CHEMSTRY SUMMARIZED NOTE FOR GRADE 10

Unit 3

Electrochemistry

After completing this unit, you will be able to:

- understand how a chemical reaction produces an electric current and how electricity brings about chemical reactions in electrochemical cells;
- understand the differences between metallic conduction and electrolytic conduction;
- develop skills in writing the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten electrolytes that occur in electrolytic cells; \
- know three types of voltaic cell; (understand the difference between electrolytic cells and voltaic cells;
- appreciate the industrial applications of electrolysis in the production of certain metals, non metals and chemicals and electroplating, and purification of metals;

3.1. Electrochemistry

At the end of this topic, you will be able to:

- explain electrochemistry

Electrochemistry is a field of chemistry that studies how chemical reactions produce electricity and how electricity is used to bring about chemical reactions in electrochemical cells.

The devices that convert chemical energy to electrical energy or electrical energy to chemical energy are called **electrochemical cells.**

These cells can be classified as electrolytic cells and galvanic or voltaic cells.

3.2. Electrical Conductivity

After completing this topic, you will be able to:

- define electrical conductivity
- explain metallic conductivity
- explain electrolytic conductivity
- distinguish between metallic and electrolytic conduction
- distinguish between weak and strong electrolytes

Electrical conductivity: is the capacity of a substance to transmit electricity.

The materials that allow the passage of electricity through them are called **electrical conductors**.

Conductivity apparatus is used to test the conductivity of the substance.

The components of the apparatus are:

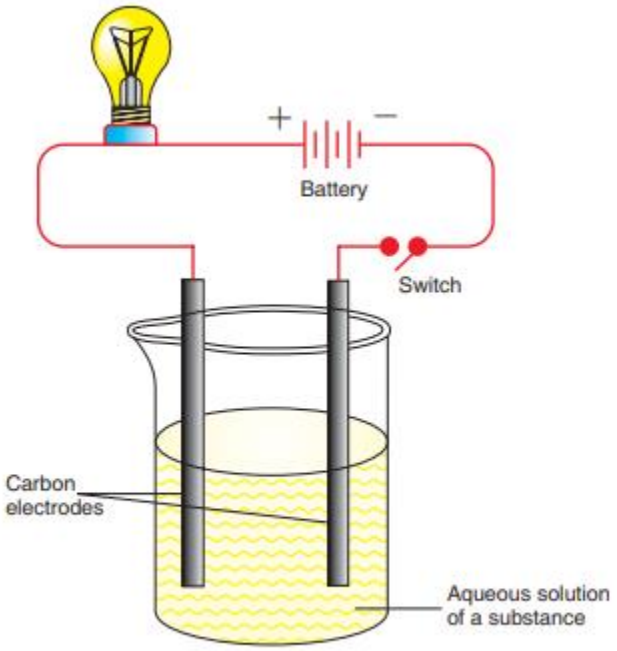


Figure 3.1 Conductivity cell.

Electrical conductivity is Electrical conductivity is the ability of substances to conduct electricity. It can be classified as ***metallic conductivity or electrolytic conductivity***.

A. Metallic conductivity

Metallic conductivity refers to the transmission of electric current through metals. because metals have free electrons or mobile electrons or delocalized electrons.
The charge carriers in metallic conduction are **electrons.**
Hence, metallic conductivity is also called **electronic conductivity.**

B. Electrolytic conductivity

Electrolytes are substances that transmit electricity in a molten state or in aqueous solution. Based on their degree of ionization or the extent to which they produce anions and captions, electrolytes can be classified as **strong electrolytes or weak electrolytes**.

- **Strong electrolytes** ionize almost completely in aqueous solutions. **Strong electrolytes** ionize almost completely in aqueous solutions.

  Example: Strong acid and Strong base

- **Weak electrolytes** ionize only slightly in aqueous solutions.
  Example: Weak acid and Weak base

When electrical potential is applied through an electrolyte solution, the positive ions (cations) move in one direction and the negative ions (anions) move in the opposite direction. This movement of ions through the electrolyte, brought about by the application of electricity, is called **electrolytic conductivity.**

Hence, the charge-carriers in electrolytic conductivity are ***ions (anions and cations).***

Non-electrolytes: are the substances that do not transmit electricity either in solution or in a molten state**.**

Example: sugar, ethanol, oil, benzene, and liquid nitrogen.

3.3. Electrolysis

After completing this lesson, you will be able to:

- Define the term electrolysis;
- Define the terms electrode, anode, cathode, electrolyte, anion and cation;
- Describe an electrolytic cell;
- Draw and label a diagram of an electrolytic cell;
- Define the terms half-cell reaction and cell reaction;
- Write the oxidation half-reaction, reduction half-reaction and cell reaction for the electrolysis of molten or fused electrolytes.

Electrolysis is a process in which electrical energy is used to produce chemical changes. This process is carried out in an electrochemical cell known as an electrolytic or electrolysis cell.

Electrodes are strips of metal or graphite that allow electrons to leave or enter the electrolytes. They can be chemically active or inert.
An anode is the electrode attached to the positive terminal of a direct current source, at which oxidation (loss of electrons) by anions occurs, and electrons leave the cell.
A cathode is the electrode attached to the negative terminal of a dc source, the negative electrode at which reduction (gain of electrons) of cations occurs and electrons enter the cell.

During electrolysis, **anions** move to the **anode** and **captions** move to the **cathode.** The reaction taking place at each electrode (cathode or anode) is said to be a **half-cell reaction.**

electrolytic cell are represented by :

$MX \xrightarrow{\text{melting}} M^+ + X^-$

Cathode reaction: $2M^+ + 2e^- \rightarrow 2M$ **(Reduction-half reaction)**

Anode reac tion: $2X^- \rightarrow X_2 + 2e^-$ **(Oxidation half-reaction)**

Cell reaction: $M^+ + X^- \rightarrow M + X$ **(Oxidation-reduction reaction)**

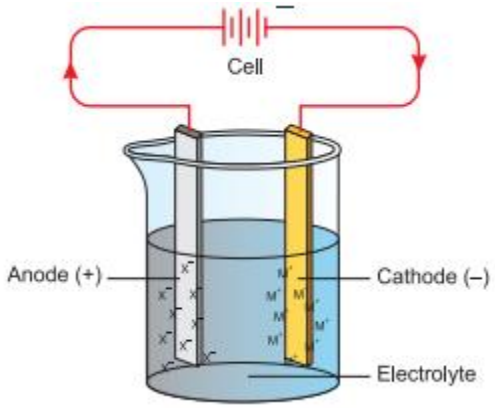


Fig 3.2**:** Electrolysis of fused Electrolyte, **MX**

Electrolysis of Molten (Fused) NaCl Electrolytes solution

Cathode reaction: $2Na^+ + 2e^- \longrightarrow 2Na$ **(Reduction-half reaction)**

Anode reac tion: $2Cl^- \longrightarrow Cl_2 + 2e^-$ **(Oxidation half-reaction)**

Cell reaction: $2Na^+ + 2Cl^- \longrightarrow 2Na + Cl_2$ **(Oxidation-reduction)**

QUESTIONS

1. What is the purpose of the salt bridge in Figure 3.3?
2. What are the differences between voltaic cells and electrolytic cells?
3. What are the differences between Primary and secondary cell?

