UNIT - 1

Metallurgy

FORMULAE TO REMEMBER

Metal	Ore	Composition	Metal	Ore	Composition
Aluminium	Bauxite	$Al_2O_3.nH_2O$	Zinc	Zinc blende or Sphalerite	ZnS
	Diaspore	$Al_2Si_2O_5(OH)_4$		Calamine	$ZnCO_3$
	Kaolinite	Al_2O_3		Zincite	ZnO
Iron	Haematite	Fe_2O_3	Lead	Galena	PbS
	Magnetite	Fe_3O_4		Anglesite	$PbSO_4$
	Siderite	$FeCO_3$		Cerrusite	$PbCO_3$
	Iron pyrite	FeS_2	Tin	Cassiterite (Tin stone)	SnO_2
	Limonite	$Fe_2O_3.3H_2O$	Silver	Silver glance (Argentite)	Ag_2S
Copper	Copper pyrite	$CuFeS_2$		Pyrargyrite (Ruby silver)	Ag_3SbS_3
	Copper glance	Cu_2S		Chlorargyrite (Horn Silver)	AgCl
	Cuprite	Cu_2O		Stefinite	Ag_5SbS_4
	Malachite	$CuCO_3.Cu(OH)_2$		Proustite	Ag_3AsS_3
	Azurite	$2CuCO_3.Cu(OH)_2$			

MUST KNOW DEFINITIONS

Mineral : A naturally occurring substance obtained by mining which contains the metal in free state or in the form of compounds like oxides, sulphides etc... is called a **mineral**.

Ores : Minerals that contains a high percentage of metal, from which it can be extracted conveniently and economically are called **ores**.

Concentration of Ore : The preliminary step in metallurgical process is removal of these impurities. This removal process is known as **concentration of ore**.

Roasting : **Roasting** is the method, usually applied for the conversion of sulphide ores into their oxides. The concentrated ore is oxidised by heating it with excess of oxygen in a suitable furnace below the melting point of the metal.

Calcination : **Calcination** is the process in which the concentrated ore is strongly heated in the absence of air.

Refining process : Removal of such impurities associated with the isolated crude metal is called **refining process**.

Ellingham diagram : The graphical representation of variation of the standard Gibbs free energy of reaction for the formation of various metal oxides with temperature is called **Ellingham diagram.**

Application of Ellingham diagram : **Ellingham diagram** helps us to select a **suitable reducing agent** and **appropriate temperature** range for reduction.

Electrolytic refining : In electrolytic refining of the metal :

Cathode : Pure metal

Anode : Impure metal

Electrolyte : Acidified aqueous solution of salt of the metal

PUBLIC EXAM FREQUENTLY ASKED QUESTIONS

1 Mark

Choose The Correct Answer

1. Bauxite has the composition *[HY. '19; May-'22]*

a) Al_2O_3 b) $Al_2O_3.nH_2O$

c) $Fe_2O_3.2H_2O$ d) None of these

[*Ans.* (b) $Al_2O_3.nH_2O$]

2. Roasting of sulphide ore gives the gas (A).(A) is a colourless gas. Aqueous solution of (A) is acidic. The gas (A) is *[FRT-'22]*

a) CO_2 b) SO_3 c) SO_2 d) H_2S

[*Ans.* (c) SO_2]

3. Wolframite ore is separated from tinstone by the process of *[PTA - 2; Mar-2020]*

a) Smelting

b) Calcination

c) Roasting

d) Electromagnetic separation

[*Ans.* (d) Electromagnetic separation]

4. Which one of the following ores is best concentrated by froth – floatation method? *[Govt.MQP_'19; FRT-'22]*

a) Magnetite b) Haematite

c) Galena d) Cassiterite

[*Ans.* (c) Galena]

5. Zinc is obtained from ZnO by *[FRT & July '22]*

a) Carbon reduction

b) Reduction using silver

c) Electrochemical process

d) Acid leaching **[*Ans.* (a) Carbon reduction]**

6. Extraction of gold and silver involves leaching with cyanide ion. Silver is later recovered by *(NEET-'17)*

a) Distillation

b) Zone refining

c) Displacement with zinc

d) liquation **[*Ans.* (c) Displacement with zinc]**

7. The following set of reactions are used in refining Zirconium *[Aug-'21]*

$$Zr(\text{impure}) + 2I_2 \xrightarrow{523K} ZrI_4.$$

$$ZrI_4 \xrightarrow{1800K} Zr(\text{pure}) + 2I_2$$

This method is known as

a) Liquation b) Van Arkel process

c) Zone refining d) Mond's process

[*Ans.* (b) van Arkel process]

