23

GENERAL METALLURGICAL PRINCIPLES

23.1 INTRODUCTION

Metals are extensively used in our day to day life. They are used for making machines, railways, motor vehicles, bridges, buildings, agricultural tools, aircrafts, ships etc. Therefore, metals and their alloys* are used for different purposes. Therefore, production of a variety of metals in large quantities in necessary for the economic growth of a country. Only a few metals such as gold, silver, mercury etc. occur in free state in nature. Most of the other metals, however, occur in the earth's crust in the combined form, i.e., as compounds with different anions such as oxides, sulphides, halides etc. In view of this, the study of recovery of metals from their ores in very important. In this lesson, you shall learn about some of these processes of extraction of metals from their ores, called **metallurgical processes.**

23.2 OBJECTIVES

After reading this lesson, you will be able to:

- differentiate between minerals and ores.
- cite the place of occurance of the metals Na, Al, Sn,Pb, Ti, Fe, Cu,Ag, and Zn.

* An alloy is a material consisting of two or more metals, or a metal and a non-metal. For example, brass is an alloy of copper and zinc; steel is an alloy of iron and carbon. An alloy may be a compound or a mixture of components.

- write the names of the common ores of the above metals.
- cite examples of oxide, sulphide, halide and carbonate ores.
- list the different steps involved in the extraction of metals from their ores.
- suggest the choice of an appropriate reducing agent for a particular ore.
- explain froth-floatation process, gravity separation process and electromagnetic separation process of purfication of ores.
- explain the terms roasting, calcination and smelting by giving suitable examples.
- differentiate between flux and slag.

23.3 MINERALS AND ORES

Metals occur in nature in free as well as combined form. Metals having low reactivity show little affinity for air, moisture, carbon dioxide or other non-metals present in nature. Such metals remain in elemental or native (free) state in nature. Such metals are called "noble metals" as they show the least chemical reactivity. For example, gold, silver, mercury and platinum occur in free state.

On the other hand, most of the metals are active and combine with air, moisture, carbon dioxide and non-metals like oxygen, sulphur, halogens etc. to form their compounds, i.e., they occur in nature in a combined state.

A naturally occurring material in which a metal or its compound occurs is called a *mineral*. A mineral from which a metal can be extracted economically is called an *ore*.

> An ore is that mineral in which the metal is present in large quantities and from which a metal can be extracted in pure and high quality, economically.

The main active components present in nature, especially in the atmosphere are oxygen and carbon dioxide. In the earth's crust, sulphur and silicon are found in large quantities. Sea-water contains large quantities of chloride ions (obtained from dissolved sodium chloride). Most active metals are highly electropositive and therefore exist as ions. It is for this reason that most of the important *ores* of these metals occur as (i) oxides (ii) sulphides (iii) carbonates (iv) halides (v) silicates. Some sulphide ores undergo oxidation by air to form sulphates. This explains the occurrence of sulphate ores

Ores are invariably found in nature in contact with rocky materials. These rocky or earthy impurities accompanying the ores are termed as *gangue* or *matrix.*

Some important ores and the metals present in these ores are listed in Table 23.1

23.4 MINERAL WEALTH OF INDIA

India possesses large deposits of some important minerals of metals such as iron, manganese, aluminium, magnesium, chromium, thorium, uranium, titanium and lithium. Mineral fuels (like coal, lignite, petroleum and natural gas) constitute more than 80% while metallic minerals constitute only about 10% of the total value of mineral production in a year. In this section, we shall list some of the important minerals of a few common metals such as Fe, Cu, Ag, Zn, Ti, Al Sn, Pb and Na and their locations in India.

TABLE 23.1: SOME IMPORTANT ORES.