3.4. GALVANIC (VOLTAIC) CELLS

After completing this lesson, you will be able to:

- construct a simple galvanic cell, using strips of zinc, copper, $ZnSO_4$ and $CuSO_4$ solutions;
- mention different types of voltaic cells;

- ❖ describe how voltaic cells can be used to make commercially useful batteries;
- ❖ distinguish between voltaic cell and an electrolytic cell;
- ❖ Describe voltaic cells.

GALVANIC (VOLTAIC) CELLS

Definition

Voltaic (Galvanic) cells are electrochemical cells in which a spontaneous redox reaction generates electricity. They convert chemical energy into electrical energy.

Galvanic or voltaic cells are classified into **primary cells, secondary cells, and fuel cells.**

A. Primary Cells; are those cells that are not rechargeable. because the electrode reaction as well as the entire cell reaction cannot be reversed on recharging.

Examples: **Daniel's cell and zinc-carbon (Leclanche) dry cells.**

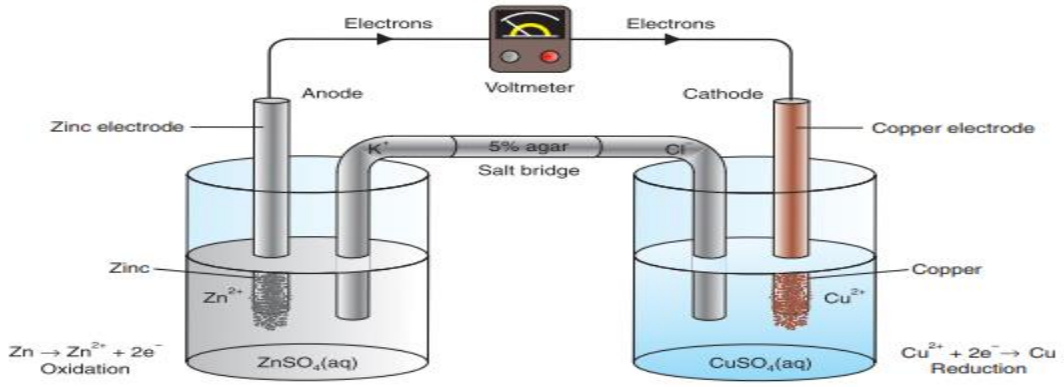


Figure 3.3.The Daniel Cell

The half-cell reactions and the cell reaction in Daniel cells are:

Anode reaction: $Zn\ (s) \rightarrow Zn^{2+}\ (aq) + 2e^-$

Cathode reaction: $Cu^{2+}\ (aq) + 2e^- \rightarrow Cu\ (s)$

Cell reaction: $Zn\ (s) + Cu^{2+}\ (aq) \rightarrow Zn^{2+}\ (aq) + Cu\ (s)$

What is the purpose of the salt bridge in Figure 3.3?

B. Secondary Cells

Secondary cells are voltaic cells that are rechargeable since the reactions taking place in them are reversible.

Example; Lead Storage Battery

A single lead-storage cell delivers **2 volts**. Therefore, a **12 V** battery contains six cells connected in series.

When a lead-storage battery is in operation (on discharge), the following reactions occur at the electrodes:

Anode reactions: $Pb\,(s) + SO_2^{-4}\,(aq) \rightarrow PbSO_4\,(s) + 2e-$

Cathode reactions: $PbO_2\,(s) + 4H^+\,(aq) + SO_2^{-4}\,(aq) + 2e^- \rightarrow PbSO_4\,(s) + 2H_2O\,(l)$

Cell reaction is: $Pb\,(s) + PbO_2\,(s) + 4H^+\,(aq)\ 2SO_2^{-4}\,(aq) \rightarrow 2PbSO_4\,(s) + 2H_2O\,(l)$

The reaction that takes place on recharging a lead storage battery is given by the following equation.

$$2PbSO_4\,(s) + 2H_2O\,(l) \rightarrow Pb\,(s) + PbO_2\,(s) + 2H_2SO_4\,(aq)$$

3.5. INDUSTRIAL APPLICATIONS OF ELECTROLYSIS

After completing this topic, you will be able to:

- Describe selected industrial applications of electrolysis

Industrial application of electrolysis is:

A. The production of chemicals like sodium hydroxide, from electrolysis of brine (concentrated NaCl solution), using inert electrodes.
B. For the production of metals and non-metals.
C. For the Purification of Metals.
D. Electroplating

Please do the Review exercise on unit 3

Unit-4

Chemistry in Industry and Environmental Pollution

4.1. INTRODUCTION

After completing this section, you will be able to:

- ❖ List general characteristics of chemical industries.

Chemistry in Industry

A chemical industry is an institution involved in the production of chemical products.

Chemical industries:

- ➢ Use naturally-available raw materials to produce the desired products.
- ➢ Involve chemical reactions to transform raw materials into finished and semi-finished products.
- ➢ Consume relatively large quantities of energy during the manufacturing process.
- ➢ Use safe operation methods in their manufacturing processes.

4.2. NATURAL RESOURCES AND INDUSTRY

After completing this section, you will be able to:

- ❖ define natural resources;
- ❖ list natural resources;
- ❖ classify natural resources as renewable and non-renewable;
- ❖ describe the applications of minerals in industry

Natural resources are classified as **renewable and non-renewable resources**.

A. **Renewable resources:** are replenished (replaced) by natural processes.

Examples: Plants, animals, soil and water.

B. Non-renewable resources: are resources that are found in a fixed amount in nature and cannot be replenished.

Examples: Natural gas, and coal.

4.3. PRODUCTION OF SOME IMPORTANT METALS AND NON-METALS

After completing this section, you will be able to:

- outline the extraction of Aluminum by the Hall process;
- describe the main physical, chemical properties and uses of aluminum
- outline the extraction of iron by the blast furnace;
- describe the conversion of pig iron in steel;
- describe wrought iron;
- describe the main chemical properties and uses of iron;
- outline the extraction of copper;
- describe the main chemical properties and the uses of copper;
- outline the production of nitrogen;
- describe the main chemical properties of nitrogen;
- outline the production of phosphorus;
- describe the main chemical properties of phosphorus;
- outline the production of oxygen;
- describe the main chemical properties of oxygen;
- outline the production of sulphur;
- describe the main chemical properties of sulphur;
- Outline the production of chlorine; and describe the chemical properties of chlorine.

4.3.1 Production of Some Important Metals

Aluminum is the most abundant metal and the **third most plentiful element** after oxygen and silicon in the earth's crust.

