CHAPTER – 6

General Principles and Processes of Isolation of Elements

Earth crust is a source of many nutrients. Of these elements, 70% are metal. Aluminium is the most abundant crust in the world and steel comes second. The percentage of variants in the globe is:
O - 49%, Si-26%, Al-7.5%, Fe-4.2%, Ca-3.2%, Na-2.4%, K-2.3%, Mg-2.3%, H-1%
Metals occur in two forms (i) native or (ii) composite forms, depending on their chemical regeneration.
Metals have lot of importance in our day to day life.

Uses of metals:-
The buildings around us are made up of steel, iron; wires that carry current are made up of metals.

The bridges, tall towers are all made up of metals.

The vessels which are made up of stainless steel; the body of ships made up of metals.

The batteries, vehicles, engines are made up of metals.

Pure metals can be extracted from ores by some chemical reactions.

Native State
Elements which have low chemical reactivity or noble metals having least electropositive character are not attacked by oxygen, moisture and CO_2 of the air. These elements, therefore, occur in the Free State or in the native state, e.g., Au, Ag, Pt, S, O, N, noble gases, etc.

Combined State
Highly reactive elements such as F, CI, Na, K, etc., occur in nature combined form as their compounds such as oxides, carbonates sulphides, halides, etc.

Hydrogen is the only non-metal which exists in oxidised form only.

Metal	Ores	Composition
Aluminium	Bauxite	$AlO_x(OH)_{3-2x}$ [where $0 < x < 1$]
	Kaolinite (a form of clay)	$[Al_2(OH)_4 Si_2O_5]$
Iron	Haematite	Fe_2O_3
	Magnetite	Fe_3O_4
	Siderite	$FeCO_3$
	Iron pyrites	FeS_2
Copper	Copper pyrites	$CuFeS_2$
	Malachite	$CuCO_3.Cu(OH)_2$
	Cuprite	Cu_2O
	Copper glance	Cu_2S
Zinc	Zinc blende or Sphalerite	ZnS
	Calamine	$ZnCO_3$
	Zincite	ZnO

Minerals:

Minerals are those in which individual crystals are composed of unit cells or basic unit layers of two or more types. Minerals are inorganic catalysts that function as regulators of metabolic activities in the body.

Ores:

Most metals are too reactive to exist on their own in the ground. Instead, they exist combined with other elements as compounds called ores. Ores are raw materials for making metals.

Difference between ores and minerals

Ores	Minerals
Ores are usually used to extract metals economically. A large number of ores are present.	All the naturally occurring substances that are present in the earth's crust are known as Minerals.
All ores are minerals.	All Minerals are not ores.
Ores are mineral deposits.	Minerals are native forms in which metals exist.

Gangue:

Gangue can be defined as impurities in the form of sand, rock or any other material surrounding a mineral in a metal reservoir. This is a common occurrence when it comes to mining.

The extraction and separation of metals includes the following major steps:

- Concentration of the ore,
- Isolation of metal its concentrated ore, once
- Metal cleaning.

Metallurgy:

The extraction of metals from their ores and then refining the metal for their use is known as metallurgy.

Metallurgy steps:

- Iron fullness.
- The conversion of concentrated ore into oxide.
- Reduction of oxide into iron.
- Metal refining.

Removal of unwanted earth and silicious impurities in the ore is called ore-dressing or ore concentrations and the process used to concentrate the metal is called the gain process.

Concentration of ore is achieved by:

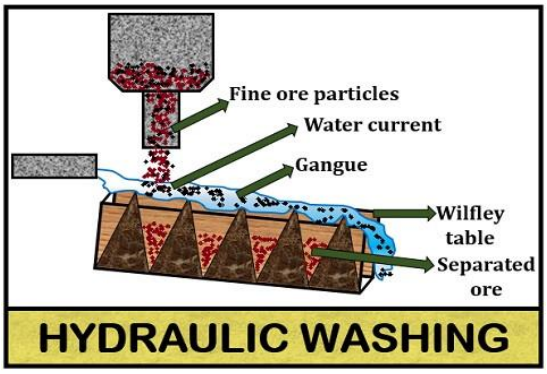
1 Physical methods
2 Chemical methods

Physical methods are:

Hand picking - In the event that the stain is very different from the ores so that the eye of the flesh separates, this may be separated by hand selection.

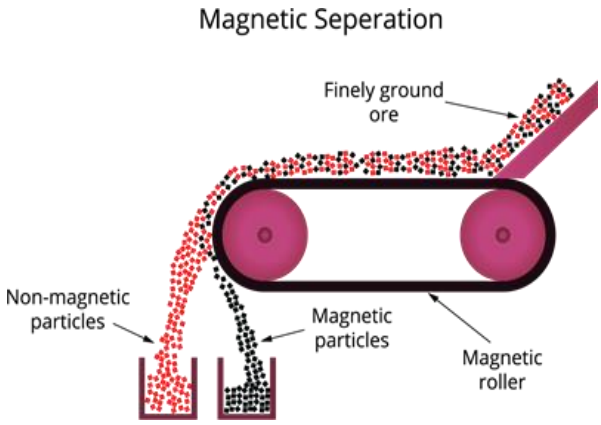
Hydraulic washing (Levigation separation or Gravity) - This method is based on the weight difference between the gangue and the metal. Generally, iron ore particles are heavier than impurities. So we use the principle of division of gravity to separate the two.

Here the crushed metal is mixed with a flowing stream of rising water. Simple gangue particles float in flowing water. Heavy metal particles settle to the ground and can be easily separated. We use this method for ores containing lead and tin as these are very heavy.

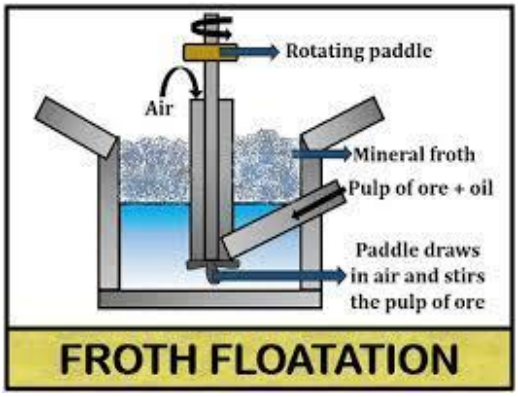


Electromagnetic separation - This involves the use of magnetic properties of either the ore or the gangue to separate them. The ore is first ground into fine pieces and then passed on a conveyor belt passing over a magnetic roller. The magnetic ore remains on the belt and the gangue falls off the belt.

Example: Fe $(CrO_2)_2$ (Chromite) is a magnetic field, separated from the non-magnetic silicious gangue.



Froth floating process - This method is mainly used to remove gangue from sulphide ores. The ore is powdered and a suspension is created in the water. To this are added, Collectors and Froth Stabilizers. Collectors (pine oils, fatty acids etc) increase the non-wettability of the metal part of the ore and allows it to form a froth. Froth Stabilizers (cresols, aniline etc) sustain the froth. The oil wets the metal and the water wets the gangue. Paddles and air constantly stir up the suspension to create the froth. This frothy metal is skimmed off the top and dried, to recover the metal.



Chemical methods:
Chemical methods include calcination, roasting and leaching the metal.

Calcination
It is a chemical method of separating carbonate or hydrated oxide ores.
Carbonate ore produces carbon dioxide under heat exposure.

CARBONATE ORE

- $ZnCO_3 \xrightarrow{\Delta} ZnO + CO_2$
- $CaCO_3 \xrightarrow{\Delta} CaO + CO_2$

Hydrated oxide ore releases water under heat exposure.

HYDRATED OXIDE ORE

- $Al_2O_3 . 2H_2O \xrightarrow{\Delta} Al_2O_3 + 2H_2O$
- $2Fe_2O_3 . 3H_2O \xrightarrow{\Delta} 2Fe_2O_3 + 3H_2O$

Roasting
It is a process commonly performed on sulphide ores under the influence of heat and air. Once roasted, sulphide ore is heated to a temperature below the melting point. For example:

- $2PbS + 3O_2 \xrightarrow{\Delta} 2PbO + 2SO_4$
- $ZnS + 2O_2 \xrightarrow{\Delta} ZnSO_4$
- $CuS + 2O_2 \xrightarrow{\Delta} CuSO_4$

Difference between calcination and roasting

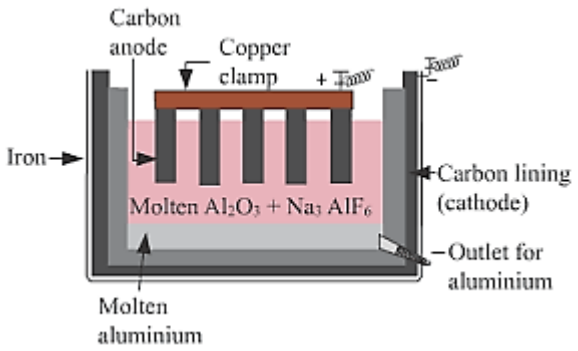
Calcination	Roasting
Calcination is a process in which ore is heated in the absence of air or air might be supplied in a limited quantity	Roasting involves the heating of ore lower than its melting point in the presence of air or oxygen.
Calcination involves the thermal decomposition of carbonate ores.	Roasting is carried out mostly for sulfide minerals.
During calcination, moisture is driven out from an ore.	Roasting does not involve dehydrating an ore.
Carbon dioxide is given out during calcination	During roasting, large amounts of toxic, metallic and acidic compounds are released.

