ELECTRONICS

Electronic Fundamental & Application
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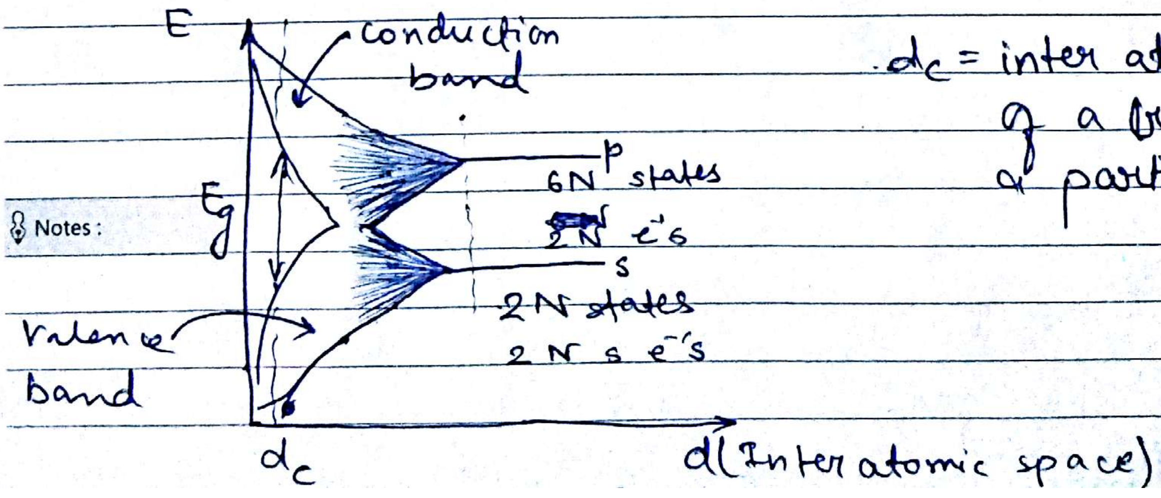
Formation of Energy band in Solid.

An isolated atom of any substance should have discrete energy levels and it is verified by Bohr's atomic model.
We look into the energy band diagram of a solid formed by periodic arrangement of similar atoms.
Let us take ~~their~~ there N no. of atoms are forming a solid 3-D ~~crl~~ crystal.
In the crystal the spacing between atoms are very small, so interaction between them will be very high.

Let us consider silicon (14) or germanium (32) specimen.

$Si_{14} = 1s^2 2s^2 2p^6 3s^2 3p^2$



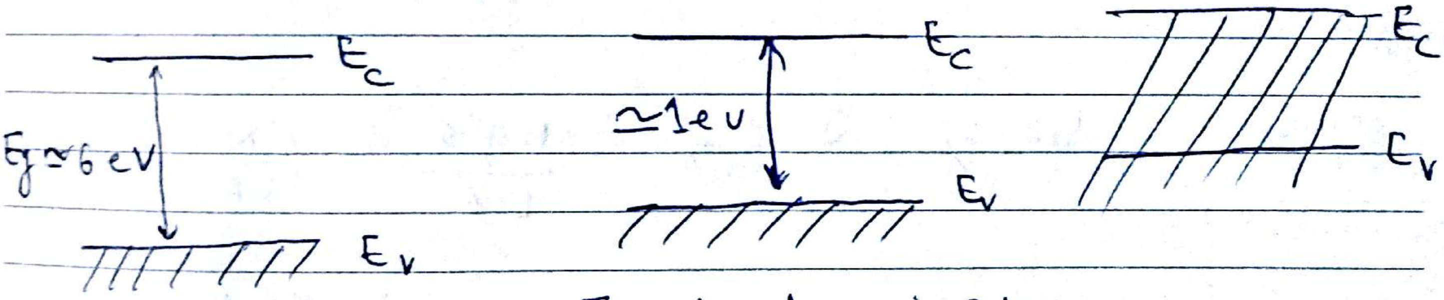
d_c = inter atomic spacing of a crystal at a particular temp.

The sample has 2s e's and 2p e's in a distinct shell. There are 2N s states and 100% are occupied and 6N p states and only 2N are occupied. As the inter atomic space is decreased the p and s shell will split as shown in fig. And if the space is decreased then p and s will merge together. When p and s subshells merge together, then we have a total of 8N states and only 4N e's are available. If we further decrease 'd', then the 4N e's will form a band containing 4N states and remaining 4N states will be empty. The filled 4N states are called valence band. And empty 4N states together form conduction band.

Depending upon the value of Eg (Energy gap) we can classify the solid as:-

Insulator Semiconductor Metals.

KT = 0.026 eV



Notes:

Si → 1.21 eV
Ge → 0.785 eV
at 0°K

The band gap is ≥ 1 eV
If there is sufficient KT i.e. thermal energy hence e's can jump to the conduction band.

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WK	S	M	T	W	T	F	S	WK	S	M	T	W	T	F	S
35						1	2	40	1	2	3	4	5	6	7
36	3	4	5	6	7	8	9	41	8	9	10	11	12	13	14
37	10	11	12	13	14	15	16	42	15	16	17	18	19	20	21
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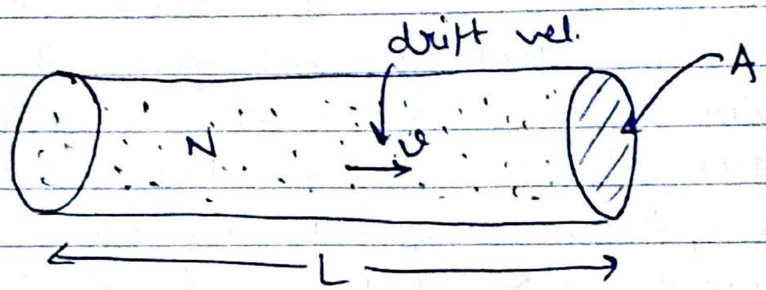
39	24	25	26	27	28	29	30	44	29	30	31				

At room temperature i.e. 300 K $E_g = 1.1\,eV$ for Si
$= 0.72\,eV$ for Ge.

Conduction Phenomenon in solid



There are 2 processes by which conduction takes place in a solid (conductor or semiconductor)

Drift phenomenon - occurs due to the application of voltage across the specimen.
An e^- takes a time T to move a dist 'L'.
∴ Total no. of e^- passing through any cross sections of the solid in unit time is N/T.

∴ The current, $I = \frac{Nq}{T} = \frac{Nqv}{l}$

Current density, $J = \frac{I}{A} = \frac{Nqv}{LA} = \left(\frac{N}{LA}\right) qv$

$= nqv$
↳ e^- density

Notes:

$= nq\mu E$
↳ mobility

$= \sigma E$
↳ conductivity

Now $J_{n\,drift} = nq\mu_n E$; $J_{p\,drift} = pq\mu_p E$ $\left\{ \begin{array}{l} p = \text{hole } ~~conc~~ \\ n = \text{electron con} \end{array} \right.$

If we consider it as a semiconductor, then current will be contributed by both the carriers. Therefore the total drift current density will be equal to :-

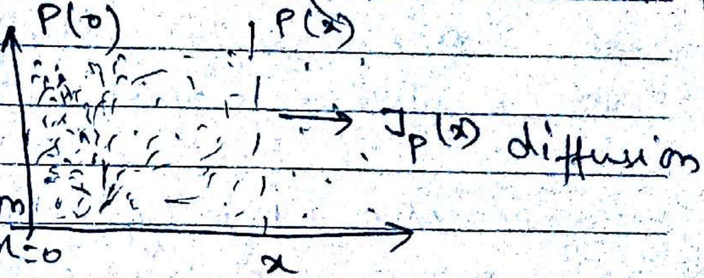
$$J_{drift} = J_{n\,drift} + J_{p\,drift}$$

$$\Rightarrow J_{drift} = (n\mu_n + p\mu_p)\, qE$$

$$\Rightarrow J_{drift} = \sigma_{total} \cdot E \qquad (\sigma_{total} = n\mu_n + p\mu_p$$

(ii) Diffusion phenomenon :-

~~Let us consider the system in which hole concentration~~ decreases in positive x-direction as shown in the figure. at



x=0, the concentration of carriers is P(0) ~~at~~ and that at x=x is P(x).