It is the second-most important metal, after iron, in terms of consumption.

Aluminum does not occur as a free metal in nature.

Its principal ore is bauxite **($Al_2O_3.2H_2O$).**

Other minerals containing aluminum are orthoclase (**$KAlSi_3O_8$**), Cryolite (Na_3AlF_6), corundum (**Al_2O_3),** beryl **($Be_3Al_2Si_6O_8$)** and china clay **($Al_2Si_2O_7.2H_2O$).**

Aluminum is extracted industrially, from bauxite, **$Al_2O_3•2H_2O$,** by the **Hall process.**

In this process aluminium oxide is converted to soluble sodium aluminate.

$$Al_2O_3\ (s) + 2NaOH\ (aq) \longrightarrow NaAlO_2\ (aq) + H_2O\ (l)$$

Then the solution is treated with acid to precipitate aluminum hydroxide.

$$AlO_2^-\ (aq) + H_3O^+\ (aq) \longrightarrow Al(OH)_3\ (s)$$

Aluminum hydroxide is collected by filtration, washed, dried, and then heated strongly in a furnace to get Al_2O_3.

$$2Al(OH)_3 \xrightarrow{heat} Al_2O_3 + H_2O$$

Pure aluminum oxide is mixed with some cryolite, Na_3AlF_6 **,** and then melted.

Cryolite is added to Al_2O_3 to reduce its melting point from 2045^{o}C to 1000^{o}C.

The molten mixture is then electrolyzed to obtain **aluminum.**

Physical Properties:

- It is a soft silvery-white metal having a density of 2.7 g/cm^3.
- It melts at 660°C.
- It can be shaped into wires, rolled, pressed or cast into different shapes.
- It is a good conductor of heat and electricity.

Chemical Properties:

Aluminum is a reactive metal, even though its reactions are not vigorous in comparison with those of sodium, potassium, calcium and other metals of group IA and IIA.

It undergoes the following reactions:

A. Reaction with Oxygen:

Aluminum has affinity for oxygen and reacts with atmospheric oxygen to form a thin film of aluminum oxide on its surface.

$$4Al\ (s) + 3O_2\ (g) \longrightarrow 2Al_2O_3\ (s)$$

B. Reaction with dilute acids:

Aluminum reacts with dilute acids like HCl and H_2SO_4 , forming salts and liberating hydrogen gas.

$$2Al\ (s) + 3H_2SO_4\ (aq) \longrightarrow Al_2(SO_4)_3\ (aq) + 3H_2\ (g)$$

$$2Al\ (s) + 6HCl\ (aq) \longrightarrow 2AlCl_3\ (s) + 3H_2\ (g)$$

C. Aluminum burns in chlorine gas to form Aluminum chloride:

$$2Al\ (s) + 3Cl_2\ (g) \longrightarrow 2AlCl_3\ (s)$$

d. Aluminum reacts with sodium hydroxide solution:

$$2Al\ (s) + 2NaOH\ (aq) + 6H_2O\ (l) \longrightarrow 2NaAl(OH)_4\ (aq) + 3H_2\ (g)$$

Uses of Aluminum:

- Aluminum is lightweight and corrosion resistant, so it is used to make light alloys like duralumin (mixture of Al, Cu and Mg).
- Alloys of aluminum are extensively used in the transport industry to make aircraft, ships and cars.
- It is used in the manufacture of household cooking utensils due to its high thermal conductivity and resistance to corrosion.
- It is also used to make door and window frames and roofing for buildings, as packaging material in food industries, and for electrical transmission lines.

B. Iron

Occurrence and Extraction

- Iron is the second-most abundant metal next to aluminum, in the earth's crust and it is the fourth most abundant element.
- It is never found as a free metal in nature.
- It occurs in nature only in the form of compounds, such as oxides, carbonates and sulphides.
- The chief ores of iron are hematite **(Fe_2O_3),** limonite **($Fe_2O_3.H_2O$),** magnetite **(Fe_3O_4**), and siderite **($FeCO_3$).**
- It is also found in the form of iron pyrites **(FeS_2)** which is commonly called fool's gold.
- The extraction of iron from its ores is carried out in **a blast furnace.**
- The raw materials for the extraction of iron are **iron ore, coke, limestone and hot air**.

The overall reactions in the blast furnace can be summarized as follows:

1. Oxidation of coke to carbon dioxide:

   $$C\ (s) + O_2\ (g) \longrightarrow CO_2\ (g) + heat$$

2. Reduction of carbon dioxide to carbon monoxide:

   $$CO_2\ (g) + C\ (s) \longrightarrow 2CO\ (g)$$

3. Reduction of iron oxides to metallic iron by carbon monoxide:

   $$3Fe_2O_3\ (s) + CO\ (g) \longrightarrow 2Fe_3O_4\ (s) + CO_2\ (g)$$

$$\mathbf{Fe_3O_4\ (s) + CO\ (g) \longrightarrow 3FeO\ (s) + CO_2\ (g)}$$

$$\mathbf{FeO\ (s) + CO\ (g) \longrightarrow Fe\ (l) + CO_2\ (g)}$$

4. Decomposition of the limestone by heat in the blast furnace serves as a flux to remove impurities:

$$\mathbf{CaCO_3\ (s) \xrightarrow{heat} CaO\ (s) + CO_2\ (g)}$$

5. Reaction of calcium oxide with impurities like silica (SiO_2) to form calcium silicate which is a glass-like material called **slag.**

$$\mathbf{CaO + SiO_2 \longrightarrow CaSiO_3}$$

The slag is used mostly for the manufacture of cement.

