HANDWRITTEN NOTES OF

(MATERIAL SCIENCE)

BY

ENGGBUZZ.COM

Material science:

Ref.
IES (1). material science & Engg.
— Callister
(2). material science
→ I.P. Singh.

- Relationship between structure and properties of Engg. materials

manufacturing processes → Structure
Structure → Material Science
↓
properties → Material Science
↓
Functional performance

Inside materials → molecular level Bonding, Ionic level Bonding

- Properties:- Quantiative indices (Expressed as) of behaviour (or responce) of a material subjected to ~~external~~ external stimulli
↓
diff. types of stimulation, like optical, chemical mechanical magnetic, electrical – different type properties.

Structure : 3 levels.

1. microstructure (>100X)
2. macrostructure (<100X)
3. crystal structure.

→ is defined as internal structure of a material which can be observed under the metallurgical microscope at high magnification of order of ($\geq$ 100X).

metallur → used for opaque samples

→ microstructure consists of grains, grain boundary, phases, phase boundary & grain orientation lustre.

- Grains, Grain Boundary
- phases, phase Boundaries
- Grain orientation lustre.

Ferrite :- ver soft and weak

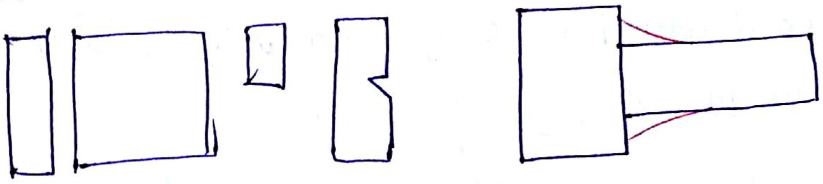
Austenite: - Hard and ductile

ee **Martensite**: - Hard and Brittle.

Macrostructure :-

Defined as External Geometrical characteristics of a material which can be observed with naked eye or under the microscopic at lower magnification of order of (< 100X)

Microstructure :-



↳ properties dependents on defects in & Intermolecular bonding.

Crystal structure :-

⇒ To get stability, liquid metal crystallises into solid state by reduced minimising (potential energy of molecules)

atomic arrangement → Generally – Simple
– Body centered
– face centered
– End centered.

14 Bravais Lattice → low energy lattice, other 14 maybe are unstable at those condition.

Engg. materials – canbe classified in two ways

Tho

Crystalline materials

→ Exhibits 3-Dimensional long range periodicity of arrangement of atoms/ ions/ molecules in the internal exto structure.

① atomic solids (atoms)
↓
Ex: metals

② ionic level Bonding
↓
ionic solids
Ex: ceramics

③ molecular level Bonding
↓
molecular solids
↓
Ex: crystalline polymers.

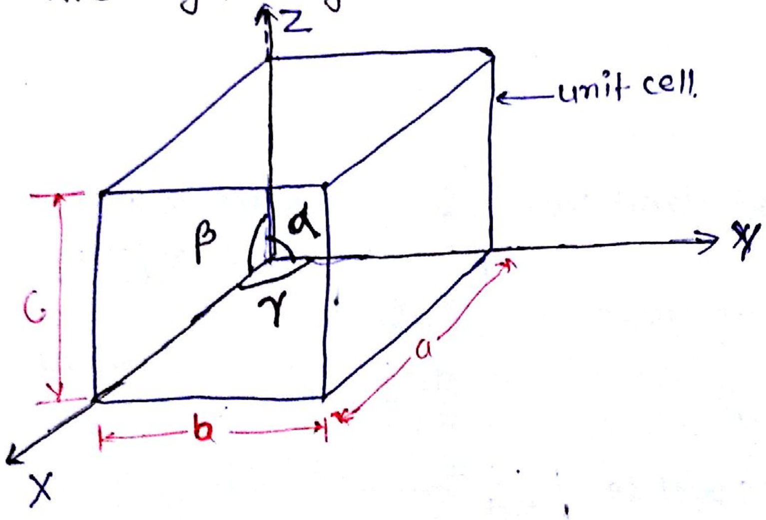
amorphous materials

→ do not exhibit regular or repeated, orderly arrangement atoms / ions/ molecules.

Ex: Glass, Rubber, plastics etc.

- molten state ——→ solid state
  - by rapid cooling → amorphous materials
  - by gradual cooling → crystalline materials

- Crystalline materials are grouped under '7' crystal systems (Basic shape of unit cell) & these crystals systems are intern-classified in '14' Bravais lattices. (Atomic arrangement within a unit cell).



— 7 crystal systems
↓
— 14 Bravious lattices
↓

⇒ a, b, c → lattice parameters denotes the dimensions of unitcell.

⇒ X, Y, Z, → Crystal directions

⇒ α, β, γ → Inter axial angles

- The crystall structures of unknown material can be determined by X-Ray diffraction technique.

⇒ macrostructure > microstructure > crystal structure.

***

Crystal system	Geometry	Bravais lattices.
cubic	$a=b=c$; $\alpha=\beta=\gamma=90^\circ$	SC, BCC, FCC
Tetrogonal	$a=b\neq c$; $\alpha=\beta=\gamma=90^\circ$	ST, BCT
OrthoRhombic	$a\neq b\neq c$; $\alpha=\beta=\gamma=90^\circ$	SO, BCO, FCO, ECO
Rhombohedral	$a=b=c$; $\alpha=\beta=\gamma\neq 90^\circ$	SR
Hexagonal	$a=b\neq c$; $\alpha=\beta=90^\circ$ $\gamma=120^\circ$	SH
Monoclie	$a\neq b\neq c$; $\alpha=\gamma=90^\circ\neq\beta$	SM, ECM
Triclinic	$a\neq b\neq c$; $\alpha\neq\beta\neq\gamma\neq 90^\circ$	ST,

Crystal systems (Basic shape of unit shell) & Bravais lattices (atomic arrangement)

↓

constitute

↓

⇒ Crystal Structure ⇐

⇒ Crystal structure can be changed by Heat treatment and effect of alloying elements.

FCC austenite → BCC pearlite → BCT martensite

(1) Unit cell :- defined as smallest representative group of atoms which when repeated in all the crystallographic direction for a infinite no. of times results in the development of crystal ~~lat~~ lattice.

(2) Cry. lattice A crystal lattice is defined as 3-D dimensional arrange-ment of lines in space. It is also called as a line lattice.

(3) space lattice :- 3D arrangement of points in space. it is also known as point lattice.

(4) Primitive cell : A simple cubic unit cell having atoms only at the corners →

(5). lattice parameters :- Distance b/w centers of neighbouring corners atoms.

Crystal Structure characteristics :-

Crystal characteristics	Structure BCC	FCC	HCP
a to r relations	$a = \frac{4}{\sqrt{3}} r$	$a = \frac{4r}{\sqrt{2}}$	$a = 2r$
Av. no of atoms (Nav).	$= \frac{8}{8} + \frac{0}{2} + \frac{1}{1}$ $= \boxed{2}$	$= \frac{8}{8} + \frac{6}{2} + \frac{0}{1}$ $= 1 + 3 = \boxed{4}$	$= \frac{12}{6} + \frac{2}{2} + \frac{3}{1}$ $= \boxed{6}$
Coordination Number	= 8	= 12	= 12
Atomic packing factor	0.68	0.74	0.74

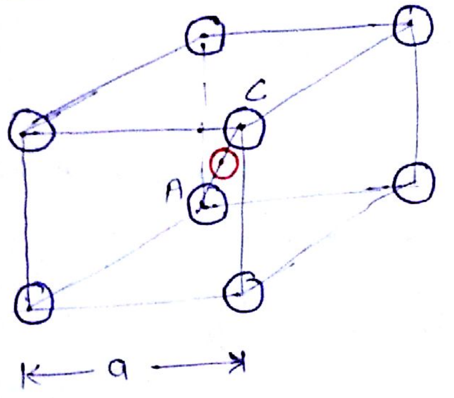
***: Only crystalline materials are used 90-99%

→ Only metals are to be considered - thus BCC, FCC, HCP

└ crystallisation into Body centr, Hexagona

let a = lattice parameter
r = atomic radius.

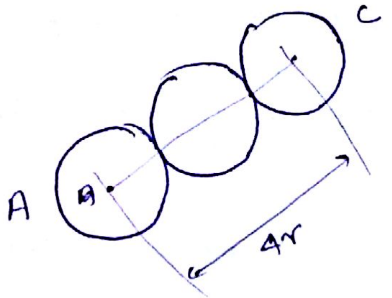
BCC :-



→ one extra ~~element~~ atom at centre of body diagonals

⟹ AC = Body diagonal of unit cell

⟹ $AC = a\sqrt{3}$



$$\Rightarrow a\sqrt{3} = 4r$$

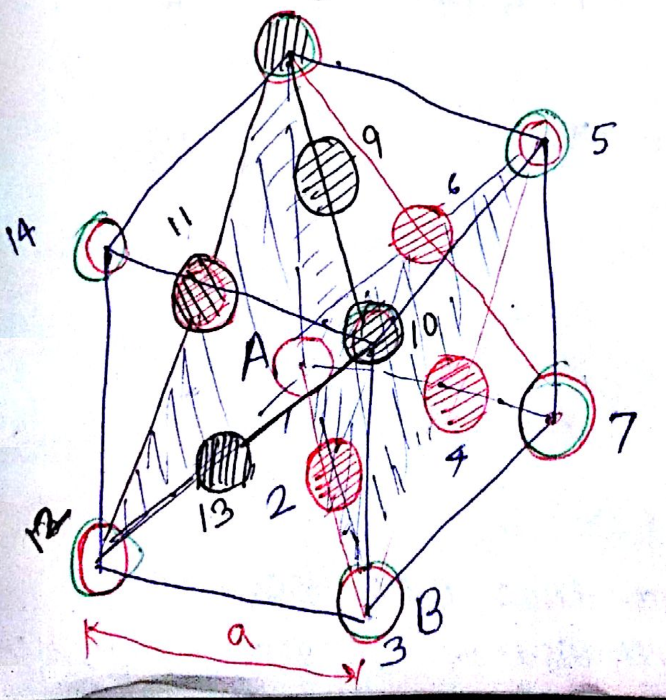
$$\boxed{a = \frac{4r}{\sqrt{3}}}$$

Example: Fe except (910 - 1400°C)
W, Cr, V, Mo, Ta, Na, Li etc.

BCC elements → generally hard & Brittle.

addition of BCC element to increase the properties (hardness ↑, strength ↑ wear resistance ↑,

FCC :-



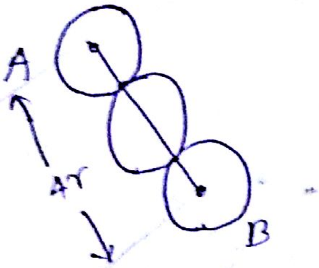
⇒ AB = face diagonal of unit cell

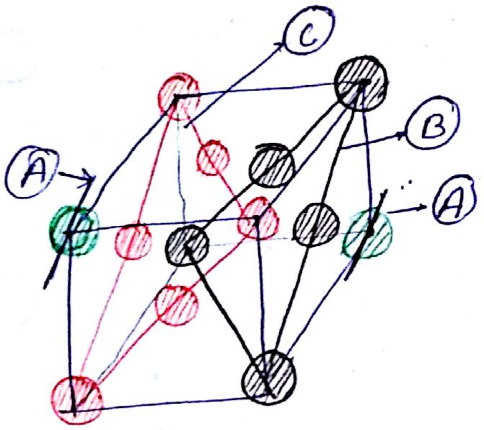
AB = $a\sqrt{2}$

AB = 4r

$a\sqrt{2} = 4r$

$$\boxed{a = \frac{4r}{\sqrt{2}}}$$





Example :- Fe in range of [910-1400°C]

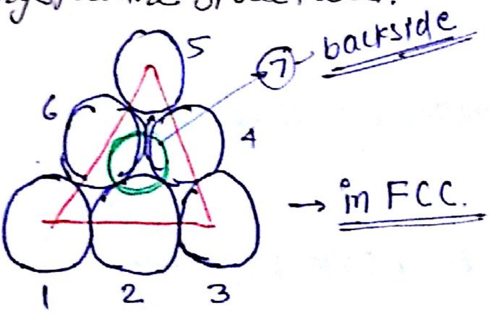
Al, Cu, Ni, Pt, Au, Ag, Pb

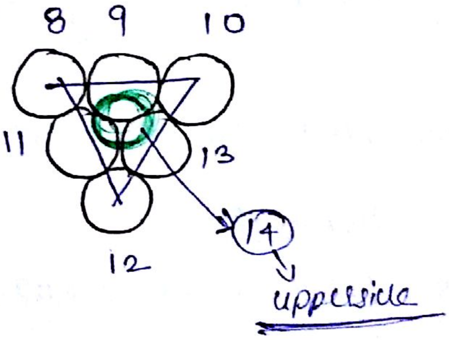
→ str

• FCC elements are "strong & Ductile"

→ Toughness increase due to addition of "FCC". [area load-deflection increases].

⇒ Stacking sequence :→ defined as the sequence of arrangement of atomic planes one above the other, in order to result in stability to the crystalline structure.





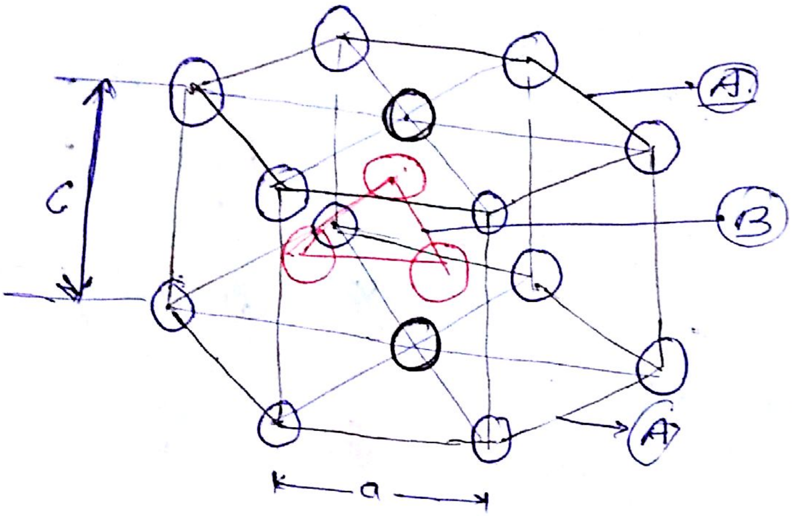
Start ↓ ↓ S

⇒ plane A-B-C-A-B-C-A-.............- ∞ constitute crystal structure [stacking sequences will be ABCABCABCA ...... ∞]

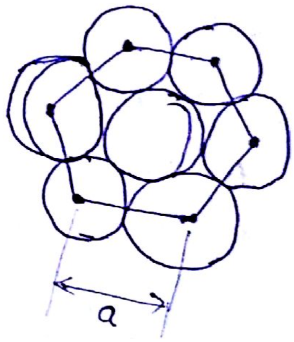
↑ ↑

HCP:-

c = height of the unit cell



⇒ atomic arrangement



⇒ $\boxed{a = 2r}$

⇒ Stacking sequence ⇒ ABABABA .... ∞

⇒ for ideal HCP structure like Mg $\boxed{c/a = 1.633}$

Example :- Mg, Zn, Ti, Zr, Be, Cd, CO, Be,

⇒ HCP elements are "generally less ductile compared to FCC elements".

⇒ HCP → less shear (due to weak bonding) → easy shearing so used as solid lubricant (Graphite).

⇒ Because of HCP " Be and Cd replaces the Pb in bearings" (babbit materials).

Avg no. of atoms

- defined as the no. of atoms which originally belongs to particular unit cell, calculated by following :.

$$\boxed{N_{av} = \frac{N_c}{8} + \frac{N_f}{2} + \frac{N_i}{1}}$$ [for cubic unit cells]

$$\boxed{N_{av} = \frac{N_c}{6} + \frac{N_f}{2} + \frac{N_i}{1}}$$ (for HCP only)

N_c = no. of atoms at corners

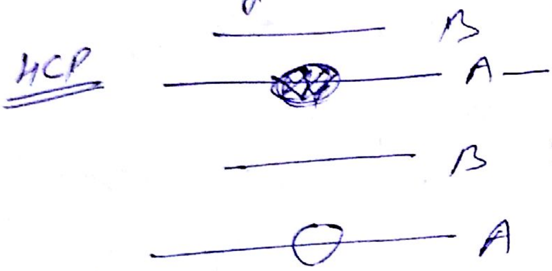
N_f = no. of atoms at face centre

N_i = no of ~~atoms~~ interior atoms (inside the unit cell volume)

Co-ordination no.

⇒ defined as the number of nearest and equidistant atoms surrounding an atom under consideration.