The diffusion current density

$$J_{p(x)\,diffusion} \propto \frac{dP(x)}{dx}$$
$$= -qD_p \frac{dP(x)}{dx}$$

D_p is also diffusivity of holes. $J_{p\,diff}$ and $\frac{dP(x)}{dx}$ ~~is~~ opposi directed. So negative sign is introduced.

Similarly, $J_{n(x)\,diffusion} = qD_n \frac{d_n(x)}{dx}$

Then, for electrons in semiconductor

$$J_{nt} = J_{n\,drift} + J_{n\,diffusion}$$

$$\Rightarrow J_{nt} = nq\mu_n E + qD_n \frac{d_n(x)}{dx}$$

Similarly $J_p^t = pq\mu_p E + qD_p \frac{d_p(x)}{dx}$

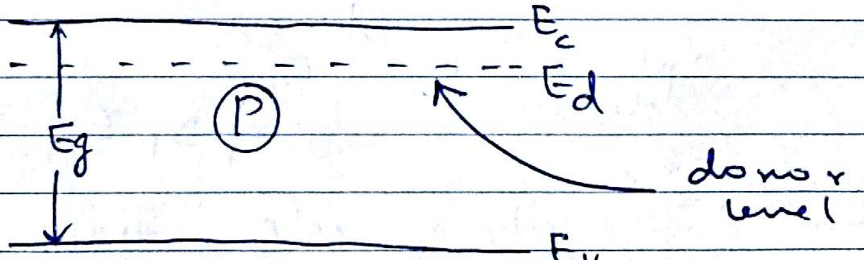
Semiconductor

(i) Intrinsic (ii) Extrinsic

In intrinsic semiconductor, there is no doping i.e. within the crystal intentional defects are not introduced.
But in extrinsic semiconductor, we dope some foreign atoms inside the crystal. So, in this case we are intentionally introducing some defects inside the crystal.

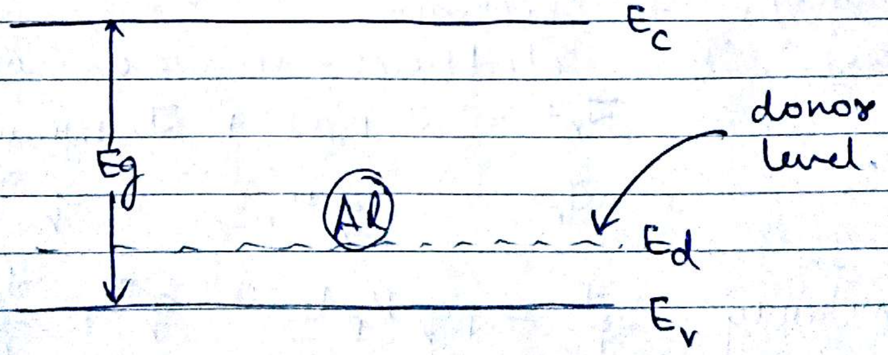
There are two types of extrinsic semiconductor:-
(i) N-type (pentavalent atoms are doped to create excess free e^- concentration inside the crystal).

The band diagram is as shown below:-



(ii) P-type (trivalent atoms are doped to create excess holes)

Notes:



The concentration of n-types or p-types dopants are very less. So the interaction between dopants is very less. Therefore we get discrete energy level for dopant. As the donor level is just below E_c ~~and j~~ for n-type and just above E_v for p-type, then at thermal equilibrium each ~~all the~~ dopant atoms will contribute a single free electron to the crystal.(For n-type).

$$E_c - E_d = 0{\cdot}01\,eV \quad Ge$$
$$= 0{\cdot}05\,eV \quad Si$$

Mass Action Law :-

The addition of n-type ~~and p-type~~ impurities decreases the no. of holes. and vice versa.

Under thermal equilibrium, the product of negative and positive charge concentration is constant and equal to n_i^2.

$$np = n_i^2$$

n = Free electron conc. } in extrinsic semiconductor
p = Free hole conc. }

n_i = intrinsic ~~area~~ carrier concentration.

Notes :

Charge density in semiconductor :-

Let the semiconductor is doped with both type of impurities. Under equilibrium the free electron concentration is given by n and that of free hole is given by p. If we consider complete ionisation then concentration of positive ions will be equal to donor conc. N_D, similarly negative ion conc. will be equal to ~~app~~ acceptance conc. N_A. Due to charge neutrality, total ~~char~~ +ve charge conc. will be equal to total −ve charge conc.

$$n + N_A = p + N_D .$$

For n type material, $N_A \longrightarrow 0$

$$\therefore n = p + N_D$$

$$\simeq N_D$$ (∵ in n type semiconductor free e⁻ conc >>> free hole conc.)

$$n_n = N_D$$

$p_n = ?$ $\qquad n_n \cdot p_n = n_i^2$

$$\therefore p_n = \frac{n_i^2}{n_n}$$

$$\boxed{p_n = \frac{n_i^2}{N_D}}$$

Notes :

For p-type material; $N_D \to 0$.

$$\therefore p = n + N_A \left[\because \text{hole conc} >>> e^- \text{ conc.}\right]$$
$$\simeq N_A$$

$\therefore p_p = N_A$ $\qquad n_p \cdot p_p = n_i^2$

$n_p = ?$ $\qquad \Rightarrow n_p = \dfrac{n_i^2}{n_p}$

$$\boxed{n_p = \frac{n_i^2}{N_A}}$$

<u>Fermilevel in semiconductor</u>:

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

Electrons inside the crystal obey Fermi-Dirac statistics and the distribution function in a particular energy level E is given by the function $f(E)$.

where, E_f is the fermi energy level
$f(E)$ denotes the occupancy factor for a particular energy level E.
Let us first consider intrinsic semiconductor is at absolute 0 K.

