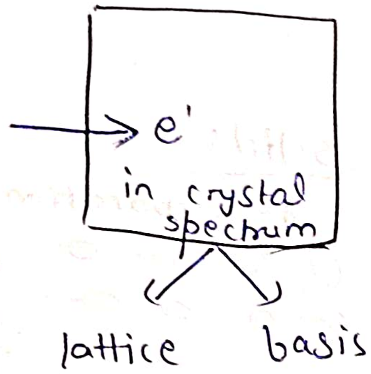
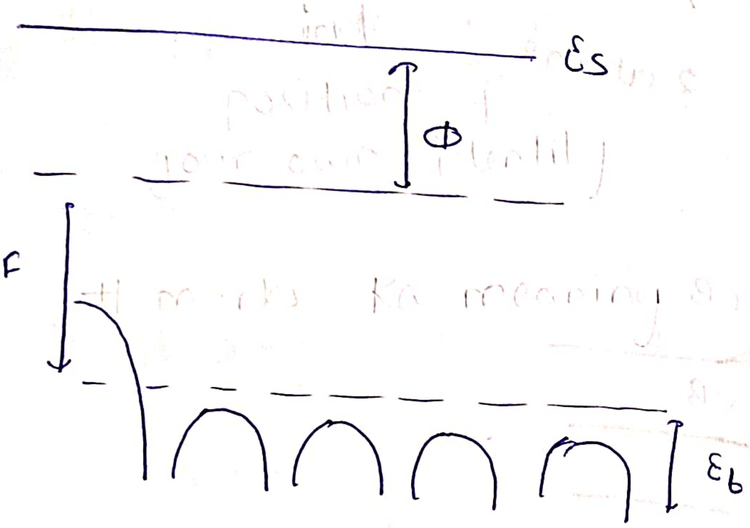
SEMI-CONDUCTING PHYSICS

- Kronig - penny model :-





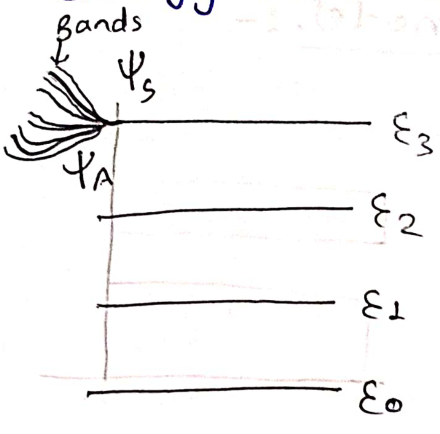
fermi energy → max. energy of e^- at a particular temperature

Periodic potential

E_F → Highest occupied energy at 0K. All energy levels below E_F are completely filled and all energy levels above E_F are empty.

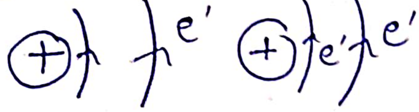
- Band theory of solids :-

energy band diagram of atom or molecules :-



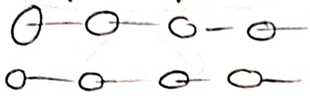
atoms

MOT.

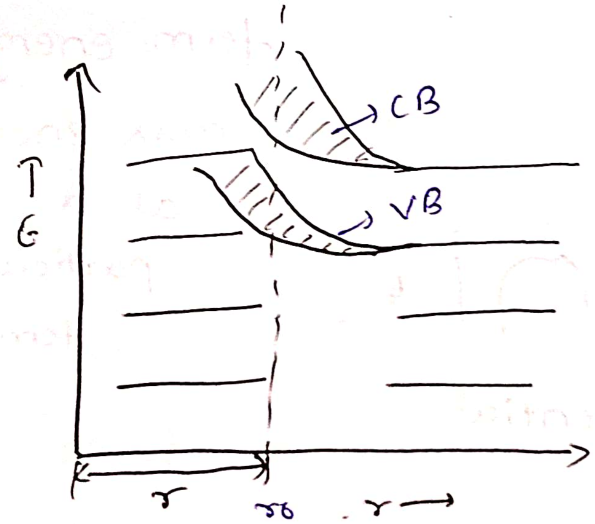


2 atoms.

solids



→ Arthur Beisen.



- fermi function :- (fermi - Dirac Distribution function)

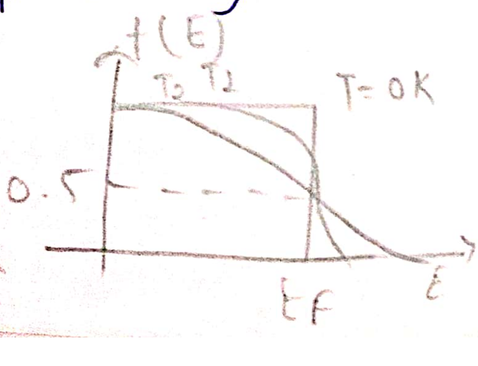
$$f(E) = \frac{1}{\left[e^{(E-E_f)/KT} + 1\right]}$$

$K = 1.38 \times 10^{-23}$ J/K
$= 8.625 \times 10^{-5}$ eV/K

probability of finding the electron with energy E.

