i>Observation</i>	
	<i>Bromide</i>	<i>Iodide</i>
1. Warm the solid with conc. H_2SO_4	Misty fumes of HBr mixed with red Br_2 fumes are formed	A dark blue ppt is formed
2. Warm the solid with MnO_2 and conc. H_2SO_4	A red gas and liquid (Br_2) are formed	A violet vapour and black solid (I_2) are formed
3. Add $AgNO_3$	A pale yellow ppt	A yellow ppt

solution to the aqueous solution of the solid	slightly soluble in dilute aqueous ammonia is formed	insoluble in aqueous ammonia is formed
4. Add chlorine water to the aqueous solution of the solid	A red solution giving a red liquid bromine is obtained	A brown solution giving a black ppt of iodine is formed

Write-up of analytical data

All the observations made and any experimental data obtained during the experiment (or test) must be presented in a tabular form as shown below. Results presented in a table are concise, easy to read and understand. The last column of the table gives the conclusions based on the observations made.

Table 5.14 Table of results

<i>Experiment</i>	<i>observation</i>	<i>Inference</i>
1. Appearance	Colourless crystals	Absence of coloured salts e.g. iron (II), iron (III), copper, etc.
2. Action of heat on the solid	No water vapour was given off. A gas was given off which turned lime water milky and turned moist blue litmus paper red. The residue was a white powder	The substance is anhydrous. It is a carbonate. The residue is probably calcium oxide formed by the reaction: $\text{CaCO}_{3(s)} \rightarrow \text{CaO}_{(s)} + \text{CO}_{2(g)}$
3. The substance was added to water	The substance was found to be insoluble	The carbonate cannot be that of potassium or sodium, otherwise it would dissolve in water
4. Flame test	A red colour was	Sodium is confirmed

	<i>observed</i>	<i>to be present</i>
5. The solid was reacted with dilute HCl	A gas was evolved which turned moist, blue litmus paper red and turned lime water milky	This confirms the presence of a carbonate
6. The substance is calcium carbonate (CaCO_3)		