
UNIT 3 METALS

Structure

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3.1 INTRODUCTION

Since ancient times, metals have been very important in human life. In fact, many time periods have been called as iron age, bronze age etc. in history. Metals find diverse uses in our daily life. We use utensils made of aluminium, copper, brass and stainless steel. Metals are also used in construction of bridges, houses, buildings etc. Metals also find important role in the manufacture of automobiles, aeroplanes, trains, ships etc. In fact, metals are basic materials in the national economy.

Some common metals being iron, aluminium, copper, gold, cobalt, lead, manganese, magnesium, platinum, nickel, silver, tin, sodium, uranium and zinc.

In this unit, you will study about the occurrence, extraction, purification and important uses of some metals such as iron, copper and aluminium. **Alloys** which are derived from metals also no less important than metals. The constituents and uses of some alloys are also discussed in this unit.

Objectives

After studying this unit, you should be able to

- state the importance of metals,
- list various ores of iron and discuss its metallurgy,
- describe different types of iron,
- explain different types of steel and their properties,
- describe the manufacture of steel,
- name various ores of copper and explain its metallurgy,
- list some important properties of copper,
- name various ores of aluminium and explain the extraction of aluminium,
- define the term alloy, and
- list some important alloys and their uses.

3.2 OCCURRENCE AND PROPERTIES OF METALS

The earth's crust contains many different rocks. Rocks are a mixture of *minerals*. A **mineral** can be a solid metallic or non-metallic element or a compound found naturally in the earth's crust. Those minerals (or mixtures of minerals) from which metals can be obtained economically are called **ores**. Generally, the ores contain metals in the form of oxides, carbonates or sulphides from which metals are extracted using various physical and chemical processes. However, some metals such as gold, platinum, silver etc. which are quite unreactive in nature are found in the free or native state.

Metals have unique physical properties such as metallic lustre, good electrical and thermal conductivity. They also form positive ions by losing the electrons. Their mechanical properties include high tensile strength, malleability and ductility. These properties, in fact, are responsible for a variety of uses of metals.

3.3 IRON AND STEEL

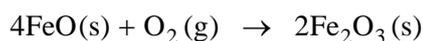
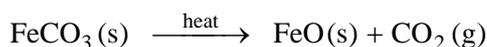
Despite the growth of aluminium and plastics, iron still ranks first as the structural material of modern times.

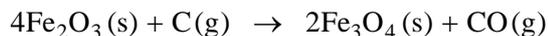
Iron is the most abundant transition metal and it constitutes 4.7% of the mass of the earth's crust. It is also the fourth most abundant element after aluminium in the earth's crust. The most important iron ores are **magnetite** (Fe_3O_4), **siderite** (FeCO_3), **iron pyrite** (FeS_2) and **hematite** (Fe_2O_3). These are shown in Figure 3.1.

Figure 3.1 : Important Iron Ores : Magnetite, Siderite, Iron Pyrite and Hematite

Iron pyrite is widely distributed but is not suitable for production of iron and steel because it is not possible to remove last traces of sulphur present in it. The presence of sulphur causes resulting steel to be too brittle to be useful. Iron pyrite is also known as *fool's gold* because of its appearance. *Siderite* can be converted into iron oxide by heating.

The oxide ores of iron are more important and out of them *magnetite* is predominant. It is magnetic in nature. While concentrating the ore, the Fe_3O_4 particles are separated from gangue by magnets. The other non-magnetic ores are also converted to magnetite by the following processes :

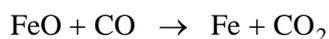
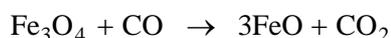




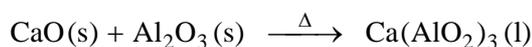
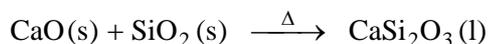
The oxide ores are reduced in a **blast furnace**. The modern blast furnace is about 100 ft high and 25 ft wide (Figure 3.2).

