☆ Semiconductor diode and applications ☆

☆ Type of material:

1) conductors: metals, salt, water (Resistance lo
2) Insulator: wood, paper (Resistance - very high)
3) semiconductor: Those material having conductivity in b/w conductors and insulators. they have moderate resistance.
Ex: Ge, Si, GaAs

~~Silicon~~ silicon is most common semiconductor.

Si : atomic number = 14

$1s^2, 2s^2, 2p^6, \underbrace{3s^2, 3p^2}$

4 valence electrons.

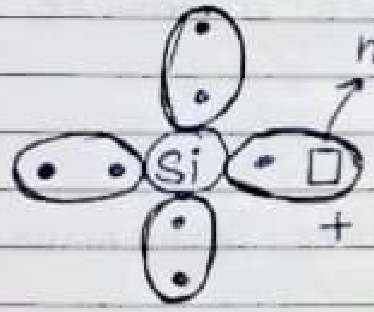
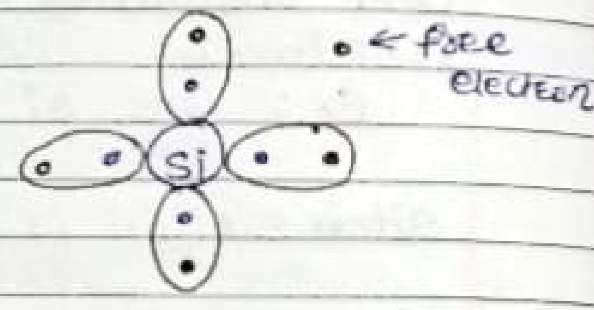
Types of semiconductor:

1. Intrinsic semiconductor: Pure
2. Extrinsic semiconductor: doped

Doping: It means adding impurity to intrinsic semiconductor

→ extrinsic semiconductor are of two type:
1. P-type semiconductor: when elements of group 14 in periodic table is doped with element of group 13. Then conductivity of group 14 element increases. this is called as P-type doped semiconductor.

② n-type semiconductor: element of ~~gr~~ group 14 are doped with group 15 element then the conductivity increases due to electrons (free).

p-type	n-type
	

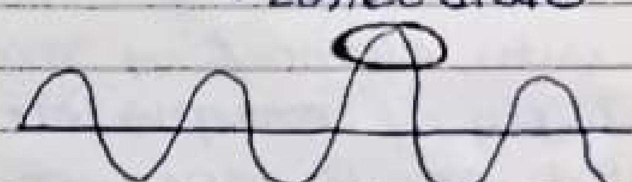
★ Semiconductor diodes: on doping we ge p-tye or n-type semiconductur which is of limited use and they can be used to conduct in both direction. On intermixing p-type & n-type semiconductor we get p-n junction diode, p-n junction diode allow to conduction in one direction only and blocks the another.

applications:

rectification ← i/p AC → o/p dc

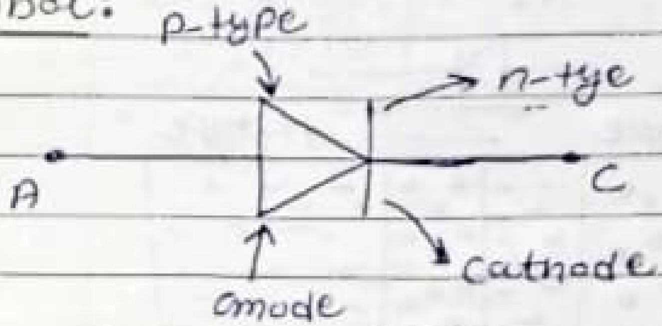
regulation ← $\boxed{5V}$ → 6V, 3V

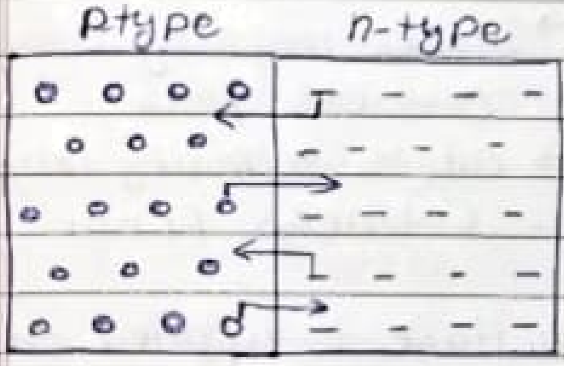
↘ zener diode

Clipping: 

Clamping: 

