22/8/23

→ Reference Books :

1) Materials – William D Callister

2) Material Science – Michael Ashby

→ Material Science :

Structure ← Processing

- Subatomic
- Atomic
- Micro
- Macro

Properties → Performance

- Mechanical
- Electrical
- Magnetic
- Optical
- Detereorative

23/8/23

→ Note :

1) T_m is larger if E_b is more.

2) Atomic Packing Factor

$$APF = \frac{\text{Volume of atoms in unit cell}}{\text{Volume of Unit Cell}}$$

(Assume Hard Spheres) → (Solid State)

25/07/23

α - Fe : BCC ~~(<912°c)~~ (25°c - 912°c)

γ - Fe : FCC ~~(1394°c)~~ (912°c - 1394°c)

δ - Fe : BCC ~~(1538°c)~~ (1394° - 1538°c)

(liquid) Fe : liquid (>1538°c)

7 crystal systems

a b c ⟶ Lattice points

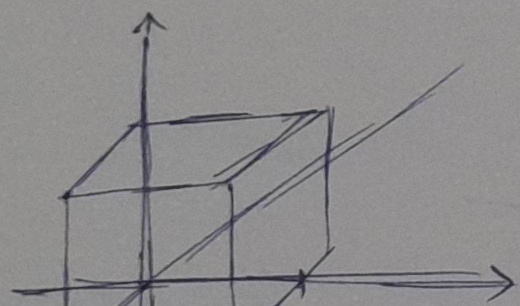
Cubic : $a = b = c$ $\alpha = \beta = \gamma = 90°$

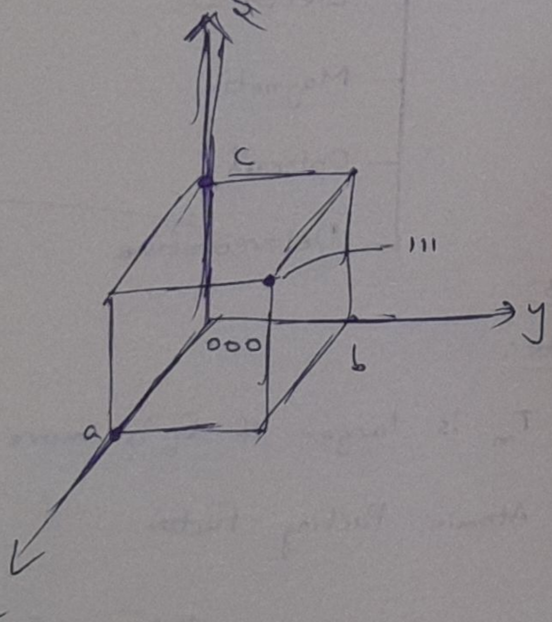
Hexagonal : $a = b \neq c$ $\alpha = \beta = 90°, \gamma = 120°$

Tetragonal : $a = b \neq c$ $\alpha = \beta = \gamma = 90°$

Triagonal (Rhombohedral) : $a = b = c$ $\alpha = \beta = \gamma \neq 90°$

Orthorhombic

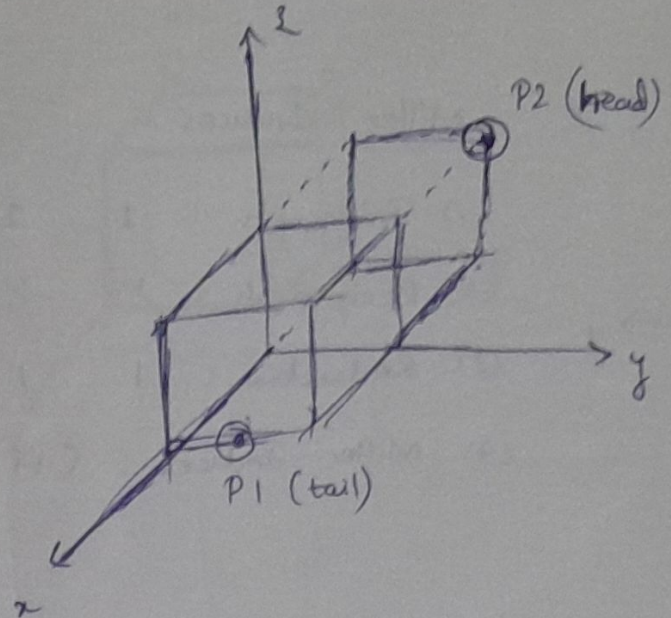




Indices : Fractional Multiples of a, b, c

Position coordinate for unit cell corner are 111

(P_x P_y P_z)



$x_1 = a \quad y_1 = b/2 \quad z_1 = 0$

$x_2 = -a \quad y_2 = b \quad z_2 = c$

$$\frac{-a-a}{a} \quad \frac{b-b/2}{b} \quad \frac{c-0}{c}$$

$\Rightarrow -2, \frac{1}{2}, 1$

$\Rightarrow -4, 1, 2$

$\Rightarrow [\bar{4}12]$

Crystallographically Equivalent :

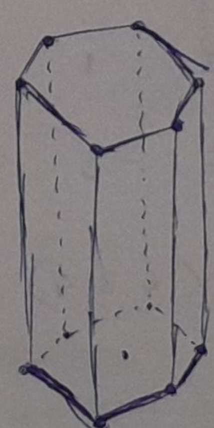
Several non-parallel directions with different Indices have ~~spaces~~ spacing of atoms

Ex. $[100]$, $[\bar{1}00]$, $[010]$, $[0\bar{1}0]$

Family of Directions : $\langle 100 \rangle$

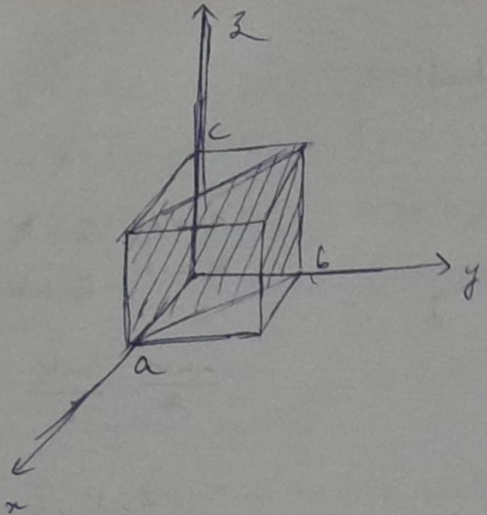
↳ Represents $[100]$ and $[\bar{1}00]$

HCP :



Family of Directions ~~{~~ : $\langle pqrs \rangle$

Ex.



Miller Indices :

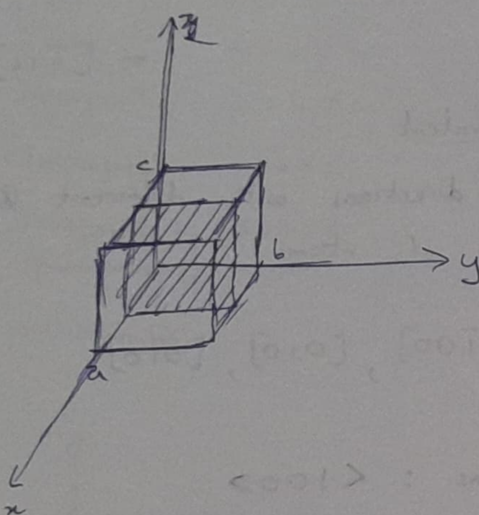
(1) Intercepts : 1 1 ∞

(2) Reciprocals : $\frac{1}{1}$ $\frac{1}{1}$ 0

(3) Reduction : 1 1 0

(4) Miller Indices : (1 1 0)

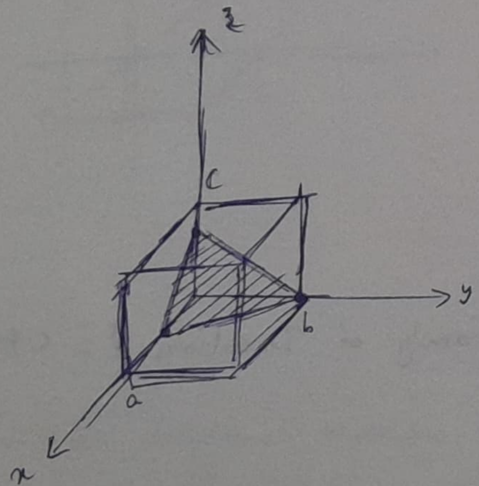
Ex.



Intercepts : $\frac{1}{2}$ 0 0

Miller Indices : (1 0 0)

Ex.



$\frac{1}{2}$	1	$\frac{3}{4}$
2	1	$\frac{4}{3}$
6	3	4

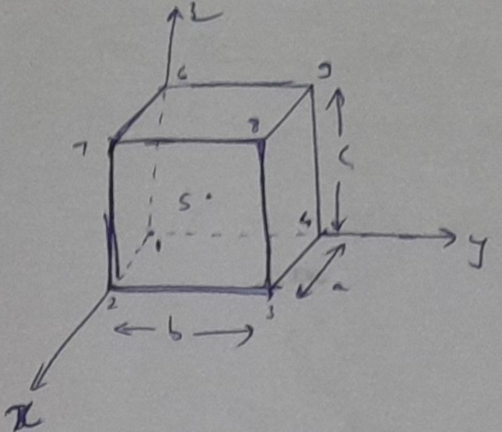
Miller Indices : (6 3 4)

Family of Planes : {h k l}

Ex. {1 0 0} = (1 0 0), (0 1 0), (0 0 1), ($\bar{1}$ 0 0), (0 $\bar{1}$ 0), (0 0 $\bar{1}$)

True only for Cubic Systems

Q)



1 (0, 0, 1)

2 (1, 0, 0)

3 (1, 1, 0)

4 (0, 1, 0)

5 ($\frac{1}{2}$, $\frac{1}{2}$, $\frac{1}{2}$)

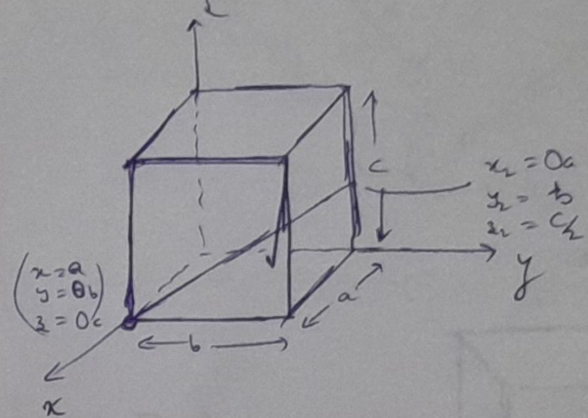
6 (0, 0, 1)

7 (1, 0, 1)

8 (1, 1, 1)

9 (0, 1, 1)

Q)

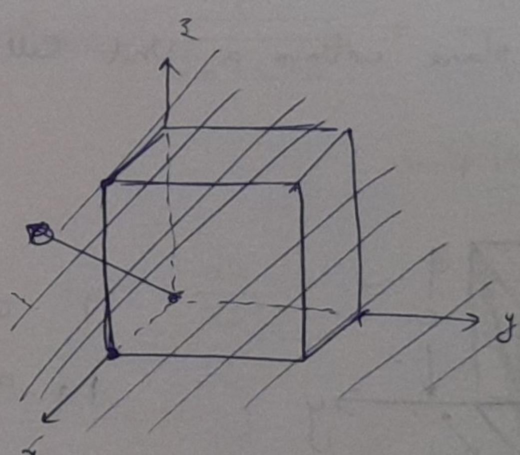


$-2 \quad 2 \quad 1$

$[\bar{2}21]$

$-a \quad b \quad c/2$

Q) Within a Unit Cell draw a [1 -1 0] direction



Assume tail @ origin (0, 0, 0)

$x_1 = 0a$

$x_2 = 0b$

$x_3 = 0c$

Head @ $[1 \ -1 \ 0]$
u v w

~~$x_2 = ua + x_1$~~

$u = \frac{x_2 - x_1}{a}$

$v = \frac{y_2 - y_1}{b}$

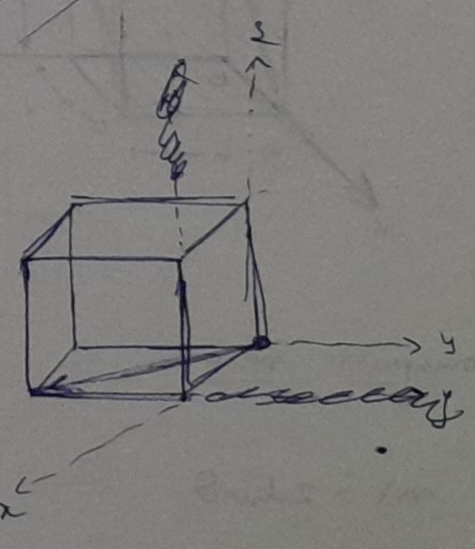
$w = \frac{z_2 - z_1}{c}$

$\Rightarrow$

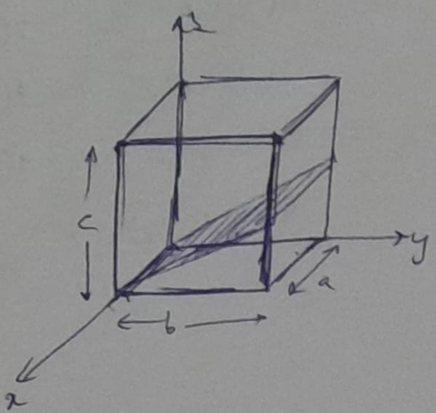
$x_2 = ua + x_1$

$y_2 = vb + y_1$

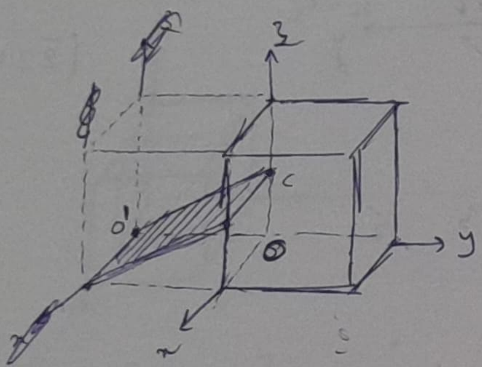
$z_3 = wc + z_1$



Q) Determine Miller Indices

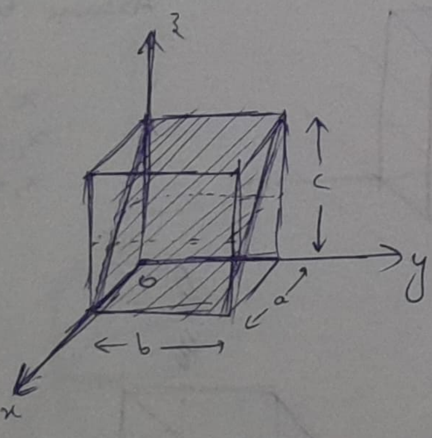


Sol :



$(0\bar{1}2)$

Q) Construct a $(10\bar{1})$ plane within a Unit Cell



1 0 1

1a ∞b 1c

→ Electromagnetic Spectrum:

$n\lambda = 2d\sin\theta$

Bragg's Law ;

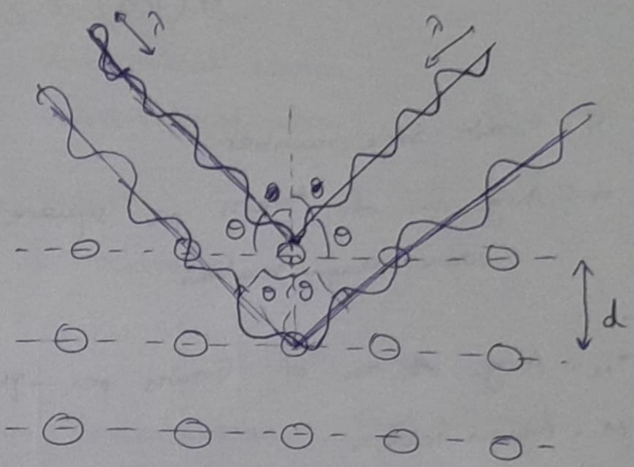
Assumption - Atoms are only at corners

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

For BCC, $h+k+l$ must be even

For FCC, $h+k+l$ can be either odd or even

$h, k, l \longrightarrow$ Miller Indices



9) $n\lambda = 2d\sin\theta$

$n = 1$
$a = 0.2866$ nm
$\lambda = 0.1790$ nm
Fe, BCC, (220)

$$d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}} = \frac{0.2866\times10^{-9}}{\sqrt{8}}$$

$$= 0.1013 \text{ nm}$$

$$\sin\theta = \frac{n\lambda}{2d}$$

$$= 1\frac{\lambda}{2d}$$

$$\theta = \sin^{-1}\left(\frac{0.1790}{2\times0.1013}\right)$$

$$\Rightarrow \boxed{\theta = 62.13^\circ}$$

Diffraction Angle $\approx 124^\circ$ $(= 2\theta)$

→ Grain Size Determination:

$$\bar{l} = \frac{L_T}{PM}$$

↳ mean Intercept width

P: Total no of Intersections
M: Magnification
L_T: Total Length of lines

Method-2

for 100x Magnification, | for other magnification,

$n = 2^{G-1}$ | $n_M \left(\frac{M}{100}\right)^2 = 2^{G-1}$

G: Grain Size number

n: Avg. no. of Grains per square inch at 100x Magnification

n_M: Avg. ~~of~~ no. of Grains per square Inch

M: Magnification

Q) Length of scale bar = 16 mm
Length of each line = 50 mm

$$M = \frac{16\times10^{-3}}{100\times10^{-6}} = \frac{16\times10^{-3}}{10^{-4}} = \underline{\underline{160x}}$$

Line	
Total : 7	Total : 58

First Quiz: Sept 18

$$\bar{l} = \frac{L_T}{PM} = \frac{7\times50}{58\times160} = 7.5\times10^{-4}\times50$$
$$= 0.0375$$

$$\cancel{n_M \left(\frac{16}{10}\right)^2 = 2^{G-1}}$$

$$G = -6.6457\log(\bar{l}) - 3.298$$
$$= 9.4765 - 3.298$$
$$= 6.17856$$

1/9/23:

Imperfections / Defects

Point defects:

- Vacancy atom
- Interstitial atoms
- Substitutional atom

Line Defects:

- Dislocation

→ Equilibrium Concentration: Point Defects

$$\frac{N_v}{N}$$

N_v → No. of defects

N → No. of Potential defect sites

$$\frac{N_v}{N} = e^{\left(-Q_v/kT\right)}$$

Q_v : Activation Energy

k : Boltzmann's constant

$k = 1.38 \times 10^{-23}$

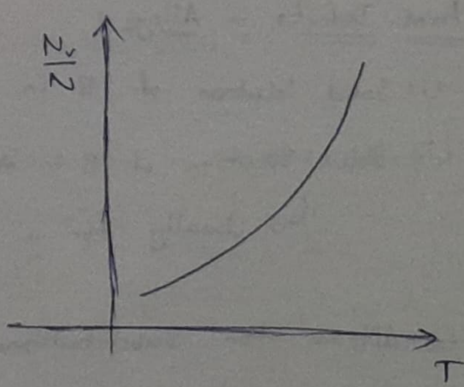
T : Temperature

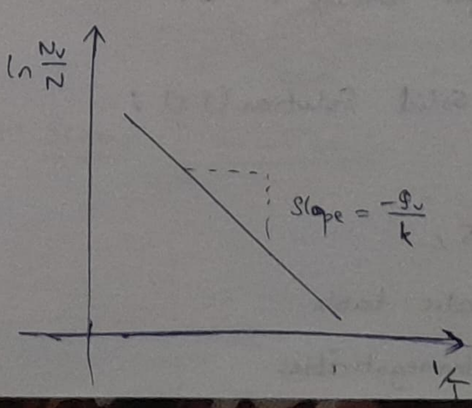
H.W

Q) Why are there more vacancies sites than self Interstitial sites?