Figure 3.2 : Blast Furnace

The blast furnace can operate continuously. It is charged at the top with a mixture of iron ore, coke and limestone (CaCO_3). Coke is used to reduce iron oxides to free metal while limestone is added to remove silica which is present in varying amounts in the ore. The preheated compressed air and oxygen are blown in near the bottom of the furnace (zone A in figure). The reaction of coke and oxygen to give CO_2 produces a lot of heat and the temperature in this region of the furnace is about 1900°C . As CO_2 rises up, it reacts with more coke to produce CO (zone B), which reduces iron ore to iron (in stages).



The molten metal flows from zone C to zone A. The melting point of pure iron is 1540°C but when mixed with 4% carbon, it melts at 1015°C . The conversion of CO_2 to CO (in zone B) is endothermic and lowers the temperature to 1300°C . In the upper part of the furnace, limestone undergoes thermal decomposition to lime (CaO) and CO_2 . Lime removes acidic and amphoteric impurities from the ore as shown below.



The mixture of these products is called **slag**. Slag is molten in nature and floats on molten iron. It is drawn off from the furnace. Slag is used in building materials and as rail road ballast.

The exhaust gas contains CO which combines with air to give CO₂.

The iron obtained from the blast furnace is called **pig iron**. It contains 90-95% iron, 3-5% carbon, 2% silicon and other impurities (Mn, Si, P, S) present in the ore. Production of 1 kg of pig iron requires about 2 kg of ore, 1 kg of coke, 0.3 kg of limestone and 1.5 kg of air. Pig iron is brittle, difficult to weld and not strong enough for structural use. Hence, it is converted to **steel**.

Cast iron is similar to pig iron but has lesser impurities. Its carbon content is still greater than 2%.

Steel

Steel is an *alloy* of iron and contains 2% or less carbon. An **alloy** is a substance consisting of a mixture of elements and has metallic properties. You will study more about alloys later in this unit.

Steel can be classified as **carbon steel** or **alloy steel**. *Carbon steel* contains upto about 1.5% carbon whereas *alloy steel* contains other metals such as Cr, Co, Mn and Mo in addition to carbon. Carbon steel can be of different types as is shown in Table 3.1 according to the difference in the carbon content.

Table 3.1 : Types of Steel and its Properties

Sl. No.	Types of Steel	% of Carbon	Properties	Applications
1	Low-carbon steel	< 0.15	Malleable, ductile, low hardness	Iron wire
2	Mild carbon steel	0.15 – 0.25	Malleable, ductile	Cables, nails, chains
3	Medium carbon steel	0.20 – 0.60	Tougher than mild steel	Structural material for beams and girders
4	High carbon steel	0.61 – 1.5	Hard	For making drill bots, razors knives, other tools

Stainless steel is highly corrosion resistant and contains high percentages (15%) of chromium and nickel. It is used for cutlery and hospital equipment.

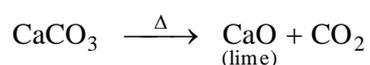
Steel can be made from pig iron using a variety of processes all of which are based on the use of oxygen for oxidation of most of impurities. Some examples of these processes are as follows :

(a) **Open Hearth Process**

In this process, a mixture of molten pig iron, scrap steel and limestone is heated in a shallow hearth furnace as shown in Figure 3.3.

Figure 3.3 : Open Hearth Process

An external source of heat is required in this process to keep the iron in molten state. The concave roof reflects the heat back towards the molten iron. A blast of air or oxygen is passed over iron which oxidizes the impurities. Silicon and manganese on oxidation give oxides which form slag. Then, carbon gets oxidized to carbon monoxide. This reaction liberates heat which increases the temperature and as a result the limestone calcines to give calcium oxide (lime)



The lime so produced floats on the surface and combines with phosphates, silicates, sulphates etc. which are formed by the oxidation of other impurities present.