Leaching
It is a chemical process, in which the metal is treated with a suitable reagent to dissolve the metal.

- $Al_2O_3 + 2NaOH \longrightarrow 2NaAlO_2 + H_2O$

Soluble ore or mineral can be separated from the insoluble gangue. After the ore is separated, it can be recovered by several chemical methods.

Leaching is used when the ore is soluble in a solvent. The powdered ore is dissolved in a chemical, usually a strong solution of NaOH. The chemical solution dissolves the metal in the ore and it can be extracted and separated from the gangue by extracting the chemical solution. Extraction of the Aluminium metal from Bauxite ore is done using this process.



Other examples

In the metallurgy of silver and that of gold, the respective metal is leached with a dilute solution of NaCN or KCN in the presence of air (for O2) from which the metal is obtained later by replacement:

$4M_{(s)} + 8CN^-_{(aq)} + 2H_2O_{(aq)} + O_{2\ (g)} \rightarrow 4[M(CN)_2]^-_{(aq)} + 4OH^-_{(aq)}$

(M= Ag or Au)

$2[M(CN)_2]^-_{(aq)}] + Zn_{(s)} \rightarrow [Zn(CN)_4]^{2-}_{(aq)} + 2M_{(s)}$

Reduction of oxides to metals:

The process of converting iron oxides into metals is called a reduction. To reduce, different types of reducing agents are used depending on the re-processing of ores.

OR

Oxide reduction can be achieved by removing the lattice oxygen or by dissolving the reductant in the lattice. Oxygen lattice removal can be achieved by many different mitigation agents. Common ones include hydrogen, carbon monoxide, ammonia gas, and hydrocarbons.

Thermodynamic Principles of Metallurgy:

Metallurgy is an important process of extraction of metals from their ores, and it is based upon various principles of chemistry. Several steps are followed to make the processes efficient and effective at the end of each process. Not only are the purity of the metals extracted at the end of each process important, but it is equally essential to ensure the extraction process by itself does not take more than the necessary time, effort, or any other chemical incompatibilities. Hence, the principles are very significant, and while there are many, the upmost amongst these principles is the thermodynamic principles which are applied to the metallurgical processes to make them much more efficient. The idea is to apply the thermodynamic principles of metallurgy and the basic concepts of thermodynamics, such as Gibb's free energy, in the metallurgical transformations.

Application of Thermodynamic Principles in Metallurgical Process

The concept of thermodynamics suggests that the Gibbs free energy change for a particular process at a particular temperature is given by:

$\Delta G = \Delta H - T\Delta S$

Here, the ΔH is enthalpy change, ΔS is entropy change and ΔG is the free energy change.

The change for any reaction could be explained with the help of the reaction:

$\Delta G^0 = -RT \ln K$

Where, K is the equilibrium constant of that particular reaction at temperature, T. When the ΔG is negative, it implies that the K is positive. This means the reaction is proceeding in the forward direction.
Hence, accordingly, when:

ΔG value is negative in a metallurgical process; the reaction will only proceed in the forward direction. At this time, the ΔH is always positive and ΔS is also positive. And, at a very high temperature, TΔS > ΔH.

When the ΔG of a reaction is positive, it can be made spontaneous by coupling it with another reaction that has a large ΔG negative value. That way, the sum of two ΔG of the coupled reactions becomes negative.

For example, the reduction of metal oxides to metal using a reducing agent is the subtraction of two half equations. The decomposition of Fe_2O_3 to Fe is not a spontaneous reaction and has a (ΔG^0 value of +1487KJ/mol. However, the burning of CO in the presence of oxygen is spontaneous (ΔG^0 =−514.4KJ/mol).

$2Fe_2O_3(s) \rightarrow 4Fe + 3O_2$ .....(1)
$2CO(g)+O_2(g) \rightarrow 2CO_2(g)$ ...(2)
(ΔG^0 = −514.4KJ/mol)

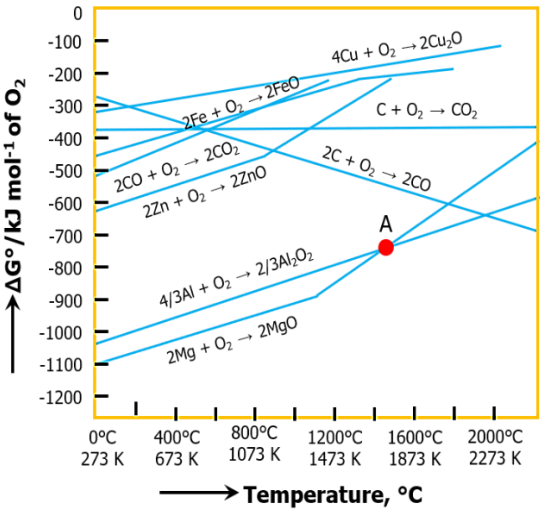
On multiplying (2) by 3
$6CO+3O_2 \rightarrow 6CO_2$ .....(3)
ΔG^0 =−1543.2KJ/mol

Adding equation (3) with (1):
$2Fe_2O_3 + 6CO \rightarrow 4Fe + 6CO_2$
ΔG^0 =−56.2KJ/mol

With this, the ΔG∘ value has become negative, making the reaction feasible as well as spontaneous. The feasibility of the thermal reduction of ores can be predicted by drawing a plot of Gibbs energy and temperature for the reactions.

Ellingham Diagram

The Ellingham diagram shows the relationship between temperature and stability of a combination. It basically represents the image of the Gibbs Energy Flow.



Some important features of Ellingham Diagram

- Here ΔG is organized according to temperature. The curve slope is entropy and the intercept represents the enthalpy.
- As you know ΔH (enthalpy) is not affected by temperature
- Even entropy ΔS is not affected by temperature. However, there is a condition here that class modification should not occur.

- We will set the temperature at Y-axis and ΔG at X-axis
- The curved irons at the bottom of the drawing reduce the metal found at the top to the top

Limitations of Ellingham Diagram

- It does not consider reaction kinetics.
- Also, it does not provide complete information about oxides and their composition. Give an example of more than one possible oxide.

Iron oxide reduction in blast furnace:

Extraction of iron from its ore is the third and the penultimate process in the Metallurgy. The extraction of metals and its isolation occurs over a few major steps:

- Concentration of Ore
- Extraction of metal from concentrated Ore
- Purification of the metal

Extraction: It's a long process which begins with Concentration through calcination roasting. Concentration removes the water and other volatile impurities such as sulphur and carbonates. This concentrated ore is mixed with limestone ($CaCO_3$) and Coke and fed into the blast furnace from the top. It is in the blast furnace that extraction of iron occurs. The extraction of iron from its ore is a long and subdued process that helps in separating the useful components from the waste materials such as slag.

The purpose of a Blast Furnace is to reduce the concentrated ore chemically to its liquid metal state. A blast furnace is a gigantic, steel stack lined with refractory brick where the concentrated iron ore, coke, and limestone are dumped from the top, and a blast of hot air is blown into the bottom. All the three ingredients are crushed into small round pieces and mixed and put on a hopper which controls the input.

Hot air is blown from the bottom and coke it burned to yield temperatures up to about 2200K. Burning coke provides the majority of the heat required for this process. At such high temperatures, Coke reacts with the oxygen in the hot air to form Carbon Monoxide (CO). The CO and heat now move upwards and meet the raw material running down from the top. The temperature in the upper parts of the Blast Furnace is considerably lower than the 2200K at the bottom. In this part, Haematite (Fe_2O_3) and Magnetite (Fe_3O_4) are reduced to Ferrous Oxide (FeO).

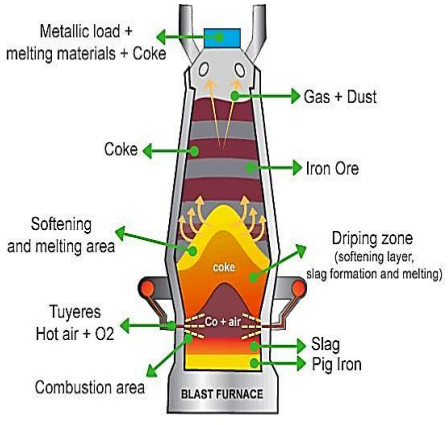


Figure 1 - Blast Furnace Operation

Reactions in the Blast furnace at 500 – 800 K, In the upper parts with lower temperatures,

$2Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2$

$Fe_3O_4 + 4CO \rightarrow 3Fe + 4CO_2$

$Fe_2O_3 + CO \rightarrow 2FeO + CO_2$

At 900 – 1500 K, In the lower sections of the furnace,

$C + CO_2 \rightarrow 2CO$

$FeO + CO \rightarrow Fe + CO_2$

The limestone also decomposes to CaO which removes the silicate impurity of the ore in the form of Slag. It can be easily separated out of molten iron. The iron manufactured in Blast Furnaces contain about 3 – 4 % of Carbon and smaller quantities of many other impurities such as sulphur, Silicon, etc. This is called Pig Iron. It is a hard but brittle metal and the impurities severely hamper its strength. Carbon seems to play a significant role in influencing the brittleness and hardness balance in iron. To further reduce the carbon content of pig iron, it is melted again with scraps of iron and coke and subjected to the blast of hot air. This kind of iron is called Cast Iron and has a slightly lower carbon content 2 – 3 %. This is even harder than pig iron.