TYPE OF ORE	METALS (COMMON ORES)
Native Metals	Gold (Au), silver (Ag)
Oxide ores	Iron (Haematite, Fe_2O_3); Aluminum (Bauxite, $Al_2O_3.H_2O$); Tin (Cassiterite, SnO_2); Copper (Cuprite, Cu_2O); Zinc (Zincite, ZnO); Titanium (Ilmenite, $FeTiO_3$, Rutile, TiO_2)
Sulphide ores	Zinc (Zinc blende or blackjack, ZnS); Lead (galena, PbS); Copper (Copper glance, glance, Cu_2S); Silver (Silver glance or Argentite, AgS); Iron (Iron pyrites, $FeSe_2$)
Carbonate ores	Iron (Siderite, $FeCO_3$); Zinc (Calamine, $ZnCO_3$), Lead (Cerrusite, $PbCO_3$)
Sulphate ores	Lead (Anglesite, $PbSO_4$)
Halide ores	Silver (Horn silver, AgCl); Sodium (Common salt or Rock salt, NaCl); Aluminium (Cryolite, Na_3AlF_6)
Silicate ores	Zinc (Hemimorphite, $2ZnO.SiO_2.H_2O$)

Iron — Iron ore reserves in the country are estimated at 1750 crore tonnes. Major iron ore mining is done in Goa, Madhya Pradesh, Bihar, Karnataka, Orissa and Maharashtra.

Aluminium — Its chief ore, bauxite is available in India in abundance. The annual production of bauxite is estimated to be more than 2 million tonnes. Important deposits of bauxite in the country occur in Bihar, Goa, Madhya Pradesh, Maharashtra, Tamil Nadu, Gujarat, Karnataka, Orissa, Uttar Pradesh, Andhra Pradesh, Jammu & Kashmir and Rajasthan.

Copper — India does not have rich copper ore deposits. The total reserves of the ore in the country are estimated around 60 crore tonnes. Major ore producing areas are in Singhbum district (Bihar), Balaghat district (Madhya Pradesh) and Jhunjhunu district (Rajasthan).

Zinc and Lead — India has no significant deposits of lead ores. Lead and Zinc have been locted at Zawar mines near Udaipur (Rajasthan) and at Hazaribagh (Bihar), Sargipalli mines in Orissa and Bandalamottu lead project in Andhra Pradesh. Some reserves have been located in Gujarat and Sikkim. The total reserves are estimated at about 36 crore tonnes in which lead content is estimated to be around 0.5 crore tonnes and zinc to be around 1.6 crore tonnes.

Tin — Deposits of tinstone (SnO_2) are found Hazaribagh (Bihar) and Orissa.

Silver — India does not possess rich silver deposits. Gold from Kolar fields and Hutti gold fields (Karnataka) and lead-zinc ores of Zawar mines (Rajasthan) contain some silver.

Titanium — Ilmenite ($FeTiO_3$) is recovered from beach sands of Kerala and Tamil Nadu. The estimated reserves are around 100 to 150 million tonnes.

Sodium : — Tincal or Native borax ($Na_2B_4O_7.10H_2O$) is found in Ladakh and Kashmir.

23.5 EXTRACTION OF METALS

The process of extracting the metals from their ores and refining them is called *metallurgy*. The choice of the process depends upon the nature of the ore and the type of the metal. The metal content in the ore can vary depending upon the impurities present and chemical composition of the ore. Some common steps involved in the extraction of metals from their ores are:

(i) Crushing and pulverization

(ii) Concentration or dressing of the ore

(iii) Calcination or roasting of the ore

(iv) Reduction of metal oxides to free metal

(v) Purification and refining of metal.

23.6 CRUSHING AND PULVERIZATION

The ore is generally obtained as big pieces. These big lumps of the ore are crushed to smaller pieces by using *jaw-crushers* and *grinders*. It is easier to work with crushed ore. The big lumps of the ore are brought in between the plates of a crusher forming a jaw. One of the plates of the crusher is stationary while the other moves to and fro and the crushed pieces are collected below as shown in Fig. 23.1

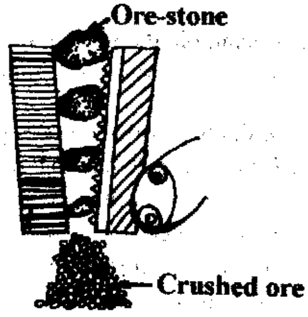

Fig. 23.1: The Jaw crusher.

The crushed pieces of the ore are then pulverized (powdered) in a stamp mill shown in Fig 23.2 The heavy stamp rises and falls on a hard die to powder the ore. The powdered ore is then taken out through a screen by a stream of water. Pulverization can also be carried out in a ball mill. The crushed ore is added in a steel cylinder containing iron balls. The cylinder is set into revolving motion. The striking balls pulverize the crushed ore into fine powder.