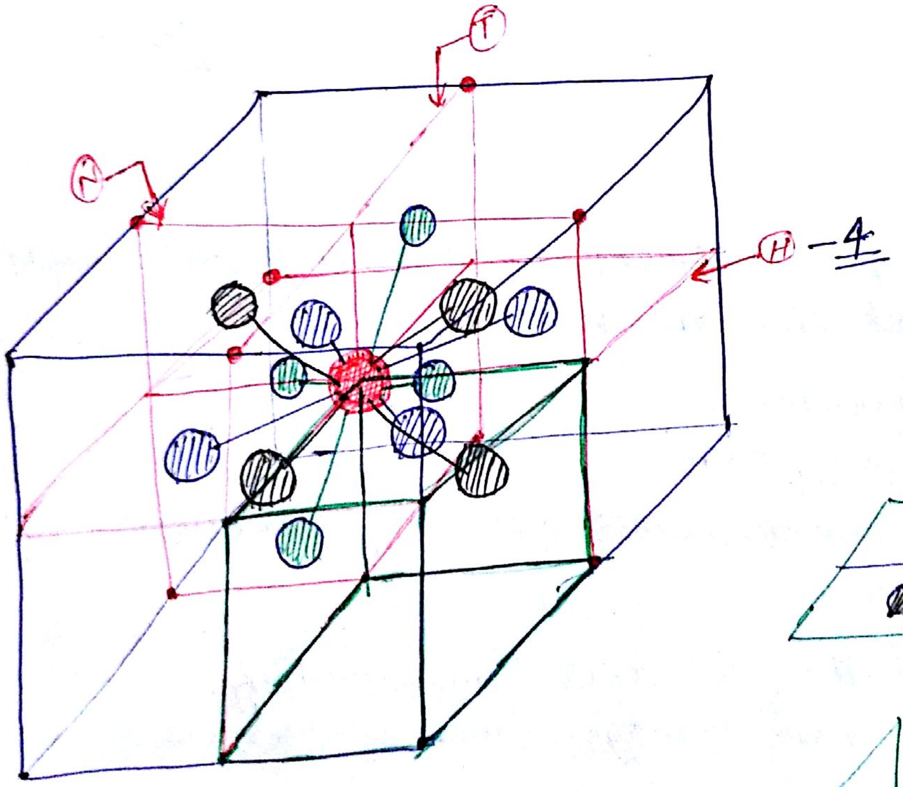
HCP

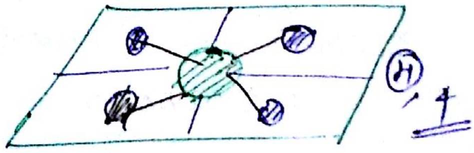


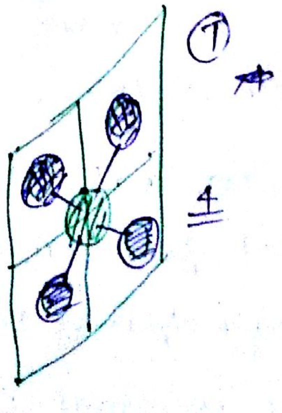
= 3+6+3

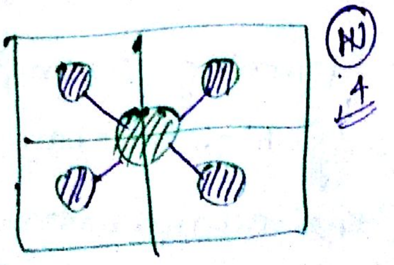
= 12 atoms nearest to an atom.

To find coordination no. of FCC









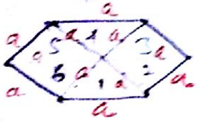
Atomic Packing factor:-

⇒ defined as "The ratio of volume occupied by the avg. no. of atoms to the volume of unit cell."

$$APF = \frac{\text{volume occupied by avg. no. of atoms}}{\text{volume of unit cell}}$$

$$APF = \frac{\frac{4}{3}\pi r^3 \times N_{av}}{\text{Volu. of unit cell}} = \frac{\cdots r^3}{\cdots r^3} = \text{numelical value}$$

⇒ 6 equilateral Traiangle



for BCC

$$\text{Volu. of unit cell} = a^3 = \left(\frac{4r}{\sqrt{3}}\right)^3$$

FCC

$$\text{volume of unit cell} = a^3 = \left(\frac{4r}{\sqrt{2}}\right)^3$$

HCP

volume of unit cell

$$= \text{base area} \times \text{height}$$

$$= (\quad) a^2 \times c$$

$$= (\quad) (2r)^2 \times (1.633) a$$

$$= (\quad) (2r)^3 \times (1.633)$$

Allotropy :-

- defined as tendency of an element to exist in different crystalline structure at different temp and pressures.

→ allotropic transformation causes

(1) Changes in density, volume

(2) change in cordination number → (index of stiffness) E will ~~the~~ change

(3). more value of APF – less voids – more ductility.

more voidage – more brittleness

→ solubility ↑ with voidage.

Coordination no. indicates the (Bonding strength of atoms)

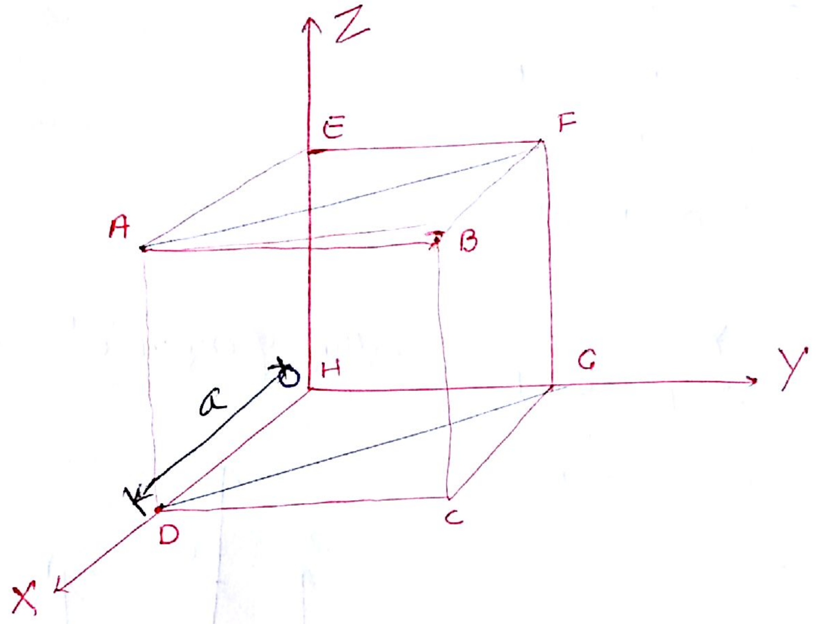
⇒ as material goes in state of high energy (Due to application of external load), the coordination helps to retain the original Bond length distance (after the removal of external load)

Miller indices of planes:-

Rationalised Reciprocal of fractional intercepts, taken along the three ~~christ~~ crystallographic direction and written inside parenthesis without a seperating comma between them.

→ Indicated by (hkl)

→ ~~smallest~~ always expressed as smallest integers.



→ origin can be at any corner.

Ex1 plane ABCD;

	X	Y	Z
(1) Interceps	1	∞	∞
(2) Reciprocal	1	1/∞	1/∞
(3) Ratiolisation	1	0	0
(4) Indices	(1	0	0)

along x-axis ⇒ $OD = a = \underline{1}\,a$

Ex2 AFGD

	X ,	Y ,	Z
(1). intercepts →	1	1	∞
(2). reciprocal →	1	1	0
(3) Rationialisation →	1	1	0
(4). Indices →	(1	1	0)

Ex: Plane DGE

	x	y	z
(1). Intercepts	1	1	1
(2) Reciprocal	1	1	1
(3) Rationalisation	1	1	1
(4). Indices	(1	1	1)

Ex. 4. plane BFGC

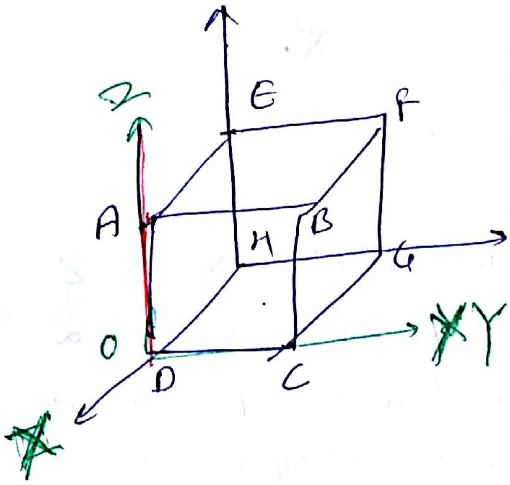
	x	y	z
→ intercepts	∞	1	∞
→ Reciprocal	0	1	0
→ Rationalisation	0	1	0
→ indices	(0	1	0)

Ex5 planee EFGH

	X	Y	Z
intercept	0	0−1	0−1
Reciprocal	1/0	$\frac{1}{0-1}$	$\frac{1}{0-1}$
Rationalisat	∞	---	---
Indices	(∞	----	---)

$\underbrace{(\infty}_{\text{not defined}}$

⇒ Shifting of origin 'O' at point 'D'



	X	Y	Z
intercept	−1	∞	∞
Reciprocal	$\frac{1}{-1}$	$\frac{1}{\infty}$	$\frac{1}{\infty}$
Rationalisation	$\bar{1}$	0	0
Indices	~~(−1~~	~~0~~	~~0)~~

$(\bar{1}, 0\ 0)$

⇒ Characterstic of miller indices of plane :-

(1) when a plane is parallel to an axis, its miller index on that axis is zero

(2). Two parallel planes will have quantitatively the same miller indices.

(3) Two planes (h_1, k_1, l_1) & $(h_2 k_2 l_2)$ will be perpendicular if

$$\boxed{h_1 h_2 + k_1 k_2 + l_1 l_2 = 0}$$

(4) The angle 'θ' between two intersecting plane $(h_1 k_1 l_1)$ and $(h_2\ k_2\ l_1)$

$$\Rightarrow \boxed{\cos\theta = \frac{h_1 h_2 + k_1 k_2 + l_1 l_2}{\sqrt{h_1^2+k_1^2+l_1^2}\cdot\sqrt{h_2^2+k_2^2+l_2^2}}}$$

(5). planes having low incides are far away from the origin than the planes having high indices.

⇒ Let d = interplaner distance

$$d = \frac{a}{\sqrt{h^2+k^2+l^2}}$$

where $(h\,k\,l)$ are miller indices of given plane

⇒ interplaner distance denotes, distance between two parallel plane one of which is passing through the origin.

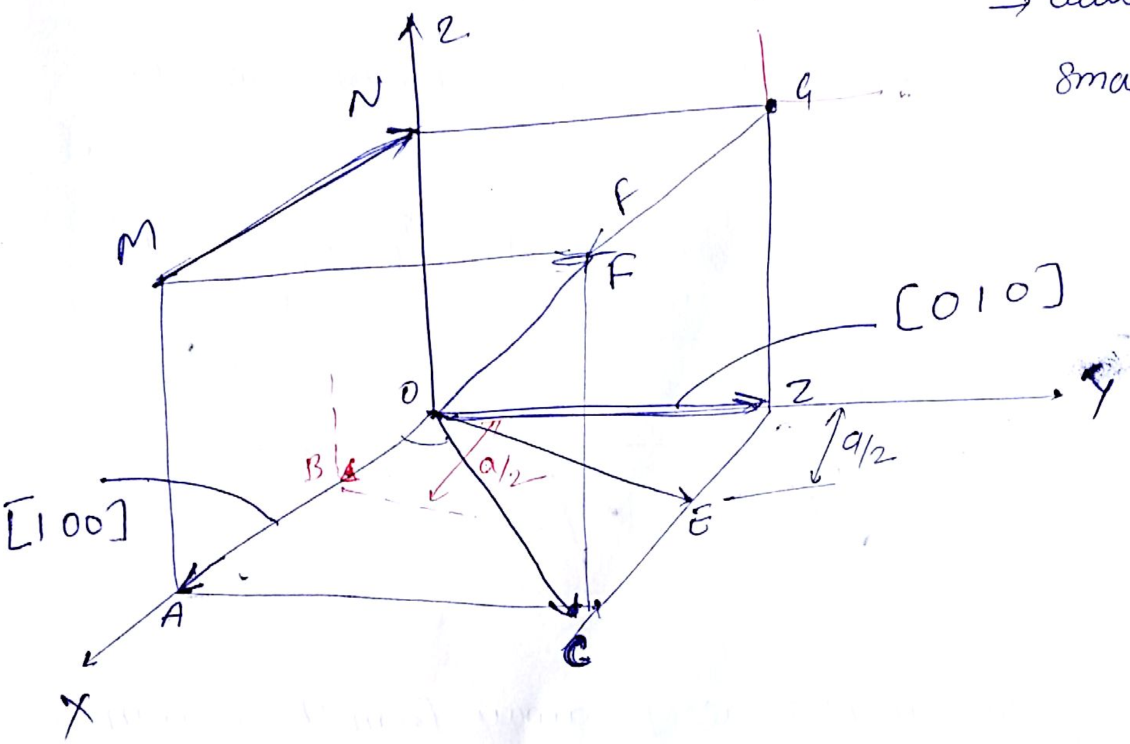
⇒ same as distance of given plane from origin.

$$\left[\begin{aligned} d_{(110)} &= \frac{a}{\sqrt{2}} = \frac{a}{\sqrt{2}} \\ d_{(220)} &= \frac{a}{\sqrt{8}} = \frac{a}{2\sqrt{2}} \\ d_{(330)} &= \frac{a}{\sqrt{18}} = \frac{a}{3\sqrt{2}} \end{aligned}\right.$$

- Millider indices of directions: - Indicated as $[u\,v\,w]$

rationalised components of a given direction vector taken along the 3 ~~crystalline~~ crystallographic directions.

→ always expressed as smallest integers.



$\vec{OA} = [\ OA$

$\vec{OA} = [1\ 0\ 0]$

$\vec{OB} = [\frac{1}{2}, 0\ 0] \Rightarrow \vec{OB} = [1\ 0\ 0]$

⇓
not proper

$\vec{OC} = [1\ 1\ 0]$

$\vec{OE} = [\frac{1}{2}\ 1\ 0] = [1\ 2\ 0]$

$\vec{OF} = [1\ 1\ 1]$

$\vec{GF} = [1\ 0\ 0]$

$\vec{FG} = [\bar{1}\ 0\ 0]$ $\vec{MN} = [\bar{1}\ 0\ 0]$

$\vec{ON} = [0\ 0\ 1]$

⇒ Characteristics of miller indices of directions:

(1) if a direction is perpendicular to an axis its miller indices on its that axis is zero

(2) Two parallel directions will same quantitatively same miller indices.

(3) Two direction $[u_1 v_1 w_1]$ & $[u_2 v_2 w_2]$ will be perpendicular if $\boxed{u_1u_2 + v_1v_2 + w_1w_2 = 0}$

(4). The angle 'θ' between two intersecting directions $[u_1 v_1 w_1]$ & $[u_2 v_2 w_2]$ is given by

$$\boxed{\cos\theta = \frac{u_1u_2 + v_1v_2 + w_1w_2}{\sqrt{u_1^2 + v_1^2 + w_1^2}\sqrt{u_2^2 + v_2^2 + w_2^2}}}$$

(5) The plane & the direction having same miller indices will be perpendicular to each other.

Density Calculation in ptar crystal structures:

There are three types of densities in crystal structures.

(1). Volume density: (ρ_v):

(2) planer density: (ρ_{pl}):

(3). Linear density: (ρ_l):

Volume Density:

Volume density is defined as $\rho_v = \frac{\text{weight of } N_{av.}}{\text{volume of unit cell.}}$

$$\boxed{\rho_v = \frac{N_{av.} \times \text{Atomic Wt.}}{\text{Volume of unit cell}}} \quad \left(\frac{\text{gram} \times \text{atoms}}{cm^3}\right)$$

(atoms) (gr/mole)

$$\boxed{\rho_v = \frac{N_{av} \times \text{Atomic weight}}{[6.023\times10^{23}] \times \text{vol. of unit cell}}}$$

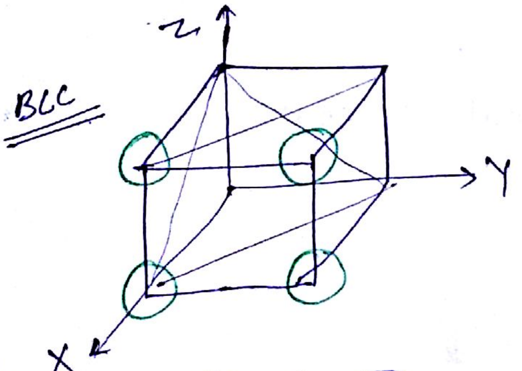
(atoms/mole) (cm^3)

- Planar pe density:-

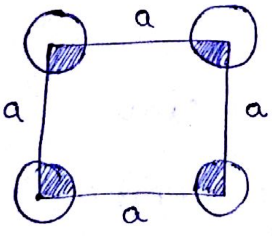
⇒ Planar density is defined as the ratio of no. of atoms whose centers are intersected by a plane to the area of the plane itself.

$$\boxed{\rho_{pla} = \frac{\text{no. of atoms}}{\text{Area of the plane}}}$$

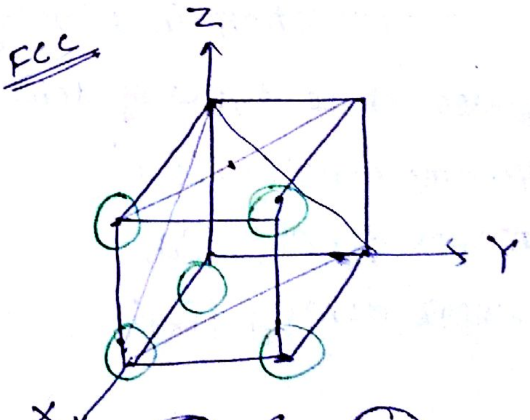
plane	BCC	FCC
(1,0,0)	$= \frac{1}{a^2}$	$\frac{2}{a^2}$
(1,1,0)	$\frac{2}{\sqrt{2}.a^2}$	$\frac{2}{\sqrt{2}.a^2}$
(1,1,1)	$\frac{1/2}{\sqrt{3}/2\,a^2}$	$\frac{2}{\frac{\sqrt{3}}{2}a^2}$

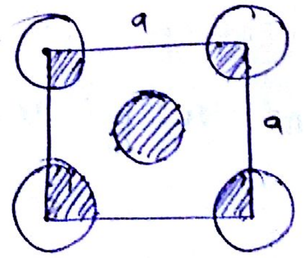


Plane (100)
2D—



no. of atoms intersected By plane $= \frac{1}{4}\times4 = 1$



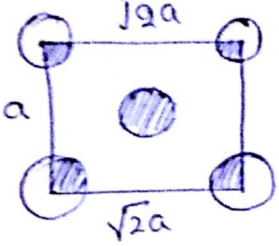


$=$ no. of atoms $= \frac{1}{4}\times4+1$

$= 2$

plane (1 1 0)

BCC



$area = \sqrt{2}.a^2$

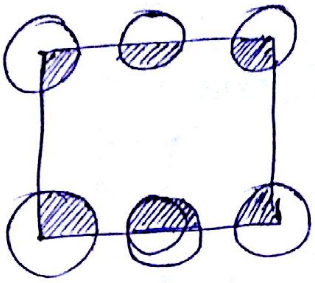
$=$

no. of atoms

$= \frac{1}{4} \times 4 + 1$

$= 1+1 = 2$

FCC

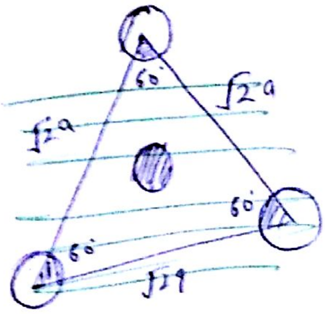


no. of atoms $= \frac{1}{4} \times 4 + \frac{1}{2} \times 2$

$= 1+1$

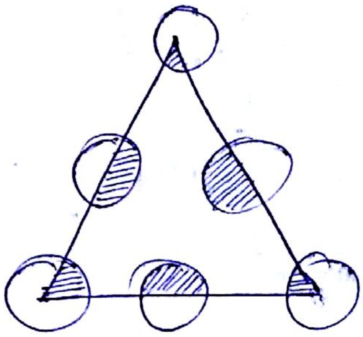
$= 2$

plane (1 1 1):



area of triangle

$= \frac{\sqrt{3}}{2} a^2$



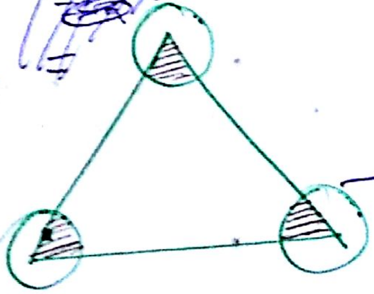
$= \frac{1}{6} \times 3 + \frac{1}{2} \times 3$

$= \frac{1}{2} + \frac{3}{2} = 2$

~~no of atoms~~

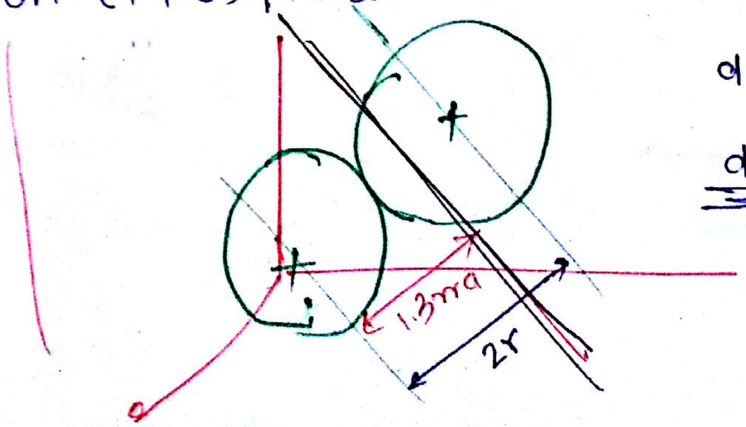
~~$= \frac{1}{6} \times 3$~~

BCC



$=$ no. of atoms $= \frac{1}{6} \times 3 = \frac{1}{2}$

Note the centre of body centered atom will not be intersected by the ~~one one~~ (1 1 1) plane in BCC structure, Hence Body Centred atom should not be counted in the calculation of planer density on (1 1 0) plane.



