

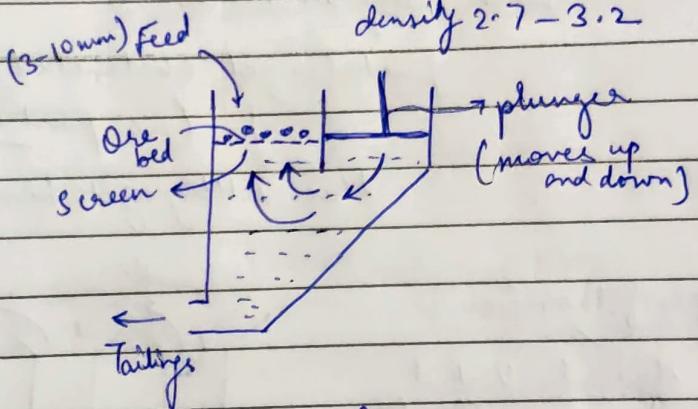
## POST-MINOR 1

### LECTURE 17 (10/02/2023)

#### 67] Gravity concentration Froth Flotation

Fe, W, Cu ores  
Coal washing

One of the important  
(& one of the oldest methods) → Tipping : 3 - 10 mm  
particle size



gneissic layers  
stratification

Denser  
particles  
remain  
at bottom  
& lighter particles  
go up

Very fine particles  
pass through the  
screen, and are  
removed

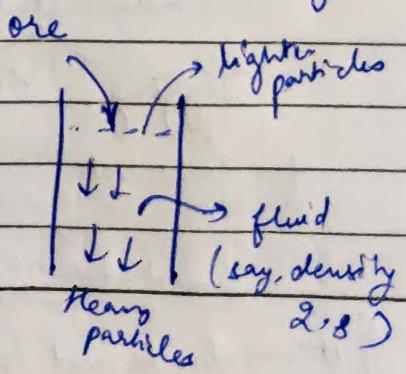
as tailings

#### 68] Heavy Media Separation

Based on the fact that  
if we put ore particles  
in liquid

Also called  
"Sink and Float  
method"

heavier will settle down  
& lighter stay up



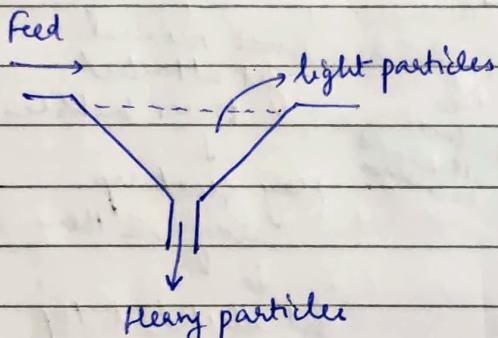
Heavy density liquid used  
obtained by  
either or  
mixing some  
salt in water      using some  
organic liquid

At industrial scale

Suspension of heavy minerals  
(with vs. fine particles) is produced

e.g.: Fe-Si (6.8)  $\downarrow$  particle size  $\approx$  100 mesh  
Fe<sub>3</sub>O<sub>4</sub> (5.1)  
etc.

Consists of  
< 30% solid by weight  
70-80% by vol.



$\rightarrow$  particle size  $> 3 \text{ mm}$

## 69] Flotation [Froth Flotation]

$\downarrow$   
very important &  
is replacing many of the  
other gravity cone methods

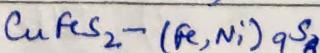
### Importance

- Grinding upto -400 mesh needed  $\rightarrow$  finely disseminated  
 $\downarrow$   
 $38 \mu\text{m}$

difficult to  
perform gravity cone.  
on such fine particles

- Many complexes (e.g.: PbS-ZnS,

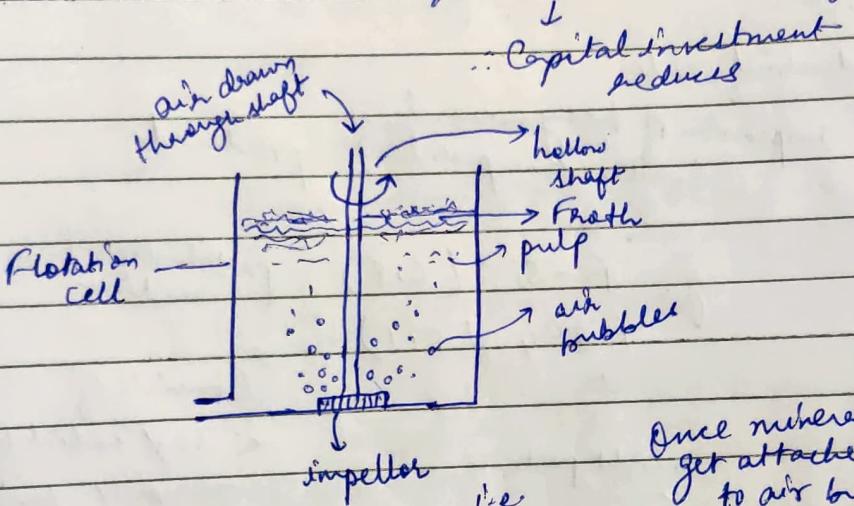
$\downarrow$   
multiple  
useful  
metal present



chalcopyrite - pentlandite)

Differential  
Flotation

3. Many have tendency to float
4. Flotation doesn't require much of the preliminary treatment like sizing & classification
5. Flotation machines require smaller area (floor area)



Once minerals get attached to air bubbles they float up along with them  
 get collected at top as concentrate in the form of froth

\* eg: Water-repellent gets stuck to bubbles i.e. hydrophobic & those which do not attach to bubbles, get collected at bottom in the form of tailings.