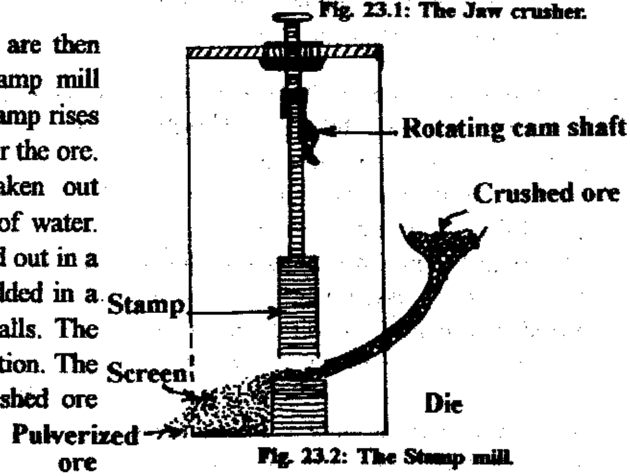

Fig. 23.2: The Stamp mill.

23.7 CONCENTRATION OR DRESSING THE ORE

Generally, the ores are found mixed with earthy impurities like sand, clay, lime stone etc. These unwanted impurities in the ore are called *gangue* or *matrix*.

> **The process of removal of gangue from powdered ore is called concentration or ore dressing.**

There are several methods for concentrating the ores. The choice of method depends on the nature of the ore. Some important methods are:

(i) **Gravity separation:** In this method, the light (low specific gravity) earthy impurities are removed from the heavier metallic ore particles by washing with water. It is therefore, used for the concentration of heavier oxide ores, like haematite (Fe_2O_3) tinstone (SnO_2) and gold (Au). In this method, the powdered ore is agitated with water or washed with a strong current of water. The heavier ore settles down rapidly and the lighter sandy and earthy materials are washed away. The two common methods employed for this hydraulic washing of the ore are generally (A) Hydraulic classifier and (B) Wilfley's washing table.

(ii) **Magnetic separation** method : By this method, only those ores can be concentrated which either contain impurities which are magnetic or the metals which are to be extracted are magnetic in nature.

This method in used to separate magnetic materials from the nonmagnetic ores.

For example,the tin ore, tin stone (SnO_2) itself is non-magnetic but contains magnetic impurities such as iron tungstate and manganese tungstate ($FeWO_4$ and $MnWO_4$).

The finely powdered ore is passed through a conveyer belt moving over two rollers and one of which is fitted with an electromagnet (Fig. 23.3). The magnetic material is attracted by the magnet and thus falls the belt in a heap nearer the magnet. This way magnetic impurities are separated from nonmagnetic material.

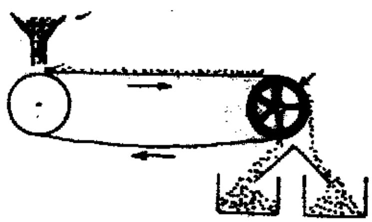

Fig. 23.3: Magnetic separation method.

(iii) **Froth floatation method:** This method is especially applied to low grade sulphide ores, such as **galena** (PbS), **Zinc blende** (ZnS), or **copper pyrites** ($CuFeS_2$). It is based on the different wetting properties of the surfaces of the ore and gangue particles. The sulphide ore particles are wetted preferentially by oil and gangue particles by water. In this process, finely powdered ore is mixed with either pine oil or eucalyptus oil. It is then mixed with water. Air is blown through the mixture with a great force. Froth is produced in this process which carries upwards with it the purified ore. Impurities (gangue particles) are left in water and sink to the bottom from which these are drawn off (Fig 23.4)

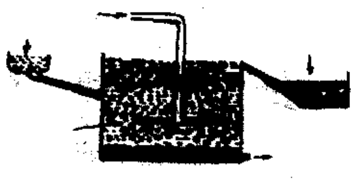

Fig. 23.4: Froth flotation method.

