UNIT 11 EXTRACTION OF THE METALS AND NON-METALS

Structure

11.1 INTRODUCTION

Metals are an inseparable part of modern civilized human society. In the earlier times only a few metals were known to human beings. Their usability and importance led to the discovery of many more metals. Today we have around 80 metals. Do these metals occur in nature as pure metals ? If they do not exist in pure form then how do we get them as pure metals ? Do all the metals display similar properties and do all of them exist in the same abundance in nature? In this unit you will find answers to these questions and also the ways and methods to convey this information to your students.

The main thrust of the unit is on the extraction of metals and various techniques applied to obtain pure metals. It also deals with the extraction of non-metals like sulphur and phosphorus. The unit also provides some questions and assignments for you to check your own knowledge about metals, their extraction and purification on the one hand, and how to teach them on the other hand.

11.2 OBJECTIVES

After going through this unit, you should be able to:

- explain the existence of metals in different types of ores depending on their reactivity;
- suggest teaching aids for teaching different methods of extracting metals from their ores;
- justify the need for using different methods for concentrating the ores;
- describe various methods of reduction of ores;
- state the rationale of using of various techniques for purifying different metals;

- describe the methods of extraction of Sulphur and Phosphorus;
- summarize the process of extraction of Aluminium and Iron.

11.3 OCCURRENCE OF METALS

Main Teaching Points

- Metals found in free state
- Metals found in combined state in the form of ores
- Types of ores (sulphide, carbonate, and oxide).

Introduction

In nature, metals may occur in free or combined state. Metals occurring in free state are gold, silver, platinum and bismuth. They are present in the earth crust in small quantities and so, they are called noble metals.

Metals occurring in combined state are present in nature mostly as their oxides, carbonates, sulphide and chlorides. These compounds are called minerals. Those minerals from which metals can be extracted in profitable amounts are called ORES.

Teaching Learning Process

11.3.1 Occurrence of Metals

We use metals in our daily life. Just think about the articles made up of metals in your surroundings. Are all these material/articles made up of the same metal? No, they are not. They are made up of a variety of metals such as Aluminium, Iron, Copper, Silver, Gold etc. Out of 105 elements known till date, 80 are metals. Where do these metals come from? These metals are present in the earth's crust. Some of these metals like Gold, Silver, Platinum and Bismuth are found in the free state while others are found in the form of compounds of metals. Metals are usually reactive elements and exist as compounds e.g. Aluminium, Iron, Calcium, Sodium, Potassium, Magnesium, Titanium, etc. Aluminium is the most abundant metal on the earth crust followed by Fe and Ca. The rest of the metals which are less reactive are present to a smaller extent in the earth's crust.

Metals are present in the form of minerals. Minerals are naturally occurring crystalline substances that have characteristic chemical composition. In minerals, metals are present in the form of Oxides, Sulphides, Carbonates and Silicates. Minerals from which we can profitably extract metals are called ORES. Let us see how we get metals from ORES.

Methodology used : In the above paragraph you have noted that all the information is not given directly to the pupils. It is dotted with questions followed by the presentation of the information. This interactive method is also known as discussion method. Discussion method is the method of learning which involves probing questions followed by explanation.

Check Your Progress

Notes : a) Write your answers in the space given below.
b) Compare your answers with those given at the end of the unit.

1. Mention 5 pure metals used in your home appliances/articles.

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2. Mention 5 metals which you do not usually use as pure metals in your home but are familiar with.

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11.4 CONCENTRATION OF ORES

Main Teaching Points

- **Concentration**
  - a) Physical Method
    - i) Hydraulic washing
    - ii) Froth floatation Method
    - iii) Magnetic Separation
  - b) Chemical Method
    - i) Chemical Separation
    - ii) Calcination
    - iii) Roasting
  - c) Conversion of metal ore to metal
    - i) Heating
    - ii) Reduction by Carbon/Aluminium/Sodium/Calcium
    - iii) Electrolytic Process

Teaching Learning Process

Concentration is the process of increasing the amount of desired substance in a solution or mixture by reducing/removing the undesired substance from it. First we shall study the Physical Method of concentrating ORES. You are familiar with terms like 'physical properties', 'physical change' etc. Similarly, physical methods are those methods which do not involve altersation or change in chemical composition of substances. Physical methods of concentration of ores refers to those methods in which compounds of desired metals are separated from undesired particles like sand, stone etc. These undesired particles are called 'GANGUE'

ORE = METAL COMPOUND + GANGUE

11.4.1 Physical Method of Concentration of Ores

Following are the Physical Methods of concentration of Ores.

i) Hydraulic Washing

As the name suggests it is just simple washing of ore with water. Look at the Fig. 11.1. Why do you think the hurdles are placed on the surface of the slightly inclined table? They are there to hold back the heavier metal compound. The crushed ore is placed on one side of the table and washed with a stream of water. What do you think would happen? The lighter gangue particles will cross the barriers leaving heavier ore between the barriers This method is used when there is a considerable difference in the densities of metal compounds and gangue particles. Ores of tin and lead are concentrated by this method.