Types of metal

Pig iron:

Crude iron that is the direct product of the blast furnace and is refined to produce steel, wrought iron, or ingot iron.

Cast Iron:

Cast iron, an alloy of iron that contains 2 to 4 percent carbon, along with varying amounts of silicon and manganese and traces of impurities such as sulphur and phosphorus. It is made by reducing iron ore in a blast furnace.

Wrought iron:

Wrought iron is the purest form of iron available commercially available and is prepared from cast iron by heating cast iron in a furnace lined with Haematite (Fe_2O_3). The Haematite reacts with Carbon in the cast iron to give pure iron and carbon monoxide gas which escapes.

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

Limestone is then added as flux, and it creates the slag. Impurities such as S, Si pass into the slag and the slag later can be easily separated to yield pure iron.

Extraction of copper from cuprous oxide [copper [I] oxide]

Considering the Graph (1) the Cu2O line is at the top.

So to reduce oxide ores of copper directly to the metal by heating with coke (both the lines of C, CO and C, CO2 are at much lower positions in the graph particularly after 500 – 600K).

Most of the ores are sulphide and some may also contain iron. The sulphide ores are roasted/smelted to give oxides:

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

The oxide can then be easily reduced to metallic copper using coke:

$Cu_2O + C \rightarrow 2\ Cu + CO$

In actual process, the ore is heated in a reverberatory furnace after mixing with silica. In the furnace, iron oxide 'slags of' as iron silicate and copper is produced in the form of copper matte. This contains Cu_2S and FeS.
$FeO + SiO_2 \rightarrow FeSiO_3$ (Slag)

Copper matte is then charged into silica lined convertor.

Some silica is also added and hot air blast is blown to convert the remaining

FeS_2, FeO and Cu_2S/Cu_2O to the metallic copper.
Following reactions take place:
$2FeS + 3O_2 \rightarrow 2FeO + 2SO_2$
$FeO + SiO_2 \rightarrow FeSiO_3$ (6.38)
$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$
$2Cu_2O + Cu_2S \rightarrow 6Cu + SO_2$
The solidified copper obtained has blistered appearance due to the evolution of SO_2 and so it is called blister copper.

Extraction of Zinc from Zinc Oxide

The reduction of zinc oxide is done using coke. The temperature in this case is higher than that in case of copper.

For the purpose of heating, the oxide is made into brickettes with coke and clay.

ZnO + C àZn + CO (where coke is the catalyst, and temperature is 673 K)

The metal is distilled off and collected by rapid chilling.

Electrolytic Reduction (Hall-Heroult process) -

The Hall – Héroult process is a major industrial process for dissolving aluminium. It involves dissolving aluminium oxide (alumina) (commonly found in bauxite, large aluminium ore, by Bayer process) in molten cryolite, and electrolyzing insertion in a molten salt bath, usually in a purpose-built cell.

Extraction: The process used to extract metals from the free state of a concentrated ore is called extraction.

Refining or Purification of crude metals

A metal extracted by any method is usually contaminated with some impurity.

For obtaining metals of high purity, several techniques are used depending upon the differences in properties of the metal and the impurity.

Physical methods

Liquation:

It is a method of separating parts of ore, iron, or alloy by melting the part. Previously it was used to extract antimony minerals from stone and to separate silver and copper using lead as a solvent. It is still used for some metal cleaning.

Distillation:

This is helpful for low boiling metals such as Zn, Hg. Dirty liquid metal evaporates to obtain a pure metal like distillate.

Cupellation:

Cupellation is a refining process in metallurgy where metals or metallic metals are subjected to very high temperatures and have been regulated to separate important metals, such as gold and silver, basic metals, such as lead, copper, zinc, arsenic, antimony, or bismuth, which is present in stone.

Chemical methods:

Poling:

A metallurgical method used for cleaning copper containing copper oxide as impurities and for tin refining containing tin oxide as impurities. Contaminated metal, usually in the form of molten copper, is placed in the anode furnace in two stages of refining.

Electro-refining:

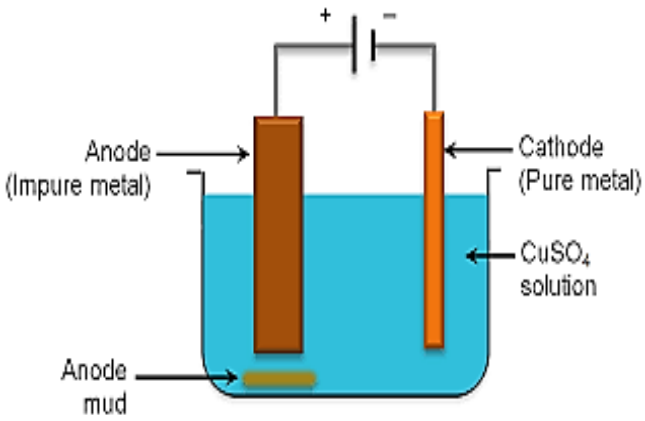
In this method the impure metal is made to act as anode. A strip of the same metal in pure form is used as cathode.

They are put in a suitable electrolytic bath containing soluble salt of the same metal.

The more basic metal remains in the solution and the less basic ones go to the anode mud.

The reactions are:

Anode: $M \rightarrow Mn^+ + ne^-$
Cathode: $Mn^+ + ne^- \rightarrow M$
This method is used to refine Copper, Zinc etc.
In case of copper refining-
Anodes are of impure copper and pure copper strips are taken as cathode.
The electrolyte is acidified solution of copper sulphate and the net result of electrolysis is the transfer of copper in pure form from the anode to the cathode:
Anode: $Cu \rightarrow Cu2^+ + 2\ e–$
Cathode: $Cu2^+ + 2e^- \rightarrow Cu$
Impurities from the blister copper deposit as anode mud which contains antimony, selenium, tellurium, silver, gold and platinum; recovery of these elements may meet the cost of refining.



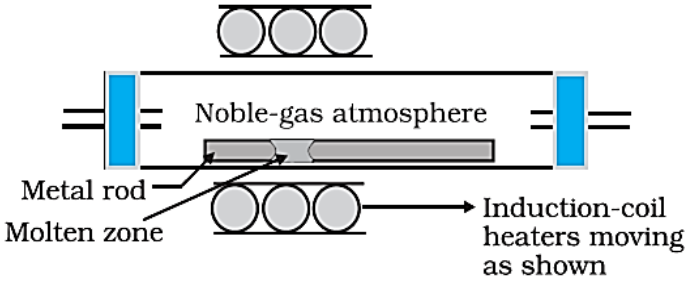
Zone-refining:

This method is based on the principle that the impurities are more soluble in the molten form as compared to the solid state of the metal.

A circular mobile heater is fixed at one end of a rod of the impure metal.

The molten zone moves along with the heater which is moved forward. As the heater moves forward, the pure metal crystallises out of the melt and the impurities pass on into the adjacent molten zone.
The process is repeated several times and the heater is moved in the same direction. At one end, impurities get concentrated.

This end is cut off. This method is very useful for producing semiconductor and other metals of very high purity, e.g., germanium, silicon, boron, gallium and indium.



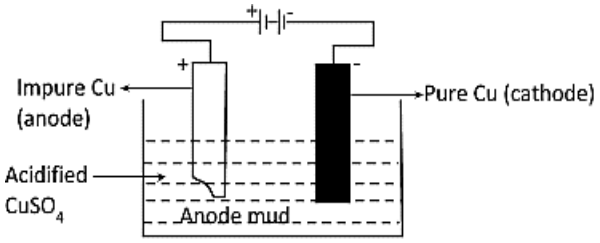
Zone refining process

Vapour phase refining:
The metal is converted into its volatile compound and collected elsewhere. It is then decomposed to give pure metal.

There are 2 requirements for this method:-
The metal should form a volatile compound with an available reagent,
The volatile compound should be easily decomposable, so that the recovery is easy.

Example

Mond Process for Refining Nickel and van Arkel Method for Refining Zirconium or Titanium.



Van-Arkel Method:
The Van Arkel method is a metallurgical method used to refine zirconium and titanium metal. The main impurities that must be removed from this refinery are oxygen and nitrogen. These impurities are removed by heating the zirconium or titanium iron in an extracted vessel containing iodine.
$Zr\ (s)\ 2I_2 \rightarrow ZrI_4$
(Impure)

$ZrI_4 \rightarrow Zr + 2I_2$
(Pure)

$Ti + 2I_2 \rightarrow TiI_4\ (g)$
(Impure)

$TiI_4 \rightarrow Ti + 2I_2$
(Pure)

Mond's process:
Ludwig Mond invented the Mond process in the year 1890. This technique is also known as the carbonyl process because it involves the rapid and reversible reaction of carbon monoxide with nickel to produce nickel tetracarbonyl. Nickel is extracted and purified using this method.

Nickel oxides are converted to high-purity nickel metal in this procedure.