(iv) **chemical method:** In this method the ore is treated with a suitable chemical reagent which dissolves the ore leaving behind insoluble impurities. The ore is recovered by a suitable chemical method. It is employed when the ore is to be concentrated to a very pure form. This is applied for aluminium extraction from bauxite ($Al_2O_3.2H_2O$). Bauxite is contaminated with Iron (III) oxide (F_2O_3) Titanium oxide (TiO_2) and (SiO_2). These impurities are removed by digesting the powdered ore with aqueous solution of sodium hydroxide at 420 K under pressure. Aluminium oxide dissolves in sodium hydroxide, whereas, Iron (III) oxide, silica and titanium oxide (SiO_2 and TiO_2) remains insoluble and removed by filtration.

$$Al_2O_3 + 6NaOH \longrightarrow 2Na_3AlO_3 + 3H_2O$$

Sodium aluminate is diluted with water to obtain precipitates of aluminium hydroxide. It is filtered and ignited to obtain pure alumina.

$$Na_3AlO_3 + 3H_2O \longrightarrow Al(OH)_3 + 3NaOH$$

$$2Al(OH)_3 \xrightarrow{\Delta} Al_2O_3 + 3H_2O$$

INTEXT QUESTIONS 23.1

1. Write the names of eight important metals. Give an example of one important ore of each metal.

   ....

2. What is the difference between an ore and a mineral?

   ....

3. Name some important methods of concentrating the ores of metals.

   ....

4. Which method of concentration is applied in the following cases?

   (i) Magnetic ores (ii) Sulphide ores of poor metal content

   (iii) Bauxite ore

   ....

5. Which metal is extracted from the mineral Black jack?

   ....

23.8 CALCINATION AND ROASTING OF THE ORE

The concentrated ore is converted into metal oxide by calcination or roasting.

(A) Calcination:

Calcination involves heating of the concentrated ore in a limited supply of air so that it loses moisture, water of hydration, gaseous volatile substances. The ore is heated to a temperature so that it does not melt. The process involves the following steps:

(i) Removal of water of hydration

$$Al_2O_3.2H_2O \longrightarrow Al_2O_3 + 2H_2O$$

(ii) **Expulsion of water from a hydroxide**

$$2Fe_2(OH)_3 \longrightarrow Fe_2O_3 + 3H_2O$$

(iii) Expulsion of CO_2 from carbonate

$$Zn_2CO_3 \longrightarrow ZnO + 2CO_2$$

(iv) To make the ore porous, so that it can be easily reduced to metallic state in the next step.

(B) **Roasting:**

Roasting is a process in which the concentrated ore is heated in a free supply of air at a temperature insufficient to melt it. The following changes take place during roasting.

(i) Drying of the ore.

(ii) Removal of the volatile impurities like Arsenic, suplhur, phosphorus and organic matter.

$$4As + 3O_2 \longrightarrow 2As_2O_3\,(g)$$

$$S + O_2 \longrightarrow SO_2\,(g)$$

$$4P + 5O_2 \longrightarrow 2P_2O_5\,(g)$$

(iii) Conversion of the sulphide ores into oxides

$$2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2$$

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

(v) Making the ore porous which makes its reduction into metallic state easier.

Calcination and roasting are generally carried out in a reverberatory furnace or in multiple hearth furnace.

23.9 REDUCTION OF THE METAL OXIDES TO FREE METAL

This process is carried out after calcination and roasting of ores. In this process, called *smelting*, the oxide ores are converted into the metallic state by reduction using chemical or electrolytic methods.

> *Smelting* is a process in which the oxide ore in molten state is reduced by carbon (reducing agent) to the free metal. The reduction is carried out in presence of some flux in a suitable furnace.

(i) *Smelting; using carbon as a reducing agent*: This method is used for the isolation of iron, tin and zinc metals from their respective oxides. The oxide ores are strongly heated with charcoal or coke. Reduction occurs by the action of carbon and/ or carbon monoxide which is produced by the partial combustion of coke or charcoal.

$$Fe_2O_3 + 3C \longrightarrow 2Fe + 3CO(g)$$
(Haemitite) (Iron)

$$Fe_2O_3 + CO \longrightarrow 2FeO + CO_2(g)$$

$$FeO + CO \longrightarrow Fe + CO_2(g)$$

$$SnO_2 + 2C \longrightarrow Sn + 2CO$$
(cassiterite) (Tin)

$$ZnO + C \longrightarrow Zn + CO$$
(Zincite) (Zinc)

Although the ore has been concentrated in an earlier step, it is still contaminated with some gangue material which is finally removed in the reduction process by the addition of *flux* during smelting.

