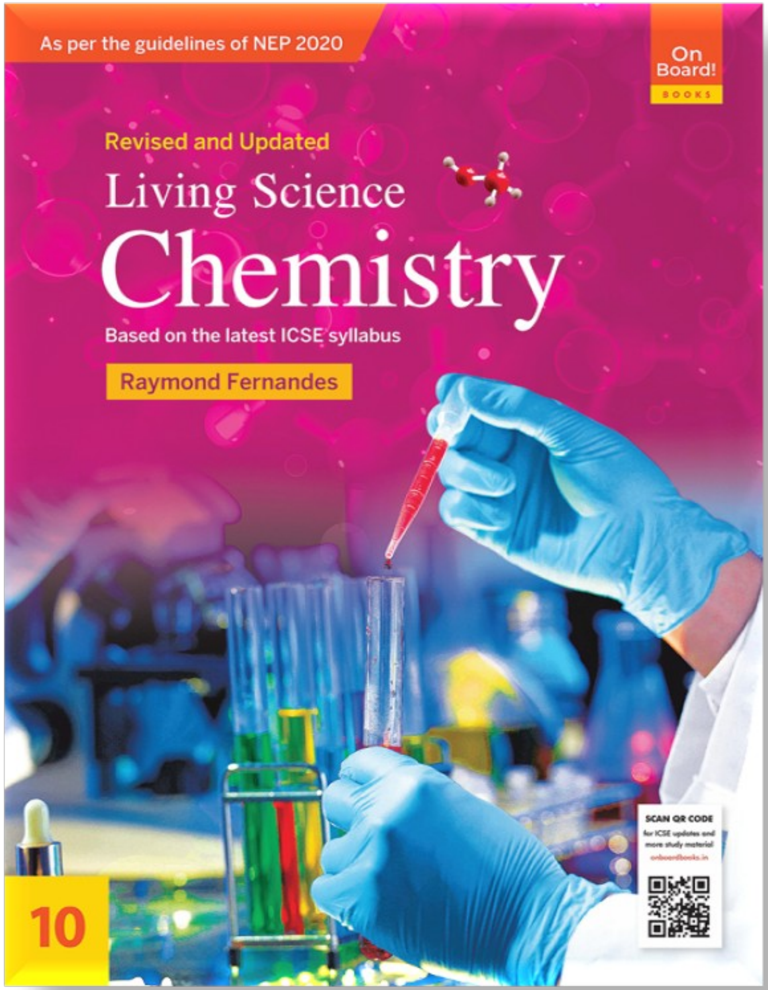
# On Board!

# ICSE
# Living Science
# Chemistry

## Class 10

## Chapter-7 Metallurgy


As per the guidelines of NEP 2020
On Board! BOOKS
Revised and Updated
Living Science
Chemistry
Based on the latest ICSE syllabus
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10
SCAN QR CODE

## LEARNING OBJECTIVES

**Reactivity series and metallurgical processes**

**Metallurgy**

- ❖**Processes involved in metallurgy**
- •Concentration of ore
- •Conversion of concentrated ore into metal oxide
- •Extraction of the metal by the reduction of metal oxide
- •Refining of impure metals

**Aluminium**

- ❖**Extraction of aluminium**
- ❖**Electrolytic reduction of fused alumina**
- ❖**Purification of aluminium**

**Alloys**

- ❖**Purpose of making alloys**

## Minerals and Ores

The elements or compounds, which occur naturally in the earth's crust are known as **minerals**.

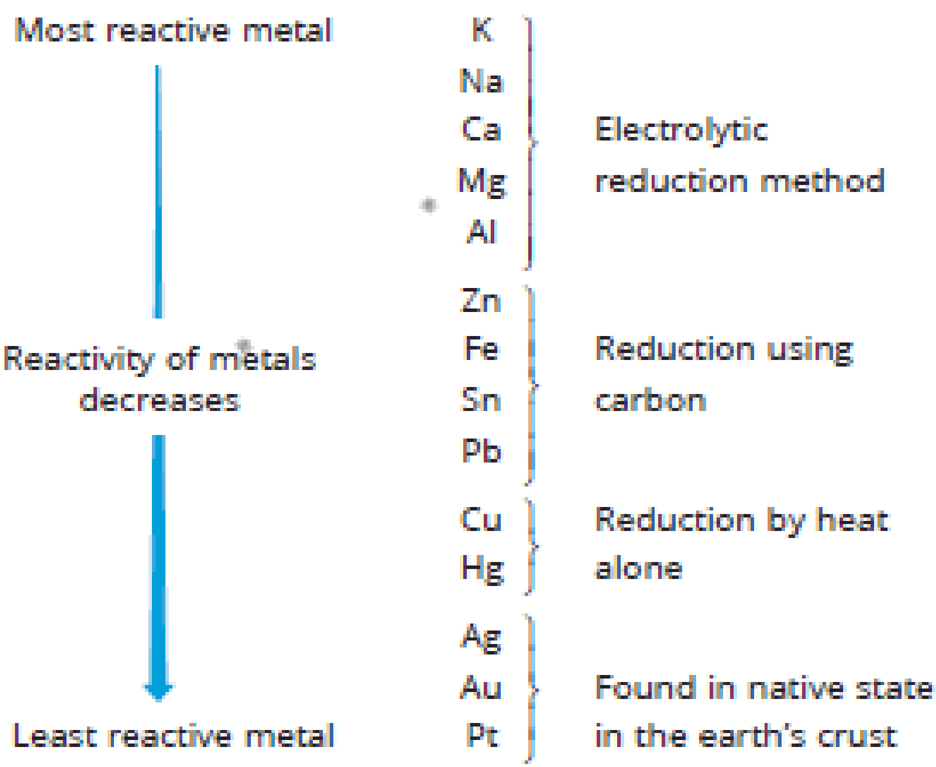
The naturally occurring minerals from which metals can be extracted profitably are called **ores**.

