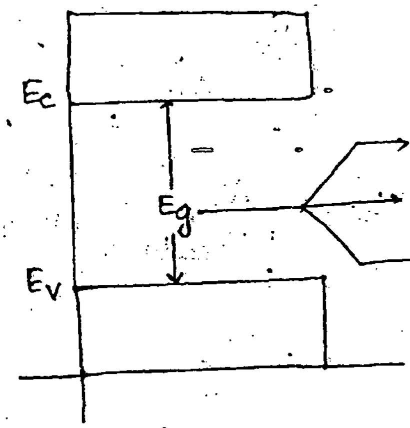
SEMI CONDUCTOR PHYSICS.

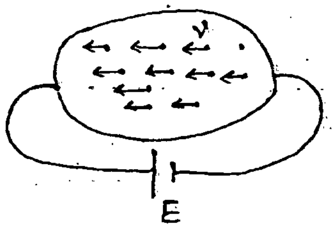
☐ SILICON, GERMANIUM AND GaAs.

QUESTION :- Why silicon and Germanium are preferred to GaAs.



- 0 ev (Metal)
- 1 ev (Semiconductor) →
  - $T = 0K\ (-273°C)$
  - * Ge ($E_{g0} = 0.785$ ev)
  - * Si ($E_{g0} = 1.21$ ev)
  - GaAs ($E_{g0} = 1.58$ ev) → more conductivity
- 6 ev (Insulator)

MOBILITY :- (μ)



$V \propto E$ → μ (mobility)

$\boxed{V = \mu E}$

$$\mu = \frac{\text{Drift Velocity}}{\text{Electric Field}} = \frac{m^2}{V.sec}$$

$$\boxed{\begin{aligned} {}^{*}\mu_e(si) &= 1300\ cm^2/Vsec \\ {}^{*}\mu_e(Ge) &= 3800\ cm^2/Vsec \\ \mu_e(GaAs) &= 8500\ cm^2/Vsec \end{aligned}}$$ → Low Speed Operation

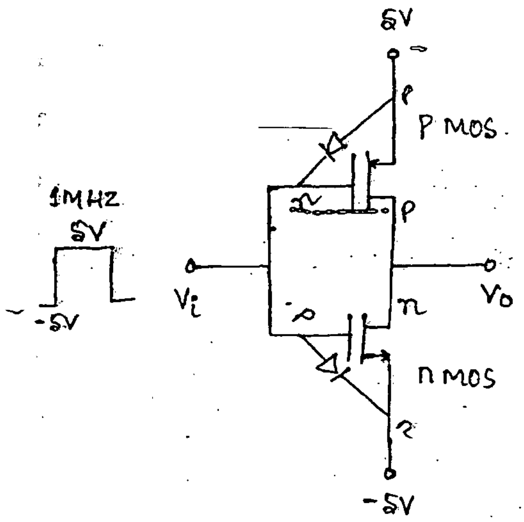
$\boxed{E_g(T) = E_{g0} - \beta T}$ where $\beta(si) = 3.6 \times 10^{-4}\ \frac{ev}{K}$

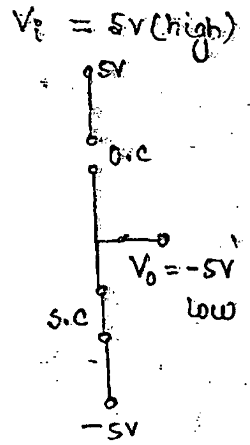
$\beta(Ge) = 2.23 \times 10^{-4}\ ev/K.$

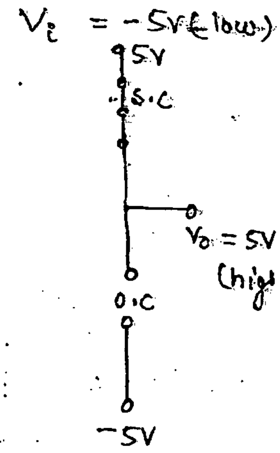
CONCLUSION :- 1. The conductivity is more for Si & Ge compared to GaAs.

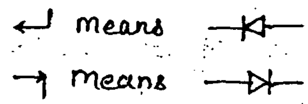
2. The mobility is less for silicon which can be used for low frequency appl^n ex- rectifier.

QUESTION :- Why GaAs is used in CMOS technology.







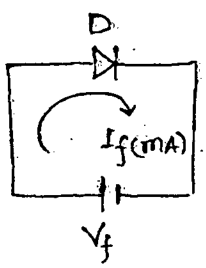


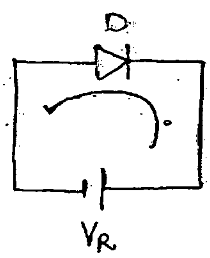
NOTE :- PMOS Never work for (+)ve value
NMOS Never work for (-)ve value.

CONCLUSION :- For high speed appl^n GaAs is best because the mobility is high.

QUESTION :- Why Si is more important than Ge in Semiconductor technology.

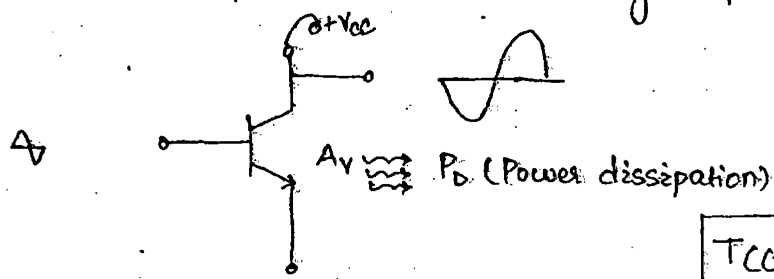
1. I_0 (Reverse saturation current)
or
(Leakage current)



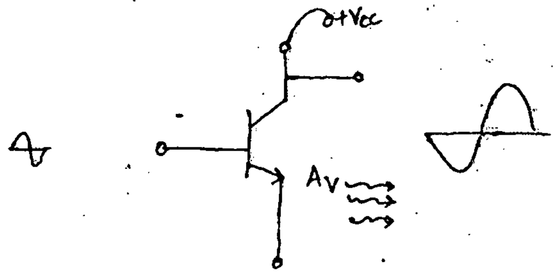


$I_0 = 0 \rightarrow$ ideal
$= \mu A \rightarrow$ (Ge)
$= nA \rightarrow$ (Si)*

2. Temperature with standing capability. ——



T(Ge) →	100°C
*T(Si) →	200°C



3. PIV of Ge = 400V.
*PIV of Si = 1000V

QUESTION :- Write the important property of GaAs.

1. At high frequency application GaAs is used (mobility is high)

2. GaAs :- $\mu_e \rightarrow 8500\ cm^2/Vsec.$
$\mu_h \rightarrow 400\ cm^2/Vsec.$

Ge :- $\mu_e \rightarrow 3800\ cm^2/Vsec$
$\mu_h \rightarrow 1800\ cm^2/Vsec$

Si :- $\mu_e \rightarrow 1300\ cm^2/sec$
$\mu_h \rightarrow 500\ cm^2/sec.$

~~3.~~ GaAs is best example for direct band gap. (→ gives light)
Si & Ge is best example for Indirect band gap. (→ gives heat)

4. GaAs is a compound semi conductor.

Ga As

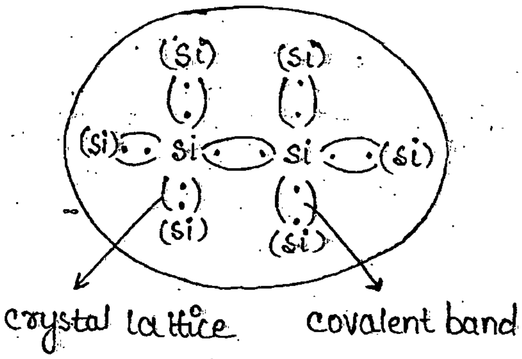
3rd group + 5th group

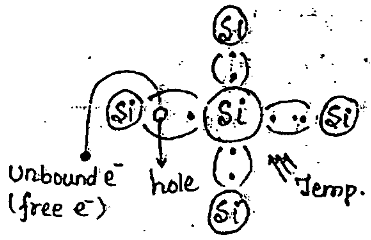
$\downarrow$

IV th group (Semiconductor.

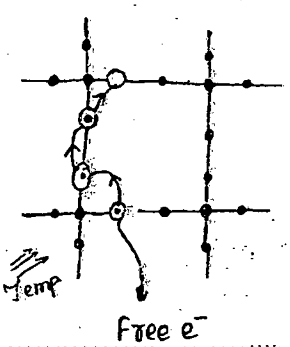
5. GaAs is used in optics.