→ $$\frac{N_v}{N} = e^{-Q_v/RT}$$

$$\Rightarrow \ln\left(\frac{N_v}{N}\right) = \frac{-Q_v}{RT}$$





Q) Estimating Vacancy Concentration

Find the eq. No. of Vacancies in $1\ m^3$ of Cu at $1000°C$

$\rho = 8.4\ g/cm^3$

$Q_v = 0.9\ eV/atom$

$A_{Cu} = 63.5\ g/mole$

$N_A = 6.02 \times 10^{23}$ atoms/mol.

$$\frac{N_v}{N} = e^{-Q_v/kT}$$

$$\Rightarrow N_v = N e^{-Q_v/kT}$$

$$= (N)\ e^{\left(-0.9/8.62\times10^{-5}\times1273\right)}$$

& $N = \rho \times \frac{N_A}{A_{Cu}} \times 1\ m^3 = 8\times10^{28}$ sites

$$N_v = 8\times10^{28} \times e^{\frac{-0.9}{8.62\times10^{-5}\times1273}}$$

$$= 2.7\times10^{-4}$$

→ **Point Defects :**

(i) Frenkel Defect

(ii) Schottky Defect

Point Defects in Alloys :

(i) Solid Solution of B in A (random dist. of point defects)

(ii) Solid solution of B in A + particles of a new phase

↳ Usually for a larger amount of B.

Conditions for Substitutional Solid Solution (S.S) :

→ W. Hume - Rothery Rules

High priority ① Δr (atomic radii) < 15%

② Proximity ~~of~~ in periodic table

i.e. Similar Electronegativities

③ Same crystal structure for pure metals

④ Valency

→ Specification of Composition :

$$C_1 = \frac{m_1}{m_1 + m_2} \times 100$$

m_1 : mass of 1st Component

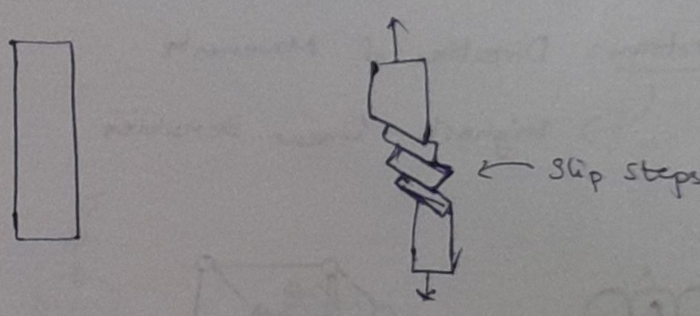
$$C_1' = \frac{n_{m_1}}{n_{m_1} + n_{m_2}}$$

n_{m_1} : no. of moles of 1st Component

~~Line~~

→ Line Defects :

Schematic of Zinc (HCP) : (Dislocation)



Before Deformation

After Deformation

→ Edge Dislocation Line :

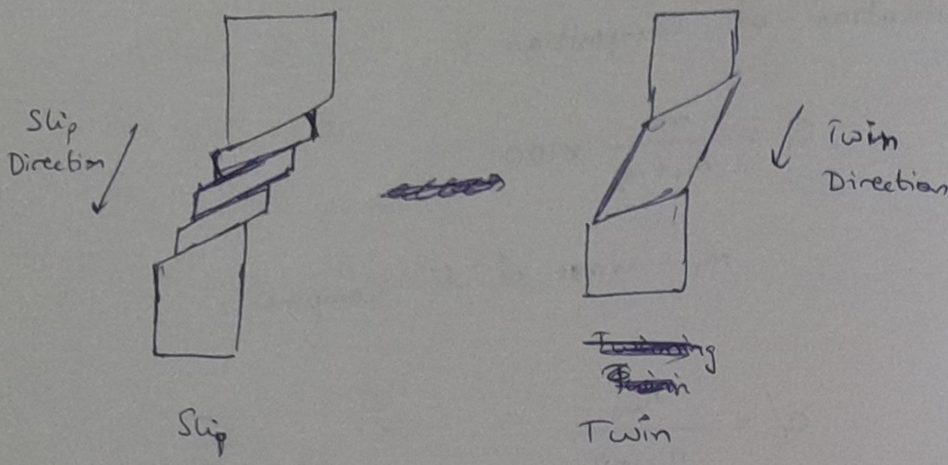
burgers Vector ⊥ Edge Dislocation plane
($\vec{b}$)

→ Amount of ~~da~~ Distortion in Lattice when Edge is Dislocated
[Forming Circuit]

→ Screw Dislocation :

4/9/23

Slip Systems:



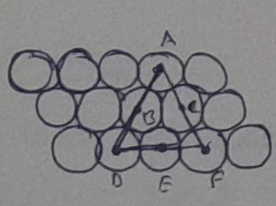
Plastic Deformation is due to movement of Dislocations

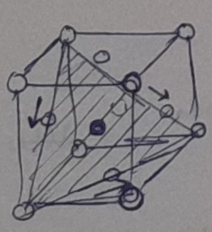
Slip Plane: Plane having the highest Density

↳ Plane on which easiest Plane occurs

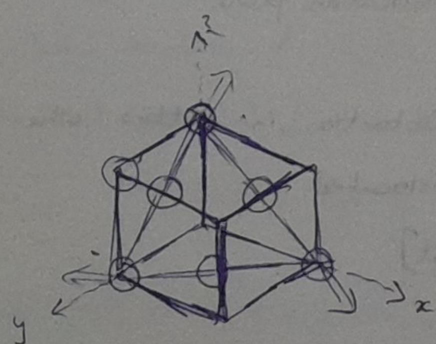
Slip Directions: Direction of Movements

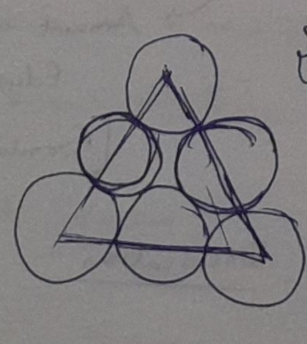
↳ Highest Linear Densities





↳ Total of 12 planes in FCC





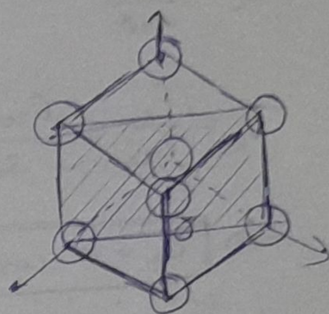
{1, 1, 1}

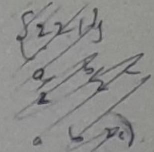
FCC	Slip Planes	Directions
12	4	3

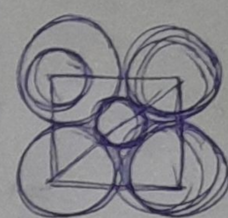
BCC	Slip Planes	Directions
12	6	2

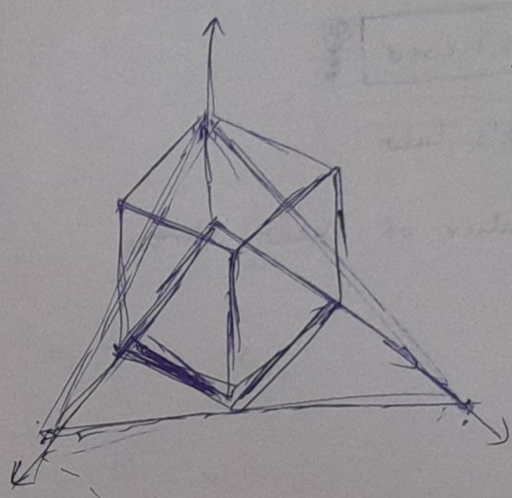
{110}

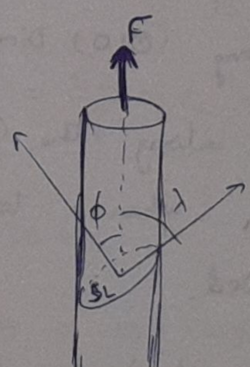
{211}







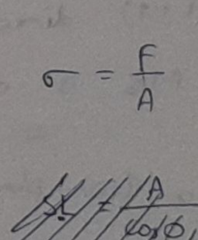




$\tau_R = F\cos\lambda$

$\sigma = \frac{F}{A}$

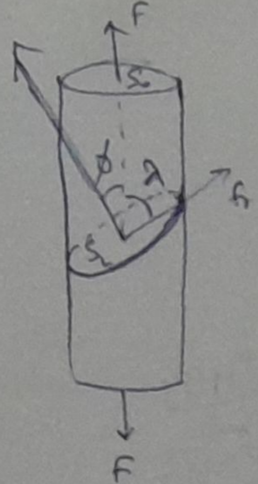
$S_L = \frac{A}{\cos\phi}$



$\tau_R = \frac{F_r}{S_L} \Rightarrow F\cos\lambda = \frac{F_r}{A}\cos\phi$

$\Rightarrow \tau_R = \sigma \cdot \cos\lambda \cdot \cos\phi$

6/9/23



$\phi \neq 90 - \lambda$ (always)

3D figure

$$\sigma = \frac{F}{A} = \frac{F}{S_0}$$

$$F_r = F\cos\lambda$$

$$S_1 = \frac{S_0}{\cos\phi}$$

$$\tau_R = \frac{F_r}{S_1} = \frac{F\cos\lambda}{S_0} \cdot \cos\phi$$

$$\Rightarrow \boxed{\tau_R = \sigma \cdot \cos\lambda \cdot \cos\phi}$$

Schmidt's Law

τ_R = Critical Value of sheer stress

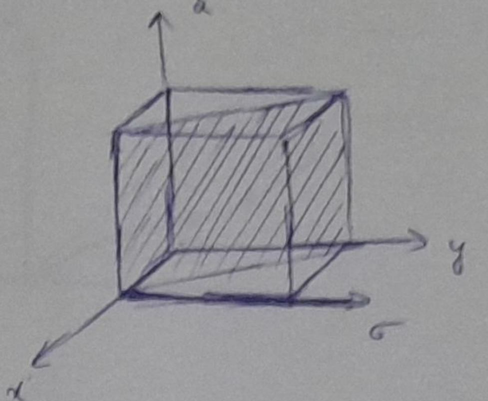
$$\Rightarrow \tau_R = \tau_{crss}$$

$$\sigma_Y = \frac{\tau_{crss}}{\cos\lambda \cdot \cos\phi}$$

Q) Consider a single crystal of BCC Iron oriented such that a tensile stress is applied along (010) Direction

(i) Compute the Resolved Sheer stress along the (110) plane and in a $(\bar{1}11)$ direction when a Tensile stress of 52 MPa is applied

(ii) If Slip occurs on a (110) plane and in a $(\bar{1}11)$ direction, the Critical Resolved Sheer Stress is 30 MPa. Calculate the magnitude of the applied tensile stress necessary to initial slipping.



(i) $$\theta = \cos^{-1}\left(\frac{u_1u_2 + v_1v_2 + w_1w_2}{\sqrt{u_1^2+v_1^2+w_1^2}\ \sqrt{u_2^2+v_2^2+w_2^2}}\right)$$

$$\lambda = \cos^{-1}\left(\frac{0\cdot(-1) + 1\cdot 1 + 0\cdot 1}{\sqrt{0^2+1^2+0^2}\ \sqrt{1+1+1}}\right)$$

$u_1 = 0$ $\quad u_2 = -1$
$v_1 = 1$ $\quad v_2 = 1$
$w_1 = 0$ $\quad w_2 = 1$

$$= \cos^{-1}\left(\frac{1}{\sqrt{3}}\right)$$

$$\Rightarrow \lambda \approx 54.7^\circ$$

$u_1 = 0$
$v_1 = 1$
$w_1 = 0$

$$\phi = 45^\circ$$

$u_2 = 1$
$v_2 = 1$
$w_2 = 0$

$$\tau_R = 52 \times \frac{1}{\sqrt{3}} \times \frac{1}{\sqrt{2}}$$

$$= \frac{52}{\sqrt{6}}\ MPa = 21\ MPa$$

(ii) $\tau_R = 30\ MPa$

$$\Rightarrow \sigma \cos\lambda \cdot \cos\phi = 30\ MPa$$

$$\Rightarrow \sigma = \frac{30}{\cos\lambda \cdot \cos\phi}$$

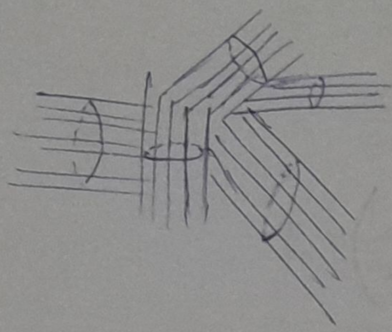
$$\Rightarrow \sigma = \frac{30}{\frac{1}{\sqrt{3}} \times \frac{1}{\sqrt{2}}} = 30\sqrt{6}$$

$$\therefore \sigma = 73.485\ MPa$$

$\tau_R = \sigma \cos\lambda \cos\phi$

$\tau_{CRSS} = \sigma_Y \cos\lambda \cos\phi$

→



Difficult for Plastic Deformation due to Uneven Slip directions

(Movement of Slip of Grains oppose each other)

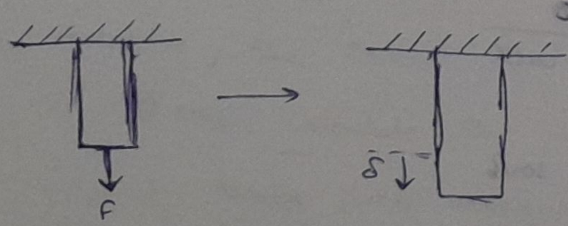
Grain Boundaries are strong, Hence not easy to deform

↳ Due to Surface Tension (Imbalance forces of Surface atoms)

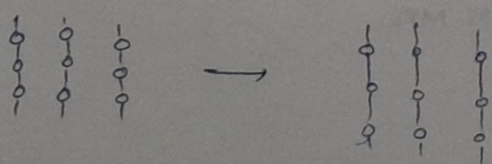
<u>11/9/23</u>

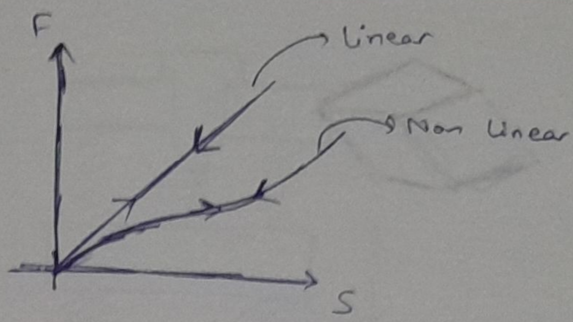
Mechanical Properties :

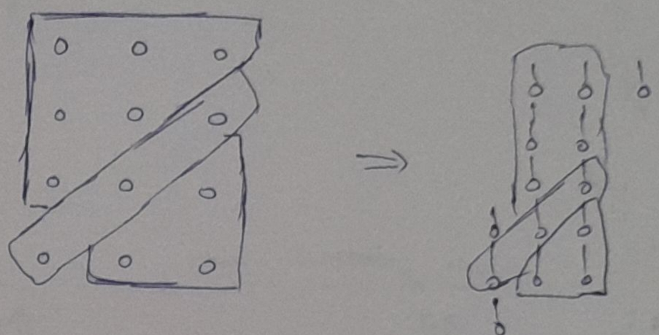
- Stress
- Strain
- Elastic Behaviour
- Plastic Behaviour (Metals)



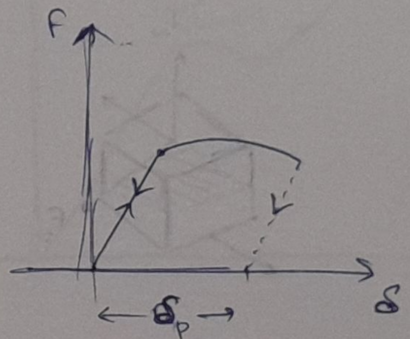
(Elastic Behaviour)



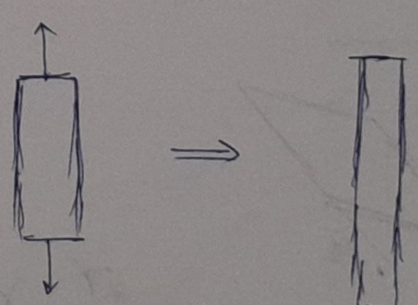


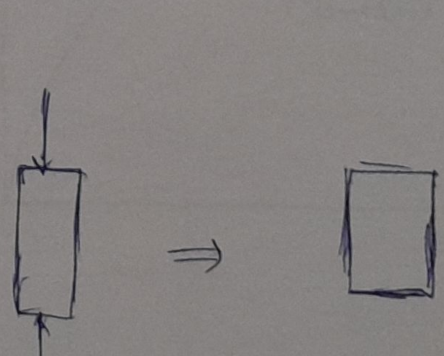


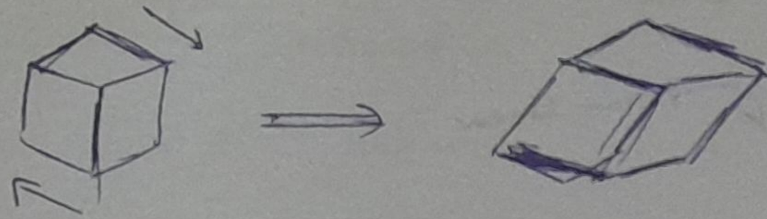
(Plastic Behaviour)



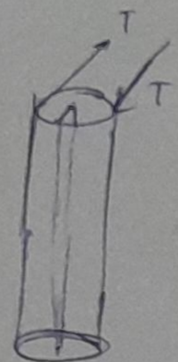
→ <u>Tensile</u> :







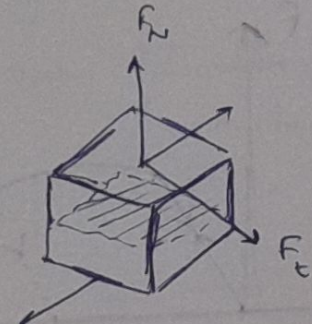
Torsion:



→ **Engineering stress:**

Tensile, $\sigma = \frac{F}{A} = \frac{F}{A_0}$

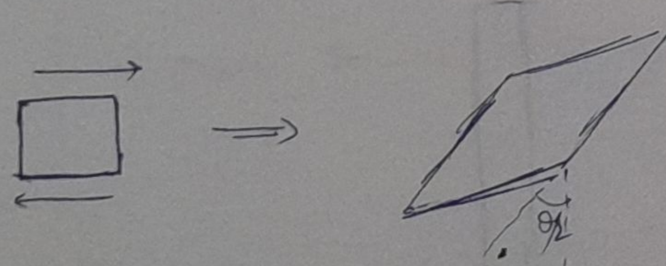
Sheer, $\tau = \frac{F_r}{A_0}$



Strain:

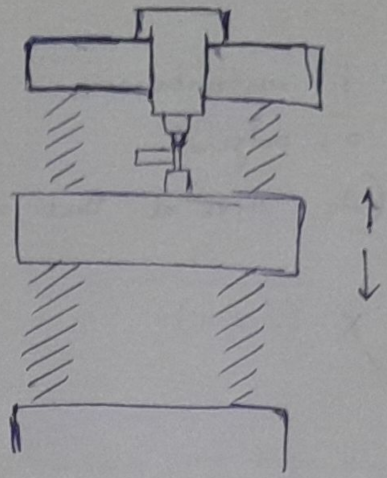
$\varepsilon = \frac{\Delta l}{l}$ (Linear Strain)

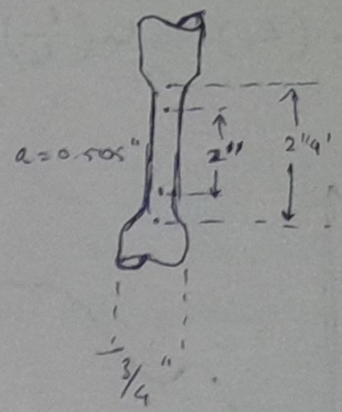
$\varepsilon_L = \frac{-\Delta d}{d}$



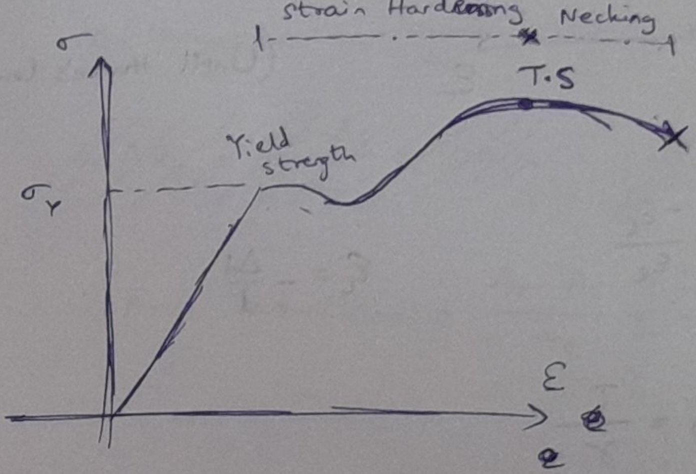
∗ $\gamma = \tan\theta$

→ **Universal Testing Machine**





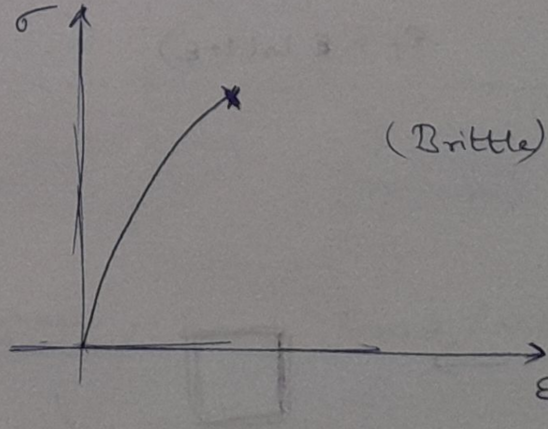
Any material's shape before testing in UTM.



(Ductile)

Necking : Cross sectional area decreases

Strain Hardening : Atoms rearrange themselves in a manner where the bonds are stronger because of the extending.

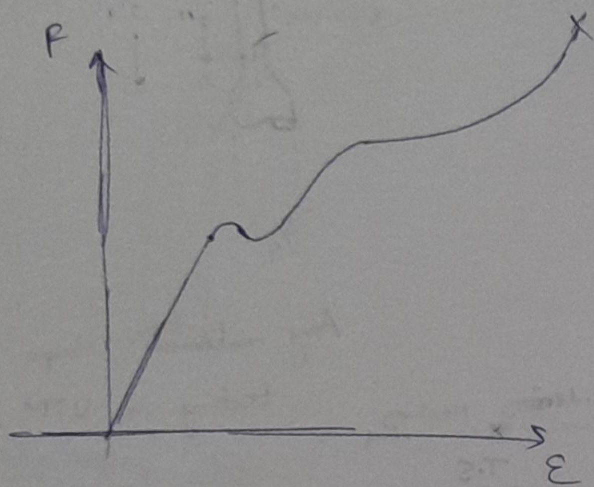


(Brittle)

True Stress $(\sigma_T) = \frac{F}{A_i}$

i : instantaneous
o : original
(A_i : Area at that instant)

Strain $(\varepsilon_T) = \ln\left(\frac{l_i}{l_o}\right)$



Young's Modulus $= \frac{\text{Stress}}{\text{strain}}$

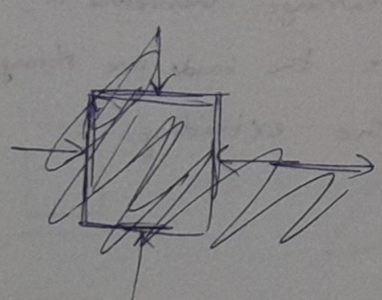
(Until Hooke's Law)

Poissons Ratio $= \nu = \frac{-\varepsilon_l}{\varepsilon_e}$

$\varepsilon_l = -\frac{\Delta d}{d}$

Sheer modulus $= G = \frac{\tau}{\gamma}$

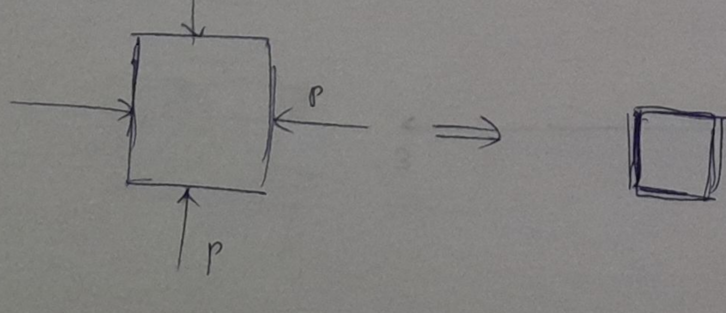
Bulk modulus $= B = k = \frac{-p}{(\Delta V / V_0)}$



$\sigma_T = k \varepsilon_T^n$

$\sigma_T = \sigma(1+\varepsilon)$

$\varepsilon_T = \varepsilon \ln(1+\varepsilon)$



$$G = \frac{E}{2(1+\gamma)}$$

$$K = \frac{E}{3(1-2\nu)}$$

13/9/23

$\varepsilon_p = 0.002 \longrightarrow$ Max elongation for not getting into plastic zone

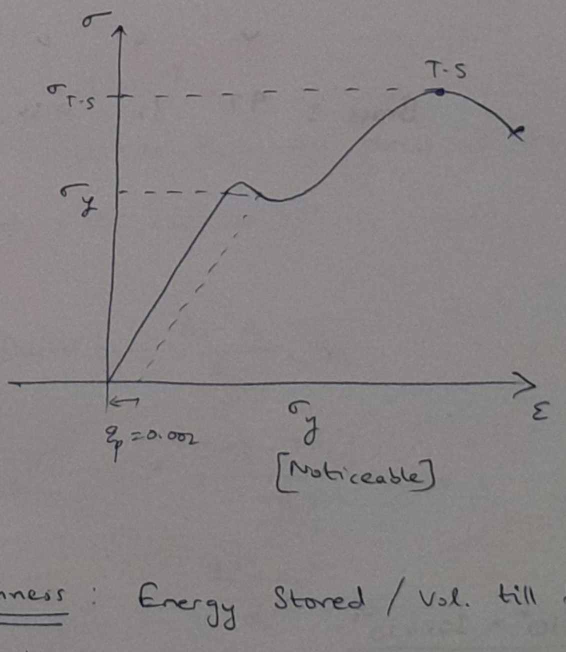
Ductility:

$$\%\ \text{Elongation} = \frac{L_f - L_0}{L_0} \times 100\ \% \longrightarrow \left[\begin{array}{ll} > 5\% & : \text{Ductile} \\ < 5\% & : \text{Brittle} \end{array}\right]$$

$$\cancel{\%\ AR = \frac{d_0 - d_f}{d_0} \times 100\%}$$

$$\%\ \text{Area Reduction} = \frac{A_0 - A_f}{A_0} \times 100\ \%$$

Strain Hardening $\propto \sigma_{T.S}$



Toughness: Energy Stored / Vol. till fracture

↳ Area under the curve until fracture

Resilience ≡ Toughness

↳ Area under the curve until Elastic limit

Modulus of Resilience $U_r = \frac{1}{2} \sigma_y \cdot \varepsilon$

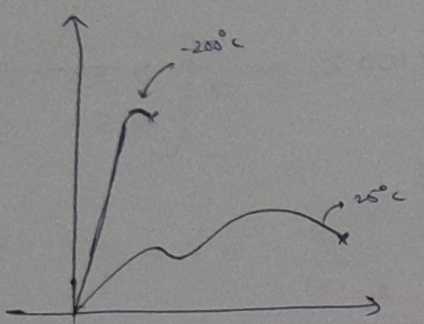
$$\Rightarrow \boxed{U_r = \frac{\sigma_y^2}{2E}}$$

→ <u>Anelasticity</u> :

Time dependent elasticity

Ex. Polymers

→ Ex. Iron



Ductile at 25°c

Brittle at -200°c

Q) $l_0 = 305$ mm (12 inches)

$\sigma = 276$ MPa

(40,000 psi)

	Y	G	ν
Brass :	97	37	0.34

& $Y = 110$ GPa

<u>Sol</u> : $Y = \frac{\sigma}{\varepsilon}$

$\Rightarrow Y = \frac{\sigma}{\Delta l} \cdot l_0$

$\Rightarrow \Delta l = \frac{\sigma l_0}{Y}$

$= \frac{276 \times 10^6 \times 305 \times 10^{-3}}{110 \times 10^9}$

$= 765.2727 \times 10^{-6}$

$\boxed{\Delta l = 0.765 \text{ mm}}$ ⟶ Ans

$\boxed{l_f = 305.765 \text{ mm}}$

Q) $d_o = 10\ mm$

$= 10^{-2}\ m$

$\Delta d = 2.5 \times 10^{-3}\ mm$

$= 2.5 \times 10^{-6}\ m$

Sol:

$\varepsilon_x = \frac{\Delta d}{d_o} = \frac{2.5 \times 10^{-6}}{10^{-2}}$

$= 2.5 \times 10^{-4}$

$\nu = 0.34$

$\nu = -\frac{\varepsilon_x}{\varepsilon_l}$

$\varepsilon_l = \frac{2.5 \times 10^{-4}}{0.34}$

$\Rightarrow \boxed{\varepsilon_l = 7.353 \times 10^{-4}}$

$Y = \frac{\sigma}{\varepsilon_l}$

$\Rightarrow \sigma = 97 \times 7.353 \times 10^{-4} \times 10^{9}$

$= 713.23 \times 10^{-4} \times 10^{9}$

$= 713.23 \times 10^{5}$

$\sigma = \frac{F}{A_o}$

$\Rightarrow F = 713.23 \times 10^{5} \times \pi (r^2)$

$= 713.23 \times 10^{5} \times \pi \times 25 \times 10^{-6}$

$= 56017.37 \times 10^{-1}$

$\boxed{F = 5601.737\ N}$

Q) $d_o = 12.8 \times 10^{-3}\ m$

$\sigma_f = 460 \times 10^{6}\ Pa$ ⟶ Stress at fracture

$d_f = 10.7 \times 10^{-3}\ m$

(i) Ductility $= \frac{A_o - A_f}{A_o} \times 100\ \%$

$= \frac{\pi d_o^2/4 - \pi d_f^2/4}{\pi d_o^2/4} \times 100\ \%$

$= \frac{d_o^2 - d_f^2}{d_o^2} \times 100\ \%$

$= \frac{(12.8)^2 - (10.7)^2}{(12.8)^2} \times 100\ \%$

$= \frac{163.84 - 114.49}{163.84} \times 100\ \%$

$= 30.121\ \%$

(ii) σ_T @ Fracture

$\sigma_T = \frac{F_n}{A_i}$ & $\sigma_E = \frac{F_n}{A_o}$

$\Rightarrow \sigma_T = \frac{\sigma_E \times A_o}{A_i}$

$= \frac{460 \times 10^{6} \times d_o^2}{d_f^2}$

$\boxed{\sigma_T = 658.3 \times 10^{6}\ N}$

Q) $\sigma_T = 415 \times 10^6$ MPa

$\varepsilon_T = 0.1$

$K = 1035 \times 10^6$ Pa

$$\sigma_T = K \varepsilon_T^n$$

$$\Rightarrow \log(\sigma_T) = \log K + n \log(\varepsilon_T)$$

$$\Rightarrow \log(415) + \cancel{6} = \log(1035) + \cancel{6} - n$$

$$\Rightarrow \boxed{n = 0.39689}$$

Strain-Hardening Exponent 'n'

→ Hardness :

- Brinell Hardness : $H(B) = \dfrac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$

Vicker's Hardness : $H(V) = \dfrac{1.854P}{d_1^2}$ (136°)

Knoop Microhardness : $H(k) = \dfrac{14.2P}{l^2}$

For Most Steels,

$TS\ (MPa) = 3.45 \times H(B)$

$TS\ (psi) = 500 \times H(B)$

Q)

Sample	Tensile Strength
1	520
2	512
3	515
4	522

(a) Compute the avg Tensile Strength

(b) Determine the st. deviation

(a) $\dfrac{(520)\times 4 + 2 - 5 - 8}{4}$

$= \dfrac{2080 - 11}{4}$

$= \dfrac{2069}{4}$

$= 517.25$ MPa

$\therefore$ Avg $= 517.25$

(b)

$$s = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

$$\Rightarrow s = \sqrt{\frac{(2.75)^2 + (4.75)^2 + (5.25)^2 + (2.25)^2}{3}}$$

$$= \sqrt{\frac{11^2 + 19^2 + 21^2 + 9^2}{48}}$$

$$\Rightarrow s = \frac{1}{4}\sqrt{\frac{11^2 + 19^2 + 21^2 + 9^2}{3}}$$

~~Q) A Tensile~~

Q) Max. Load $= 220000$ N $= 50000$ lb_f

Min. Yield $= 310$ MPa (σ_Y)

Tensile Strength $= 565$ MPa

Factor of Safety $= 5$

$$\sigma_{working} = \frac{\sigma_Y}{N}$$

$$= \frac{310}{5}$$

$$\Rightarrow \sigma_{working} = 62 \text{ MPa}$$

$$A_0 = \left(\frac{d}{2}\right)^2 \pi = \frac{F}{\sigma_w} \Rightarrow d = 2\sqrt{\frac{F}{\pi \sigma_w}}$$

Q) (a) $r = 50 \times 10^{-3}$ m

$t = 2$ mm

$P_{in} = 20$ atm $= 2.027$ MPa

$P_{out} = 0.5$ atm $= 0.057$ MPa

$N = 4.$

$$\sigma = \frac{r_i \Delta p}{t}$$

Sol :

$$\sigma_w = \frac{5 \times 10^{-2} \times 1.97}{2 \times 10^{-3}}$$

$$\Rightarrow \sigma_w = 49.25$$

$$\sigma_Y = 49.25 \times 4 = 197 \text{ MPa}$$

$$\boxed{\sigma_Y = 197 \text{ MPa}}$$

→ Objective function for light-strong stiff Rod :

$$m = AL\rho \qquad \frac{F^*}{A} \leq \sigma_y$$

F^* : Functional Constraint

L : Geometrical constraint

$$m \geq (F^*)(L)\left(\frac{\rho}{\sigma_y}\right)$$

Material Index : $\frac{\sigma_y}{\rho}$

$$M_{b1} = \frac{\sigma_y}{\rho}$$

Let $\frac{\sigma_y}{\rho} = C_1$

$\Rightarrow \sigma_y = C_1 \cdot \rho$

$\Rightarrow \log(\sigma_y) = \log(C_1) + \log(\rho)$

[Comparing this with $y = mx + c$]

$m = 1$

→ **Strengthening Mechanics :**

(i) Grain Size Reduction

(ii) Solid Solution Alloying

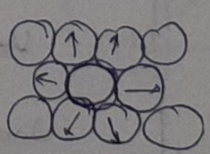
(iii) Strain Hardening

(i) $\sigma_y = \sigma_0 + k_y d^{-1/2}$

d : Avg. Grain Diametre

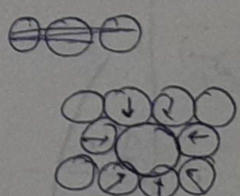
σ_0 & k_y : Constants

(ii) High Purity metals are generally softer and weaker than alloys of the same base material.



~~(Tensile loading)~~

(Compressive loading)



(Tensile loading)

(iii) $\% CW = \left(\frac{A_0 - A_d}{A_0}\right) \times 100 \%$.

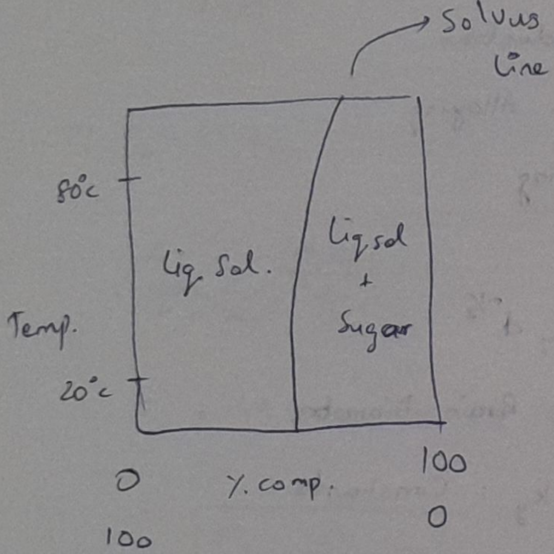
27/09/21

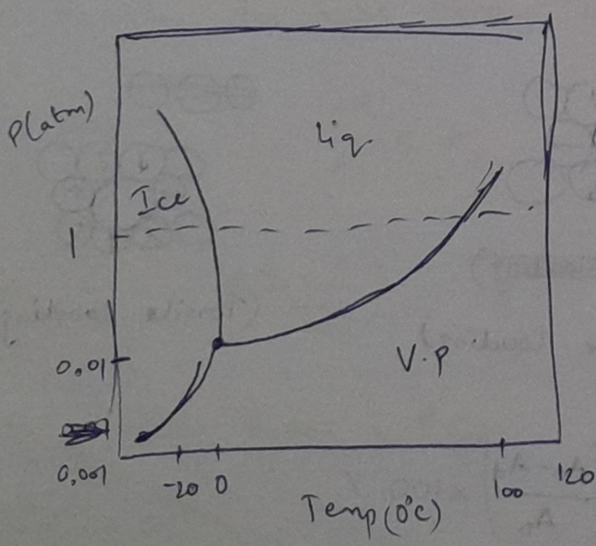
If Strain > 5% : Ductile (Generally)

Strain < 5% : Brittle

→ Heat Treatment (Annealing)

- Revert materials back to its precold worked state
  - Recovery
  - Recrystallisation
  - Recrystallization temp.