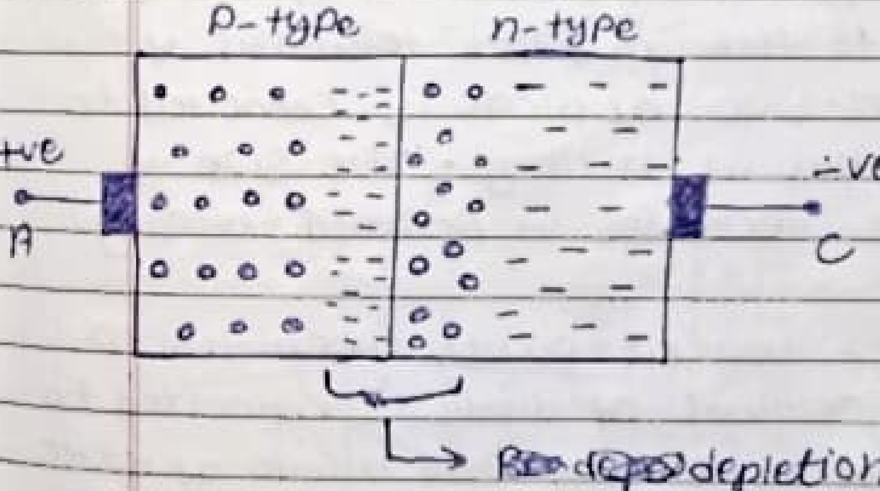
Symbol:





→ 2 layers
→ 1 jonction
→ unidirectional device
→ current is due to both holes and $e^{\ominus}$ so called bipolar
→ it normally operate as switch

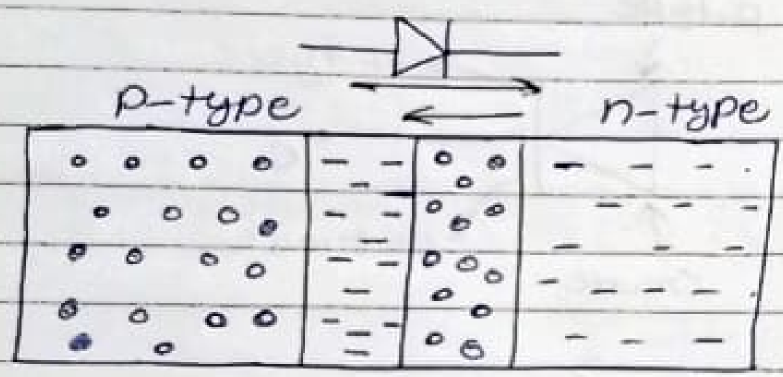
majority-hole majority-e
minority-e^- minority-hole



V_d = Ge = 0.2 to 0.3 V
V_d = Si = 0.6 to 0.7 V

☆ Biasing of p-n junction diode:

Zero bias:



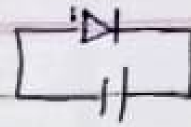
→ blocks majority charge carriers flow

→ allows minority charge - carriers flow.

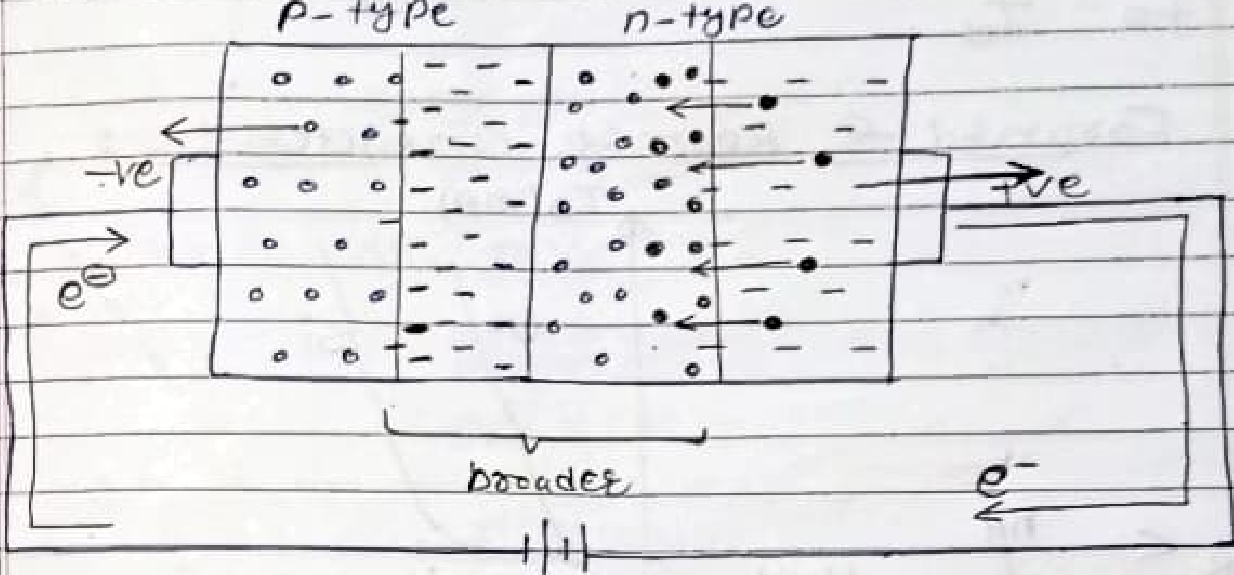
Biasing: When a dc voltage is applied on a device.