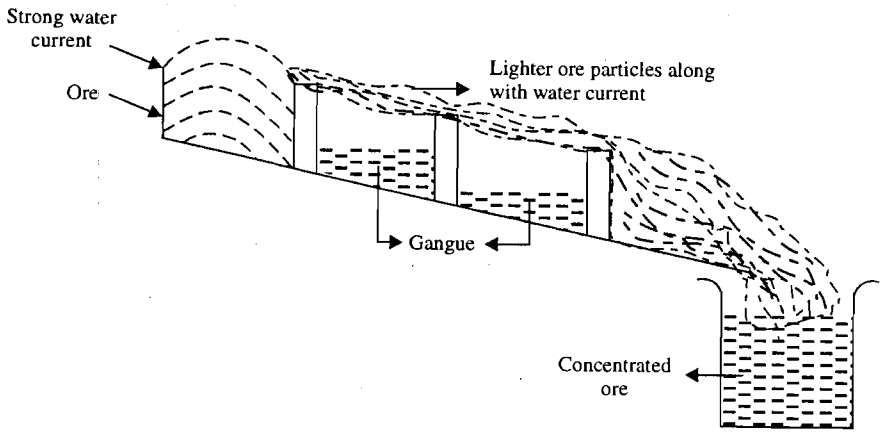

Fig. 11.1 : Hydraulic washing

ii) Froth Floatation Method

Sulphide ores of copper, lead and zinc are concentrated through this method. Sulphide ores are insoluble in water. A mixture of water and pine oil is used for washing. Gangue particles get wetted by water while metals Sulphide get wetted by oil. Fig. 11.2 clarifies the process.

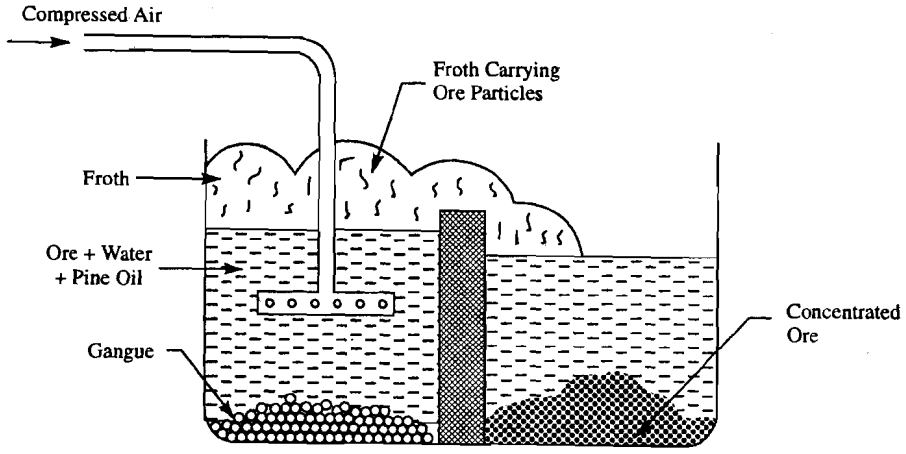

Fig. 11.2 : Froth Floatation Process

On agitating the mixture of water and pine froth bubbles are produced. Particles of Sulphide ore stick to these bubbles. Gangue particles do not stick to the froth and remain in water. Froth with ore particles is separated and kept for some time. As it settles down Sulphide ore is collected.

iii) Magnetic Separation

Which type of ore can be concentrated through this method? It is useful when either the gangue or the metal compound has magnetic properties. As you can see in Fig. 11.3, the powdered metal ore is placed on the leather belt which rotates on two wheels. One wheel has a powerful magnet which attracts the magnetic substance (usually metallic ore), and we get two separate piles of substance one of metal compound and other gangue. Magnetite (Fe_3O_4), Chromite ($FeCrO_2$) and Pyrolusite (MnO_2) are concentrated using this method.