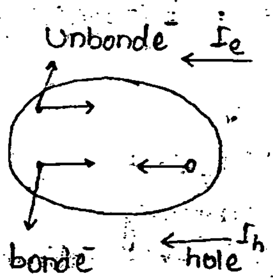
HOLE CONCEPT IN SEMICONDUCTOR.





CRYSTAL LATTICE.



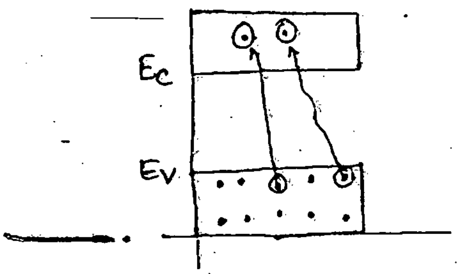


$$\boxed{I_{s.c} = I_e + I_h}$$

CONCLUSION :- The mobility of unbound e^- (free e^-) is always greater than mobility of bond electron (hole).

SEMICONDUCTOR.

1. INTRINSIC SEMICONDUCTOR.

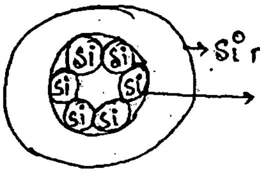


n = Concentration of Electron/cm^3.

P = Concentration of holes/cm^3.

n_i = intrinsic Concentration/cm^3.

$$\boxed{n = p = n_i}$$



si material:

No. of "si" atoms/cm^3 = 5×10^{22}/cm^3

n_i (300K) = 1.5×10^{10}/cm^3.

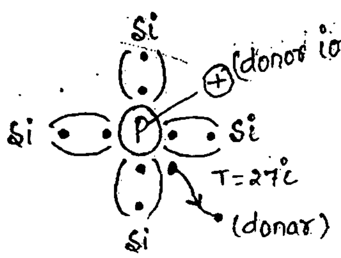
} conductivity for intrinsic semiconductor is Less

2. EXTRINSIC SEMICONDUCTOR.

$\boxed{\text{Intrinsic S.C}}$ + $\boxed{\text{Impurity}}$ = Extrinsic S.C.

- Pentavalent impurity
  - Ex:- Arsenic, Antimony, Bismuth, Phosphorous etc
- Trivalent impurity
  - Ex:- Galium, Indium, Boron, Aluminium etc

PENTAVALENT IMPURITY :- (N-TYPE)

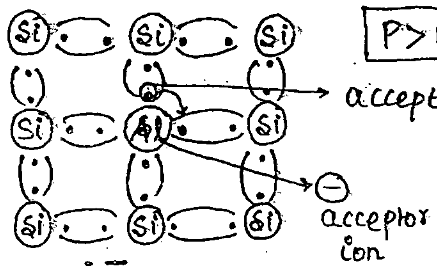


$$\boxed{n > p}$$

Majority Carrier → Electrons

Minority carriers → Holes.

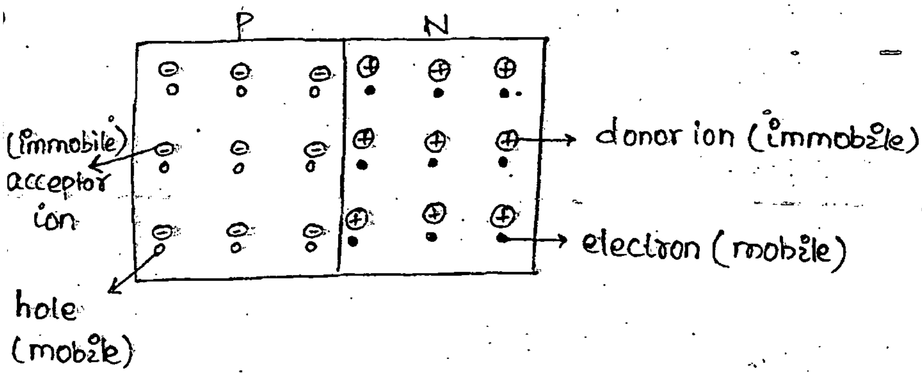
TRIVALENT IMPURITY (P TYPE)



$\boxed{p > n}$

Majority carrier → holes.

Minority carrier → Electron.



FERMI LEVEL.

Fermi Dirac probability function.

$$\boxed{F(E) = \frac{1}{1 + e^{(E-E_F)/KT}}}$$

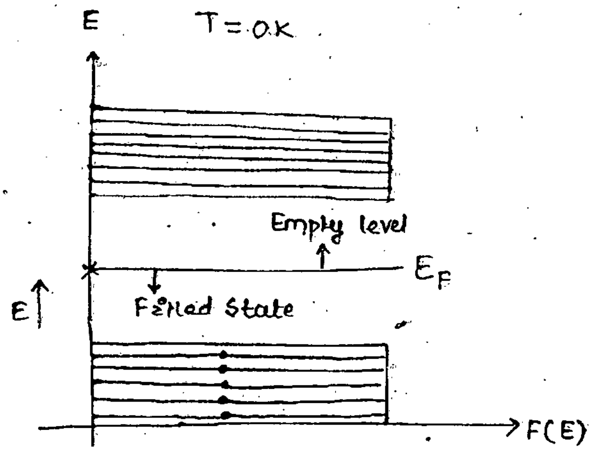
Where, $F(E)$ = Probability for finding an e^-

E = Energy ~~from~~ for an e^-

E_F = Fermi Energy Level.

K = Boltzmann constant $= 1.38 \times 10^{-23}$ J/k.

T = Temperature in Kelvin.



$$F(E) = 1 \; ; E < E_F$$
$$= 0 \; ; E > E_F$$
$$= \text{indeterminate} \; ; E = E_F$$

$\boxed{T = 0K}$

Case I :- $E < E_F$

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

Put $T = 0$

$$= \frac{1}{1 + e^{-E/0}} \Rightarrow F(E) = 1.$$

Case II :- $E > E_F$

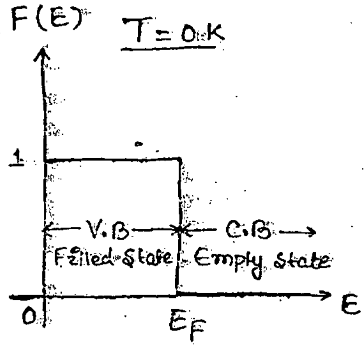
$$F(E) = \frac{1}{1 + e^{(E-E_F)/KT}}$$

$$= \frac{1}{1 + e^{E_x/0}} \Rightarrow F(E) = 0$$

Case III :- $E = E_F$

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

$$= \frac{1}{1 + e^{0/0}} \Rightarrow F(E) = \text{indeterminate}$$



$T \neq 0$

Case I :- $E < E_F$.

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

$$= \frac{1}{1 + e^{-E_x/KT}} = \frac{1}{1 + \frac{1}{e^x}} = \frac{e^x}{1 + e^x}$$

Case II :- $E > E_F$.

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

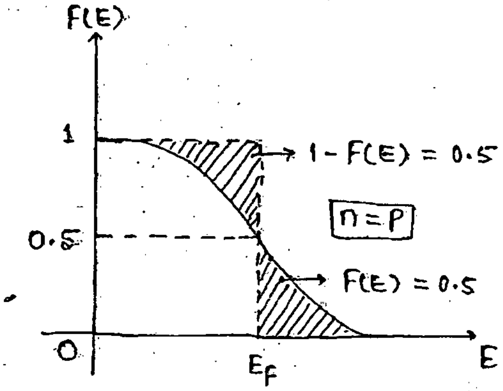
$$= \frac{1}{1 + e^{E_x/KT}} \Rightarrow F(E) = \frac{1}{1 + e^x}$$

Case III :- $E = E_F$

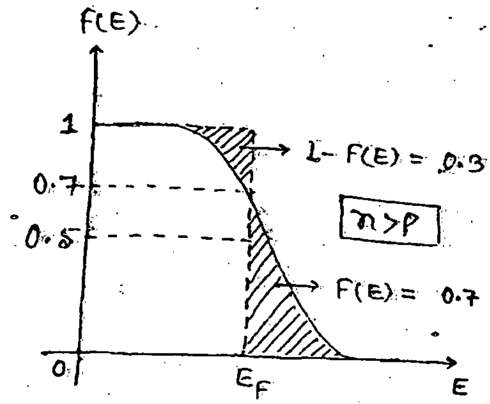
$$F(E) = \frac{1}{1 + e^{(E-E_F)/KT}}$$

$$= \frac{1}{1 + e^{0/KT}} = \frac{1}{1+1} = \frac{1}{2} = 0.5 \Rightarrow F(E) = 0.5.$$