At $T = 0K$; $f(E) = \dfrac{1}{1 + e^{\infty}} = 0$; $(E > E_F)$

Notes:

$T = 0K$; $f(E) = \dfrac{1}{1 + e^{-\infty}} = 1$; $(E_F > E)$

ie. at $T = 0K$; the available energy level upper the fermi level is vacant and at $T = 0K$, the

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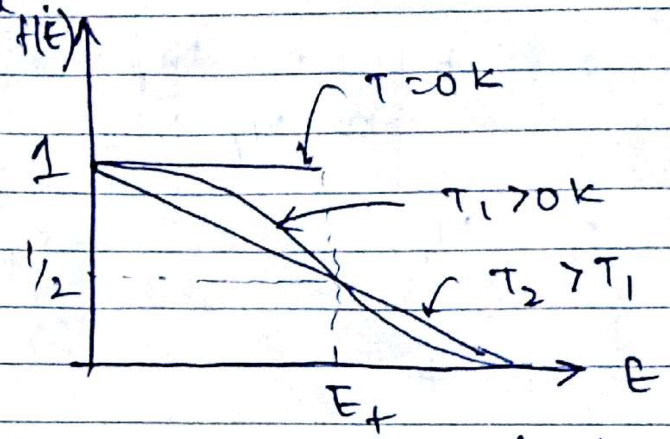
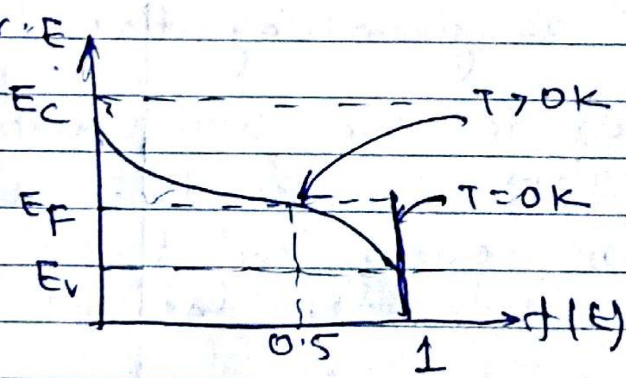
39	24	25	26	27	28	29	30	44	29	30	31				

available energy level and at T = 0K; the available energy level below the fermi level is completely occupied.

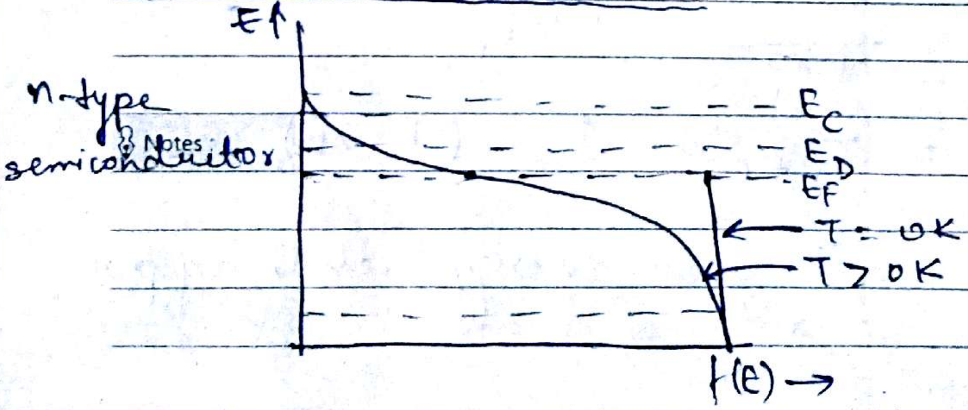


If we increase temperature, we find that some of the valence e⁻ will move to the conduction band. i.e. occupancy factor above E_F will be non-zero for T > 0K. At any temperature the occupancy factor at $E = E_f$ will be 1/2.

If we consider n type semiconductor then the band diagram along with the occupancy. For n type, the following figure indicates the venn diagram and occupancy factor.

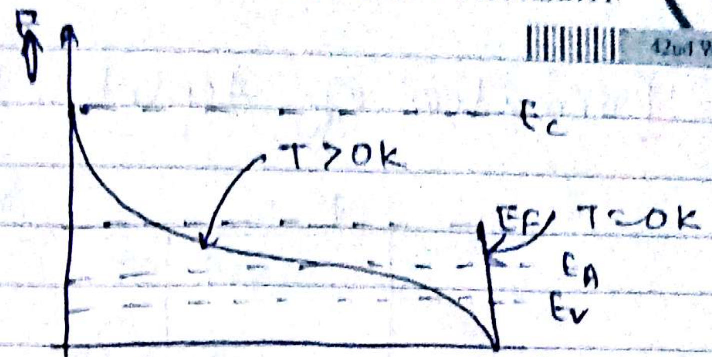


Intrinsic semiconductor



(E_D = Donor energy level)

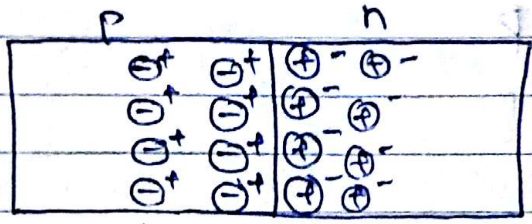
Similarly for the p-type semiconductor



Effect of temperature on doped semiconductor $f(E)$ →

If we increase the temperature ; say for n-type semiconductor to high value then large number of e-h pair will be generated. So the electron concentration of the thermally generated carrier will be very large compared to that of generated from donor atoms. Therefore the total electron concentration will be dominated by thermal generation and electron-hole concentration will be same at high temperature; i.e. they will act as intrinsic semiconductor.

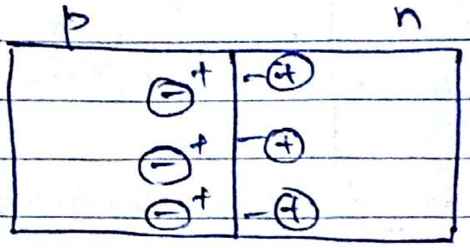
p-n junction diode :-



To form a p-n junction diode, we first take a series of semiconductor bar. Now this bar is placed in a doping chamber containing n type dopant. So some portion of the bar becomes n-type semiconductor and this region is controlled by proper environment within the chamber (temp, pressure, condition of dopant). After that the n type dopant is removed from the chamber and p type dopant is introduced. So the remaining portion of the silicon bar will be doped.

Notes :

Formation of depletion layer



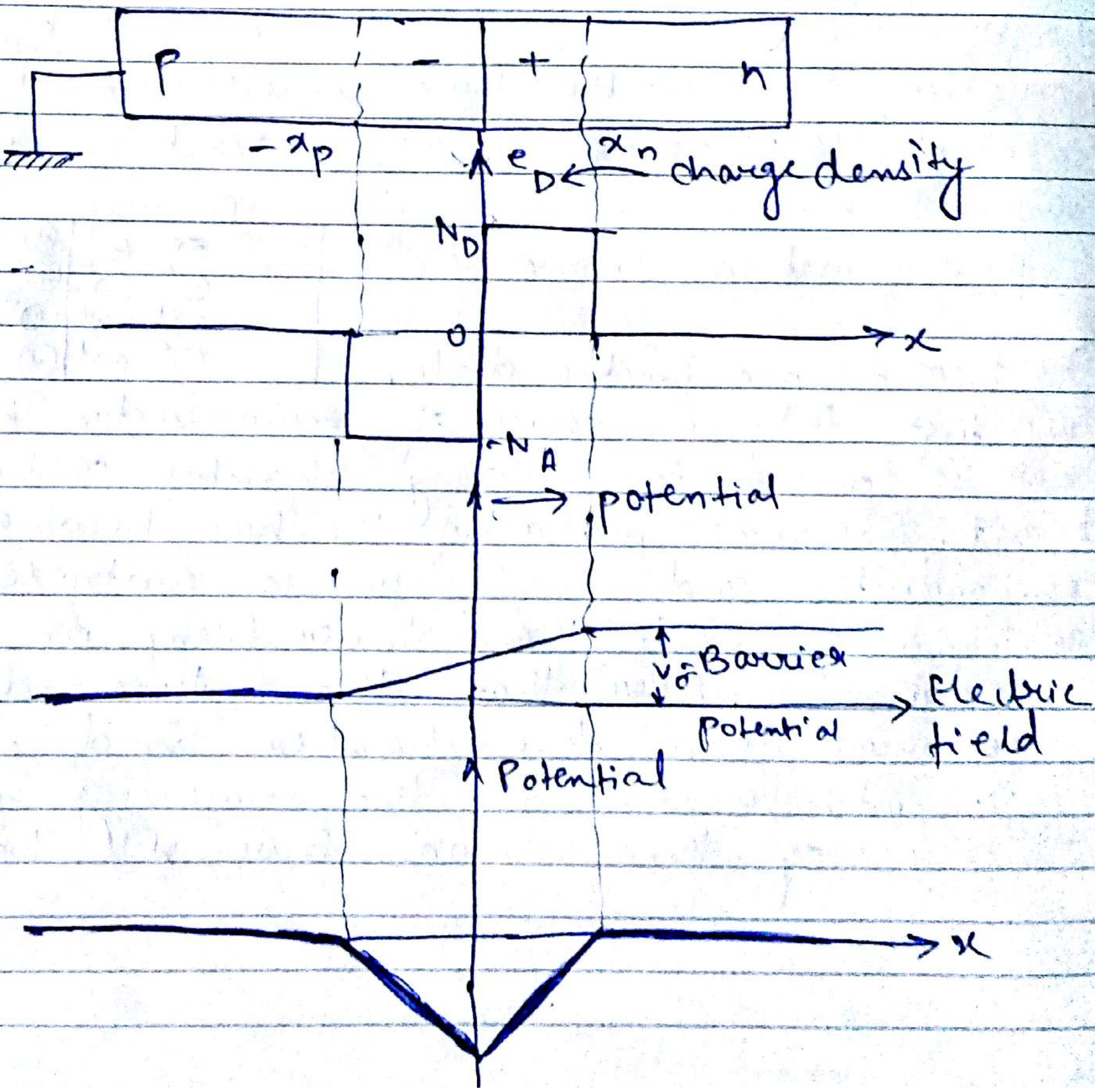
Depletion region is also called space charge region.