Further refinement involves continued oxidation of carbon and other impurities followed by addition of alloying metals such as vanadium, chromium, nickel, titanium etc.

(b) **Basic Oxygen Process**

This process is faster than the open hearth process and takes about only one hour whereas the open hearth process requires eight hours of processing. Molten pig iron and scrap iron are added to a barrel shaped furnace (Figure 3.4).

Figure 3.4 : The Basic Oxygen Process

A high pressure blast of oxygen is passed through molten iron for oxidation of impurities. This is followed by the addition of limestone which forms slag with the oxides of the impurities. Here, the reactions

involved produce a large amount of heat and hence, the external source of heat is not required.

(c) **The Electric Arc Process**

In this process, an electric arc between carbon electrodes is used for melting the mixture of pig iron and scrap steel (Figure 3.5).

Figure 3.5 : The Electric Arc Process

Higher temperatures can be attained in this method as compared to open hearth or basic oxygen processes. Hence, impurities such as sulphur and phosphorous are more effectively removed. This process is used for manufacturing alloys and high quality steels.

SAQ 1

- (a) Name two important ores of iron.
- (b) Why is iron pyrite not suitable for the extraction of iron?
- (c) Why are limestone and coke added to the blast furnace?
- (d) What is pig iron? Give its composition.
- (e) What is high carbon steel? Give its important uses.

3.4 COPPER

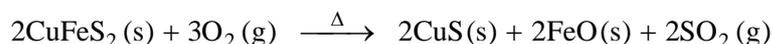
Copper has atomic number 29 and its valance electron configuration is $3d^{10}4s^1$. Its melting and boiling points are 1083°C and 2567°C , respectively. It generally occurs as various sulphides. Some important copper ores are *chalcopyrite* (CuFeS_2), *malachite* ($\text{CuCO}_3 \cdot \text{Cu}(\text{OH})_2$) and *chalcocite* (Cu_2S). These are shown in Figure 3.6.

Figure 3.6 : Ores of Copper : Chalcopyrite, Malachite and Chalcocite

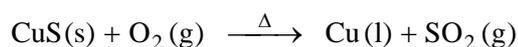
Copper is mainly extracted from the *chalcopyrite* ore. The ore is first crushed and ground to fine particles. It is then separated from excess rock by **froth flotation process**. This process is shown in Figure 3.7. It involves the blowing of air through a mixture of powdered ore with oil, water and detergents. The oil coated particles of the ore float to the surface with froth. The unwanted **gangue** remains at the bottom and is removed from there.

Figure 3.7 : Froth Flotation Process

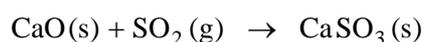
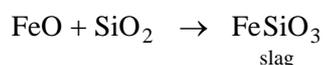
The concentrated ore is then heated in air (roasted) to yield copper sulphide as follows :



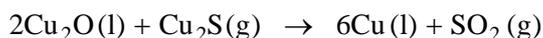
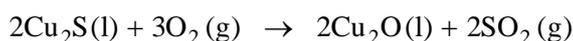
CuS so obtained is then **smelted** in a reverberatory furnace. This process involves reduction by melting with another compound.



Silica, FeO and limestone which are added at the smelting stage form molten **slag** which contains iron silicate (FeSiO_3) and molten **matte** consisting of Cu_2S and FeS.



The slag is lighter than matte and is skimmed off. After the slag is removed, air is again passed to get copper in the following two stages :

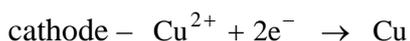
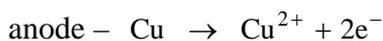


The copper thus obtained is called **blister copper** because of the appearance of air bubbles in the solidified metal. Blister copper being insoluble in matte, settles at the bottom of the furnace. It is 96 – 99.5% copper.

The copper metal is purified by electrolysis as shown in Figure 3.8. The impure metal is made the anode. The cathode is made of a thin plate of pure copper. The electrolyte is a solution of copper sulphate containing a small amount of dilute sulphuric acid.