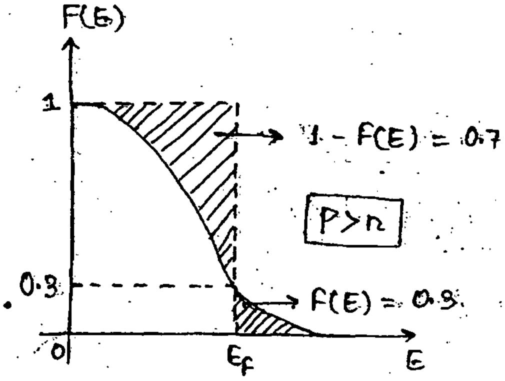
INTRINSIC SEMICONDUCTOR

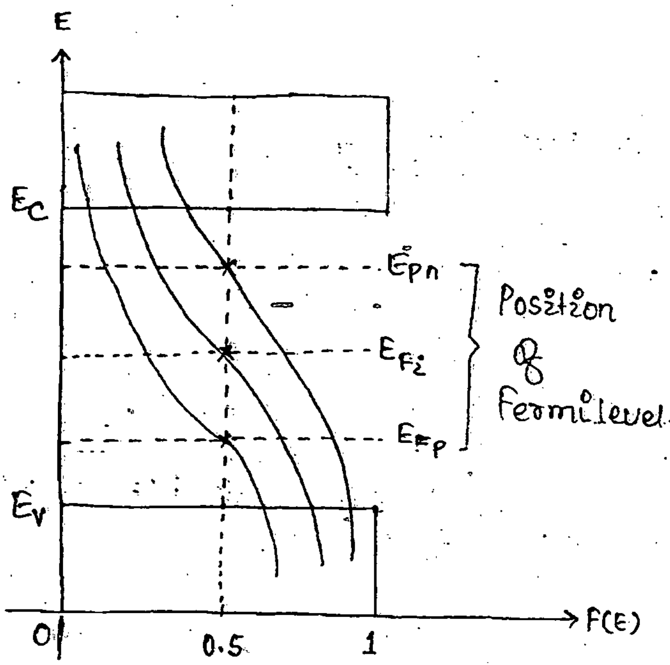


P- TYPE



N TYPE





$$n = N_c\, e^{-(E_c - E_F)/kT}$$

$$P = N_v\, e^{-(E_F - E_v)/kT}$$

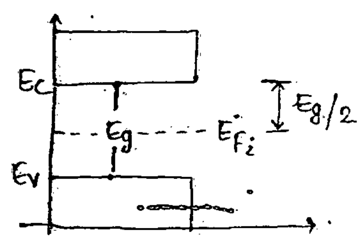
$$n = N_c\, e^{-(E_c - E_F)/kT}$$

$$N_c = n\, e^{(E_c - E_F)/kT}$$

Intrinsic Semiconductor

$$n = n_i \;;\; E_F = E_{Fi}$$

$$N_c = n_i\, e^{(E_c - E_{Fi})/kT}$$



$$N_c = n_i \cdot e^{E_g/2KT}$$

Si ($T = 300K$)

$n_i = 1.5 \times 10^{10}/cm^3$

$E_g(300K) = 1.21 - 3.6 \times 10^{-4} \times 300$

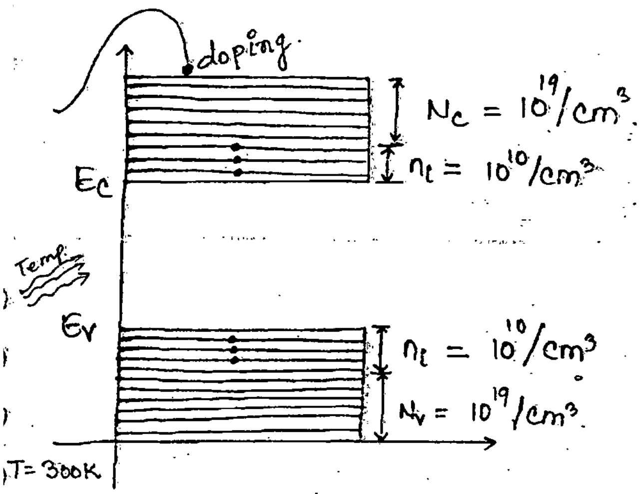
$E_g(300K) = 1.12\ eV$

$$N_c = 1.5 \times 10^{10}\ e^{\frac{1.12}{2 \times 1.38 \times 10^{-23} \times 3}}$$

$N_c \simeq 10^{19}/cm^3 \rightarrow$ Effective density of State Conduction band

|||ly

$N_v \simeq 10^{19}/cm^3 \rightarrow$ Effective density of State in Valence band.



$$N_c = 4.82 \times 10^{15} \left(\frac{M_n}{M}\right)^{3/2} \cdot T^{3/2}$$

$$N_v = 4.82 \times 10^{15} \left(\frac{M_p}{M}\right)^{3/2} \cdot T^{3/2}$$

Where M_n = Effective Mass of electron

M_p = " " " holes

M = Rest mass of an e^-

$= 9.31 \times 10^{-31}$ kg.

☐ EXPRESSION FOR FERMI LEVEL IN CASE OF INTRINSIC S.C

$n = p$

$$\Rightarrow N_c \cdot e^{-(E_c - E_{Fi})/KT} = N_v \cdot e^{-(E_{Fi} - E_v)/KT}$$

$$\Rightarrow KT \ln \frac{N_c}{N_v} = E_c + E_v - 2E_{Fi}$$

$$\Rightarrow E_{Fi} = \frac{E_c + E_v}{2} - \frac{KT}{2} \ln\left(\frac{N_c}{N_v}\right)$$

$\boxed{N_c \simeq N_v} \rightarrow$ for intrinsic

$$\boxed{E_{Fi} = \frac{E_c + E_v}{2}}$$

EXPRESSION FOR FERMI LEVEL IN CASE OF EXTRINSIC S.C.

→ **Law of Mass Action :**

$\boxed{n \cdot p = \text{constant}}$ → At Thermal equilibrium condⁿ.

$\boxed{n \cdot p = n_i^2}$

Intrinsic Semiconductor :

$$n = N_c e^{-(E_c - E_F)/KT}$$

$$n = N_c e^{-(E_c - E_{Fi}) + (E_F - E_{Fi})/KT}$$

$$= \underbrace{N_c \cdot e^{-(E_c - E_{Fi})/KT}}_{n_i} \cdot e^{(E_F - E_{Fi})/KT}$$

$$\Rightarrow n = n_i \cdot e^{(E_F - E_{Fi})/KT}$$

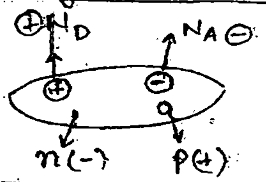
Similarly

$$p = n_i \cdot e^{-(E_F - E_{Fi})/KT}$$

$$\boxed{n \cdot p = n_i^2}$$

N-TYPE	P-TYPE
$E_{Fn} > E_{Fi}$	$E_{Fp} < E_{Fi}$
$n = n_i \cdot e^{(E_{Fn} - E_{Fi})/KT}$	$n = n_i \cdot e^{(E_{Fp} - E_{Fi})/KT}$
$p = n_i e^{-(E_{Fn} - E_{Fi})/KT}$	$p = n_i \cdot e^{-(E_{Fp} - E_{Fi})/KT}$
$\boxed{n\uparrow \; p\downarrow = n_i^2}$	$\boxed{n\downarrow \; p\uparrow = n_i^2}$