$d = \frac{a}{\sqrt{3}} = \frac{4r}{\sqrt{3}.\sqrt{3}}$

$d = 1.33r$

$1.333 < 2r$

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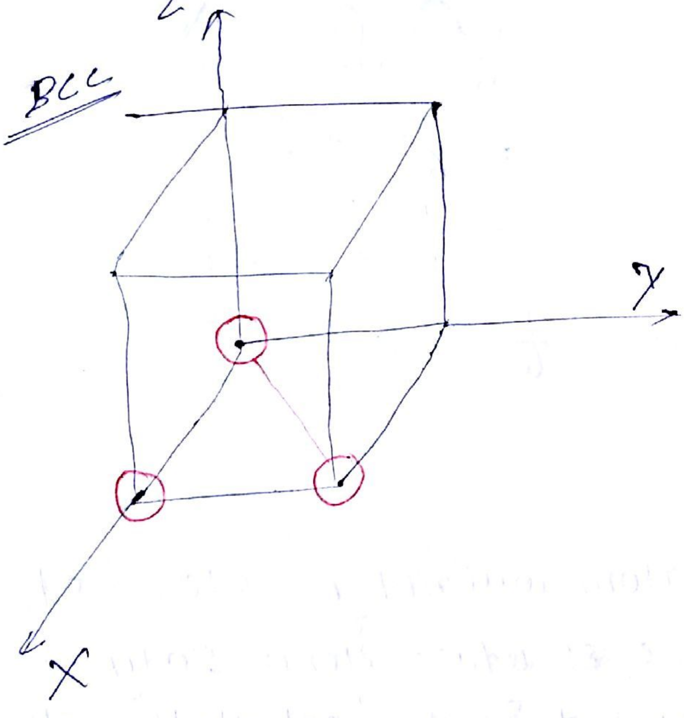
linear density (ρ_L)

→ no. of atoms whose centers are intersected per unit length of a direction vector.

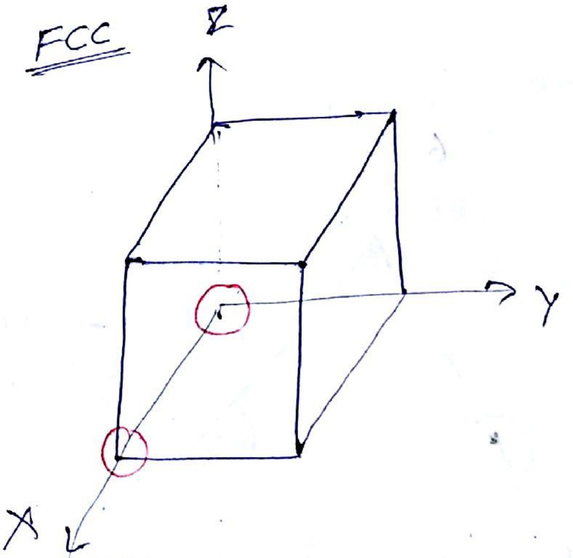
$$\boxed{\rho_L = \frac{\text{no. of atoms}}{\text{length of direct}^n\text{ vector}}}$$

Dir^n	BCC	FCC
[100]	$\frac{1}{a}$	$\frac{1}{a}$
[110]	$\frac{1}{\sqrt{2}a}$	$\frac{2}{\sqrt{2}a}$
[111]	$\frac{2}{\sqrt{3}a}$	$\frac{1}{\sqrt{3}a}$

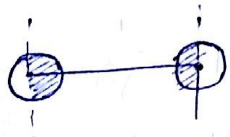
BCC



FCC

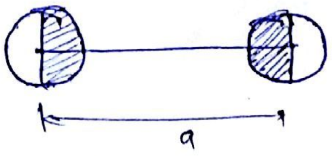


dir^n [100]



no. of atoms within given length $= \frac{1}{2} \times 2 = 1$ atom

$\rho_L = \frac{1}{1a}$

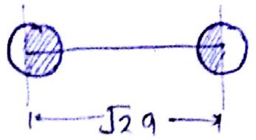


no of atoms $= \frac{1}{2} \times 2 = 1$

$\rho_L = \frac{1}{a}$

dir^n (1 1 0)

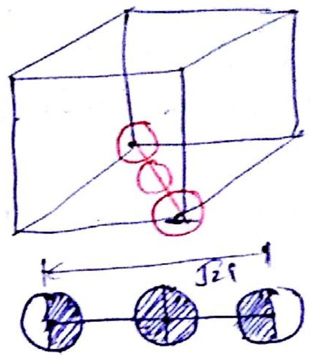
BCC



no. of atoms $= \frac{1}{2} \times 2 = 1$

$\rho_L = \frac{1}{\sqrt{2}a}$

FCC

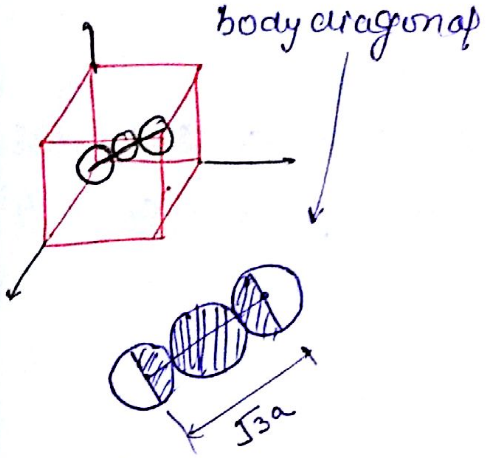


no. of atoms $= \frac{1}{2} \times 2 + 1$

$= 2$

$\rho_l = \frac{2}{\sqrt{2}a}$

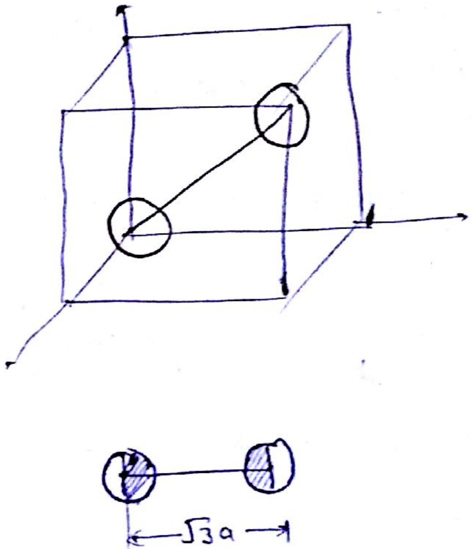
dir [1,1,1]



no. of atoms $= \frac{1}{2} \times 2 + 1$

$= 2$

$\rho_L = \frac{2}{\sqrt{3}a}$



no. of atoms $\Rightarrow \frac{1}{2} \times 2 = 1$

$\rho_L = \frac{1}{\sqrt{3}a}$

⇒ In crystal structures, the planes having highest value of planer density are called as closed packed planes 'or' slip-planes.

For example in BCC structure ~~Ex.~~ (110) is closed plane whereas in FCC structures (111) is closed packed plane.

Similarly, The direction in crystal structures which have highest value of linear density are known as closed packed direction 'or' slip directions.

For example! in BCC structure [1,1,1] is closed packed ~~plane~~ direct^n. whereas in FCC structure [1 1 0] is closed pack direct^n.

→ no. of slip system defined as the product of no. of closed planes and no. of closed pack direction.

$$\boxed{\text{No. of slip System} = \text{No. of CPP} \times \text{No. of CPD}}$$ *

⇒ crystal structure → different planes have different plane densities then; a crystalline solids are Anisotropic.

⇒ [no. of atoms are different in different planes, no. of ~~pro~~ ~~bods~~ bands different different properties will be]

⇒ no. of slip system → indicates (the plastic deformation) generally i.e ductility. (more no. of ~~due~~ slip system, more will be ductility).

⇒

Slip → permanent deformation at low Temp & low stress

Twinning → ______ at low Temp & high stress

- Slip is due to motion of dislocation.

$$\boxed{\uparrow W = F \times d \downarrow}$$

as, d = ~~dista~~ interatomic distance in CPP decreases.
less work to be done to move the dislocation.

⇒ By Resisting the movement of ~~slip~~ disslocation, ductility can be Resisted and brittleness is promoted

→ thus, the above is done by cold working, work hardening

no. of Slip system

FCC — ~~more~~ less
BCC — more

Rules fails

FCC → more
HCP — less

⇒ Since BCC are having more no. of slip system, But they are brittle & Because Random orientation of closed packed planes resists the motion of dislocation, thus ~~increa~~ decrease the ductility. (Brittleness will be promoted). [The Reason of BCC to be Brittness – Randomness

⇒ FCC are having more no. of slip system than HCP, FCC are ductile & HCP are less ductile.

⇒ Due to Randomness in orientation in neighbouring closed pack plane → BCC is Brittle.
Though FCC are having less no. of slip system than BCC, in FCC all closed pack planes are systematically aligned to facilitate to active movement of dislocation.

⇒ Ductile-to – Brittle transition conditions:–

- under the following conditions even originally ductile materials will fail in Brittle manner (1).

(1). low tempratures
(2). High Strain rate
(3). Presence of surface notches

- In ~~add~~ addition to the above the following factor also contribute to the Brittleness in solids.

(1). Strain Hardening effect caused by cold working process.
(2). Residual stresses induced into the material. by cold working or Hardening treatment.
(3). Presence of internal carbide & nitride phases.
(4). low atomic packing factor (~~Voitao~~ large voidage in the internal structure)
(5) ~~Radam~~ Random orientation b/w closed packed planes within internal structures.

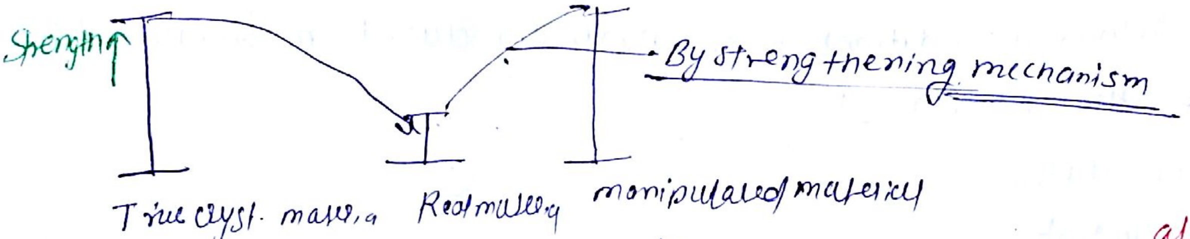
- : Structural Imperfections :-

→ Deviation from True crystallinity. over a sharp range

Indices of True crystallinity :-

- 3-D, long range, periodicity.
- all atomic sites must be completely filled with own atoms.
- Lattice should be at low potential energy.
- Atoms must be at Bond length distance.
- lattice must be Stable.
- Atomic planes must be discrete

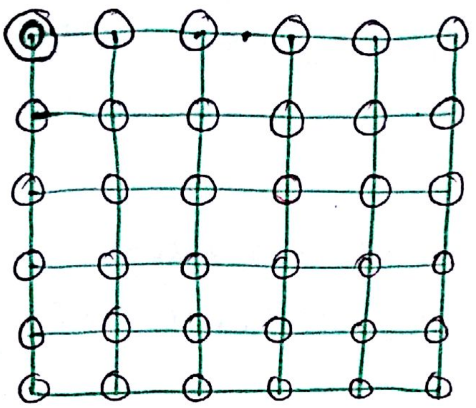
At absolute zero, all the conditions are satisfied But above absolute zero, then atoms are vibrating (at energy state).



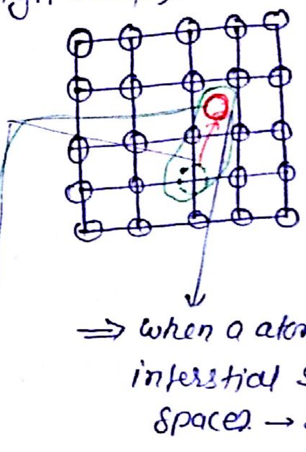
already in other parts

1. point defects (zero-D defects)
   - Vacancies
   - self interstitialy
   - Impurity
     - Interstitial
     - Substitutional
   - frenkel defect
   - Schottky defect
2. line defects (one-D defects)
   - Edge dislocations
   - Screw dislocations
3. surface defects (Two-D defects)
   - Grain Boundaries
   - low angle Boundaries
   - Twin boundary
   - stacking faults
4. volume defects (3-D. defects)
   - casting defects
   - welding defects
   - forming defects.

point Defects:



⇒ due to un-intential Heating. The atoms may escape and form a vacanices. (strength decrease at high temp).

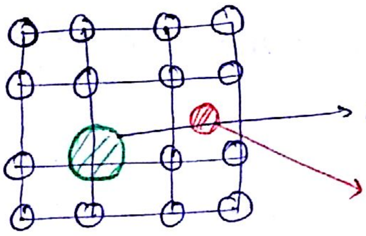


⇒ when a atoms goes into interstial space (narrow spaces → self-interstialiay

~~E~~ when Vaconocies & self-intertials space existing side by side → frenkel defect.

⇒ self-interstitiacy / interstitialcy may increase the strength slightly. → [The strength is temperory – because atom is not stable at interstitial space due to thermal excitation].

⇒ Due to addition of foreign atoms ⇒ impurities in parent atoms.



→ substitutional impurties occupies the vacancies.

→ ~~interstial imp~~ interstitial impurities occupies the interstatial space.

→ ~~In ionic solids (when anion and cation) are~~

⇒ The Term Vacancy denotes the position vacanted by atom in parent metal lattice,

⇒ Self-interstitialcy denotes a parent ~~po~~ metal atoms exists in a interstitia site.

⇒ Impurities denotes ~~the~~ A foregin atoms existing in a parent metal lattice.

Interstitial impurities:- A foreign atoms (smaller than parent metal atoms)

Substitutional impurities:- A foregin atoms (bigger than the parent metal atoms).

⇒ Frenkel defect: denotes ~~on~~ a vacancy and self-interstitialy existing together within a neighbourhood.

⇒ ~~Sbe~~ Schottkey defect: denotes a pair of vacancy. due to. cation and anion formed in ionic solids.

Let ~~n_v~~ n_v = no. of vaconicies in atom
n_t = ~~no. of~~ Total no. of lattice site in a metal
E = activation energy (enthapy of formation of a vacancy.
K = Boltzman Constant
T = Absolute Temp.

Then,

$\frac{n_v}{n_t}$ = vacancy concentration / fraction of vacancy sites in a metal

$$\boxed{\left(\frac{n_v}{n_t}\right) = e^{-\left(\frac{E}{Kt}\right)}}$$

⇒ Above expression, vacancy concentration in a metal increases with increase in temprature.

Reason for point defect :-

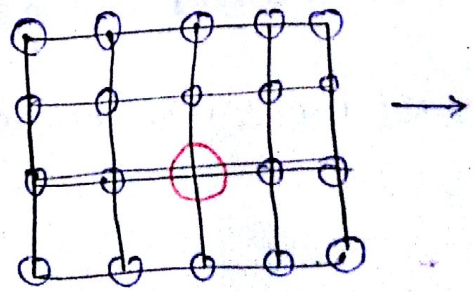
(1). Vacancies are formed due to thermal excitation caused by Heating externally.

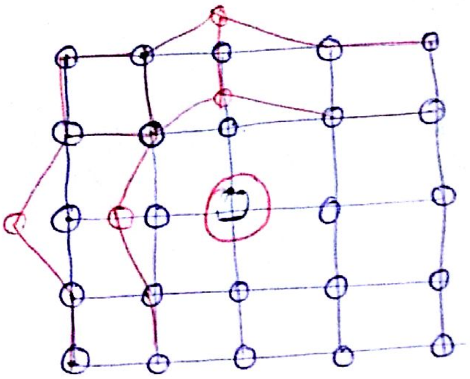
(2). Impurities are formed, when alloying atoms are added to pure metals.

