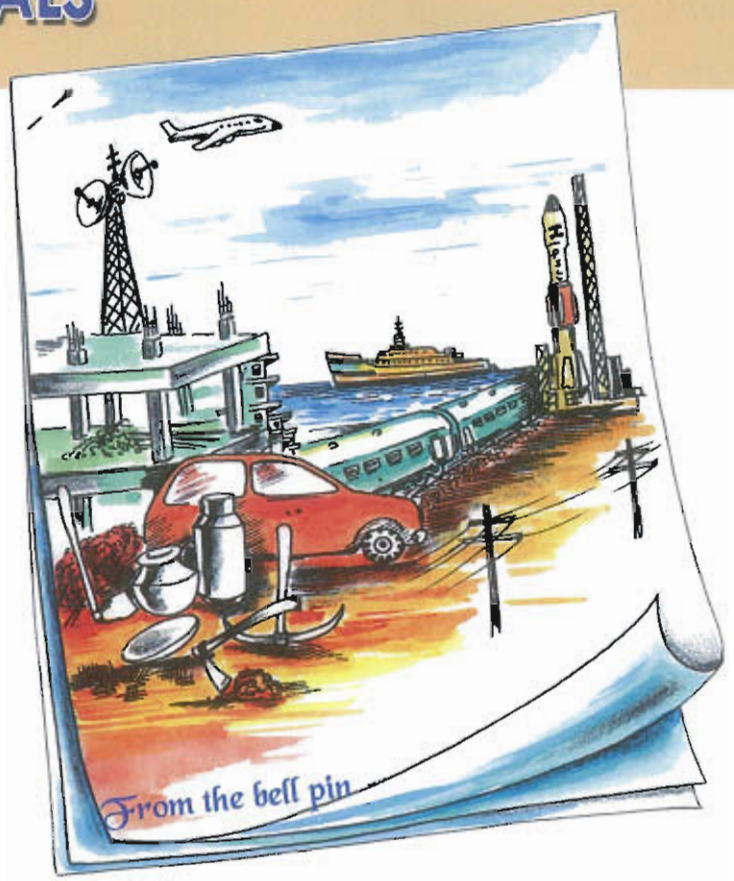
4 METALS



Most of the objects seen around us are made up of metals. The unique properties of metals are made use of in these different objects.

* What may be the reasons for using aluminium for making household utensils?

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* What may be the basis of using copper for making electric cables?

Can you find more such instances in which metals are used?

Which of the common properties of metals are utilized here?

- Thermal conductivity
-
-

Like these common physical properties do metals exhibit any similarity in their chemical properties? Haven't you already done experiments on the reaction between dilute acids and metals? What was your observation? Will there be any difference

in the chemical reactivity among metals?

Reaction of metals with water

Allow the metals Na, Mg, Cu and Fe to react with water. What is your observation?

* Do you find any difference in their reactivity?

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* What is the gas formed when sodium reacts with water? Can you write the chemical equation?

Allow the metals Mg and Cu to react with hot water. Record your observations.

What are the products formed here?

See the chemical equation.

$$Mg + H_2O \rightarrow MgO + H_2$$

You have observed the action of the metals Na, Mg, Cu and Fe on water.

Sodium reacts vigorously even with cold water. Though the reaction of Mg with cold water is slow, it reacts faster with hot water to produce hydrogen. Cu and Fe do not react with water. However, Fe reacts with superheated steam to produce hydrogen gas.

Can you arrange the metals Mg, Na, Fe and Cu in the decreasing order of their reactivity with water?

Reaction of metals with air

Do you think that the painting done occasionally on window grills made of iron in your home is merely to make it look better? What happens if this is not done?

The rusting of iron is due to its reaction with the moisture, oxygen and carbon dioxide in the atmosphere.

Cut a small piece of sodium with a blade. Notice the lustre at the freshly cut surface. Do you notice any change occurring on the shining surface after some time?

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* How did this happen?

Sodium reacts with the water vapour and carbon dioxide in the atmosphere.

$$2Na + 2H_2O \rightarrow 2NaOH + H_2$$

$$2NaOH + CO_2 \rightarrow Na_2CO_3 + H_2O$$

Do gold ornaments react chemically in an environment like this?