→ **Charge Neutrality Theorem :**



Net charge density = 0

$$\boxed{p + N_D = n + N_A}$$

N TYPE

$N_A^- \approx 0$; $n > p$

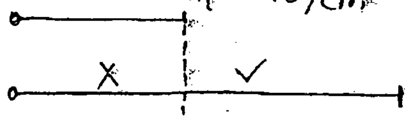
$p + N_D = n$

$\frac{n_i^2}{n} + N_D = n$

$n^2 - N_D n - n_i^2 = 0$

$n = \frac{N_D}{2} + \sqrt{\left(\frac{N_D}{2}\right)^2 + n_i^2}$

$n_i = 10^{10}/cm^3$



$N_c = 10^{19}/cm$

$N_D > n_i$

$n = \frac{N_D}{2} + \frac{N_D}{2}$ $\Rightarrow$ $\boxed{n = N_D}$

Ill/y $p = \frac{N_A}{2} + \sqrt{\left(\frac{N_A}{2}\right)^2 + n_i^2}$

$N_A > n_i$ $\Rightarrow$ $\boxed{p \simeq N_A}$

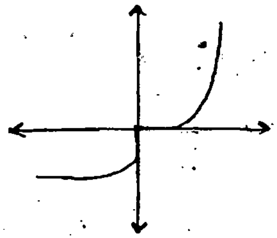
DOPING:-

10^8 s.c atoms — 1 impurity

5×10^{22} s.c atoms — N (doping)

$N = \frac{5 \times 10^{22}}{10^8} = 5 \times 10^{14}/cm^3$

$\boxed{N > n_i \text{ (ordinary pN diode)}}$

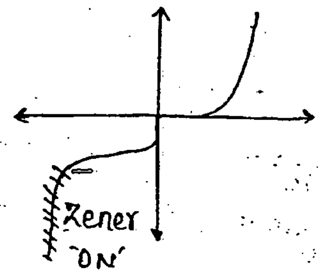


10^6 s.c atoms — 1 impurity

5×10^{22} s.c atoms — N

$N = \frac{5 \times 10^{22}}{10^6} = 5 \times 10^{16}/cm^3$.

$\boxed{N >> n_i \text{ (Moderate dopping) Zener diode}}$

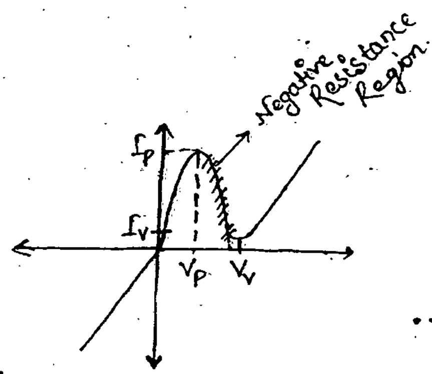


10^3 s.c atoms — 1 impurity

5×10^{22} s.c atoms — N

$N = \frac{5 \times 10^{22}}{10^6} = 5 \times 10^{19}/cm^3$

$\boxed{n_i << N \geq N_c \text{ (Tunnel diode)}}$



$r = \frac{\Delta V}{\Delta I} = \frac{V_v - V_p}{I_v - I_p} = (-)ve.$

N- TYPE

$$n = N_c \cdot e^{-(E_c - E_F)/KT}$$

$$\boxed{n = N_D} \qquad \boxed{E_F = E_{Fn}}$$

$$N_D = N_c \cdot e^{-(E_c - E_{Fn})/KT}$$

$$KT \ln \frac{N_c}{N_D} = E_c - E_{Fn}$$

$$\boxed{E_{Fn} = E_c - KT \ln \frac{N_c}{N_D}}$$

P- TYPE

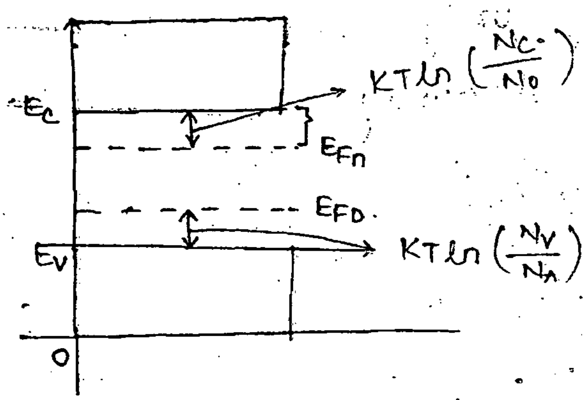
$$P = N_V \cdot e^{-(E_F - E_V)/KT}$$

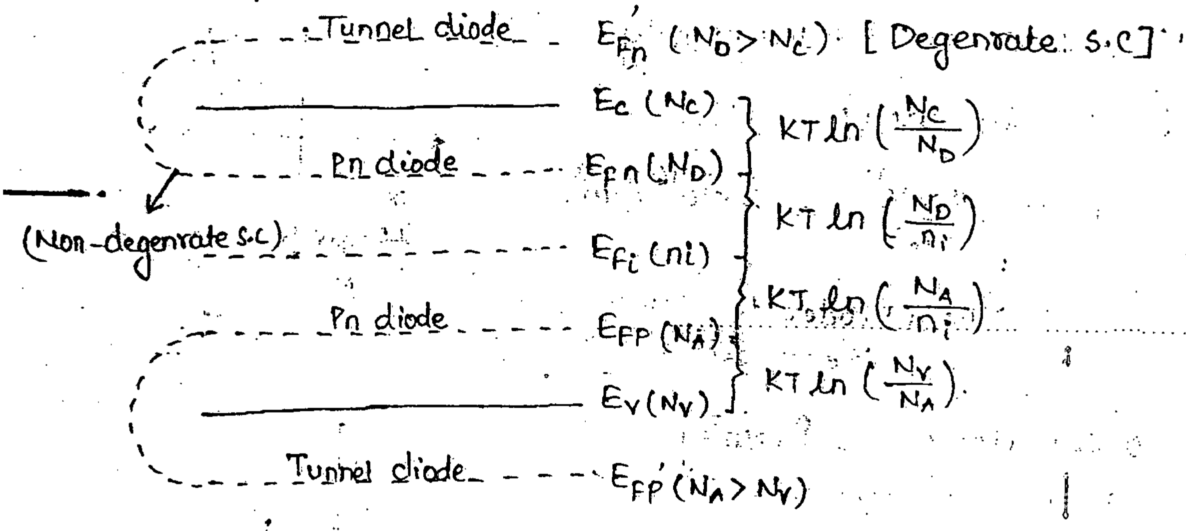
$$\boxed{P = N_A} \qquad \boxed{E_F = E_{FP}}$$

$$N_A = N_V \cdot e^{-(E_{FP} - E_V)/KT}$$

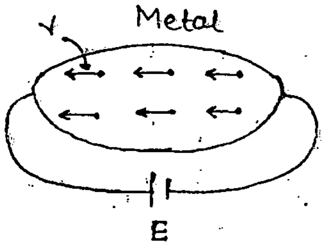
$$KT \ln \frac{N_V}{N_A} = E_{FP} - E_V$$

$$\boxed{E_{FP} = E_V + KT \ln \frac{N_V}{N_A}}$$





DRIFT CURRENT.



$V \propto E$

$\downarrow$

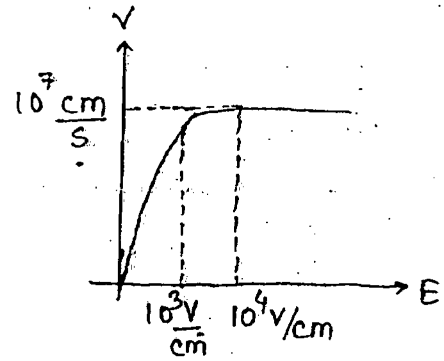
μ (Mobility)

$\boxed{V = \mu E}$

$$\text{Mobility}\ (\mu) = \frac{\text{Drift Velocity}}{\text{Electric field}} \quad \frac{m^2}{\text{Sec}}$$

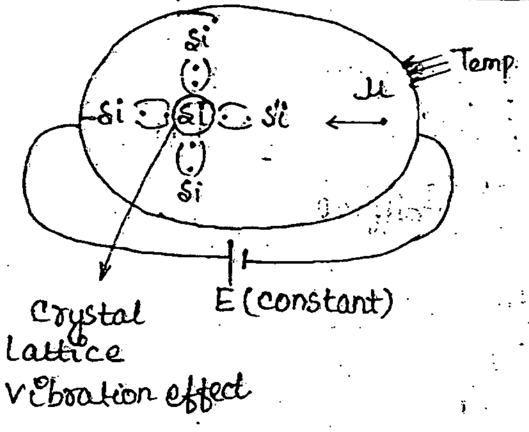
$\boxed{\mu \propto \frac{1}{E}}$

1. Electric Field vs Mobility :-



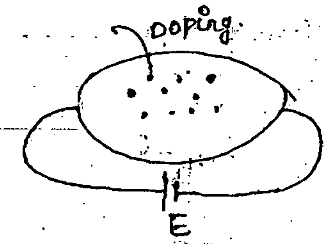
$E > 10^4 \frac{V}{cm}$; $\mu \propto \frac{1}{E}$