Effects of point defects :-

(1) Vacancy formation results in decrese in strength of metal.

(2). Impurity formation results in lattice distortion.





⇒ Due to this, randomisation of closed pack planes will take place,

→ moving dislocation will be stopped,

→ slip gets arrested.

→ Resistance to permanent deformation increases.

– Hence, Strength & Hardness of metal increases, Ductility decreases. & Brittleness increases.

⇒ Due to which (impurities) → alloys are more stronger than pure metals.

d_{IM} = dia. of interstitial impurities

d_{PN} = dia. of parent metal atom

d_{IV} = dia. of interstitial void:

$\boxed{d_{IM} < d_{PM}}$

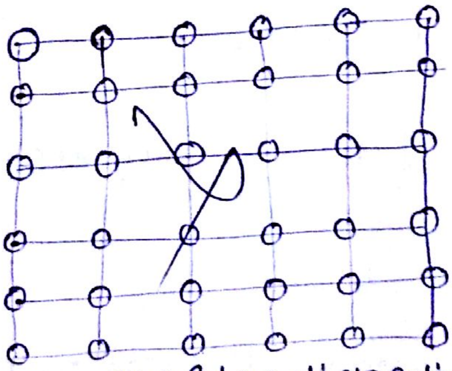
$\boxed{d_{IV} < P_{PM}}$

→ $\boxed{d_{Imp.} > d_{IV}}$ ~~always~~ practically,

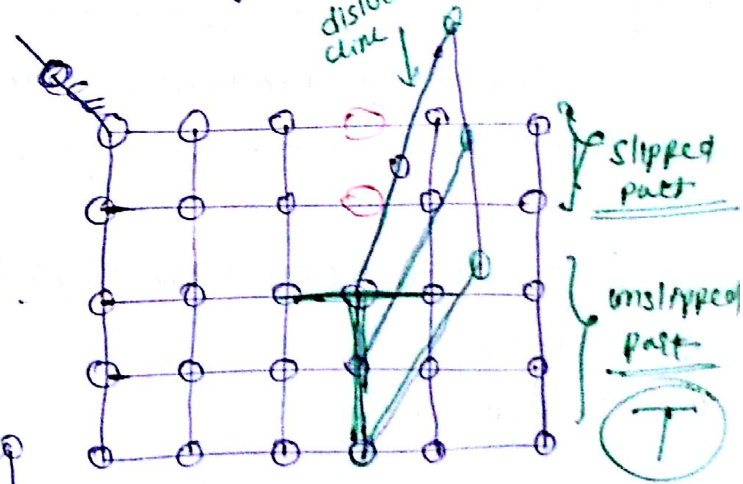
↳ such distortion is possible with interstitial impurities.

• Line Defects: (Dislocation):

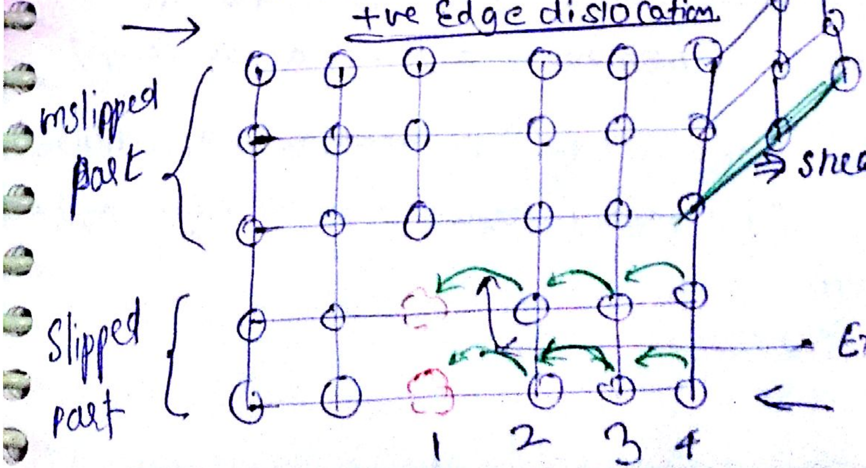
A dislocation is defined as the boundary b/w slipped and unslipped portion of crystal.



+ve Edge dislocation



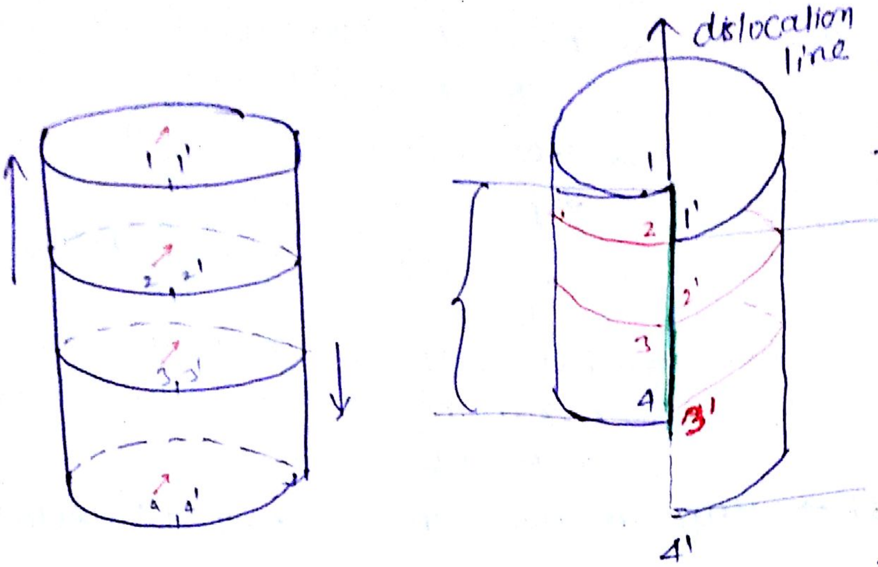
–ve edge dislocation



⇒ shear component will only be responsible for dislocation movement

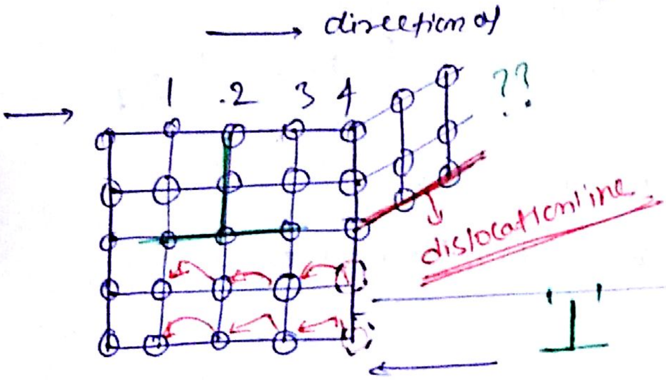
→ Exchange of neighbouring vacancy (called slip)

← Such a mass transpose



→ seperated plane lost their seperation, then became helix.

⇒ screw dislocation → mass transport via helical path.



[lower boundary of partial plane] Vacancies below dislocation line [+ve dislocation line]

= dislocation (group ~~of~~ of atoms) is moving →(1→2→3→4) →

⇒ Burger's vector ($\vec{b}$) :- which is used for characterization of movement of dislocation within a lattice

→ ~~imp~~ Burger's vector of edge dislocation is perpendicular to dislocation line

→ Edge dislocation have two degrees of freedom, they are.

* glide motion:

* climb motion:

⇒ Glide motion, denotes the movement of edge dislocation ~~pa~~ line parallel to closed packed plane. (permanent deformat at low Temp.) whereas climb motion, denotes the movement of edge dislocation perpendicular to the closed packed plane. (permanent deformation at high Temp).

→ Glide motion → contribute slip

→ Climb motion → contribute cross slip

→ when a Truely crystalline material is subjected to shear force, A discreteness of the atomic planes may be lost and gets converted into surface of a helix around a dislocation line this type of structural deviation from true crystallinity is ~~use~~ known as screw dislocation.

⇒ Burger's vector of screw dislocation is parallel to dislocation line

⇒ screw dislocation contribute to ~~plo~~ permanent deformation at high temp.

⇒ no. of dislocation — depends upon manufacturing process.

⇒ Highest no. of dislocation → coldworking process

→ Interactions between dislocation:

⇒ When Two opposite edge dislocation travels towards each other on the same slip plane, they attracts each other and combine into a perfect plane.

⇒ when Two opposite edge dislocation travels towards each other on parallel slip planes a group of vacancies formed between them

⇒ when Two ~~two~~ similar edge dislocation travels towards each other on the same slip planes, they repel eachother.

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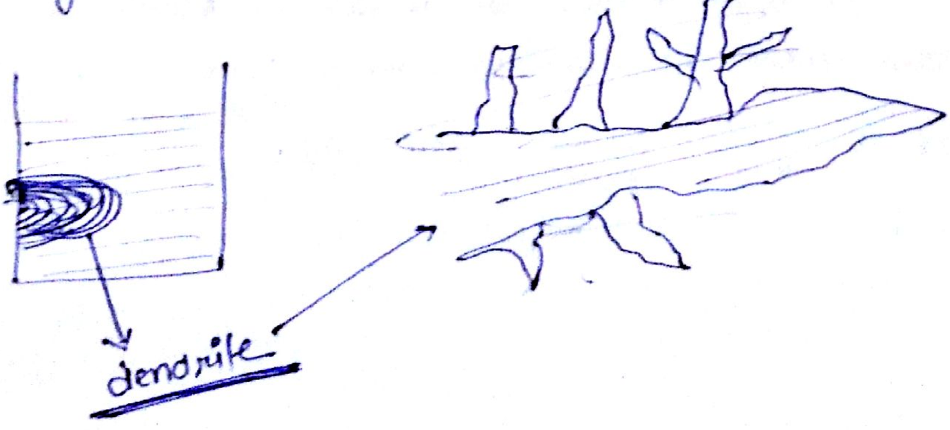
Surface Defects: (2-D defects)

(1) Grain Boundaries:-

→ formed during solidification of metals.



⇒ A dendrite is defined as randomly growing solid phase in the molten metal.

⇒ Grain boundary is defined as the junction b/w two randomly growing dendrite.

dendrite] Grain is same as dendrite

⇒ Characteristics of grain boundaries:

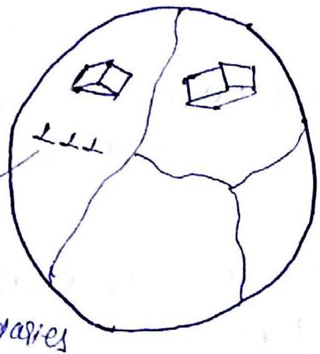
(1) Reigons of High Energy. (interatomic distance reduces due to Randomly going ~~joint~~ dendrites)

(2) GB — Regions of Orientation of mismatch

(3) GB → low melting point Regions.

(4) GB → Regions of heavy impurity concentrations. (Slag inclusions, goes to GB).

⇒ fine grains structure more strength than coarse grain at low temp. only



→

at low Temp

⇒ dislocation are resisted by grain boundaries

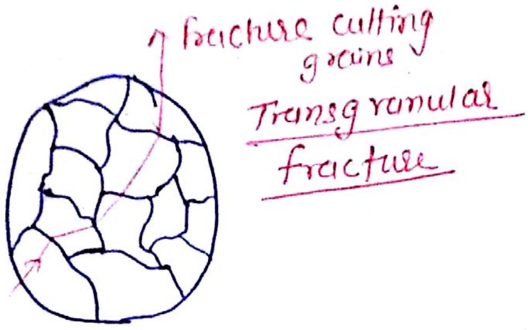
↓

more grain boundaries → more fine grains → more hardness & strength:-

at high temp → Grain boundaries gets melted (to minimise grain boundaries at high temp)...

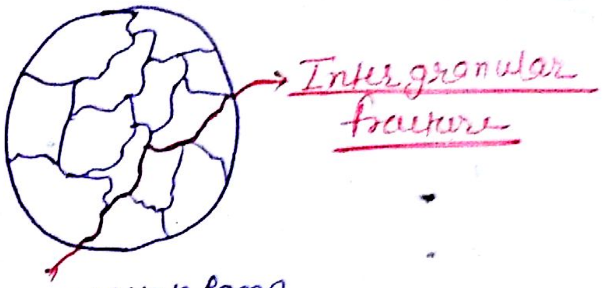
– Grain boundaries corroded fast-(hence for corrossion resistance less no. of grain boundaries).

→ Single crystal materials are materials having zero grain boundaries in them. they are developed by special manufacturing process called as crystal ~~pooling~~ pulling method.



at low temp

G – Relatively weaker
GB – stronger



at High temp

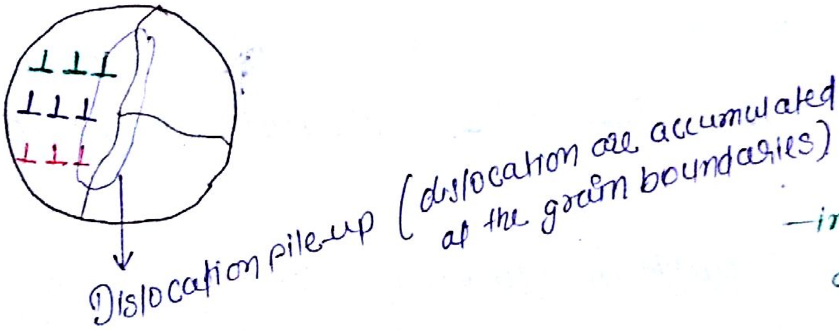
G → stronger
GB – weaker

⇒ for Better creep Resistence, coarse grain structures are preffered.

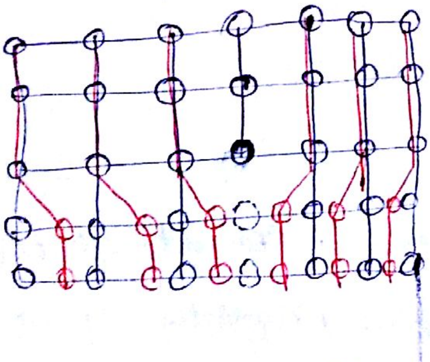
Equi-cohesive temp.

→ defined as the temp. at which Both grains and grain boundaries will have same strength.

(2) low angle boundaries :-



⟹ When Two or more no. of edge dislocations are accumulated one above other in a grain boundary, the resulting lattice will be called as low angle Tilt boundaries.

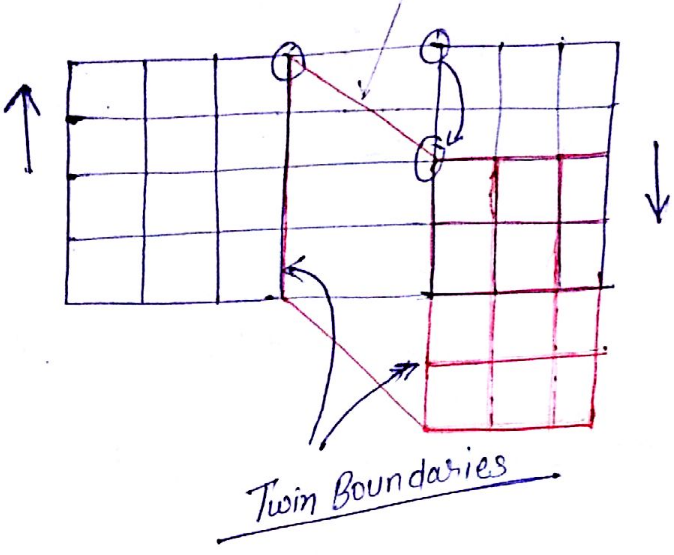


→ lattice distortion occur due to dislocation. Thus there no. of dislocation accumulated at the grain boundaries, there will be more lattice vibration.

→ So lattice vibration caused by

→ When similar lattice distortion takes place due to accumulation of skew dislocations one above the other in a grain boundary, it is known as low angle twist boundaries.

(III) Twin Boundaries:



⇒ when a finely crystalline material subjected to shear distortion, the atomic arrangement in slipped and unslipped portion of the crystal will become mirror images of each other, about Two boundaries. these two boundaries are known as twin boundaries

⇒ Twin boundary formation result in increased in net potential energy of lattice and makes it unstable and non-uniform property will be present in the lattice.

(IV) Stacking faults:

are faults in stacking sequences.

⇒ Stacking sequences in FCC : ABCABCABCA. . . . ∞
in HCP : ABABABA. . . . ∞

- (escape of group of atoms is plane)
- stacking fault formation results in increase in the net potential energy, makes it unstable and non-uniform properties will be present in the lattice.

Strengthening mechanisms

- Grain Size Refinement
- Coldworking
- solid solution Strengthening
- Composits

Grain Size Refinement
↓
Hall-petch eqⁿ
(1) Hotworking :
(2) adding alloyingelements.
(3) Heat treatment:

solid solution Strengthening

1. Solid solution → ~~soltns in~~ solutions in state
2. They consists → solvent
   → solute — impurities
3. There are two types (on basis of impurities)
   → interstitial solid solutions
   → substitutional solid solutions

Hot working → improve the grains size and causes the ~~etir~~ formation of grain boundaries → Grains are refined.

Heat treatment: Grainsizes are Refined.

Hall-petch equⁿ

$$\boxed{\uparrow\sigma_y = \underline{\sigma_i} + K.d^{-1/2}\downarrow}$$

σ_y = yield stress of polycrystalline material
σ_i = yield stress of the material at an infinite grain size.
K = Hall-petch constant
d = Avg. grain diameter.

Coldworking cold working of metal results in increasing ~~the result~~ the no of dislocations due to this entropy of lattice increases.

→ (due to this randomness b/w between closed pack plane will increase the dislocation movement will be stopped, slip gets arrested and Resistance to permanent deformation increases. Hence Ductility decreases.

→ Brittness increases, because, strength & Hardness increases by cold working. (Strain Hardening process).

→ This increases in Hardness & Strength by cold working is known as Strain hardening or work hardening.

Solid Solution Strengthening

- Solute – (impurities like)
- Solvent – parent

→ Reason for strength improvement by solid solution strengthening is lattice distortion caused by solute impurities.

→ More significant improvement in strength solid strengthening the following two suggestion are made.