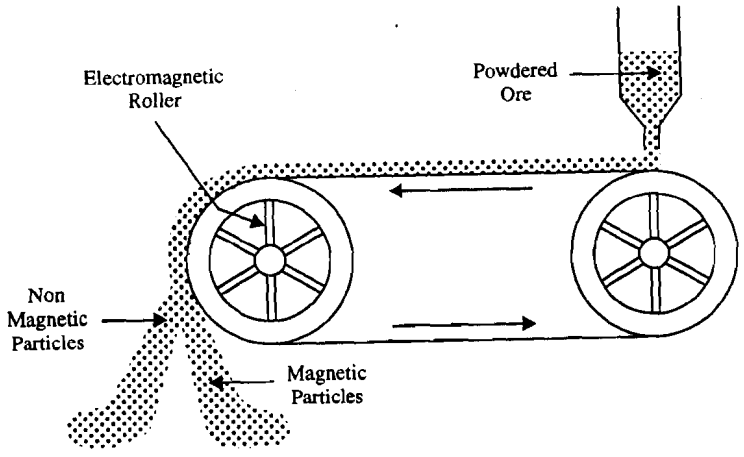

Fig. 11.3 : Magnetic separation

11.4.2 Chemical Method of Concentration of Ores

This method is used when chemical properties of metal ore and gangue are different, for example, a metal ore reacts with a reagent to form water soluble product and gangue particles may not dissolve in that reagent. Bauxite ore of Aluminium metal is concentrated by treating it with hot sodium hydroxide solution. Sodium hydroxide reacts with Aluminium to form water soluble Sodium Aluminate.

$$\underset{\text{(From Bauxite)}}{Al_2O_3 + 2NaoH} \longrightarrow \underset{\text{(Sodium Aluminate Soluble)}}{2NaAlO_2 + H_2O}$$

Gangue present in ore does not dissolve in sodium hydroxide, so it can be separated by filtration. The filtrate containing sodium aluminate is acidified with HCl to get white precipitate of $Al(OH)_3$ which on heating give pure Aluminium Oxide.

$$NaAlO_2 + H_2O \longrightarrow Al(OH)_3 + NaCl$$

$$2Al(OH)_3 \xrightarrow{Heat} \underset{\text{(Pure)}}{Al_2O_3 + H_2O}$$

Methodology used : Visual presentations in the form of films and cassettes, demonstration of the processes, use of flash cards followed by the explanations will help in the learning of the above content.

Check Your Progress

Notes :a) Write your answers in the space given below.
b) Compare your answers with those given at the end of the unit.

3. Which of the following metal is most abundant in nature?
   a) Sodium
   b) Calcium
   c) Aluminium
   d) Iron

   .....

4. Metals usually exist as :
   a) Free metal
   b) Carbides
   c) Silicates
   d) Oxides

   .....

5. Hydraulic washing is done for the ores in which.....
   a) Metal Compound is lighter than gangue
   b) Metal Compound is heavier than gangue
   c) Metal Compound is soluble in water
   d) Metal Compound is insoluble in water.

   .....

11.5 REDUCTION OF CONCENTRATED ORE

Main Teaching Points

- Conversion of metal oxide to metal
- Heating
- Heating with Carbon /Aluminium
- Electrolytic process

11.5.1 Conversion of Ore into Metal Oxide

The process of conversion of concentrated ore into oxide form is called Preliminary Treatment. Depending upon the type of ore, it may be either CALCINATION OR ROASTING.

i) Calcination

To convert Carbonate ores into oxide form, to expel water from hydrated ores or to remove volatile impurities from ores, the process of calcination is applied. In this process the metal carbonates are heated in the absence of air. What do you think would happen to carbonates on heating ? The Carbonates would decompose into oxides and release carbon dioxide. For example

$$\underset{\text{(Calamine ore)}}{Zn\,CO_3} \longrightarrow ZnO + CO_2$$

You can see here that oxygen is not required for the reaction hence Carbonate ores are heated in the absence of air. Presence of CO_2 will confirm that the ore is in carbonate form.

ii) Roasting

Roasting on the other hand, is heating the ore in the presence of air. Sulphide ores are heated in the presence of air to remove sulphur and other volatile impurities.