(OR). It can be understand, probability that E to be filled by electrons.

$E_F \Rightarrow$ fermi energy



$T_2 > T_1 > 0K$

→ ~~PK~~ Kshirsagar
VNIT Nagpur

i) At absolute zero temperature,

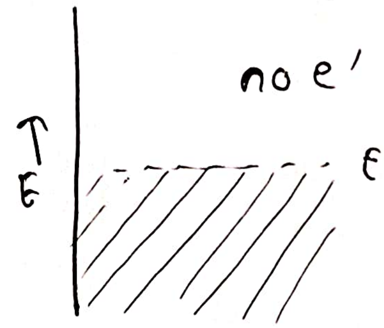
$T = 0K.$

→ if $E < E_F$,

$$f(E) = \frac{1}{e^{-\infty}+1} = 1$$

→ if $E > E_F$,

$$f(E) = \frac{1}{e^{\infty}+1} = 0$$



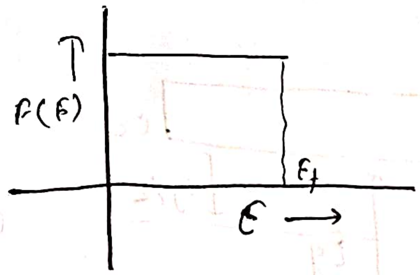
* Maximum energy achieved by electron at absolute zero or $T = 0K$, is called Fermi Energy.

(ii) At any finite T,

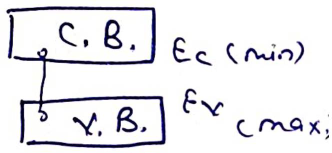
if $E = E_f$

$$\boxed{K = 8.628 \times 10^{-5}\ eV/°K}$$

$$\boxed{f(E) = \frac{1}{2}}$$



- Position of fermi energy in case of Intrinsic Semiconductor:-



$$f(E_c) + f(E_v) = 1$$

$E_c \rightarrow$ minimum of C.B.

$E_v \rightarrow$ maximum of V.B.

$$\frac{1}{[e^{(E_c - E_F)/KT} + 1]} = 1 - \frac{1}{[e^{(E_v - E_F)/KT} + 1]}$$

$$f(E) = \frac{1}{[e^{(E-E_F)/KT} + 1]}$$

→ At ambient temperature,

$$E_c - E_F > KT$$

⇒ Robert Pierre → Ref.
Ber G. spectrum

$$\Rightarrow \frac{E_c - E_F}{kT} > 1$$

$$\boxed{e^{(E_c - E_F)/kT} >> 1} \quad -(1)$$

$$E_F - E_v > kT$$

$$E_v - E_F < kT$$

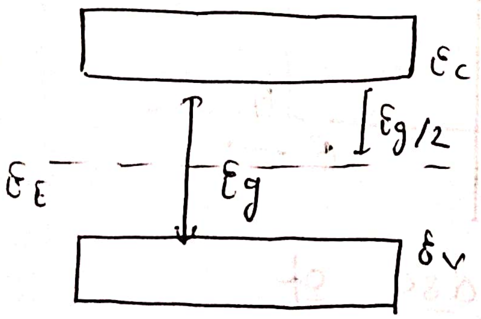
$$\frac{(E_v - E_F)}{kT} < 1$$

$$\Rightarrow \boxed{e^{(E_v - E_F)/kT} << 1} \quad -(2)$$

(#) becomes →

$$\frac{1}{(e^{E_c - E_F/kT} + 1)} = \frac{e^{(E_v - E_F)/kT}}{(e^{(E_v - E_F)/kT} + 1)}$$

$\approx$ 1 → can be ignored $\qquad\qquad \approx 1$



$$e^{(E_F - E_c/kT)} = e^{(E_v - E_F/kT)}$$

$$E_F - E_c = E_v - E_F$$

$$\Rightarrow \boxed{E_F = \frac{E_c + E_v}{2} = \frac{E_g}{2}}$$

- Carrier concentration in intrinsic semiconductor :-
(n_e / n_h)

→ Density of states :- $g(E), \rho(E), G(E), D(E)$

→ No. of energy states per unit rate of energy per unit volume.

$$\boxed{\rho(E) = \frac{4\pi}{h^3}(2m)^{3/2}(E-E_c)^{1/2}}$$

* $$\boxed{n_e = \int_{E_c}^{\infty} \rho(E) f(E) dE}$$

$$= \frac{4\pi}{h^3}(2m)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2}\frac{1}{[e^{(E-E_F)/KT}+1]}dE$$

1 can be removed.