Some common ores are given in Table 7.1 in the textbook. Ores of aluminium, iron and zinc are given in Tables 7.2 to 7.4 in the textbook.

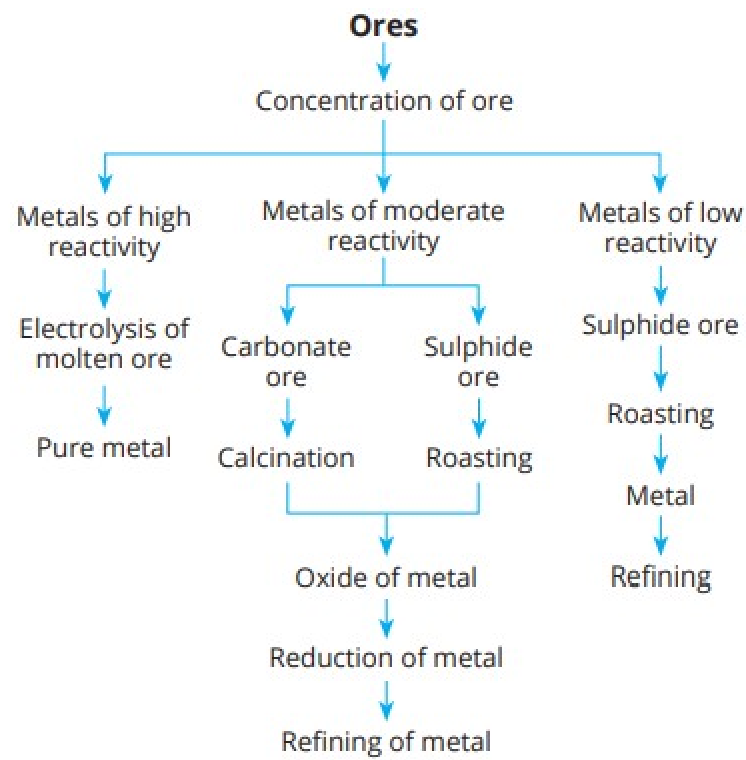
## Reactivity series and metallurgical processes

On the basis of reactivity, metals can be grouped into three categories.

- Metals of high reactivity
- Metals of medium reactivity
- Metals of low reactivity.




## Steps involved in the extraction of metals from ores



## Common Terms Used in Metallurgy

**1. Minerals**: Compounds of metal found in nature associated with earthy impurities like mud, sand stones, etc. are called minerals.
**2. Ore**: The naturally occurring mineral from which a particular metal can be extracted economically and conveniently is called ore.
**3. Matrix**: The unwanted impurities like mud, sand, stone, etc. associated with an ore is called matrix or gangue.
**4. Flux**: The substance added to the ore to remove the unwanted matrix, resulting in the formation of fusible compound is called flux.
**5. Slag**: The fusible compound formed by the reaction of matrix with flux is called slag.
**6. Metallurgy**: The processes involved in the extraction of metals from their respective ores are together called metallurgy.

## Metallurgy

Metallurgy is the process of extracting metals economically from their ores and refining the extracted raw material into purer form. The process of extraction of a metal depends on the nature of the ore, impurities present in the ore and physical and chemical properties of the metal to be extracted.

## Processes involved in metallurgy

The process of metallurgy consists of the following steps.

1. Concentration of ore
2. Conversion of concentrated ore into metal oxide
3. Extraction of the metal by the reduction of metal oxide
4. Refining of impure metals

**1. Concentration of ore:** The impurities present in an ore are called **gangue**. The process of removal of unwanted material (gangue) from an ore is called **concentration, dressing** or **benefaction of ore**. The following methods are used for the concentration of ores.