2. Temperature vs Mobility :-



$\boxed{\mu \propto T^{-m}}$

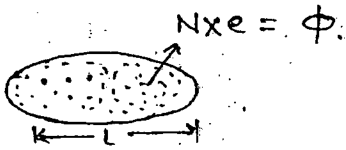
3. Doping vs Mobility



$\boxed{\mu \propto \frac{1}{\text{doping concentration}}}$

CURRENT DENSITY (J)

$\boxed{J = \frac{I}{A}}$ $\boxed{I = \frac{N \times e}{T}}$ $J = \frac{N \times e}{T \times A}$



$$\text{Time}, T = \frac{\text{Distance}}{\text{Velocity}} = \frac{L}{V}$$

$$J = \frac{N \times e}{L \times A} \times V$$

$\frac{N}{L \times A} \rightarrow n$ (concentration on $\bar{e}$)

$\boxed{J = n \times e \times V}$

Metals :-

$J = n \times e \times v \Rightarrow \boxed{v = \mu E}$

$J = n \times e \times \mu \times E$

$n \times e = \rho$ (charge density)

$n \times e \times \mu = \sigma$ (conductivity)

$$\boxed{J = \sigma E}$$

Semiconductor :-

$J_{s.c} = J_n + J_p$

$J_n = n \times q \times \mu_n \times E$

$J_p = p \times q \times \mu_p \times E$

$J_{s.c} = \underbrace{(n\mu_n + p\mu_p)q}_{\sigma_{s.c}} \times E$

$$\boxed{\sigma_{s.c} = (n\mu_n + p\mu_p)q}$$

INTRINSIC :-

$\sigma_{intrinsic} = n_i(\mu_n + \mu_p)q$

N-TYPE

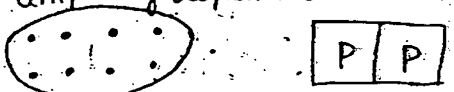
$\sigma_{N\text{-}Type} = N_D q \mu_n$

P-TYPE :-

$\sigma_{P\,Type} = N_A q \mu_p$

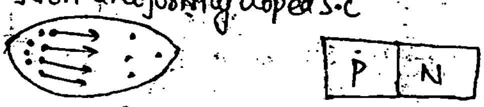
DIFFUSION CURRENT.

uniformly doped s.c.



$I_{diff} = 0$

Non uniformly doped s.c



$\longrightarrow x$ $I_{diff} \neq 0$

$J_n \propto q \cdot \frac{dn}{dx}$ $\qquad \boxed{J_n = q D_n \frac{dn}{dx}}$

D_n (Diffusion const for electron) $\qquad \boxed{I_n = A q D_n \frac{dn}{dx}}$

$J_p \propto q\left[-\frac{dp}{dx}\right]$ $\qquad \boxed{J_p = -A q D_p \frac{dp}{dx}}$

D_p (Diffusion const for holes) $\qquad \boxed{I_p = -q D_p \frac{dp}{dx}}$

Defination :→ The rate of change of concentration w.r.t distance x is called as diffusion current.

D_n AND D_p :-

Kinetic Gas Theory :- (atomic Theory) $D \propto \mu$ → V_T (Thermal voltage). $\boxed{D = V_T \mu}$

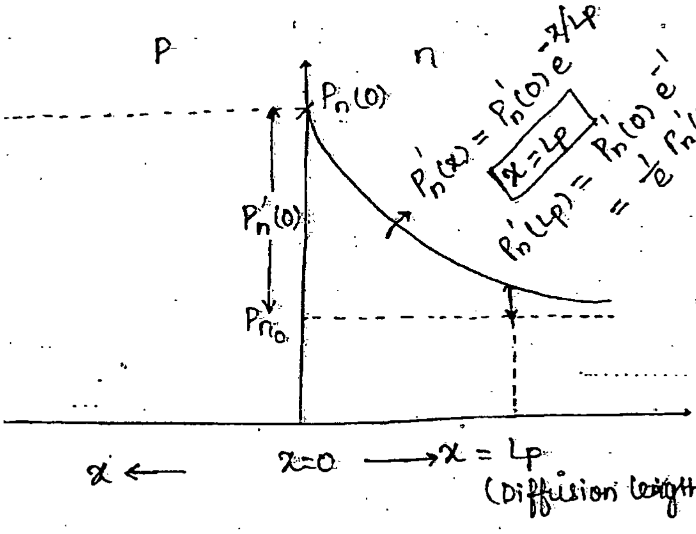
Where $\boxed{V_T = \frac{KT}{q}}$

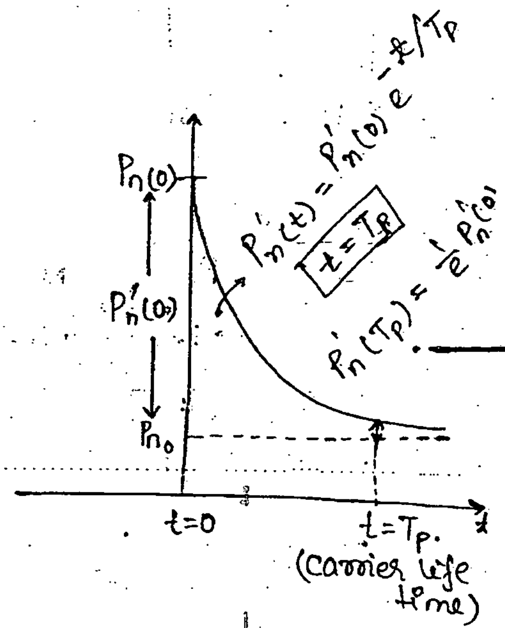
Semiconductor Theory :-

Electron Theory	Hole theory.
$D_n \propto \mu_n$ → V_T	$D_p \propto \mu_p$ → V_T.
$\boxed{D_n = V_T \mu_n}$	$\boxed{D_p = V_T \mu_p}$

$$\boxed{\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T} \rightarrow \text{Einstein Relation Theory.}$$

▫ DIFFUSION GRAPHICAL THEORY.





Where; $P_n(0)$ = injected Minority carrier concentration

P_{n0} = Thermal equilibrium Minority concentration

$P_n'(0)$ = Excess concentration

T AND L

$$\boxed{L^2 = D \times \tau}$$

$$\boxed{L = \sqrt{D\tau}}$$

$L^2 \rightarrow m^2$

$D = \mu V_T \rightarrow \frac{m^2}{\cancel{V}sec} \times \cancel{V}$

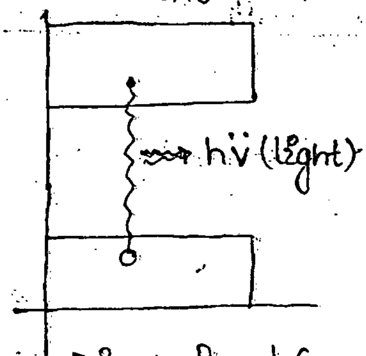
$\tau \rightarrow sec$

$D\tau \rightarrow m^2$

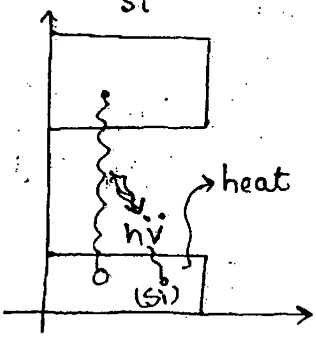
GaAs $\rightarrow$ carrier life time is less.

Si and Ge $\rightarrow$ carrier life time will be more.

$\tau = \frac{L^2}{D}$; $\tau = \frac{L^2}{\mu V_T}$. $\boxed{\tau \propto \frac{1}{\mu}}$

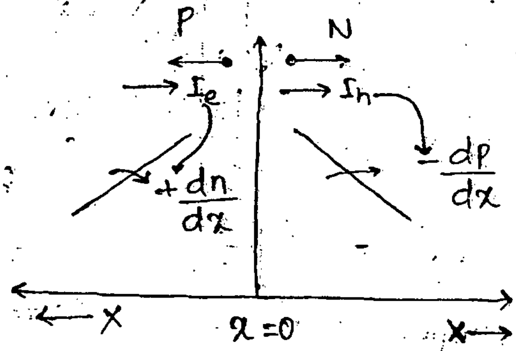


Direct Band Gap

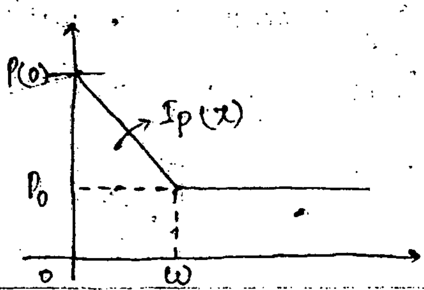


Indirect band gap.