Figure 3.8 : Electrolytic Refining of Copper

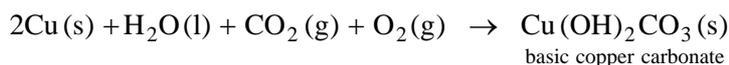
When electric current is passed, copper from anode passes into the electrolyte. An equivalent amount of copper deposits on the cathode from the electrolyte. The reactions on anode and cathode can be represented as follows :



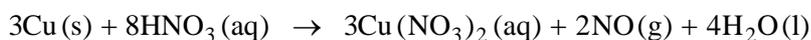
The impurities such as tellurium, silver, gold, platinum etc. accumulate below the anode and form anode mud. These metals are recovered from anode mud and hence the cost of electrolysis is recovered.

Copper is a soft and ductile metal. After iron and aluminium, it is the most important metal. It is a good electrical conductor. Only silver is better conductor than copper but being very costly, hence it is not used widely.

Although copper is fairly unreactive but its surface turns pale green on long exposure to air due to the formation of basic copper carbonate.



Copper reacts with oxidizing acids such as dilute nitric acid or hot concentrated sulphuric acid to give the following products :



Most of the copper compounds involve Cu (II) state. Cu (II) salts are mostly blue or bluish-green. $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ is such an example. It forms beautiful blue crystals.

Cu^+ is unstable and disproportionates into metallic copper and Cu^{2+} ions as follows :



SAQ 2

- Name two important ores of copper.
- What is gangue?
- What is blister copper?
- How is copper purified? Explain.
- Why does copper turn pale green on long standing?

3.5 ALUMINIUM

Aluminium is the third most abundant element in the earth's crusts. The percent abundance of aluminium is 8.3% by weight. The other two more abundant elements being oxygen (45.5%) and silicon (25.7%).

Since aluminium is a very reactive metal, it is not found free in nature. The important minerals of aluminium are as follows :

- bauxite, $\text{AlO}_x(\text{OH})_{3-2x}$ ($0 < x < 1$)
- cryolite, Na_3AlF_6
- beryl, $\text{Be}_3\text{Al}_2\text{Si}_6\text{O}_{18}$
- corundum, Al_2O_3
- mica, $\text{KAl}_2(\text{SiAlO}_{10})(\text{OH})_2$

When first isolated, aluminium was a rare and expensive metal. It is said that Napoleon III served his most honoured guests with aluminium fork and spoons. The Washington Monument also has the aluminium tip.

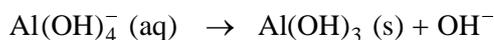
In 1854, a process was developed to get metallic aluminium using sodium but the aluminium remained still very expensive.

The most useful ore of aluminium is **bauxite** (named after *Les Baux*, France where it was discovered in 1821). The major impurities found in bauxite are silica (SiO_2), iron oxides, titanium oxide, clays etc. Bauxite is refined by the **Bayer process** which is **hydrometallurgical method**. Hydrometallurgical methods

(using water) are preferred over pyrometallurgical methods (using heat energy) because of lesser energy use and less pollution. In Bayer process, the ore is first crushed, ground and then digested in concentrated aqueous NaOH solution (30%) at 150 – 230°C temperature and 4 – 30 atm pressure. This leads to the formation of sodium aluminate which contains the complex ion $[\text{Al}(\text{OH})_4]^-$ and sodium silicate by the dissolution of alumina and silica.



Silica then forms insoluble aluminosilicate salts with aluminate ion. These settle down as red ‘mud’ alongwith iron oxides. The amphoteric nature of Al^{3+} is responsible for the above reaction. Fe^{3+} , on the other hand, is not amphoteric and hence does not react in a similar way. The undissolved solid impurities are filtered and the filtrate is diluted with water to yield a precipitate of $\text{Al}(\text{OH})_3$.