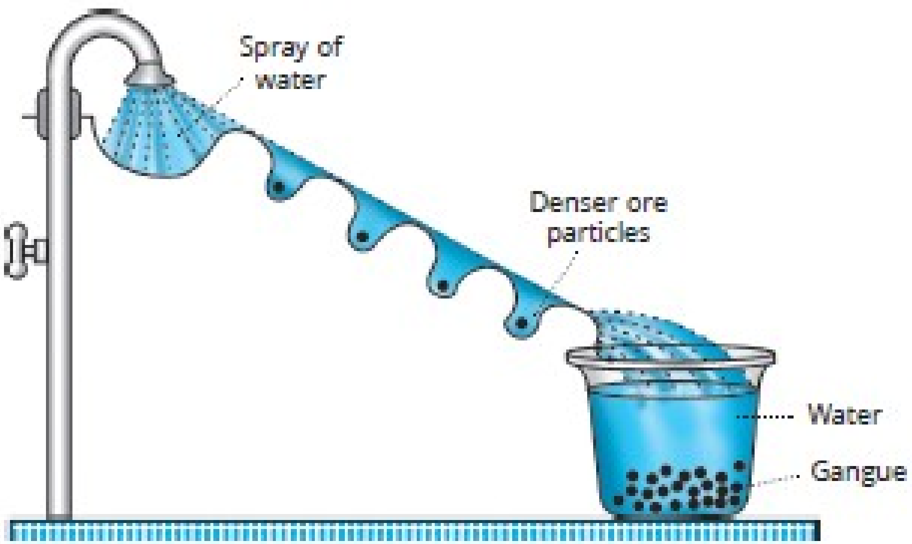
**a. Hand-picking**: Unwanted stones and rocks are removed manually from the ore.

**b. Grinding and crushing**: Ores with big lumps of rocks are crushed in jaw crushers to small pieces. These pieces are further converted into small pieces by hammering them in the hammer mills.

**c. Pulverizing**: The crushed ore is then grounded to form a fine powder in the stamp mills or ball mills

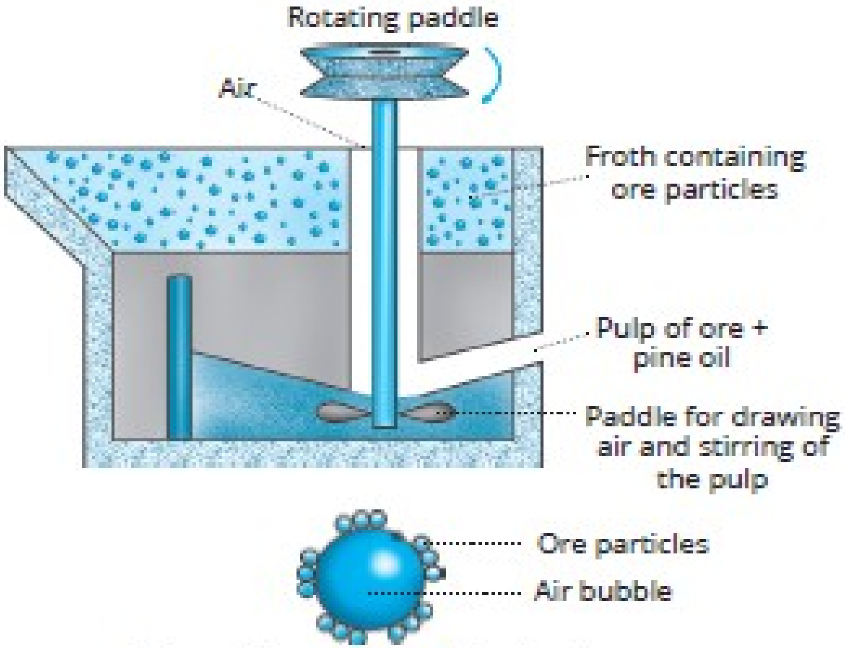
## d. Gravity separation or hydraulic washing

This method is based upon the difference in the densities of the ore and the gangue particles. The powdered ore is spread on tables having grooves on the top. The powdered ore is then washed with upward stream of water. The lighter gangue particles are washed away and the heavier ore particles are left behind. This method is used for the oxide ores of heavy metals such as iron and tin and native ores of silver, gold and platinum.



## e. Froth floatation process

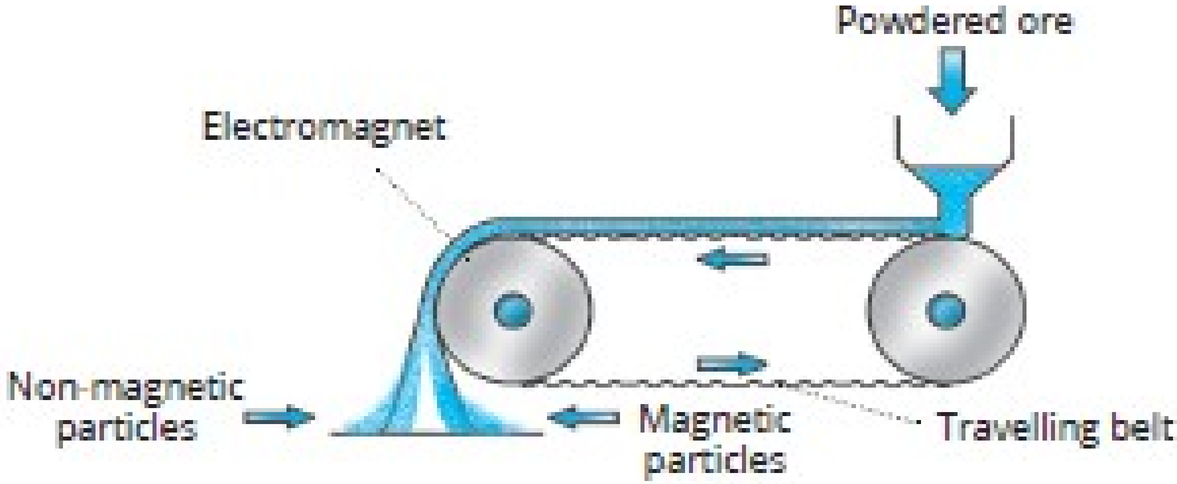
This method is based on the principle that the ore particles are preferentially wetted by oil while the gangue particles are wetted by water. The powdered ore is taken in a tank containing water and a little pine oil. The mixture is agitated by means of a rotating shaft and the air is blown through the mixture to create froth. The concept used in this technique is to alter the surface of the particles of the ore in such a way that the ore particles are attracted to the air bubbles and then float with the froth on the surface.