Can you arrange the metals Fe, Na and Au in the order of their reactivity with the atmosphere?

Reaction of metals with acids

Clean the surface of iron, magnesium, copper, zinc and aluminium pieces of the same size by scrubbing and then treat them with dilute hydrochloric acid having the same molar concentration.

Is the vigour of the chemical reaction of all these metals with the acid the same? Observe the reactivity and fill the Table 4.1. Write the chemical equation also in the appropriate column.

Metal	Observation	Chemical equation
Zn		$Zn+2HCl \rightarrow ZnCl_2+H_2$
Fe		
Cu		
Mg		
Al		

Table 4.1

★ Which metal among these participates most actively in the chemical reaction?

- -

★ Is there any metal which does not take part in the chemical reaction with acid?

- -

★ Can you arrange these metals in the order of their chemical reactivity with the acid?

- -

Displacement reaction of metals

Solutions of $MgSO_4$, Na_2SO_4 and $CuSO_4$ having same molar concentration are prepared and taken in three test tubes. Into each test tube add zinc pieces of the same size. Observe the reactions taking place in each test tube. Use the information given below for preparing notes. Can you add more data?

★ Do you notice any change in the zinc added to each solution?

- -

★ Is there a change in colour for any of the solutions?

- -

Let us see how Zn displaces copper from copper sulphate solution.

★ What is the colour of Zn metal?

- -

★ And the colour of $CuSO_4$ solution?

- -

There are Cu^{2+} ions and SO_4^{2-} ions in $CuSO_4$. Of these Cu^{2+} ions are responsible for the colour.

★ What change occurs to the colour of the solution when zinc is kept for some time in $CuSO_4$ solution?

- -

★ What change occurs to the colour of zinc?

- -

Let us see what the chemical reaction taking place here is.

$$Zn + CuSO_4 \rightarrow ZnSO_4 + Cu$$

- Zn metal changes to Zn^{2+} ions and passes into the solution.
- Cu^{2+} ions change to Cu and get deposited on the surface of Zn.

The ionic equation of this process is given below.

$$Zn + Cu^{2+} + SO_4^{2-} \rightarrow Zn^{2+} + SO_4^{2-} + Cu$$

This can also be written as

$$Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$$

How can the change in zinc during this process be represented?

$$Zn \rightarrow Zn^{2+} + ...$$

Along with this Cu^{2+} ions change to Cu

$$Cu^{2+} + ... \rightarrow Cu$$

The process involving the loss of electrons is known as oxidation and the process involving the gain of electrons is known as reduction.

★ Is it zinc or copper that got oxidized in the above reaction?

- -

When one species gets oxidized in this process, the other gets reduced at the same time. Since both the changes take place simultaneously this process is known as a redox reaction.

We saw that zinc displaced copper from $CuSO_4$ solution when the zinc metal was placed in it.

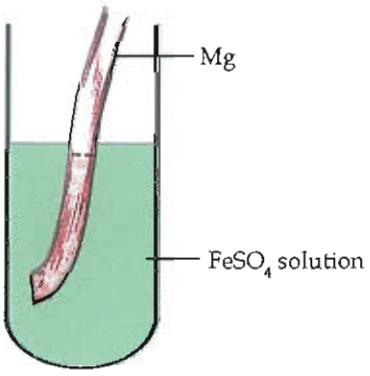


Fig. 4.1 (a)

If a strip of Mg is introduced into ferrous sulphate solution, does it displace Fe?

Try this experiment.

Is there any change in the colour of $FeSO_4$ solution?

- -

Does Fe get deposited on the surface of Mg?

Can you write the equation for the chemical reaction that has taken place here?

$$Mg + FeSO_4 \rightarrow MgSO_4 + ...$$

$$Mg \rightarrow ..... + 2e$$

$$Fe^{2+} + ... \rightarrow Fe$$

Oxidation takes place for .....