(1). Increase the concentration of (impurities) solute

(2) Increase the size difference b/w (solute (impurity) ~~and~~ and Solvent (parent metal).

* concentration of solute. ↑ – (then chances of precipitation)

* Atomic size ~~of~~ difference of between solute & solvent.

Huth – Rothery's Rule for extensive solid solubility :→

(1). Crystal Structure factor:

The crystal structure of both the elements should be the same.

(2). Relative size factor :– (<15%)

The difference in atomic raddii b/w the two elements ~~will~~ should be less than 15%.

(3) chemical Affinity factor:–

Greater the chemical affinity b/w the two elements, more restricted will be the solubility.

(4). ~~Rela~~ Relative Valancy factor :–

An elements of lower valancy can dissolve more amount of another element of higher valancy. than the reverse.

Alloy

⇒ An alloy is defined as any substance having metallic characters and composed of two or more no. of chemical element out of which atleast one is a metal

phase: defined as microstructurly ~~distinct~~ distinct and chemically Homogenous & mechanically seperable part of system.

To find no. of phases (P) , Gibb's equ.

$$P+F=C+①$$

- Stands for Temp. as the only variable in the study of alloy phases.

⇒ f = degree of freedom

⇒ P = no. of phases.

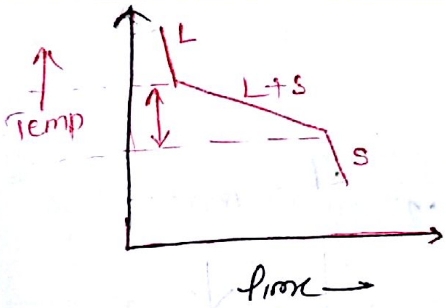
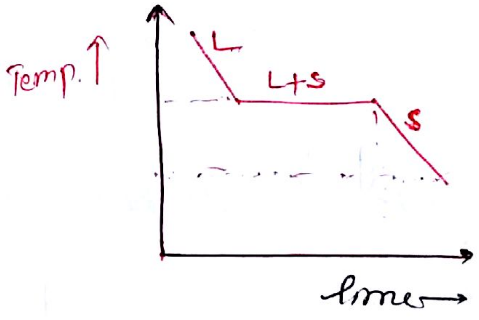
⇒ C = ~~no. of components~~ no. of chemical elements, used in alloy formation &

- if degree of freedom = 0 ; in any alloy transformation, such a process or Reaction is known as invariant reaction.
- if F = 1 ; the resulting transformation in alloy is known as uni-variant reaction:
- if F = 2 ; The resulting tranformation in alloy is known as bi-variant reaction:

classification of Binary alloy:-

① Homogenous alloys / single phase alloys
  - Solid solutions
  - Compounds

② Mixtures (Multi-phase alloy)
  - Two or more no. of solid solution ≥ 2 solids
  - Two or more no. of ~~solid~~ Compound Solution. ≥ 2 compounds
  - 1 solid + 1 compound

Solid solutions	Compounds
1. made on ~~peercentage~~ weight % on basis	1. made on molar volume Basis.
2 ~~A~~ concentration of solute is variable	2. molar volume ratio remains constant
3. produced due to mutual dissolution of two metals.	3. produced ~~to~~ due to chemical reaction.
4 Cannot be expressed as a chemical formula. They are indicated by greek letters. In microstructure and phase diagrams.	4. Compounds can be expressed as chemical formula:
5 Solid solution melts or solidify over a range of temp. known as melting range or freezing range.	5. compound melts or solidify at constant temp. like pure metals.
	
(6). Are addressed by ~~[illegible]~~ ~~[illegible]~~ "minor element in major element" Ex: α-ferrite solid solution of C in Fe Duralumin solid solution of Cu in Al	(7) "major element minor element" Ex: Fe_3C → compound of iron and carbon $MgPb_2$ → compound of Mg & Pb Mg_2Sn - compound of Mg and Sn.

→ less chemical affinity, more solid solubility.

→ on the basis of valany, the solute and solvent are characterised.

→ lower valany → Solvent
→ Higher valany → solute. | Relative valany factor **

→ **Composits:** Always 2 phase materials
① matrix
② Reinformment (Discontinuous)

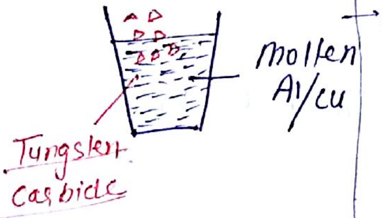
→ In the manufacturing of composits the Reinforcement material is so selected that it has superior properties than the matrix material.

→ Composits are classified as.

① Particulate composits

↓

Hard particles of carbides are dispersed into soft molten ~~material~~ metal:



'or' (SiC).

↓

Dispersion strengthening

Carbide are hard ~~(ceo~~ having ~~1000~~ high melting point, they do not melt and no ~~molecular~~ Atomic Bonding → Thus they resist the motion of dislocation

② fiber Reinforced ~~dent~~ composits

→ The fiber denoted fine thread like structure from metallic or non-metallic family.

→ In the manufacturing of fibre Reinforced composits. fibre material is so selected that its ~~youngs~~ young modulus (E) more than that of matrix material $E_f >> E_m$

→ The properties of fibre reinforced ~~ed~~ composits depends upon:

(1) Size/shape/distribution of fibres in the matrix.

(2) Aspect ratio of fibre $\left(\frac{l}{d}\right)$

(3). fibre matrix interfacial bond strength.

(4) relative orientation of axis of the fibre w.r.t. to ~~x~~ direction of External

③ laminated Composits (claddings)

load applied.

- The mayour objective fibrely Reinforcement composits is to improve the stiffness of composits. The stiffness of composite material can be calculated using the rule of mixture given below for various loading condition:

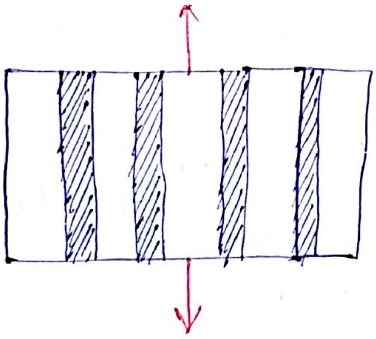
Let E_f = Young's modulus of fibre
E_m = Young's modulus of matrix

$$\boxed{E_{ff} >> E_m}$$

V_f = volume fraction of fibres
V_m = Volu. fraction of matrix.

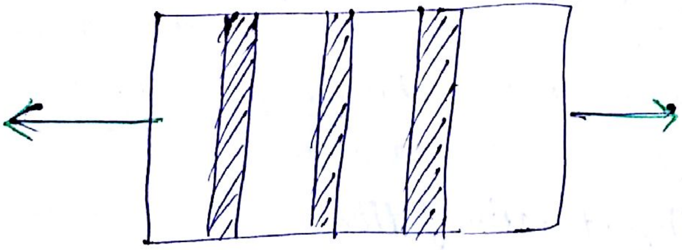
⇒ Estimation of young's modulus of composite (E_c) :-
(Rule of mixtures):

(1) longitudinal loading: (Isolation condition):



$$\boxed{E_c = E_m V_m + E_f V_f}$$

(2) Transverse loading (Isostress condition):



$$\boxed{E_c = \frac{E_m E_f}{E_m V_f + E_f V_m}}$$

$$\boxed{\frac{1}{E_c} = \frac{V_f}{E_f} + \frac{V_m}{E_m}}$$

⇒ for a given volume fraction of fibres, A fibre reinforced composits will exhibit ~~superstion~~ superior ~~that~~ stiffness in longitudinal loading rather in transverse loading [~~Ex~~

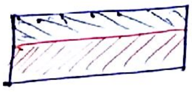
→ CFRP: ~~very costlie~~ 'Carbon-fibre Reinforced Polystyrene

→ GFRP: Glass-fibre Reinforced Polystrene.

→ CFRP→ exhibits. superior stiffness compared to GFRP composits.

3 laminated composites: (claddings):

Ex: Bimetallic strips



⇒ The objectives of laminated objectives are ① to improve surface properties like electrical, magnetic properties ② to improve corrosion resistance ~~wear~~ wear resistance. fatigue resistance, creep resistance.

③ To improve uniformity of Heat distribution in various application.

Some practical:

* Al-clad:→ Aluminium cladding → denotes high purity aluminium layer bonded to commericial purity aluminium,
for use in aerospace industry.. for light weight & good corrosion resistance.

* Cu-clad-Al:→ used for improving creep resistance of aluminium.

* Cu-clad Steel:→ denotes copper layer bonded to ~~steel~~ steinless steel for uniformity of heat distribution in cooking.

phase diagrams:

[Constitutional diagram & equilibrium diagram]

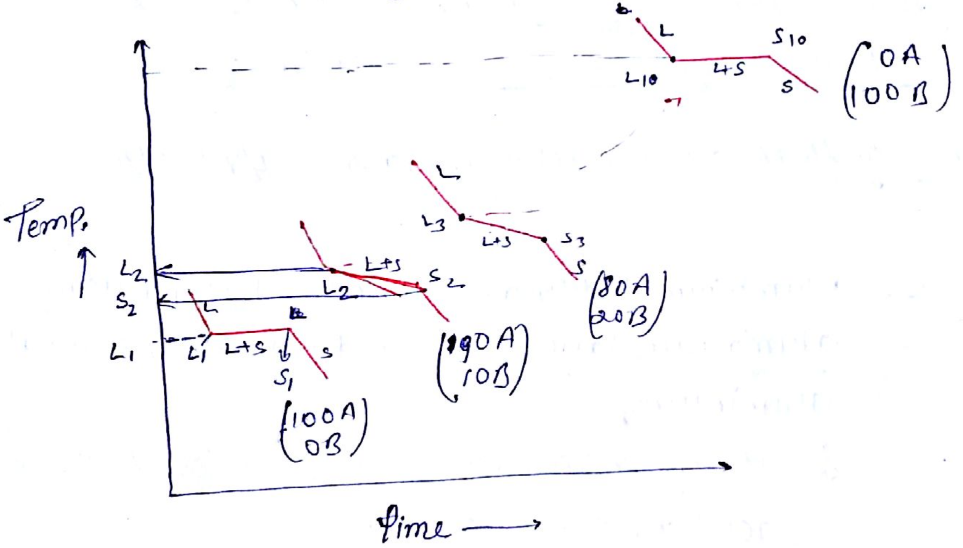
Type-I phase diagrams :- Isomorphous System:

→ In this system of alloy the two elements added will exhibit the complete solubility in both liquid & solid state.

Examples are: copper-nickel [Cu-Ni], [Au-Cu]
Gold-silver [Au-Ag],
moly - Tungs. [Mo-W],

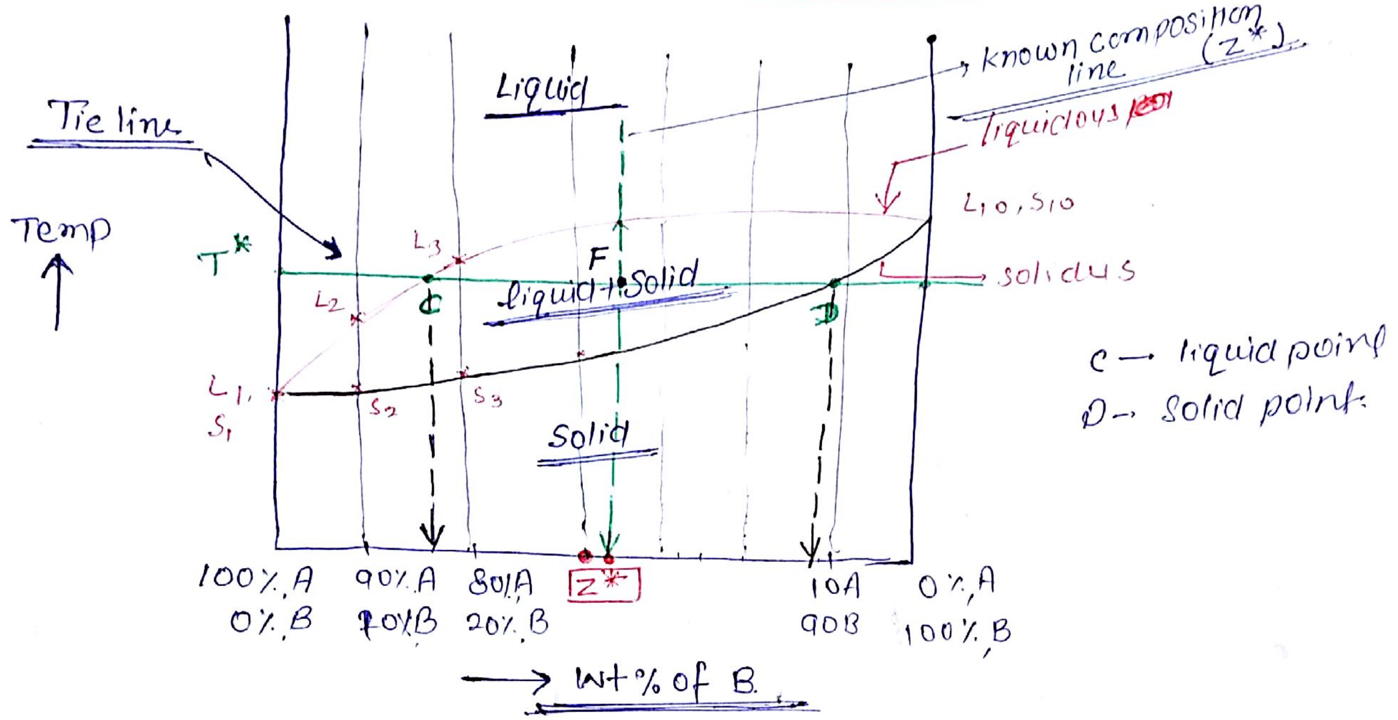
⇒ isomorphous - same crystal structure [Both must have same crystal structure]

⇒ phase diagrams for single phase alloy.



— the solidification and liquid point temp. are measured according to the composition.

then plotted a against temp-composition curve - called phase diagram.



Uses:-

(I) Tie line Rule Tie line is a Horizontal line drawn at any given temp.

Let T* = any given temp

⇒ It is used for determination of composition of liquid and solid phases existing in an alloy at any given temp.

(II) Lever Rule:- Let z* = Any given composition

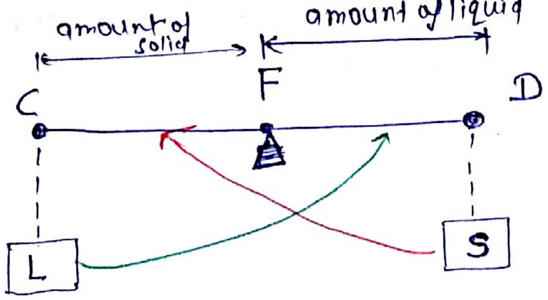
⇒ Lever Rule is used for determination of Relative amount of liquid and solid phases, existing in an alloy of given composition.

⇒ At a specific temp.

Let z* = any given composition.

point of intersection of z* and Tieline (x ⟶ F = fulcrum.

let:-



According to lever Rule,

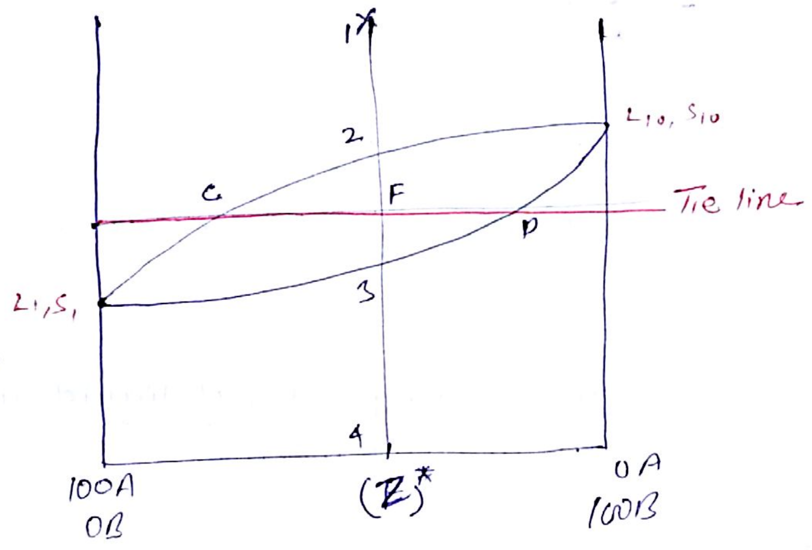
$$\text{amount of liquid @ } (L) = \left(\frac{FD}{CD}\right) \times 100$$

$$\text{amount of solid } (S) = \left(\frac{CF}{CD}\right) \times 100$$

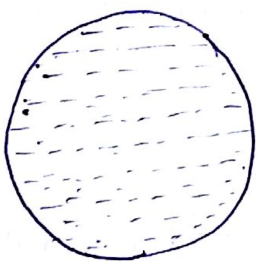
$$L+S = \left(\frac{CD}{CD}\right) \times 100$$

$$\boxed{L+S = 100\%}$$

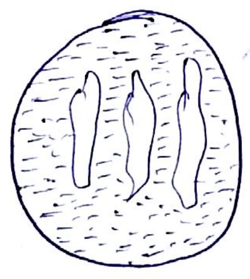
(III) Cooling behaviour :- [of Isomorphous alloy]



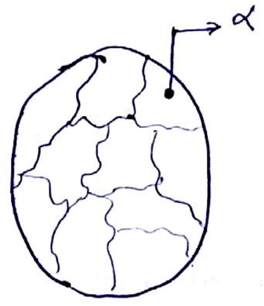
→ in every region '2' point, evely neighbouring poregion have common point



between 1 and 2



between 2 and 3



between 3 and 4

Type-II Eutetic system →

⇒ In this system of alloys, Two elements added will exhibit complete solubility in the liquid state. & complete insolubility in solid state

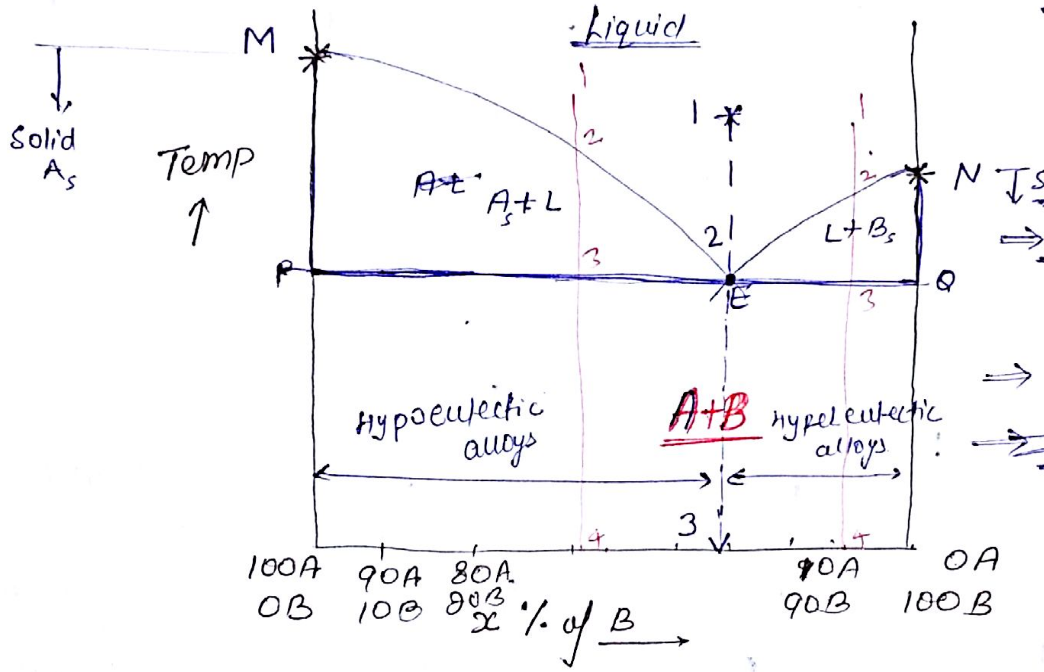
~~Complete~~ Example   Pb – As , Bi – Cd , Au – Si

Let M = melting point of element 'A'
N = melting point of element 'B'

⟹ Raoult's law states that...