Enlarged view of air bubble showing the ore particles attached to it.

## f. Magnetic separation

This method is used where either the ore or the impurities are magnetic in nature. The powdered ore is fed onto a conveyer belt which moves over two rollers, one of them being magnetic. The magnetic constituents are attracted by the magnetic roller whereas the non-magnetic constituents are collected separately.




## g. Chemical separation or leaching process

This method is based on the difference in the chemical reactivity of the ore and the gangue towards a particular reagent. The powdered ore is treated with a suitable chemical reagent. The reagent selectively dissolves the desired metallic component of the ore to form a soluble product. On filtration, impurities are left behind. The filtrate, is treated with suitable chemical reagent which precipitates the ore.

## 2. Conversion of concentrated ore into metal oxide

The concentrated ore is subjected to any one of the following processes.

### a. Calcination

Calcination is the process of heating the concentrated ore below its melting point in the absence or limited supply of air it. This removes the volatile impurities and the mass becomes porous.

$$ZnCO_3 \xrightarrow{heat} ZnO + CO_2$$

$$Al_2O_3 \cdot 2H_2O \xrightarrow{heat} Al_2O_3 + 2H_2O$$

### b. Roasting

Roasting is the process in which the concentrated ore is heated strongly below its melting point in the presence of excess of air. This removes the volatile impurities and the ore changes to its oxide.

$$2ZnS + 3O_2 \xrightarrow{heat} 2ZnO + 2SO_2$$

$$4FeS_2 + 11O_2 \xrightarrow{heat} 2Fe_2O_3 + 8SO_2$$

Roasting is generally used for sulphide ores.

## 3. Extraction of the metal by the reduction of metal oxide

The metals are grouped into the following three categories for the purpose of their extraction:

**a.** Metal of high reactivity

**b.** Metals of moderate reactivity.

**c.** Metals of low reactivity.

The techniques used for the extraction of metals from their oxides belonging to the above three categories are given below.

| | | |
|---|---|---|
| Highly reactive metals | K, Na, Ca, Mg, Al | By electrolysis |
| Moderately reactive metals | Zn, Fe, Pb, Cu | By reduction of oxide ore with carbon |
| Less reactive metals | Cu, Hg, Ag | By self-reduction of sulphide ore (by heating alone) |
| Least reactive metals | Au, Pt | Occur in nature in the native state |

**Reduction of oxides of highly reactive metals:** The highly reactive metals such as potassium, sodium, calcium, magnesium and aluminium are obtained by the electrolysis of their molten or fused oxides or chlorides.

The cathode is usually made of iron and the anode of graphite.

Example:

Potassium: Fused potassium chloride is taken.

**Reaction:** $KCl \rightleftharpoons K^+ + Cl^-$

**At the cathode:** $K^+ + e^- \longrightarrow K$

**At the anode:** $Cl^- - e^- \longrightarrow Cl$

$Cl + Cl \longrightarrow Cl_2$

**Note**: The oxides of highly reactive metals cannot be reduced by heating with carbon or carbon monoxide. These metals have great affinity for oxygen and thus the oxides are very stable.

**Reduction of oxides of moderately reactive metals:** The oxides of moderately reactive metals cannot be reduced by heating alone. The oxides are reduced to corresponding metals by using suitable reducing agent such as carbon (coke), carbon monoxide or aluminium.

$$Fe_2O_3(s) + 3C(s) \xrightarrow{\text{heat}} 2Fe(s) + 3CO(g)$$

$$ZnO(s) + C(s) \xrightarrow{\text{heat}} Zn(s) + CO(g)$$

Carbon monoxide formed also acts as a reducing agent.

$$Fe_2O_3(s) + 3CO(g) \xrightarrow{\text{heat}} 2Fe(s) + 3CO_2(g)$$

$$ZnO(s) + CO(g) \xrightarrow{\text{heat}} Zn(s) + CO_2(g)$$

Since the carbon impurity is difficult to remove from many metals (e.g., Mn, Cr, Fe), the carbon reduction method is unsuitable for the metallurgy of these metals in pure form. In such cases, a reactive electropositive metal aluminium is used as a reducing agent.

$$Fe_2O_3(s) + 2Al(s) \longrightarrow 2Fe(l) + Al_2O_3(s) + \text{Heat}$$

The reaction is highly exothermic. The amount of heat evolved is so large that the metals are obtained in the molten state.