Charge | Potential & Electric field profile

$N = x_n + x_p$

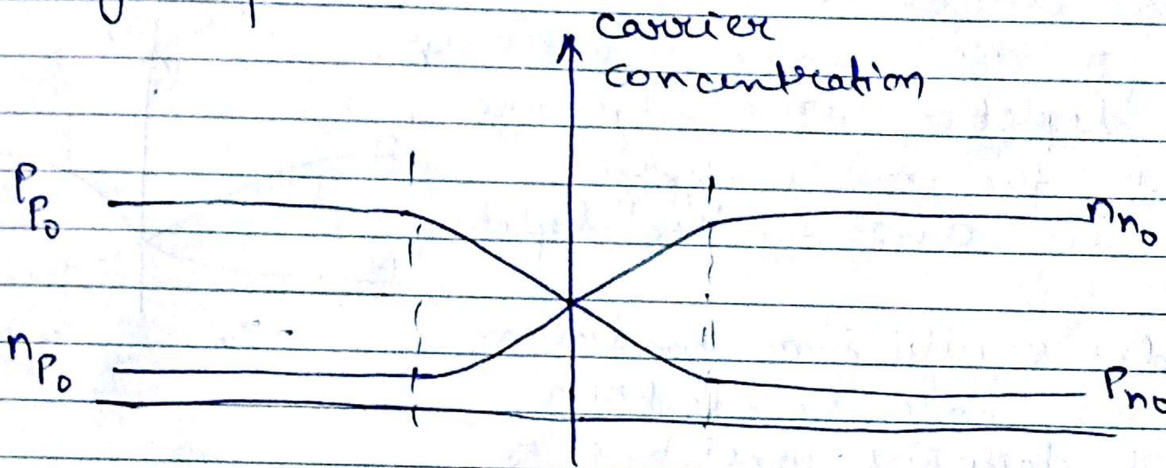
$N_A = N_p$

$\Rightarrow x_n = x_p$



Notes :

If we consider abrupt junction on step graded junction then the p-n junction will be strictly defined.

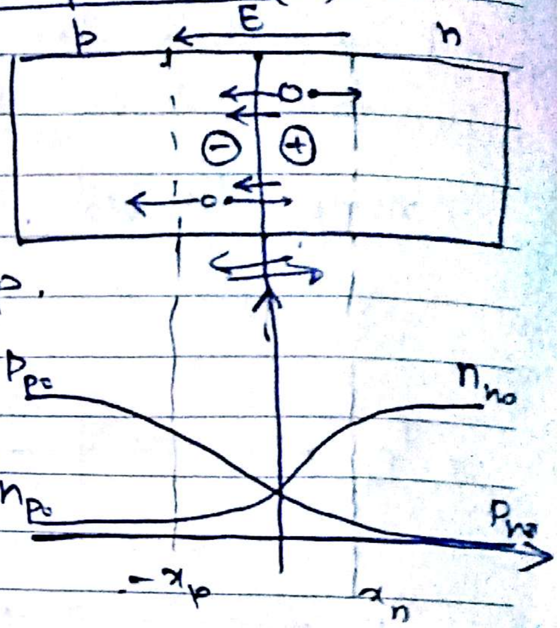


$$\boxed{n = N_D = n_{n_0}}$$

$$\boxed{p = \frac{N_i^2}{N_D} = p_{n_0}}$$

Notes :

Calculation of built-in/barrier potential (V_0):



To calculate the barrier potential (V_0), we should consider:

(i) The junction is abrupt or sharp.

(ii) The depletion region edges are sharp ie. the mobile charge density are 0 within the depletion layer.

(iii) Under equilibrium condition, the total hole or electron current densities consisting of drift and diffusion is equal to zero.

Therefore, $J_p(x) = J_{p\,drift}(x) + J_{p\,diffusion}(x)$

$$= p(x)\, q\, \mu_p E(x) + \left(-q D_p \frac{dp(x)}{dx}\right) = 0$$

$$E(x) = \frac{D_p}{\mu_p} \frac{1}{p(x)} \frac{dp(x)}{dx}$$

$$= \frac{kT}{q} \cdot \frac{1}{p(x)} \cdot \frac{dp(x)}{dx}$$

$$\boxed{\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = \frac{kT}{q}}$$

einstein's relation

$$V_0 = \int_{-x_p}^{x_n} E(x)\, dx = -\frac{kT}{q} \int_{-x_p}^{x_n} \frac{dp(x)}{p(x)}$$

$$= -\frac{kT}{q} \left[\ln\{p(x = x_n)\} - \ln\{p(x = -x_p)\} \right]$$

$$= -\frac{kT}{q} \left[\ln p_{no} - \ln p_{po} \right]$$

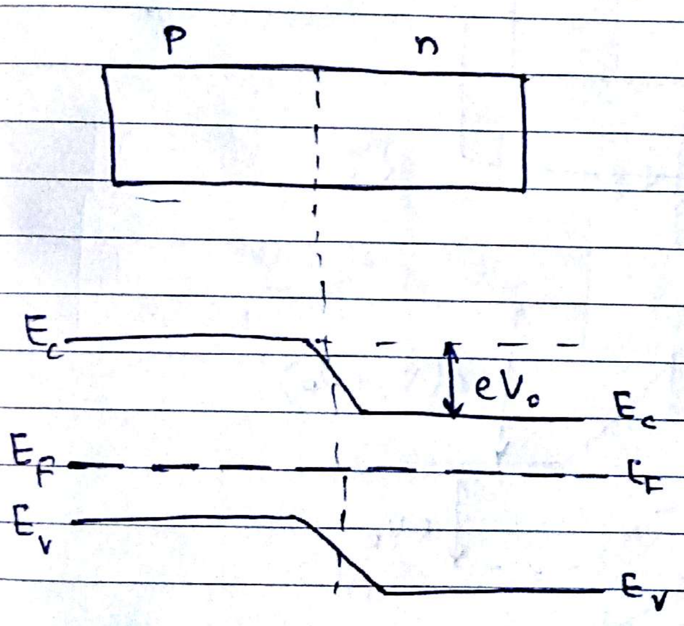
Notes :