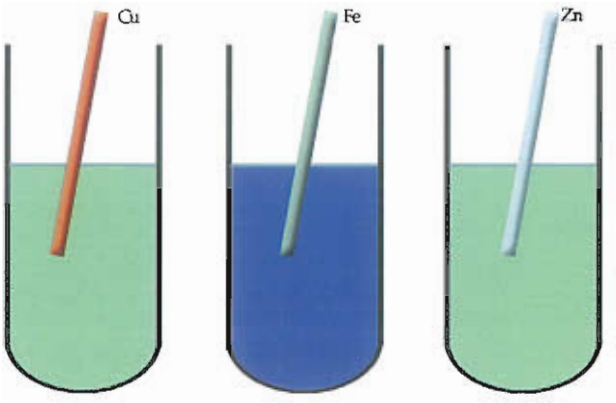


Fig. 4.1 b, c, d

Reduction takes place for .....

Let us do some more experiments.

What if a Cu rod is dipped in $FeSO_4$ solution? Carry out the experiment (Fig. 4.1b).

Does the colour of $FeSO_4$ change?

Can Cu displace Fe from $FeSO_4$ solution?

Repeat the experiment by dipping an iron rod in $CuSO_4$ solution (Fig. 4.1c). What is the observation?

Can you write the chemical equation?

Similarly, what if a Zn rod is kept in contact with the $FeSO_4$ solution? (Fig. 4.1d). Try it.

Is it Zn or Fe that has more ability to release electrons?

When a Zn rod is placed in solutions of $ZnSO_4$, $CuSO_4$ and $FeSO_4$, to which of these solutions does electron release occur?

- -

★ And if it is an iron rod?

- -

★ Why can't Fe give electrons to Zn^{2+}?

- -

★ And if it is a Cu rod?

★ Among Fe, Cu and Zn, which has more ability to take part in a chemical reaction by releasing electrons?

★ Can you arrange these metals in the decreasing order of their ability to take part in chemical reactions by releasing electrons?

Reactivity series

We have learnt that metals differ in their chemical reactivity. Metals can be arranged on the basis of their chemical reactivity to obtain a series. The reactivity series of some familiar metals is given below. In this series the reactivity of metals decreases as we move from top to bottom. Is the same order maintained in the case of the reactivity of the metals with water and dilute acids?

Arrive at a conclusion analysing the observations of the previous activities.

- Potassium (K)
- Sodium (Na)
- Calcium (Ca)
- Magnesium (Mg)
- Aluminium (Al)
- Zinc (Zn)
- Iron (Fe)
- Lead (Pb)
- Copper (Cu)
- Silver (Ag)
- Gold (Au)

When a metal is in contact with the solution of a compound of another metal, electrons are exchanged in accordance with the reactivity of the two metals. Can we construct electrochemical cells utilizing such processes involving transfer of electrons?

Let us construct an electrochemical cell.

Take solutions of $ZnSO_4$ and $CuSO_4$ of the same concentration in two beakers. Place a Zn rod in $ZnSO_4$ solution and a Cu rod in $CuSO_4$ solution. Then connect the negative terminal of a voltmeter to zinc rod and the positive terminal to the copper rod. Connect the two solutions with a folded filter paper soaked in KCl solution.

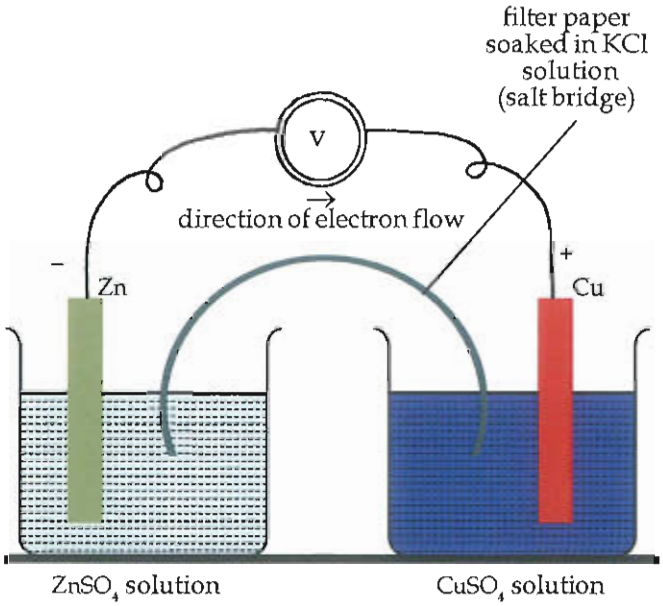


Fig. 4.2

In such arrangements a metal (element) kept in contact with the solution of its compound is called an electrode.