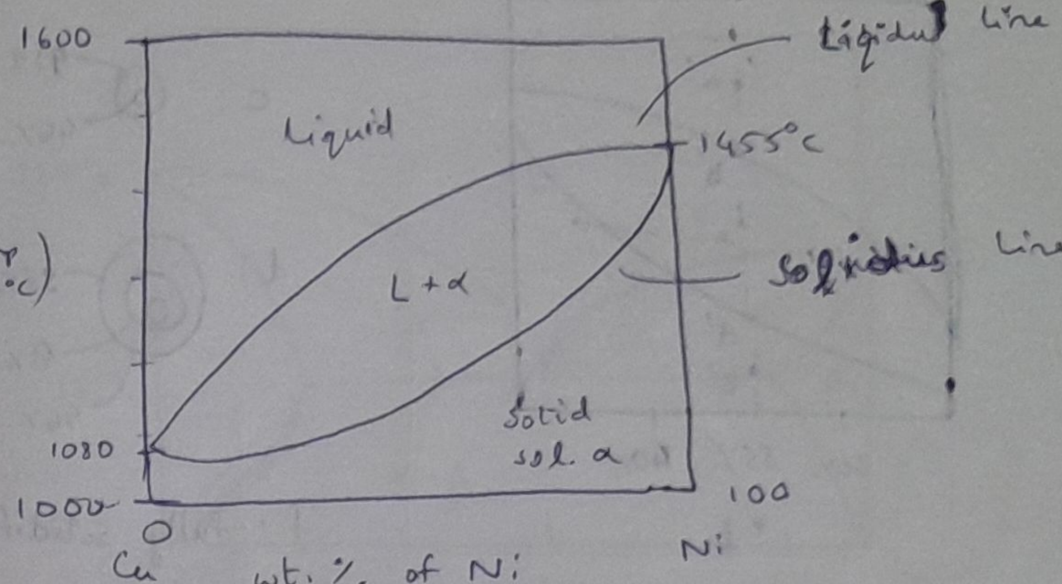


~~Unary Phase~~

Unary Phase Diagrams

~~Binary~~

Binary Phase Diagrams : (Isomorphous)

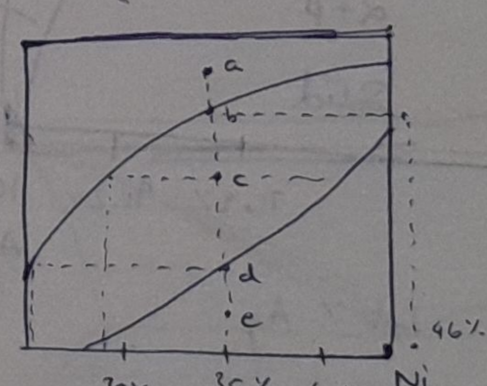


$$W_L = \frac{R}{R+S} \Rightarrow W_L = \frac{C_\alpha - C_0}{C_\alpha - C_L}$$

$$W_\alpha = \frac{S}{R+S} \Rightarrow W_\alpha = \frac{C_0 - C_L}{C_\alpha - C_L}$$

→ Equilibrium Cooling :

↳ Slow cooling



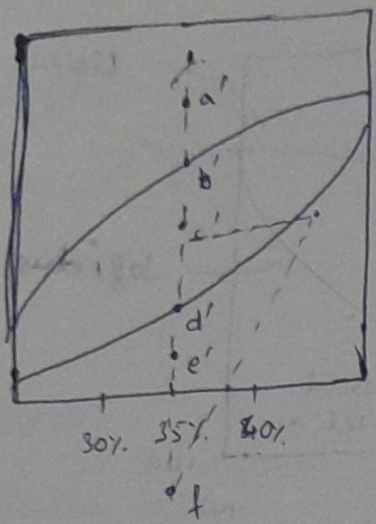
a → liquid only

c → liquid + α

e → α only

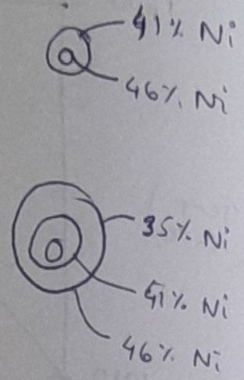
	L	α
b →	46% Ni	+ 35% Ni
c →	29% Ni	+ 35% Ni
d →	24% Ni	+ 35% Ni

→ Non-Equilibrium Cooling :



c :

d :

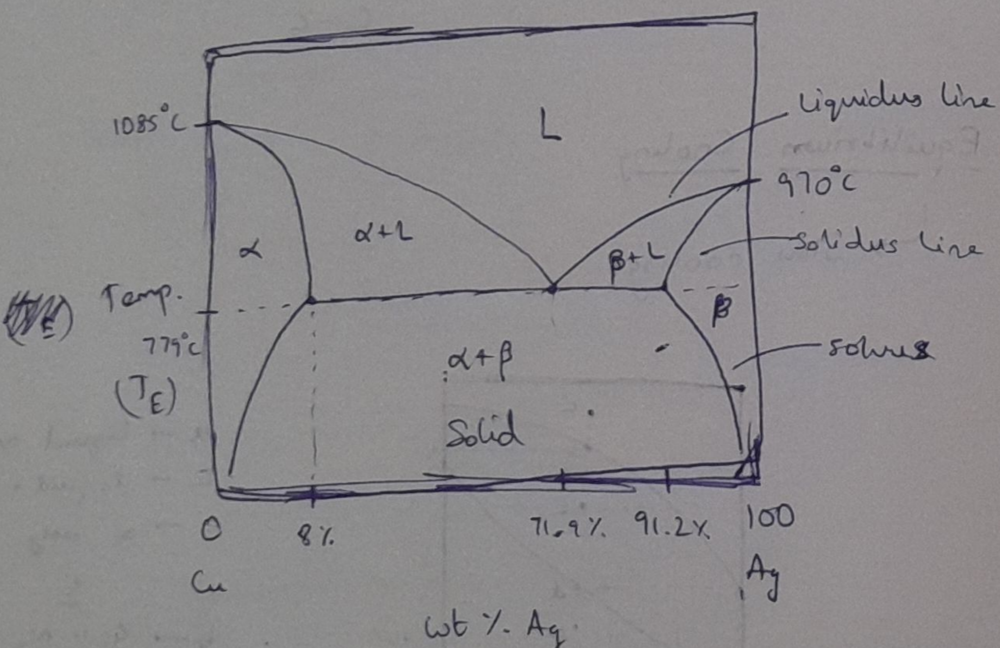


f : fully solidified

∴ Layerlike Grains

→ Binary Eutectic System : (Cu + Ag)

↳ Melts Easily

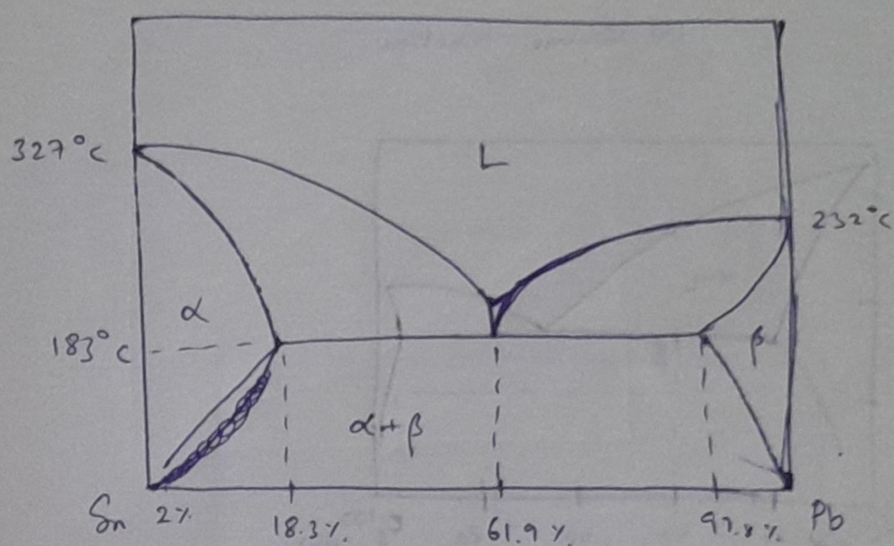


T_E : 779°C (Eutectic Temp.)

$$L\,(71.9\%\ Ag) \rightleftharpoons \underset{(8\%)}{\alpha} + \underset{(91.2\%)}{\beta}$$

~~Binary~~

Ex. Sn + Pb



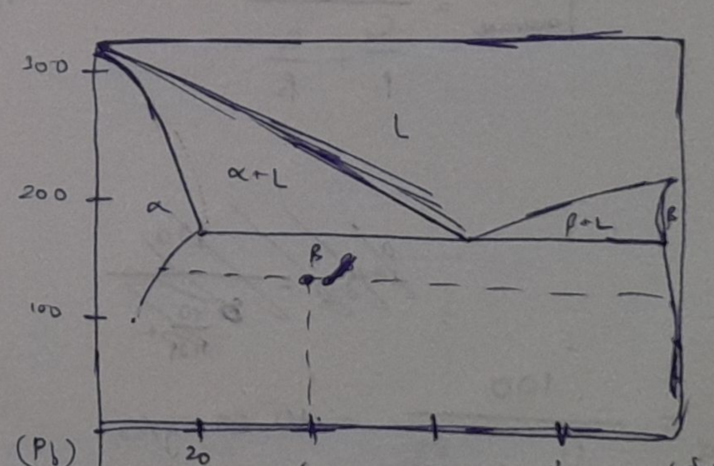
~~L(9 + L(9~~

$L(61.9\%\ Sn) \rightleftharpoons \underset{(18.3\%)}{\alpha} + \underset{(97.8\%)}{\beta}$

Q) 40% wt. Sn & 60% wt. Pb Alloy at (150°c) 300°f.

(a) What Phases are present ?

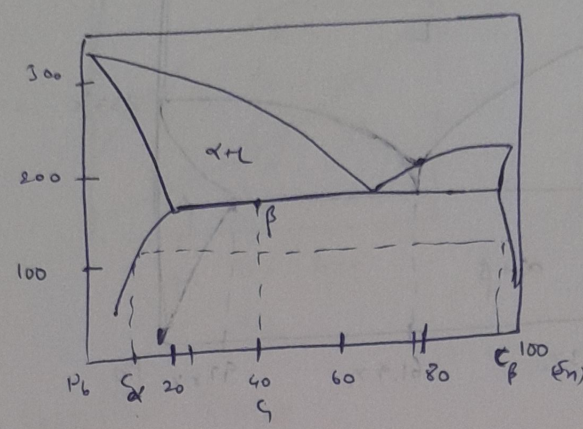
(b) What are the compositions ?



9) At 150°C, Densities of Pb and Sn are 11.39 and 7.29 g/cc.

Calculate relative amount of ~~each~~ each phase present in terms of (a) mass fraction

(b) Volume fraction



Ans:

$$W_\alpha = \frac{C_\beta - C_1}{C_\beta - C_\alpha} = \frac{98-40}{98-11} = 0.67$$

$$W_\beta = \frac{C_1 - C_\alpha}{C_\beta - C_\alpha} = \frac{40-11}{98-11} = 0.33$$

$$V_\alpha = \frac{\frac{W_\alpha}{\rho_\alpha}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}} \quad \& \quad V_\beta = \frac{\frac{W_\beta}{\rho_\beta}}{\frac{W_\alpha}{\rho_\alpha} + \frac{W_\beta}{\rho_\beta}}$$

ρ_{avg_β}

ρ_{avg_α}

$$\rho_{average} = \frac{100}{\frac{C_1}{\rho_1} + \frac{C_2}{\rho_2}}$$

$$\cancel{\rho_{avg_\alpha} = \frac{100}{\frac{40}{11.39} +}}$$

$$\rho_{avg_\alpha} = \frac{100}{\frac{11}{7.29} + \frac{89}{11.35}} = 10.691 \text{ g/cc}$$

$$\rho_{avg_\beta} = \frac{100}{\frac{98}{7.29} + \frac{2}{11.35}} = 7.34 \text{ g/cc}$$

$\therefore V_\alpha = 0.58$

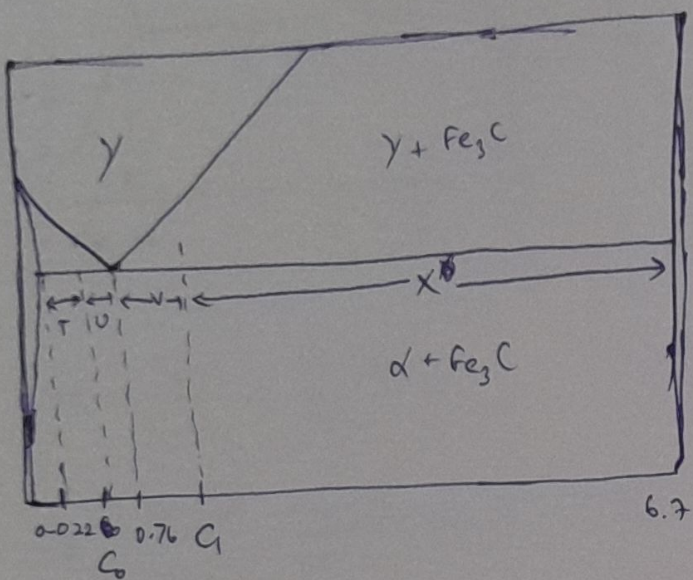
$V_\beta = 0.42$

Q) For a 99.5 wt% Fe - 0.35 wt. C alloy at a temperature just below the ~~eut~~ eutectoid, determine the following:

(i) The fractions of total ferrite and cementite phases

(ii) The fractions of the proeutectoid ferrite and pearlite

(iii) The fraction of eutectoid ferrite



(a) $T + U + V + X = 6.7 - 0.022$

$= 6.678$

$$\frac{6.7 - 0.35}{6.7 - 0.022} = \text{wt\% of } \alpha$$

$1 - \text{wt. of } \alpha = \text{wt\% of Cementite}$

$$\text{wt\% of } \alpha = \frac{6.35}{6.678} = 0.95088$$

$= 0.951 = 95.1\%$

wt.% of Cementite $= 0.049 = 4.9\%$

(b) $$W_p = \frac{T}{0.76 - 0.022}$$

$$W_\alpha = \frac{V}{0.76 - 0.022}$$

(c) $$1 - W_\alpha = 1 - \frac{V}{0.76 - 0.022}$$

$$W_{Fe_3C} = \frac{T}{6.7 - 0.022}$$

→ **Bainite** :

↳ Consists of Cementite and Dislocation - Rich ferrite

Forms at temperatures $125° - 550°C$.

→ **Martensite** :

↳ $\underbrace{\text{Rapid Cooling}}_{\text{[Quenching]}}$ of Austentite ~~A~~ form of Iron

→ Diffusion-less process

→ Needle-like Fe_3C.

→ **Possible Phase Transformation** :

Austenite

→ slow cooling → Pearlite + a Proeutectoid phase
  - Very slow → Spherolite
  - → Coarse Pearlite
  - → Fine Pearlite

→ Moderate cooling → Bainite

→ Rapid cooling → Martensite $\xrightarrow{\text{Reheat}}$ Tempered Martensite

Spheroidite $\longrightarrow$ Soft and Ductile

$\downarrow$

Coarse Pearlite

$\downarrow$

Fine Pearlite

$\downarrow$

Bainite (Dislocation Rich)

$\downarrow$

Tempered Martensite

$\downarrow$

Martensite $\longrightarrow$ Very hard and Very Brittle

1/11/23

CERAMICS

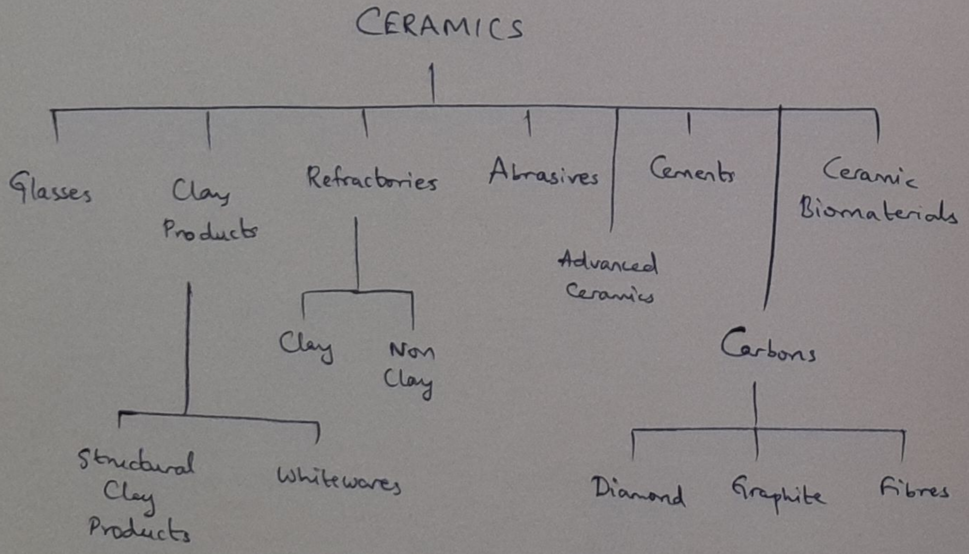
- Neither metallic nor Organic
- May be crystalline, glassy or both.
- Ex. Bricks, Tiles, Glass, Cement
- Used in Spark Plugs, Optics, Artificial joints, etc
- Usually relatively high M.P
- Ionic bonding (or) Covalent Bonding

% Ionic Character :

$$\left(1 - e^{-(0.25)(\chi_A - \chi_B)^2}\right) \times 100\ \%$$

χ_A and χ_B are the electronegativities of the elements forming the ceramics

Ex. CaF_2 — 89 %
SiC — 12 %



(1) Glasses and Glass Ceramics :

- Non Crystalline,
  Often Transparent Amorphous Solid
  Mainly Contains SiO_2.