Hydrogen also acts as a reducing agent.

$$ZnO(s) + H_2(g) \xrightarrow{\text{heat}} Zn(s) + H_2O(g)$$

**Reduction of oxides of very less reactive metals:** The oxides of very less reactive metals (Cu, Hg, Ag, Pt and Au) can be reduced to free metals by the action of heat alone. No reducing agents is required. Mercury occurs in nature as the sulphide ore, cinnabar (HgS). When concentrated cinnabar is roasted in the presence of excess of air, mercury(II) sulphide is converted into mercury(II) oxide which is thermally unstable and decomposes to form mercury.

$$2HgS(s) + 3O_2(g) \xrightarrow[\text{(roasting)}]{\text{heat}} 2HgO(s) + 2SO_2(g)$$

$$2HgO(s) \xrightarrow[\text{(reduction)}]{\text{heat}} 2Hg(l) + O_2(g)$$

The equation for the overall reaction occurring during roasting of cinnabar is obtained by adding the above two equations.

$$HgS(s) + O_2(g) \xrightarrow{\text{heat}} Hg(l) + SO_2(g)$$

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## 4. Refining of impure metals

The metals obtained after the reduction of the metallic oxides are often associated with small amounts of various impurities. The presence of impurities within a metal alters the properties of a metal, therefore, impurities should be removed from the metal. The process of purifying a metal is called **refining**. Depending upon the nature of the metal and the nature of the impurities present within the metal, the following refining process can be used:

**a. Liquation:** This method is used for the refining of metals with low melting points like lead and tin.

**b. Distillation:** This method is used for refining volatile metals such as zinc and mercury.

**c. Oxidation:** This method is used for refining those metals that contain volatile impurities like sulphur and phosphorus.

**d. Electrorefining:** This method is widely used to refine a number of metals like copper, silver, gold and aluminium/

## Aluminium

Aluminium belongs to group 13 of the periodic table. Aluminium never occurs free in nature and its most common ore is bauxite. The three ores of aluminium are: Bauxite: $Al_2O_3 \cdot 2H_2O$,

Cryolite: $Na_3AlF_6$, Corundum: $Al_2O_3$

## Extraction of aluminium

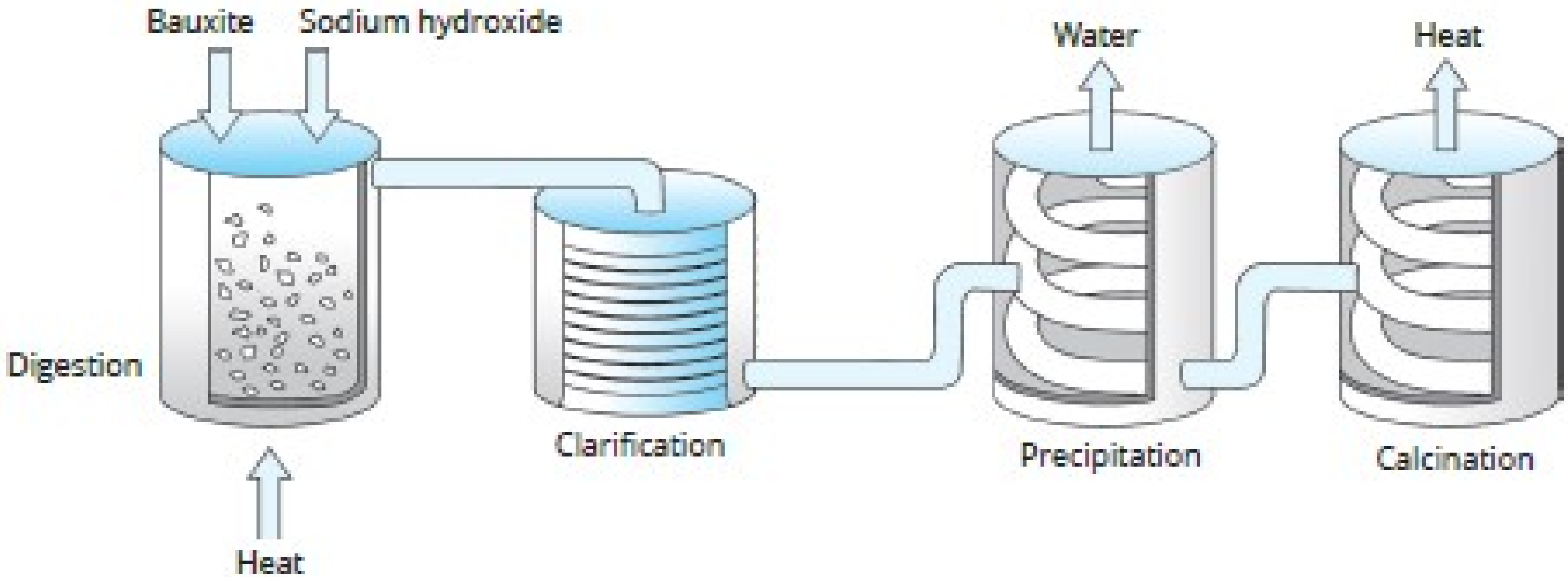
Aluminium is extracted mainly from bauxite, $Al_2O_3 \cdot 2H_2O$.