⟹ When ~~an~~ impurity is added to pure metal, its ~~metal~~ melting point temp. decreases.

← Let M>N



⇒ E = Eutetic
→ lowest melting point

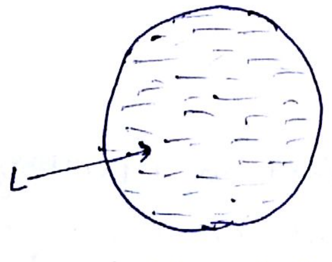
⇒ MEN = liquidus curve

~~⇒ PEQ = Solidus curve~~

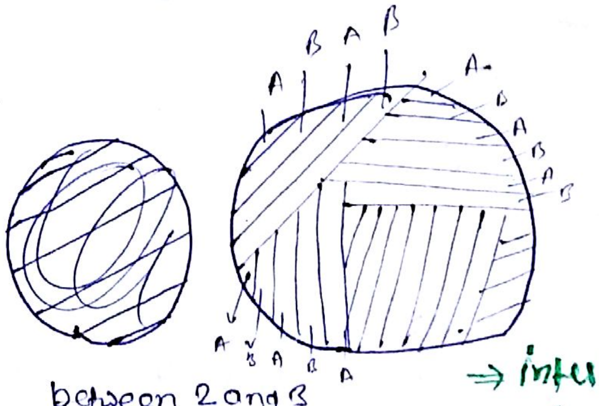
→ MPEQN = solidus-curve

⇒ Cooling behaviour of eutectic alloys :-

two zones 1–2 , 2–3



between 1, 2

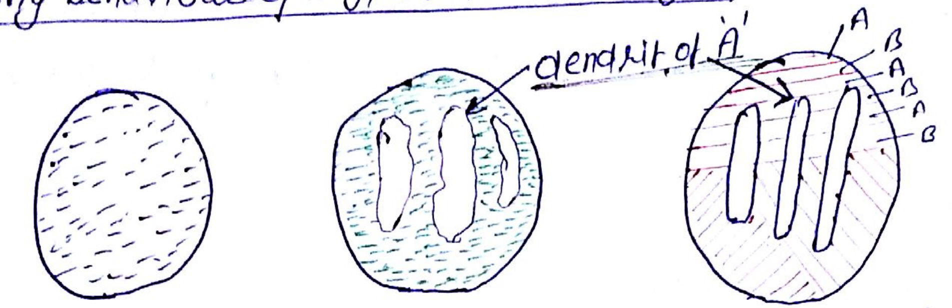


between 2 and 3

→ interlamellar structure of A & B

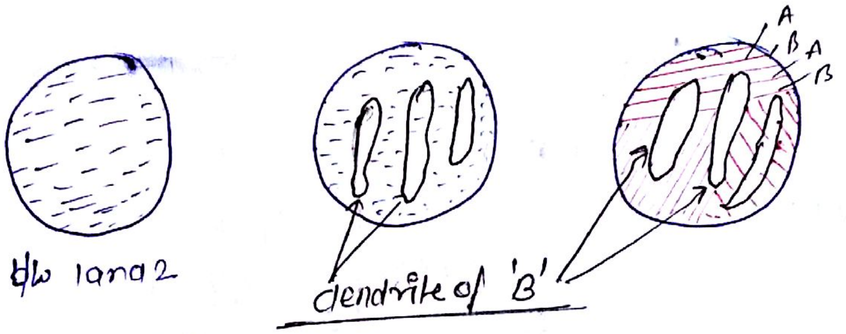
~~Colling be~~

Cooling behaviour of Hypo eutectic alloys:



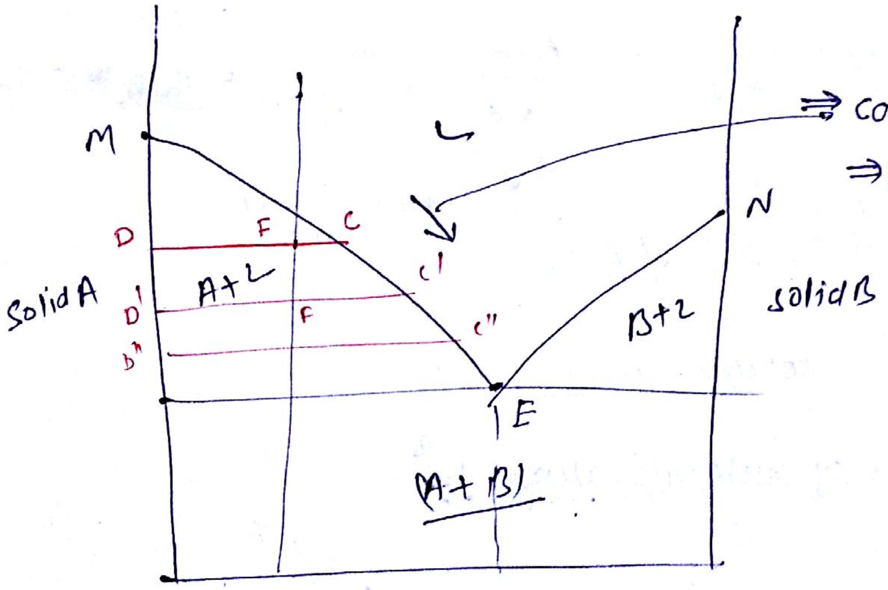
b/w 1 and 2 b/w 2 and 3 b/w 3 and 4

Cooling behaviour of & hypereutetic alloys:



⇒ Interlamellar structure of A and B

b/w 1 and 2



⇒ composition of liquid ⇒ going towards Eutectic composition thus at last the & liquid will be solidified at point E and interlamellar structure will be formed.

Type-III partial Eutectic system:-

⇒ In this system of alloys the two elements added will exhibity complete solubility in liquid state and partial solubility in solid state.

Ex: Ag-Cu alloys, Pb-Sn, Sn-Bi, Pb-Sb

Let M = melting point of 'A'

N = melting point of 'B'

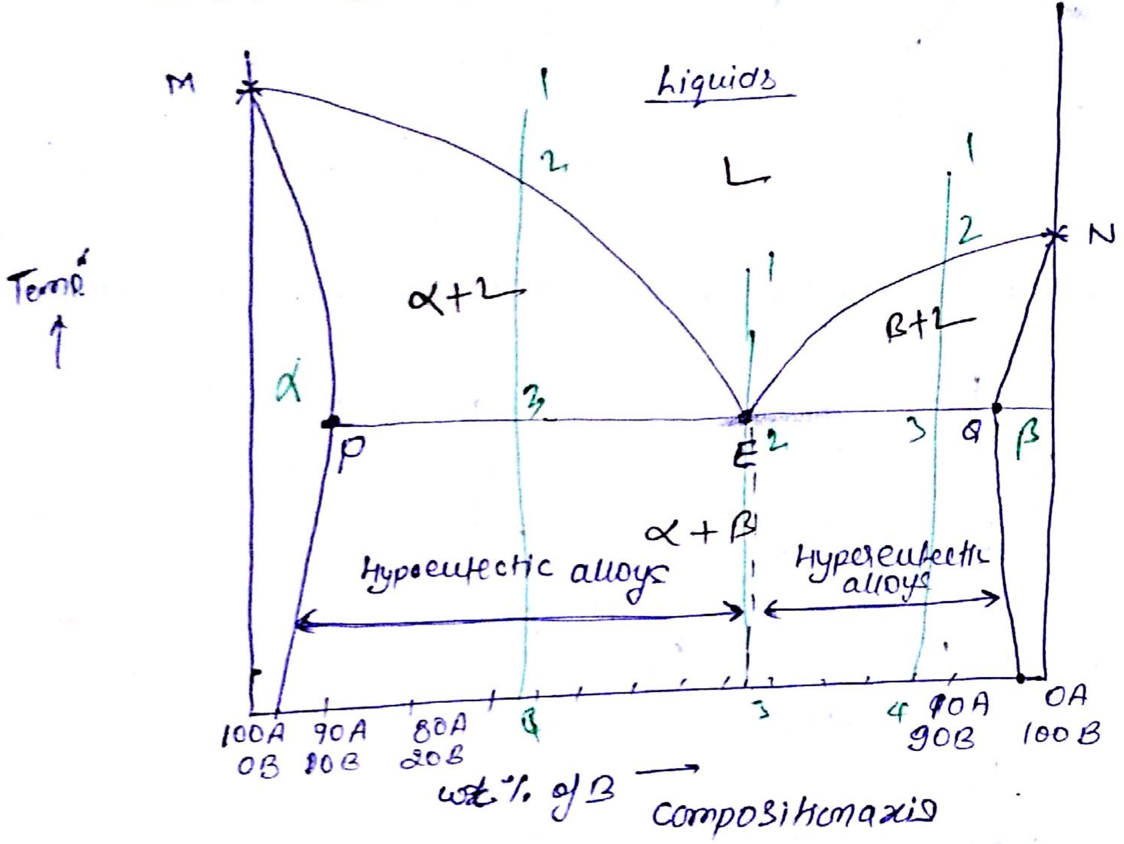
E = Eutectic

MEN = Liquids

MPEQN = Solidus.

→ Roult's law is valid for partial eutectic alloys. *

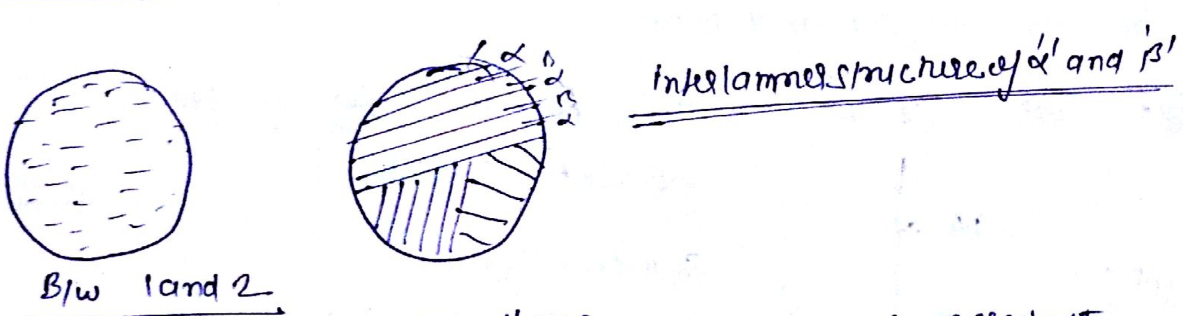
Let M>N



Let α = solid solution of B in A.

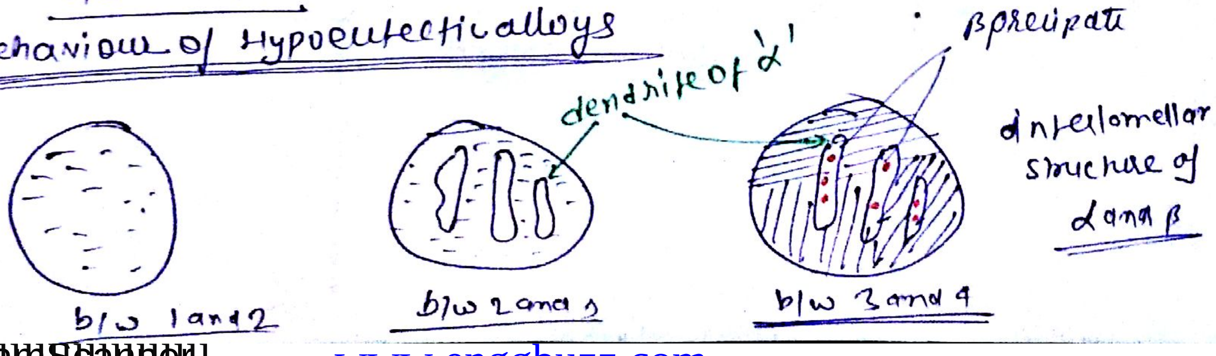
& β = solid solution of A in B.

- cooling behaviour of eutectic alloys:-



B/w 1 and 2

- cooling behaviour of Hypoeutectic alloys

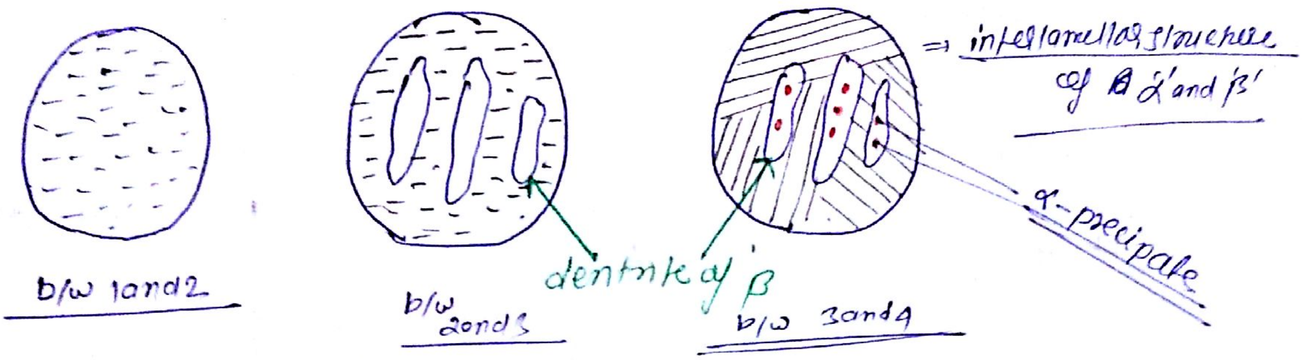


b/w 1 and 2

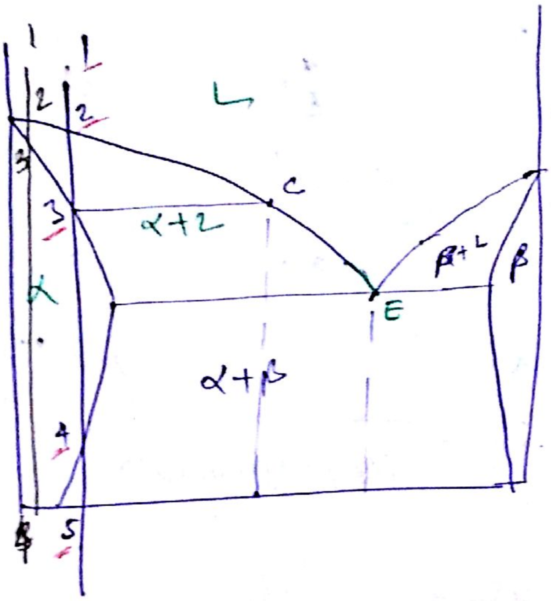
b/w 2 and 3

b/w 3 and 4

• Cooling behaviour of hypereutectic alloys :-



as temp. ↓, solubility ↓, thus 'β' or 'α' will precipate out of ~~them~~



1–2 ⟶ liquid

2–3 – dendentite α

3–4 → Grain + Grain boundaries of 'α'

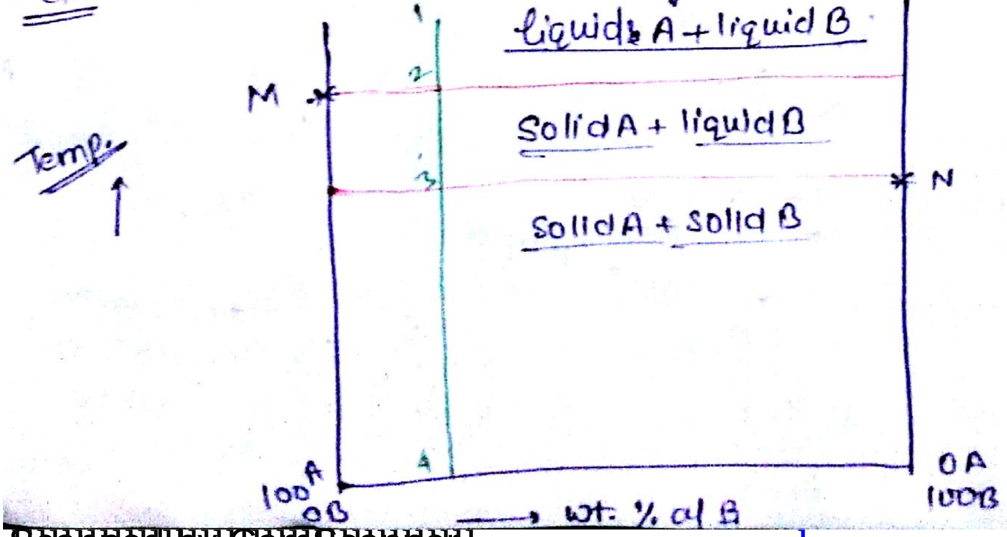
4–5 – Grain of dentrite 'α' with precipate of 'β'

Type-IV layer system phase diagrams:

→ In this system the elements added will exhibit complete insolubility in Both liquid and solid.