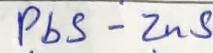
But, if easily wetted then will not get attached to air bubbles

These surface attachment properties can be changed as well by adding chemicals

### 1) Collectors (also called Promoters)

increase the tendency of attachment (by increasing water repellent properties)

eg: If we have to separate



naturally floats      naturally doesn't float

But if we add some collector mineral

then ZnS will also be able to float

& thus we can obtain PbS & ZnS separated from gangue.

eg: Xanthates  $\rightarrow$  increases floatability of some minerals

2) Frothers  $\rightarrow$  purpose is to stabilize the froth until it is removed from the cell.

eg: Pine oil is a common frother

NOTE: In reality, there is not just a single cell  
there are multiple cells kept in series

3) Depressors and Activators

to depress minerals

(i.e. inhibit

floatation of some minerals

& prevent collector from acting on it)

acts in such a way that makes collector act more easily

This is often used in Differential Float

$\text{CuSO}_4$  acts as activator for ZnS

eg:  $\text{NaCN}$

acts as depressor for ZnS

separation of these two requires differential float

4) Conditioner: Purpose is to  
 ↓ maintain the pH of  
 eg:  $\text{Na}_2\text{CO}_3$  the solution  
 and  $\text{CaO}$   
 are common  
 conditioners

NOTE: Quantity of chemicals 1)-3)  $\Rightarrow$   $<0.1\%$  by wt.  
 Only conditioner  $\Rightarrow$   $0.2-0.5\%$  by wt.

### 70] Magnetic Separation

Minerals which are strongly attracted  
 by magnets  
 ↓  
 are known as  
Ferromagnetic

which are weakly attracted  $\rightarrow$  Paramagnetic  
 which are hardly attracted  $\rightarrow$  Diamagnetic  
 (Non-magnetic)

### 71] Relative Intensity of Attractability of Some Minerals

<u>Classification</u>	<u>Mineral</u>	<u>Relative Attractability</u>
strong magnetic	Fe (standard)	- 100.0
	magnetite ( $\text{Fe}_3\text{O}_4$ )	- 40.2
	Ilmenite ( $\text{FeO}-\text{TiO}_2$ )	- 24.7

weakly magnetic	Pyrrhotite ( $\text{FeS}$ )	- 6.7
	Siderite ( $\text{FeCO}_3$ )	- 1.8
	Hematite ( $\text{Fe}_2\text{O}_3$ )	- 1.3
	Pyrochlore ( $\text{MnO}_2$ )	- 0.7

Non magnetic      Quartz ( $SiO_2$ ) - 0.4  
 Pyrite ( $FeS_2$ ) - 0.2  
 Sphalerite ( $ZnS$ ) - 0.2  
 Galena ( $PbS$ ) - 0.1

## LECTURE 18 (14/02/2023)

72] Magnetic separation is carried out for separation of

↓  
generally: magnetic minerals from non-mag. gangue

(e.g.: magnetite, from silica, etc.) alumina

{ eg: In Tin-ore,  $Fe_3O_4$  (magnetite) and Wolframite  
 ↓  
 mineral is the impurity here  
 is Tin ( $Sn$ ) }

73] Electrostatic separation

Based on whether property is conducting or non-conducting

Here particles should be dry

(∴ Water must be removed by "Dewatering")

↓  
also helps reduce the weight

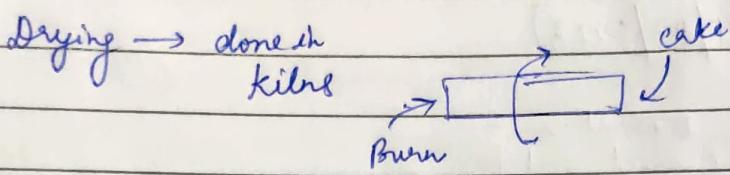
Useful for separation of heavy minerals

eg: Ilmenite & Rutile - conductors  
 monazite, Zircon - Non conductors

also valuable  
 (Uranium & Thorium ore)

## 74] Dewatering

- (i) Sedimentation Thickening
- (ii) Filtration —
  - Drum
  - Vacuum
  - Flotation



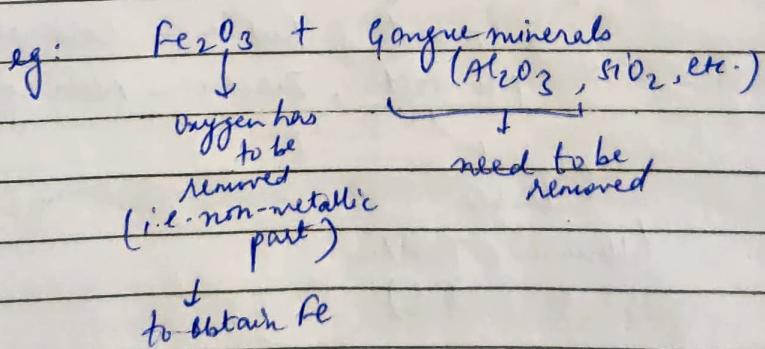
## 75] Extraction of Metals

Elementary Concepts of extraction of metals from their ores :

- (i) Mineral Beneficiation → physical or ~~chemical~~ mechanical separation of valuable minerals from gangue minerals
- (ii) Extractive metallurgy ↓
  - preliminary step