CONCLUSION :-



~~QUESTION~~ :→



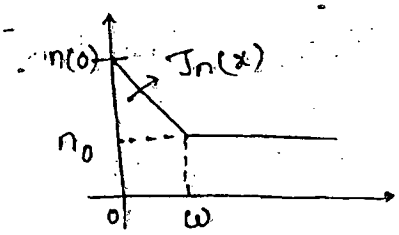
Solution :→ $J_p(x) = -q D_p \frac{dp}{dx}$

$$= q \cdot D_p \frac{P(0) - P_0}{0 - \omega}$$

$$= (+) \cdot q D_p \frac{\{P(0) - P_0\}}{\omega}$$

$\rightarrow I_h \}$ (+)ve.

QUESTION-2 :-



SOLUTION :- $J_n(x) = q D_n \frac{dn}{dx}$

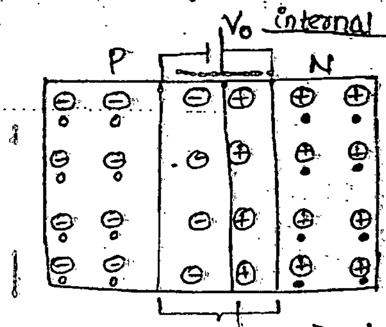
$$= q \cdot D_n \frac{n(0) - n_0}{0 - \omega}$$

$$= (-) q D_n \cdot \frac{n(0) - n_0}{\omega}$$

−ve $\} \leftarrow I_e$

☐ PN JUNCTION.

OPEN CIRCUIT PN JUNCTION.



→ V_0 (or) V_j (or) V_γ

Barrier potential (or) contact potential (or) Built in voltage (or) cut in Voltage

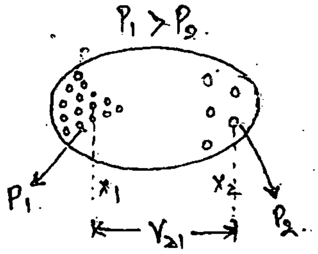
$\boxed{\text{Net current Density} = 0}$

→ Depletion Region (or) Transition Region (or) Space charge Region.

$$\boxed{\begin{gathered} J_{drift} + J_{Diff} = 0 \\ J_{n\,drift} + J_{p\,drift} + J_{n\,diff} + J_{p\,diff} = 0 \end{gathered}}$$

EXPRESSION FOR BARRIER POTENTIAL ~~(V_0) USING~~ BOLTZMANN THEORY.

BOLTZMANN THEORY.



Net current Density = 0.

$J_{drift} + J_{diff} = 0.$

$J_{n\,drift} + J_{n\,diff} + J_{p\,drift} + J_{p\,diff} = 0.$

$J_{n\,drift} + J_{n\,diff} = 0$, and $J_{p\,drift} + J_{p\,diff} = 0.$

HOLE THEORY :-

$\Rightarrow J_{p\,drift} + J_{p\,diff} = 0.$

$\Rightarrow P q \mu_p E - q D_p \dfrac{dP}{dx} = 0$

$\Rightarrow E = \underbrace{\dfrac{D_p}{\mu_p}}_{V_T} \cdot \dfrac{1}{P}\dfrac{dP}{dx}$

$\Rightarrow E = V_T \cdot \dfrac{1}{P}\dfrac{dP}{dx}.$

$\Rightarrow E = \dfrac{dV}{dx}$ (uniform Field) ✗

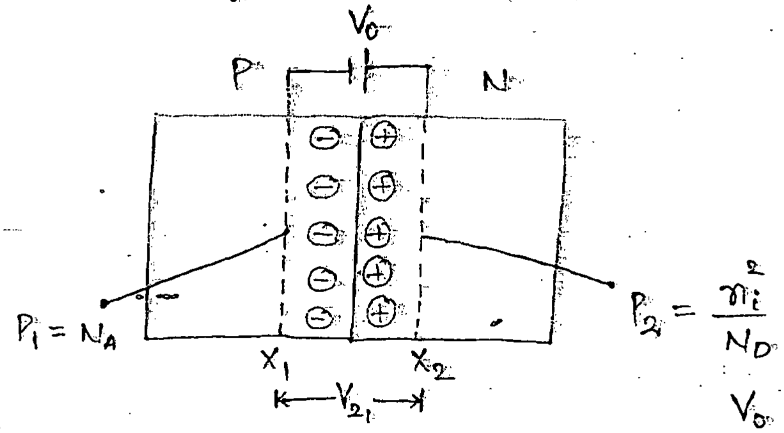
$\Rightarrow E = -\dfrac{dV}{dx}$ (Non-uniform Field) ✓

$\Rightarrow -\dfrac{dV}{dx} = V_T \cdot \dfrac{1}{P} \cdot \dfrac{dP}{dx}$

$\Rightarrow \displaystyle\int_{V_1}^{V_2} dV = V_T \cdot \int -\frac{1}{P}\,dP \quad \Rightarrow V_2 - V_1 = V_T\,(-\ln P)_{P_1}^{P_2}$

$$\Rightarrow \boxed{\begin{aligned} V_{21} &= V_T \ln\left(\frac{P_1}{P_2}\right) \\ P_1 &= P_2 \cdot e^{V_{21}/V_T} \end{aligned}}$$

→ Boltzmann Rl^n from Kinetic gas Theory.



$$P_2 = \frac{n_i^2}{N_D}$$

$$\boxed{V_{21} = V_0}$$

$$V_0 = V_T \ln\left(\frac{N_A}{n_i^2/N_D}\right)$$

$$\boxed{V_0 = V_T \ln\left[\frac{N_A \cdot N_D}{n_i^2}\right]}$$

$V_0 =$ 0.1V to 0.3V (Ge)

$V_0 =$ 0.5V to 0.7V (Si)

n_i^2

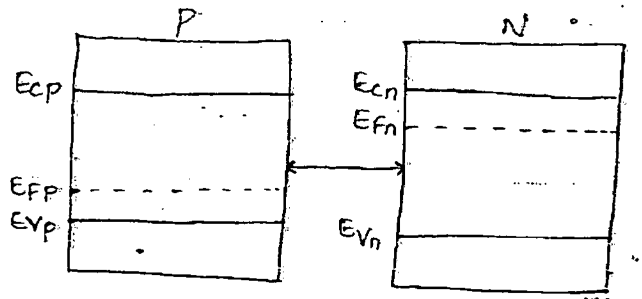
$$n \cdot p = n_i^2$$

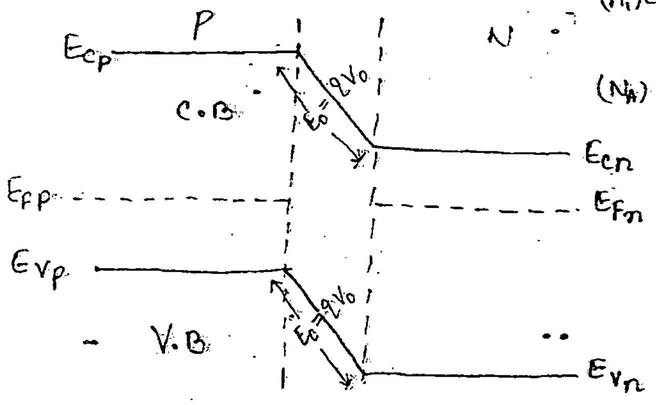
$$\Rightarrow n_i^2 = N_c \cdot N_v \cdot e^{-\overbrace{(E_c - E_v)}^{E_g}/KT}$$

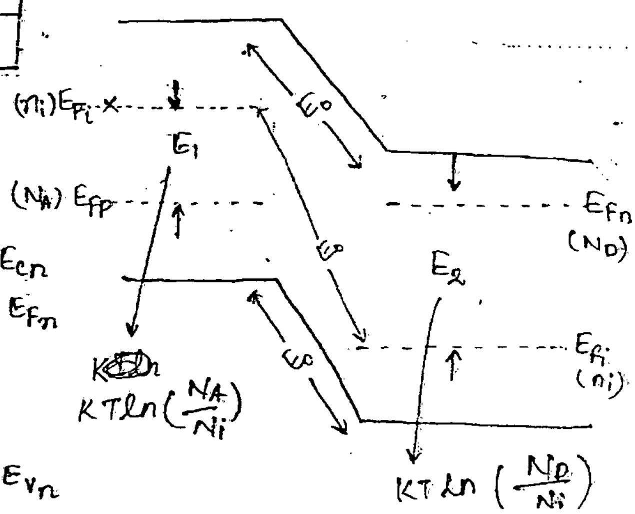
$$\Rightarrow n_i^2 = 4.82 \times 10^{15} \left(\frac{M_n}{M}\right)^{3/2} \cdot T^{3/2} \times 4.82 \times 10^{15} \left(\frac{M_p}{M}\right) T^{3/2} \cdot e^{-E_g/KT}$$

$$\boxed{n_i^2 = A_0 T^3 e^{-E_{g0}/KT}} \qquad \boxed{n_i \,\alpha\, T^{3/2}}$$

ENERGY BAND THEORY FOR A PN JUNCTION.