at ambient temperature,

$$E - E_F > KT$$

$$\frac{E-E_F}{KT} > 1$$

$$e^{(E-E_F)/KT} >> 1$$

$$\Rightarrow n_e = \frac{4\pi}{h^3}(2m)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2} e^{(E_F-E)/KT} dE$$

$$= \frac{4\pi}{h^3}(2m)^{3/2}\int_{E_c}^{\infty}(E-E_c)^{1/2} e^{(E_F-E_c+E_c-E)/KT} dE$$

$$n_e = \frac{4\pi}{h^3}(2m)^{3/2} e^{\frac{-E_g}{2KT}}\int_{E_c}^{\infty}(E-E_c)^{1/2} e^{-(E-E_c)/KT} dE$$

Let $\frac{E-E_c}{KT} = x$

$dE = KT dx$

K = Boltzmann constant.

$$\Rightarrow n_e = \frac{4\pi}{h^3}(2m)^{3/2}(KT)^{3/2} e^{-E_g/2KT}\int_0^\infty x^{1/2} e^{-x}dx$$

Ans - $\boxed{\sqrt{\frac{\pi}{2}}}$

m = mass of electron

- Fermi energy in intrinsic semiconductor :-

$$n = \int_0^\infty \rho(E)\,dE\,f(E)$$

$$f(E_c) = 1 - f(E_v)$$

$$f(E_c) + f(E_v) = 1$$

$$= \int_0^\infty \rho(E)\,dE\,f(E)$$

$$\Rightarrow \rho(E) = \frac{4\pi}{h^3}(2m)^{3/2}E^{1/2}$$

$$n = \int_0^{E_f}\rho(E)\,dE\,f(E) + \underbrace{\int_{E_f}^\infty \rho(E)f(E)\,dE}_{0.}$$

$$\Rightarrow n = \frac{4\pi}{h^3}(2m)^{3/2}\int_0^{E_F}(E)^{1/2}dE$$

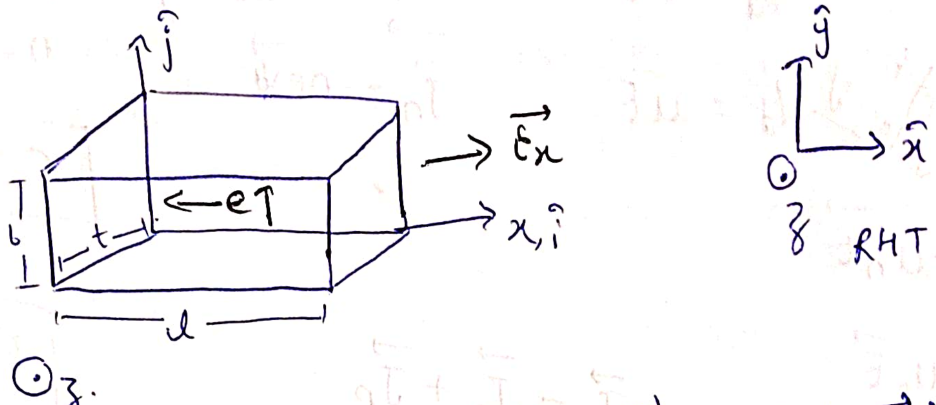
$$\boxed{n = \frac{4\pi}{h^3}(2m)^{3/2}\frac{E_F^{3/2}}{3/2}}$$

$$n = \frac{8\pi}{3h^3}(2m)^{3/2}E_F^{3/2}$$

$$\Rightarrow E_F^{3/2} = \frac{3nh^3}{8\pi(2m)^{3/2}}$$

$$\star\ \boxed{E_F = \left(\frac{3n}{8\pi}\right)^{2/3}\frac{h^2}{2m}}$$

Hall Effect :-



$$\vec{F} = q(\vec{v} \times \vec{B})$$

$$\vec{F} = -e(-v_x \hat{i} \times H_z \hat{k})$$

$$\boxed{\vec{F} = -e v_x H_z \hat{j}}$$

* In steady state condition,

$$\cancel{e} \varepsilon_H = \cancel{e} V_x H_z$$

$$\boxed{J_x = n e \vec{v}_x}$$

$$\varepsilon_H = V_x H_z$$

$$\varepsilon_H = \frac{1}{ne} J_x H_z$$

$$\vec{F} = q\vec{\varepsilon}$$

$$\vec{F} = -e\vec{\varepsilon}$$

$$\Rightarrow \boxed{\varepsilon_H = R_H J_x H_z}$$

$$R_H = \frac{-1}{ne}$$

R_H = Hall coefficient

$$\varepsilon_H \propto J_x H_z$$

$$\boxed{\varepsilon_H = R_H J_x H_z}$$

$$\frac{V_H}{b} = \frac{-1}{ne} \cdot \frac{I}{bt} H_z$$

$$\boxed{V_H = \frac{R_H I H_z}{t}}$$

– Mobility :–

$\vec{V_d} \propto \vec{E}$

drift velocity $\vec{V_d} = \mu \vec{E}$

$V_d = -\mu_n \vec{E}$

$V_d = \mu_p \vec{E}$

Current density

$\vec{J_n} = -ne\vec{V_d}$

$\sigma = (ne\mu_n + pe\mu_p)$

$n = p = n_i$

$\boxed{\sigma = n_i e(\mu_n + \mu_p)}$

$\boxed{\sigma = ne\mu}$

(e) (p)

N_d & N_a

donor or acceptor concentration, resp.