Three phases are included in the Mond nickel extraction process:

In the first step, syngas (a combination of hydrogen and carbon monoxide gas) is mixed with nickel oxide at 200°C, along with iron and cobalt impurities.

$NiO_{(s)} + H_{2(g)} \rightarrow Ni_{(s)} + H_2O_{(g)}$

In the next process, the carbon monoxide reacts with impure nickel to form nickel tetracarbonyl, the impurities will remain as solids.

$Ni_{(s)} + 4CO_{(g)} \rightarrow Ni(CO)_{4(g)}$

Then the mixture of syngas and nickel carbonyl is heated. This results in the decompositions back to carbon monoxide and nickel.

$Ni(CO)_{4(g)} \rightarrow Ni_{(s)} + 4CO_{(g)}$

Pure Nickel is collected, and carbon monoxide is recycled to continue the process.

As this process can be used to extract and purify Nickel.

$$\underset{\text{impure}}{Ni} + 4CO \xrightarrow{330-350K} Ni(CO)_4$$

$$\underset{\text{impure}}{Ni} + 4CO \xrightarrow{330-350K} Ni(CO)_4$$

$$\downarrow 450 - 470\ K$$

$$Ni + 4CO \uparrow$$
Pure

Chromatographic Method:
The principle of this method is that different components of a mixture are differently adsorbed on an adsorbent. The mixture is put in a liquid or gaseous medium which is moved through the adsorbent.

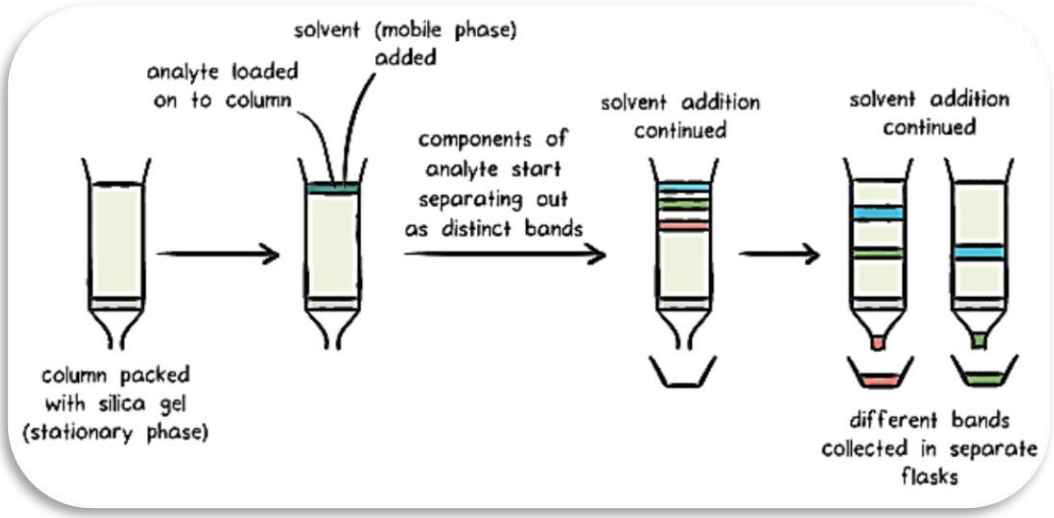
Different components are adsorbed at different levels on the column.

The adsorbed components are removed or eluted by using suitable solvents.

Depending upon the physical state of the moving medium and the adsorbent material and also on the process of passage of the moving medium, the chromatographic method is given the name.

The Al_2O_3 is prepared in a glass tube and the moving medium containing a solution of the components is in liquid form. This is an example of column chromatography.

There are several chromatographic techniques such as paper chromatography, column chromatography, gas chromatography, etc.



Uses of Aluminium, zinc, copper and iron

Aluminium

Aluminium foils are used as wrappers for chocolates.

The fine dust of the metal is used in paints and lacquers.

Aluminium, being highly reactive, is also used in the extraction of chromium and manganese from their oxides. Wires of aluminium are used as electricity conductors.

Alloys containing aluminium, being light, are very useful.

Copper

Copper is used for making wires used in electrical industry and for water and steam pipes.

It is also used in several alloys that are rather tougher than the metal itself, e.g., brass (with zinc), bronze (with tin) and coinage alloy (with nickel).

Zinc

Zinc is used for galvanising iron. It is also used in large quantities in batteries, as a constituent of many alloys, e.g., brass, (Cu 60%, Zn 40%) and German silver (Cu 25-30%, Zn 25-30%, Ni 40–50%).

Zinc dust is used as a reducing agent in the manufacture of dye-stuffs, paints, etc.

Iron

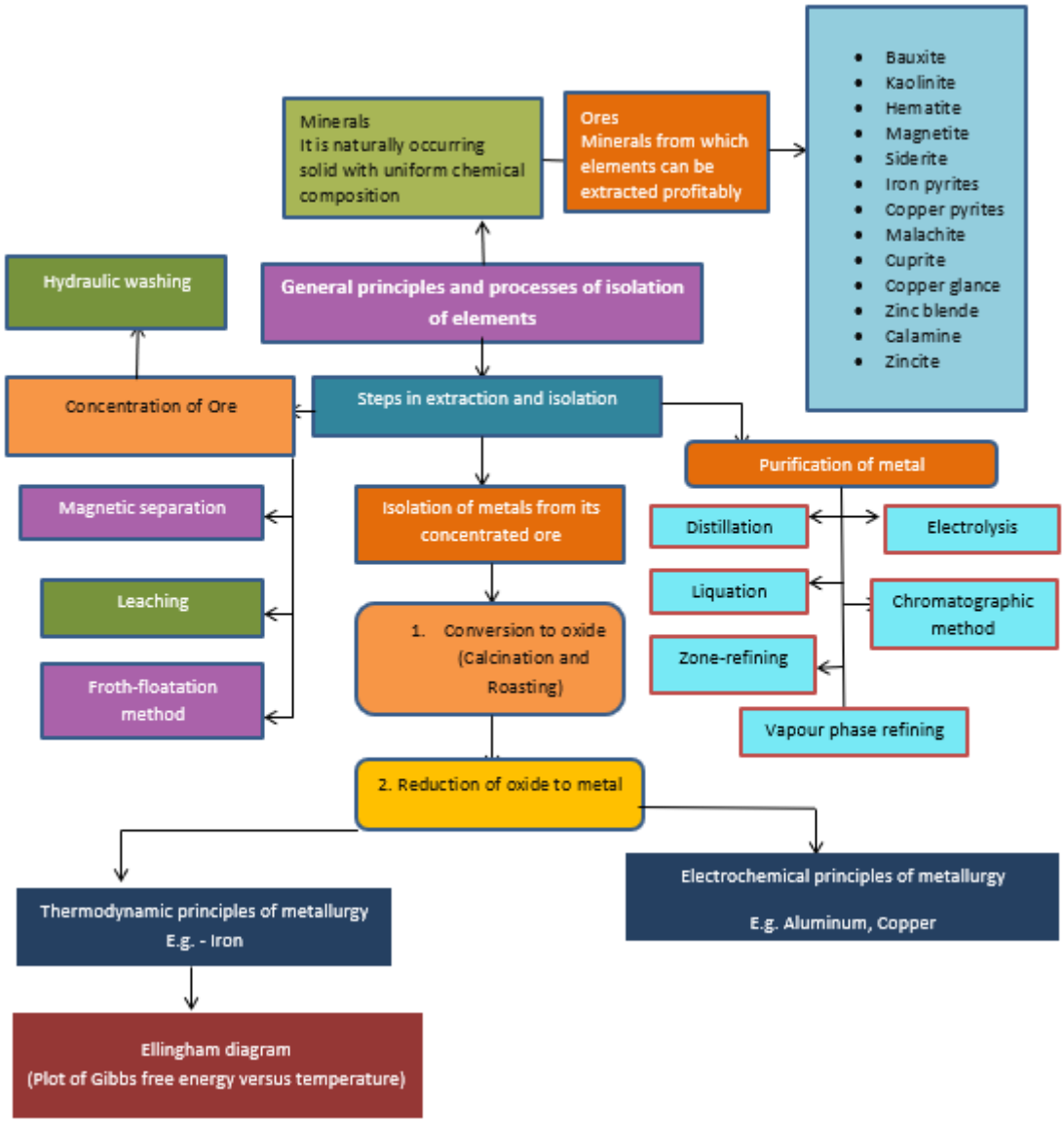
- Cast iron, which is the most important form of iron, is used for casting stoves, railway sleepers, gutter pipes, toys, etc. It is used in the manufacture of wrought iron and steel.
- Wrought iron is used in making anchors, wires, bolts, chains and agricultural implements.
- Steel finds a number of uses. Alloy steel is obtained when other metals are added to it.
- Nickel steel is used for making cables, automobiles and aeroplane parts, pendulum, measuring tapes, chrome steel for cutting tools and crushing machines, and stainless steel for cycles, automobiles, utensils, pens, etc.