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

11.5.2 Conversion of Metal Oxides to Metals

In the previous step you have seen that metal ores are converted to their oxide form. Once we have the metal in their oxide form it will be easier to get metal from them. There are various ways of getting metal from their oxides. They are as follows.

i) Heating

What types of metals do you think could be obtained by simply heating their oxides? Those metal which are less reactive or comparatively unreactive or those which lie in the lower side of the reactivity series, for example Mercury are obtained by heating their oxides. Mercury is a less reactive metal. It is found in the form of its sulphide (HgS) as CINNABAR ORE. Once HgS is converted to Hgo during the process of roasting, further heating will convert Hgo to Hg.

$$HgO \xrightarrow{3000^{\circ}C} Hg + O_2$$

In fact the conversion of metal ore to its oxide from and from oxide form to metal go side by side in case of mercury.

ii) Reduction by Carbon/Aluminium/Sodium/Calcium

Carbon and Aluminium act as reducing agents for converting metal oxide into metal. The purpose is the removal of oxygen from metal oxide. And so, the selection of reducing agent depends upon the reducing agents, relative affinity for oxygen as compared to the affinity for oxygen of the metal from which oxygen has to be removed. Metals in the middle of reactivity series of Zn, Fe, Cu, Ni, Sb, Pt etc., can be reduced from their oxide using carbon as the reducing agent, since carbon has more affinity for oxygen than these metals.

$$2\,ZnO + C \longrightarrow 2\,Zn + CO_2$$

Carbon is used in the form of Coke. Fe is obtained from it's oxide (haematite) in a blast furnace as shown in Fig. 11.4. The working of blast furnace will be explained to students.

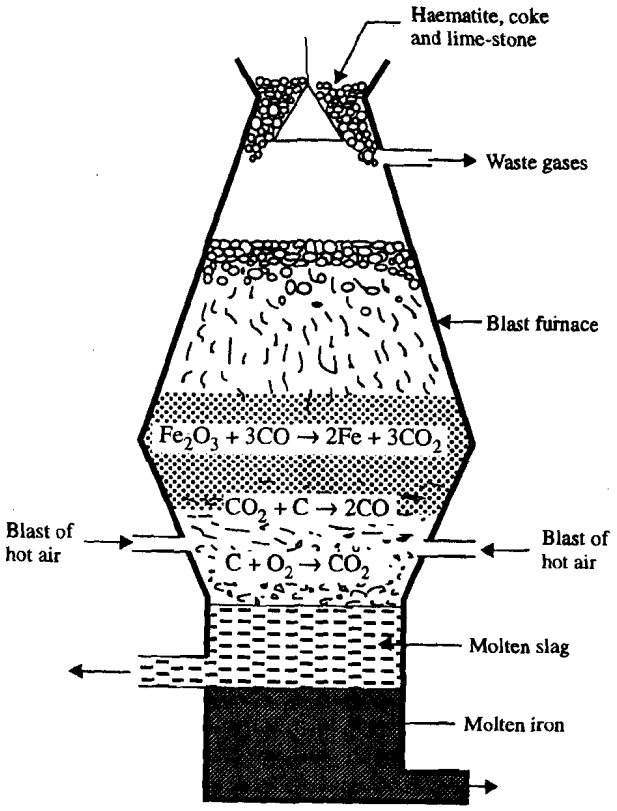

Fig. 11.4 : Blast furnace for the extraction of iron from haematite

Oxides of more reactive metals like sodium, potassium, calcium, magnesium, aluminium, manganese, chromium, etc. cannot be reduced by carbon because they have more affinity for oxygen than does carbon. Oxides of manganese and chromium therefore can be reduced to metals by using aluminium.

$$3MnO_2 + 4Al \longrightarrow 3Mn + 2Al_2O_3$$

This process of obtaining metal using Aluminium is also called Alumino Thermite Process.

iii) Electrolytic Process

Oxides and chlorides of highly reactive metals like sodium, potassium, aluminium, magnesium, calcium are very stable. That is why, they cannot be reduced by chemical reduction using at carbon or magnesium, aluminium. So, they are extracted from their molten oxide or chlorides by electrolytic reduction.

Let us take the example of Aluminium oxide. Molten Al_2O_3 or alumina contains free aluminium ions. During electrolytic process Al^{3+} ions are reduced by cathode (which provides electrons) to form Al atoms. Look at Fig. 11.5. The reaction that occurs at the cathode is

At Cathode

$$Al^{3+} + 3e^- \longrightarrow Al \text{ (metal)}$$

The reaction that occurs at the anode is

$$O^{2-} - 2e^- \longrightarrow O$$

$$O + O \longrightarrow O_2$$

So, oxygen gas is liberated at anode.