$\sigma = N_d e \mu_e$ (n-type)

$\sigma = N_a e \mu_p$ (p-type)

$\vec{J} = \vec{J_n} + \vec{J_p}$

$= -ne(\vec{V_d})_e + pe(\vec{V_d})_p$

$= ne\mu_n\vec{E} + pe\mu_p\vec{E}$

$\boxed{\vec{J} = (ne\mu_n + pe\mu_p)\vec{E}}$

$(J = \sigma E)$

$\sigma = ne\mu_n + pe\mu_p$

for intrinsic,

$n = p = n_i$

$\sigma = n_i e(\mu_n + \mu_p)$

$\boxed{\sigma = \frac{1}{\rho}}$

$n_i = n = p = AT^{3/2} e^{-E_g/2KT}$

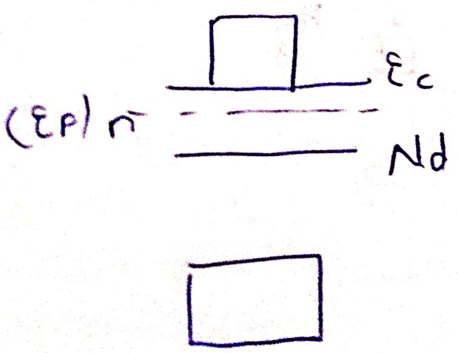
$n = AT^{3/2} e^{-E_g/2KT}$

$$\boxed{\begin{aligned} n &= N_c e^{-E_g/2KT} \\ p &= N_v e^{-E_g/2KT} \end{aligned}}$$

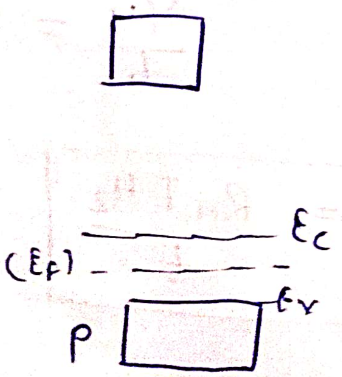
– Extrinsic Semiconductor :–

n/p.

n type



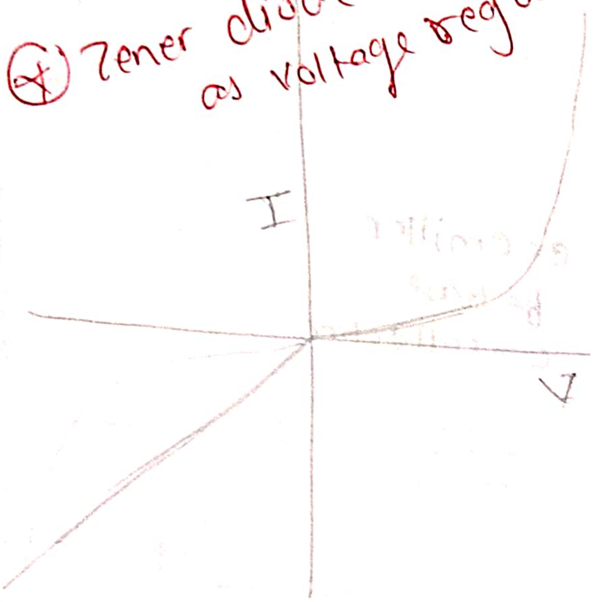
p type



- P-N Junction Diodes :-

PN

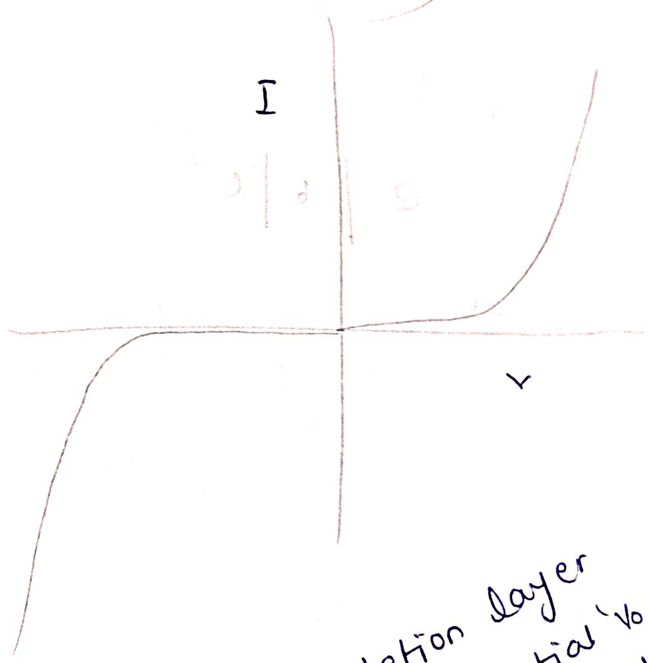
(*) Zener diode used as voltage regulator.