8. The incorrect statement among the following is *[QY. '19; Sep-2020]*

a) Nickel is refined by Mond's process.

b) Titanium is refined by Van Arkel's process.

c) Zinc blende is concentrated by froth floatation.

d) In the metallurgy of gold, the metal is leached with dilute sodium chloride solution.

[*Ans.* (d) In the metallurgy of gold, the metal is leached with dilute sodium chloride solution]

9. Which of the following reduction is not thermodynamically feasible? *[PTA - 3]*

a) $Cr_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Cr$
b) $Al_2O_3 + 2Cr \longrightarrow Cr_2O_3 + 2Al$
c) $3TiO_2 + 4Al \longrightarrow 2\,Al_2O_3 + 3Ti$
d) none of these

[*Ans.* (b) $Al_2O_3 + 2Cr \longrightarrow Cr_2O_3 + 2Al$]

10. Sulphide ores of metals are usually concentrated by froath floatation process. Which one of the following sulphide ore offers an exception and is concentrated by chemical leaching. *[PTA - 4]*

a) Argentite b) galena
c) Copper pyrites d) Sphalerite

[*Ans.* (a) Argentite]

11. Which method of purification represented by the equation? *[PTA - 5]*

$$Ti(impure) + 2I_2 \xrightarrow{550K} TiI_4$$
$$\xrightarrow{1800K} Ti(pure) + 2I_2$$

a) Cupellation b) Zone refining
c) Van - Arkel method
d) Mond's process

[*Ans.* (c) Van - Arkel method]

12. The process of converting hydrated aluminia into anhydrous alumina is called. *[PTA - 6]*

a) Roasting b) Smelting
c) Auto-reduction d) Calcination

[*Ans.* (d) Calcination]

13. Elements like silicon and Germanium to be used as a semiconductor is purified by

a) heating under vaccum *[PTA - 1]*
b) Van - Arkel method
c) Zone refining
d) Electrolysis **[*Ans.* (c) Zone refining]**

14. The metal which is used in packing metarial for food items : *[Sep-2020]*

(a) Zn (b) Zr (c) Al (d) Au

[*Ans.* (c) Al]

15. CaO (flux) + SiO_2 (gangue) → ? (slag) *[FRT-'22]*

(a) $CaSiO_2$ (b) $CaSiO_3$
(c) Ca_2SiO_4 (d) Ca_3SiO_4

[*Ans.* (b) $CaSiO_3$]

16. Titanium is purified by : *[FRT-'22]*

(a) Mond process (b) Electrolytic refining
(c) Van-Arkel process (d) Liquation

[*Ans.* (c) Van-Arkel process]

17. Considering Ellingham diagram, which of the following metals can be used to reduce alumina? *(NEET-'18)*

a) Fe b) Cu c) Mg d) Zn

[*Ans.* (c) Mg]

2 Marks

1. What are the differences between minerals and ores? *[QY_'19; Sep-2020; FRT, May-'22]*

Ans.

Minerals	Ores
A naturally occurring substance obtained by mining which contains the metal in free state or in the form of compounds.	Ore contains a high percentage of metal, from which it can be extracted conveniently and economically.
All minerals are not ores	All ores are Minerals
It contains a low percentage of metal.	It contains a high percentage of metals
Ex : Mineral of Al is bauxite and china clay	**Ex :** Ore of Al is bauxite

2. Which type of ores can be concentrated by froth floatation method? Give two examples for such ores. *[FRT-'22]*

Ans. *(i)* Sulphide ores can be concentrated by froth floatation method.

(ii) **Ex :** Lead sulphide **galena** (PbS) and zinc blende (ZnS).

3. Describe a method for refining nickel. *[PTA - 3; May-'22]*

Ans. **Mond process for refining nickel :**

(i) The impure nickel is heated in a stream of carbon monoxide at around 350K.