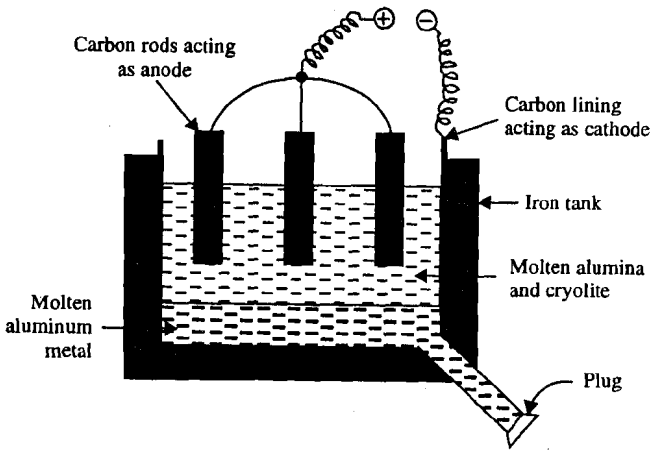

Fig. 11.5 : Electrolytic cell (The Hall's process) for the extraction of aluminium

In case of molten NaCl

$$NaCl \xrightarrow{\text{Electrolysis}} NaCl^-$$

At Cathode

$$Na^+ + e^- \longrightarrow Na \text{ (metal)}$$

At Anode

$$Cl^- \longrightarrow Cl + e^-$$

or In case of molten magnesium chloride $MgCl_2 \longrightarrow Mg^{2+} + 2Cl^-$

At Cathode

$$Mg^{2+} + 2e^- \longrightarrow Mg \text{ (metal)}$$

What do you observe in all of these cases?

We get metal at the Cathode end.

Methodology used : Video cassettes of actual process can be shown. Otherwise photographs or pictures or three dimensional models of actual processes could be used that will help in developing the understanding of the concept.

Check Your Progress

Notes : a) Write your answers in the space given below.
b) Compare your answers with those given at the end of the unit.

6. If ore is in its Carbonate form which of the following methods could be used for its concentration
   a) Calcination
   b) Roasting
   c) Heating with Carbon
   d) Heating only

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7. Identify the ore for which Electrolytic process is used to convert it into oxide form
   a) $Al_2O_3\ 2H_2O$ (Bauxite)
   b) $CaCO_3$ (Limestone)
   c) $CaCO_3$ (Fluorspar)
   d) $ZnCO_3$ (Calamine)

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8. To convert a metal oxide into metal, heating method is employed when.....
   a) Metal content is more in the oxide
   b) Metal is less reactive
   c) Metal has low melting point
   d) Metal has high melting point

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11.6 PURIFICATION OF METALS

Main Teaching Points

- Liquation
- Distillation
- Oxidation
- Electrolytic Refining
- Van Arkel Method
- Zone Refining

Teaching Learning Process

Like all other steps during the extraction of metals, the refining or purification of metal also depend upon the nature of the metal. Depending upon the properties of metals, following methods are employed for the purification of metals.

a) Liquation

The metals which can be easily liquefied or metals with low melting points are purified by this method. These metals can be easily fused and their impurities do not fuse easily. Metals like, Bismuth, Antimony, and Lead etc. are purified by this method. So, on the sloping hearth, the impurities are left behind and pure metal passes over as shown in Fig. 11.6.

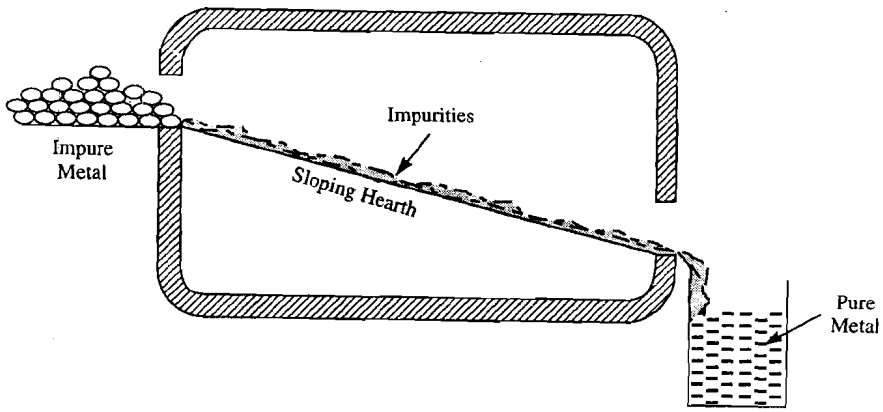

Fig. 11.6 : Liquation process

As you see in Fig. 11.6, blocks of impure metal are placed at the top of the hearth of a furnace. Have you noticed the slope of the hearth? Why do you think it is made sloping ?