→ **Crystallization :**

Non Crystalline State $\xrightarrow[\text{(ii) Slow Cooling}]{\text{(i) } \Delta \text{ (High Temp)}}$ Crystalline

(Most Inorganic Glasses) (Fine-Grained Poly Crystalline Material)

↓

Glass Ceramic

% SiO_2 :

Fused Silica – 99.5%

96% Silica (Vycor) – 96%

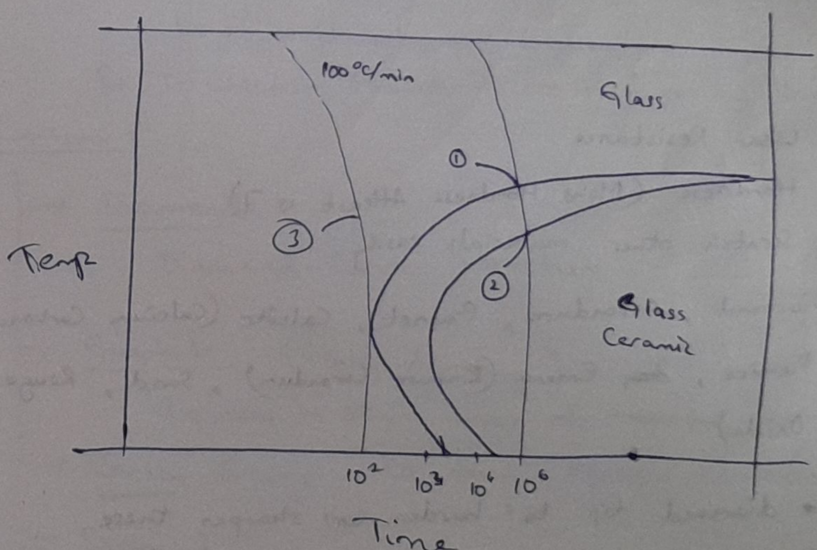
Borosilicate – 81%

Soda lime – 74%

Fibre Glass – 55%

Optical Flint – 54%

Pyroceram – 43.5%



① - Crystallization Begins

② - Crystalline Ends

③ - Critical Cooling Rate

② **Clay Ceramics :**

→ Clay : Silica + Alumina

→ Clay $\xrightarrow[\text{Firing } (\Delta)]{\text{High Temp.}}$ Whiteware (White)

Ex. Pottery, Tableware, Porcelein, China and Plumbing Fixtures

For Structural Clay:

Ex. Bricks, tiles, Sewer pipes, etc.

③ <u>Refractories:</u>

Clay-Refractories { Fire Clay, Alumina (High)

(Clay) <u>FireClay</u> – 25 to 45% Al_2O_3, 70-50% SiO_2

(Non-Clay) Periclase – 95% MgO

(Non-Clay)
- Extra High Alumina – 87.5-99% Al_2O_3
- Zircon – 34 to 31% SiO_2 + 63-66% ZrO_2
- Silicon Carbide – 80-90% SiC

(Clay)
- High Alumina <u>Fireclay</u> – 50-87.5% Al_2O_3, 45-10% SiO_2
- Silica – 94-96% SiO_2

Zircon – Used in Rings in Replacement of Diamond.

④ <u>Abrasives:</u>

→ High Wear Resistance
High Hardness (Mohs Hardness Atleast is 7)
Can Scratch other materials easily

→ Ex. Diamond, corondum, Garnet, Calcite (Calcium Carbonate), Pumice, Emery (Impure Corandum), Sand, Rouge (Iron Oxide)

→ Uses diamond tip to harden (or) sharpen these Grinding Tools.

⑤ <u>Cements:</u>

→ Hardens and acts as a Binding Material when reacted with water.

→ Inorganic Cements: Sand and Gravel along with Binder → (Limestone (or) Calcium silicate)

→ Produced by Calcination.

Grinding and Mixing Clay in proper proportion.
@ 1400°c.

$CaCO_3 \longrightarrow CaO + CO_2$

Portland Cement :

Grinding & Mixing → Calcination (1400°c) → Clinker (Gypsum is added) → Portland Cement

$2CaO + SiO_2 + xH_2O \longrightarrow 2CaO - SiO_2 - xH_2O$

(Hydration Reaction)

⑥ Ceramic Biomaterials :

→ Used in orthopedic Implants, Biomedical Applications
→ Ex. Zirconia (Dental Implants), Aluminium Oxide (Load Bearing)
→ Inert to Body Fluids, Bones, (Inside Body)
→ Chemical Inertness, Hard, High Wear Resistance and Low coefficient of friction

Ex. TriCalcium Phosphate → Absorbed by Body when bone grows

⑦ Carbons :

→ Diamonds :
Diamond-Cubic Structure

→ Graphite : [Highly Anisotropic]
Graphene - Single Layer of ~~Hexagon~~ Carbon atoms formed to form Hexagon structure

→ Carbon Fibres

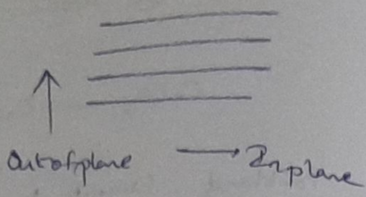
→ Diamond :

→ sp^3 strong Interatomic bonds
→ Chemically Inert
→ Low Density
→ Hardest and strongest
→ High Refractive Index, Transparent
→ High Modulus of Elasticity
→ High Thermal Conductivity
→ Low Coefficient of Thermal ~~and~~ Expansion
→ High Electrical Resistance.

→ <u>Graphite</u> :

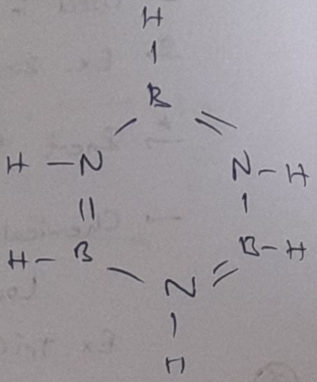
High Adsorption of Gases

Ex. Purification of Gases



In plane	Out of Plane
High Modulus of elasticity	Low
High Strength	–
High Thermal Conductivity	Low
Less electrical Resistance (10^{-5})	More electrical Resistance (10^{-2})
Coefficient of Thermal expansion = −1	High Coefficient of Thermal expansion.

– Graphene > Borazon ($(BN)_n$)
v
Diamond



→ ~~E~~ <u>Carbon Fibres</u> :

→ Made up of Graphite but different structure

→ High length compared to Diametre.

→ Two types :

(i) Graphitic :

Layers are in ordered way.
High ~~[illegible]~~ Modulus of Elasticity

(ii) ~~Ex~~ Turbostratic :

Tilted (or) Bent Layers (Random)
~~Higher Modulus of Elasticity~~
High Tensile strength.

→ Very low Electrical Resistance.

→ Tensile strength : Carbon fibres > Glass fibres
(Expensive)

→ Properties Similar to Graphite (Inplane & Outofplane)

(8) Advanced Ceramics :

Ex. MEMS (Micro-Electric Mechanical Systems)

→ Placed on Electronic Circuits

→ Silicon

C_{60} — 20 Hexagon Rings + 12 Pentagon Rings

→ Fullerenes

→ Used in Biopharmatic things

→ Dom Kind of Structure.

Graphene — Ultimate Material

→ Very Strong (Extremely strong & flexible)

→ No Atomic Impurities / Deformities

→ High Electrical & Thermal Conductivity

→ Used in many Electronic Conductors & Artificial Muscle Ensymes & DNA Biosensors

CNT → Very Strong

→ Used in Solar Cells, Body Armor, Cancer Treatment, Capacitors

→ Low Density

} (Nanotubes)

→ Glass-Transition Temperature :

→ For Amorphous Material

Solid @ Lower Temp.

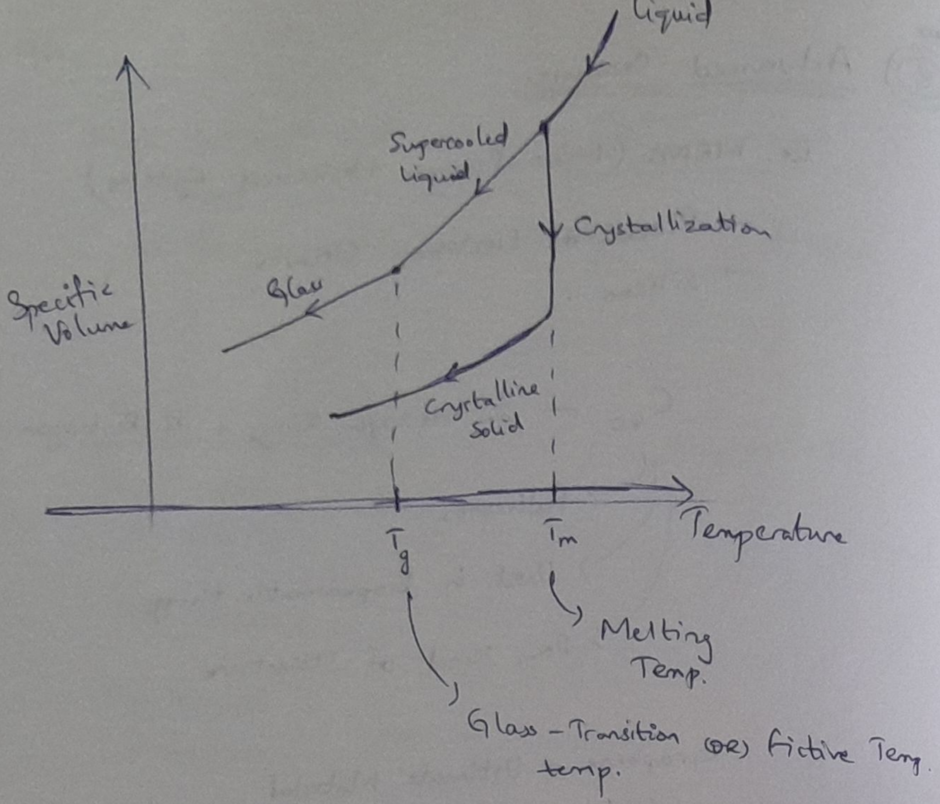
Liquid @ Higher Temp. ← Rubbery/Leathery state

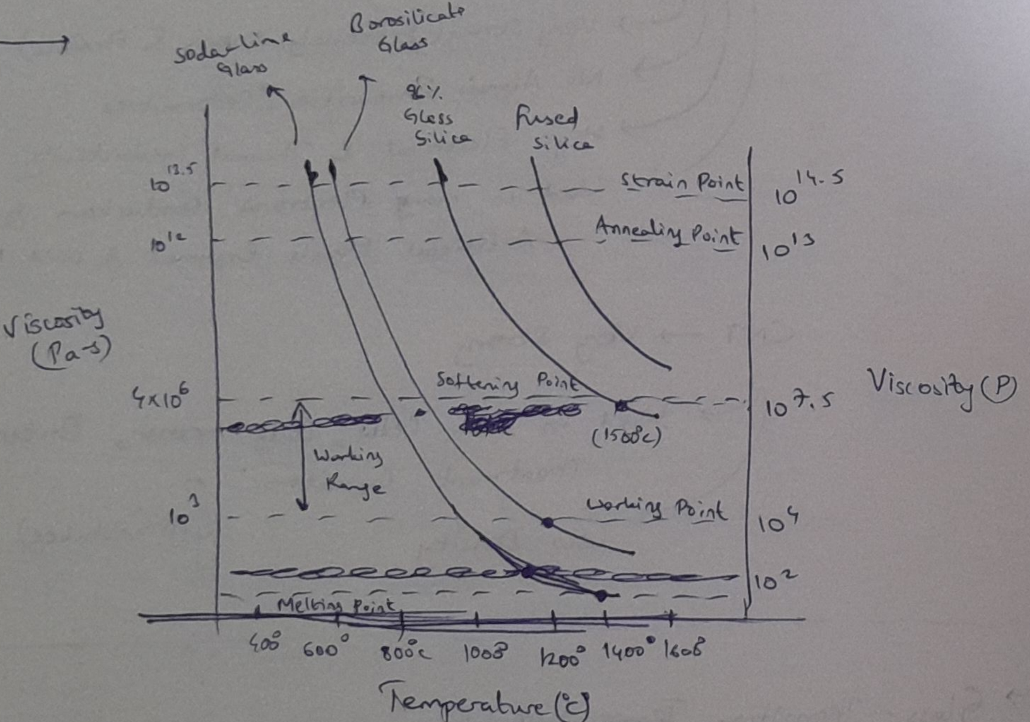
(Viscous)

(i) Crystalline materials solidify @ Melting Temp, T_m

(ii) Charecteristic of non-Crystalline state is T_g.

As $T\downarrow \Rightarrow V\downarrow$ for Glassy Materials





Summary:

Melting Point ~~Room temp~~. (Liquid) ~~Hard & Brittle~~ (10 Pa-s) $\xleftrightarrow{\Delta}$ 708°C Soft (4×10^6 Pa-s) Liquid State (Softening Point) → (Now it became soft) → Easy to Deform

Δ Working State (10^3 Pa-s) Δ

Δ

Sufficiently Rapid Atomic Diffusion (Annealing) ($\times10^{12}$ Pa-s)

(3×10^{13} Pa-s) [Strain Point] $\xleftrightarrow{\Delta}$ Sufficiently Rapid Atomic Diffusion

Δ

Fracture beyond Strain Point.

Ceramic fabrication Techniques

- Glass Forming ~~Proces~~ Processes
  - Pressing
  - Blowing
  - Drawing
  - Forming of fibre
- Particulate Forming Processes
  - Powder Pressing ⇓ Drying ⇓ Firing
  - Hydroplastic forming ⇓ Drying ⇓ frying
  - Slip Casting ⇓ Drying ⇓ Firing
  - Tape Casting ⇓ Drying ⇓ Firing
  - 3D printing ⇓ Drying ⇓ Firing
- Cementation

→ Glass - Forming

(i) Pressing :

(i) Heat Glass

(ii) Put ~~a~~ in mould

(iii) Punch glass into mould (press)

(Thick-Walled ~~a~~ Product as Output)

(ii) Blowing :

(i) Heat Glass

(ii) Put in a mould

(iii) Inject air into it

↳ Compressed air

(iii) Drawing :

To make sheets of glass by using rollers.

(i) Heat Glass

(ii) Pass it onto rollers

Length ↑

Thickness ↓

[Float Bath Furnace]

Heating Zone

⇓

Fire Polishing Zone ⇒ Annealing Furnace

⇓ ⇓

Cooling Zone Cutting

(iv) Fibre Forming :

Cylindrical cross ~~-~~ sectional area instead of Rectangular one.

Heat Treatment of Ceramics :

(Weaken it / Fracture it)

① Annealing :

→ Thermal stresses cause Thermal Shock

Releases Internal Stress / Residual stress when cooled from high Temp.

Makes Glass Weaker

Heat to high extent and cool slowly.

[Unconditional & Uncontrolled]

↳ Cooling slowly i.e Glass Tempering

② Glass Tempering :

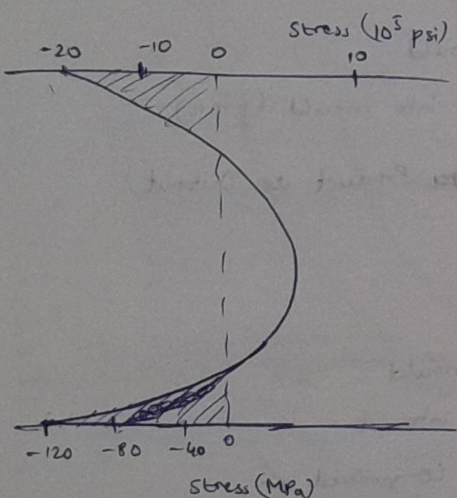
Hardness Increases. & Strength Increases

Cooling Rate is controlled. (Thermal Tempering)

→ Tensile Strength applied on the surface fractures the glass.

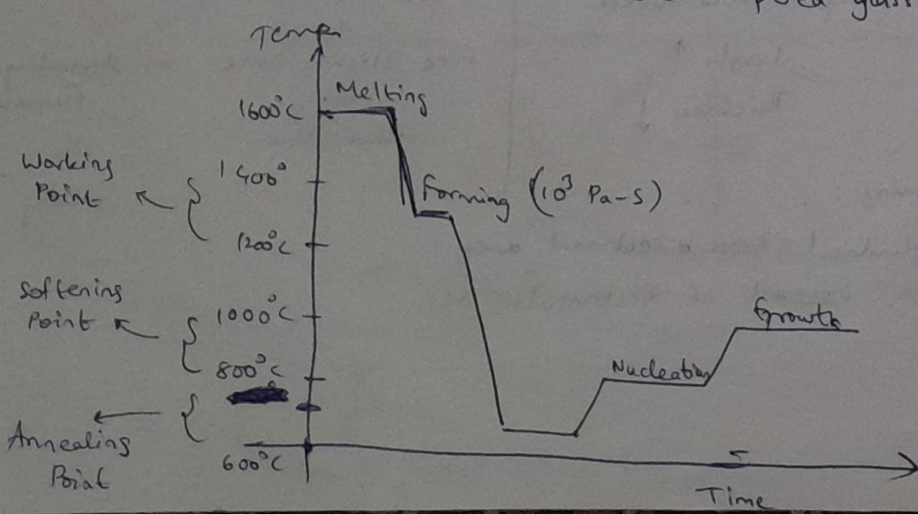
→ Tempered Glass is stronger.

Ex. Large doors, Mobile Screens, etc



First -20 to 0 and then → positive.

∴ More Tensile stress needs to be applied to break tempered glass.



Clay Products

Water + Clay ⟶ Plastic-like Material

(Hydroplasticity)

Melts over a wide range of temp.s.

(i) Place Clay in Mould.
(ii) Add Water & Water is Absorbed.

(OR)

(i) Place clay in mould.
(ii) Invert mould to drain water
(iii) top-trimming

Hydroplasting :

Mix with water and pass through desirable orefice and make patterns (layer on layer) → [Green]

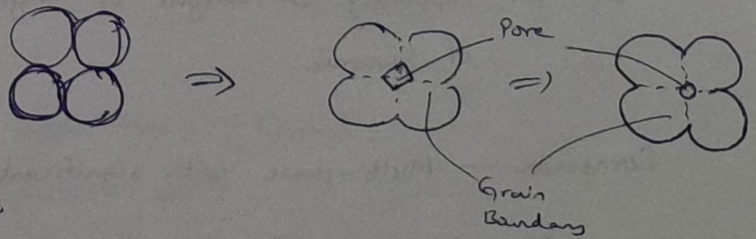
Then Drying & Firing.

→ Syntering ??

∵ Water will make it plastic & Strength decreases
∴ Water is Removed by drying.

~~Powder Pressing~~

After removing water, we need to do firing.



Powder Pressing :

Powder form ⟶ Compact

$\underbrace{\text{Drying \& Firing}}$

↳ Remove Pores & Increase Strength

3D Printing:

(i) Roller spreads thin layer of Ceramic Powder.

(ii) Liquid Binder Deposited on Desired Places through Ink jet. And Liquid Binder binds it.

(iii) Layer above will be deposited and loop will continue and height will keep increasing.

(iv) Shake and Remove Excess Material.

∴ Selectively bind material based on the end product.

Stereolithography (SLA) 3D printing:

Ex. Alumina, Zirconia, Tricalcium Phosphate, hydroxyapatite

Photocurable - polymer is used along with ceramic powder [Unpolymerised polymer]

$$\text{Unpolymerised material} \xrightarrow[\text{(Laser)}]{\text{Light}} \text{Polymerised material.}$$

~~Ceramic — low~~

Polymer — low Melting Point.

End Product:

$$\text{Ceramic + Polymer} \xrightarrow{\Delta} \text{Pure Ceramic.}$$

8/11/23

COMPOSITES:

Mix (or) Combine materials → composite is formed

Ex. Get flexibility & weight of Polymer + Strength of Ceramic.