The electrode obtained by dipping a Zn rod in $ZnSO_4$ solution or a Cu rod in $CuSO_4$ solution has the capacity to release or accept electrons. We have already learnt that the ability to take part in a chemical reaction by the release of electrons is more

for Zn than Cu. While comparing the Zn and Cu electrodes is the possibility of electron transfer from Zn to Cu or Cu to Zn?

Which of the following reactions is likely to take place at the Zn electrode when electrons flow in the external circuit from Zn electrode to Cu electrode. (✓ the correct answer)

- $Zn \rightarrow Zn^{2+} + 2e$ ☐
- $Zn^{2+} + 2e \rightarrow Zn$ ☐

And at the copper electrode?

Now isn't it clear that the flow of electricity is the result of chemical reactions that take place in metals and their salt solutions. The electric current is the result of the redox reaction $Zn + Cu^{2+} \rightarrow Zn^{2+} + Cu$, obtained by adding the equations of the reactions taking place at the two electrodes.

Here which is the electrode at which oxidation took place? And, at which reduction took place?

The electrode at which oxidation occurs is the anode and the electrode at which reduction occurs is the cathode.

Now, can you construct a cell using Mg electrode and Cu electrode?

Requirements

Procedure

Can you draw the cell?

Here which is the electrode that releases electrons?

In the figure of the cell indicate the direction of electron flow.

Can you identify the cathode and the anode in the Zn - Cu and Mg - Cu cells that you have constructed?

Is there any difference in the voltage of the two cells?

Which is higher?

A few metal rods and some salt solutions are given (Fig. 4.3). Which are the cells you can construct by selecting the suitable ones? Now can you draw the figures of the cells constructed? Also indicate the direction of electron flow in each figure.

If so, can't you fill Table 4.2?