It is because when the hearth is heated and the temperature is maintained at a temperature slightly higher than the melting point of the metal to be refined then metal flows down the

slope and gets collected at the bottom. Impurities that have higher melting points than the metal remain there on the hearth.

b) Distillation

What is distillation? You are familiar with this term when used in the context of purification of water. It is a process of converting a substance into its vapour form and then condensing the vapour to get pure material. In case of volatile metals like Zinc, Cadmium or Mercury in which the impurities are non-volatile, this process of purification is used. Impure metal is heated and its vapours are condensed separating them from the impurities which do not vaporise.

c) Oxidation or Oxidative Refining

Some metals like Iron contain non-metals like Sulphur, Phosphorus, Carbon, Silicon etc. as the impurities. These non-metals or impurities are removed by converting them into oxides which are usually gases. Air is passed through molten impure metal. Oxygen of the air reacts with non-metals which are easily converted into their oxides. As they are usually in gaseous state, they escape leaving pure metal behind.

d) Electrolytic Refining

What is electrolytic refining ? As the term suggests, it is the refining or purification of metals through the process of electrolysis. What are the requirements of electrolysis? The requirements are i) an anode of impure metal connected to the positive terminal of a battery, ii) a cathode of pure metal (thin strip) connected to the negative terminal of the battery, and iii) a water soluble salt solution of the metal to be purified taken as electrolyte. Why do you think we take pure metal as cathode and impure metal as an anode? Metals are electropositive elements. When electricity is passed through metal salt solution, the solution gets ionised into anions and cations, the cations i.e., the metal ions move towards cathode take electrons from it and get deposited on cathode as metal atoms. At the same time metal atoms from impure anode get oxidised by losing electrons and move into the solution as metal ions. So there will be a continuous flow of metal from anode towards cathode through salt solution. In this way, metal gets purified leaving other impurities at the bottom of the anode as anode mud.

Suppose there are other metals present as impurities. What will happen to them? If the metal is less reactive then it will not ionise and remain there as anode mud. If it is reactive and gets ionised, then its ions will remain in the salt solution.The process is clarified in Fig. 11.7.

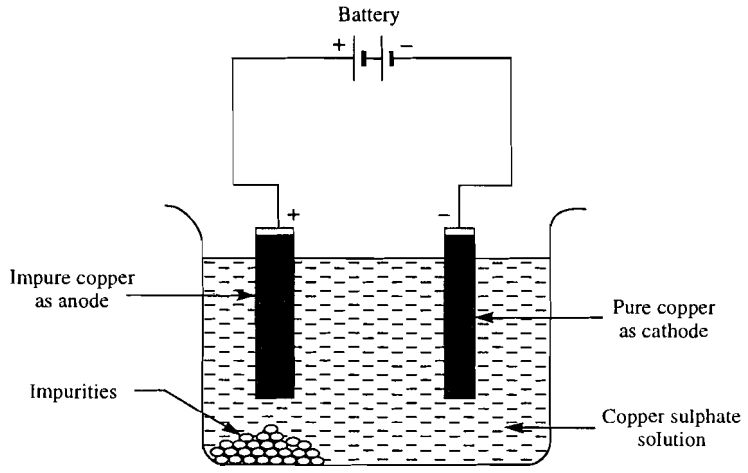

Fig. 11.7 : Experimental set up for the electrolytic refining of copper.

e) Van Arkel Method

Sometimes we require metals of high purity for their specialised uses. One such metal is Titanium metal.

Van Arkel method is used for obtaining highly pure Titanium metal. It works on the principle of thermal decomposition of metal compounds. Thermal decomposition is a process of decomposing or breaking a compound into its constituent elements or molecules through heating. But in this method impure Titanium is first heated with Iodine at 2500° C to form a volatile compound of Titanium Iodide.

$$Ti + 2I_2 \xrightarrow{2500°C} TiI_4$$

The vapours of Titanium Iodide thus formed are passed over hot Tungsten filament having a temperature of 1400°C. What do you think would happen to Titanium Iodide? Titanium Iodide will decompose into Titanium metal and Iodine gas. Titanium will be deposited on the Tungsten filament and Iodine will escape.

$$TiI_4 \xrightarrow{1400°C} Ti + 2I_2$$

In this way we get highly pure Titanium.

f) Zone Refining

This is another method of obtaining highly pure metal. It is based on the principle that impure molten metal on gradual cooling will deposit crystals of pure metal while impurities will remain in the molten part. This method is used for refining Germanium, Silicon and Gallium metals.

Germanium metal used in semiconductors is refined by taking impure Germanium in the form of a rod. A circular heater which can move along the length of the rod is fitted around the rod, as shown in (picture on flash card or chart could be used) Fig. 11.8.