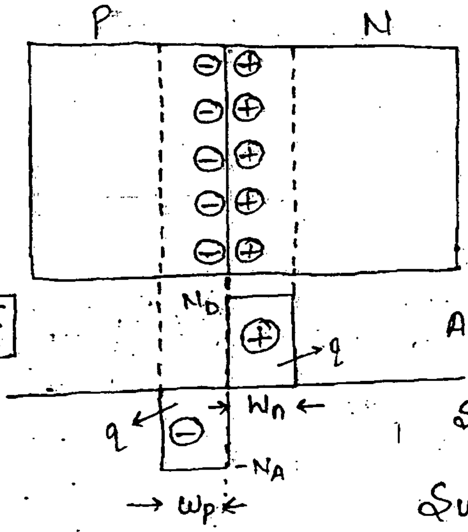




$$E_0 = E_1 + E_2 = KT \ln\left(\frac{N_A N_D}{n_i^2}\right).$$

$$\boxed{V_0 = \underbrace{\frac{KT}{q}}_{V_T} \ln\left(\frac{N_A N_D}{n_i^2}\right)}$$

DISTRIBUTION OF CHARGE IN DEPLETION REGION.



$$\boxed{W = W_n + W_p}$$

$$\boxed{W \propto \sqrt{V_j}}$$

Alloy type
(or)
Step graded Junction
(or)
Sudden charge (or) abrupt charge.

Charge Neutrality :⇒

$$|\cancel{q} N_A W_p| = |\cancel{q} N_D W_n|.$$

$$\boxed{N_A W_p = N_D W_N}$$

$$W = \frac{N_A W_p}{N_D} + W_p$$

$$= W_p\left[\frac{N_A}{N_D} + 1\right]$$

$$= W_p\left[\frac{N_A + N_D}{N_D}\right] \Rightarrow \boxed{W_p = W \cdot \frac{N_D}{N_D + N_A}}$$

$$\boxed{W_n = W \cdot \frac{N_A}{N_D + N_A}}$$

$$\boxed{\frac{\partial^2 V}{\partial x^2} = -\frac{\rho}{\varepsilon}}$$ → Poisson Eq^n.

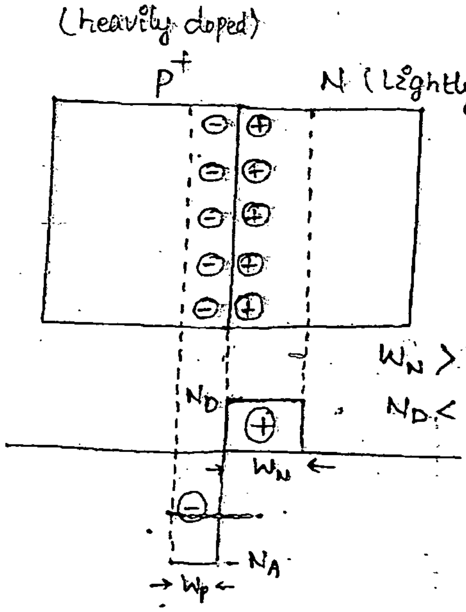
$V \rightarrow$ voltage
$\rho \rightarrow$ charge density.
$\varepsilon = \varepsilon_0 \varepsilon_r$

$\varepsilon_0 = 8.85 \times 10^{-12}\ F/m$; $\varepsilon_r = 12\ (Si)$
$= 16\ (Ge)$

$$V_j = \frac{q\left[N_A W_p^2 + N_D W_n^2\right]}{2\varepsilon}$$

$$V_j = \frac{q\left[N_A \cdot \frac{W^2 N_D^2}{(N_D+N_A)^2} + N_D \cdot \frac{W^2 \cdot N_A^2}{(N_D+N_A)^2}\right]}{2\varepsilon}$$

$$V_j = \frac{q N_A N_D W^2}{2\varepsilon}\left[\frac{N_A+N_D}{(N_A+N_D)^2}\right] \Rightarrow \boxed{W = \left[\frac{2\varepsilon_0\varepsilon_r V_j}{q}\left[\frac{1}{N_A}+\frac{1}{N_D}\right]\right]^{1/2}}$$



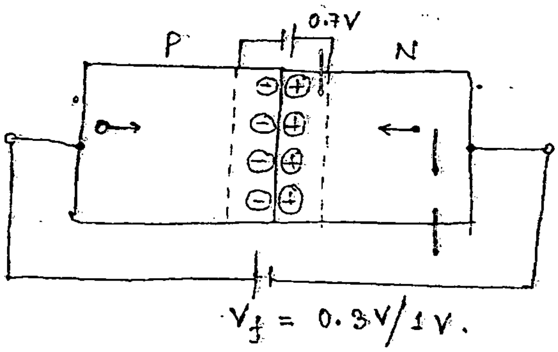
$W_N > W_p$

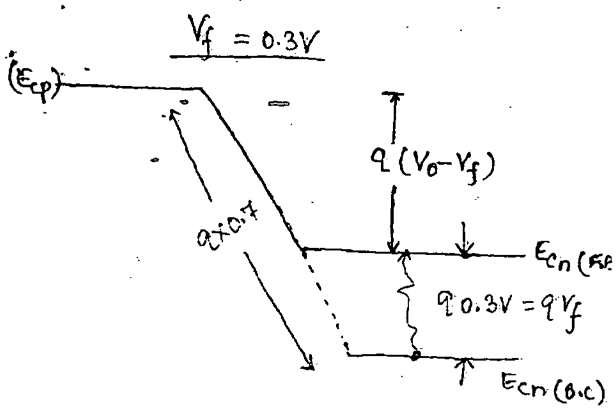
$N_D < N_A$

NOTE :- 1. When the material is lightly doped the penetration of depletion region will be wider.

2. When the material is heavily doped the penetration of depletion region will be Narrower.

□ FORWARD BIASED.

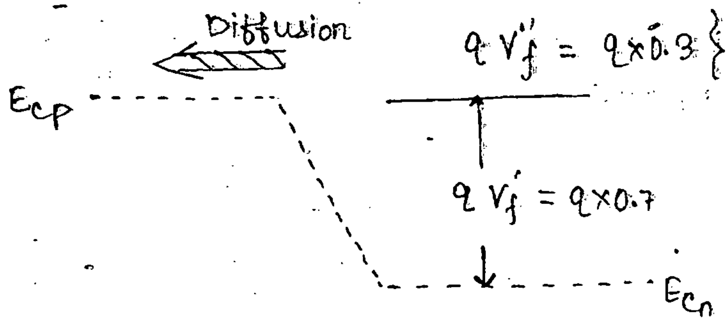


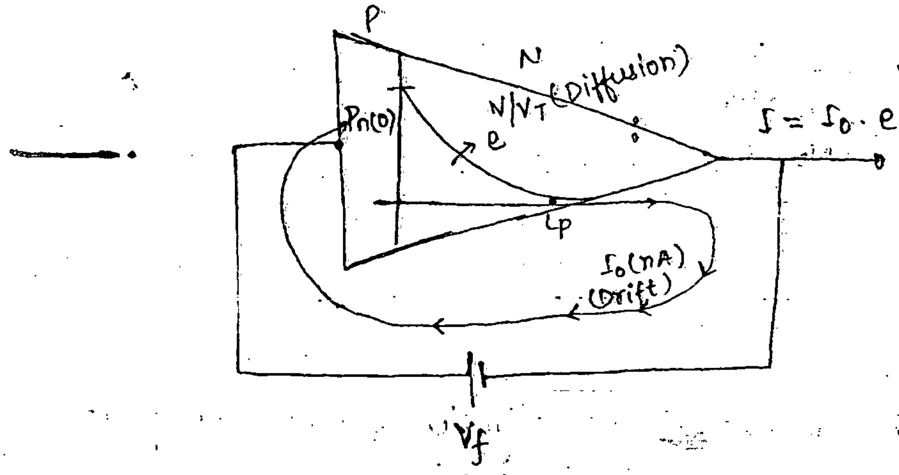


$$W = \left[\frac{2\varepsilon_0 \varepsilon_r}{q} \cdot V_j \left(\frac{1}{N_A} + \frac{1}{N_D} \right) \right]^{1/2} \longrightarrow \text{open circuit.}$$

$$W = \frac{2\varepsilon_0\varepsilon_r}{q} (V_j - V_f) \cdot \left[\frac{1}{N_A} + \frac{1}{N_D} \right]^{1/2} \longrightarrow \text{Forward Biased.}$$