> *Flux* is a chemical substance which-combines with gangue at higher temperatures to form easily fusible material called *slag* which is not soluble in the molten metal.

In the smelting of iron ores, calcium carbonate (lime stone) is used as a flux. On heating, lime stone is converted into calcium oxide (CaO) which combines with acidic impurities like silica (SiO_2) present in iron ores forming fusible calcium silicate ($CaSiO_3$)

$$CaCO_3 \longrightarrow CaO + CO2(g)$$
(limestone)

$$CaO + SiO_2 \longrightarrow CaSiO_3$$
(Basic flux) (Acidic gangue) (Slag)

> Slag is a fusible chemical compound formed by the reaction of flux with gangue.

The fusible slag, such as calcium silicate ($CaSiO_3$) formed during smelting floats over the molten metal and is thus easily removed. Another advantage is that the slag provides a covering to the molten metal thus preventing it from getting oxidized by air.

(ii) **Smelting;** *using other reducing agents (such as Al, Na, Mg or H_2)*: Ores which cannot be reduced by carbon or show affinity to carbon in forming metal carbides, are reduced by reducing agents like Aluminium, Sodium, Magnesium or hydrogen. Oxide ores like chromium oxide (Cr_2O_3) or Manganese oxide (Mn_3O_4) are reduced by aluminium powder in a highly exothermic reaction. This process is known as *Goldscmidt's Alumino-thermite reduction method.*

$$Cr_2O_3 + 2Al \longrightarrow 2Cr + Al_2O_3 + Heat$$

$$3Mn_3O_4 + 8Al \longrightarrow 9Mn + 4Al_2O_3 + Heat$$

(Heat is generated in the process due to the formation of Al_2O_3 which is a highly exothermic reaction).

Titanium is obtained by the reduction of $TiCl_4$ by Mg in an inert atmosphere of argon (Kroll process).

$$TiCl_4 + 2Mg \xrightarrow[830°C]{Heat} Ti + 2MgCl_2$$

(iii) *Self-reduction Method*: Smelting can also be carried out by self-reduction. This is applied to the sulphide ores of lead (Pb), mercury (Hg) and copper (Cu). The ores are heated in air, a part of these sulphide ores is changed into the oxide or sulphate which then reacts with the remaining part of the sulphide ore to give the metal and sulphurdixide. The reactions showing their extraction are given below:

(i) $2HgS + 3O_2 \longrightarrow 2HgO + 2SO_2 (g)$
(Cinnabar)

$2HgO + HgS \longrightarrow 3Hg + SO_2 (g)$

(ii) $2Cu_2S + 3O_2 \longrightarrow 2Cu_2O + 2SO_2 (g)$
(Copper glance)

$2Cu_2O + Cu_2S \longrightarrow 6Cu + SO_2 (g)$

Copper produced at this stage is called Blister copper. The evolution of sulphurdioxide produces blisters on the surface of solidified copper metal.

(iii) $2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2 (g)$

$PbS + 2O_2 \longrightarrow PbSO_4$

$PbS + 2PbO \longrightarrow 3Pb + SO_2 (g)$

$PbS + PbSO_4 \longrightarrow 2Pb + 2SO_2 (g)$

(iv) *Reduction by precipitation*: Noble metals like silver and gold are extracted from their concentrated ores by dissolving metal ions in the form of their soluble complexes. The metal ions are then regenerated by adding a suitable reagent. For example, concentrated argentite ore (Ag_2S) is treated with a dilute solution of sodium cyanide (NaCN) to form a soluble complex:

$Ag_2S + 2NaCN \longrightarrow 2Na[Ag(CN)_2] Na_2S$
(argentite)

This solution is decanted off and treated with zinc to precipitate silver,

$$2Na[Ag(CN)_2] + Zn \longrightarrow Na_2[Zn(CN)_2] + 2Ag \downarrow$$

(v) *Electrolytic Reduction:* Active metals like sodium, potassium and aluminium etc., are extracted by the electrolysis of their fused salts. For example, sodium is obtained by the electrolysis of fused sodium chloride (Down's process). The reactions taking place in the electrolytic cell are:

Fusion $NaCl \rightleftharpoons Na^+ + Cl^-$

The ions are mobile and move towards the electrodes.