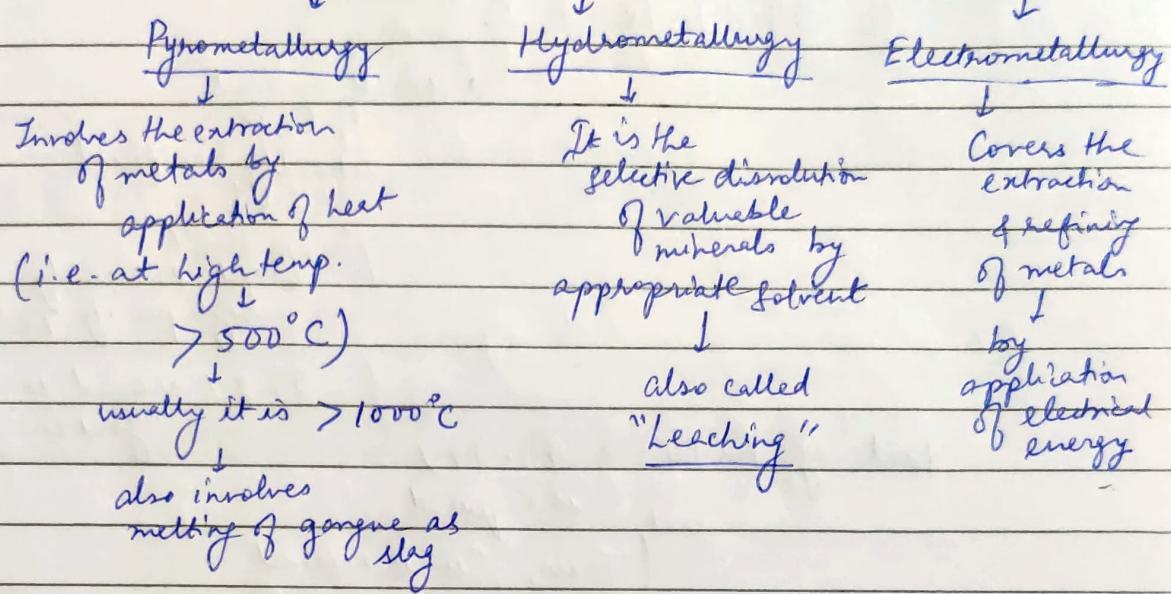
Definition:

It is the breaking of ore minerals & removal of gangue minerals by chemical process, & collecting & refining of metals.



NOTE: There is no standard chemical method that works for separation in all cases. (due to differences in properties)

76] We can classify diff. chemical processes in 3 categories:



77] Factors deciding the choice of the process

- (i) Nature & Stability of the ore mineral
- (ii) Properties of the metal concerned
- (iii) Degree of purity required of the metal
- (iv) Local facilities available

(i) Nature & Stability

More stability of ore  $\rightarrow \Delta G$  is more Negative

$\therefore$  difficult to break down a more stable ore

These are relatively stable

e.g.:  $\text{HgS}$  and  $\text{Ag}_2\text{S}$ ,  $\text{Cu}_2\text{O}$

{  $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{ZrO}_2$

↓  
N. stable in general

{  $\text{ZnO}$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{PbO}$

→ These are relatively less stable & can be reduced by C

↑  
\* cannot be separated by pyrometallurgy

### (ii) Purity of metal

e.g.: 99.8% Fe + C

↓ small amount

of C is  
actually beneficial

∴ We don't  
want extremely  
high purity Fe

(∴ 99.8% around is  
good enough)

But, e.g.: For Cu → 99.99%  
is required

(Thus, Cu is refined  
starting with Pyro  
but then also Electrometallurgy  
is needed)

### (iii) Local facilities

e.g.: In Scandinavian countries → Hydroelectric power is in large amount

∴ Electrometallurgy is preferable there

### (iv) Concentration of ore

Cu sulphide - 1% Cu → 35% Cu

Cu oxide - 1% Cu - Hydromet (Pyromet.)

NOTE: Often combination is used:

e.g.: Iron - Mainly only Smelting, fire-refining, ...  
Pyromet is used

Copper - Pyromet & Electrometallurgy

Zinc - Pyromet & Refining by Distillation

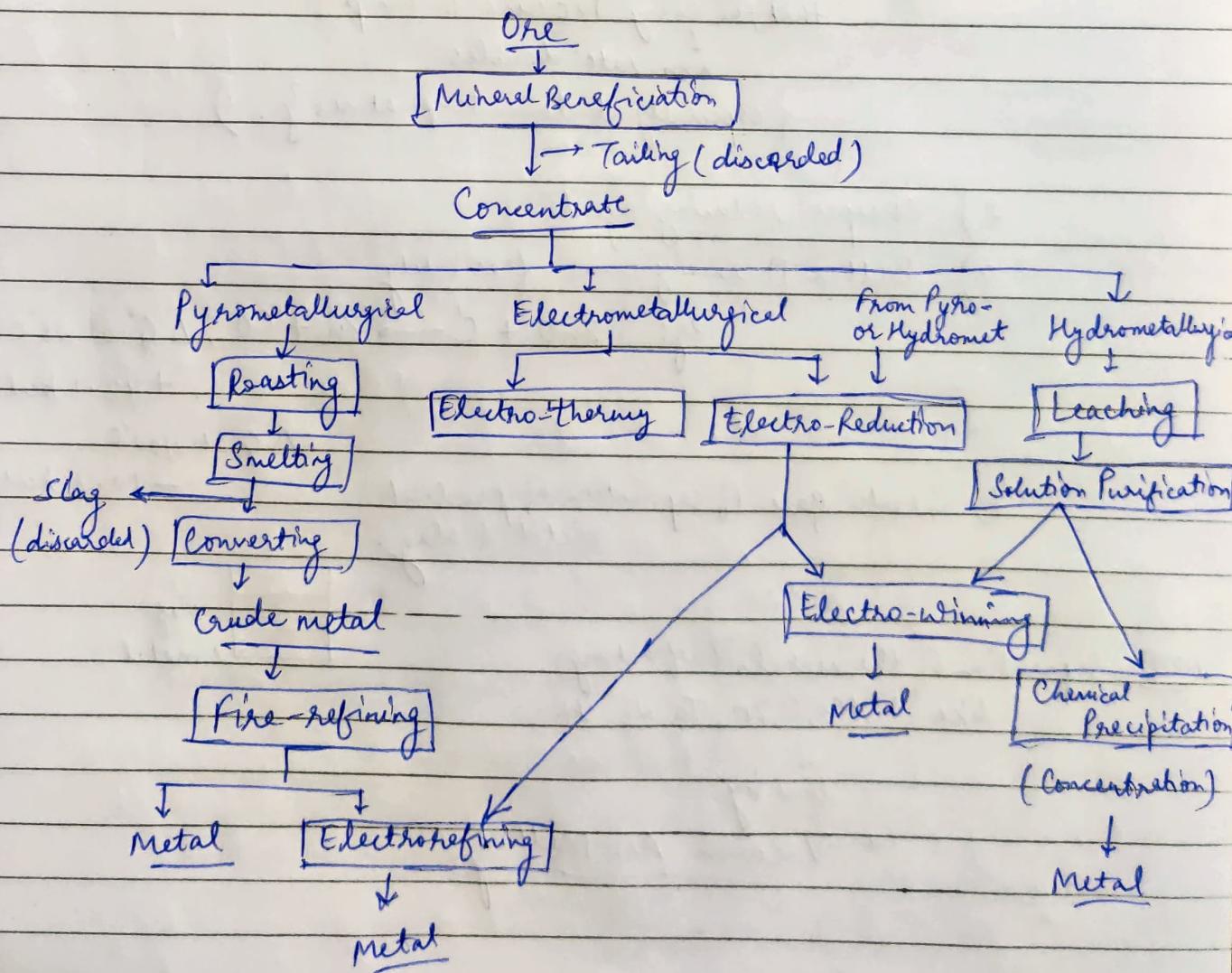
Pyromet - Hydromet - Electromet

Al - Hydro-Electro

NOTE: Due to high melting pt. of  $\downarrow$   $\text{W}, \text{Mo}, \text{Ti}, \text{Zr}, \text{Ta}, \text{Nb}$   $\uparrow$ , called Refractory metals  
 they cannot be melted & thus Pyrometallurgy  
 Cannot be used to separate them  
 \* Thus, they are expensive (even though eg:  $\text{Ti} \rightarrow$  relatively abundant in Earth's crust)  
 { & they are also v-useful? }

## LECTURE 19 (16/02/2023)

### 78] Treatment of Ores by various Extractive Metallurgy Roots



## 79] Pyrometallurgical Extraction of metals

Based on chemical & physical changes of ore  
i.e. melting of ore layers of ore  
By heating ore/concentrate to 500 - 2000 °C temp.

cheap & root / technique  
& also most versatile method

### Advantages of Pyrometallurgy:

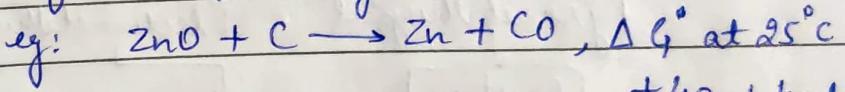
1) High rxn. rate

(it is estimated that for every 10°C rise in temp rxn. rate doubles

{especially at lower temperatures}.)

2) Cheaper reducing agents

3) Better Thermodynamic feasibility

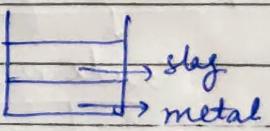


+43.1 kcal

$\Delta G^\circ$  at 1100°C

-10.2 kcal

4) Greater ease of separation of product metal & slag.



NOTE: Separation of the metals (refractory) like W, Mo, Ti, Zr, Ta, Nb, etc.

done by

\* Vacuum Arc Melting

## 80] Unit Processes of Pyrometallurgy

(i) Drying (may or may not be necessary)

↓  
done by  
heating the  
minerals  
are a little  
above boiling temp.

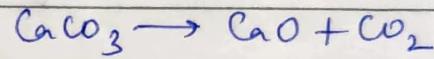
but it is necessary  
after mineral  
beneficiation, to remove  
moisture.)

↓ (i.e.  $> 100^{\circ}\text{C}$ )

process carried out  
in a Rotary kiln

(ii) Calcination : Initially it meant

↓ actual definition



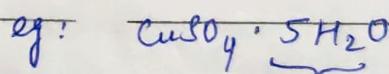
It is the process  
where the solid is  
heated to

(decomposition  
of calcium  
carbonate)

drive off chemically bonded  
volatile elements.

water of  
crystallization

↓  
The purpose of  
calcination  
is to make the  
product more  
reactive.



↓  
this  $\text{H}_2\text{O}$  is  
chemically  
bonded

(e.g.  $\text{CaCO}_3$  doesn't react  
with water)

↓  
Calcination  
required  
to remove

(& cannot simply  
be removed  
by heating  $> 100^{\circ}\text{C}$ )

But  $\text{CaO}$  vigorously reacts with  
 $\text{H}_2\text{O}$

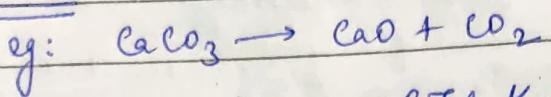
to form  $\text{Ca}(\text{OH})_2$ )

eg: Bauxite  $\rightarrow$  calcination

removes not only water of crystallization  
but also oxide atoms which  
are not needed.

## LECTURE 20 (17/02/2023)

### 81] Calcination



$$\text{Now, } \Delta G = -RT \ln K \xrightarrow{\text{eqbm. const.}} K = \frac{a_{\text{CaO}} \cdot b_{\text{CO}_2}}{a_{\text{CaCO}_3}} = b_{\text{CO}_2}$$

$$\Rightarrow \Delta G = -RT \ln b_{\text{CO}_2}$$

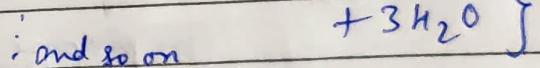
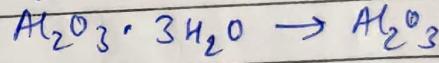
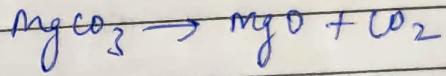
$$\therefore \text{At 1 atm} \Rightarrow \Delta G = 0$$

$$\text{Using formula for } \Delta G \Rightarrow 55000 - 44T = 0$$

$$\Rightarrow \therefore \text{Decomposition Temperature, } T = 970^\circ\text{C}$$