Composite — Multi-phase with significant proportion of each Phase

Matrix Phase — Continuous

Dispersed Phase — ~~Phase~~ Enhancing Matrix Properties

Matrix
- Metal MC
- Polymer MC
- Ceramic MC

Matrix Phase
- Transfer Stress to other phases
- Protect dispersed phase from environment.

Dispersed Phase
- Particle
- Fibre
- Structural

Dispersed Phase mixed with Matrix Phase
- Metal Matrix : $\sigma_y \uparrow$, TS $\uparrow$, Creep Resist $\uparrow$
- Polymer Matrix : $E \uparrow$, $\sigma_y \uparrow$, TS $\uparrow$, Creep Resist $\uparrow$
- Ceramic Matrix : $K_c \uparrow$

Matrix Phase — Main

Dispersed Phase - Mixed in Matrix Phase to Increase Properties

Concentration, Size and Shape of Dispersed Phase can be changed to Yield different properties.

Composites
- Particle-Reinforced
  - Large-Particle
  - Dispersion Strengthened
- Fibre-Reinforced
  - Continuous (Aligned)
  - Discontinuous (Short)
    - Aligned
    - Randomly Oriented
- Structural
  - Laminates
  - Sandwich Panels

① __Particle - Reinforced Composites__ :

Ex. Matrix : Metal (cobalt)

Reinforcement : (Tungsten Carbide) [Particles] Ceramic

↳ Hard & Brittle

Ex. Concrete : Sand + Gravel + Cement

Compression - $\uparrow$

Tensile Strength - $\downarrow$

Sand Packs into Gravel voids.

Reinforced Concrete : Reinforce with Steel rerod (or) remesh

Tensile Strength $\uparrow$ (any case)

Prestressed Concrete :

Tension Released $\Rightarrow$ Concrete under compressive force

Note :

Applied Tension > Compressive force

Post ~~stress~~ tensioning :

Lighter nuts

→ Rule of Mixtures :

Upper Limit : $E_c = V_m E_m + V_p E_p$

Lower Limit : $\frac{1}{E_c} = \frac{V_m}{E_m} + \frac{V_p}{E_p}$

If Young's Modulus ↑ with increase of Vol % of a material, Then that material is Reinforcement.

Electrical Conductivity :

σ_e replaces E.

$(\sigma_e)_c = V_m(\sigma_e)_m + V_p(\sigma_e)_p$ [Upper]

$\frac{1}{(\sigma_e)_c} = \frac{V_m}{(\sigma_e)_m} + \frac{V_p}{(\sigma_e)_p}$ [Lower]

Thermal Conductivity

k replaces E.

$k_c = V_m k_m + V_p k_p$ [Upper]

$\frac{1}{k_c} = \frac{V_m}{k_m} + \frac{V_p}{k_p}$ [Lower]

② Fibre - Reinforced Composites :

→ Fibres are very strong.

→ Fibre materials :

(i) Whiskers :

Large Length to Diameter Ratio

Thin Single Crystals ⟶ Very strong, but weaker compared to Polycrystalline.

Ex. SiN, SiC, Graphite

Expensive. ∵ Extremely Strong

(ii) Fibres :

PolyCrystalline (or) Amorphous

Generally Polymers (or) Ceramics

Ex. Al_2O_3, ~~Al~~ Aramid, Boron, E-Glass

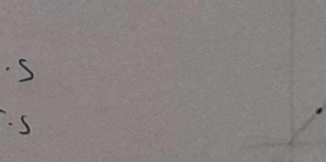
(iii) Wires :

Metals

Ex. Steel, W, Mo

→ Fibre Allignment

Can be Continuous (or) Discontinuous



→ Matrix - Low T.S

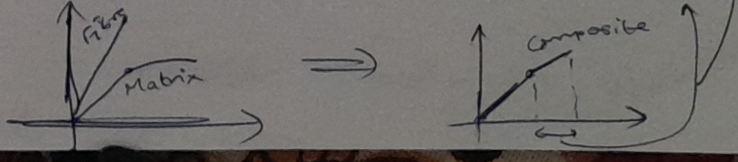
Fibre - High T.S

Resultant Polymer - In between the Matrix & Fibre (TS)

↳ Different slopes for both stages

Plastic Deformation - Matrix (Stage II)

Elastic Deformation - Fibre (Stage II)



→ Critical fibre Length : $(l_c) = \frac{\sigma_f d}{2\tau_c}$

↳ Effective Stiffening and strengthening

→ Optimal fibre Length $> 30 \cdot \left(\frac{\sigma_f \cdot d}{2\tau_c}\right)$ & $l_c = \frac{\sigma_f d}{2\tau_c}$

$[l_f > 30\, l_c]$

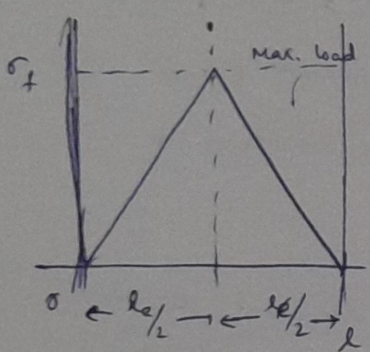
τ_c : sheer Strength of Fiber-Matrix interface

σ_f : fibre Strength in Tension

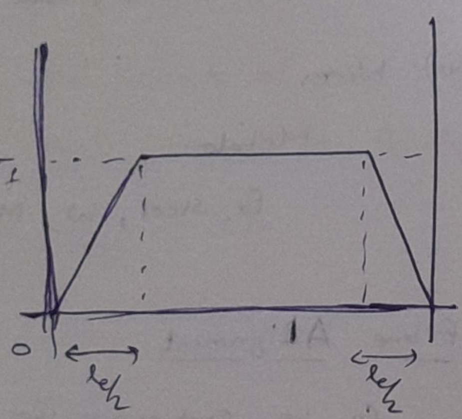
d : fiber Diameter.

For fibre Glass, fibre length > 15 only.

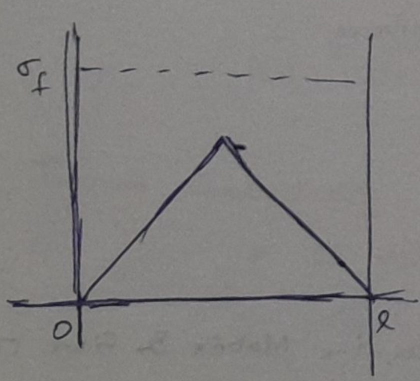
∵ Long fibres carry stress Efficiently



(If $l = l_c$)



(If $l > l_c$)



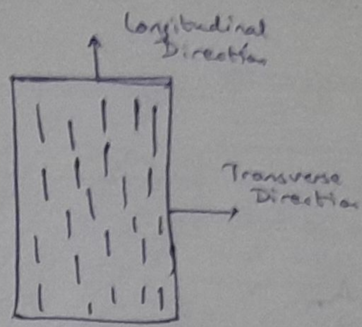
(If $l < l_c$)

$l > 15\, l_c$ → Continuous

$l < 15\, l_c$ → Discontinuous & Short.

→ Assumption of an iso-strain state

i.e. $\varepsilon_c = \varepsilon_m = \varepsilon_f$



$F_c = F_m + F_f$

composite → F_c, Matrix → F_m, fibre → F_f

$\Rightarrow \sigma_c A_c = \sigma_m A_m + \sigma_f A_f$

$\Rightarrow \sigma_c = \sigma_m \cdot \frac{A_m}{A_c} + \sigma_f \frac{A_f}{A_c}$

$= \sigma_m \cdot V_m + \sigma_f V_f$

$$\boxed{E_c = E_m \cancel{V}_m + E_f V_f}$$

$$\frac{F_f}{F_m} = \frac{E_f \cdot V_f}{E_m \cdot V_m}$$

Assume it is continous.

Transverse Loading :

Stress → Same (Isostress)

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

$\sigma_c = \sigma_m = \sigma_f = \sigma$ (Lowest Stress)

$\varepsilon_c = \varepsilon_m V_m + \varepsilon_f V_f$

Highest Stress —— Longitudinal Loading

Q) 40% Vol Glass Fibre

60% Vol Polyester Resin

$E_f = 69$ GPa

$E_m = 3.4$ GPa

(i) $E_c = E_m \cdot V_m + E_f \cdot V_f$ [Longitudinal]

$= \left(3.4 \times 10^9 \times \frac{60}{100}\right) + \left(69 \times 10^9 \times \frac{40}{100}\right)$

$= 2.04 \times 10^9 + 27.6 \times 10^9$

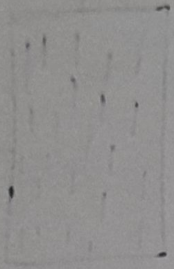
$\Rightarrow E_c = 29.64$ GPa

(ii) $A = 250\ mm^2$

$\sigma = 50\ MPa$

Load Magnitude = ? (Longitudinal Stress)

↳ of each phase



$F_c = F_f + F_m$

$\Rightarrow \sigma_c A_c = \sigma_f A_f + \sigma_m A_m$

$\Rightarrow 50\times10^6 \times 250\times10^{-6} = F_f + F_m$

$$\boxed{F_f + F_m = 12500\ N}$$

$$\frac{F_f}{F_m} = \frac{E_f \cdot V_f}{E_m \cdot V_m} = \frac{69\times10^9\times40}{3.4\times10^9\times60} = \frac{276}{20.4} = 13.53$$

$F_f = 13.53\,F_m$

$\Rightarrow 14.53\,F_m = 12500$

$$\boxed{F_m = 860.3\ N}$$

$$\boxed{F_f = 11640\ N}$$

$\sigma_f = \frac{F_f}{A_f}$

$\sigma_m = \frac{F_m}{A_m}$

∴ The fiber phase supports the vast majority of the applied load,

$$\frac{\sigma_f}{\sigma_m} = \frac{F_f}{F_m}\times\frac{A_m}{A_f}$$

$$\frac{\sigma_f}{\sigma_m} = \frac{A_m}{A_f}\times13.53$$

$$= \frac{3}{2}\times13.53$$

$$\boxed{\frac{\sigma_f}{\sigma_m} = 20.3}$$

$\Rightarrow \sigma_f = 20.3\,\sigma_m$

(iii) $\frac{V_f}{V_m} = \frac{A_f \cdot L}{A_m \cdot L} = \frac{A_f}{A_m}$ & $A_f = A\times V_f$, $A_m = A\times V_m$

$$\frac{A_f}{A_m} = \frac{40}{60} = \frac{2}{3}$$

$3A_f = 2A_m \Rightarrow \frac{A_m}{A_f} = \frac{3}{2}$

& $\sigma_f A_f + \sigma_m A_m = \sigma_c A_c$

$A_c = A_f + A_m$

$$\sigma_f A_f + \sigma_m\left(\frac{3}{2}A_f\right) = \sigma_c A_c$$

$$\cancel{AV = AV_f + AV_m}$$

$$\Rightarrow \boxed{A_c = A_m + A_f}$$

$$\Rightarrow A_f\left(\sigma_f + \frac{3}{2}\sigma_m\right) = \sigma_c A_c$$

$$\Rightarrow A_f\left((21.8)(\sigma_m)\right) = 12500$$

$$\cancel{\Rightarrow A_f = \frac{12500}{}}$$

$$\boxed{\begin{aligned} V_c &= V_f + V_m \\ \Rightarrow AV_c &= AV_f + AV_m \\ \Rightarrow A_c &= A_f + A_m \end{aligned}}$$

$$\cancel{\Rightarrow E_f + \frac{3}{2}\left(\frac{E_m}{A_m}\right)(A_f) = 12500}$$

$$\cancel{\Rightarrow \frac{3}{2}E_m\frac{A_f}{A_m}}$$

$\sigma_M = 5.73$ MPa

$\sigma_f = 116.4$ MPa

$$\varepsilon_m = \frac{\sigma_m}{E_m} = 1.69\times10^{-3}$$

$$\varepsilon_f = \frac{\sigma_f}{E_f} = 1.69\times10^{-3}$$

(OR) $A_f = A\times V_f = 250\times 40$

$A_m = A\times V_m = 250\times 60$

E in Transverse :

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

$$\Rightarrow \frac{1}{E_c} = \frac{60}{E_m} + \frac{40}{E_f}$$

$$= \frac{60}{3.4\times10^9} + \frac{40}{69\times10^9}$$

$$= (17.65 + 0.58)\times10^{-9}$$

$$= 18.227\times10^{-9}$$

$$\Rightarrow E_c = \frac{1}{18.227}\times10^{+9}$$

$$= 0.05486\times10^{+9}$$

$$= 5.486\times10^{7}\ \text{Pa}$$

$$\therefore \boxed{E_c = 54.86\ \text{MPa}}$$

→ **Structural Composites :**

(i) Laminate fiber-reinforced sheets :

→ Stacking on top of each other

→ Advantage : Balanced Property, Equal Stress/strain in Longitudinal & Transverse direction.

Ex. Plywood.

(ii) Sandwich Panels

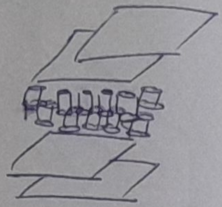
→ Low Density

→ Can withstand large Bending stress/stiffness

Adhesive layers

(Core) → Honeycomb structure

Adhesive layers



→ Types of Laminate Lay-ups :

(a) Unidirectional

(b) Cross-ply

(c) Angle-ply

(d) Multidirectional

→ ① Polymer Matrix Composites :

→ Matrix : Thermoplastics, Thermosettings Polymers

Matrix → soft

Fibres : Aramid, Glass fibres, Carbon fibres

→ High strength ~~[illegible]~~

Disadvantages : Low service Temp. (Low MP of Polymers)

Advantages :

Glass-fibres : Automotive

Carbon-fibres : Sports

Aramids : ~~[illegible]~~ Bulletproof vests

Carbon Fibres → Strongest → Longitudinal Tensile Modulus ↑

Longitudinal Tensile Strength ↑

Matrix Phase

- MMC → metal
- CMC → ceramic
- PMC → Polymer

Glass Fibres → Lowest service Temp.

★ $\frac{\text{Stiffness}}{\text{Density}}$ Ratio Increases $= \frac{E}{\rho}$ (Specific stiffness)

Dispersed Phase : Ceramic, Metals

↳ Has to be stronger

Summary:

Density Remains same but stiffness increase.

$E \uparrow$, $\sigma_y \uparrow$, TS $\uparrow$ & Creep Resistance $\uparrow$

① Metal Matrix Composites :

↳ Dispersed Phase : SiC

Matrix Phase : Ti

↳ More Expensive than PMC. (Polymer matrix Composites)

Suitable for High Temp.

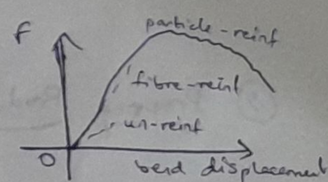
Automobile & Aerospace Industries

Matrix : 6061 Alloy of Al

Main Benefit : Creep Resistance $\uparrow$, $\sigma_y \uparrow$, TS $\uparrow$

↳ ~~More~~ Same stress, strain does not increase much

③ Ceramic Matrix Composites



↳ High MP

Brittle Fracture ⟶ Can be increased when ceramic is used as Matrix

Strength ≈ Metals

Advantage : Toughness Increases ($K_c \uparrow$) → Fracture Toughness

fracture strength ∝ Whisker Content (vol%)

Fracture Toughness — Highest (7-9) @ 20% vol.

Tetragonal ZrO_2 Particles $\xrightarrow[CaO]{MgO\text{ (or)}}$ Monoclinic (Most stable) [for some time]

(Partially stable)

[Meta stable]

Stabilizes

Compressive stresses reduce propagation of cracks.

Matrix - particles

Dispersed Phase - ZrO_2 (or) other

→ Composite Production Methods :

① ~~Pultrusion~~ Pultrusion :

- → Continuous fibres pulled through resin tank
- → Performing die
- → Oven to cure ~~die~~ die

[Coated with Resin/ Thermosetting polymer]

Fibre Rovings ⟶ Resin Impregnation Tank → Performing die → Curing die ⟶ Pullers

[Polymerisation occurs & polymer sets]

② Prepreg Production Processes :

Release Paper ↓ Spooled fibre ↑ ~~Carrier Paper~~ Carrier Paper → Calender Rolls → Waste Release Paper & Spooled Prepeg through carrier paper

Partially Cured (Not fully)

∵ Directly molds and fully cures without adding any resin.

③ Filament Winding : Continuously wound over mandrel

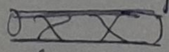
Ex. Pressure Tanks

Used for :

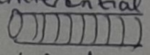
(i) Lower MP

(ii) Made of Sand

- Helical Winding



- Circumferential Winding



- Polar Winding

→ ~~Boeing 78~~

→ Boeing 787 Dreamliner — First aeroplane to use composite materials

Advantages :

20% more fuel Efficiency,

Longer flying ranges,

fewer emmission,

Less noise pollution.

Continuous Carbon-fibre Epoxy Laminates — Major Composite

50000 Rivets (Before Boeing 787)

→ Drag

→ frequent Checking & Maintenance

Hybrid Composite - Glass fibre and Carbon fibre

(Multiple ~~dispe~~ dispered Phases)

→ **Nanocomposites** :

Dispersed Phase — Particulate form

(size ≈ 100 nm)

Ex. Dental Restoration, Energy Storage, Mechanical strength enhancements

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ELECTRICAL PROPERTIES

→ **Electron Mobility** :

Impurities hinders motion of electrons.

$$V_d = \mu_e E$$

μ_e : Electron Mobility

Conductivity $(\sigma) = n|e|\mu_e$

$|e| = 1.6 \times 10^{-19}$

n = no. of free e^- per unit vol.