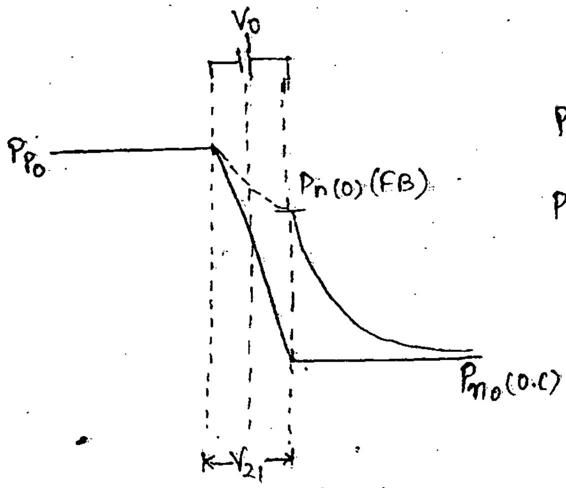
$V_f = 1V.$





$I = I_0 \cdot e^{V_D/V_T}$ (mA).

☐ LAW OF JUNCTION THEORY. (PN DIODE)



open circuit Theory

$$P_1 = P_2 \, e^{V_{21}/V_T}$$

$$P_{P_0} = P_{n0} \cdot e^{V_0/V_T}$$

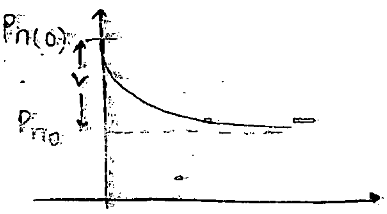
Forward Biased.

$$P_{P_0} = P_{n(0)} \, e^{(V_0 - V)/V_T}$$

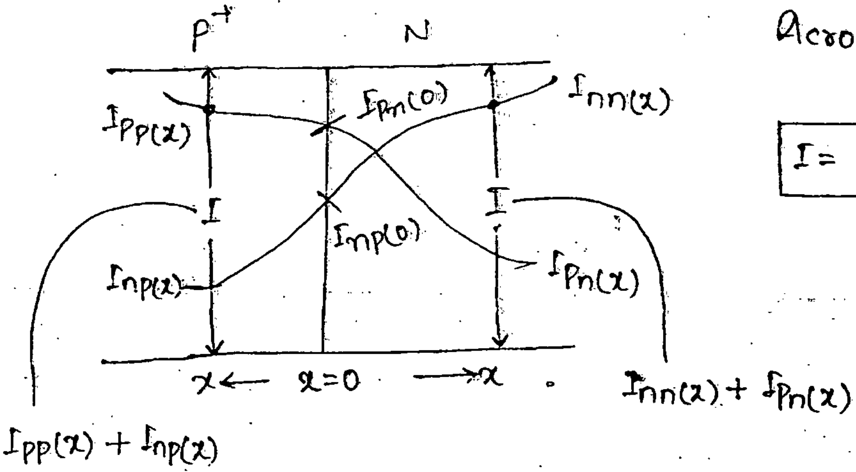
$$P_{P_0} = P_{n(0)} \, e^{V_0/V_T} \cdot e^{-V/V_T}$$

$$P_{n_0} e^{V_0/V_T} = P_{n(0)} e^{V_0/V_T} \cdot e^{-V/V_T}$$

$$\boxed{\begin{aligned} P_{no} &= P_{n(0)}\, e^{-V/V_T} \\ P_{n(0)} &= P_{no}\, e^{V/V_T} \end{aligned}}$$



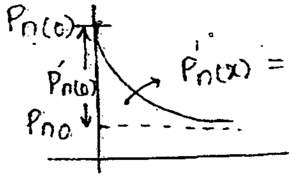
⊡ DIODE CURRENT EQUATION.



Across the junction. $(x=0)$

$$\boxed{I = I_{pn(0)} + I_{np(0)}}$$

$$I_{pn}(x) = -Aq\,D_p \frac{dP_n'(x)}{dx}$$



$$P_n'(x) = P_n'(0)\cdot e^{-x/L_p}$$

$$I_{pn}(x) = \frac{\cancel{-}\, Aq\,D_p\, P_n'(0)\cdot e^{-x/L_p}}{\cancel{-}\, L_p}$$

$x=0$

$$I_{pn}(0) = \frac{Aq\,D_p\,P_n'(0)}{L_p} \Rightarrow I_{pn}(0) = \frac{Aq\,D_p\,(P_{n(0)} - P_{no})}{L_p}$$

$$P_n'(0) = P_{n(0)} - P_{no} \qquad \boxed{P_{n(0)} = P_{no}\cdot e^{V/V_T}} \rightarrow \text{Law of junction}$$

$$I_{pn}(0) = \frac{Aq\,D_p\,P_{no}}{L_p}\left(e^{V/V_T} - 1\right) \quad \text{—— (1)}$$

$$I_{np}(0) = \frac{Aq\,D_n\,n_{po}}{L_n}\left(e^{V/V_T} - 1\right) \quad \text{—— (2)}$$

$$\boxed{I = \underbrace{\left[\frac{Aq\,D_p\,P_{no}}{L_p} + \frac{Aq\,D_n\,n_{po}}{L_n}\right]}_{I_o\text{ (minority current)}}\left(e^{V/V_T} - 1\right)}$$

<u>Ch-2</u>
<u>Q2.</u>

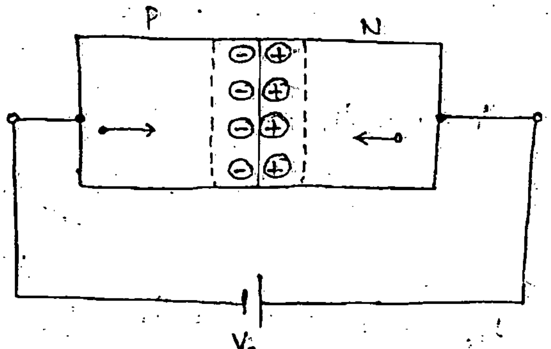
$$I_o = Aq\left[\frac{D_p P_{no}}{L_p} + \frac{D_n n_{po}}{L_n}\right]$$

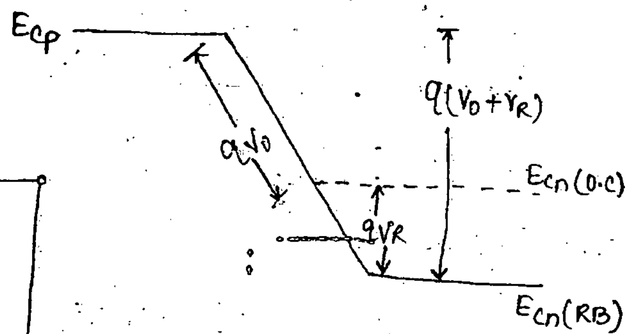
$$= Aq\left[\frac{D_p}{L_p N_D} + \frac{D_n}{L_D N_A}\right] n_i^2$$

$\boxed{I_o \propto \text{Area}}$ $\Rightarrow$ $\boxed{I_o \propto \frac{1}{\text{doping concentration}}}$ $\boxed{I_o' \propto \text{Temp}}$

$\therefore$ 2.8 <u>Ans</u>.

☐ REVERSED BIASED.





$$\boxed{W_{RB} = \left\{\left[\frac{2\varepsilon_0\varepsilon_r(V_j+V_R)}{q}\right]\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\right\}^{1/2}}$$