Cell	Anode	Cathode

Table 4.2

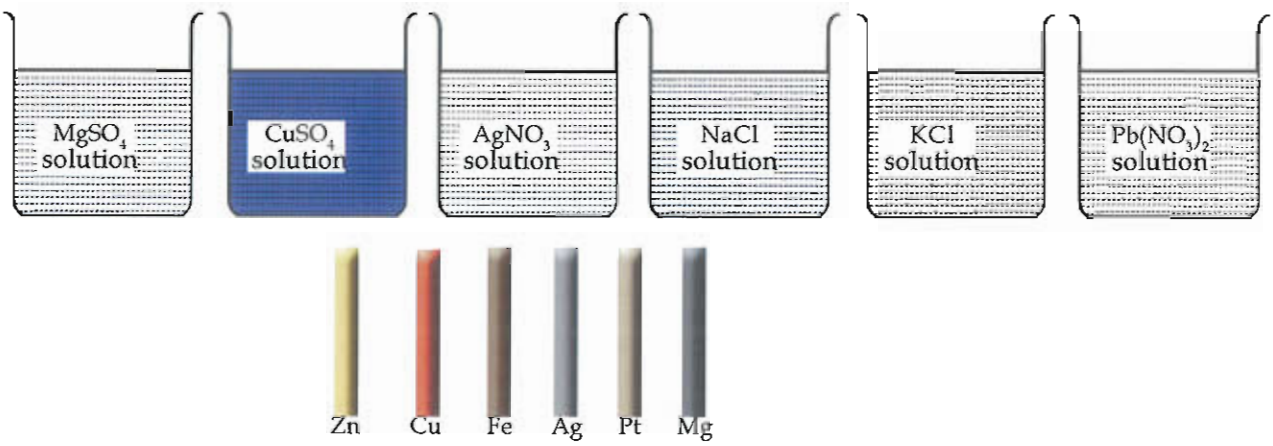


Fig. 4.3

Metals - Historical background

We use metals for hundreds of purposes including the making of electrochemical cells. Metals have a unique place in the history of the growth and progress of human civilisation and culture. This is highlighted by the different metal ages in human civilisation. The discovery of metals and weapons made from them were a blessing for man who had been using stones and wooden logs till then for hunting animals and for cutting them into pieces for food. This helped him to reduce his workload to a great extent. Later when he started using the implements made of metals to prepare land for cultivation, the course of history itself changed. And when metals established their unique place in the field of industry as machines, it turned out to be a revolution. Just think of a world without the iron used for the production of a large variety of articles ranging from tiny pins to huge ships, and the copper and aluminium used in the field of electricity and for making household utensils!

Have you ever thought how the largely used iron and the precious gold are obtained from nature?

Are they available in nature in a form that can be directly used?

The compounds of metals seen in nature are generally called minerals. The same metal may occur as different minerals. However the metals are extracted only from suitable minerals.

Aluminium exists in nature in various mineral forms. Aluminium is present in clay and mica. The important constituents of many precious stones are also compounds of aluminium. But it is the mineral bauxite that is generally used to produce aluminium. What may be the reason?

Table 4.3 shows the names of minerals of certain metals and their chemical formulae.

Metal	Compounds of the metal occurring in nature (mineral)	Chemical formula
Sodium	Rock salt Chile salt petre	NaCl $NaNO_3$
Potassium	Carnalite	KCl $MgCl_2 6H_2O$ Sylvine KCl
Magnesium	Magnesite Dolomite	$MgCO_3$ $MgCO_3$ $CaCO_3$
Iron	Iron pyrites Haematite Magnetite	FeS_2 Fe_2O_3 Fe_3O_4
Aluminium	Cryolite Bauxite	Na_3AlF_6 $Al_2O_3 2H_2O$
Copper	Copper pyrites Cuprite	$CuFeS_2$ Cu_2O

Table 4.3

What characteristics should a mineral have if it is to be used for the extraction of the metal?

- The mineral should be abundant
- Extraction should be easy
- Cost of production should be low
-
-

The mineral from which the metal can be extracted easily and economically is called its ore.

Metal	Ore	Chemical formula
Aluminium	Bauxite	$Al_2O_3 2H_2O$
Iron	Haematite	Fe_2O_3
Copper	Copper pyrites	$CuFeS_2$

Table 4.4

Processing in various stages is required for the extraction of a metal from its ore. The ore occurring in the earth's crust contains various impurities. The removal of these impurities is the first step in metal extraction. This is known as the concentration of the ore.

Depending on the nature of the ore and the nature of impurities present different methods are used for concentration. The ores obtained after concentration are almost free from impurities.

✶ Do metals release or receive electrons while forming their compounds?

- -

✶ Is the tendency to release electrons by all metals the same?

- -

✶ Should oxidation or reduction be done to extract metals from their compounds?

- -

Different reducing agents are to be used for this, depending on the reactivity of metals.

The metals Fe, Zn etc. can be extracted from their ores using carbon. But for highly reactive metals like aluminium stronger reducing agents are necessary. They are prepared by reduction using electricity.

And what about metals with very low reactivity like gold, platinum etc.? Do they occur in nature in free form or combined form?

Now, let us study the methods of extraction of certain metals.

Extraction of iron

Can you name the important ore of iron?

- -

The earthy impurities present in the iron ore mined from the earth's crust have to be removed. In haematite impurities like silicate, silica (SiO_2) etc. are present. When the ore is washed in running water, some of the impurities get removed.

The concentrated ore (haematite) is heated in a current of air. While heating, impurities like sulphur, arsenic, moisture etc. get removed.

The haematite thus obtained is then reduced in a blast furnace. (Fig. 4.4)

The mixture of concentrated haematite, coke and limestone are added from the top into the blast furnace. A powerful current of hot air is blown from the bottom.