$$= \frac{KT}{q} \ln\left(\frac{p_{po}}{p_{no}}\right)$$

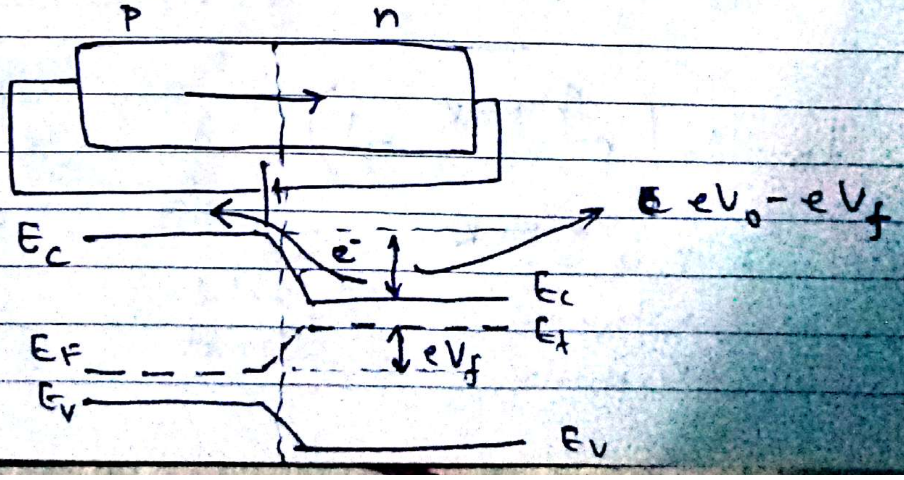
$$= \frac{KT}{q} \ln\left(\frac{N_A}{n_i^2/N_D}\right)$$

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

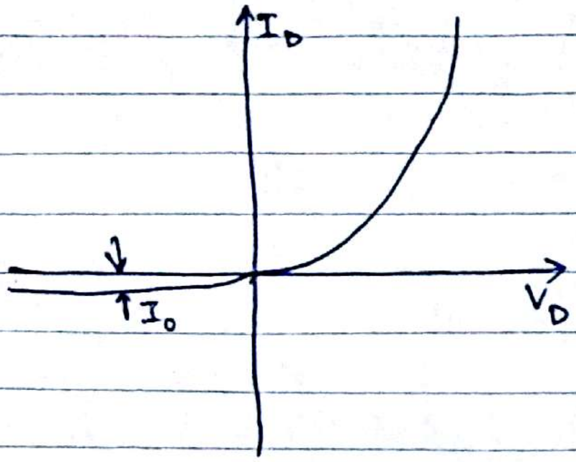
Energy band diagram of p-n diode under no bias:-



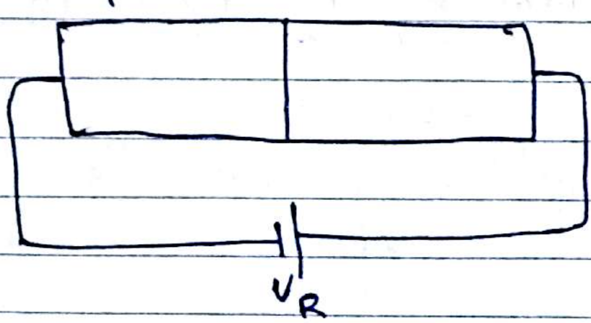
Under forward biased :-

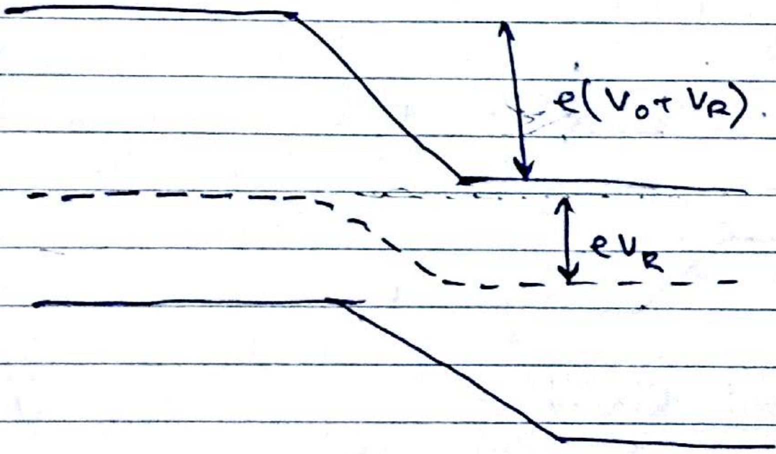


Notes :



Reverse bias :-



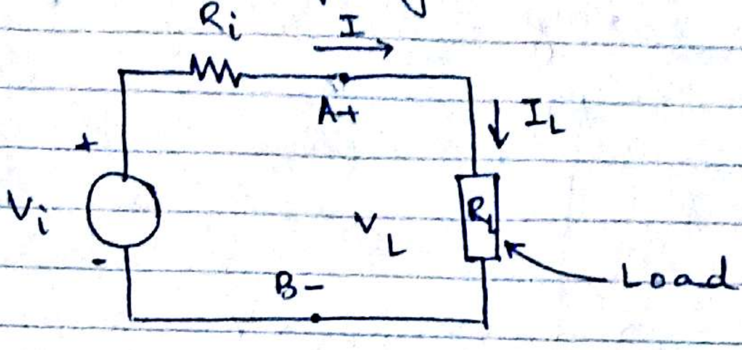


$$I_D = I_0 \left(e^{qV_D/nKT} - 1 \right)$$

Notes :

$$= \underbrace{I_0 e^{qV_D/nKT}}_{\text{Diffusion}} - \underbrace{I_0}_{\text{Drift}}$$