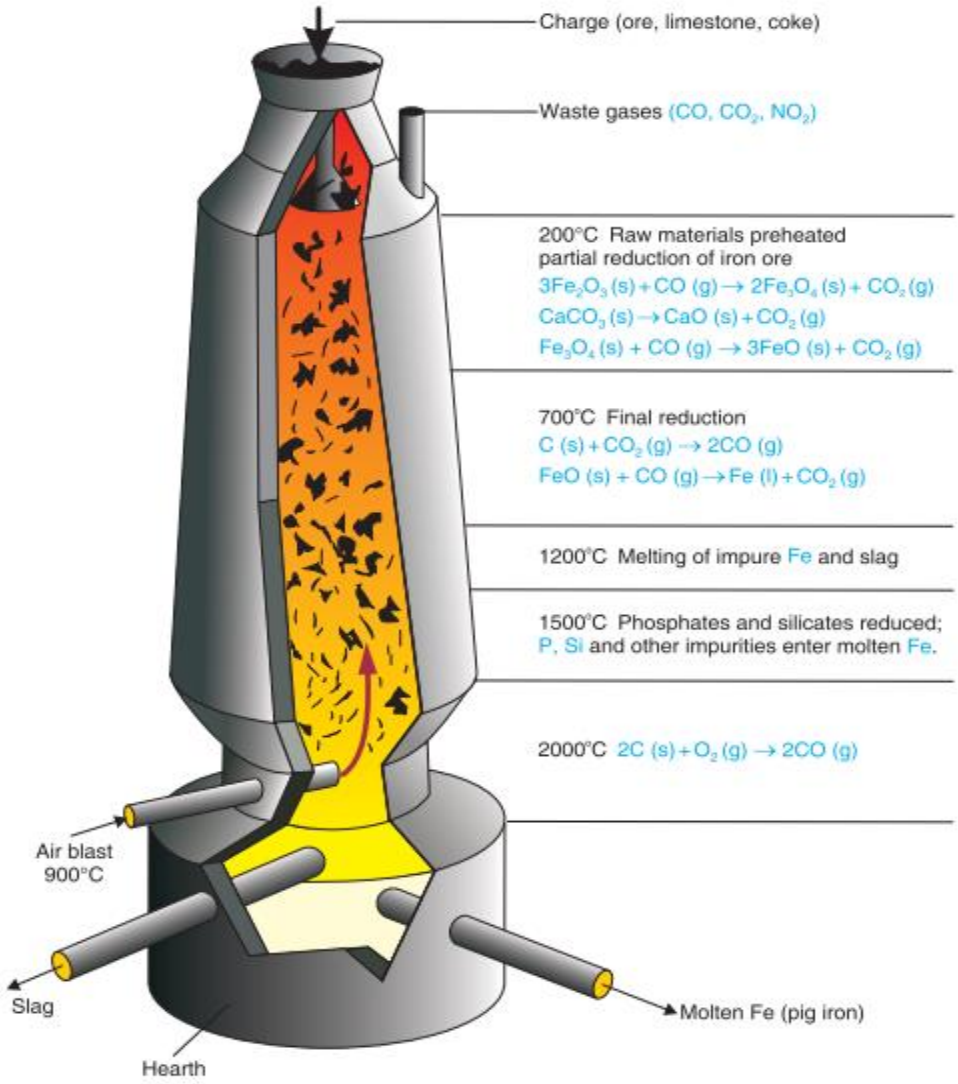


Figure 4.2 Blast furnace

The iron obtained directly from the blast furnace is called **pig iron**. It is impure and contains about 2% silicon, up to 1% phosphorus and manganese, and traces of sulphur. These impurities make pig iron **brittle**.

When pig iron is re-melted with scrap iron and cast into moulds, it forms **cast iron.**

Wrought iron: is the purest form of commercial iron. It is manufactured by heating impure iron with hematite and limestone in a furnace. This increases the purity of the iron to 99.5%. Wrought iron is a tough, malleable and ductile form of iron.

Conversion of Pig Iron to Steel

- The relatively high carbon-content of the iron recovered from the blast furnace (pig iron) makes it very hard and brittle.
- The conversion of pig iron to steel is essentially a purification process in which impurities are removed by oxidation.
- This purification process is carried out in a furnace at high temperatures. In the conversion of pig iron to steel, three different methods are used. These are the Bessemer Converter, Open-hearth Furnace and the Basic Oxygen Process.

Physical Properties of Iron

- Iron is a grey, lustrous, malleable and ductile metal.
- It is a good conductor of heat and electricity.
- It has a high melting point (1580°C) and a high density (7.87 g/cm3).
- It is a ferromagnetic metal, which means it can be permanently magnetized.

Chemical Properties of Iron

Iron is a reactive metal. Its reactivity is very slow, compared to group IA and IIA metals.

Iron rusts in the presence of air and moisture to form hydrated iron (III) oxide.

$$\mathbf{4Fe\,(s) + 3O_2\,(g) \xrightarrow{moisture} 2Fe_2O_3 .x\,H_2O(s)\ (rust)}$$

Iron reacts with dilute acids, like **HCl** and $\mathbf{H_2SO_4}$ **,** forming iron (II) salts and liberating hydrogen gas.

$$\mathbf{Fe\,(s) + 2HCl\,(aq) \longrightarrow FeCl_2\,(aq) + H_2\,(g)}$$

$$\mathbf{Fe\,(s) + H_2SO_4\,(aq) \longrightarrow FeSO_4\,(aq) + H_2\,(g)}$$

Uses of Iron

- Iron is the most widely used metal and takes first position in worldwide consumption.
- It is used as a structural metal in the construction of buildings and bridges.
- In the form of pig iron, it is used to make domestic boilers, hot-water radiators, railings, water pipes, castings, and mouldings.

- As wrought iron, it is used in making nails, sheets, horseshoes, ornamental gates, door knockers, farm machinery etc.
- Iron is also used in the manufacture of alloys such as **carbon steels and alloy steels**.

Carbon steels can be classified as **mild steel, medium steel and high-carbon steel,** based on the amount of carbon.

Mild Steel: contains up to 0.2% carbon and is used in making screws, motors, car batteries, railway lines, ships, bridges, nuts and bolts.

Medium Steel: contains 0.3–0.6% carbon and is used to make springs and chains.

High-Carbon Steel: contains 0.6–1.5% carbon and is used to make drill bits, knives, hammers and chisels

Alloy Steel: contains iron and a relatively higher percentage of other metals. For example, **stainless steel contains chromium (14–18%) and nickel (7–9%).**

Tool steels include **tungsten steel and manganese steel**. These metals give the alloy hardness, toughness and heat resistance. They are used in rock drills, cutting edges and parts of machinery that are subjected to heavy wear.

C. Copper

Occurrence and extraction

Copper is occasionally found as **native copper.** However, it is found mainly in compounds such as sulphides, oxides and the carbonates.

The most important sulphide ores are chalcopyrite (**$CuFeS_2$),** chalcocite **(Cu_2S),** covellite (**CuS)** and bornite (**Cu_5 FeS_4**).

The principal oxide ores are cuprite (**Cu_2 O)** and tenorite (**CuO**).

In the carbonate form, it exists as malachite ($CuCO_3$.$Cu(OH)_2$).

Physical Properties of Copper

- Copper is a soft, ductile, malleable, reddish-brown metal with a density of 8.96 g/cm3 .
- It is second to silver in electrical conductivity.
- It melts at 1086°C and boils at 2310°C.

Chemical properties of copper

- Copper is less reactive metal that is why it is found in the native state. Although it is not very reactive, it undergoes the following reactions:
- Powdered copper, when heated in air forms a black powder of copper (II) oxide CuO.

$$2Cu\ (s) + O_2\ (g) \longrightarrow 2CuO\ (s)$$

- Copper does not react with dilute acids like HCl and H_2SO_4 .
- It cannot displace hydrogen from acids. However, it can be oxidized by oxidizing acids such as dilute and concentrated nitric acid and hot concentrated sulphuric acid, H_2SO_4 .

$$3Cu\ (s) + 8HNO_3\ (aq) \xrightarrow{\text{dilute}} 3Cu(NO_3)_2\ (aq) + 2NO\ (g) + 4H_2O\ (l)$$

$$Cu\ (s) + 4HNO_3\ (aq) \xrightarrow{\text{concentrated}} Cu(NO_3)_2\ (aq) + 2NO_2\ (g) + 2H_2O\ (l)$$

$$Cu\ (s) + 2H_2SO_4\ (aq) \xrightarrow{\text{Hot and concentrated}} CuSO_4\ (aq) + 2SO_2\ (g) + 2H_2O\ (l)$$

Uses of Copper

- **Copper** is used to manufacture alloys. **Example:**

Bronze is an alloy of **copper and tin**, and it is used to make coins, medals, bells, machinery parts, etc.