(ii) The nickel reacts with the CO to form a highly volatile nickel tetracarbonyl.

(iii) The solid impurities are left behind.

$$Ni_{(s)} + 4CO_{(g)} \xrightarrow{350\ K} [Ni(CO)_4]_{(g)}$$

(iv) On heating the nickel tetracarbonyl around 460K, the complex decomposes to give pure metal.

$$[Ni(CO_4)]_{(g)} \xrightarrow{460\ K} Ni_{(s)} + 4CO_{(g)}$$

4. What is the role of graphite rods in the electro metallurgy of aluminium? *[PTA - 1]*

Ans. *(i)* Graphite rods act as **anode** during electrolytic reduction of alumina.

(ii) At anode, O_2 gas is produced which react with the carbon of anode (rods) to produce CO_2 gas.

(iii) So these graphite rods are consumed slowly and need to be replaced from time to time.

5. Define roasting. *[PTA - 4]*

Ans. In roasting, the concentrated ore is oxidised by heating it with excess of oxygen in a suitable furnace below the melting point of the metal.

$$2Pbs + 3O_2 \xrightarrow{\Delta} 2PbO + 2SO_2 \uparrow$$

6. Explain calcination with an example. *[PTA - 4]*

Ans. *(i)* Calcination is the process in which the concentrated ore is strongly heated in the absence of air.

(ii) During this process, the water of crystallisation present in the hydrated oxide escapes as moisture.

(iii) Any organic matter (if present) also get expelled leaving behind a porous ore.

(iv) This method can also be carried out with a limited supply of air.

(v) During calcination of carbonate ore, carbon dioxide is expelled

$$PbCO_3 \xrightarrow{\Delta} PbO + CO_2\uparrow$$

5 Marks

1. Explain zone refining process with an example. *[PTA - 6; Mar-2020; FRT-'22]*

Ans. *(i)* This method is based on the Fractional Crystallisation. The impure metal is melted and allowed to solidify, the impurities prefer to remain in the molten region.

(ii) The impure metal is taken in the form of a rod.

(iii) When the metal rod is heated with a heater the metal melts.

(iv) The heater is slowly moved from one end to the other end.

(v) The impurity dissolves in the molten zone.

(vi) When the heater moves, the molten zone also moves.

(vii) This process is repeated again and again to get pure metal.

(viii) The process is carried in an inert gas atmosphere to prevent the oxidation of metals.

Example :

Elements such as Germanium (Ge), Silicon (Si) and Galium (Ga) are refined using this process.

2. Give the uses of zinc. *[PTA - 4]*

Ans. *(i)* Metallic zinc is used in **galvanising** metals such as iron and steel structures to protect them from rusting and corrosion.

(ii) Zinc is also used to produce die-castings in the automobile, electrical and hardware industries

(iii) Zinc oxide is used in the manufacture of many products such as paints, rubber, cosmetics, pharmaceuticals, plastics, inks, batteries, textiles and electrical equipment.

(iv) Zinc sulphide is used in making luminous paints, fluorescent lights and x-ray screens.

(v) Brass an alloy of zinc is used in water valves and communication equipment as it is highly resistant to corrosion.

3. Explain the electrometallurgy of aluminium. *[Govt.MQP_'19]*

Ans. **Hell - Herold Process :**

Cathode : Iron tank lined with carbon

Anode : Carbon blocks

Electrolytes : 20% solution of alumina obtained from bauxite + Molten cryolite + Calcium chloride (lowers the melting point of the mixture)

Temperature : Above 1270 K

Ionisaiton of alumina

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

Reaction at cathode

$$2Al^{3+}\ (melt) + 6e^- \longrightarrow 2Al_{(l)}$$

Reaction at anode

$$6O^{2-}\ (melt) \longrightarrow 3O_2 + 12e^-$$

(i) Since carbon acts as anode the following reaction takes place.

$$C_{(s)} + O^{2-}\ (melt) \longrightarrow CO + 2e^-$$

$$C_{(s)} + 2O^{2-}\ (melt) \longrightarrow CO_2 + 4e^-$$

(ii) During electrolysis anodes are slowly consumed due to the above two reactions.