Regulated Power Supply



$$I_L = \frac{V_i}{R_i + R_L}$$

$$V_L = I_L R_L$$

$$= \frac{V_i R_L}{R_i + R_L}$$

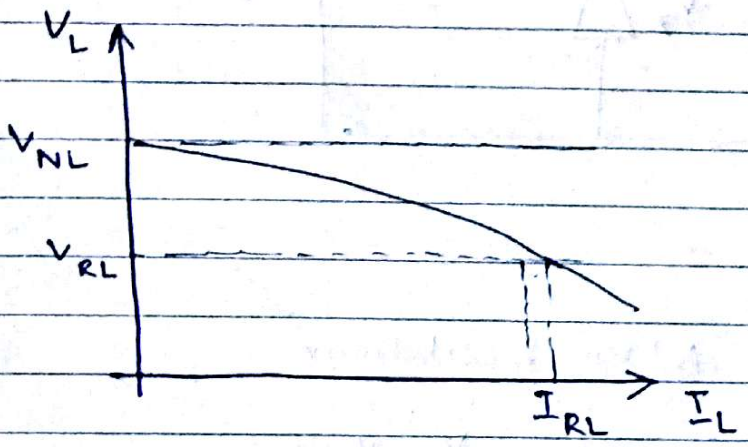
V_{NL} = No load voltage

$= V_{AB} = V_i - V_L$

$= V_i \quad (\because V_L = 0)$

V_{RL} = Rated load voltage

$= \frac{V_i R_L}{R_i + R_L} < V_i$ i.e. V_{NL}



For ideal voltage source

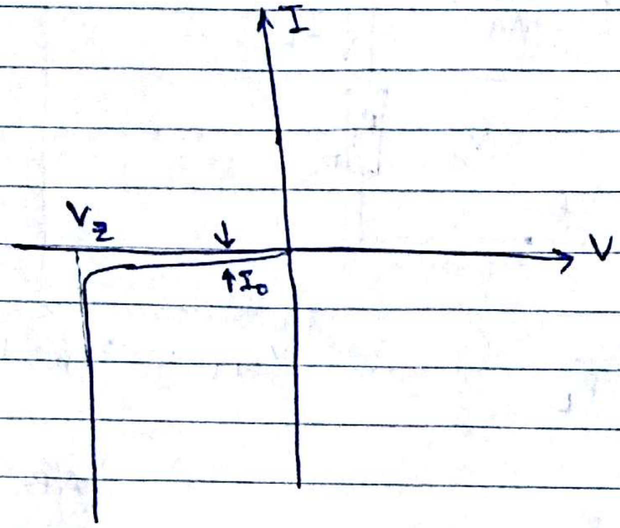
$R_i = 0$

internal impedance = 0.

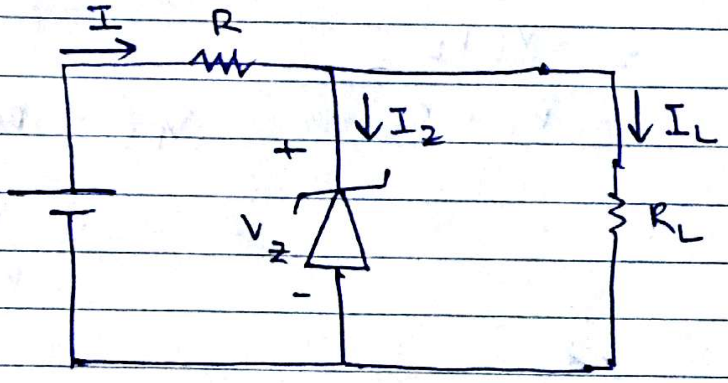
$$\% \text{ Regulation} = \frac{V_{NL} - V_{RL}}{V_{RL}} \times 100\%$$

Notes :

Use of zener diode as reference voltage source or regulated power supply.



$I = I_z + I_L$



When the zener is not on

$\therefore I_z \simeq 0$

$I = I_L$

$$V_L = \frac{V R_L}{R + R_L}$$

Breakdown condition $V_L \geq V_z$

After breakdown

$$I = \frac{V - V_z}{R}$$

$$I_L = \frac{V_L}{R_L} = \frac{V_z}{R_L}$$

Notes :

$$I_z = I - I_L$$

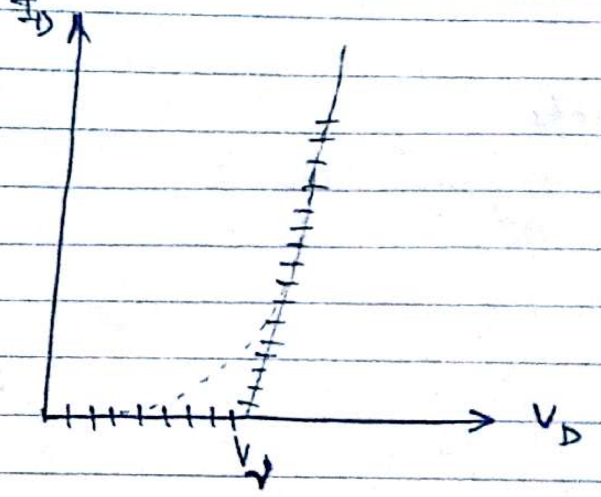
Case - I ! Let the supply voltage V is kept constant and R_L is changed.

$$\Delta I = 0 \qquad \Delta I_L \neq 0$$

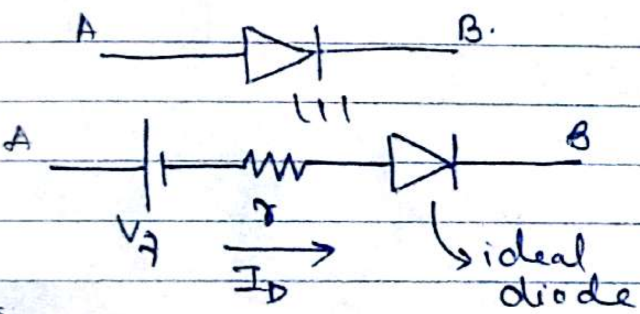
$$\Delta I = \Delta I_z + \Delta I_L$$

$$\Rightarrow 0 = \Delta I_z + \Delta I_L \Rightarrow \Delta I_L = -\Delta I_z$$

Piecewise linear approximate diode model :

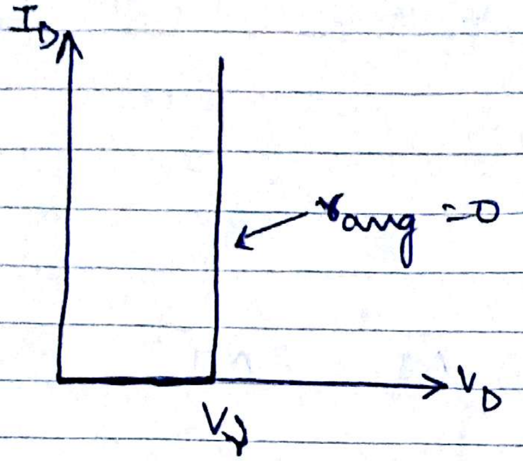


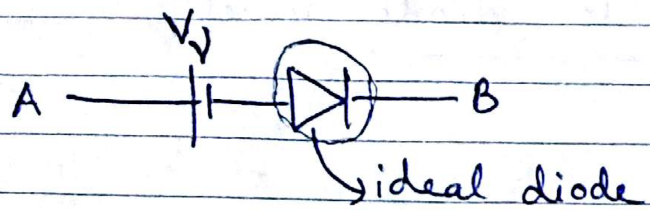
1^{st} approximation.



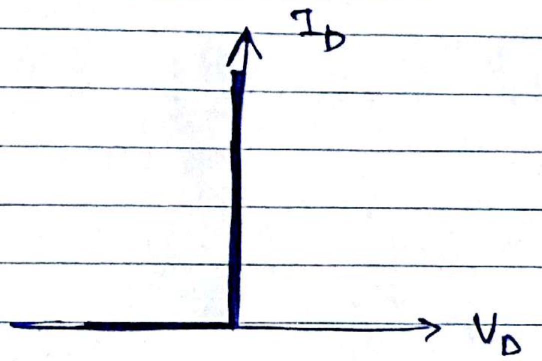
Notes :