Brass is an alloy of **copper and zinc**, and it is used for hardware tops, terminals and pipes. Copper is widely used in the electrical industry in the form of electric wires, cables etc.

- Copper compounds, such as copper chloride, copper carbonate and copper hydroxide, are used as pesticides.

4.3.2 Production of Some Important Non-metals

A. Nitrogen

Occurrence and Production

- Nitrogen occurs in nature in the elemental form.
- It also exists in the form of compounds.
- In the elemental state, it exists as a diatomic molecule, N_2 , in atmospheric air. It constitutes about 80% by volume of the atmosphere.
- In the form of compounds, it exists as sodium nitrate (Chile salt peter, $NaNO_3$) and potassium nitrate (KNO_3) also called saltpetre.
- It is also found in DNA molecules and proteins of all living things.

Physical Properties of Nitrogen

Nitrogen is colorless, odorless and tasteless gas.

It is inert under ordinary conditions, and that is why it is found in atmospheric air as N_2 .

The inertness of nitrogen at low temperatures is directly related to the strength of the triple bond, which requires high energy to break.

Chemical Properties of Nitrogen

Nitrogen reacts with metals of group IA and IIA as well as oxygen at higher temperatures. When heated with reactive metals like lithium, calcium and magnesium, it forms compounds, known as **nitrides**.

$$\mathbf{6Li\ (s) + N_2\ (g) \longrightarrow 2Li_3\ N\ (s)}$$

$$\mathbf{3Ca\ (s) + N_2\ (g) \longrightarrow Ca_3\ N_2\ (s)}$$

$$\mathbf{3Mg\ (s) + N_2\ (g) \longrightarrow Mg_3\ N_2\ (s)}$$

Nitrogen combines with oxygen at elevated temperatures or in an electric arc to form oxides.

$$\mathbf{N_2\ (g) + O_2\ (g) \longrightarrow 2NO\ (g)}$$

$$\mathbf{N_2\ (g) + 2O_2\ (g) \longrightarrow 2NO_2\ (g)}$$

Nitric oxide, also called nitrogen monoxide, **NO, is a colorless and reactive gas**.

It forms nitrogen dioxide (NO_2), a **reddish brown gas**, when it comes into contact with oxygen.

$$\mathbf{2NO\ (g) + O_2\ (g) \longrightarrow 2NO_2\ (g)}$$

This reddish brown gas dimerism at low temperatures to give a colorless gas of dinitrogen tetroxide, N_2O_4 .

$$\mathbf{2NO_2\ (g) \longrightarrow N_2\ O_4\ (g)}$$

Nitrogen also forms oxides, like dinitrogen monoxide, **N_2O, (commonly called laughing gas**), dinitrogen trioxide **(N_2O_3)** and dinitrogen pentoxide **(N_2O_5).**

Nitrogen reacts directly with hydrogen in the **Haber process** to form ammonia.

$$\mathbf{N_2\ (g) + 3H_2\ (g) \xrightarrow{400–600°C\ Fe/200–300atm} 2NH_3\ (g)}$$

The ammonia produced by this method is primarily used in the manufacture of fertilizers.

It is also used for the production of nitric acid **(HNO_3).**

Uses of Nitrogen

- Nitrogen is used in food packaging to prevent oxidation, and to create an inert atmosphere in the production of semiconductors.
- Liquid nitrogen is used as a refrigerant to preserve bulls' semen and blood.
- Its major use is in the production of ammonia.

B. Phosphorus

Occurrence and Extraction

Does phosphorus exist in the pure form (elemental state) as does nitrogen? If not, why? Phosphorus is a relatively abundant element, ranking 12th in the earth's crust. It exists naturally only in the combined state, such as in rock phosphate, **$Ca_3 (PO_4)_2$** , fluoroapatite, **$Ca_{10}(PO_4)_6 F_2$ or $3Ca_3 (PO_4)_2 .CaF_2$** .

It is also found in **teeth, bones and DNA.**

Allotropes are different forms of the same element with the same physical state but with different physical properties. This is due to the difference in the arrangement of atoms.

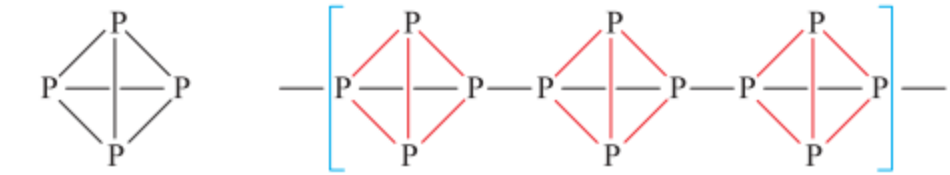
The two common allotropic forms of phosphorus are **white phosphorus and red phosphorus**.

White phosphorus:

- Is a very poisonous, white waxy-looking substance that melts at 44.1°C and boils at 287°C.
- Its density is 1.8 g/cm^3.
- It consists of individual tetra-atomic (P_4) molecules and is an unstable form of phosphorus

Red phosphorus:

- Is denser (2.16 g/cm^3) and is much less reactive than white phosphorus at normal temperatures.
- It consists of P_4 molecules linked together to form a polymer (large molecule) as shown below.



Chemical Properties of Phosphorus

Phosphorus exhibits the following common chemical reactions.

Phosphorus reacts with limited and excess supplies of oxygen to form tetra phosphorus hex oxide **(P_4O_6)** and tetra phosphorus decoxide **(P_4O_{10})** respectively.

$$P_4\,(s) + 3O_2\,(g) \longrightarrow P_4\,O_6\,(s)$$

$$P_4\,(s) + 5O_2\,(g) \longrightarrow P_4\,O_{10}\,(s)$$

$P_4\,O_6$ and $P_4\,O_{10}$ dissolve in water to form phosphorous acid, H_3PO_3 , an orthophsophoric acid, H_3PO_4 respectively.

$$P_4O_6\,(s) + 6H_2O\,(l) \longrightarrow 4H_3PO_3\,(aq)$$

$$P_4O_{10}\,(s) + 6H_2O\,(l) \longrightarrow 4H_3PO_4\,(aq)$$

Phosphorus also reacts with limited and excess supplies of chlorine to form phosphorus (III) chloride **(PCl_3)** and phosphorus (V) chloride **(PCl_5)** respectively.

$$P_4\,(s) + 6Cl_2\,(g) \longrightarrow 4PCl_3\,(s)$$

$$P_4\,(s) + 10Cl_2\,(g) \longrightarrow 4PCl_5\,(s)$$

C. Oxygen

Occurrence and Production

Oxygen is the most abundant element on earth. It constitutes about 46.6% by weight of the earth's crust in the form of compounds such as oxides, silicates, carbonates, phosphates etc.