\* Temperature, for  $\text{CaCO}_3$

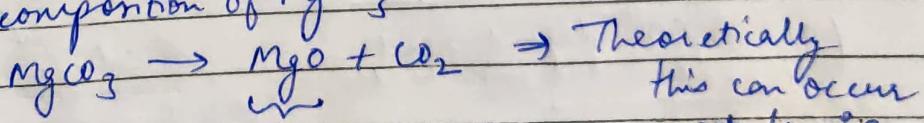
{ Similarly same can be done for



{ and so on }

NOTE:  $\text{MgCO}_3 \rightarrow$  called Magnesite

Now, in decomposition of  $\text{MgCO}_3$ :



↓  
called  
Periclase

this can occur  
at  $400^\circ\text{C}$

↓

But in reality it  
is done at

$1000^\circ\text{C}$

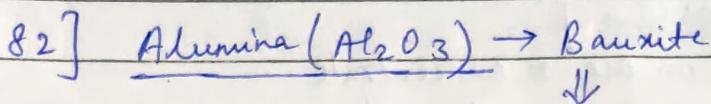
Because  
we want  $\rightarrow \text{MgO} \rightarrow$  stable  
to be crystalline

{ This is why even though  
 $\text{CaO}$  is widely available  
 $\text{CaO}$  is not used to make refractory bricks }

{  $\text{CaO}$  is not stable &  
inert  
it eventually reacts  
with  $\text{O}_2$  from air }

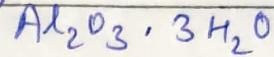
i.e.  
it should not react with  $\text{O}_2$   
etc.

{ Structure  
which should be Inert }

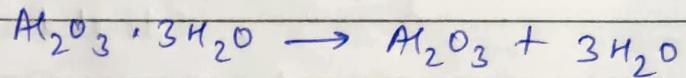


Subjected to grinding & then dissolved  
 $\downarrow$   
 in autoclave

eventually we obtain



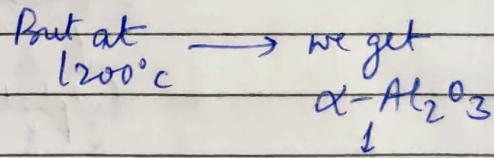
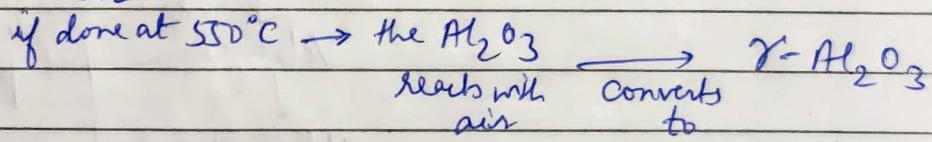
Heating is performed to  
 remove  $\text{H}_2\text{O}$ :



Theoretically can occur at  
 $\downarrow$   $550^\circ\text{C}$

But actually done at  
 $1200^\circ\text{C}$

This is bcz



which is Inert

83] Roasting

done either  
 prior to smelting  
 or  
 prior to leaching

not necessary for  
 all ores  
 it is done  
 generally  $\Rightarrow$  to reduce the  
 oxide ores  
 for other processes

But some ores  
 occur in Sulphide  
 form

(e.g:  $\text{CuFeS}_2$ ,  $\text{PbS}$ , etc.)

These need  
 to be heated  
 in  $\text{O}_2$  to  
 convert to  
 oxide

Definition: It is a process of heating an ore or concentrate in a suitable atmosphere, below fusion point to make it chemically more suitable for subsequent treatment

{ i.e. we convert sulphide to a form where it can be treated more easily }

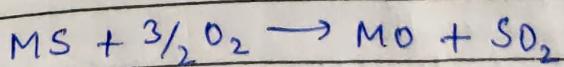
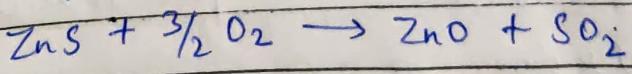
[ & this should happen below fusion pt.  
because we don't have to melt it ] }

It consists of:

Oxidation  
↓ &  
Volatilization  
↓ &  
Chlorination  
↓ &  
Sulphation  
↓ &  
Sintering

} different processes that may be used  
(these are NOT steps)

### (i) Oxidizing Roasting

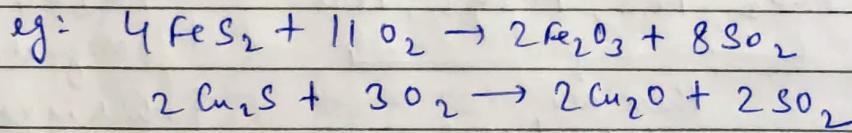


If sulphur completely removed from sulphide  
↓  
called "Dead Roasting"

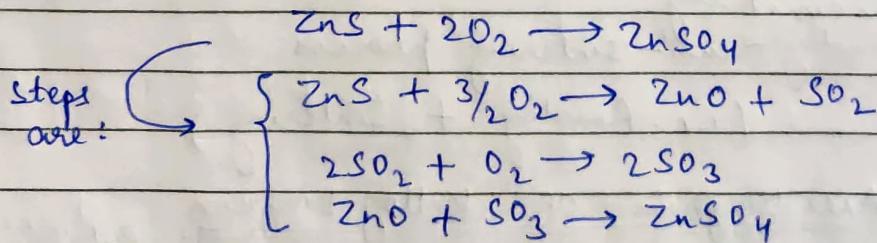
Sometimes heating/combustion process only initially needs to be started by heating at one place

↓  
+ bcz of exothermic process  
the rxn. becomes self-sustaining  
⇒ called Autogenous

Sometimes the heat becomes too high that in fact we need to cool it slightly (to prevent melting)  
i.e. we don't need more fuel to heat

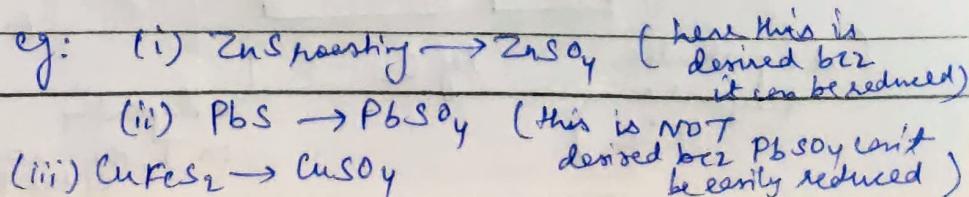


(iii) Sulphating roasting → This is an indirect rxn.