SUMMARY

Metals are required for a variety of purposes. For this, we need their extraction from the minerals in which they are present and from which their extraction is commercially feasible.These minerals are known as ores. Ores of the metal are associated with many impurities. Removal of these impurities to certain extent is achieved in concentration steps. The concentrated ore is then treated chemically for obtaining the metal. Usually the metal compounds (e.g., oxides, sulphides) are reduced to the metal. The reducing agents used are carbon, CO or even some metals. In these reduction processes, the thermodynamic and electrochemical concepts are given due consideration. The metal oxide reacts with a reducing agent; the oxide is reduced to the metal and the reducing agent is oxidised. In the two reactions, the net Gibbs energy change is negative, which becomes more negative on raising the temperature. Conversion of the physical states from solid to liquid or to gas, and formation of gaseous states favours decrease in the Gibbs energy for the entire system. This concept is graphically displayed in plots of ΔG^0 vs T (Ellingham diagram) for such oxidation/reduction reactions at different temperatures. The concept of electrode potential is useful in the isolation of metals (e.g., Al, Ag, Au) where the sum of the two redox couples is +ve so that the Gibbs energy change is negative. The metals obtained by usual methods still contain minor impurities. Getting pure metals require refining. Refining process depends upon the differences in properties of the metal and the impurities. Extraction of aluminium is usually carried out from its bauxite ore by leaching it with NaOH. Sodium aluminate, thus formed, is separated and then neutralised to give back the hydrated oxide, which is then electrolysed using cryolite as a flux. Extraction of iron is done by reduction of its oxide ore in blast furnace. Copper is extracted by smelting and heating in a reverberatory furnace. Extraction of zinc from zinc oxides is done using coke. Several methods are employed in refining the metal. Metals, in general, are very widely used and have contributed significantly in the development of a variety of industries.

Aluminium	Bauxite, Al_2O_3. x H_2O_2. Cryolite, Na_3AlF	Electrolysis of Al_2O_3 dissolved in molten Na_3AlF_6	For the extraction, a good source of electricity is required.
Iron	Haematite, Fe_2O_3 Magnetite, Fe_3O_4	Reduction of the oxide with CO and coke in Blast furnace	Temperature approaching 2170 K is required.
Copper	Copper pyrites, $CuFeS_2$. Copper glance, Cu_2S. Malachite, $CuCO_3.Cu(OH)_2$. Cuprite, Cu_2O	Roasting of sulphide partially and reduction	It is self-reduction in a specially designed converter. The reduction takes place easily. Sulphuric acid leaching is also used in hydrometallurgy from low grade ores.
zinc	. Zinc blende or Sphalerite, ZnS Calamine, $ZnCO_3$ Zincite, ZnO	Roasting followed by reduction with coke	The metal may be purified by fractional distillation

MIND MAP


Minerals
It is naturally occurring solid with uniform chemical composition
Ores
Minerals from which elements can be extracted profitably
Bauxite
Kaolinite
Hematite
Magnetite
Siderite
Iron pyrites
Copper pyrites
Malachite
Cuprite
Copper glance
Zinc blende
Calamine
Zincite
Hydraulic washing
General principles and processes of isolation of elements
Concentration of Ore
Steps in extraction and isolation
Purification of metal
Magnetic separation
Isolation of metals from its concentrated ore
Distillation
Electrolysis
Leaching
Liquation
Chromatographic method
Froth-floatation method
1. Conversion to oxide (Calcination and Roasting)
Zone-refining
Vapour phase refining
2. Reduction of oxide to metal
Thermodynamic principles of metallurgy
E.g. - Iron
Electrochemical principles of metallurgy
E.g. Aluminum, Copper
Ellingham diagram
(Plot of Gibbs free energy versus temperature)

QUESTIONS FOR PRACTICE

Q1. The salt which is least likely to be found in minerals is
(a) Chloride (b) Sulphate
(c) Sulphide (d) Nitrate

Q2. Which of the following metals is leached by Cyanide process?
(a) Ag (b) Na
(c) Al (d) Cu

Q3. In the equation $4\ M + 8\ CN^- + 2H_2O + O_2 \rightarrow 4\ [M(CN)_2]^- + 4OH^-$, the metal M is
(a) Copper (b) Iron
(c) Gold (d) Zinc

Q4. Pyrolusite is a/an
(a) Oxide ore (b) Sulphide ore
(c) Carbide ore (d) not an ore.

Q5. Which of the following metals is sometimes found native in nature?
(a) Aluminium (b) Copper
(c) Iron (d) Magnesium

Q6. The method of zone refining of metals is based on the principle of
(a) greater mobility of pure metal than that of the impurity. (b) higher m.pt. of the impurity than that of the pure metal.
(c) greater noble character of the solid metal than that of the impurity (d) greater solubility of the impurity in the molten state than in the solid.

Q7. In the extraction of copper from its sulphide ore, the metal is formed by the reduction of Cu2O with
(a) FeS (b) CO
(c) Cu_2S (d) SO_2.

Q8. Heating pyrites to remove sulphur is called
(a) Smelting (b) Calcination
(c) Liquation (d) roasting

Q9. In the metallurgy of which of the following, cupellation process is used?
(a) Copper (b) Silver
(c) Iron (d) Aluminium

Q10. Which of the following metals is most abundant in the earth's crust?
(a) Mg (b) Na
(c) Al (d) Fe

Q11. Which of the following benefication process is used for the mineral $Al_2O_3.2H_2O$?
(a) Froth Floatation (b) Leaching
(c) Liquation (d) Magnetic separation

Q12. The Mond's process of refining is used for which of the following metals?
(a) Gold (b) Copper
(c) Iron (d) Nickel

Q13. During smelting an additional substance is added which combines with impurities to form a fusible mass. The additional substance is called
(a) Flux (b) Slag
(c) Gangue (d) Ore.

Q14. Which of the following metals is obtained by leaching the ore with dilute cyanide solution?
(a) Silver (b) Titanium
(c) Vanadium (d) Zinc

Q15. Zone-refining process has been employed for preparing ultrapure samples of
(a) Cu (b) Zn
(c) Ge (d) Ag

Q16. The process of isolation of metals by dissolving the ore in a suitable chemical reagent following by precipitation of the metal by a more electropositive metal is called
(a) Electrometallurgy (b) Hydrometallurgy
(c) Electro-refusing (d) Zone-refining

Q17. Smelting involves reduction of the metal oxide with
(a) Carbon (b) CO
(c) Magnesium (d) Aluminum

Q18. Which of the following is an ore of Aluminium?
(a) Na_3AlF_6 (b) $Al_2O_3.2H_2O$
(c) Al_2O_3 (d) $Al_2O_3.H_2O$

Q19. The process of extracting the metal from its ore is called
(a) Metallurgy (b) Refining
(c) Concentration (d) Leaching

Q20. In the Froth floatation process for beneficiation of the ores, the ore particles float because
(a) they are light
(b) their surface is not easily wetted by water.
(c) they bear electrostatic charge
(d) they are insoluble.

Q21. In the Aluminothermite process, aluminium acts as
(a) an oxidising agent (b) a flux
(c) a reducing agent (d) a solder

Q22. An alloys is
(a) intermetallic compound
(b) solid substance containing two or more metallic element
(c) a solid which contains one non metal
(d) solid which contains more than one non metal

Q23. Which of the following is correct
(a) tin stone is magnetic in nature
(b) wolframite is non-magnetic m nature
(c) wolframite is (Fe, Mn) WO_4
(d) cassiterite and rutile are sulphides of the metals

Q24. Corundum is an ore of
(a) boron (b) copper
(c) aluminium (d) sodium

Q25. An example of halide ores is:
(a) Galena (b) Cryolite
(c) Bauxite (d) Cinnabar

Q26. Which of the following is not an ore
(a) Bauxite (b) Zinc blended
(c) Malachite (d) Pig iron

Q27. Which of the following is not a carbonate ore?
(a) siderite (b) bauxite
(c) calamine (d) malachite

Q28. In which of the following minerals, aluminium is not present?
(a) cryolite (b) bauxite
(c) fluorspar (d) fledspar

Q29. The ore having two different metal atoms is
(a) copper pyrites (b) haematite
(c) calamine (d) magnetite

Q30. The chief ore of zinc is
(a) cryolite (b) calamine
(c) calcite (d) cuprite

Q31. The main ore of aluminium is
(a) alumina (b) potash alum
(c) cryolite (d) bauxite

Q32. Which of the following are the correct matching of metals with the most commonly employed ores for their extraction?
(a) Fe: Chalcocite: Al: Bauxite
(b) Fe: Siderite; Al: Clay
(c) Fe: Haematite; Al: corundum
(d) Fe: Haematite; Al: Bauxite

Q33. Which one of the furnaces among the following can produce the highest temperature?
(a) muffle furnace
(b) blast furnace
(c) reverberatory fumace
(d) electric furnace

Q34. Which statement is correct?
(a) gangues are carefully chosen to combine with the slag present in the ore to produce easily fusible flux to carry away the impurities
(b) slags are carefully chosen to combine with the flux present in the ore to produce easily fusible gangue to carry away the impurities
(c) gangues are carefully chosen to combine with the flux present in the ore to produce easily fusible slag to carry away the impurities
(d) fluxes are carefully chosen to combine with the gangue present in the ore to produce easily fusible slag to carry away the impurities