It exists in nature in the elemental state in atmospheric air constituting about 20% by volume.

Oxygen is manufactured industrially by the **fractional distillation** of liquid air in a way similar to that of nitrogen.

Chemical Properties of Oxygen

Oxygen is relatively reactive and combines directly with most elements to form oxides.

It combines with metal to form metal oxides (basic oxides).

Example: $2Mg\,(s) + O_2\,(g) \longrightarrow 2MgO\,(s)$

$$2Ca\,(s) + O_2\,(s) \longrightarrow 2CaO\,(s)$$

Oxygen combines with non-metals to form acidic oxides;

example $S_8\,(s) + 8O_2\,(g) \longrightarrow 8SO_2\,(g)$

$P_4\,(s) + 5O_2\,(g) \longrightarrow P_4O_{10}\,(g)$

Oxygen supports combustion and is necessary for the burning of substances like charcoal, hydrocarbon fuel, etc

$C\,(s) + O_2\,(g) \longrightarrow CO_2\,(g)$

$CH_4\,(g) + 2O_2\,(g) \longrightarrow CO_2\,(g) + 2H_2O\,(g)$

D. Sulphur

Occurrence and Extraction

Sulphur is found in nature and in the form of compounds such as galena (PbS), pyrites (FeS_2) (fool's gold), cinnabar (HgS), sphalerite (ZnS), gypsum ($CaSO_4 .2H_2O$), barite ($BaSO_4$), and as hydrogen sulphide (H_2S) in natural gas and crude oil.

It is extracted from underground deposits of elemental sulphur by the **Frasch process.**

Uses:

- Nearly one-half of the sulphur needed by chemical industries is obtained as a waste product of other industrial processes. example, sulphur can be obtained in the form of hydrogen sulphide (H_2S) from natural gas and during the purification of crude oil.
- It can also be obtained in the form of sulphur dioxide from the roasting of sulphide ores during the manufacture of metals.
- The use of sulphur obtained from waste products of other industries reduces the demand for the element from natural deposits. This also reduces the pollution of atmospheric air and the formation of acid rain.

Sulphur exhibits allotropy. The most important allotropes of sulphur are **rhombic and monoclinic sulphur.**

Rhombic sulphur

is the most stable form of sulphur consisting of S_8 molecules.

Chemical Properties of Sulphur

Sulphur is relatively stable and unreactive at room temperature. However, it reacts with metals and non-metals when heated.

Sulphur combines with metals when heated to form sulphides.

$$\mathbf{8Fe\ (s) + S_8\ (s) \longrightarrow 8FeS\ (s)}$$

Sulphur burns in oxygen to form oxides.

$$\mathbf{S_8\ (s) + 8O_2\ (g) \longrightarrow 8SO_2\ (g)}$$

Sulphur is the raw material for the production of sulphuric acid (H_2SO4) by the **Contact Process**. This process of sulphuric acid production involves the following steps.

Step 1: Sulphur is first oxidized to produce sulphur dioxide:

$$\mathbf{S_8\ (s) + 8O_2\ (g) \longrightarrow 8SO_2\ (g)}$$

Step 2: Sulphur dioxide is converted to sulphur trioxide at high temperatures in the presence of a catalyst: $\mathbf{2SO_2\ (g) + O_2 \xrightarrow{V_2O_5} 2SO_3\ (g)}$

Step 3: Sulphur trioxide is absorbed into concentrated sulphuric acid to produce oleum($H_2S_2O_7$).

$$\mathbf{SO_3\ (g) + H_2SO_4\ (l) \longrightarrow H_2S_2O_7\ (l)}$$

Step 4: The oleum is then diluted with water to produce the desired concentration of sulphuric acid. Commercially used concentrated sulphuric acid is **98% H_2SO_4.**

$$\mathbf{H_2S_2O_7\ (l) + H_2O\ (l) \longrightarrow 2H_2SO_4\ (aq)}$$

E. Chlorine

Occurrence and Extraction

- **Chlorine** belongs to group **VIIA,** known as the **halogens**.
- It is the most abundant element among the halogens.
- It is found in nature in the form of compounds only.

Chlorine is found in nature chiefly in the form of chlorides of sodium, potassium, calcium and magnesium.

- Sodium chloride is the chief source of chlorine, and it is obtained from seawater or as deposits of rock salt.

Physical Properties of Chlorine

Some of its physical properties are the following:

- Chlorine is a greenish-yellow gas at room temperature.
- It melts at –102°C and boils at –34°C.
- It is fairly soluble in water.
- It is extremely poisonous, causing inflammation of the lungs and mucous membranes if inhaled, even in very small amounts. It is fatal if inhaled in higher amounts.

Chemical Properties of Chlorine

Chlorine is a highly reactive non-metal.

It reacts directly with almost all elements except the noble gases, carbon and nitrogen.

It is a powerful oxidizing agent and oxidizes most of the elements with which it reacts.

The following are the main reactions of chlorine

Chlorine reacts with heated metals to form chloride salts

$$\mathbf{2Fe\ (s) + 3Cl_2\ (g) \longrightarrow 2FeCl_3\ (s)}$$

$$\mathbf{2Al\ (s) + 3Cl_2\ (g) \longrightarrow 2AlCl_3\ (s)}$$

Chlorine reacts smoothly with hydrogen, in the presence of a charcoal as a catalyst, at room temperature to form hydrogen chloride.

$$\mathbf{H_2\ (g) + Cl_2\ (g) \longrightarrow 2HCl\ (g)}$$

4.4 SOME INDUSTRIES IN ETHIOPIA

After completing this section, you will be able to:

- define industry;
- list some industries in Ethiopia;
- describe the general characteristics of industries;
- outline the important steps in the productions of ceramics;
- mention some uses of ceramics;
- outline the important steps in the production of cement;
- outline the important steps in the production of sugar;
- outline the important steps in the production of pulp and paper;

- ❖ explain how tanning is carried out;
- ❖ describe the application of the chemical preservation of skin and hides; • mention some uses of skin and hides;
- ❖ explain the process of food packing and preservation; and present a report to the class after visiting a nearby food factory.

Glass

Glass is an amorphous or non-crystalline solid material. Almost all glass contains silica as the main component.

Quartz glass is made by melting pure silica, SiO_2, at a temperature of about 2300°C and then pouring the molten viscous liquid into moulds.

It is of high strength, low thermal expansion and highly transparent.