→ Matthiessen's rule :

$$\rho_{total} = \rho_t + \rho_i + \rho_d$$

ρ_t → Thermal, ρ_i → Impurities, ρ_d → Plastic

$$\rho_t = \rho_0 + aT$$

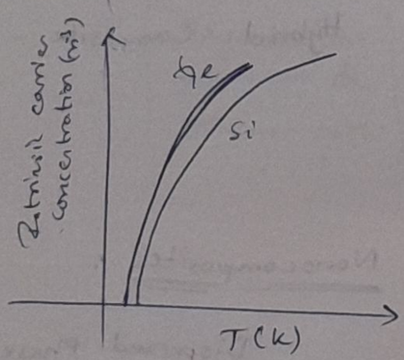
$$\rho_i = \rho_\alpha V_\alpha + \rho_\beta V_\beta$$

→ Semiconductors :

(a) Band Gap < 2eV [(Intrinsic) ⟶ Need to be >500°C to work]

Ex. Si, Ge, GeAs, InSb

Si → 1.11, Ge → 0.67 [Band Gap (eV)]



$$\sigma = n|e|\mu_e + p|e|\mu_h$$

$$n = p = n_i$$

$$\sigma = n|e|(\mu_e + \mu_h) = p|e|(\mu_e + \mu_h)$$

$$= n_i|e|(\mu_e + \mu_h)$$

Q) $\sigma = 3 \times 10^{-7}$ $(\Omega m)^{-1}$

$\mu_e = 0.8$ $m^2/V\text{-}s$

$\mu_h = 0.04$ m^2/Vs

$$n = \frac{3 \times 10^{-7}}{1.6 \times 10^{-19} \times 0.84} = 2.232 \times 10^{12} \ m^{-3}$$

(b) Extrinsic Semiconductors :

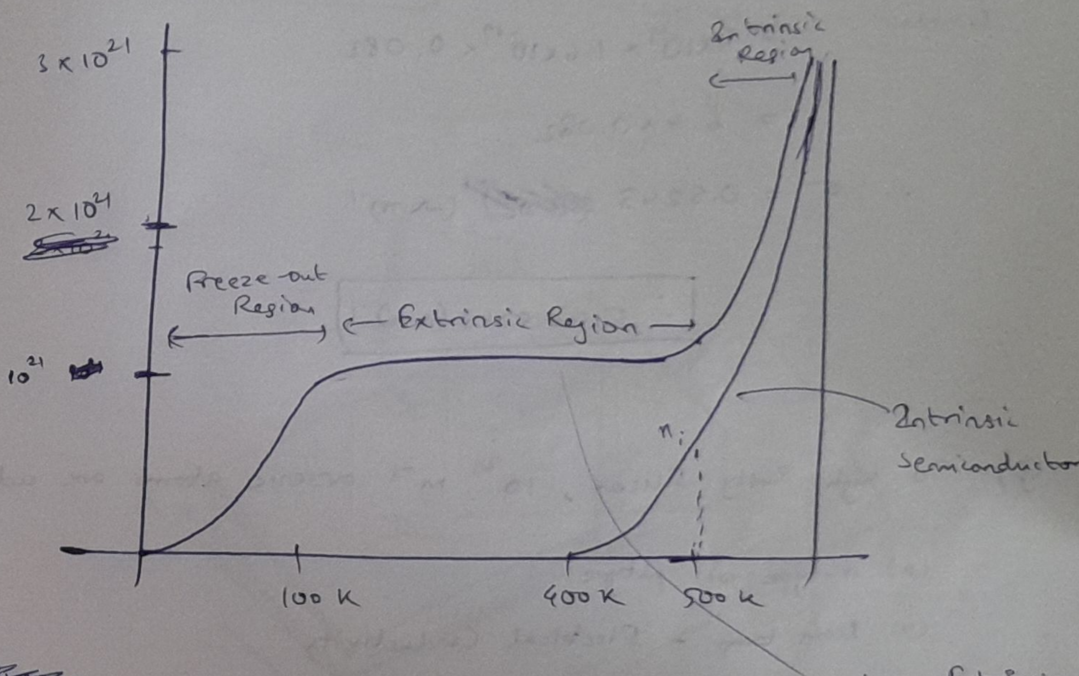
(i) n-type : [e^- → Charge Carrier]

$\sigma \cong n |e| \mu_e$ (Phosphorus)

(ii) p-type [Hole → Charge Carrier]

$\sigma \cong p |e| \mu_h$ (Boron)

Need to be 150° - 475°C to work. - Extrinsic



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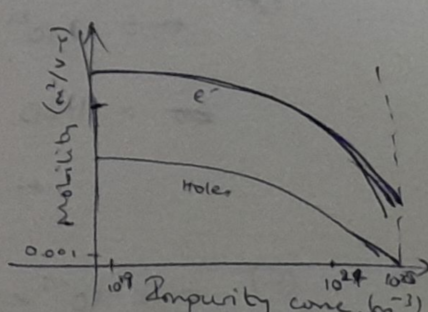
→ Factors Affecting carrier mobility :

(1) Influence of dopant concentration :

$$\text{Mobility} \propto \frac{1}{\text{Inc. in Impurities}}$$



(2). Temparature

Lower Impurity conc. :

$$\text{Mobility} \propto \frac{1}{\text{Temp.}}$$

Higher Impurity conc. :

Mobility Increases then decreases.

Q) Calculate Electrical Conductivity of Intrinsic silicon at 150°C.

μ_e : 0.06 $m^2/V.s$

μ_h : 0.022 $m^2/V.s$

n : 4×10^{19} m^{-3}

150°C → Extrinsic
Si → n-type

A) $\sigma = n|e|\cdot(\mu_e + \mu_h)$

$= 4\times10^{19} \times 1.6\times10^{-19} \times 0.082$

$= 6.4 \times 0.082$

$\therefore \sigma = 0.5248 \ (\Omega m)^{-1}$

$\boxed{\therefore \sigma = 0.5248 \ (\Omega m)^{-1}}$

Q) To high Purity Silicon, 10^{23} m^{-3} arsenic atoms are added

(a) n-type or p-type

(b) Room temp. - Electrical Conductivity

(c) Compute Conductivity @ 100°C

$\mu_{298 K} = 0.07$

$\mu_{373 K} = 0.04$

A) (a) n-type

(b) $\sigma = 10^{23} \times 1.6\times10^{-19} \times 0.07$

$= 1120$

$\therefore \sigma = 1120 \ (\Omega m)^{-1}$

Generally:
$\mu \propto T^{-3/2}$

	Si	Ge	GaAs
(e^-) μ_e	$T^{-2.4}$	$T^{-1.7}$	$T^{-1.0}$
(h) μ_h	$T^{-2.2}$	$T^{-2.3}$	$T^{-2.1}$

(c) $\sigma = 10^{23} \times 1.6\times10^{-19} \times 0.04$

$= 640$

$\therefore \sigma = 640 \ (\Omega m^{-1})$

→ **Hall Effect** :

Turning ⟹ Steady state Achieved

Hall Voltage (V_H) : (−) ve / (+) ve

(−) ve ⇓ e^- → major carriers [n-type]

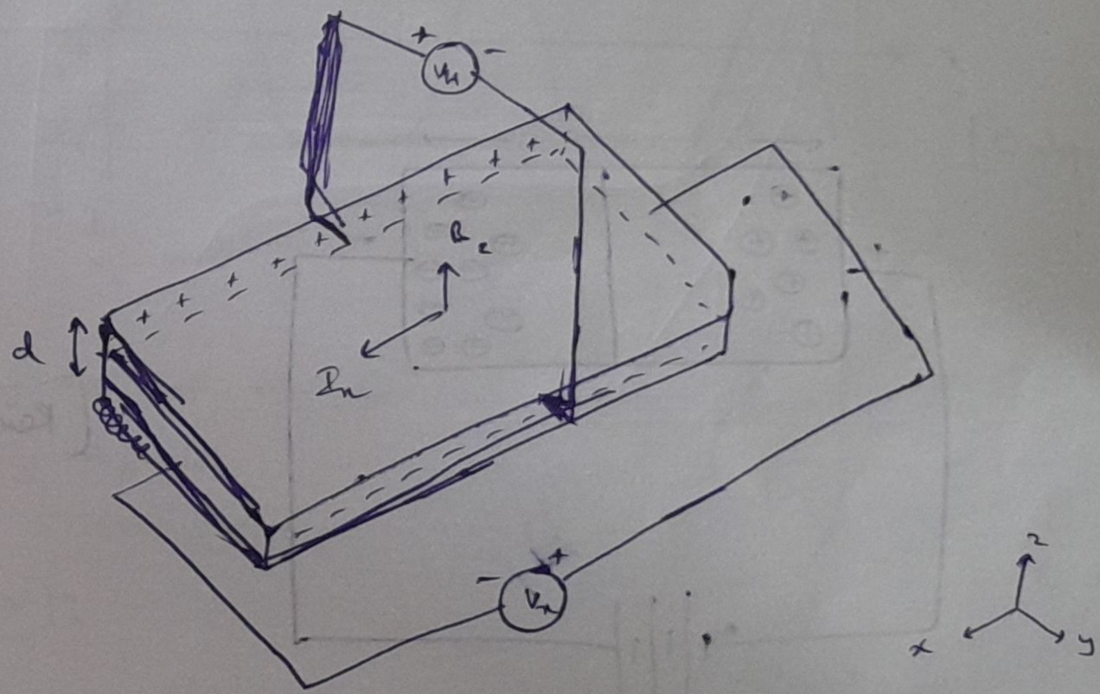
(+) ve ⇓ h → major carriers [p-type]

$$\boxed{V_H = \frac{R_H I_x \cdot B_z}{d}}$$

d : Specimen Thickness

R_H : Hall Coefficient ↳ constant for a material

Steady state : $F(+y) = F(-y)$



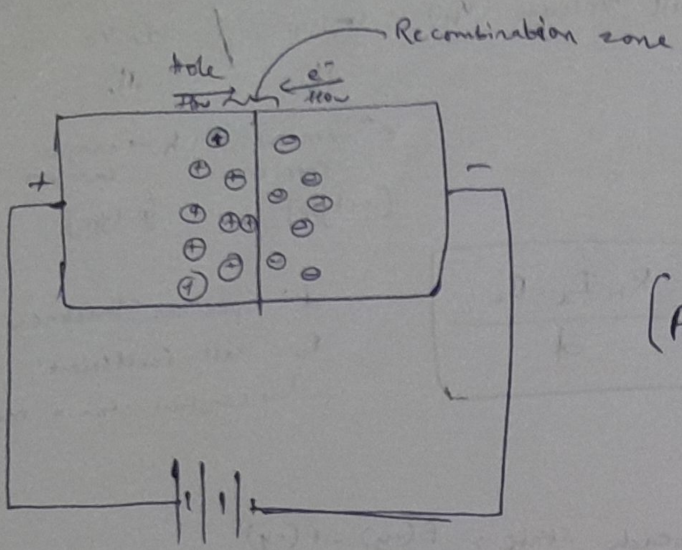
$$R_H = \frac{1}{n|e|}$$

$$\mu_e = \frac{\sigma}{n|e|}$$

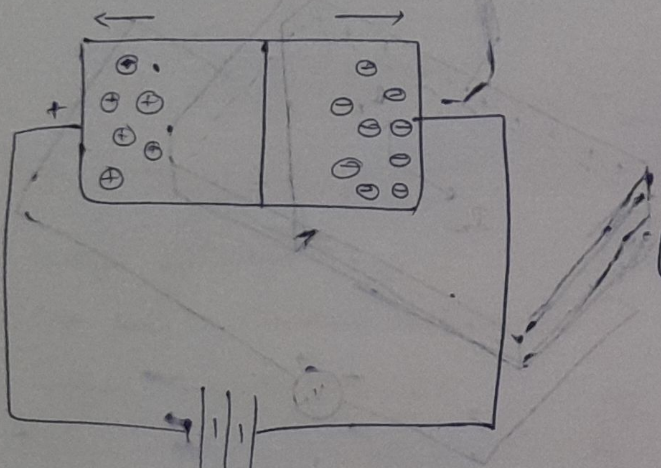
$$\Rightarrow \mu_e = |R_H|\,\sigma$$

→ Semiconductor Devices :

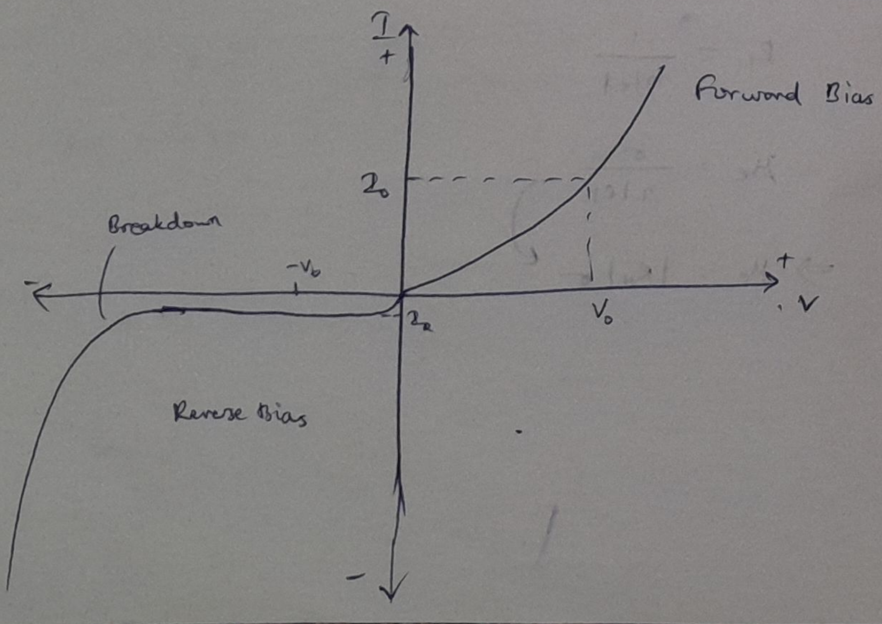
① [PN Junction Diode]



[Forward Bias]

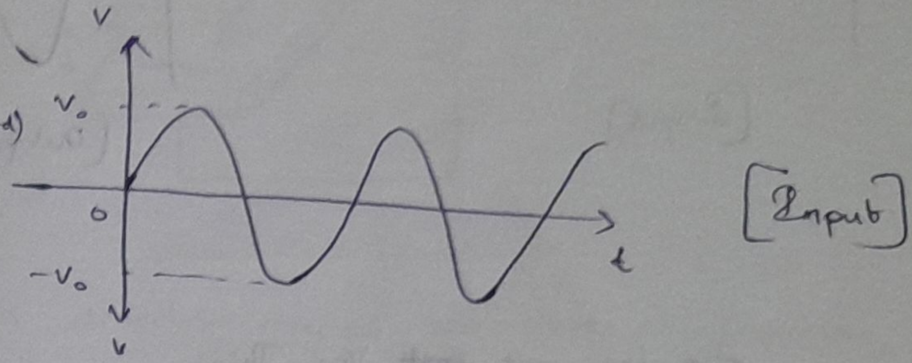


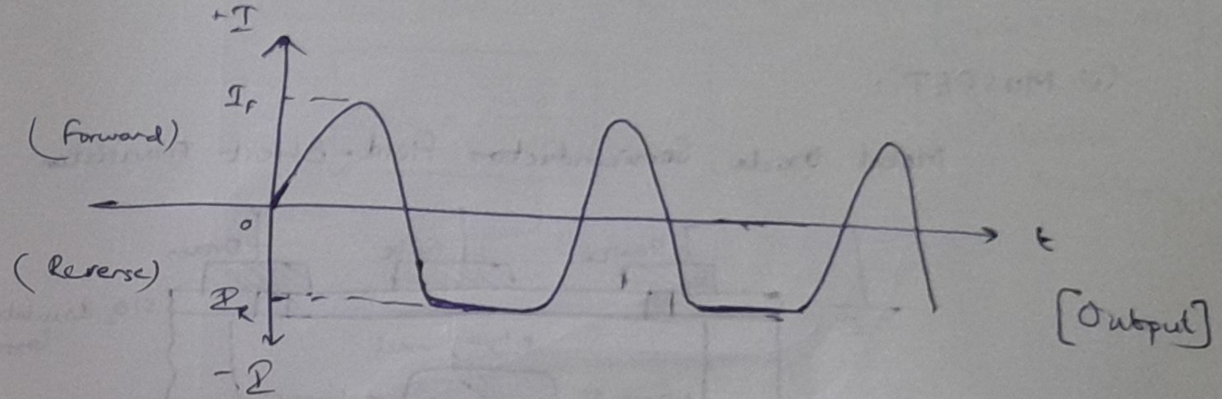
[Reverse Bias]



Use of Diodes :

(i) Rectifiers : AC to DC



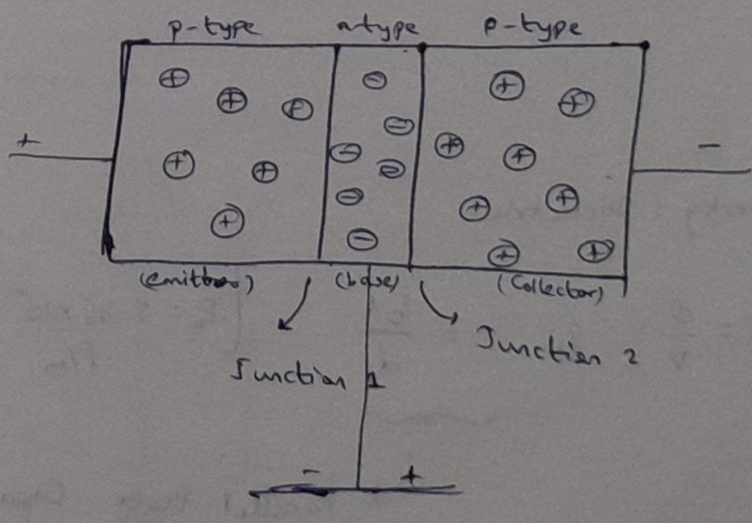


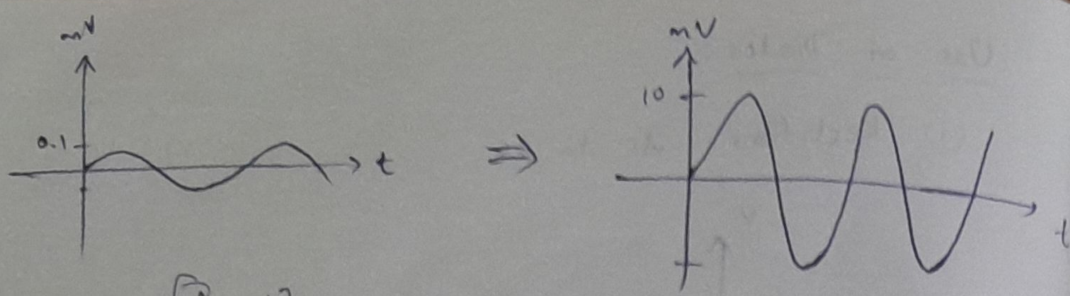
(ii) Controlling size of signals.

(iii) Multiplexing signals

② [Transistor] :

(1) p-n-p Transistor



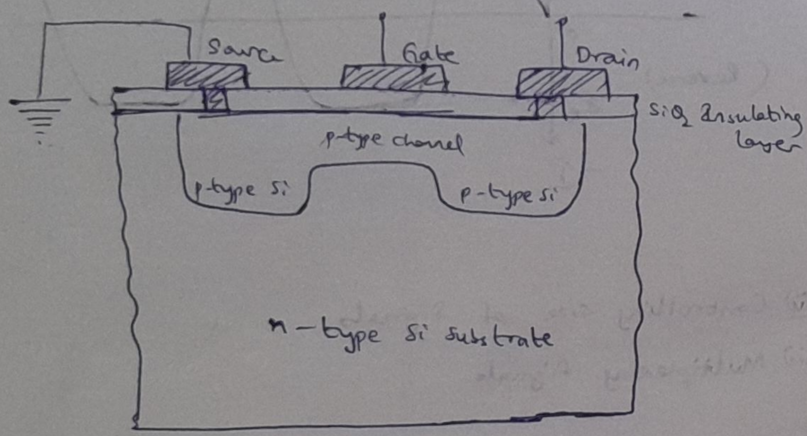


[Input] [Output]

Ase base → ~~bat~~ Very Thin
e^- will jump.