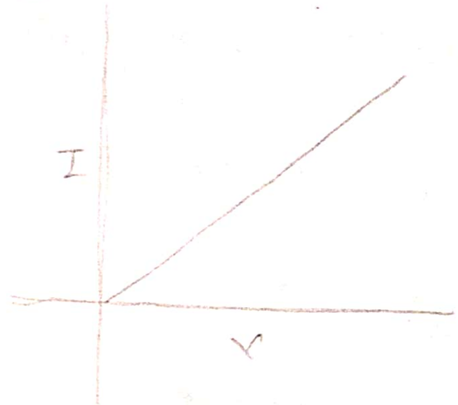
Carriers

	p	n
majority -	h	e
minority -	e	h

PNN

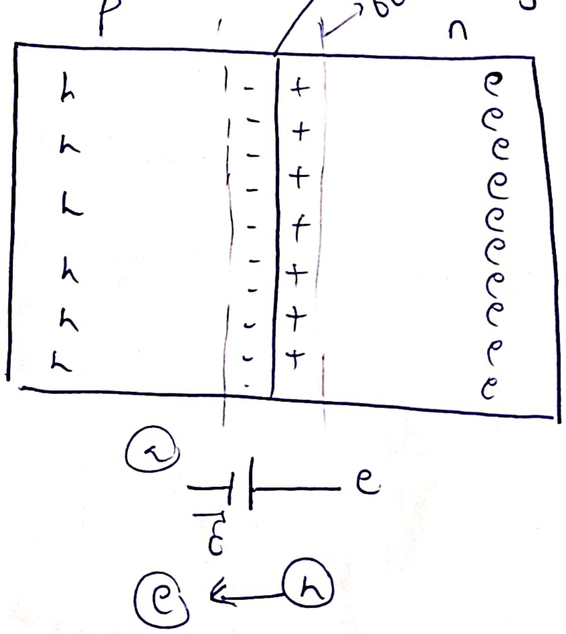


PN



Depletion layer

built in potential 'Vo'
junction voltage

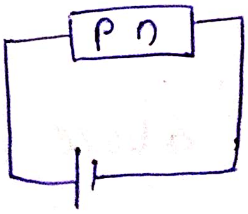


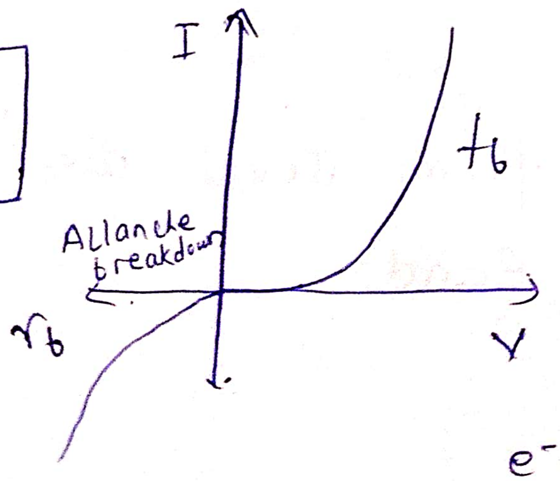
Carriers

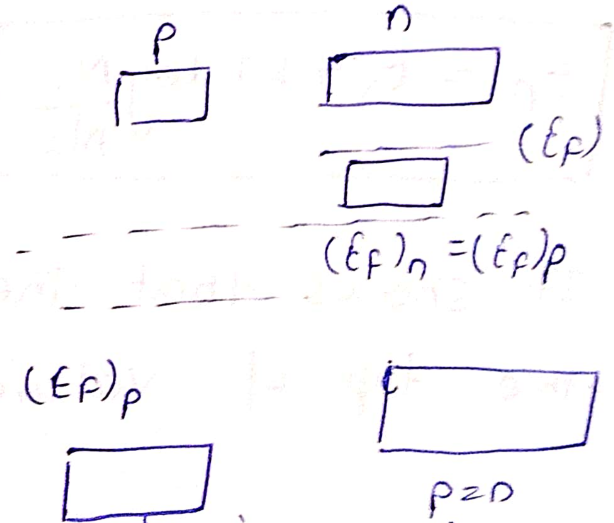
majority -

minority -

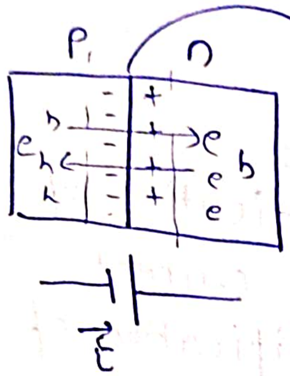
P- N Junction Diode !-







When Fermi energy of e^- and h transfer stops.