Soda-lime glass is ordinary glass which is a mixture of **sodium silicate** and **calcium silicate**.

$$\mathbf{Na_2CO_3 + SiO_2 \longrightarrow Na_2SiO_3 + CO_2}$$

$$\mathbf{CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + CO_2}$$

This type of glass is widely used for window panes, bottles, dishes etc.

Borosilicate glass is commonly known as **Pyrex**. It is manufactured using **boron (III) oxide**, $\mathbf{B_2O_3}$, instead of **limestone or calcium oxide**.

It is widely used to make ovenware and laboratory equipment such as flasks, beakers, and test tubes.

Steps in glass production

i. Batch preparation

ii. Glass melting

iii. Glass forming

iv. Annealing

v. Inspection

vi. Packing and dispatching

Ceramics

Ceramic is an inorganic, non-metallic solid prepared by the action of heat and subsequent cooling.

The processes of manufacturing ceramics include:

A. Moulding

B. Densification

In general, most ceramics are hard and wear-resistant, brittle, refractory, thermal and electrical insulators, non-magnetic, oxidation-resistant, and chemically stable.

Uses of ceramic:

- art sculptures, dishes, platters and other kitchenware,
- kitchen tiles and bath room structures.
- bones in hips, knees and shoulders.

Cement

- **Cement** is made by heating limestone (chalk), alumina ($\mathbf{Al_2O_3}$) and silica-bearing materials such as clay to 1450°C in a kiln using a process known as **calcinations.**
- Cement is made by heating limestone (chalk), alumina ($Al_2 O_3$) and silica-bearing materials such as clay to 1450°C in a kiln using a process known as calcinations.
- Cement mainly consists of calcium silicate ($\mathbf{CaSiO_3}$ **),** calcium aluminate ($\mathbf{CaAl_2O_4}$ **),** iron (III) oxide ($\mathbf{Fe_2O_3}$ **)** and magnesium oxide **(MgO).**

Raw Materials:

Limestone and clay are the chief raw materials used in the manufacture of **Portland cement.**

Sugar Manufacturing

Sugarcane is a perennial herb belonging to the grass family.

Planting: Sugarcane is planted in fields by workers or mechanical planters.

Sugar manufacturing process

1. Collecting the Harvest
2. Cleansing and Grinding:

3. Juicing:
4. Clarifying
5. Evaporation
6. Crystallization
7. Refinery
8. Separation and packaging

Tannery

Tanning is a process of converting raw animal hides and skin to leather, using tannin. **Leather** is a durable and flexible material created by the tanning of animal hides and skin.

Tannin is an acidic chemical that permanently alters the protein structure of a skin so that it can never return to rawhide or skin again.

Leather production involves various preparatory stages, tanning, and crusting

1. **Preparatory stages** are those in which the hide or skin is prepared for tanning. This stage includes curing, soaking, flesh removal, hair removal, scudding, and deliming.
    - **A. Curing:** This process involves salting or drying the hide once it has been removed from the animal. Curing is employed to prevent putrefaction of the protein substance, collagen, from bacterial infection. Curing also removes excess water from the hide and skin. Brine curing is the simplest and fastest method.
    - **B. Soaking:** In this process, cured hides are soaked in water for several hours to several days to remove salt, dirt, debris, blood and excess animal fat from the skin.
    - **C. Flesh removal:** In this process, animal hides are moved through a machine that strips the flesh from the surface of the hide.
    - **D. Hair removal:** In this step, the soaked hides and skins are transported to large vats where they are immersed in a mixture of lime and water. This process is called **liming**.

      It loosens the hair from the skin and makes hair-removal easier. After 1–10 days soaking, the hair is mechanically removed from the hide by a hair-removing machine.

E. **Scudding:** This is the process in which hair and fat missed by the machines are removed from the hide with a plastic tool or dull knife.

F. **Deliming:** This process involves the removal of lime from the skin or hide in a vat of acid. After this preparatory process, the skin or hide is ready for tanning.

2. Tanning is a process that converts the protein of the raw hide or skin into a stable material.

There are **two** main types of tanning:

A. Vegetable or natural tanning: The skin is placed in a solution of tannin. Tannins occur naturally in the barks and leaves of many plants. The primary barks used in modern times are chestnut, oak, tanoak, hemlock, quebracho, mangrove, wattle (acacia) and myrobalan. Naturally tanned hide is flexible and is used for making shoes, luggage and furniture.

B. Mineral tanning: In this process, the skin is placed in solutions of chemicals such as chromium sulphate and other salts of chromium. Chrome tanning is faster than natural (vegetable) tanning and requires only twenty four hours. The leather is greenish-blue in color derived from the chromium. This process produces stretchable leather that is used for making garments and handbags.

3. Crusting: This is the final stage in leather manufacturing and includes dyeing, rolling the leather to make it strong, stretching it in a heat-controlled room and performing a process that involves covering the grain surface with chemical compounds such as wax, oil, glazes etc. to make the leather very attractive.

Food Processing and Preservation

Food preservation is the process of treating and handling food to stop or greatly reduce spoilage, loss of quality, edibility or nutritive value caused or accelerated by microorganisms.
Preservation usually involves preventing the growth of bacteria, fungi and other microorganisms, as well as reducing the oxidation of fats, which causes **rancidity.**

Modern methods of food preservation are:

A. **Freezing:** This is one of the most commonly used processes, commercially and domestically, for preserving a very wide range of foods such as potatoes, as well as prepared foodstuffs that would not require freezing in their normal state.

B. **Freeze-drying:** Water vapor has easier access through the cell structure of any product compared to water-penetrating the product and evaporating from the surface of the product as is the case of other drying methods. The gentle escape of water vapor in the freeze-drying process leaves the product close to its original shape, taste, and color and there is no loss of aroma or flavor. For example, liquids such as coffee, tea, juices and other extracts, vegetables, segments of fish and meat products. Freeze-drying is a superior preservation method for a variety of food products and food ingredients.

C. **Vacuum-packing**: Stores food in a vacuum environment, usually in an air-tight bag or bottle. The vacuum environment strips bacteria of the oxygen needed for survival, slowing down the rate of spoiling. Vacuum-packing is commonly used for storing nuts to reduce loss of flavor from oxidation.

4.5. ENVIRONMENTAL POLLUTION

Pollution is any discharge of a solid, liquid or gaseous substance or radiation (energy) into an environment that causes unwanted changes. Pollution causes short-term or long-term harm that affects the earth's ecological balance and lowers the quality of life in the environment.

A pollutant is any substance that changes air, water or any other natural resource in a way that impairs the use of the resource. Pollutants are discharged into the environment as a result of natural events (like a volcanic eruption) and as a result of human activities (such as the operation of chemical industries, agriculture, etc.). **Pollutants** can be classified by the type of pollution they cause: **air pollution, water pollution, and land pollution. Air Pollution.**

Air pollution is caused by the presence of contaminant gaseous substances in the air that affect the lives of plants and animals on earth.