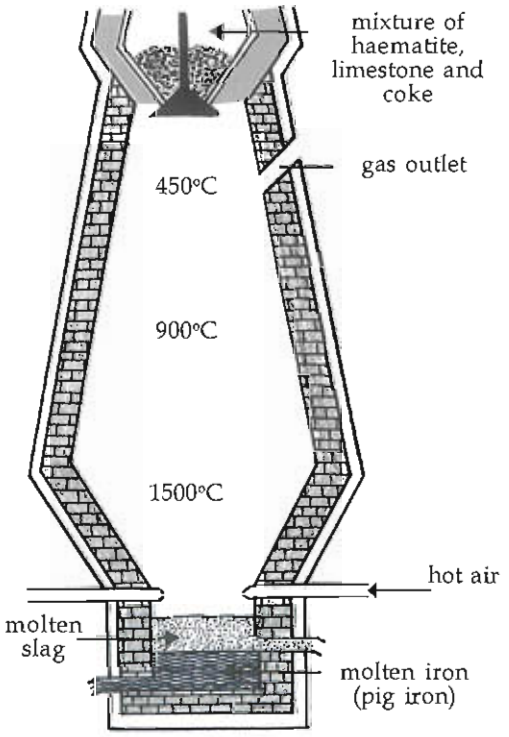


Fig. 4.4

Carbon is added to reduce the ore. And limestone?

Gangue, flux and slag

Fluxes are substances added to the ore during metal extraction to remove the impurities (gangue) which are not removed during ore concentration. The selection of flux is based on the nature of the gangue. If the gangue is acidic, a basic flux is used and if the gangue is basic, an acidic flux is added. Non-metallic oxides like SiO_2, P_2O_5 etc. have acidic character and metallic oxides like CaO, FeO etc. have basic character. The easily fusible substance formed from flux and gangue is called slag.

Silicon dioxide impurity will be present in the concentrated haematite. How this is removed during iron extraction can be understood from the reactions taking place in the blast furnace.

During the flow of hot air from bottom to top, coke combines with oxygen in the air.

$$C + O_2 \rightarrow CO_2 + \text{heat}$$

$$CO_2 + C + \text{heat} \rightarrow 2CO$$

Calcium carbonate decomposes under the high temperature within the furnace.

$$CaCO_3 \rightarrow CaO + ...$$

The impurity SiO_2 in the ore reacts with CaO and forms calcium silicate.

$$CaO + SiO_2 \rightarrow CaSiO_3$$

$$\text{flux} + \text{gangue} \rightarrow \text{slag}$$

Since the density of calcium silicate in the molten state is low, it floats over the molten iron.

The acidic character of SiO_2 is the reason for using the basic flux CaO.

Can you suggest a substance that can be used as flux for an ore containing FeO as gangue?

It is mainly the CO formed in the furnace that reduces haematite.

$$Fe_2O_3 + 3CO \rightarrow 2Fe + ...$$

Iron and slag in molten form are drained out separately from the furnace.

There are methods at the industrial level for manufacturing iron by the reduction of rusted iron articles (scrap iron) thrown away after use.

The iron obtained from the furnace contains carbon, sulphur, phosphorous, manganese, silicon etc. in very small quantities. Iron obtained in this form is known as pig iron. Pig iron is heated to melting and again solidified to get cast iron.

Fig. 4.5

In cast iron 95% is iron, 3% carbon and the remaining part contains manganese, silicon etc.

Are you familiar with any article made of cast iron?

- Lamp posts
-

Though they are strong they can't be bent or welded together.

Can we use cast iron for making rods used in concrete?

Iron is used commonly in the form of steel for various purposes. Ordinary steel contains 0.1 to 1.5% carbon. Steel is also used in the form of various alloys.

★ Can you find from Table 4.5, two alloy steels with the same components but showing different properties?

The reason for the difference in the properties of alloys with the same components is the difference in the relative amount of the components in the alloy.

Alloy steel	Components	Peculiarity	Use
Stainless steel	Fe, Cr, Ni and C	strong, not corroded by rusting	Making utensils, automobile parts
Alnico	Fe, Ni, Al and Co	Magnetic in nature	Used for making permanent magnets
Nichrome	Fe, Ni ,Cr and C	High electrical resistance	Making heating coils for iron box

Table 4.5

✶ What may be the reason for the alloys alnico and nichrome to show a large difference in their properties?