(ii) MOSFET :

Metal Oxide Semiconductor Field - Effect Transistor



By Applying any Voltage to Gate,
Conduction of that layer decreases

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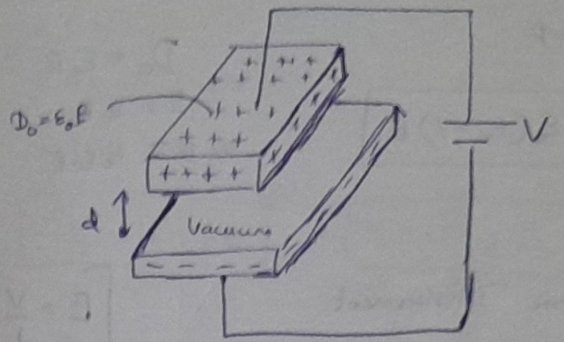
→ Capacitor :

↳ Property : Dielectric

$C = \frac{Q}{V}$ & $\underbrace{C = \frac{\varepsilon A}{d}}$ $\left[\varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m}\right]$

↳ Parallel Plate Capacitor



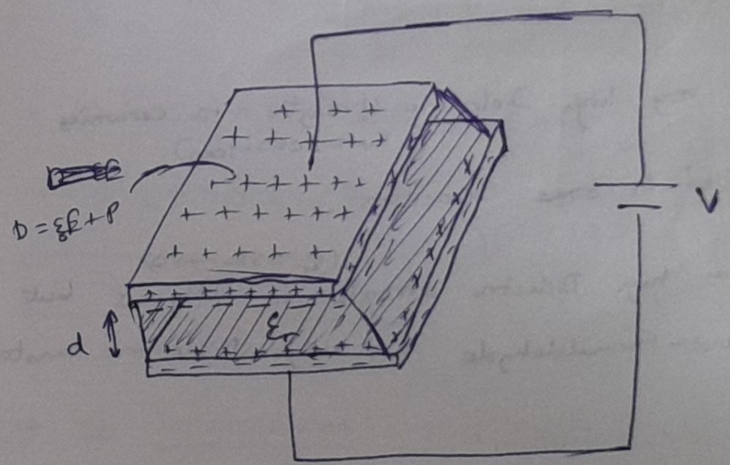
If dielectric inserted b/w plates of Capacitor,

$$C = \frac{\varepsilon A}{d} \qquad [\varepsilon = \varepsilon_0 \varepsilon_r]$$

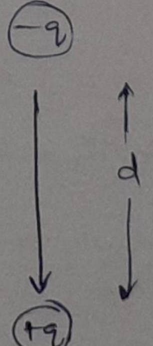
[$\varepsilon_r = 1$ for air]

Relative Permittivity

$$\boxed{\therefore C = \frac{\varepsilon_0 \varepsilon_r A}{d}}$$



Dipole moment :



$$\vec{p} = q\vec{d}$$

[d : -ve to +ve]

$D = \varepsilon_0 E + P$

$$\boxed{P = \varepsilon_0(\varepsilon_r - 1)E}$$

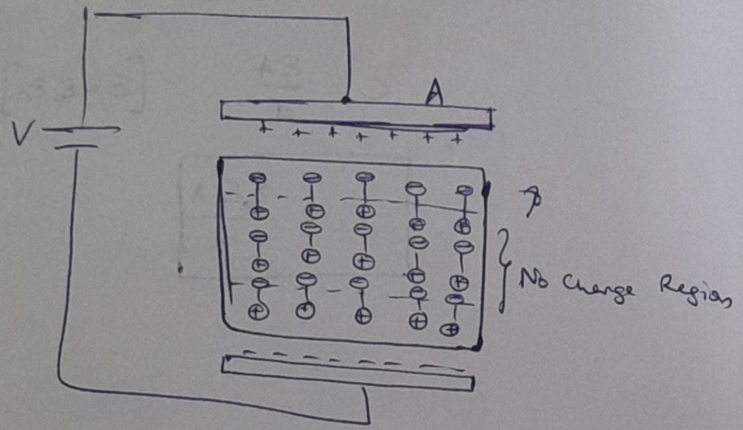
Dielectric Displacement

$D_0 = \varepsilon_0 E$

$D = \varepsilon E$

$\Rightarrow D = \varepsilon_0 \varepsilon_r E$

$\left[E = \frac{V}{d}\right]$



→ Mica has very high Dielectric strength in ceramics ($\varepsilon_r = 2000-3000$)

∴ Used in Some Capacitors

Polyester has high Dielectric strength in Polymers ($\varepsilon_r = 500-750$) but Phenol-Formaldehyde has high Dielectric constants.

Q) $A = 6 \times 10^{-4}\ m^2$

$d = 2 \times 10^{-3}$

$V = 10\ V$

Dielectric constant = 6.

A) (a) $C = \frac{\varepsilon A}{d} = \varepsilon_0 \varepsilon_r \times 3 \times 10^{-1}$

$= 8.85 \times 10^{-12} \times 0.3 \times 6$

$= 1.593 \times 10^{-11}$

$$\boxed{\therefore C = 1.6 \times 10^{-11}\ F}$$

$$\boxed{\therefore C = 16\ pF}$$

(b) $q = CV$

$= 16\,pF \times 10\,V$

$= 160\,pC$

$\boxed{\therefore q = 160\,pC}$ $\boxed{q = 159.3\,pC}$

(a) $D = \varepsilon_0 E + P$

$P = \varepsilon_0(\varepsilon_r - 1) \times \frac{V}{d}$

$= 8.85 \times 10^{-12} \times 5 \times \frac{10}{2} \times 10^{3}$

$\boxed{\therefore P = 2.2125 \times 10^{-7}\ C/m^2}$

(c) $D = \varepsilon_0 E + P$

$= \left(8.85 \times 10^{-12} \times \frac{10}{2} \times 10^{3}\right) + 2.2125 \times 10^{-7}$

$= (0.4425 \times 10^{-7}) + (2.2125 \times 10^{-7})$

$= 2.6550 \times 10^{-7}$

$\boxed{\therefore D = 2.655 \times 10^{-7}}$

→ <u>Types of Polarisation</u>:

(a) Electronic Polarisation : All Dielectric Materials only when $\vec{E}$ is present

(b) Ionic Polarisation

(c) Orientation Polarisation : Polarisation ↓ with ↑ in Temp.

→ <u>Ferroelectricity</u>:

Ex. Barium Titanate ($\varepsilon_r = 5000$)

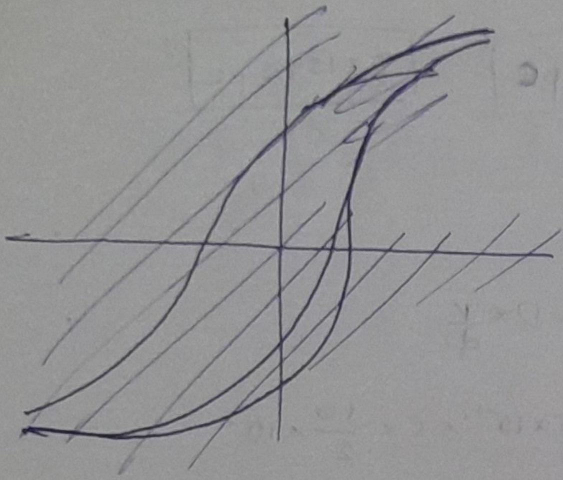
→ Acquires spontaneous polarisation below a certain temp. only AKA Ferroelectric Curie Temp.

Used as Capacitors ∵ They have high ε_r.

~~Ex.~~

Ex. Rochelle's Salt ($NaKC_4H_4O_6 \cdot 4H_2O$),

KH_2PO_4, $KNbO_3$, $Pb[ZrO_3, TiO_3]$



→ Piezoelectricity :

↳ Apply pressure on material → Polarisation occurs
→ $\vec{E}$ created.

Used in Transducers

Ex. Gas, ZnO, CdS, ~~Also~~

Ex. Also used in Ink-Jet Printer

MAGNETIC PROPERTIES

→ Magnetic Properties :

Magnetic Field Strength ⇒ $H = \frac{Ni}{l}$ A/m $\left[E = \frac{V}{l}\right]$

l: Length of Conductor

i: Current in Conductor

~~N: Number of turns in the coil~~

N: No. of turns in the coil

Magnetic Flux Density → $B = \mu H$ $[D = \varepsilon E]$

$\mu_0 = 4\pi \times 10^{-7}$ Wb/(A·m)

Magnetization (M)

$B = \mu_0 H + \mu_0 M$ $[D = \varepsilon_0 E + P]$

$M = \chi_m H$

$\chi_m \rightarrow$ Magnetic Susceptibility

$\chi_m = \mu_r - 1$ $\qquad [\chi_\varepsilon = \varepsilon_r - 1]$

Net Magnetic moment (atomic) = sum of moments of all electrons.

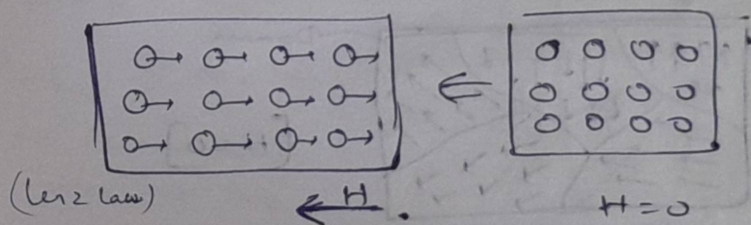
For many, it is 0

For some, non-zero (Incomplete Cancellation) (1L)

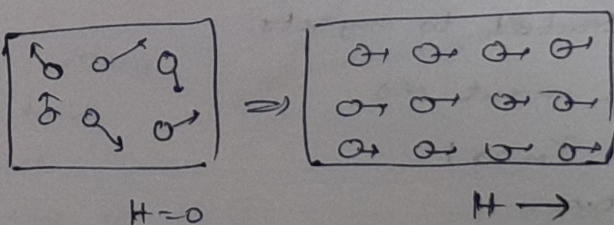
→ Classification :

(i) Diamagnetic materials
(ii) Paramagnetic materials
(iii) Ferromagnetic materials

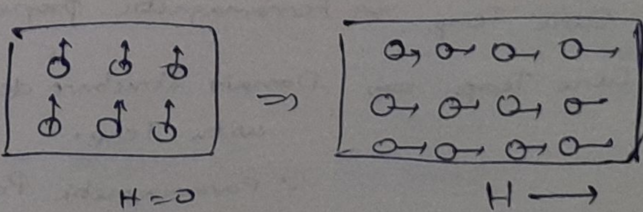
} Exhibit magnetisation only in the presence of magnetic field (external)



[Diamagnetic]
(Net magnetic moment = 0)



[Paramagnetic]
(Net Magnetic Moment [illegible])



[Ferromagnetic]
(M > 0)

~~Res~~ Dipole Arises because motion of e^- changes

(i) Diamagnetic materials :

Weakly repelled by magnets, No permanent Dipoles

Ex. Bi, Cu, Pb

μ_r → very low i.e $\mu_r < 1$

χ_m → Negative (-10^{-5})

↳ Susceptibility (A measure of the relative amount of Induced Magnetism)

(ii) Paramagnetic materials:

Randomised in Absence of Magnetic field.

Weakly Attracted to Magnetic fields.

$\mu_r > 1$

$\chi_m > 0$ (But low)

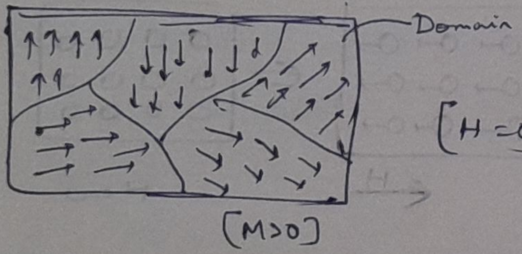
Motion:
Weak to strong

Ex. Na, Cr, Al, etc

(iii) Ferromagnetic materials:

Permanent dipoles, but already aligned in some direction in each domain.

Ex. Co, Ni, Fe, etc



Strongly attracted to magnets.

Net magnetic moment ≠ 0.

$\mu_r >> 1 \Rightarrow \chi_m >> 1$

Motion:
Weak Magnetic field to strong

→ Curie Temperature:-

Below Curie Temp. ⇒ Ferromagnetic property

After Curie Temp. ⇒ Domain structure desintegrate with Temp.

∴ Paramagnetic Property.

~~Domain Structure~~ [Phase Transition]

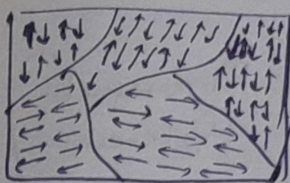
$$\chi_m = \frac{C}{T - T_c}$$

χ_m → Susceptibility

T_c ↳ Curie Temp.

Ferro Magnetics Materials

Anti-ferromagnetism



Extremely sensitive to Interatomic Spacing.

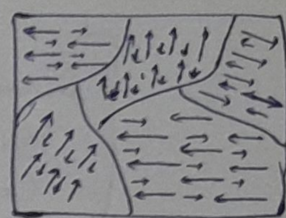
Ex. MnO, NiO, CoO, etc

$M = 0$

$(\chi_m)_{max}$ @ Neel Temp.

i.e. Paramagnetism after Neel Temp.

Ferri-Magnetism

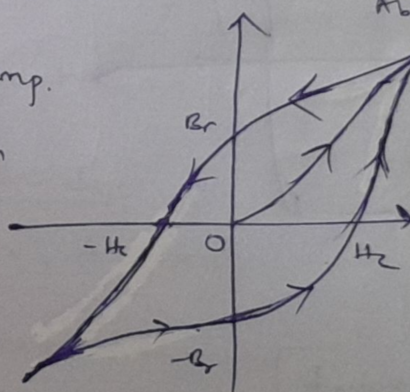


Ex. Fe_3O_4, $NiFe_2O_4$, etc.

$M > 0$

Below Neel Temp: ferromagnetic

Above Neel Temp: Paramagnetic



Value of H @ c → Coercitivity

Make Flux Density → 0
How much Magnetic Field is required?

Size of Hysteris Curve → small

∴ Soft Magnet   Coercivity: Low

$(BH)_{max}$ – ↓ [2–80 kJ/m^3]

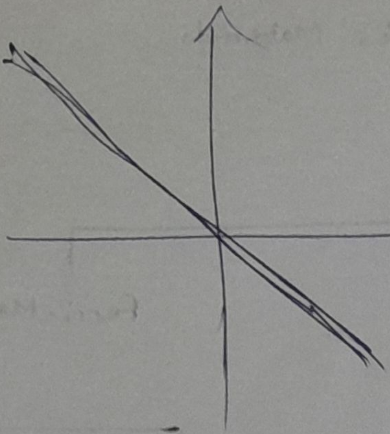
Size of Hystesis Curve → Large

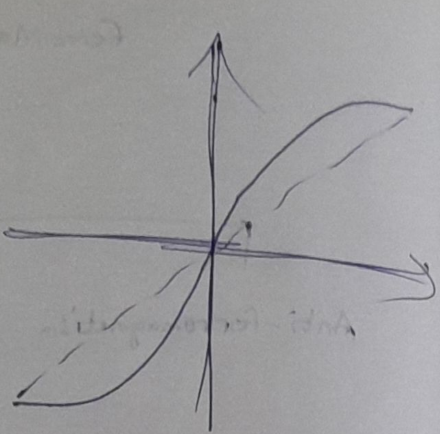
∴ Hard Magnet   Coercivity: High

$(BH)_{max}$ – ↑ [> 80 kJ/m^3]

Area of Largest rectangle → Energy Product $(BH)_{max}$

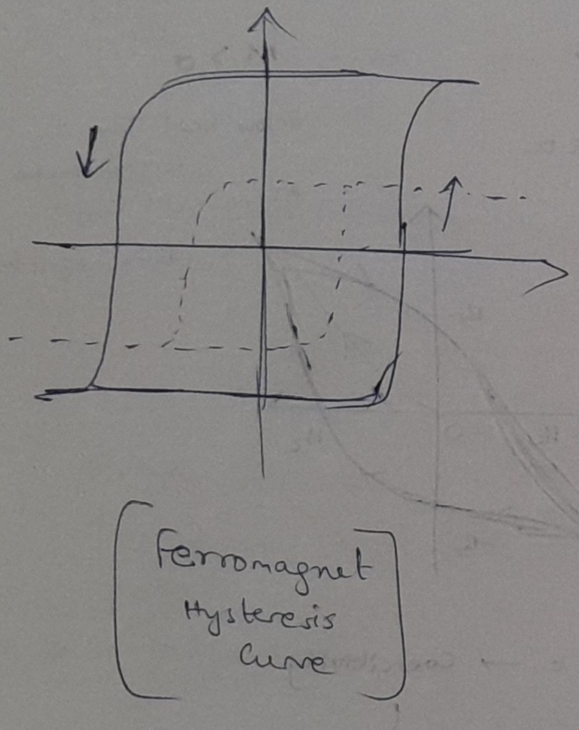
Hysterisis means lagging behind





Diamagnetic Hysterisis Curve

Paramagnetic Hysteresis Curve



Ferromagnet Hysteresis Curve

→ Soft-Magnetic Materials → Must be free of Structural Defects

Ex. Transformer core

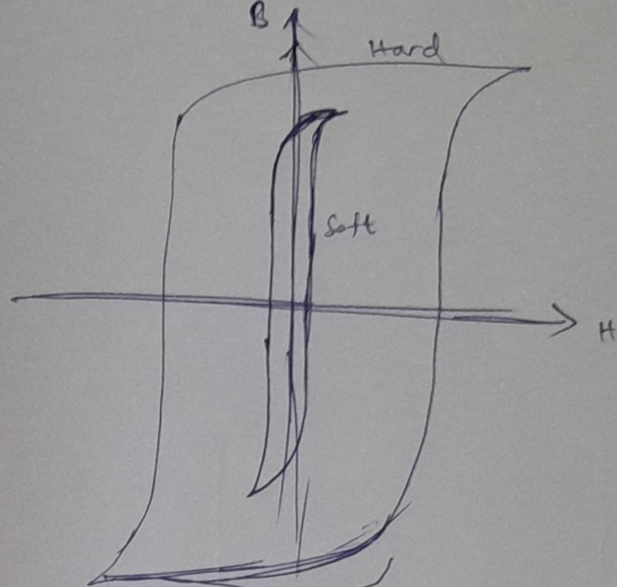
Energy loss will be low in devices

High Initial ~~Coercivity~~ Permeability

Low Coercivity

Small, Thin & Narrow Hysteriesis Curve

Reaches Saturation with less Applied field & ∴ low hysteresis Energy losses.



Eddy Currents : Energy losses result in ~~eddy~~ currents that are induced in a magnetic field by a magnetic field that varies in mag. & direction with time.

Soft - Magnetic Materials are used to reduce these.

→ Hard Magnetic Materials:

Ex. Screwdrivers, Automobiles

→ Used in Permanent Magnets, having high resistance to demagnetisation

High Remanence
High Coercivity
High Saturation Flux Density
Low Initial Permeability
High Hysteresis Losses

Energy Product $= (BH)_{max}$

Conventional : 2 to 80 → Ex. Ni, Cu, Fe alloys
High Energy : > 80 kJ/m³ → Ex. $SmCo_5$

= Largest rectangle's Area (in Second Quadrant) of Hysteresis Curve

$(BH)_{max} \uparrow \Rightarrow$ Harder the material in terms of its magnetic characteristics