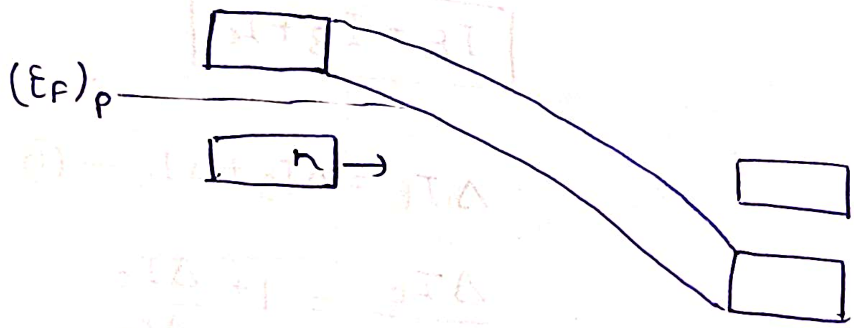
Depletion layer

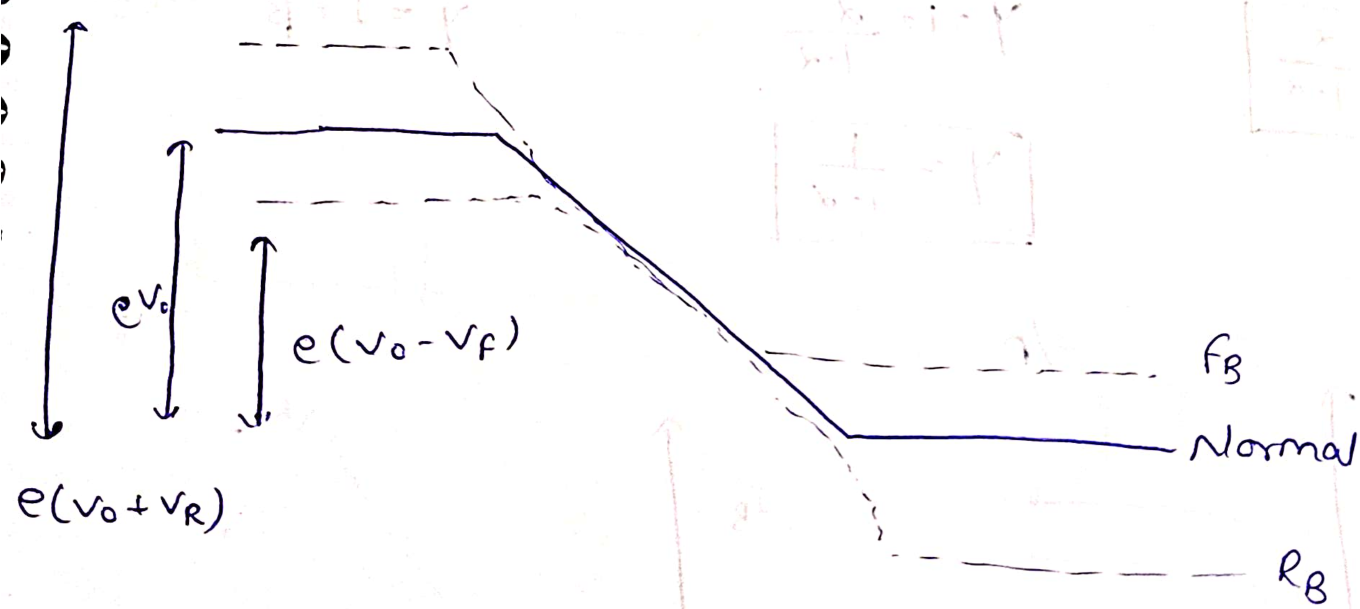
Built in potential 'V_0' junction voltage,

$$\vec{E} = \frac{V_0}{d}$$

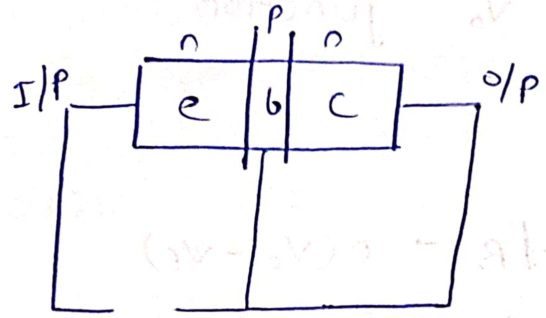
FB → $e(V_0 - V_F)$

RB → $e(V_0 + V_R)$





Transistor:-



Uses.