Different types of alloys are prepared by varying the component elements and their percentage composition.

Aluminium

What are the purposes for which aluminium is generally used?

•

•

•

Take note of the characteristic features that make aluminium useful.

- Good thermal conductivity
- Can be used as thin sheets
- Low weight
- Does not easily undergo corrosion
- Electrical conductivity

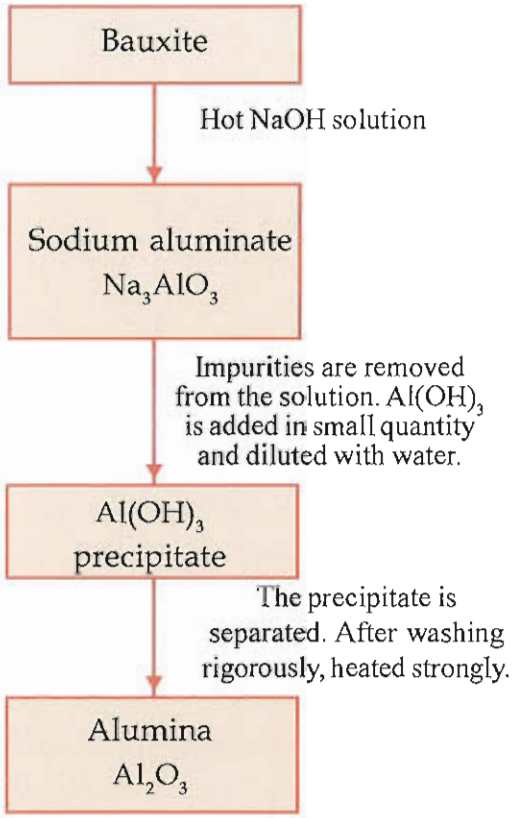
and many more!

Preparation of aluminium - early attempts

Charles Martin Hall

There was a time when aluminium was costlier than gold! In those days aluminium was extracted from clay. It was a very complex and costly process. Through a series of experimental activities the young scientist Martin Hall developed a scientific and cost-effective method for preparing aluminium. In the same period another scientist Paul Heroult also developed a similar method for preparing aluminium. Hence the preparation of aluminium is known as the Hall-Heroult process.

Bauxite ($Al_2O_3 2H_2O$) is the ore of aluminium. The flow chart of the concentration process of bauxite is given below.



Pure Al_2O_3 obtained in this way is dissolved in molten cryolite and subjected to electrolysis (Fig. 4.6).

The melting point of alumina is very high. So cryolite is added to it and melted. Al_2O_3 dissolves in molten cryolite. There will be Al^{3+} ions in it, isn't it?

During electrolysis, will the aluminium be liberated at positively charged electrode or the negatively charged electrode?