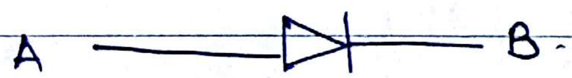
2nd approximation





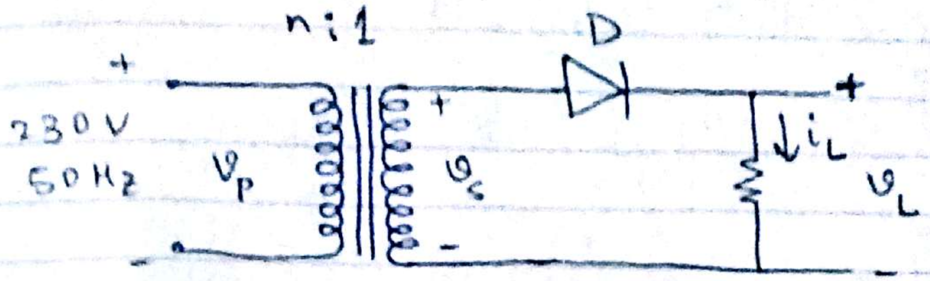
3rd approximation

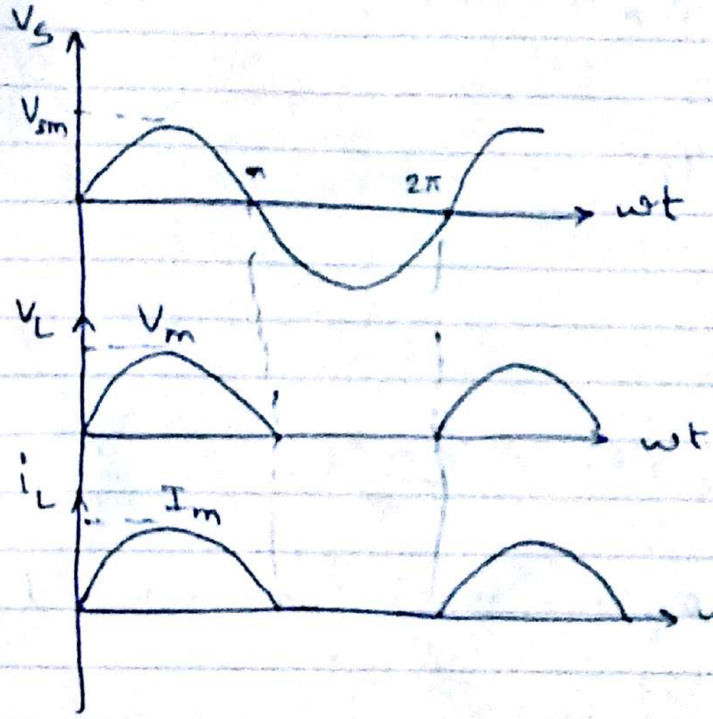




Notes :

Half Wave Rectifier:





V_{sm} = secondary max. voltage

let $v_s = V_{sm} \sin\omega t$.

$$i_L = \frac{v_s}{R_f + R_L}$$; R_f is the resistance of diode

$$= \frac{V_{sm} \sin\omega t}{R_f + R_L}, \quad 0 \leq \omega t \leq \pi$$

Notes :

$= I_m \sin\omega t$ where, $I_m = \frac{V_{sm}}{R_f + R_L}$

$= 0$, $\pi \leq \omega t \leq 2\pi$

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Therefore the d.c load current,

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)$$

$$= \frac{1}{2\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t)$$

$$= \frac{1}{2\pi} I_m (2)$$

$$= \frac{I_m}{\pi}$$

$$V_{dc} = I_{dc} \times R_L = \frac{I_m R_L}{\pi} = \frac{V_m}{\pi}$$

The rms value of the total load current, i_L is given by

$$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{4\pi}\int_0^{\pi} (1-\cos 2\omega t) \, d(\omega t)\right]^{1/2}$$

Notes :

$$= \left(\frac{I_m^2}{4}\right)^{1/2} = \frac{I_m}{2}$$

$$V_{rms} = I_{rms} \cdot R_L$$

$$= \frac{I_m R_L}{2} = \frac{V_m}{2}$$

The total load current ~~I_L~~ i_L consists of two components :-

(i) dc component (I_{dc})

(ii) AC or repel component (i')

$$i_L = I_{dc} + i'$$

The rms ~~com~~ value of the repel component is given by :-

$$I'_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i'^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{2\pi} (i_L - I_{dc})^2 \, d(\omega t)\right]^{1/2}$$

$$= \left[\frac{1}{2\pi}\int_0^{2\pi} (i_L^2 + I_{dc}^2 - 2 i_L I_{dc}) \, d(\omega t)\right]^{1/2}$$

$$= \left[I_{rms}^2 + I_{dc}^2 - \frac{2 I_{dc}}{2\pi}\int_0^{2\pi} i_L \, d(\omega t)\right]^{1/2}$$

$$= \left[I_{rms}^2 + I_{dc}^2 - 2 I_{dc} \frac{I_m}{\pi}\right]^{1/2}$$

Notes :

$$= \left[I_{rms}^2 + I_{dc}^2 - 2 I_{dc}^2 \right]^{1/2}$$

$$= \left[I_{rms}^2 - I_{dc}^2 \right]^{1/2}$$

Therefore the ripple factor is defined as

$$\gamma = \frac{\text{rms value of the ripple comp. of the load current}}{\text{avg. value of or dc value of load current}}$$

$$\gamma = \frac{I'_{rms}}{I_{dc}}$$

$$= \frac{\left[I_{rms}^2 - I_{dc}^2 \right]^{1/2}}{I_{dc}}$$

$$= \left[\left(\frac{I_{rms}}{I_{dc}} \right)^2 - 1 \right]^{1/2}$$

$$= \sqrt{\left(\frac{I_m/2}{I_m/\pi} \right)^2 - 1} = \sqrt{\left(\frac{\pi}{2} \right)^2 - 1}$$

Notes :

$$= 1.21$$

Rectification efficiency is defined as the ratio of dc output power to the ac input power.

$$\eta = \frac{P_{dc}}{P_{in(AC)}} \times 100\% = \frac{I_{dc}^2 \cdot R_L}{(R_f + R_L)\, I_{rms}^2} \times 100\%$$

$$P_{i_{AC}} = \frac{1}{2\pi}\int_0^{2\pi} v_s\, i_L\, d(\omega t) \qquad = \frac{40.6}{1 + R_f/R_L}\ \%$$

$$= \frac{1}{2\pi}\int_0^{2\pi} \{(R_f + R_L) i_L\}\, i_L\, d(\omega t)$$

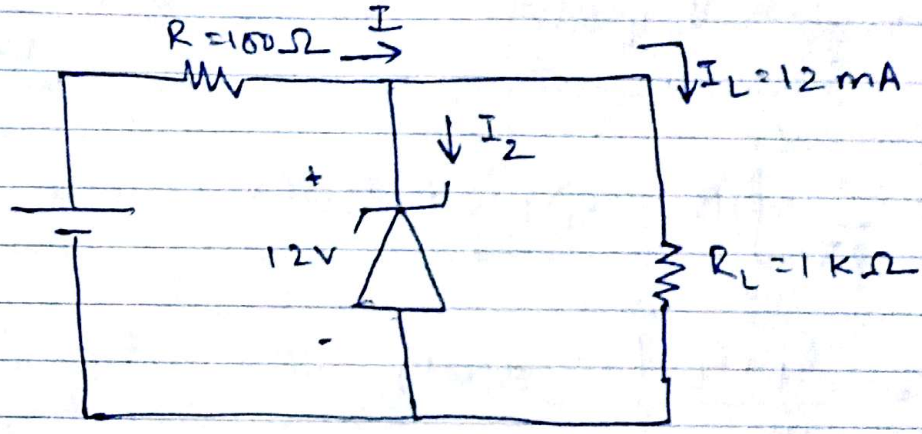
$$= \frac{R_f + R_L}{2\pi}\int_0^{2\pi} i_L^2\, d(\omega t)$$

$$= (R_f + R_L)\, I_{rms}^2$$

max. efficiency $= 40.6\%$ (considering $R_f = 0$)

Notes :

8] In a zener regulator, a 12 V, 0.36 W zener diode operates at a min. diode current of 2 mA. The value of R (series resistance) is 100 Ω and load resistance $R_L = 1\ k\Omega$. Determine the limits between which the supply voltage V can vary without loss of regulation in the circuit.