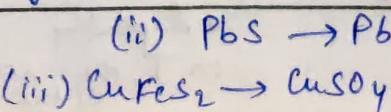


This happens if partial pressure of  $\text{SO}_3$  or  $\text{SO}_2$  is high

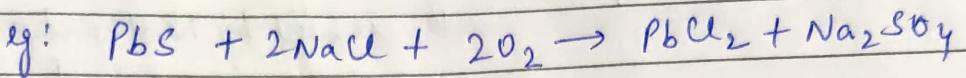
since probability of this process increases



This is also desirable ← (ii)  $\text{PbS} \rightarrow \text{PbSO}_4$  (this is NOT derived bcz  $\text{PbSO}_4$  can't be easily reduced)

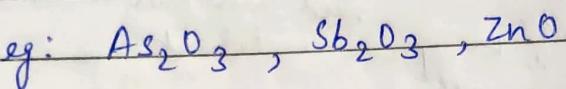


### (iii) Chloriding Roasting



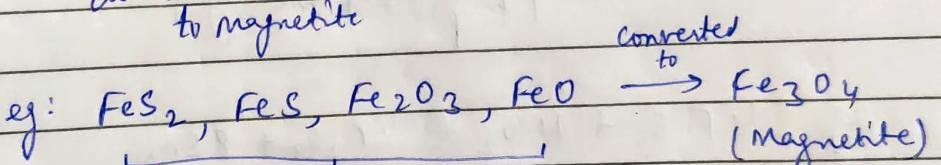
### (iv) Volatileizing Roasting

done to remove  
volatile oxides  
from ore  
(to purify it)



### (v) Magnetizing Roasting

done to convert  
to magnetite



there are  
impurities

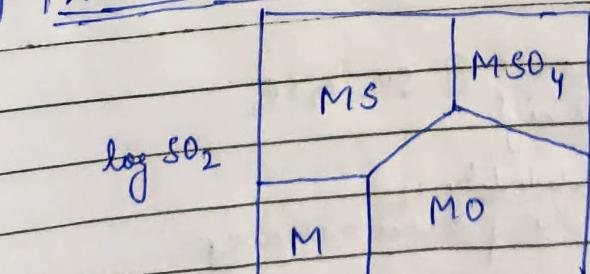
{ which is easy to  
remove }

### (vi) Blast Roasting

this is essentially  
roasting - cum - sintering process

(i.e. Roasting + Sintering)

## 84] Predominance Area Diagram OR Kellog Diagram



(at a particular  
temperature  
 $T^\circ\text{C}$ )

this diagram is  
plotted to  
know stability  
of diff. forms

Kellog-Basse  
diagram

to know when  
roasting should  
be done

dependency  
on  $T$ , the various  
phases will change

## 85] Smelting

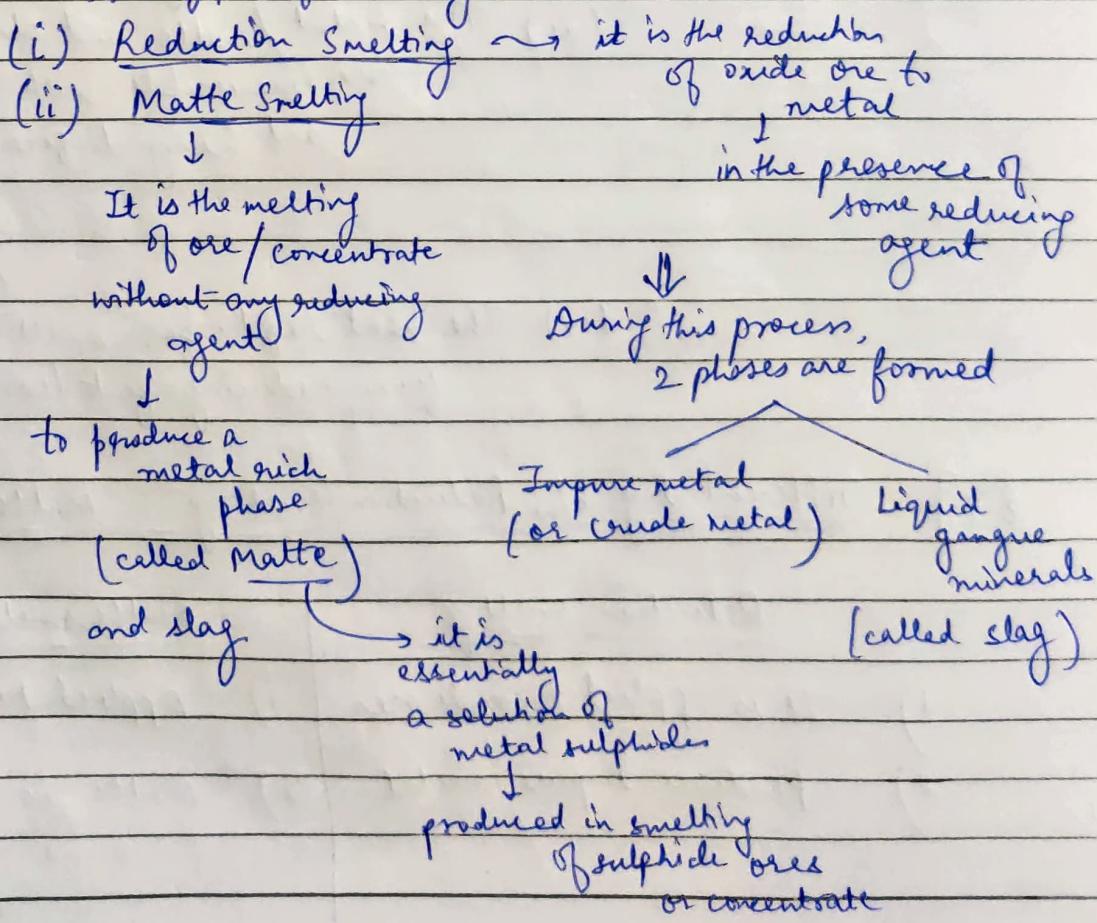
\* Need to be precise with the terms used in this definition