Q35. The froth flotation process is based upon
(a) preferential adsoprtion of gangue particles oil
(b) specific gravity of ore particles
(c) preferential wetting of ore particles by oil
(d) magnetic properties of gangue

Q36. Sapphire is a mineral of
(a) Hg (b) Cu
(c) Zn (d) Al

Q37. The most common constituent of steel is
(a) S (b) O
(c) C (d) Cr

Q38. Purest form of iron is
(a) cast iron (b) hard steel
(c) stainless steel(d) wrought iron

Q39. Which of the following is not an ore of iron?
(a) magnetite (b) limonite
(c) siderite (d) casseterite

Q40. Which of the following is not an ore of aluminium?
(a) feldspar (b) corrundum
(c) bauxite (d) carnallite

Q41. Blister copper is
(a) Pure copper
(b) Alloy of coppeer
(C) Copper containing 2% impurity
(d) Ore of copper

Q42. Which of the following metals does not occur as oxide?
(a) iron (b) Aluminium
(C) Copper (d) sodium

Q43. Which of the following contains both Ca and Mg?
(a) gypsum (b) chalk
(C) limestone
(d) Dolomite

Q44. The removal of impurities from a molten mass is called
(a) calcination (b) levigation
(c) refining (d) slagging

Q45. Pn and Sn are extracted from their chief ore by
(a) carbon reduction and self-reduction
(b) self-reduction and carbon reduction respectively
(c) electrolysis and self reducton
(d) self-reduction and electrolysis

Q46. Which of the following is gangue?
(a) waste material left after concentration
(b) waste material left after purification of metal
(c) waste material after electrolysis
(d) waste material present in ore to be removed during concentration

Q47. Which of the following is correct?
(a) gangue + FluX= slag
(b) froth + slag =gangue
(c) gangue + slag= flux
(d) flux + slag=gangue

Q48. What type of flux is used when the gangue is acidic?
(a) acidic (b) basic
(c) neutral (d) alcoholic

Q49. The extraction of metals from oxide ore involves
(a) decarboxylation
(b) hydrolysis
(c) electrolysis
(d) reduction

Q50. The metallurgical process in which a metal is obtained in fused state is called
(a) calcination (b) roasting
(C) froth flotation (d) smelting

Q51. The colour of zinc sulphide is
(a) black
(b) yellow
(C) white
(d) brown

ASSERTION AND REASONING

Q1. Assertion: Levigation is used for the separation of oxide ores from impurities.
Reason: Ore particles are removed by washing in a current of water.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q2. **Assertion:** Zinc can be used while copper cannot be used in the recovery of Ag from the complex $[Ag(CN)_2]^-$
Reason: Zinc is a powerful reducing agent than copper.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.

Q3. **Assertion:** Leaching is a process of reduction.
Reason: Leaching involves treatment of the ore with a suitable reagent so as to make it soluble while impurities remains insoluble.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct

Q4. **Assertion:** Coke and flux are used in smelting.
Reason: The phenomenon in which ore is mixed with suitable flux and coke is heated to fusion is known as smelting.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct.

TRUE/FALSE

Q1. In extraction of iron from haematite ore, the reduction reactions take place in the lower temperature range and in the higher temperature range, in the blast furnace.
(a) True (b) False

Q2. Sphalerite is a carbonate ore of zinc.
(a) True (b) False

Q3. The principal ore of aluminium, bauxite, usually contains silica, iron oxides and titanium oxide as impurities.
(a) True (b) False

QUESTIONS FOR PRACTICE

Q1. The powdered ore is agitated with water or washed with running stream of water. The heavy ore particles and lighter impurities are separated. This method of concentration is known as
(a) metallurgy
(b) leaching
(c) froth floatation process
(d) gravity separation.

Q2. The inner lining of a blast furnace is made up of:
(a) graphite bricks (b) silica bricks
(c) fire clay bricks (d) basic bricks

Q3. The method of concentrating the ore which makes use of the difference in density between ore and impurities is called
(a) levigation (b) leaching
(c) magnetic separation (d) liquifaction

Q4. Cinnabar is an ore of
(a) Hg (b) Ag
(c) Sn (d) Al

Q5. Cassiterite is an ore of
(a) Mn (b) Ni
(c) Sb (d) Sn

Q6. Galena is an ore of
(a) Pb
(b) Hg
(c) Zn
(d) None of these

Q7. Which of the following slags is produced during extraction of iron?
(a) $CaSiO_3$ (b) $FeSiO_3$
(c) $MgSiO_3$ (d) $ZnSiO_3$

Q8. Which of the following metals is extracted using silica lined convertor?
(a) Mg (b) Al
(c) Cu (d) Zn

Q9. Which of the following metals cannot be obtained by reduction of its metal oxide by aluminium?
(a) Cr (b) Mn
(c) Fe (d) Mg

Q10. An ore of tin containing $FeCrO_4$ is concentrated by
(a) gravity separation (b) magnetic separation
(c) froth floatation (d) leaching

Q11. Sulphide ores of metals are usually concentrated by froth floatation process. Which one of the following sulphide ores offers an exception and is concentrated by chemical leaching?
(a) Galena
(b) Copper pyrite
(c) Sphalerite
(d) Argentite

Q12. Out of the given options, which of the following ore is used to extract silver?
(a) Calamine
(b) Cinnabar
(c) Argentite
(d) Malachite

Q13. Which of the cases is best for hand-picking concentration?
(a) When the ores are a good conductor of electricity
(b) When the impurities can be distinguished from the ore with the help of the naked eye
(c) When either the ore or the impurities are magnetic
(d) When the ore particles are heavier than the impurities

Q14. By electromagnetic separation, where are magnetic particles collected in concentration?
(a) Away from the magnetic roller
(b) On the conveyor belt
(c) Below the magnetic roller
(d) Above the magnetic roller

Q15. The name of the metallurgical process in which the ore is leached and the metal is extracted using electrolysis:
(a) Zone refining
(b) Hydrometallurgy
(c) Liquation
(d) Thermite process

Q16. Oxides are formed when food is roasted. What is the necessity to roast oxide ores?
(a) To avoid gangue particles
(b) To get crude metal by using an oxidizing agent
(c) To remove the volatile impurities that are present in the form of their oxides
(d) To make the ore porous

Q17. List the method used for extracting sodium from halide ores like sodium chloride (NaCl) .
(a) Pyro metallurgy
(b) Hydrometallurgy
(c) Electrometallurgy
(d) Magnetic separation

Q18. Which of the following is an illustration of metallurgical electrochemical principles?
(a) Baeyer's process
(b) Solvay process
(c) Bergius process
(d) Hall-Heroult process

Q19. An additional substance is added which combines with impurities to form a fusible mass during the process of smelting. The additional substance is called
(a) Flux (b) Slag
(c) Gangue (d) Ore

Q20. Electrolytic reduction of Al_2O_3 to Al by the Hall-Herault process is carried out
(a) in presence of NaCl.
(b) in presence of fluorite.
(c) in presence of cryolite which forms a melt with a lower melting point.
(d) in presence of cryolite which forms a melt with a high melting point.

Q21. Which of the following is present in aluminium bronze alloy?
(a) Iron (b) Bronze
(c) Copper (d) Brass

Q22. What is the name of the alloy of copper called which contains a composition of 30-35% of zinc?
(a) Brass (b) Bronze
(c) Duralumin (d) Magnalium

Q23. Which metal is used for making water and steam pipes?
(a) Zinc (b) Aluminium
(c) Copper (d) Iron

Q24. Which of the following is not an impurity generally present in crude metals?
(a) Pine oil (b) Other metals
(c) Non-metals (d) Unreacted oxides

Q25. Which of the following metals cannot be refined by distillation?
(a) Tin (b) Zinc
(c) Cadmium (d) Mercury

Q26. Which of the following processes is used to purify lead?
(a) Zone refining (b) Distillation
(c) Liquation (d) Electrolytic refining

Q27. What is the anode made up of in electrolytic refining?
(a) Double salt of metal (b) Impure metal
(c) The metal ore (d) Pure metal

Q28. Which of the following is an electrolyte used during the electrolytic refining of copper?
(a) Copper chloride (b) Copper sulphate solution
(c) Copper sulphate solution acidified with sulphuric acid (d) Sulphuric acid

Q29. Which of the following is not refined by zone refining method?
(a) Germanium (b) Silicon
(c) Gallium (d) Gold

Q30. Why is zone refining carried out in an inert atmosphere?
(a) To reduce the external temperature
(b) To prevent reduction of metal
(c) To prevent oxidation of metal
(d) To reduce the external pressure

ASSERTION AND REASONING

Q1. **Assertion:** Copper obtained after bessemerization is known as blister copper.
Reason: Blisters are produced on the surface of the metal due to escaping of dissolved SO2.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct

Q2. **Assertion:** Lead, tin and bismuth are purified by liquation method.
Reason: Lead, tin and bismuth have low m.pt. as compared to impurities.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct

Q3. **Assertion:** Nickel can be purified by the Mond process.
Reason: Ni $(CO)_4$ is a volatile compound which decomposes at 460K to give pure Ni.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct

Q4. **Assertion:** Hydrometallurgy involves dissolving the ore in a suitable reagent followed by precipitation by a more electropositive metal.
Reason: Copper is extracted by hydrometallurgy.
(a) If both Assertion and Reason are correct and the Reason is a correct explanation of the Assertion.
(b) If both Assertion and Reason are correct but Reason is not a correct explanation of the Assertion.
(c) If the Assertion is correct but Reason is incorrect.
(d) If both the Assertion and Reason are incorrect.
(e) Assertion is incorrect and Reason is correct.