Ex: ~~Cu~~ Cu-W, Cu-Mo, Ag-Au, Ag-W etc.

let M > N



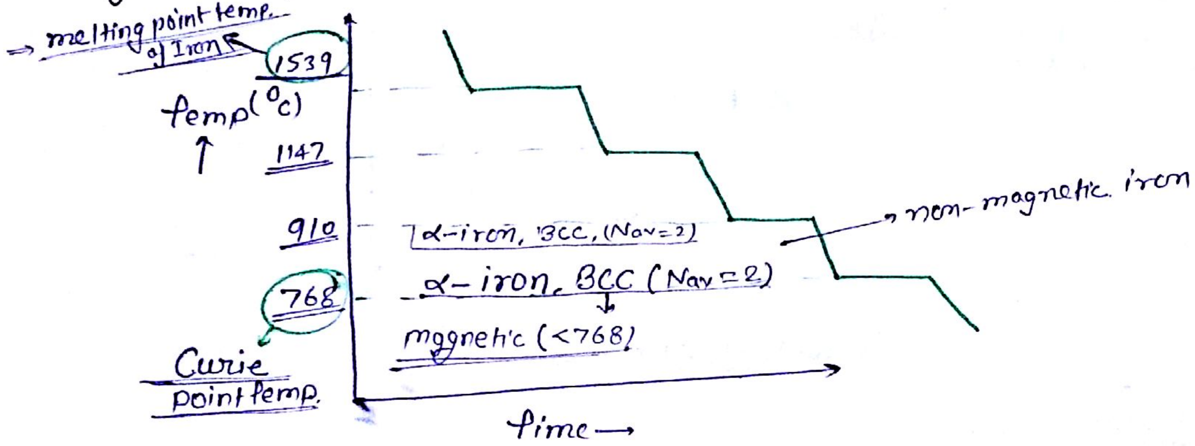
let M = melting point of 'A'
N = melting point of 'B'

⇒ for insolubility—
(1) melting temp. ~~wi~~ difference will be there
(2). High density difference.

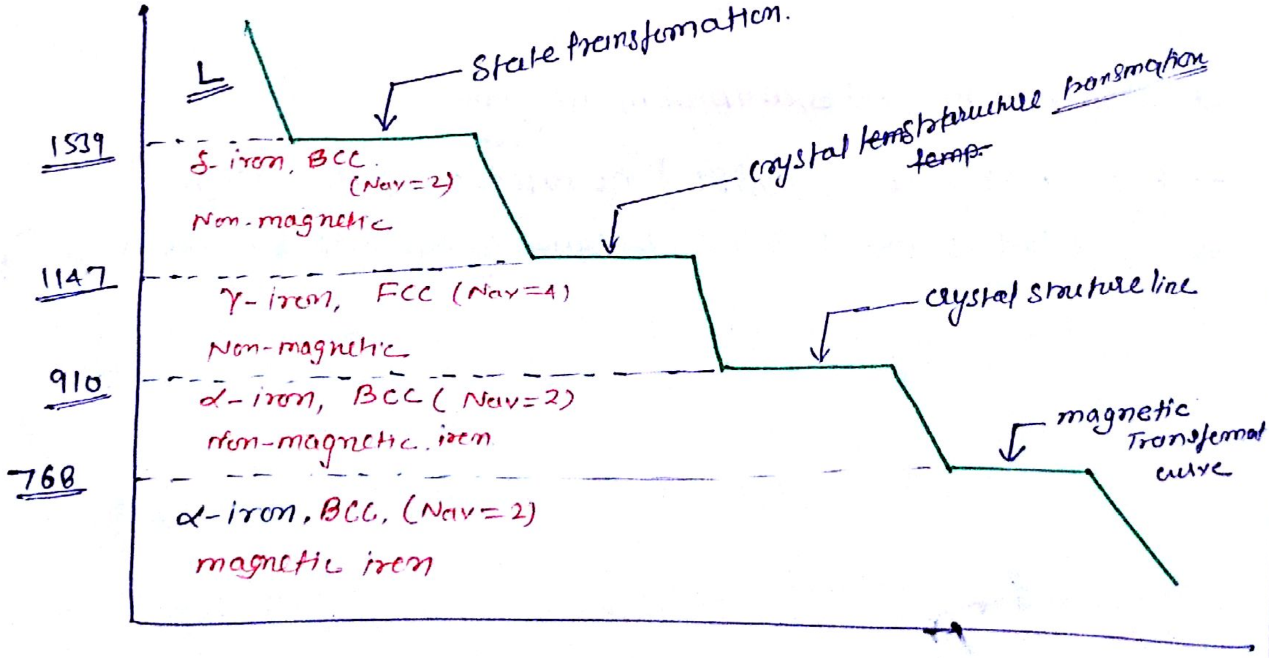
→ These alloys are not formed ~~But~~ in casting, But can be produced using powder metallurgy.

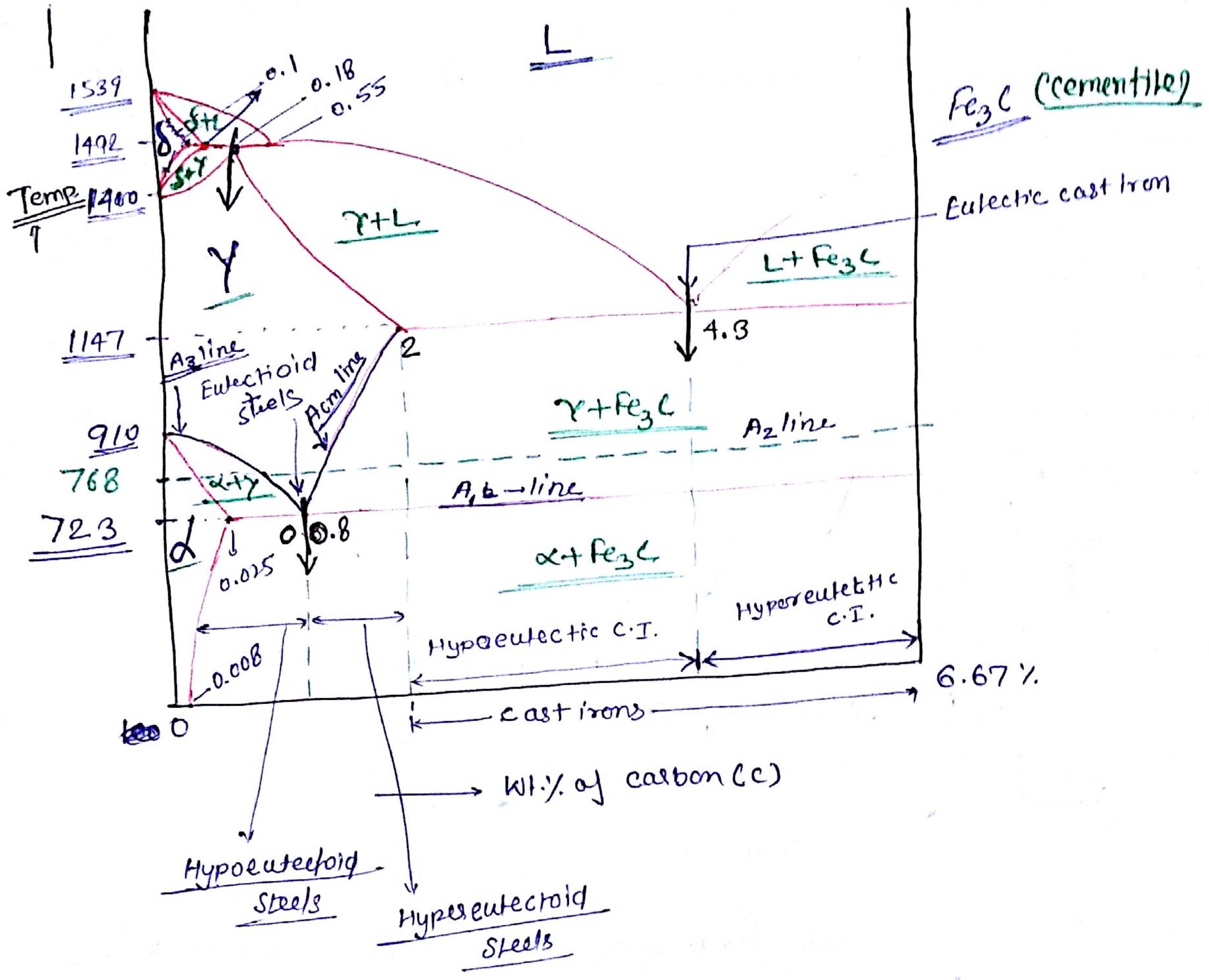
Iron & carbon diagram
Iron – Iron carbide diagram :-

Cooling curve of pure Iron :-



⇒ Ferromagnetic into paramagnetic iron [when temp > 768°C]





⇒ slow quenching — Equilibrium diagram

⇒ Fe_3C → very hard & Brittle [no practical application].

⇒ difficult to add 'C' to Fe, because of sublimation tendency of 'C'.

Scanned by CamScanner

• Definition of important phases :-

- * α — ferrite
- * γ — Austenite
- * δ — ferrite
- * Fe_3C — Cementite (compounds)

① α-ferrite:

→ Interstitial solid of 'c' in α-iron which is pure form of iron, with BCC and Nav = 2, and non-magnetic properties.

② γ-austenite:

→ Interstitial solid solution of 'c' in pure γ-iron with FCC structure and and Nav = 4, and non-magnetic properties

③ δ-ferrite:

→ interstitial solid solution of 'c' in pure δ-iron with BCC structure and Nav = 2, and Non-magnetic properties

④ Fe_3C:

→ interstitial compound of 'c' ~~in~~ ~~pure~~ of iron and carbon having solubility of 6.67% of 'c'.

Invariant Reaction:

(I) peritectic Reaction ⇒ (at 1492°c, 0.18% C)

$$\boxed{\delta + L \overset{-\Delta H}{\rightleftharpoons} \gamma}$$

$$\Rightarrow S_1 + L \rightleftharpoons S_2$$

let δ → S_1

let γ → S_2

let Fe_3 → S_3

let α → S_4

(II) Eutectic Reaction ⇒ (at 1147°c, 4.3% C)

$$\boxed{L \rightleftharpoons \gamma + Fe_3C}$$

(γ + Fe_3C) mixture → ledeburite

$$L \rightleftharpoons S_2 + S_3$$

(III) Eutectoid Reaction: (at 723°c, 0.8% C)

$$\boxed{\gamma \rightleftharpoons \alpha + Fe_3C}$$

(α + Fe_3C) → mixture → pearlite

$$S_2 \rightleftharpoons S_4 + S_3$$

⇒ $\gamma + Fe_3C$ → ledeburite

⇒ $\alpha + Fe_3C$ → Pearlite

— only one decomposition Reaction → Eutectoid Reaction

austenite $\rightleftharpoons \alpha + Fe_3C$

Solubility of Carbon in various phases:-

(1) Carbon solubility in δ-ferrite is 0.1%

(2) carbon solubility in γ-austenite is 2%.

(3) Carbon solubility in α-ferrite is ~~0.0025~~ 0.025% (at 723°C)

(4) carbon solubility in α-ferrite at room temp. 0.008%.

(5) carbon solubility in cementite is 6.67%

• Some critical temp. line and their signifiance:

(1) A_1 — line — lower critical temp. line.

→ This line signifies the transformation of pearlite into austenite upon heating of eutectoid steels

(2) A_2 line → curie point temp. line.

— it signifies, the magnetic to non-magnetic transformation which takes place in Iron-carbon system of alloy during heating

(3) A_3 line: upper critical temp line for hypoeutectoid steels.

— this line signifies the transformation ferrite into austenite upon heating of ~~eut~~ hypoeutectoid steels.

(4) Acm line:- upper critial temp. line for hypereutectoid steels.

→ this line signifies the transformation of cementite into austenite upon heating of hypereutectoid steels.

ferrite → γ
Pearlite → γ
cementite → γ

Heat treatment

→ Recrystallisation temp of steel (625–725°c)

(1) Annealing → medium – C steels
(2) Normalising] → High carbon steels
(3) Hardening]
(4). Surface Hardening (Case Hardening)
→ Carburising] → low C steels
→ Nitriding]
→ Cyaniding]
→ ~~Carbo~~ Induction Hardening] → High – C steels.
→ flame Hardenining]

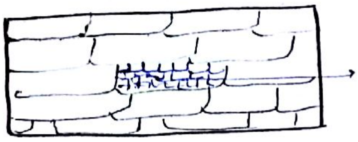
Annealing

* steel is Heated to completely (γ – austenite range) (+500–100°) about it
* Held at that point for 30–60 min. four uniform austenization.
* followed by cooling to room in the furnance itself.

Consequences:

Recovery
↓
- Residual stresses are completely removed.
↓
- Ductility recovered
- formality ↑

Recrystallisation
↓
formation of new (stress free) equi-axed fine grain structures from coarse collumnar grain structure of previously cold worked metal.



→ Recrystalisation (solid transformation process)

Grain growth.
↓
⇒ Strength will ↓ decreass
⇒ Hardness will ↓ decrease
⇒ Carse grains are formed
⇒ machibility ↑

→ By anneling → Austenite converted into coarse pearlite.

Normalising:-

→ steel is completely (γ- range) [or +(50-100) above it]

→ Held at that temprature for - 30-60 min, for uniform austenisation to take place

→ followed by cooling to room temp in open air.

Consquences:-

- * fine grain structure
- * more strength & Hardness
- * less machinability
- * ductility less
- * formability will be less
- * Residual stresses partially relieved

→ due to faster cooling rate, there is not enough time ~~to~~ for grains to grow

compared to annealed steel.

⇒ Austenite transforms into fine pearlite.

Hardening process:

• In hardening, high carbon steel is heated to completely to about 1000°c • followed by sudden cooling (quenching) in water.

quenching media → molten Pb, molten Nacl, Heated oil, Brine sol^n -

Consquences:-

- * Residual stresses are induced [due to sudden quenching]
- * surface cracking [quench cracking]
- * Corrosion can take place (metal oxide)
- * distortion of shape can take place
- * Retained Austenite formation take place.

⇒ not enough time for carbon, thus martensite goes to BCT - (Body centred Tetragonal) due to having more carbon than its capacity at room temp.

$$\boxed{\underset{(FCC)}{\gamma} \longrightarrow \underset{(BCT)}{\text{martensite}} \text{ —(supersaturated solution)}}$$

⇒ Complete austenite are not transformed to martensite ; thus some austenite is retained.

⇒ Retained austenite is unstable → (with decreasing temp. austenite goes FCC to BCC) Because (at low temp. ~~At~~ FCC is not stable in iron).

⇒ Retained austenite is unstable at room temp. It brings ~~about~~ at dimensional ~~d~~ changes in the previously hardened component. Hence it should be eliminated.

⇒ Characteristics of austenite to martensite transformation

- $\gamma \rightarrow$ martensite at the speed of sound ~~ø~~ in the material being quenched.
- $\gamma \rightarrow$ martensite transformation, does not depend on the time.
- $\gamma \rightarrow$ martensite transformation, is diffusionless process.
- $\gamma \rightarrow$ martensite, transformation, takes place by the process of "shear." [cooling stress causes shear, shear component of compress. cooling stress]
- $\gamma \rightarrow$ martensite transformation, never goes to hundred 100% completion at room temp. (Retained austenite formation takes place).

Note:

$\gamma \rightarrow$ austenite ~~de~~transformation, time-dependent, and diffusion process.

mass transport can take place → ① time depend diffusion
② time independent shear mechanism.

⇒ method of elimination of austenite :

- ~~ᵹ~~ sub-zero cooling.
- Permanent deformation :
- High temp. tempering :

(1) Sub-zero cooling:

→ at [−37°C] 100% completion of γ → martensite.
use cryogenic liquids [~~(x)~~ liquid He, liquid N_2]

→ Retained Austenite goes into martensite

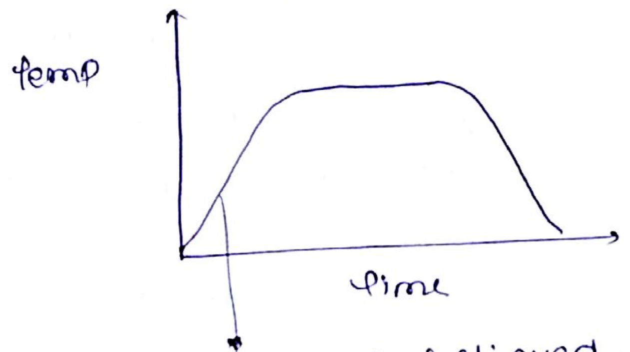
(2). permanent deformation:-

→ By adding ⊙ uniform deformation [using Hydraulic press], By Shearing → ~~BC~~ γ → BCT (martensite)

→ only allotropic Retained transformation which is influenced by pressure. But pressure changes only a small amount of crystal structure

(3) High temperature tempering:- [550° - 650°C]

→ Reaheating to high temp, Holding for long time and then gradual cooling



→ previously hardened component

→ no significant changes in marthensite
(Rc = 65)

→ Residual stresses are relieved

→ Ductility increases (Tougness increases).

and $\gamma_{RA} \longrightarrow$ Bainite
$R_c = 55$
↓
Rockwell Hardness number on 'c' scale.

⇒ High temp. tempering of alloy steel, ~~due~~ precipitation of alloy elements ~~precipitation~~ carbides, → which cause hard & brittleness ↑.

Martempering → quenching in different ~~one~~ stages.

Austempering:- quenching in molten Pb, [Pb is kept at high temp for long time]
→ from 1000°C to molten Pb temp.

Ausforming → Rapid cooling to A_1 line and then metal forming process.

• Surface Hardening :-

① Carburising → low C. steels → High C-steels

→ in the presence of charcol → solid (Pack) carburising.

→ when Heating in molten NaCl → Liquid ~~(Bath)~~ carburising.

→ using flue gas, carbon atoms into steel → gas carburising.