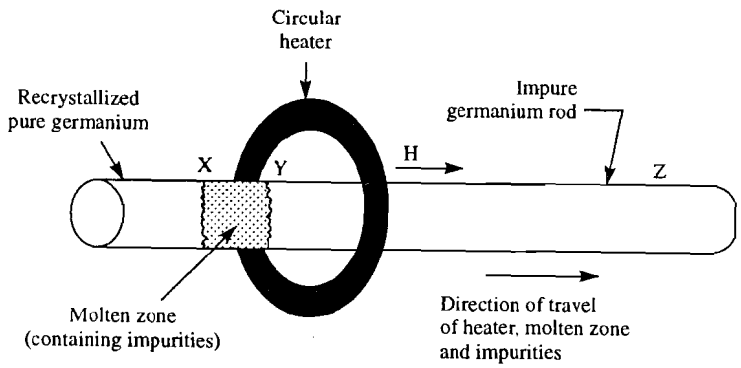

Fig. 11.8 : Zone refining of germanium metal

When the heater is at the extreme end of the rod it melts the impure Germanium in the narrow zone at that place. The heater is then moved further to melt another zone of the rod. The previously heated part now gets cooled and granules of pure Germanium are formed while other molten impurities will flow towards the high temperature zone. In this way, the slow movement of the heater on the impure rod will leave the highly pure metal rod behind while all the impurities will come to the other end and get removed.

Methodology used : Description and explanation of the processes with the help of video cassettes of actual processes or 3D-models or flash cards could be used for teaching the above concepts.

Check Your Progress

Notes : a) Write your answers in the space given below.
b) Compare your answers with those given at the end of the unit.

9. Name at least two metal which are required to be highly purified.

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10. Which of the following method could be used to obtain metal of highest purify ?

a) Electrolytic refining

b) Zone refining

c) Distillation

d) Oxidative refining

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11.7 EXTRACTION OF NON-METALS

Main Teaching Points

- Occurrence of phosphorus
- Steps involved in its extraction
- Occurrence of sulphur
- Steps involved in its extraction

Teaching Learning Process

11.7.1 Extraction of Phosphorus

Have you noticed the material used on the tips of match sticks or in fire works? These substances are compounds of a very active non-metal Phosphorus. It is a very useful element. It occurs as phosphates in rocks in the earth crust and also in living organisms. Major source of obtaining Phosphorus is rock soil and bone ash which contain 80% or more Phosphorus.

Bone ash or rock soil is heated with sand and coke in a specially designed electric furnace. Reaction follows in two steps:

Step I

Silica from sand reacts with Calcium Phosphate (present in rock soil) to form Calcium Silicate and Phosphorus Pentoxide.

$$2Ca_3(PO_4)_2 + 6\ SiO_2 \longrightarrow 6CaSiO_3 + 2P_2O_5$$

Step II

Phosphorus oxide is reduced by Coke (Carbon) to form pure Phosphorus and Carbon monoxide.

$$2P_2O_5 + 10C \longrightarrow P_4 + 10CO$$

This Phosphorus is white Phosphorus which reacts with oxygen of the air if left open and burns slowly without a flame. As the temperature rises it catches fire. It is very unstable. It's allotrope red Phosphorus is more stable.

To obtain red Phosphorus, white Phosphorus is heated to temperature of 250°C in an inert atmosphere of Nitrogen or Carbon dioxide.

$$P_4 \text{ (White)} \xrightarrow[CO_2 \text{ or } N]{250°C} P_4 \text{ (Red)}$$

11.7.2 Extraction of Sulphur

Extraction of Sulphur could be demonstrated with the help of model.

Sulphur occurs as free element deep below the surface of earth. It is extracted through **Frasch process** which is based on the fact that Sulphur has comparatively low melting point (of 115°C) due to which it can be melted by introducing jets of boiling water at 170°C in the underground sulphur deposits. The mixture of molten Sulphur and hot water is brought out by the force of hot compressed air. Frach process is illustrated in Fig. 11.9.