It is the process of metal extraction by chemical change to make separation of metal (or metal ~~oxide~~ phase) from the gangue minerals in the liquid state

OR

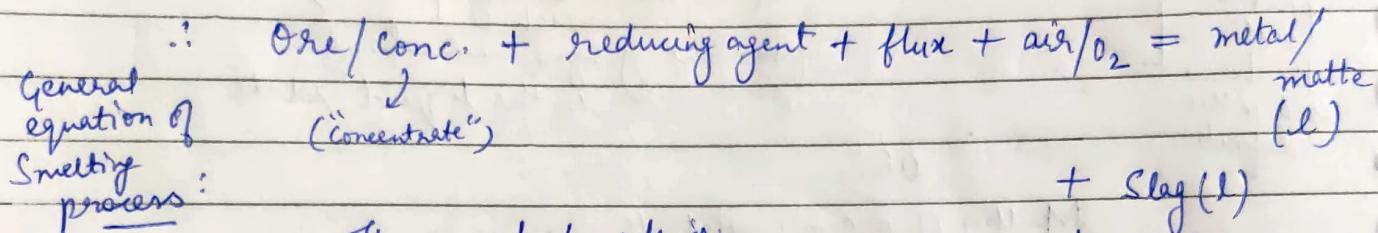
Smelting of ore or concentrate with some chemical changes to separate metal from gangue

There are essentially two diff. types of Smelting :



## LECTURE 21 (21/02/2023)

86] Flux is added during smelting  
↓  
to reduce melting point  
& allow slag formation



The general characteristics of smelting process are:

- (i) material to be smelted in solid form
- (ii) Product of smelting in liquid form
- (iii) The metal/matte and slag are immiscible with each other, and having difference in density  
∴ they get separated
- (iv) The heat reqd. for smelting comes from reducing agent/conc. or external sources

## 87] Differentiating b/w Reduction smelting & Matte smelting

### Reduction smelting

- 1) It is applied to oxide ores
- 2) Produces impure metal

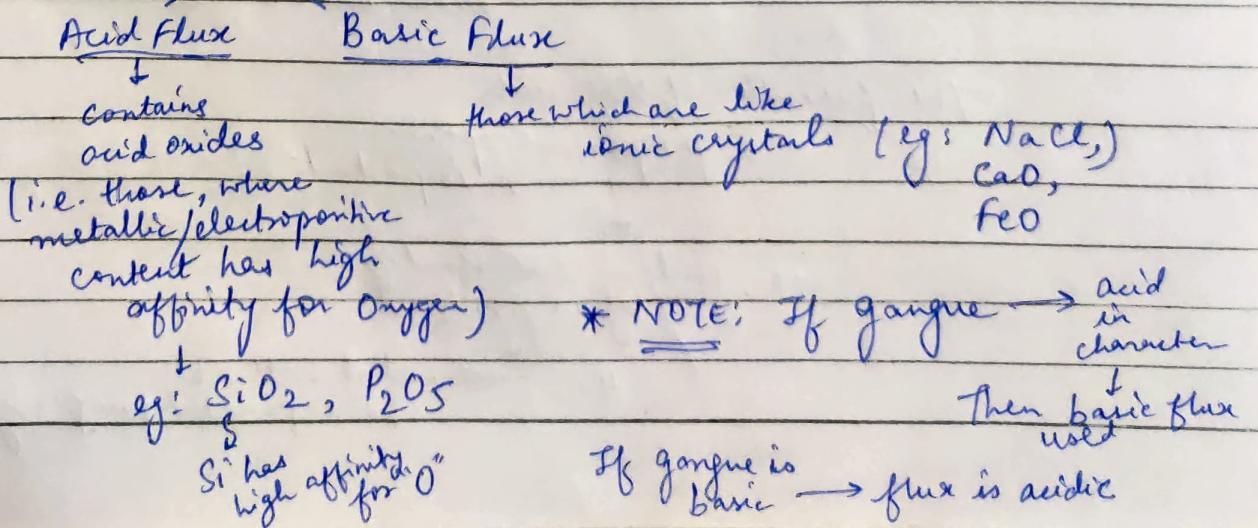
### Matte smelting

- 1) Applied to sulphide ores
- 2) Matte is the product of smelting

- |   |   |
|---|---|
| 3) There is use of reducing agent, most commonly carbon | 3) No reducing agent is used.   |
| 4) Usually it is carried out in a blast furnace         | 4) Can be done either in a reverberatory furnace, or in flash furnace |
| 5) Can be done in electric furnace                      | 5) Can be done in electric furnace                                    |
- this was done long ago (now almost never done)

88] Flux: In smelting → usually gangue minerals have high melting pt. ( $\approx 2000^\circ\text{C}$ )  
 ∵ We use flux that cannot be melted normally  
 Combines with gangue ↓ to form slag with lower melting pt. than gangue  
 Also, the flux decreases the viscosity of the gangue as well (improves flowability)

### 89] Types of Flux



There are also some types of  
Neutral flux

eg:  $\text{CaF}_2$ ,  $\text{Na}_2\text{SiO}_4$

↓  
eg. Used in fused salt electrolysis.