**Dressing of ore**

The ore is crushed, pulverized and ground into a fine powder and prepared for concentration.

**Concentration of ore**

Bauxite is not concentrated by conventional physical methods but by chemical processes. It is concentrated by the Baeyer's process.



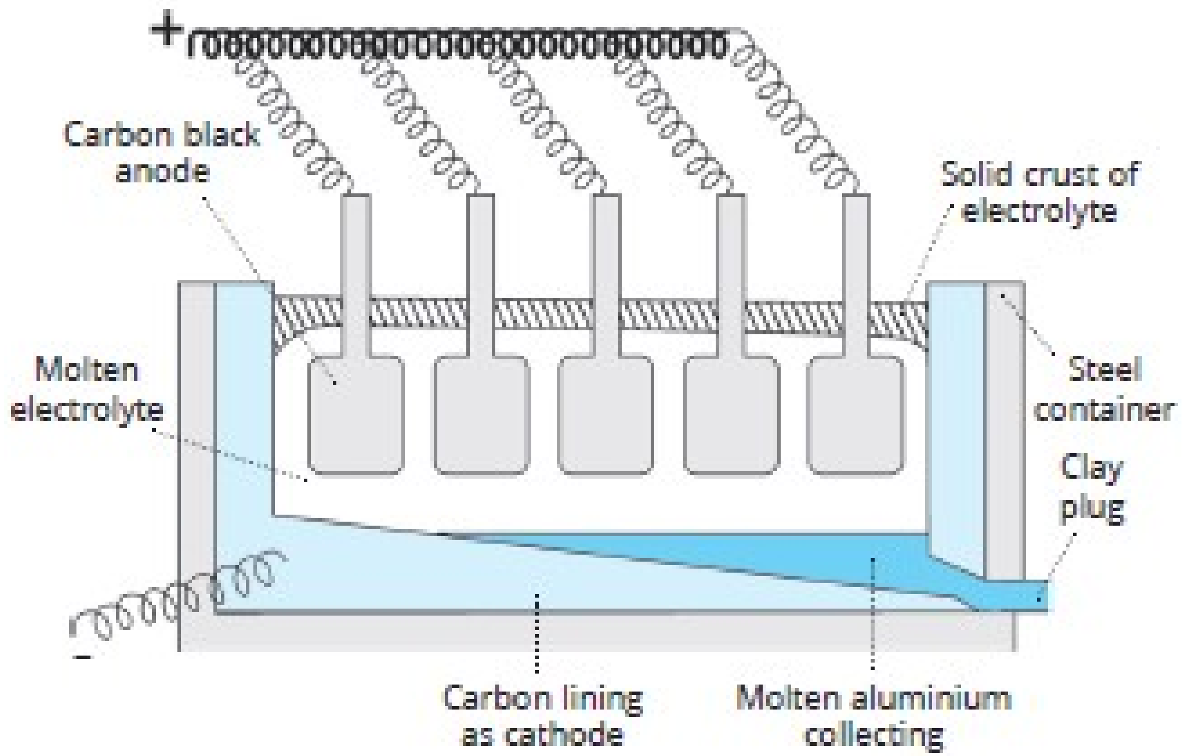

**Note:** **Pl. refer to p 140 of the textbook for steps in the Bayer's process**

## Electrolytic reduction of fused alumina

Aluminium is usually extracted by the Hall-Heroult's process. Alumina is mixed with cryolite and fluorspar (1 : 3 : 1) and the electrolytic mixture is covered with carbon dust. The inner lining of the electrolytic cell acts as the cathode and thick graphite rods connected to the positive terminal of the electrical output act as anodes.

**1.** Cryolite and fluorspar acts as a solvent for the alumina and also lowers the fusion temperature; the mixture melts at 950 °C instead of 2050 °C thereby saving electrical energy.

**2.** Addition of fluorspar enhances the conductivity of the mixture since alumina is almost a nonconductor of electricity.



**3.** A layer of powdered coke is sprinkled over the electrolytic mixture to reduce heat loss due to radiation. It also prevents the carbon anode from burning in air at the point above the electrolyte.

**4.** The carbon anode has to be replaced periodically as the oxygen released oxidizes it.

Electrolytic cell: Made of iron and lined with carbon.

Electrolyte: Mixture of molten alumina, cryolite and fluorspar (1:3:1).

Electrodes: Anode: made of graphite

Cathode: inner carbon lining of electrolytic cell

**Ionization reactions:**

Cryolite: $Na_3AlF_6 \rightleftharpoons 3Na^+ + Al^{3+} + 6F^-$

Fluorspar: $CaF_2 \rightleftharpoons Ca^{2+} + 2F^-$

Alumina: $Al_2O_3 \rightleftharpoons 2Al^{3+} + 3O^{2-}$

Since $Na^+$ and $Ca^{2+}$ are above $Al^{3+}$ in the reactivity series, $Al^{3+}$ is discharged at the cathode in preference to $Na^+$ and $Ca^{2+}$. Oxygen is discharged at the anode.