→ Amplification of current

→ Amplification of voltage

fB	fB	Saturation region
RB	RB	cut off region
fB	RB	Active region

Current gain,

CB	α	$= \Delta I_C / \Delta I_E$
CE	β	$= \Delta I_C / \Delta I_B$
CC	γ	$= \Delta I_E / \Delta I_B$

$$\boxed{I_E = I_B + I_C}$$

$$\Delta I_E = \Delta I_B + \Delta I_C \quad \text{—(I)}$$

$$\frac{\Delta I_E}{\Delta I_B} = 1 + \frac{\Delta I_C}{\Delta I_B}$$

$$\gamma = 1 + \beta \quad \text{—(II)}.$$

$$\frac{\Delta I_E}{\Delta I_C} = \frac{\Delta I_B}{\Delta I_C} + 1$$

$$\frac{1}{\alpha} = \frac{1}{\beta} + 1$$

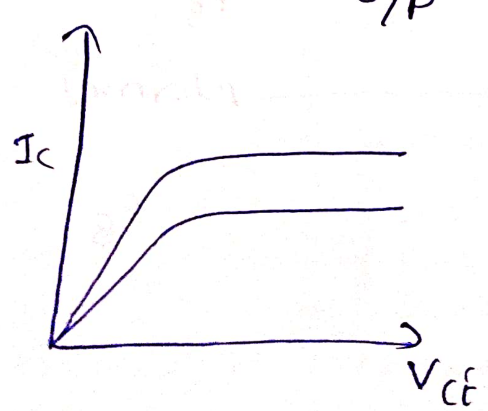
$$\frac{1}{\beta} = \frac{1}{\alpha} - 1$$

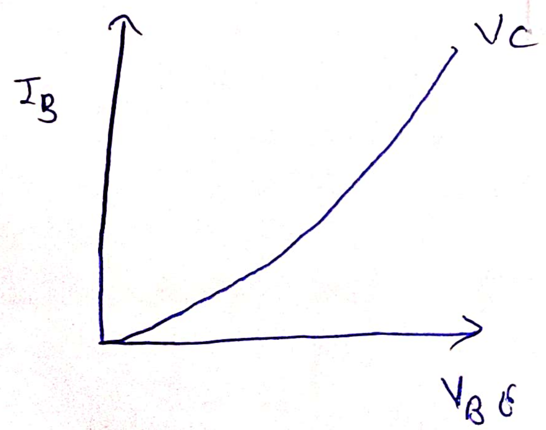
$$\boxed{\beta = \frac{\alpha}{1-\alpha}}$$

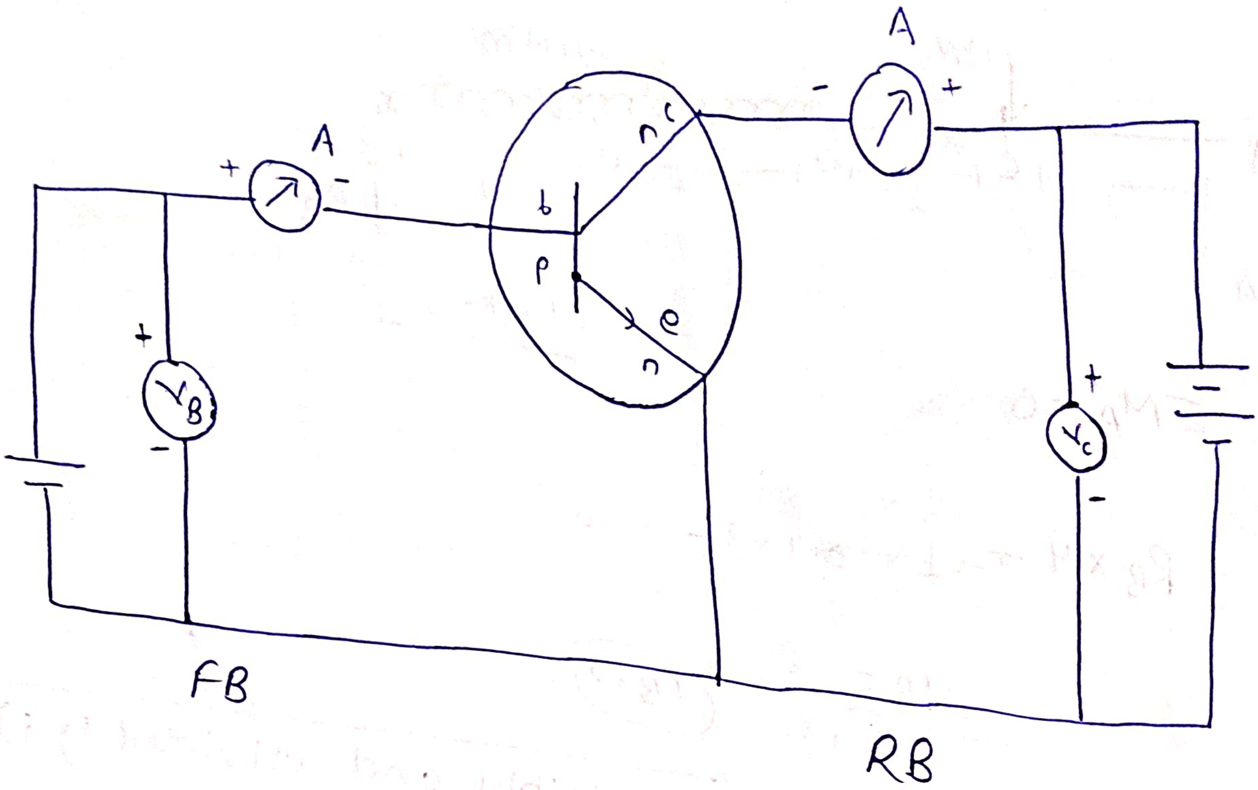
$$\gamma = 1 + \frac{\alpha}{1-\alpha}$$