90]	<u>Flux</u>	<u>Composition</u>	<u>Nature</u>
Silica	$\text{SiO}_2$	Acidic	
Limestone ( $\text{CaO}$ )	$\text{CaCO}_3$	Basic	
Dolomite	$\text{CaCO}_3 \cdot \text{MgCO}_3$	Basic	
Fluorospar	$\text{CaF}_2$	Neutral	

91] Slag: It is a fusible top layer product ( i.e. it has low density )

Has:  
Low density,  
low melting pt.  
& low viscosity  
obtained by combination of gangue materials with the added flux

\* Can also be called: "melted flux impurities"

In general they are composed of silicates combined with basic oxides

The formation of slag with proper composition is v. important

bcz, unless satisfactory slag is produced  
↓  
the pure metal will not be separated properly

92] Properties of slag reqd. :

The specific gravity

(i)

of slag should be much lower than that of metal

(to allow it to separate clearly)

(ii) It should be fluid enough for easy separation

i.e.

(otherwise a lot of metal will be entrapped)

(iii) Viscosity of slag should be less

↓

Should be immiscible

↓ (otherwise clear separation will not occur)

depends on composition of the slag

93] Some applications of Slag

↓ Used for construction

of roads,

making cement, etc.

If P (or  $P_2O_5$ ) content is high → the slag is used for making fertilizers

94] Principles of Smelting

Classification:

A. Reduction smelting

; B. Mattre Smelting

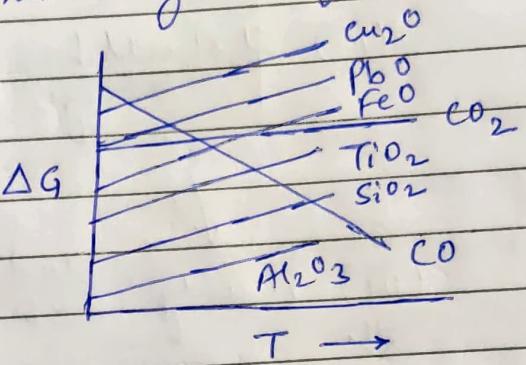
(i) Carbothermic Smelting

↓ done using carbon  
(carbon is v. readily available)

Reasons for use:

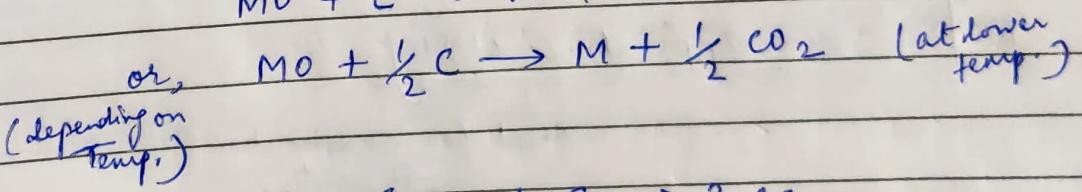
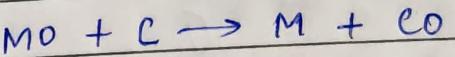
- (a) Carbon is readily available
- (b) Easy to use
- (c) The products ( $\text{CO}$  &  $\text{CO}_2$ ) are gases & thus there is no residue if pure reaction occurs

(d) From Ellingham diagram:

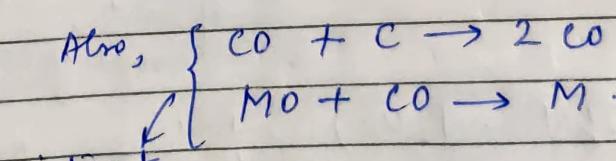


( $\therefore \text{CO}$  is highly effective reductant as  $T$  increases)

For reduction with carbon:



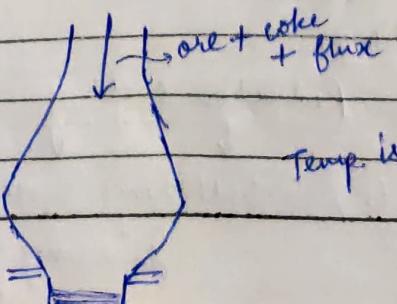
(depending on Temp.)



indirect mechanism of reaction

↓ this will again react with C to form CO

This occurs in Blast Furnace



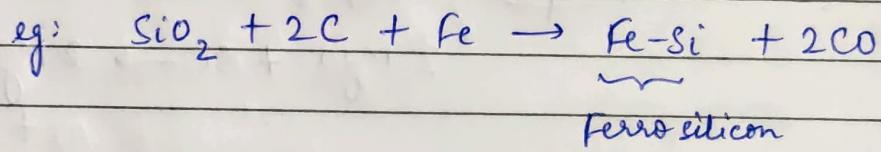
Temp. is  $< 1600^\circ\text{C}$

( $\therefore$  This is gas-solid rxn.)

95] For metals like  
 $\text{MnO}_2$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{SiO}_2$  ( also Vanadium oxide )  
 have high melting pt.  
 $(\sim 1800^\circ\text{C})$

∴ Cannot be produced in blast furnace ( Since limit is  $\sim 1500 - 1600^\circ\text{C}$ )

∴ Instead they are produced in \* Electric furnace  
 (can go to temperatures up to  $2000^\circ\text{C}$ )



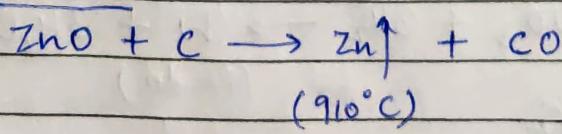
Similarly, Ferro-manganese & Ferro-Ti also produced like this

Another advantage of addition of Fe

(i) it dries the material

(ii) & further it helps improve the thermodynamic preferability of the reaction.

NOTE: Volatile Metals



needs to be  
condensed

by Shock cooling