Forward Biasing: It occurs when the positive (P) end of the diode is connected to the positive terminal of the battery and n-side of diode is connected to negative terminal of battery. The size of depletion layer decreases in forward biasing.

Reverse biasing: It occurs when the P terminal of diode is connected to negative terminal of battery and n-side of diode to positive terminal of battery. The size of depletion layer increases on reverse biasing.



① Reverse biasing :



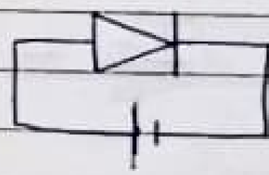
$I_d \downarrow$

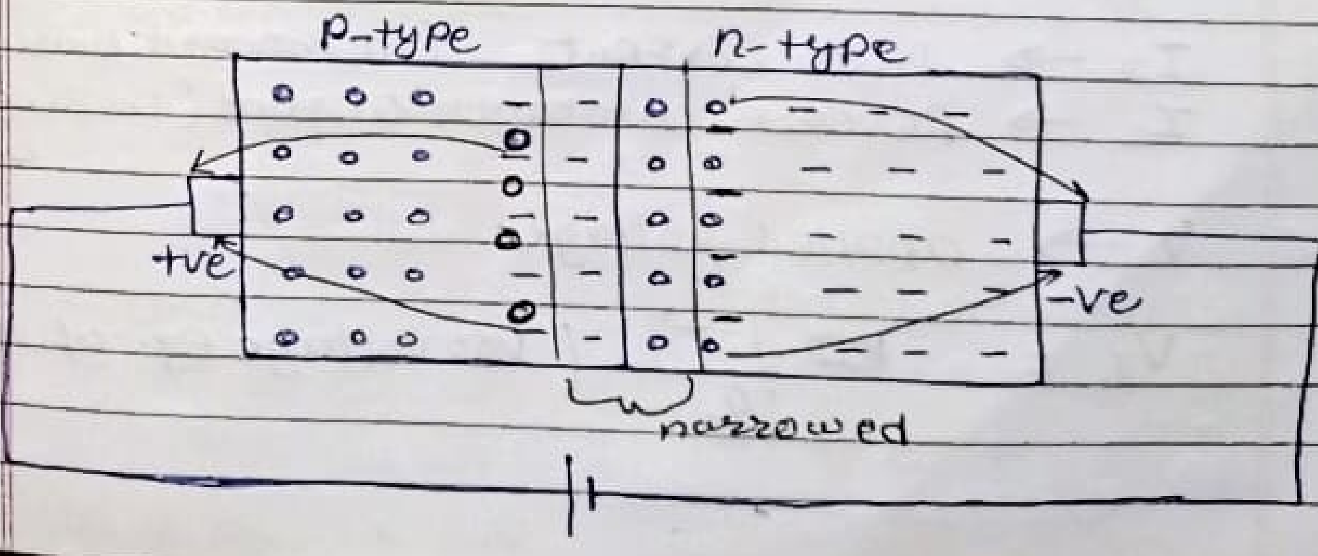
I_S - reverse saturation current : It is current due to minority charge carriers in the opposite direction that of current.