TRUE/FALSE

Q1. Solified copper obtained from silica lined convertor (Bessemer converter) has blistered appearance due to the evolution of SO_2.
(a) True (b) False

Q2. Roasting of ore is done in absence of air.
(a) True (b) False

Q3. Ores of alkali and alkaline earth metals cannot be reduced by carbon.
(a) True (b) False

Q4. In cupellation process, oval shaped crucibles made of iron are used.
(a) True (b) False

SOLUTIONS

S1. (d) The salt which is least likely to be found in mineral is Nitrate. Nitrate is used mainly in Inorganic fertilizers.

S2. (a) Cyanide process is a technique for extracting gold/silver from low-grade ore by converting the gold/silver to a water soluble coordination complex.

S3. (c) Least reactive metals like silver and gold are obtained by cyanide process. In this process the impure metal is treated with NaCN (solution) and air is passed. Metal is converted into soluble complex as

$4Au + 8CN + 2H_2O + O_2 \rightarrow 4[Au(CN)_3]^-$

Soluble complex + $4OH^-$

S4. (a) Pyrolusite is an oxide ore of manganese.
It is the most common manganese mineral with chemical formula MnO_2.

S5. (b) Copper is an unreactive metal and it reacts slowly with the atmosphere. The huge lumps of copper metal are found buried in the ground as nuggets. This is called native copper.

S6. (d) The method of zone refining of metals is based on the principle of greater solubility of the impurity in the molten state than in the solid. Elements which are used as semiconductors like Si, Ge, Ga etc. are refined by this method.

S7. (c) In the extraction of copper from its sulphide ore, the metal is formed by reduction of Cu_2O with Cu_2S.
The sulphide ore of copper is heated in air until a part is converted to oxide and then further heating in the absence of air to let the oxide react with unchanged sulphide.
Self-reduction of CuS to Cu can be carried out in either Bessemer converter or Pierce-Smith converter.

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

$2Cu_2O + Cu_2S \rightarrow 6Cu + SO_2$

S8. (d) In roasting, the ore is heated in a regular supply of air in a furnace at a temperature below the melting point of the metal.
Some of the reactions involving sulphide ores are:

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

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

$2Cu_2S + 3O_2 \rightarrow 2Cu_2O + 2SO_2$

S9. (b) Cupellation is a process where ores are treated under high temperatures and controlled operations to separate noble metals like gold and silver, from base metals like led, copper, zinc, and others present in the ore or alloyed metal.

S10. (c) Aluminum is the most abundant metal in the Earth's crust, and the third most abundant element therein, after oxygen and silicon. It makes up about 8% of the weight of the Earth's solid surface.

S11. (b) Leaching: It involves treatment of ore with leaching agents (like NaOH, NaCN, KCN or other reagents) due to which ore becomes soluble and their impurities remain insoluble. The leaching process is basically done in the extraction of Al from $Al_2O_3.2H_2O$ (Alumina).

S12. (d) The metal that is refined by Mond process or the carbonyl process is nickel. This process to extract and purify nickel was used commercially before the 19th century came to an end

S13. (a) Flux like limestone is used to remove rock, gangue as well as slag. Hence flux is an additional substance which is added during smelting, which combines with impurities to form a fusible product.

S14. (a) Leaching is a process which is used extractive metallurgy where ore is treated with chemical to convert the valuable metal into soluble salts.
Silver is obtained by leaching ore with dilute cyanide solution.

S15. (c) Zone Refining or Fractional Crystallisation is employed to get metal of very high purity i,e. ultra-pure samples of Ge Si, B, Ga, In. This method is based on the fact that impurities are more soluble than the pure metal in the melt.

S16. (b) Hydrometallurgy involves the use of aqueous chemistry for the recovery of metals from ores, concentrates, and recycled or residual materials by dissolving the ore in a suitable chemical reagent followed by precipitation of the metal by a more electropositive metal.

S17. (a) Smelting is used to produce a base metal from its ore. The reducing agent is commonly a source of carbon such as coke, or in earlier times charcoal.

S18. (b) Bauxite ore ($Al_2O_3.XH_2O$) has been the primary source of aluminium, which is a mixture of hydrated aluminium oxide. Cryolite (Na_3AlF_6) and alunite can also be used to recover aluminium.

S19. (a) The process of extracting metals from their ores is called metallurgy. The process employed in the extraction of the ore depends on the nature of the ore and the impurities present in it.
The following are the basic steps for a metallurgical operation:
Crushing and grinding of the ore.

Concentration of the ore
Working of the ore
Purification or refining of the metal

S20. (b) In the froth floatation process, for the benefaction of ores, the ore particles float because their surface is not easily wetted by water. This method is based on the difference in the wetting properties of ores and gangue particles with the water and oil.

S21. (c) Aluminium gets oxidized.
The equation is,
$2Al + Fe_2O_3 \rightarrow 2Fe_{(molten)} + Al_2O_3$

S22. (b) An alloy is a material composed of two or more metals or a metal and a nonmetal. An alloy may be a solid solution of the elements (a single phase), a mixture of metallic phases (two or more solutions) or an intermetallic compound with no distinct boundary between the phases.

S23. (c) Wolframite is $(Fe,Mn)WO_4$ which is magnetic in nature

S24. (c) Corundum is an ore of aluminium.

S25. (b) Minerals having metals associated with halogens are referred to as Halid ores. Cryolite contains halogens of aluminium oxide, therefore it is a Halid ore.

S26. (d)

S27. (b) Calamine: $ZnCO_3$
Siderite: $FeCO_3$
Bauxite: $AlO_x(OH)_{3-2x}(0 < x < 1)$
Malachite: $CuCO_3Cu(OH)_2$

S28. (c) Fluorspar (CaF_2) does not contain aluminium.

S29. (a) $CuFeS_2$

S30. (b) Calamine is $ZnCO_3$, Cryolite is Na_3AlF_6, Gibbsite is $Al(OH)_3$ and Malachite is $CuCO_3.Cu(OH)_2$
Out of the above ores, Calamine is the only ore of Zinc.

S31. (d) Main ore of aluminium is Bauxite. Pure aluminium oxide is called Alumina

S32. (d)

S33. (d)

S34. (d)

S35. (c)

S36. (d) Sapphire is a natural crystalline form of blue, transparent corundum (Al_2O_3), the colour being due to traces of cobalt and other metals.

S37. (c) Carbon is the most important constituent of steel. It raises tensile strength, hardness, and resistance to wear and abrasion.

S38. (d) The purest form of iron is wrought iron. It contains 0.12 to 0.25% carbon and it is the purest form of iron.

S39. (d)

Fe_2O_3	→	Haematite
Fe_3O_4	→	Magnetite
SnO_2	→	Tinstone or Casseterite
$Fe_2O_3.3H_2O$	→	Limonite

S40. (d) The ores of Aluminium are – Bauxite, Corundum, Felspar, Cryolite, Alunite and Kaolin.
- Carnalite is the ore of Potassium and Nitre is also an ore of this metal.
- The process of extracting metal in pure form from its ore is known as metallurgy.

S41. (c) Copper that is 97 to 98 percent pure, produced by smelting is called as Blister Copper. It has a blistery surface caused by sulphur dioxide bubbles.

S42. (d)

S43. (d) Dolomite: $CaMg(CO_3)_2$
It contains both calcium and magnesium.

S44. (d) The removal of impurities from an ore by forming a fusible (molten) mass is called slagging

S45. (b)

S46. (d)

S47. (a)

S48. (b) Basic fluxes like lime (CaO), magnesium oxide (MgO) are used to eliminate acidic gangue and impurities such as SiO_2

S49. (d) During extraction of metals from oxide ores, the reduction of metal ore to crude metal can be carried out by using several methods such as pyrometallurgy, hydrometallurgy and electrometallurgy. Various reducing agents such as carbon, hydrogen, aluminum or other metals can be used. CO also reduces metal ores to crude metals.

S50. (d) The process in which metal is obtained in fused state is called smelting. During roasting and calcination metal oxides are formed while froth floatation process is used to concentrate the ore.

S51. (c)

ASSERTION AND REASONING

S1. (c) Assertion is true but reason is false.
Oxide ores being heavier than the earthy or rocky gangue particles settle down while lighter impurities are washed away.

S2. (a) Zn is used for recovery of Ag from the complex $[Ag(CN)_2]^-$ while Cu is not used because Zn is more powerful reducing agent than Cu as Zn being more reactive than Cu as is mentioned in the reactivity series of metals.

S3. (e) Leaching is the process of concentration of ores in which metal is made soluble in a solvent while the impurities remain insoluble and get separated out. It does not involve any redox reaction.

S4. (b) Both assertion and reason are true but reason is not the correct explanation of assertion. Non fusible mass present in ore in mixing with suitable flux are fused which are then reduced by coke to give free metal.