The precipitate is filtered, dried and calcined at 1473 K to yield pure alumina.



Electrometallurgy of Aluminium

Electrolysis using aqueous medium is not possible for aluminium because water is more easily reduced than Al^{3+} ion. Hence, *molten* aluminium oxide is used for electrolysis.

The melting point of Al_2O_3 is very high (2050°C) and its electrical conductivity is too low to make its direct electrolysis commercially viable.

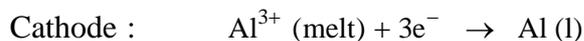
In 1886, the American Chemist Charles Hall and the French metallurgist Paul He'roult independently discovered that the mixture of alumina with the mineral cryolite (Na_3AlF_6) melted at 950°C. Also, cryolite was a good electrolyte. Hall was inspired by one of his Professors who said that any one who could manufacture aluminium cheaply would make a fortune.

The purified alumina is dissolved in molten cryolite (m. pt. 1012°C) in an electrolyte cell of the type shown in Figure 3.9.

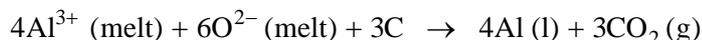
Figure 3.9 : Electrolysis Cell Used in Hall-Heroult Process

The graphite rods are used as anodes and a carbonized steel-lined vessel serves as the cathode.

The half cell reactions are as follows :



The overall reaction is



The graphite rods used as anodes are consumed in the electrolysis process and hence need to be replaced periodically. Molten aluminium is heavier than the molten salt mixture and hence, it settles at bottom from where it is drained through a plug.

The aluminium so obtained is 99.5% pure. It may be interesting to note that about 4000 kg of bauxite, 70 kg of cryolite, 450 kg of carbon anodes and 56×10^9 J energy is required to produce 1000 kg of Al.

Over so many years of Hall-He'roult process, the only change has been the addition of CaF_2 to the melt to get still lower operating temperature.

Aluminium is a light, silvery white, soft metal that resists corrosion by the formation of a tough protective layer of oxide in air. Its low density, wide availability and corrosion resistance makes it ideal for construction and aerospace industry. It is alloyed with silicon, copper, magnesium and other metals to increase strength and stiffness. Aluminium and its alloys are used for packaging, utensils, construction, transportation and aerospace etc.

SAQ 3

- Name two important ores of aluminium.
- Name two major impurities in bauxite.
- What is red mud?
- Write the formula of cryolite and its use.
- What is the anode made up of in the electrolysis of aluminium?

3.6 ALLOYS

You know that an alloy is a substance which consists of mixture of elements and has metallic properties. Alloy formation is important since it allows the modification of properties of metals. For example, gold as such is a quite soft metal and hence cannot be made into jewellery. When it alloyed with copper, we get a hard material which can be designed conveniently. You have studied earlier how various types of steels having different properties can be manufactured by alloying iron with different elements or even with the different amount of the same element.

Alloys can be classified as *homogeneous alloys*, *heterogeneous alloys* and *intermetallic compounds*. **Homogeneous alloys** are homogeneous mixtures in which the components are dispersed randomly and uniformly. They can be further classified as **substitutional** or **interstitial alloys** depending upon whether some of the host metal atom are **replaced** by atoms of the other constituent or some of the **holes** (interstitial spaces) between the metal atoms are filled by the atoms of the other component. This is shown in Figure 3.10.

Figure 3.10 : Substitutional and Interstitial Alloys

Brass is an example of a substitutional alloy in which Zn atoms have replaced some of the copper atoms in copper metal. **Mild carbon steel**, **medium carbon steel** and **high carbon steel**, about which you have read earlier, are examples of interstitial alloys. However, **alloy steels** can be called as a mixed interstitial and substitutional alloys.