At the Cathode $Na^+ + e^- \longrightarrow Na$ (metal) (Reduction)
(Negative electrode)

At the Anode $Cl^- \longrightarrow Cl + e^-$ (Oxidation)
(Positive electrode)

$$Cl + Cl \longrightarrow Cl_2$$

Aluminium is extracted from molten alumina (Al_2O_3) by electrolysis. The melting point of alumina is quite high (2050°C) which is inconvenient for electrolysis. It dissolves in molten cryolite (Na_3AlF_6) around 1000°C. The electrolytic cell contains carbon anodes. The cathode consists of a steel vessel lined with graphite which contains the molten electrolyte (alumina dissolved in Cryolite). The reactions which take place in the cell are:

At the Cathode $Al^{3+}(l) + 3e^- \longrightarrow Al$ (metal)

At the Anode $C(s) + 2O^{2-}(l) \longrightarrow CO_2(g) + 4e^-$

INTEXT QUESTIONS 23.2

1. Explain the following terms:
   Calcination, Roasting, Smelting, Flux and Slag.

   ....

2. Which is the cheapest and most abundant reducing agent employed in the extraction of metals?

   ....

3. Name the process which is used for converting sulphide ores into oxides.

   ....

4. How are oxide ores reduced?

   ....

5. Name few materials which are used as flux in metallurgical processes.

   ....

6. What happens to (i) Alumina and (ii) Calamine ores during calcination?

   ....

23.10 REFINING OF THE METALS

Except in the electrolytic reduction method, metals produced by any other method are generally impure. The impurities may be in the form of (i) other metals (ii) unreduced oxide of the metal (iii) non-metals like Carbon, Silicon, Phosphorus, Sulphur etc. and (iv) flux or slag. Crude metal may be refined by using one or more of the following methods:

(i) *Liquation*: Easily fusible metals like tin, lead etc. are refined by this process. In this method, the impure metal is poured on the sloping hearth of a reverberatory furnace (Fig 23.5) and heated slowly to a temperature little above the melting point of the metal. The pure metal drains out leaving behind infusible impurities on the hearth.

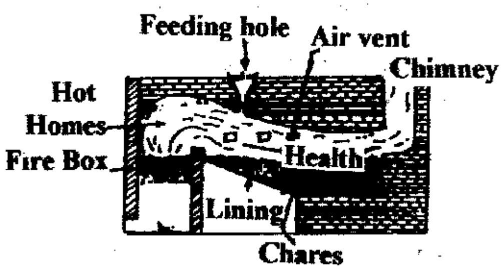

Fig. 23.5: Liquation in Reverberatoryfurnace.

(ii) *Poling*: Poling involves stirring the impure molten metal with green logs or bamboo sticks as shown in Fig. 23.6. The hydrocarbons contained in the pole reduce any metal oxide present as impurity. These oxidised impurities escape either as gas or form scum over molten metal. Copper and tin are refined by this method.

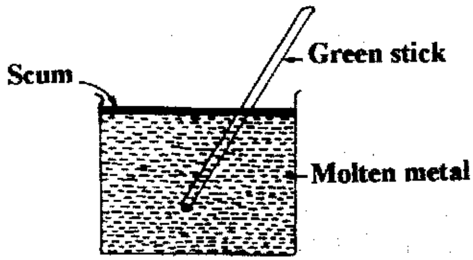

Fig. 23.6: Poling

(iii) *Distillation:* Volatile metals like zinc (Zn) mercury (Hg) are purified by distillation. The pure metal distills over, leaving behind non-volatile impurities.

(iv) *Electrolytic Refining*: A large number of metals like Copper, Silver, Zinc, Tin etc. are refined by electrolysis. A block of impure metal is made the anode and a thin sheet of pure metal forms the cathode of the electrolytic cell containing suitable metal salt solution which acts as an elctrolyte (Fig. 23.7). On passing current, pure metal deposits at the cathode sheet while more electropositive impurities are left in solution and settle below the anode as 'anode mud'.