TRUE/FALSE

S1. (a) In upper part at lower temperature reduction of Fe_2O_3 takes place by carbon monoxide but unreduced FeO is reduced by carbon at the higher temperature in the lower part of the blast furnace.

S2. (b) Sphalerite =ZnS

S3. (a) The principal ore of aluminium, bauxite, usually contains silica, iron oxides and titanium oxide as impurities

SOLUTIONS PRACTICE QUESTIONS

S1. (c) The powdered ore is agitated with water or washed with running stream of water. The heavy ore particles and lighter impurities are separated. This method of concentration is known as froth floatation process.

S2. (c) The inner lining of blast furnace is made from Fire Clay bricks. These are highly refractory in nature and does not melt at even huge temperature. The main components of fire clay bricks are Silica and alumina.

S3. (a) Levigation is based on the difference in densities of the metallic ore and gangue particles. Powdered ore is treated with a stream of running water when the lighter gangue particles are washed away and heavier ore particles are left behind.

S4. (a) Cinnabar is mined as the major ore of mercury. The ore of cinnabar is squeeze plus made warm toward let mercury goes as a vapour.

S5. (d) Cassiterite, also called tinstone, heavy, metallic, hard tin dioxide (SnO_2) that is the major ore of tin. It is colourless when pure, but brown or black when iron impurities are present.

S6. (a) Galena, also called lead glance, a grey lead sulfide (PbS), the chief ore mineral of lead.

S7. (a) In the metallurgy of iron, limestone ($CaCO_3$) acts as a flux and forms calcium silicate $CaSiO_3$ (slag).

S8. (c) Copper matte is put in a silica-lined converter to remove the remaining FeO and FeS present in the matte as slag ($FeSiO_3$).

S9. (d) Among the metals Cr, Fe, Mn, Ti, Ba, and Mg, the one that cannot be obtained by reduction of metal oxide by aluminium is. Mg reacts with C to form Magnesium carbide.

S10. (b) An ore of tin-containing $FeCrO_4$ is concentrated by magnetic separation as $FeCrO_4$ is ferromagnetic in nature. Magnetic separation based on differences in magnetic properties of the ore components.

S11. (d) Froth Floatation Process: This process is best suitable for sulphide ores. The process is based on different wetting characteristics of the ore and gangue particles with water and pine oil. The ore is wetted by oil and impurities are wetted by water. Ore particles are adsorbed on potassium or sodium ethyl xanthate (as a collector) and come at the surface along with the froth. Froth stabilizer (cresols, aniline) stabilize the froth.
But Argentite is not concentrated by this method.
The following method is used to concentrate Argentite:
$Ag_2S + 4NaCN \rightarrow 2Na[Ag(CN)_2] + Na_2S$
Silver is obtained by reaction with Zn:
$2Na[Ag(CN)_2] + Zn \rightarrow Na_2[Zn(CN)_4] + 2Ag$

S12. (c) The only silver ore of the above options having the chemical formula Ag_2S is argentite, also known as a silver glance. Silver may be easily extracted from silver glance by smelting or chemical leaching.

S13. (b) When concentration is carried out by hand picking, it is crucial that impurities can be easily distinguished from ore particles. If these impurities are visible to the human eye, the ore is

said to be pure. It is claimed that the ore is suitable for concentration by hand picking.

S14. (c) Over a conveyor belt that rotates around two rollers, one of which has an electromagnet, the powdered ore is dumped. When the ore particles travel across the belt, the magnetic roller draws the magnetic particles. Two piles therefore independently develop. Non-magnetic particles are collected away from the magnetic roller, while magnetic particles are gathered beneath it.

S15. (b) In the field of extractive metallurgy, a method for removing metals from their ores is known as hydrometallurgy. Aqueous solutions are used in the hydrometallurgy process to extract metals from ores, concentrates, and recycled or residual materials.

S16. (c) Oxides that are volatile contaminants are removed from oxide ores by roasting. By reduction, it is simpler to get metals from their oxides than from carbonates or sulfides. As a result, before the ore can be reduced, it must first be converted to metal oxide.

S17. (c) With the use of electrometallurgy or electrolysis, sodium, a highly electropositive metal, is easily extracted from sodium chloride. Pyrometallurgy and hydrometallurgy are used to extract metals like copper, iron, and silver.

S18. (d) By using an electrochemical reaction, the Hall-Heroult method converts bauxite to almost pure aluminium. The bauxite is dissolved in sodium, fluorine, and aluminium electrolyte that is molten and maintained at a high temperature. In this procedure, oxygen gas is created at the anode while aluminium is deposited at the cathode.

S19. (a) A material known as flux can either be an acidic oxide (SiO_2) or a basic oxide (CaO, MgO). Slag is created when it mixes with certain impurities (gangue particles). This is simple to remove.

S20. (c) Pure aluminium is separated from its mixture using the Hall-Heroult technique. In this procedure, the melting point of the mixture is lowered while improving electrical conductivity by mixing pure aluminium (Al_2O_3) with calcium fluoride (CaF_2) or sodium aluminium hexafluoride (Na3AlF6). In the Hall-Heroult procedure, a steel tank with a graphite and carbon rod liner is employed.

S21. (c) Aluminium bronze is an alloy made up of aluminium and copper. Its percentage composition is 95% of aluminium and 5% of copper. It is mainly used for making coins. It is a light strong alloy with golden lustre and resistant to corrosion.

S22. (a) Brass is an alloy of copper which contains 60% of copper and 40% of zinc. It is highly ductile in nature, corrosion resistant and is mainly used for making parts of machinery and condenser tubes. It is also used for making utensils.

S23. (c) Copper is used because of its high thermal conductivity. This is higher than all other metals except silver, a precious metal. Copper has a 60% better thermal conductivity rating than aluminium and a 3,000% better rating than stainless steel.

S24. (a) The impurities generally present in crude metals consist of other metals, formed by reduction of their respective oxides present in the ore, non-metals such as silicon and phosphorus, unreacted oxides and sulphides of the metals and substances taken up in the furnace such as slag.

S25. (a) Distillation process is used for refining metals that are usually volatile in nature. Zinc, cadmium and mercury are refined vial distillation where the pure metal distils over, leaving behind the non-volatile impurities.

S26. (c) Liquation is used for purification of metals that contain impurities which are less fusible than the metals themselves, that is, the melting points of the metals are lower than that of the impurities. Lead is refined by liquation process.

S27. (b) In electrolytic refining, the impure metal is converted to a block which forms the anode while the cathode is made up of a pure strip of the same metal. The electrolyte used is generally a solution of a soluble salt of the metal, usually, a double salt of the metal.

S28. (c) In the electrolytic refining of copper, crude copper or blister copper is made the anode, a thin sheet of pure copper is made the cathode and a solution of copper sulphate acidified by sulphuric acid is used as the electrolyte.

S29. (d) Zone refining is based on the principle that the impurities are more soluble in the molten state than in the solid state of the metal. Semiconductors such as germanium, silicon and gallium are refined by zone refining. Gold is generally refined via electrolysis.

S30. (c) In zone refining, when the melt of an impure metal is allowed to cool, the pure metal crystallizes out while the impurities remain in the melt. This process is usually carried out in an inert atmosphere to prevent the oxidation of the metal.

ASSERTION AND REASONING

S1. **(a)** Blisters are produced on metal surface because of SO_2. So it is called Blister Copper.

S2. **(a)** Liquation process is used when the impurity is less fusible than the metal itself.
lead, tin and bismuth have low m.pt. as compared to impurities.
Hence, lead, tin and bismuth are purified by liquation method.
Both Assertion and Reason are correct and Reason is the correct explanation for Assertion.

S3. **(a)** Nickel is heated in a stream of carbon monoxide forming a volatile complex nickel tetracarbonyl which on further decomposition gives pure Ni. This process is called Mond process.

$$Ni + 4CO \xrightarrow{330-450K} Ni(CO)_4$$

$$Ni(CO)_4 \xrightarrow{450-470K} Ni + 4CO$$

S4. **(b)** Hydrometallurgy involves dissolving the ore in a suitable reagent (like water, dilute acids or sodium cyanide solution) followed by precipitation by a more electropositive metal.
So, it is used for extraction of less electropositive metals like copper, silver, gold.
So, the assertion is correct.
Analysing reason
Copper is extracted by hydrometallurgy.
So, reason is also correct but it is not the explanation of assertion.
Both assertion and reason are true and reason is not the correct explanation of assertion.

TRUE/FALSE

S1. **(a)** Evolution of SO_2 produces blister-like appearance on the surface of solidified copper.

S2. **(b)** Roasting is a process that occurs when there is an abundance of air. Roasting is the process of rapidly heating a sulphide ore in the presence of a large amount of air. During roasting, the sulphide is converted to an oxide, and the sulphur is liberated as sulphur dioxide.

S3. **(a)** The reduction potential of alkali and alkaline earth metals is very high. They're powerful reducing agents. Other reducing agents are unable to reduce alkali and alkaline earth metal oxides or other compounds. As a result, no chemical reduction is possible.

S4. **(a)** It's composed of ceramic or bone ash and looks like a little egg cup. Copper crucibles were typically large, shallow pots used for smelting copper. Crucibles and their lids are commonly composed of porcelain, alumina, or inert metal, which can withstand high temperatures.