(iii) Aluminium is formed at the cathode and settles at the bottom.

(iv) Net electrolysis reaction is

$4Al^{3+}$ (melt) + $6O^{2-}$ (melt) + $3C_{(s)}$ ⟶ $4Al_{(l)}$ + $3CO_{2(g)}$

4. Describe the role of the following in the process mentioned.

(i) Silica in the extraction of copper.

(ii) Cryolite in the extraction of aluminium. *[QY_'19]*

(iii) Iodine in the refining of Zirconium. *[QY_'19]*

(iv) Sodium cyanide in froth floatation.

Ans. *(i)* Silica, is used as an acidic flux is used to remove slag during the process of roasting.

(ii) Lowers the melting point to 1173K and improves the electrical conductivity of the aluminium.

(iii) To form a volatile compound which on further heating decomposes to give pure Zn.

(iv) Sodium cyanide is used as an depressing agent in froth flotation. It prevents other metal sulphides coming to the froth.

For Example, when impurities such as ZnS is present in galena (PbS), sodium cyanide (NaCN) is added to depresses the flotation property of ZnS by forming a layer of zinc complex $Na_2[Zn(CN)_4]$ on the surface of zinc sulphide.

5. Explain the principle of electrolytic refining with an example. *[HY-'19; July-'22]*

Ans. *(i)* Electrolytic refining is carried out in an electrolytic cell.

(ii) **Anode** : Impure metal
Cathode : Thin strips of pure metal
Electrolyte : Aqueous solution of the salts of the metal.

(iii) The metal of interest dissolves from the anode, pass into the solution while the same amount of metal ions from the solution will be deposited at the cathode.

(iv) During electrolysis, the less electropositive impurities in the anode, settle down at the bottom and are removed as anode mud.

(v) Electrolytic refining of silver as an example.
Cathode : Pure silver
Anode : Impure silver rods
Electrolyte : Acidified aqueous solution of silver nitrate.

(vi) When a current is passed through the electrodes the following reactions will take place
Reaction at anode

$$Ag_{(s)} \longrightarrow Ag^{+}_{(aq)} + 1e^{-}$$

Reaction at cathode

$$Ag^{+}_{(aq)} + 1e^{-} \longrightarrow Ag_{(s)}$$

(vii) During electrolysis, at the anode the silver atoms lose electrons and enter the solution.

(viii) The positively charged silver cations migrate towards the cathode and get discharged by gaining electrons and deposited on the cathode.

6. Explain electrolytic refining of silver. *[PTA - 5]*

Ans. *(i)* Electrolytic refining of silver as an example.
Cathode : Pure silver
Anode : Impure silver rods
Electrolyte : Acidified aqueous solution of silver nitrate.

(ii) When a current is passed through the electrodes the following reactions will take place
Reaction at anode

$$Ag_{(s)} \longrightarrow Ag^{+}_{(aq)} + 1e^{-}$$

Reaction at cathode

$$Ag^{+}_{(aq)} + 1e^{-} \longrightarrow Ag_{(s)}$$

7. Explain extraction of copper from copper pyrites. *[PTA - 5]*

Ans. *(i)* In this method, a flux (a chemical substance that forms an easily fusible slag with gangue) and a reducing agent such as carbon, carbon monoxide (or) aluminium is added to the concentrated ore and the mixture is melted by heating at an elevated temperature (above the melting point of the metal) in a smelting furnace.

(ii) For example the oxide of iron can be reduced by carbon monoxide as follows.

$$Fe_2O_{3(s)} + 3CO_{(g)} \longrightarrow 2Fe_{(s)} + 3CO_{2(g)}\uparrow$$

(iii) In this extraction, a basic flux, limestone (CaO) is used. Since the silica gangue present in the ore is acidic in nature, the limestone combines with it to form calcium silicate (slag).

$$\underset{\text{Flux}}{CaO_{(s)}} + \underset{\text{Gangue}}{SiO_{2(s)}} \longrightarrow \underset{\text{Slag}}{CaSiO_{3(s)}}$$

(iv) In the extraction of copper from copper pyrites, the concentrated ore is heated in a reverberatory furnace after mixing with silica, an acidic flux.