nA $\longrightarrow$ Si

μA $\longrightarrow$ Ge

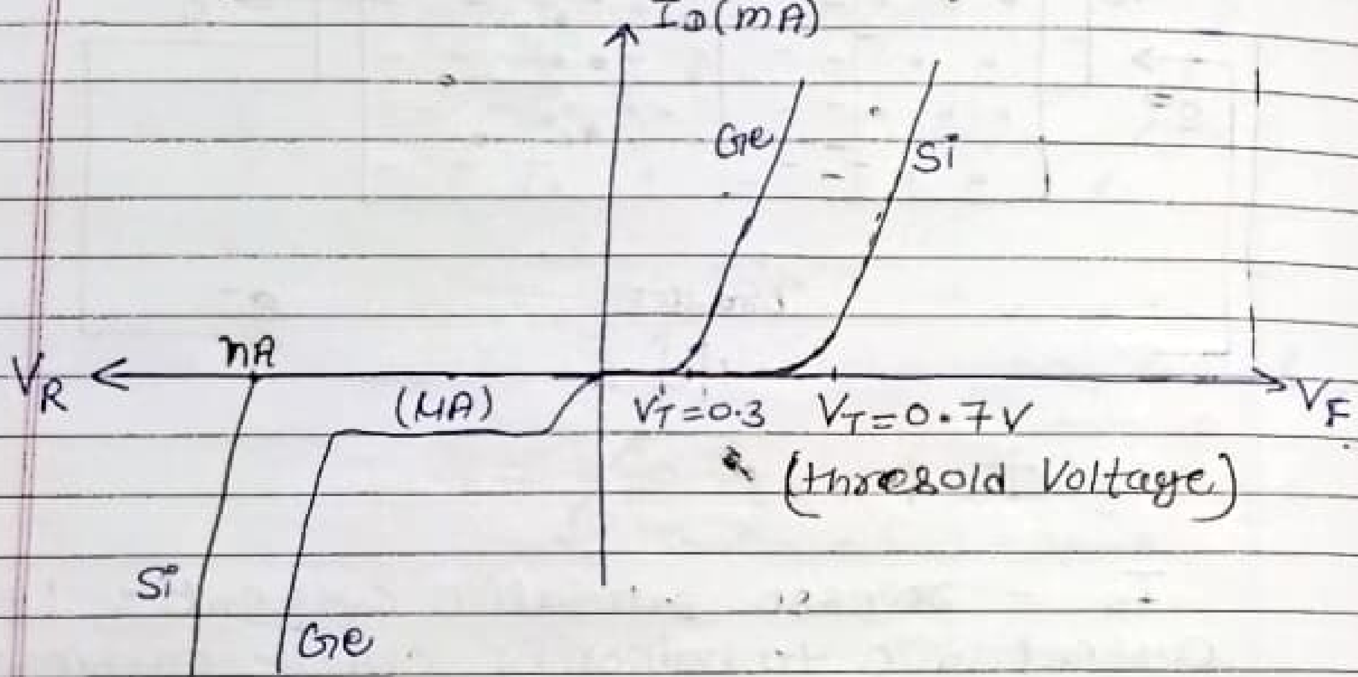
② Forward biasing :





majority carriers current $I_d \uparrow$ whereas minority current is very small as compare to I_d.

Forward & Reverse Characteristic :



☆ Diode Relationship:

$$I_D = I_S\left(e^{\frac{V}{nV_T}} - 1\right)$$

$I_D \rightarrow$ Diode current (in forward biasing only)

$I_S \rightarrow$ Reverse saturation current (in Reverse biasing only)

$V \rightarrow$ applied voltage

$V_T = \cancel{KT}\ \frac{KT}{q}$ (~~Vot~~ voltage eq. of temp)

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

q = charge on electron
$T \rightarrow$ temp. in Kelvin

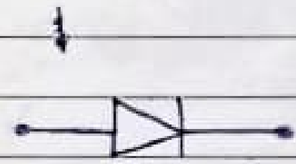
$V_T \approx 25.6\ mV$

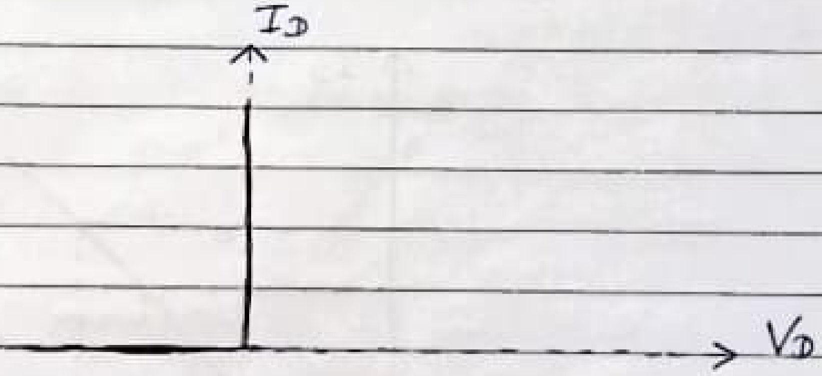
$n = 1$ (for Ge)
$= 2$ (for Si)