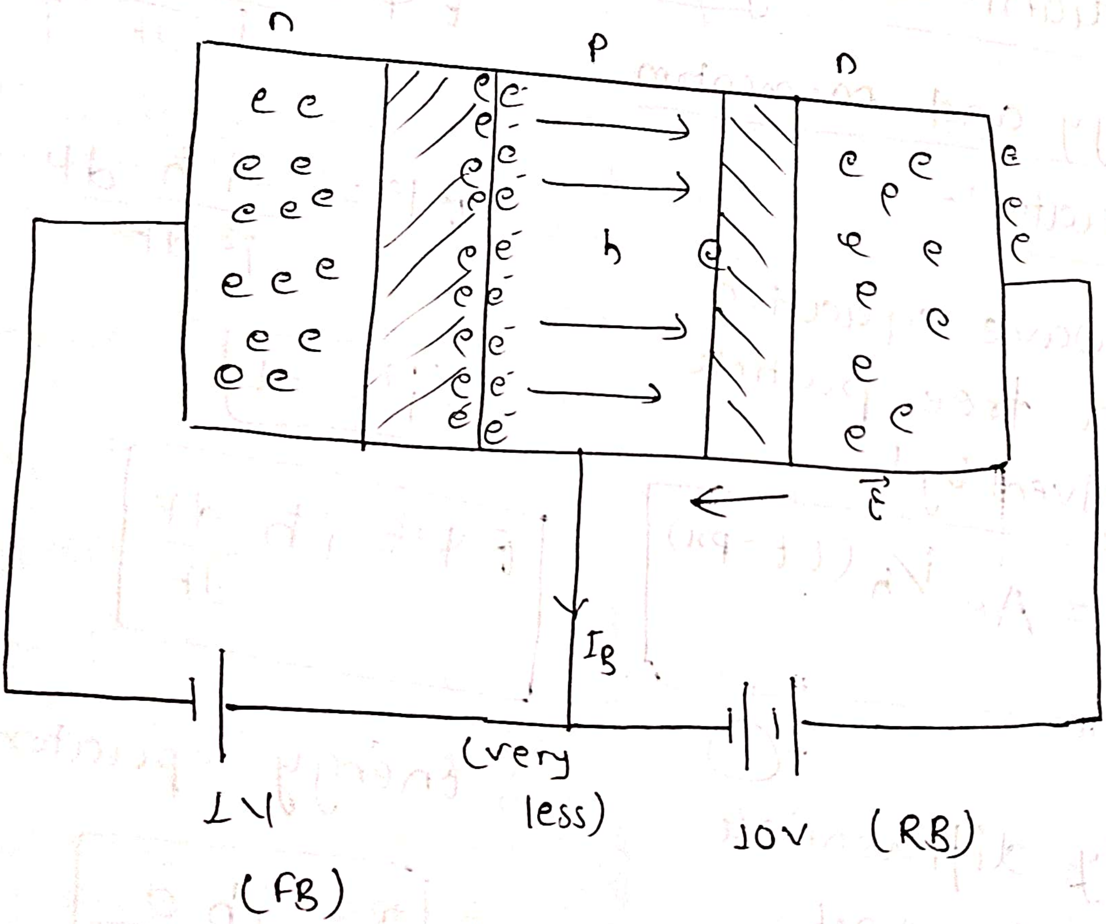
$$\boxed{\gamma = \frac{1}{1-\alpha}}$$

o/p



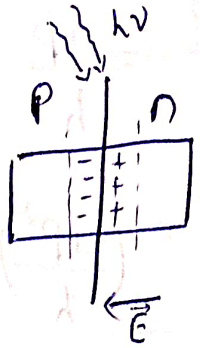




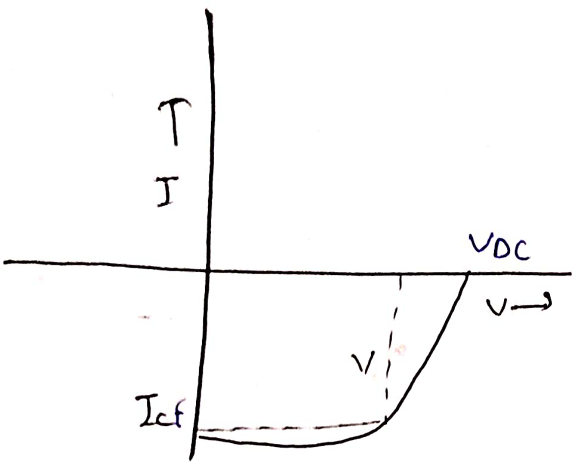


E_F of all there is same.

Solar cell / photo cell :-



(p-i-n)



$P_{st} \propto V_{oc}, I_{sc}$

Photocell.