(v) The ferrous oxide formed due to melting is basic in nature and it combines with silica to form ferrous silicate (slag).

(vi) The remaining metal sulphides Cu_2S and FeS are mutually soluble and form a copper matte.

$$2CuFeS_{2(s)} + O_{2(g)} \longrightarrow 2FeS_{(l)} + Cu_2S_{(l)} + SO_{2(g)}$$

$$2FeS_{(l)} + 3O_{2(g)} \longrightarrow 2FeO_{(l)} + 2SO_{2(g)}$$

$$FeO_{(s)} + SiO_{2(s)} \longrightarrow FeSiO_{3(s)}$$

Flux Gangue Slag

(vii) The matte is separated from the slag and fed to the converting furnace.

(viii) During conversion, the FeS present in the matte is first oxidised to FeO.

(ix) This is removed by slag formation with silica.

(x) The remaining copper sulphide is further oxidised to its oxide which is subsequently converted to metallic copper.

$$2Cu_2S_{(l,s)} + 3O_{2(g)} \longrightarrow 2Cu_2O_{(l,s)} + 2SO_{2(g)}$$

$$2Cu_2O_{(l)} + Cu_2S_{(l)} \longrightarrow 6Cu_{(l)} + SO_{2(g)}$$

(xi) The metallic copper is solidified and it has blistered appearance due to evolution of SO_2 gas formed in this process. This copper is called blistered copper.

8. Explain how gold ore is leached by cyanide process *[Govt. MQP_'19]*

Ans. *(i)* Gold is usually found in native state.

(ii) The leaching process is intended to concentrate the gold metal.

$$4Au_{(s)} + 8\ NaCN^-_{(aq)} + 2H_2O_{(aq)} + O_{2(g)} \longrightarrow 4\ Na\ [Au(CN)_2]^-_{(aq)} + 4NaOH^-_{(aq)}$$

$$2Na\ [Au(CN)_2] + Zn \longrightarrow Na_2[Zn(CN)_4] + 2Au\downarrow$$

(iii) In this reaction, gold is reduced to its elemental state and the process is called cementation.

9. How is Ni purified by Mond process? *[FRT-'22]*

Ans. The impure nickel is heated in a stream of carbon monoxide at around 350 K. The nickel reacts with the CO to form a highly volatile nickel tetracarbonyl. The solid impurities are left behind.

$$Ni\ (s) + 4\ CO\ (g) \longrightarrow [Ni(CO)_4]\ (g)$$

On heating the nickel tetracarbonyl around 460 K, the complex decomposes to give pure metal.

10. Write a note on gravity separation method. *[May-'22]*

Ans. *(i)* In gravity separation method, the ore having high specific gravity is separated from the gangue that has low specific gravity by washing with running water.

(ii) Ore is crushed to a finely powdered form and treated with rapidly flowing current of water.

(iii) During this process the lighter gangue particles are washed away by the running water.

(iv) This method is generally applied to concentrate the native ore such as gold and oxide ores such as haematite (Fe_2O_3), tin stone (SnO_2) etc.

11. How is acid leaching done for the sulphide ores? (or) Expalin Acid Leaching with an example. *[July-'22]*

Ans. *(i)* Leaching of sulphide ores such as ZnS, PbS etc., can be done by treating them with hot aqueous sulphuric acid.

$$2ZnS\ (s) + 2H_2SO_4(aq) + O_2\ (g) \longrightarrow 2ZnSO_4\ (aq) + 2S\ (s) + 2H_2O$$

(ii) In this process the insoluble sulphide is converted into soluble sulphate and elemental sulphur.

12. How are ores concentrated by magnetic separation method? *[FRT-'22]*

Ans. *(i)* This method is applicable to ferromagnetic ores and it is based on the difference in the magnetic properties of the ore and the impurities.

(ii) For example tin stone can be separated from the wolframite impurities which is magnetic.

(iii) Similarly, ores such as chromite, pyrolusite having magnetic property can be removed from the non magnetic siliceous impurities. The crushed ore is poured on to an electromagnetic separator consisting of a belt moving over two rollers of which one is magnetic.

(iv) The magnetic part of the ore is attracted towards the magnet and falls as a heap close to the magnetic region while the nonmagnetic part falls away from it as shown in the figure.

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