— need for quenching.

— High carbon steels → surface austenite → martensite. — 800 VHN

quenching

② Nitriding: faster than carburising

→ Nitrides more hard than carbon → 1100 VHN

→ But Brittle surface formation → less life of component

~~Carbon~~ ③ Cyanding (carbonitriding):-

→ ~~NaCN~~ molten salt NaCN →

⇒ where carbon is there on surface → necessory to quench to improve hardness

→ 1000 VHN →

→ cyaniding cases are having more life.

④ Induction :- due to induction, secondary current are generated on surface.

→ minimum requirement of supply 2 KHz, so need high frequency (costly).

⑤ Flames:- using Neutral flame → used for cast iron

→ cheapest for large surfaces.

Cast irons:

1. good damping capacity
2. Good wear resistance
3. self-lubricant (due to graphite flakes)
4. high compressible strength
5. (3-4 times of tensile strength) = compressive strength
6. ~~aligned~~ (form stability) → to Retain its shape.

→ flame Hardening and tempering is used to relieve stresses.

→ pipe

Pig iron - raw material .

WCI ↓ GCI

GCI → self lubricant / damping
└→ used for machine tool beds.
↓
fracture surface is grey

WCI
↓
faster cooling , ~~silicon~~
↓
internal structure → cementite
↓
hard, wear resistant.
↓
fracture surface is white

Effect of alloying elements:

Elements	Effects.
(1) Silicon : potential deoxidizers → its is a solid solution strengthens i.e. it dissolves in ferrite & increases tensile strength & toughness without decreasing ductility.	~~potent~~ → silicon increase in Resilience in spring steels → sillicon makes the steels magenetically soft. for use in electrical application.
(2). sulpher :→	it reacts with iron and produces iron-sulphide inclusions → sulpher induces cracking tendency at high tempratures. → ~~sulpher~~ iron-sulphide inclusion has low melting point temp, saggregate along the grain boundaries and increases brittleness of steel.
(3) phosphorous :–	⇒ it reacts with iron and forms iron-phosphide which makes the steel brittle. → phosphorous increases machinability

if added in small quantity.

→ phosphorus induces cracking tendency at low temp. known as- cold shortness.

(4) Mangenese: (mn)

- magnese dissolves in ferrite increases tensile strength and hardness. wear resistance.
- magnese promotes cracking tendency during quenching.
- → magnese is an austenite stablizers; when added in small quantities, ~~ma~~ Mn improves machinability of steel .

(5) Ni (Nickel)

- → austenite stabilizers.
- → nickel increases corrosion resistance. & Toughness without decreasing ductility.
- nickel decreases the coefficient of thermal expansion in steels

(6) Cr, W, V, Mo & Ta,

- → are carbide-forming elements.
- → they increase hardness and wear resistance.
- → They are used as grain size refiners.

Note → Cr → predominates increases corrosion Resistance
→ W → predominately increases Hot strength
→ Mo → predominatelay increases creep resistance
→ V → predominately increase fatigue resistance
→ Ta → predominantely increases Hot hardness and creep resistance.

(7) Boron (B).

- → it refines grain size, Increases surface Hardness.
- Corrosion resistance, wear resistance

(8) Titanium (Ti)

- → strong carbide forming elements
- → it increases the creep resistance & Refines the grain size.

(9) Nobium: (Nb)

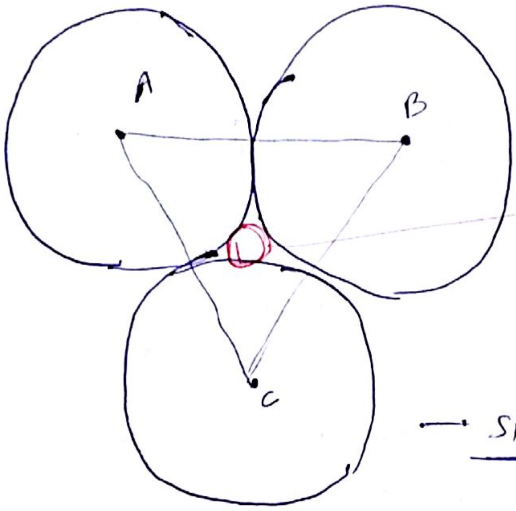
- → It forms stable carbides; Increases Hot Hardness and creep resistances

- Characteristics of ceramics:-

→ SiC – metaloid carbide (not a ceramics).
→ Hard and brittle
→ Insulators of Heat
→ at high temp – they show :

⇒ Stable crystal structures are formed in ceramics according to the following principles :-

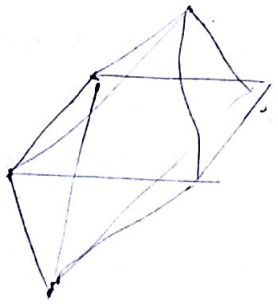
(1) minimum radius ratio b/w cations and anions.
(2) Electrical charge neutrality in the lattice.
(3)



→ stable (minimum radius) must be to stable)
↓
depends on the coordinates

— Simplest coordination

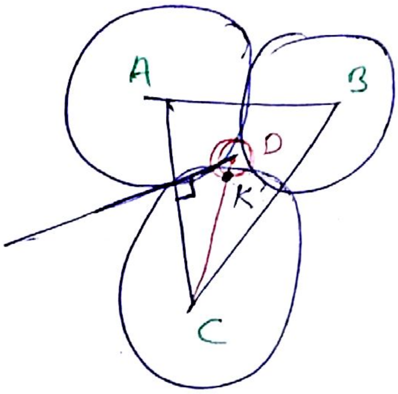
– In triangular coordination, the coordination no. of cations is 3.
→ In tetrahedral co-ordination, the coordination no. of cations is 4.
– In Octahedral co-ordination, the co-ordination no. of cations is 6.



– In cubic coordination, coordination no. of cations is 8
– In FCC, HCP coordination, coordination ~~no.~~ no. of cations is 12.

r_a = radius of anion = CK = CM

r_c = Radius of cation = KD



⇒ CD =

from ΔCMD

$$\cos\alpha = \frac{CM}{CD} = \frac{r_a}{r_a+r_c}$$

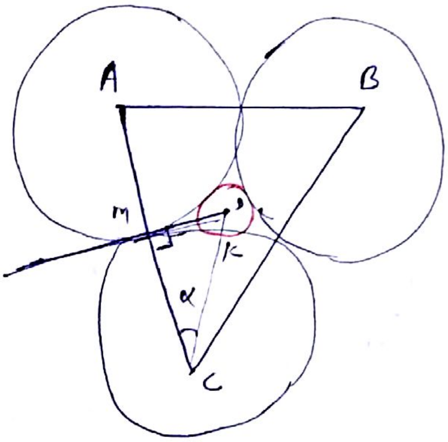
But

$\alpha = 30^\circ$, therefor

$$\cos 30 = \frac{\sqrt{3}}{2} = \frac{r_a}{r_a+r_c}$$

⇒ ~~$r_a\left(\frac{\sqrt{3}}{2}\right)$ [illegible] $+2r_a =$~~

$$\left(\frac{\sqrt{3}}{2}\right) r_c = r_a - \left(\frac{\sqrt{3}}{2}\right) r_a$$



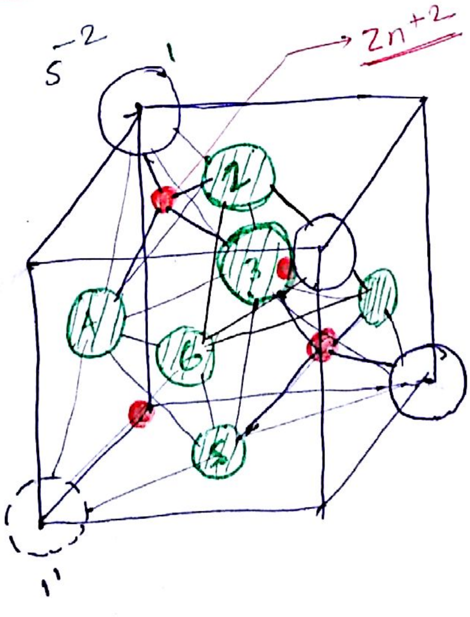
$$\Rightarrow \frac{r_c}{r_a} = \frac{2-\sqrt{3}}{\sqrt{3}} =$$

$$\Rightarrow \boxed{\frac{r_c}{r_a} = 0.1547 \simeq 0.155}$$

⇒ $r_c < r_a(0.155)$ → unstable

⇒ The above expression gives minimum radius of cations, required to make a stable crystal structure in triangular co-ordination.

Zinc Blende (ZnS) structure :-



→ coordination no. of anion (Zn^{+2}) = 4

→ Tetrahedral coordination

Nav of $\bar{S}^{2}$ = 4

⇒ each $\bar{S}^{2}$ gives a charge = −2

∴ Electrical charge due to $\bar{S}^{2}$ ions = −8 [4× −2]

⇒ each Zn^{+2} gives a charge = +2

no. of Zn^{+2} ions needed for charge neutrality = 4

- All plastics are Polymers ?? or polymers are plastics ??

→ Natural polymer – are not ~~poly~~ plastic

→ when synthetic polymer are called as plastics when additives are added to it.

additives are :- to plastics:-

(1). fillers → strength ↑ & hardness ↑
(2). Stabilizers → provide protection against uv radiation
(3). platticizers → ↑ ductility.
(4). dyes & pigments → colouring agents.
(5). fire redants → protection against fire and flames

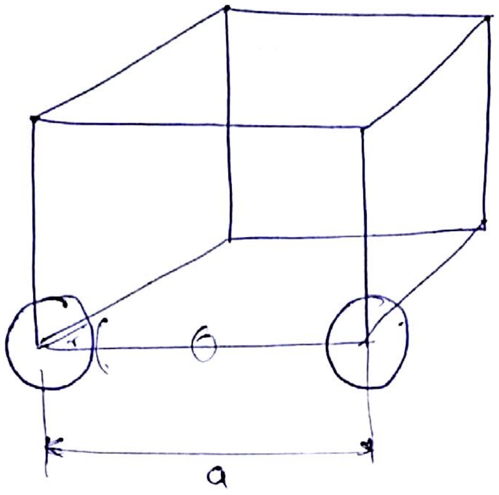
crosslinked → Rigid structure formation

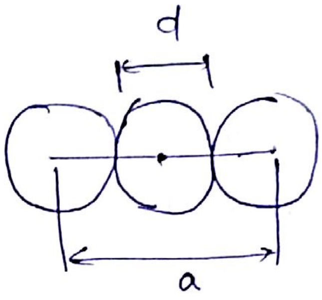
→ Thermosetting exhibit ~~the~~ sublimation tendency

→ thermosetting → decomposition →

Q Find the dia. of largest imaginary sphere which can be fittest in voids at the centre of cube edge of BCC crystal.

Soln





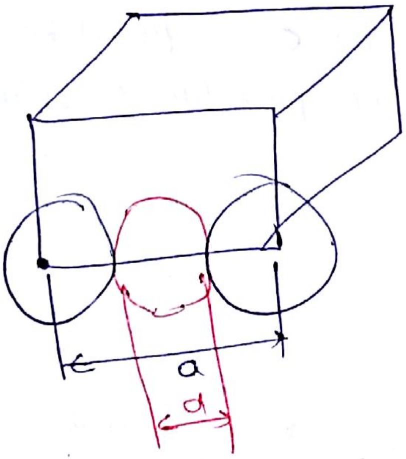
$$d = a - 2r$$

$$a = \frac{4r}{\sqrt{3}}, \quad r = \frac{\sqrt{3}}{4}a$$

$$d = a - \left(\frac{\sqrt{3}}{4}a\right)2$$

$$\boxed{d = 0.1339a}$$

Q Find the dia. of largest imaginary sphere which can be filled at the centre edge of and fcc crystal.



$$\Rightarrow d = a - 2r$$

$$d = a - \frac{2\sqrt{2}}{4}a$$

$$\boxed{d = 0.292\,a}$$

Note above two problems, it can be noted that interstitial void size in fcc is more than interstitial void size in BCC

Quest . Cu have fcc structure, its atomic radius is 1.28A° and itomic atomic mass is 63.5 calculate its density

Soln

$$\rho_v = \frac{4\times 63.5}{6.023\times10^{23}\times\left(\frac{4}{\sqrt{2}}\times 1.28\times10^{-8}\ cm\right)^3}$$

$$\boxed{\rho_v = 8.887\ gm/cm^3}$$

Ques A plane intersects the ~~coordinate~~ co-ordinate axes at $\left(x = \frac{2}{3}\right)$ $y = 1/3$ $z = 1/2$.

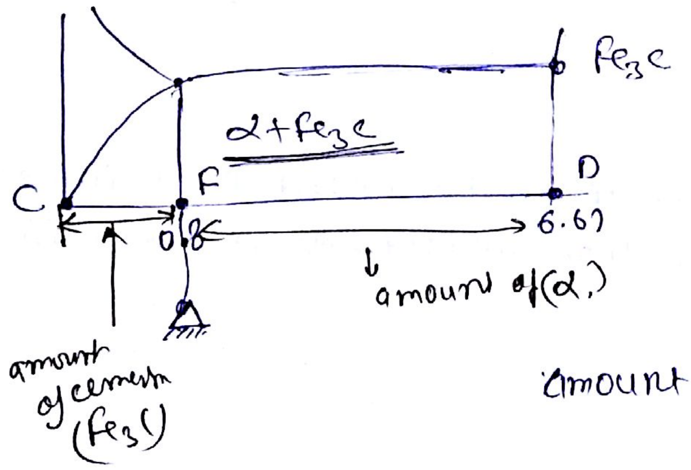
what are miller indices.

sol

	X	Y	Z
int	2/3	1/3	1/2
Recip	3/2	3.	2
Ration	~~6~~ 3	6	4
miller	[3 6 4]		

Quest At room temp α-iron contains negligible amount of carbon. cementite contains 6.67% of 'C'. pearlite contains ~~a~~ 0.8% carbon. determine pearlite contains how much amount of cementite

Soln



$\alpha + fe_3C = 0.8\ c$

$$\text{amount of cement} = \frac{CF}{CD}\times 100$$

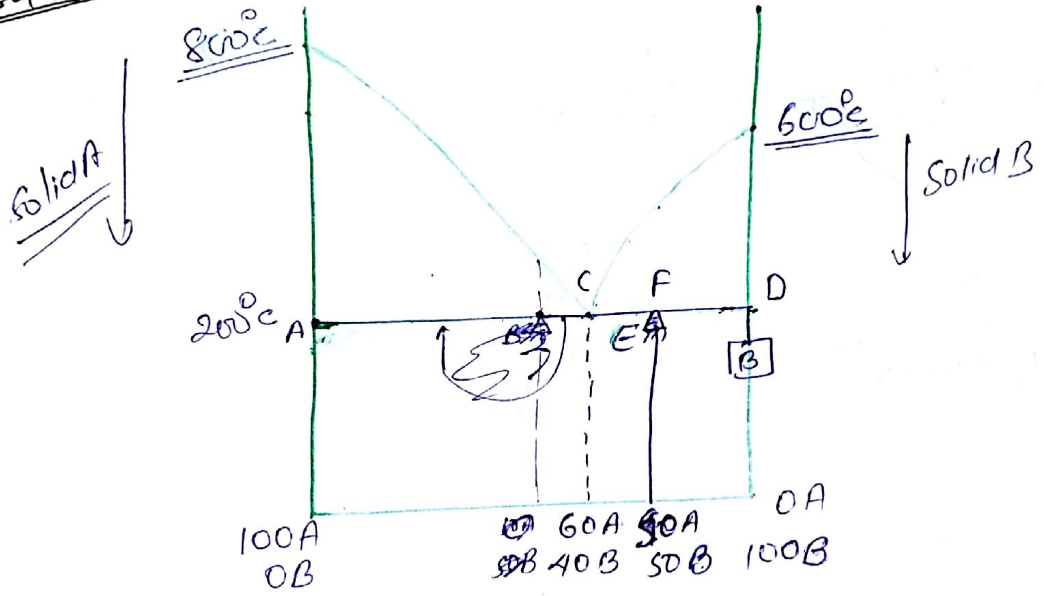
$$= \left(\frac{0.8}{6.67}\right)\times 100$$

$= 11.99\ \%$

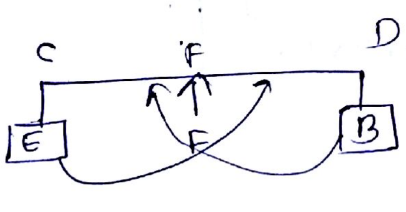
Quest. Two metals A and B are completely ~~immiscible in both~~ liquid~~s state and solute~~ solid ~~state~~. melting of 'A' ⇒ 800°c melting point B = 600°c.

they form eutectic at 200°c with 40% B and 60% A, then Determine; how much ~~m~~ amount of 'B' and eutectic will be free A in 50% B alloy.

Soln



Eutectic amount = $\frac{BA}{AE} = \frac{50}{6}$



amount of B = $\frac{CF}{CD} \times 100$

amount of Eutectic = $\frac{FD}{CD} \times 100$

amount of 'B' = $\frac{10}{60} \times 100 = 16.67\%$

amount of Eutectic = $\frac{50}{60} \times 100 = 83.33\%$

Ques

⇒ The fraction of vacancy sites in a metal is 1×10^{-10} at 500°C find out the fraction of sites at 1000°C

$T_1 = 500+273 = 773$

Soln

$$\frac{n_v}{n_t} = e^{-(E/KT)}$$

$$\Rightarrow \quad \ln\left(\frac{n_v}{n_t}\right) = -\left(\frac{E}{KT}\right)$$

$$\ln(1\times10^{-10}) = -\left(\frac{E}{K\times773}\right)$$

$$x = \ln\left(\frac{n_{v_2}}{n_{t_1}}\right) = -\left(\frac{E}{K\times1273}\right)$$

$$\Rightarrow \quad \frac{x}{\ln(1\times10^{-10})} = \frac{\cancel{-}\frac{E}{K\times1273}}{\cancel{-}\frac{E}{K\times773}}$$

$$x = \left(\frac{773}{1273}\right)\times$$

$$x = -13.9819$$

$$\log_e\left(\frac{n_{v_2}}{n_t}\right) = -13.9819$$

$$\boxed{\frac{n_{v_2}}{n_t} = 8.467\times10^{-7}}$$