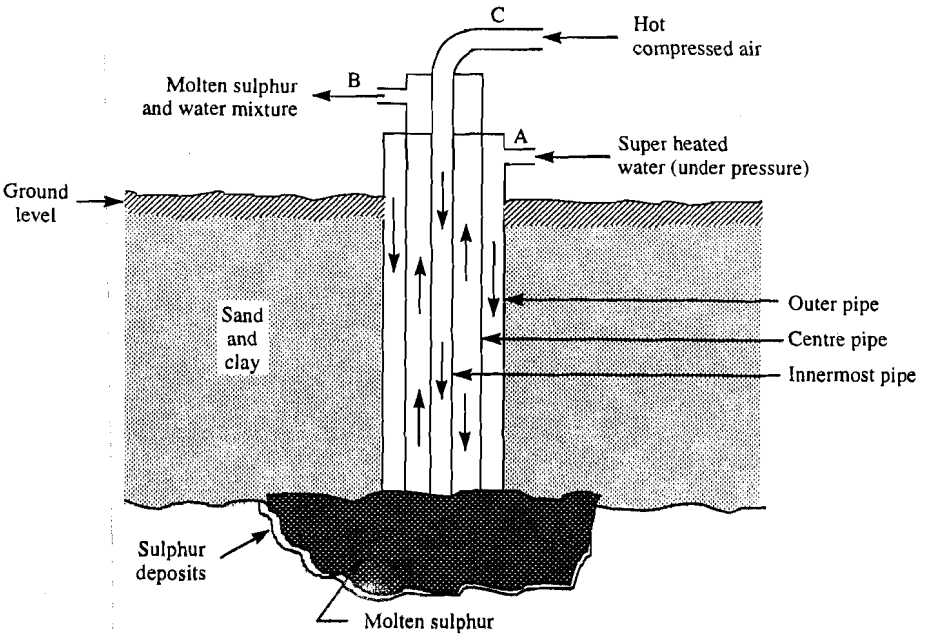

Fig. 11.9 : Frasch process for the extraction of sulphur.

Boiling water at 170°C and under pressure is forced down through an outer pipe. Why do you think pressure is kept high? It is done to maintain the higher temperature of water. The heat given out by water melts the underground Sulphur. A jet of hot compressed air is then sent down through the inner pipe. Under the pressure of hot air, the mixture of hot water and molten Sulphur comes out through the middle pipe.

This Sulphur-Water emulsion is kept in a setting tank. Sulphur gets cooled and separated as yellow solid. This is 99.5% pure Sulphur.

Methodology used : Lecture-cum-discussion method could be used. Models, flash cards or video cassettes of actual process will help in understanding this process.

Check Your Progress

Notes :a) Write your answers in the space given below.
b) Compare your answers with those given at the end of the unit.

11. Identify the property of Sulphur on which Frasch Process of extraction of Sulphur is based

a) insolubility in water

b) low specific gravity

c) low melting point

d) free state of Sulphur

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12. In the rock soil Phosphorus is present as

a) Calcium Phosphate

b) Sodium Phosphate

c) Aluminium Phosphate

d) Calcium bi Phosphate

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11.8 LET US SUM UP

In this unit you have learnt about the existence of metals in the form of their compounds usually oxides, carbonates, sulphides or chlorides. They are present in the earth with other metallic or non-metallic impurities which are known as MINERALS. Those minerals from which metal can be extracted profitably are called ORES. To extract pure metal from their ores we apply various processes depending upon the nature of metal compound and impurities.

Steps involved in the extraction of metals are roasting, concentration, reduction and refining. The method of extraction of non-metals such as sulphur and phosphorus have also been dealt with.

11.9 UNIT-END EXERCISES

You have studied the detailed unit on extraction of metals. Now answer the following questions to test your knowledge and understanding about the content given in the unit.

1. Why do most of the metals exist in the form of their compounds while some of them in free state? Give two reasons.

2. Define mineral and ores. Which type of metals exist in the form of ores?

3. Justify the need of applying a specific method of extraction of metal from their ores.

4. What kind of teaching aids could be used for teaching different techniques applied for the extraction of metals.

5. Describe with example, the necessity for applying different methods for concentration of ores.

6. Describe with the help of a diagram any method of refining a metal of highest purity.

7. Explain the difference between calcination and roasting. When do we apply these methods ?

8. Describe various steps involved in obtaining pure metal from their ores. Which method would you apply for teaching this to your students?

9. With the help of a diagram describe the refining of Aluminium. How should this material be taught to the student ? What teaching aids could be used for teaching it in the classroom?

10. Describe the principle and procedure for extracting Sulphur from its deposit. Draw a diagram to show its extraction.

11.10 ANSWERS TO CHECK YOUR PROGRESS

1. Copper, Iron, Aluminium, Silver, Gold.
2. Sodium, Potassium, Calcium, Magnesium, Platinum.
3. (c)
4. (d)
5. (b)
6. (a)
7. (a)
8. (c)
9. Titanium, Germanium
10. (b)
11. (c)
12. (a)

11.11 SUGGESTED READINGS

Teaching of Science, NCERT Publication.

Teaching of Chemistry, Newburry.

Teaching of Chemistry, Waddington.