In **heterogeneous alloys**, the constituents are not dispersed uniformly. For example, the **perlite** form of steel contains alternate layers of pure iron and cementite (Fe_3C). Properties of heterogeneous alloys can be varied by varying their composition and changing the method of cooling as different properties are obtained if the alloy is cooled rapidly or slowly.

Intermetallic compounds are homogeneous alloys having definite properties and composition. **Duralumin**, CuAl_2 is such an alloy. Ni_3Al is another intermetallic compound which has high strength and low density. These properties make it suitable for making engines of jet aircrafts. The sharp edges of razor blades are due to a coating of Cr_3Pt which gives them hardness and longer lasting sharpness.

Table 3.2 shows some important copper alloys along with their compositions.

Table 3.2 : Some Alloys of Copper and their Composition

Alloy	Composition (% by mass)
Brass	Cu (20 – 97), Zn (2 – 80), Sn (0 – 14), Pb (0 – 12), Mn (0 – 25)
Bronze	Cu (50 – 98), Sn (0 – 35), Zn (0 – 29), Pb (0 – 50), P (0 – 3)
Sterling Silver	Cu (7.5), Ag (92.5)
Gold (18 karat)	Cu (5 – 14), Au (75), Ag (10 – 20)

Brass is malleable, strong and corrosion resistant. It can be cast easily. It is used for making utensils, decorative articles, screws, nuts, bolts etc.

Bronze is very strong and highly corrosion resistant. Its main uses are making statues, coins, medals etc.

Gold is mainly used for making jewellery.

Duralumin is light and strong in nature. It is corrosion resistant and is used for making aircrafts, pressure cookers etc. Its constituents are aluminium, copper, traces of magnesium and manganese.

Magnalium consisting of aluminium and magnesium is very light and hard. It is used in making balance beams and light instruments.

3.7 SUMMARY

In this unit, you have learnt that metals play a very important role in our daily life. Iron, copper and aluminium are the metals which find diverse uses.

The important ores of iron are *magnetite*, *siderite*, *hermatite*. Iron is extracted from its oxide ores. Their reduction is done in the **blast furnace**.

Alloys are substances containing mixtures of elements and having metallic properties. Steel is an important alloy of iron. Steel can be produced using **open hearth process**, **basic oxygen process** or **electric arc process**.

The important ores of copper are *chalcopryrite*, *malachite* and *chalcocite*. The extraction of copper involves **froth floatation**, **smelting** and **electrolytic refining** etc.

Aluminium is extracted from *bauxite*. Bauxite is refined by **Bayer process**. The electrometallurgy of aluminium involves Hall-He'roult process.

Alloys are prepared to modify the properties of metals. They can be classified as *homogeneous alloys*, *heterogeneous alloys* and *intermetallic compounds*.

3.8 ANSWERS TO SAQs

SAQ 1

- Any two from magnetite, siderite, iron pyrite or hematite.
- Because it is not possible to remove last traces of sulphur present in it.
- Limestone is added to remove silica and coke is added to reduce iron oxide to iron.
- Iron as obtained from blast furnace is called pig iron. Its composition is 90-95% iron, 3-5% carbon, 2% silicon and other impurities as Mn, Si, P, S.
- High carbon steel is hard steel containing 0.61 – 1.5% carbon. It is used for making drill bots, razors, knives and tools.

SAQ 2

- Any two ores from chalcopryrite, malachite or chalcocite.
- Gangue is the unwanted material settled at the bottom in froth flotation process.
- Copper obtained in the froth flotation process.
- Copper is purified by electrolysis. See details in Section 3.4.
- It turns pale green due to the formation of basic copper carbonate ($\text{Cu}(\text{OH})_2\text{CO}_3$).

SAQ 3

- (a) Any two ores from bauxite, cryolite, beryl, corundum or mica.
- (b) Any two from silica, iron oxide, titanium oxide, clays.
- (c) Aluminosilicate salts with iron oxides form red mud.
- (d) Na_3AlF_6 . It lowers the melting point when mixed with alumina.
- (e) Graphite rods.