**Reaction at the cathode:**

$$2Al^{3+} + 6e^- \longrightarrow 2Al$$

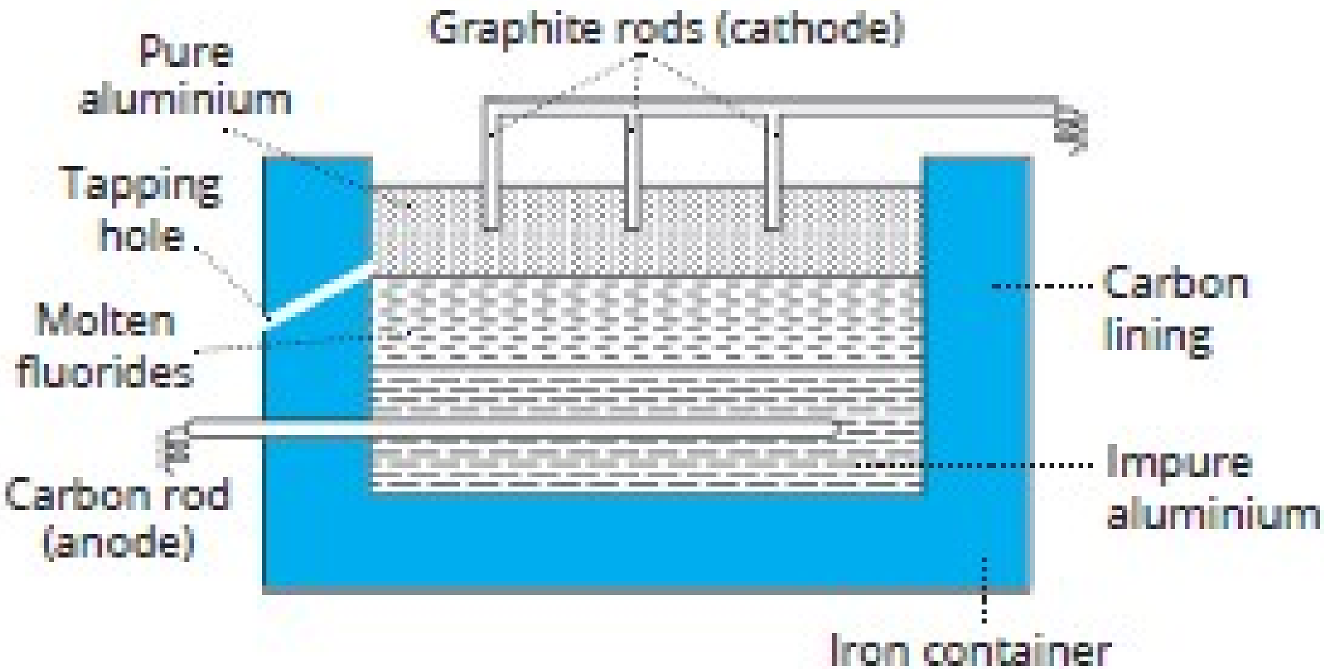
**Reaction at the anode:**

$$3O^{2-} \longrightarrow 3O_2 + 6e^-$$

$$C + O_2 \longrightarrow CO_2$$

## Purification of aluminium

Aluminium obtained can be purified further by electrolysis by a process called Hoope's process.




Hoope's process

**Refining of aluminium by Hoope's electrolytic method:** The electrolytic cell consists of iron box lined inside with carbon. The cell consists of three layers of fused mass which differ in specific gravities. The upper layer of pure aluminium acts as a cathode. The middle layer consists of a mixture of fluorides of Al, Ba and Na. The lowest layer consists of impure aluminium which acts as anode. On passing electric current, aluminium is deposited at cathode from the middle layer and an equivalent amount of aluminium is taken up by the middle layer from the bottom layer. Thus, aluminium is transferred from bottom to the top layer through middle layer while impurities are left behind.

**Electrolytic reactions:**

At the cathode: $Al^{3+} + 3e^- \longrightarrow Al$ (Pure Al ion)

At the anode: $Al \longrightarrow Al^{3+} + 3e^-$
(Impure Al from the lower layer enters the middle layer)

The aluminium obtained is 99.9% pure.