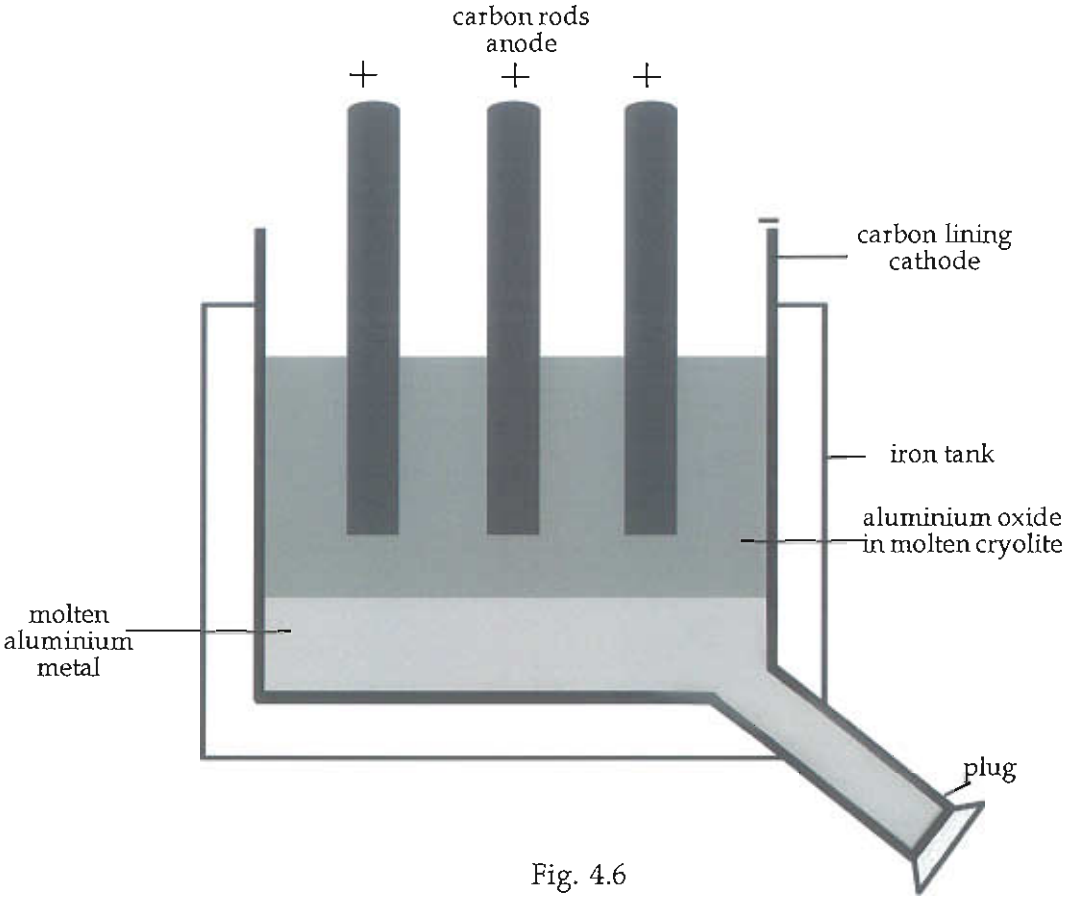


Fig. 4.6

Can you write the equation for the chemical reaction that takes place at this electrode?

Al^{3+} + ... → Al

In this electrolytic cell the carbon rods carrying positive charge are to be replaced periodically. Can you say why?

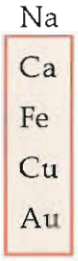
The aluminium collected from the electrolytic tank is used for various purposes after purification.

Follow up Activities

1. The reaction of metals with substances in contact with it leads to their destruction. Can you mention a few such chemical reactions?
2. Solutions of copper sulphate, zinc sulphate and silver nitrate of the same concentration are kept in different beakers. Rods of iron, zinc and silver are dipped in each solution separately.
   a) Which are the metals that iron can displace?
   b) Which are the metals that zinc can displace?
   c) Which are the metals that silver can displace?
   d) Write the equation for the chemical reaction taking place in each.
3. X and Y are metal rods of the two electrodes of an electrochemical cell. The equations for the chemical changes taking place in these electrodes are given below.

   $X \rightarrow X^{n+} + ne$ $\qquad$ $Y^{n+} + ne \rightarrow Y$

   a) Identify the cathode and the anode in this cell.
   b) Indicate the direction of electron flow in the external circuit.
4. You have connected the solutions in the two electrodes of the cell you constructed with a folded filter paper soaked in KCl solution (salt bridge). What happens to the flow of electric current when the filter paper is removed? What is the function of salt bridge in the cell?
5. The metals iron, aluminium, gold, copper etc. have great industrial significance. Which are their important ores? Enquire and find out the places where their production and purification are done in our country and prepare notes on this. Won't you also include the environmental issues due to the over exploitation of ores?
6. Find the important alloys of iron, aluminium and copper and their uses.
7. A table with metals arranged in the decreasing order of their reactivity is given. Notice the ores of a few among them given in the box.



NaCl, Fe_2O_3, $CuFeS_2$

a) What is the name of the ore of copper?

b) Which is the metal to be extracted using a powerful reducing agent?

c) Which are the ores for which carbon can be used as the reducing agent during metal extraction?

d) Prepare a note on the relationship between the metal extraction process and the position of the metal in the reactivity series.