$P = V_Z I_Z$

zener current : 2 mA – 30 mA

$P_{min} = 12 \times 2$ mW
$= 24$ mW

$P_{max} = 0.36$ W

$\Rightarrow V_Z\, I_{Z(max)} = 0.36$ W

$\Rightarrow I_{Z(max)} = 0.03$ A $= 30$ mA

$I_L = \dfrac{V_Z}{R_L} = \dfrac{12}{1 \times 10^3} = 12$ mA

Notes :

$I_{min} = (2 + 12)$ mA $= 14$ mA.

$V_{min} = V_{R_{min}} + V_Z = (14\text{ mA} \times 100\ \Omega) + 12$ V
$= 13.4$ V

$$V_{max} = V_{R_{max}} + V_2$$

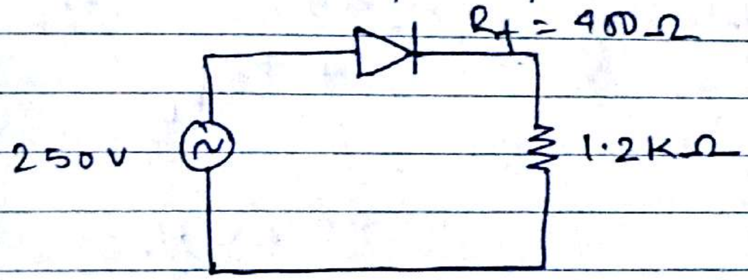
$$= (I_{max} \times 100) + 12$$

$$= (42 \times 10^{-3} \times 100) + 12$$

$$= (4.2 + 12)\ V$$

$$= 16.2\ V$$

8] A diode having forward resistance (R_F) of 400 Ω supplies power to a load resistance of 1200 Ω from a 250 V (rms) mains. Calculate ~~the~~ (i) dc load current (ii) Ac load current (iii) dc voltage across the diode. (iv) dc output power (v) conversion efficiency.



~~dc peak~~ The peak load current, $I_m = \frac{V_{sm}}{R_f + R_L}$

$$= \frac{250 \times \sqrt{2}}{1.6 \times 1000}$$

$$= 0.221\ A$$

The dc. load current $= \frac{I_m}{\pi} = 0.073$

$$I_{rms}^2 = I'^2_{rms} + I_{dc}^2$$

$$\Rightarrow I'_{rms} = \sqrt{I_{rms}^2 - I_{dc}^2}$$

$$= \sqrt{\left(\frac{I_m}{2}\right)^2 - \left(\frac{I_m}{\pi}\right)^2}$$

$$= 0.0852 \text{ A}$$

D.C voltge across the diode $= I_{dc} \times R_f$

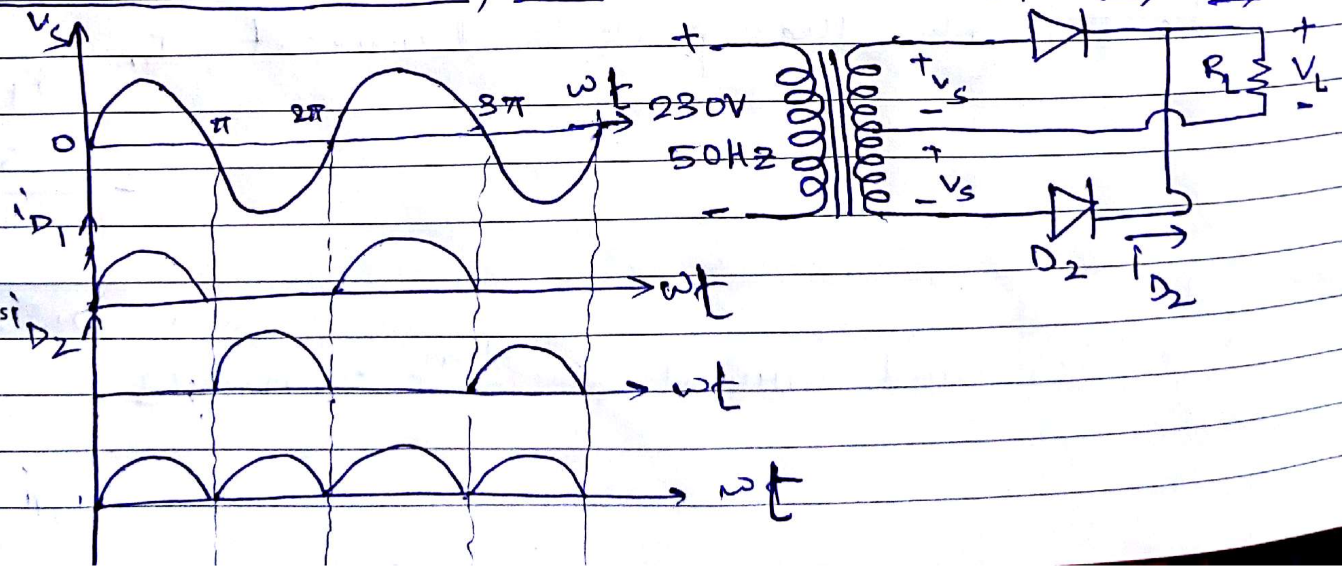
$=$

D.C output power $= I_{dc}^2 \times R_L$

The conversion efficiency $\eta = \dfrac{40.6}{1 + R_f/R_L}$ %

$= 30.45$ %

Full Wave Rectifier



Notes

$$i_L = \frac{v_s}{R_f + R_L} = \frac{V_{sm} \sin\omega t}{R_f + R_L}$$

$$= I_m \sin\omega t \, , \quad 0 \le \omega t \le \pi$$

$$= I_m \sin\omega t \quad \cancel{0} \le \omega t \le 2\pi$$

Therefore the d.c load current $I_{dc} = \frac{1}{\cancel{2}\pi}\int_0^{\pi} I_m \sin\omega t \, d(\omega t)$

$$I_{rms} = \sqrt{\frac{1}{\pi}\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t)} = \frac{2I_m}{\pi}$$

$$= \sqrt{\frac{I_m^2}{2\pi} \times 2} = \frac{I_m}{\sqrt{2}}$$

Ripple factor, $\gamma = \frac{I'_{rms}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$

$= \cancel{1.1}\ 0.482$

efficieny, $\eta = \frac{81.2}{1 + R_f/R_L}$ %

Q] A full wave rectifier uses a double diode the forward resistance of each diode is 200 Ω. The rectifier supplies current to a load resistance of 1500 Ω. The primary to secondary turns ratio of the centre tapped transformer is 1:3. The primary is fed from a supply of 240 V rms. Find (i) I_{dc} (ii) dc power output

Notes :

(iii) direct current supplied by each diode (iv) Ripple factor (v) efficiency.

Total secondary voltage = $(240 \times 3)V = 720V$ rms

∴ The peak value of the secondary voltage = $720\sqrt{2}$

Here $V_{sm} = \frac{720\sqrt{2}}{2} = \frac{720}{\sqrt{2}}$

$I_{dc} = \frac{2I_m}{\pi} = \frac{2}{\pi} \frac{V_{sm}}{R_f + R_L}$

The dc current in each diode $= \frac{I_{dc}}{2}$

dc. Power $= I_{dc}^2 \times R_L$

Ripple voltage, $V'_{rms} = I'_{rms} \times R_L$

$= \sqrt{I_{rms}^2 - I_{dc}^2} \times R_L$

Efficiency =

Notes :