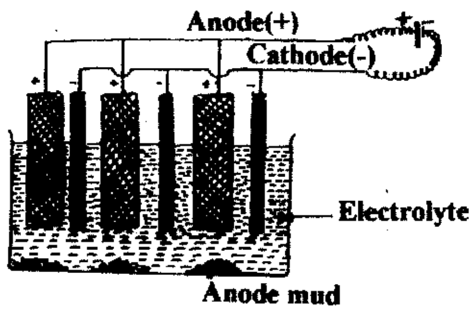

Fig. 23.7: Electrolytic cell

For example, in the electrolytic refining of crude copper (blister copper), a large piece of impure copper is made anode and a thin piece of pure copper is made the cathode. An acidified solution of Copper sulphate is used as an electrolyte. On passing an electric current of low voltage through the solution Copper (II) ions obtained from Copper sulphate solution go to the cathode where they are reduced to the free copper metal and get deposited.

$$Cu^{2+} + 2e \longrightarrow Cu \quad \text{(at cathode)}$$

An equivalent amount of the metal from the anode dissolves into the electrolyte as Cu^{2+} ions.

$$Cu \longrightarrow Cu^{2+} + 2e \text{ (at anode)}$$

As the process goes on anode becomes thinner while the cathode becomes thicker. The impurties like Silver, gold, selenium, Tellusium settle down at the bottom of the cell as *'anode mud'*.

(v) **Van Arkel-de Boer Process**: Extremely pure titanium (Ti) (also vanadium and zirconium) are made on the laboratory scale by this method in which pure metal iodide is vapourized and decomposed on a hot wire in vacuum.

$$\underset{\text{(crude)}}{Ti + 2I_2} \longrightarrow \underset{\text{(Pure)}}{TiI_4} \xrightarrow[\text{Vacuum}]{\text{hot wire}} \underset{\text{(very pure)}}{Ti + 2I_2}$$

INTEXT QUESTIONS 23.3

1. State the nature of materials used for constructing cathodes and anodes in the electrolytic cell for refining of copper. Write chemical equations for the reactions which take place.

   ....

2. Which method is used for the refining of metals that are easily fused?

   ....

3. Which metals are refined by poling?

   ....

4. Name the element which is purified by Van Arkel method?

   ....

5. Name any three elements which are refined by electrolytic refining.

   ....

23.11 WHAT YOU HAVE LEARNT

- Metals play an extremely useful role in day-today life.
- Most metals are found in nature in combined form. Only a few noble metals such as copper, gold, silver, mercury occur in nature in free state,
- The process of extraction of metals from their compounds is called *metallurgical process.*
- A naturally occurring material in which a metal or its compound occurs is called a mineral. A mineral from which a metal can be extracted economically is called an ore. Thus all minerals do not serve the purpose of ores.

- Most active metals are highly electropositive and exist as Mn^+ ions. Therefore, they are found in nature in association with some common anions, i.e., as salts like *oxides*, *sulphides*, *carbonates*, *halides*, *silicates* etc. Some sulphides slowly undergo oxidation by air to form *sulphates*.
- India possesses rich mineral wealth with abundance of iron, almunium and with some amount of copper, tin, lead, silver and gold.
- The extraction of metals from their ores is undertaken in some steps. These are:
  - (i) *Crushing and pulverization*: In this step the big lumps of ores are crushed and pulverized to a fine powder to bring it to a workable form.
  - (ii) *Concentration or dressing of the ore*: In this step the ore is separated from earthy impurities, called gangue or matrix by undertaking one or the other step. The different methods are: gravity separation, magnetic separation, froth flotation and chemical method.
  - (iii) *Reduction of the oxides to free metal*: The process, called smelting, involves conversion of metal oxide into metal by reduction using chemical or electrolytic methods. The reduction is carried out in presence of some suitable material called flux. *Flux* is a chemical substance which combines with gangue to form easily fusible material called slag. *Slag* is immiscible in the molten metal and is thus easily separable.
- The metal thus obtained is then purified by employing some suitable method like *liquation*, *poling*, *distillation* or by *electrolytic* refining.