**Bauxite ore**

↓

**Baeyer's process**

$$Al_2O_3 \cdot 2H_2O + 2NaOH \xrightarrow[\text{digestion}]{140\,°C - 150\,°C} 2NaAlO_2 + 3H_2O$$

$$NaAlO_2 + 2H_2O \xrightarrow[\text{precipitation}]{50\,°C} NaOH + Al(OH)_3\downarrow$$

$$2Al(OH)_3 \xrightarrow[\text{calcination}]{1000\,°C} Al_2O_3 + 3H_2O$$

↓

**Electrolytic reduction of fused alumina (Hall-Heroult's process)**

Electrolyte: Alumina, Cryolite and Fluorspar (1 : 3 : 1)

$$Al_2O_3 \rightleftharpoons 2Al^{3+} + 3O^{2-}$$

At cathode: $2Al^{3+} + 6e^- \longrightarrow 2Al$

At anode: $3O^{2-} \longrightarrow 3O_2 + 6e^-$

$$C + O_2 \longrightarrow CO_2$$

↓

**Purification by Hoope's process (electrolysis)**

At cathode: $Al^{3+} + 3e^- \longrightarrow Al$ (pure Al)

At anode: $Al \longrightarrow Al^{3+} + 3e^-$ (impure Al)

Flow chart showing various steps involved in the extraction of aluminium

## Alloys

An alloy is a homogeneous mixture of two or more metals or a metal and a non-metal. Alloys are prepared to enhance the properties of the metal. The Properties of alloys are entirely different from the constituent metals. This makes them more useful than the pure metals.

For example, gold is too soft to be used. But when it is mixed with copper or silver, it becomes hard. Certain non-metals like carbon and sulphur also form alloys with metals. For example, steel is an alloy of iron and carbon. It is one of the most commonly used alloys and has a variety of uses.

Alloys can be prepared by mixing two molten metals or a molten metal with a non-metal because all metals are miscible in the molten state. Therefore, most of the alloys are made by fusing them together and then allowing them to cool and solidify.

Some alloys are prepared by mixing the metals in a powdered form and then grinding and heating them to form a compact mass.

Table 7.5 in the textbook gives an account of alloys – composition, properties and uses

## Purpose of making alloys

1. **To increase hardness:** Gold becomes hard when copper is added to it.

2. **To increase tensile strength:** Chrome steel prepared by mixing iron and chrome has high tensile strength.

3. **To improve the colour of a metal:** Alloy of a metal has a different colour. For example, when copper and aluminium are alloyed, aluminium bronze is formed which has a beautiful yellow colour. It is used for interior decoration.

4. **To prevent the metal from corrosion:** Iron rust in moist air. However, stainless steel made of iron, chromium, nickel and carbon does not rust easily.

5. **To alter the chemical reactivity of a metal:** Chemical reactivity of a metal is altered by making its alloys. For example, sodium is highly reactive towards water but when alloyed with mercury, it reacts with water very slowly.

6. **To alter the melting point of a metal:** The melting points of lead (327 °C) and tin (232 °C) are very high. But the alloy solder melts at 180 °C. Thus, alloying of a metal lowers their melting point.

7. **To enhance the properties of a metal.**

## SUMMARY

**1.** Metallurgy is the process of extracting metals from their ores.

**2.** An ore is the mineral from which the metal can be extracted profitably.

**3.** Minerals are compounds or elements that occur naturally in the earth's crust.

**4.** Gangue is the impurity associated with the minerals; these impurities are usually clay and silicates.

**5.** The process of metallurgy consists of the following stages:

**a.** Hand-picking, crushing and grinding and pulverizing of ore.

**b.** Concentration (or purification) of ore to remove gangue particles. It is done by

**i.** Hydraulic washing: Carried out for iron oxide ores

**ii.** Froth flotation: Carried out for sulphide ores

**iii.** Magnetic separation: Carried out for magnetic ores or impurities

**iv.** Chemical separation: For alumina

**c.** Conversion of metal ore into metallic oxide by:

**i.** Calcination: Heating a carbonate ore in the absence of air.

**ii.** Roasting: Heating a sulphide ore in the presence of air

**d.** Reduction of metal oxide to metal

**i.** Oxide of metals of moderate reactivity reduced by heating oxide with carbon (coke), carbon monoxide, aluminium, hydrogen

**ii.** Metal oxides of very low reactivity reduced by heating alone.

**iii.** Metals of very high reactivity are reduced by electrolytic reduction.

**6.** Extraction of aluminium: Aluminium is extracted from bauxite.

a. Concentration or purification of bauxite by

Baeyer's process:

$$Al_2O_3 \cdot 2H_2O + 2NaOH \longrightarrow 2NaAlO_2 + 3H_2O$$

$$NaAlO_2 + 2H_2O \longrightarrow NaOH + Al(OH)_3\downarrow$$

$$2Al(OH)_3 \longrightarrow Al_2O_3 + 3H_2O$$

b. Electrolytic reduction of fused alumina containing cryolite ($Na_3AlF_6$) and fluorspar ($CaF_2$).

$$Al_2O_3 \longrightarrow 2Al^{3+} + 3O^{2-}$$

Reaction at the cathode:

$$2Al^{3+} + 6e^- \longrightarrow 2Al$$

Reaction at the anode:

$$3O^{2-} \longrightarrow 3O_2 + 6e^-$$

$$C + O_2 \longrightarrow CO_2$$

c. Electrolytic refining of crude aluminium by Hoope's process.

**7. Alloy:** Homogeneous mixture of two or more metals or metals and non-metals

**8. Amalgam:** An alloy of a metal with mercury

# THANK YOU