Some common air pollutants are sulphur dioxide, nitrogen oxides, carbon monoxide, ozone, hydrocarbons, particulates, chlorofluorocarbons **(CFCs),** and lead compounds.

Sulphur dioxide (SO_2): This enters the atmospheric air from the combustion of coal and petroleum, and during extraction of metals from their sulphide ores. It causes **coughing**, **chest pains** and **shortness of breath**.

It is thought to be a cause for bronchitis and lung diseases.

It slowly oxidizes to **SO_3** by reacting with the oxygen in the air.

Oxides of nitrogen: These can be formed in the atmosphere by natural processes like thunderstorms. Combustion of fossil fuel containing nitrogen compounds as impurities and exhaust gases from furnaces and engines increase the amount of nitric oxide, **NO**, and nitrogen dioxide, **NO_2** , in the atmosphere.

Nitric oxide, **NO,** catalyzes the decomposition of ozone in the upper layer of the atmosphere to oxygen, thus decreasing the ozone layer.

$$2O_3\,(g) \xrightarrow{NO} 3O_2\,(g)$$

Nitric oxide is oxidized by oxygen to nitrogen dioxide in the presence of ultraviolet light.

$$2NO\,(g) + O_2\,(g) \longrightarrow 2NO_2\,(g)$$

SO_2 , SO_3 and NO_2 react with rainwater and form sulphurous acid (H_2SO_3), sulphuric acid (H_2SO_4) and nitric acid (HNO_3), respectively and cause **acid rain**.

Acid rain accelerates corrosion and the deterioration of metals, buildings, statues and also causes tree defoliation, release of heavy metal ions from soil into water courses and drop in the pH of water in rivers and lakes.

Hydrocarbons and ozone are responsible for photochemical smog. It is characterized by a reddish-brown haze containing substances irritating to the eye, nose, and lungs, and causes extensive damage to vegetation. Considerable amounts of hydrocarbons are released into the atmosphere by the evaporation of gasoline as unburnt hydrocarbons in auto exhaust. These substances react with ozone to give compounds that contribute to the oxidizing nature of photochemical smog.

Carbon monoxide: Most of the carbon monoxide escapes into the atmosphere due to the incomplete combustion of fuel. Prolonged exposure to carbon monoxide impairs vision,

produces headaches, and exerts strain on the heart. It also reduces the oxygen-carrying capacity of the blood by reacting with hemoglobin.

Particulates: Dust storms, forest fires, volcanic eruptions and human activities such as mining and burning coal and oil increase the amount of solid particles in the air. Industrial areas contain particles of limestone, fertilizers, coal, stones, cement and silica. These particulates irritate the lungs and deleteriously affect breathing.

Chlorofluorocarbons (CFCs): Chlorofluorocarbons are used as refrigerants, solvents and plastic foam-blowing agents. When entering the atmosphere, they penetrate into the upper layers and interact with ultraviolet radiation as follows.

$$\mathbf{CF_2Cl_2 \xrightarrow{UV} CF_2Cl. + .Cl}$$

The free chlorine, Cl, reacts with ozone to form chlorine monoxide and oxygen.

$$\mathbf{.Cl + O_3 \longrightarrow ClO. + O_2}$$

These reactions result in the conversion of ozone to molecular oxygen and contribute to depletion of the ozone layer. This situation in the upper atmosphere allows dangerous ultraviolet radiation to reach the earth's surface. This radiation causes **skin cancer in human beings.**

Excess carbon dioxide: The combustion of coal and petroleum to generate electricity, move our vehicles, heat our homes and supply power to our industrial machinery causes a significant increase in the concentration of carbon dioxide in the atmosphere.

Combustion of these fuels releases about 20 billion tonnes of CO_2 annually. The increase in the concentration of CO_2 in the atmosphere has resulted in a rise in the average global temperature, owing to the greenhouse effect. Carbon dioxide and water vapour absorb infrared radiation, re-radiated from the earth, behaving like the glass in a green house. Since CO_2 and water vapour absorb heat they are called green-house gases.

Heavy metals: Lead contamination in the atmosphere is a result of vehicle engines that use fuels containing tetraethyl lead which is added to the fuel to reduce engine knocking. The use of lead paints also contributes towards lead contamination. High levels of lead cause damage to the brain, kidneys and liver.

What are the potential air pollutants in and around your home? Methods of Reducing Air Pollution:

Water Pollution

Water pollution is the degradation of the quality of water brought about by the discharge into it of untreated sewage, industrial and agricultural waste, and oil spillage.

In general, water is said to be polluted if it contains matter that affects the health of living things or causes damage to property.

The major water pollutants are nitrate and phosphate fertilizers washed out of the soil, phosphate detergents, untreated sewage, insecticides and herbicides, and the heavy metal ion, acidic and/or basic residues released by industrial processes.

Phosphate and nitrate fertilizers washed out of the soil and phosphate detergents from untreated water, enter natural water systems, such as streams, rivers, lakes, and seas. These dissolved minerals are valuable nutrients for plants, and their discharge into the water systems accelerates the growth of surface-water plants, such as algae. As a result, less light reaches the bottom-living plants, which reduces the photosynthesis they need to live, and they die. When these aquatic plants die, they rot under the action of bacteria which multiply greatly and consume the oxygen dissolved in the water at a rate faster than natural aeration or photosynthesis can replenish. Thus, the amount of oxygen in the water decreases. This depletion of oxygen kills aquatic animals like fish. This sequence of events is called **eutrophication. Insecticides (pesticides) and herbicides** applied in agriculture may also be washed into lakes, rivers, streams and seas.

Some of the insecticides and herbicides do not decompose easily and are persistent in the environment. Residues of these insecticides and herbicides may enter the food chains and accumulate in an organism that is consumed by the next organism. The increasing amount of insecticide and herbicide residue in the *bodies of animals causes health and behavioral problems.*

The release of untreated sewage to natural water systems can spread water-borne diseases such as cholera, typhoid, hepatitis, and polio.

Methods of Reducing Water Pollution:

1. Treatment of water before discharge into rivers and lakes.

2. To avoid unnatural temperature changes in natural water systems, industries should not discharge heat-ladened water into them.

3. Recycling industrial and agricultural wastes.

4. Using moderate amounts of agricultural chemicals and increasing the use of organic fertilizers and biological methods to control pests.

Land Pollution

Land pollution is caused by things we put into it. It results from the spillage of oil, leaching of harmful chemicals and heavy metal ions, and dumping of non-biodegradable wastes such as plastics.

Factors involved in land pollution include:

- Spillages of oil from leaking pipelines.
- Harmful heavy metal ions from buried waste leaching into water systems.
- Leaching of harmful chemicals from corroded metal drums which have been buried underground
- Dumping of non-biodegradable (do not decompose by the action of bacteria) wastes like plastics which remain unchanged in the soil for decades or hundreds of years. Their accumulation in the soil hinders air and water movement and affects the growth of plants.
- Excessive use of synthetic fertilizers in agricultural activities also contributes towards land pollution.