23.12 TERMINAL EXERCISE

1. Name the metal oxides that are not reduced to metallic state by heating with carbon. Which reducing agent is used for these ores?
2. Which metal sulphide combines with its oxide to form metal? Give reactions.
3. Name four reagents which are used during smelting.
4. What is the difference between calcination and roasting?
5. Give the name and composition of at least one ore of the following metals:

   (i) copper (ii) zinc (iii) iron (iv) tin
6. Which element is purified by Van-Arkel de Boer method?
7. Define: gangue, flux, slag.
8. What do you understand by the smelting process?
9. What happens when
   - (i) Calamine is calcined.
   - (ii) Zinc blende is roasted.
   - (iii) Silica is heated with lime stone.
   - (iv) Cinnabar mixed with charcoal fuel is heated in a furnace?

CHECK YOUR ANSWERS

INTEXT QUESTIONS 23.1

1. Sodium (Na), Aluminium (Al), Silver (Ag), Iron (Fe), Zinc (Zn), Lead (Pb), Gold (Au), Mercury (Hg).

2. *Mineral* is a naturally occurring material in which a metal or its compound occurs.

   An *ore* is that material in which the metal is present in large quantity and from which a metal can be extracted in pure and high quality, economically.

3. Gravity separation, magnetic separation, froth flotation and chemical method.

4. (i) Magnetic separation method

   (ii) Froth flotation method

   (iii) Chemical method

5. Zinc.

INTEXT QUESTIONS 23.2

1. *Calcination* involves heating of the ore in a limited supply of air to a temperature that the ore does not melt.

   Roasting involves heating of the ore in a free supply of air to a temperature that the ore does not melt.

   Smelting: The extraction of metal in the fused state is termed smelting. The ore is reduced by carbon to the free metal.

   Flux is a chemical substance which combines with gangue at higher temperatures to form easily fusible material called slag.

   Slag is a fusible chemical compound formed by the reaction of flux with gangue. Slag is not soluble in the molten metal and is thus separated.

2. Carbon in the form of coke.

3. Roasting; $2Zns + 3O_2 \longrightarrow 2ZnO + 2SO_2(g)$

4. Oxide ores are reduced to metal and CO by heating them with coke.

5. Silica, borax and other non-metallic oxides are acidic fluxes. Lime stone ($CaCO_3$) is basic flux.

6. $ZnCO_3 \longrightarrow ZnO + CO_2$

   $Al_2O_3.\ 2H_2O \longrightarrow Al_2O_3 + 2H_2O$

INTEXT QUESTIONS 23.3

1. Cathode: Pure metal

   Anode: Impure metal

2. Liquation
3. Blister copper and tin
4. Titanium
5. Copper (Cu), Silver (Ag), Tin (Sn).

TERMINAL EXERCISE

1. Cr_2O_3, Mn_3O_4; Reducing agent is Al.
2. Copper; $Cu_2S + 2Cu_2O \longrightarrow 6Cu + SO_2(g)$
3. Carbon, Al, Na and H_2

   $MnO_2 + 2C \longrightarrow Mn + 2CO$

   $Cr_2O_3 + 2Al \longrightarrow 2Cr + Al_2O_3$

   $TiCl_4 + 4Na \longrightarrow Ti + 4NaCl$

   $WO_3 + 3H_2 \longrightarrow W + 3H_2O$
4. *Calcination*: Removal of moisture and volatile substances from an ore by heating it in a limited supply of air without allowing the ore to melt.

   Roasting: process in which ore is oxidized on heating in presence of free supply of air without getting melted.
5. Copper glance (Cu_2S), Zincite (ZnO), Haematite (Fe_2O_3), Cassiterite (SnO_2)
6. Titanium.
7. *Gangue:* The unwanted earthy impurities are called gangue. *Flux:* is a chemical substance which combines with gangue at higher temperatures to form easily fusible material called slag.

   Slag: is a fusible chemical compound formed by the reaction of flux with gangue. Slag is not soluble in the molten metal and is thus separated.
8. *Smelting*: Reduction of oxide ore obtained after calcination or roasting by heating the former with coke in presence of flux.
9. (i) $ZnCO_3 \xrightarrow{\text{calcined}} ZnO + CO_2(g)$

   (ii) $2ZnS + 3O_2 \xrightarrow{\text{rosted}} 2ZnO + 2SO_2(g)$

   (iii) $CaCO_3 \longrightarrow CaO + CO_2(g)$
   (lime stone)

   $CaO + SiO_2 \longrightarrow CaSiO_3(g)$

   (iv) $HgS + O_2 \longrightarrow Hg + SO_2(g)$
   (cinnabar)