★ Equivalent circuit of diode:

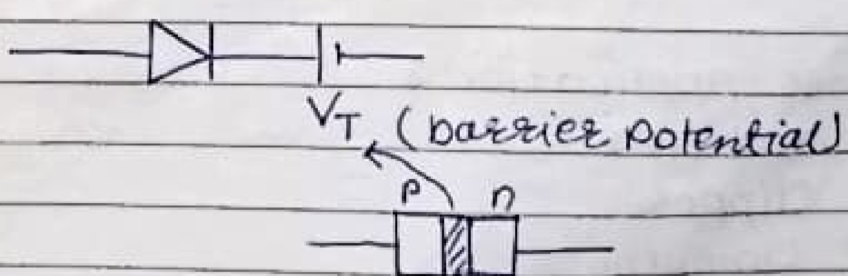
1) Ideal Diode:

Switch
$V_D > 0 \rightarrow$ on
$V_D < 0 \rightarrow$ OFF

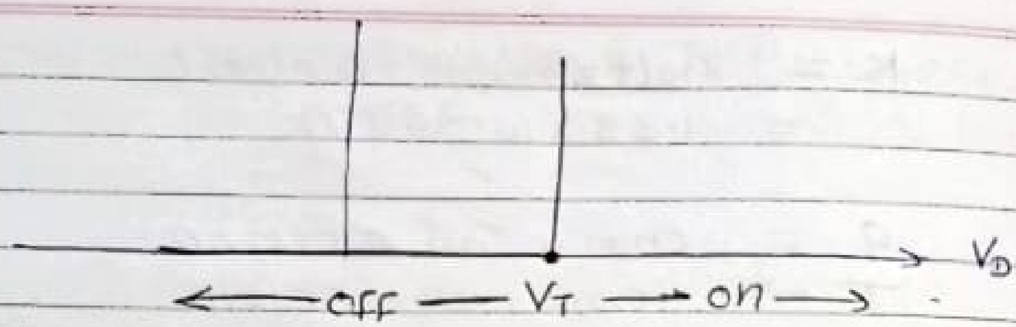




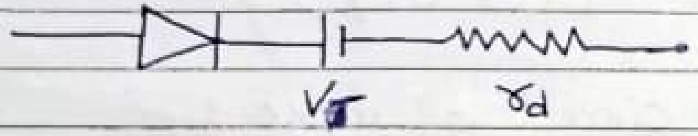
2) Approximate model:



$V_D > V_T \rightarrow$ on
$V_D < V_T \rightarrow$ off



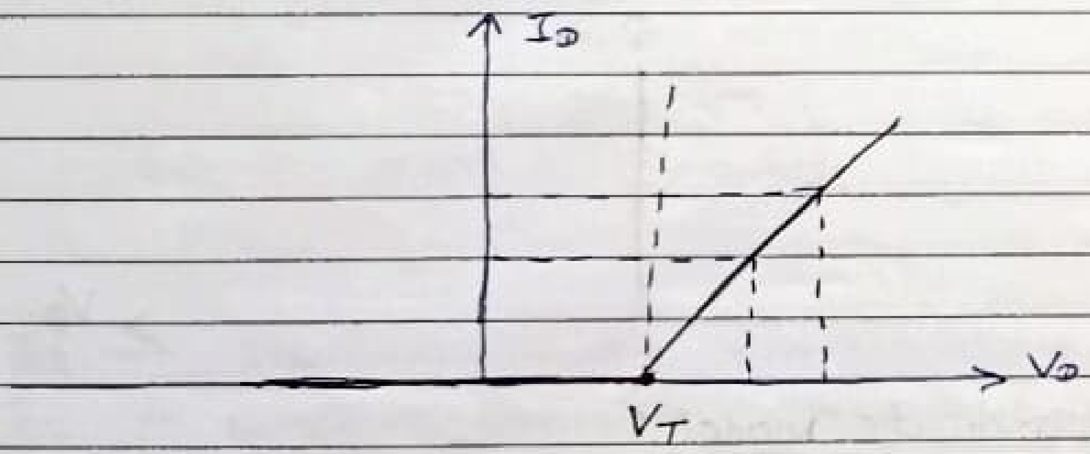
3) piecewise linear model



$$r_d = \frac{dV_D}{dI_D} \quad \text{(dynamic resistance)}$$

$V_D > V_T \longrightarrow$ on

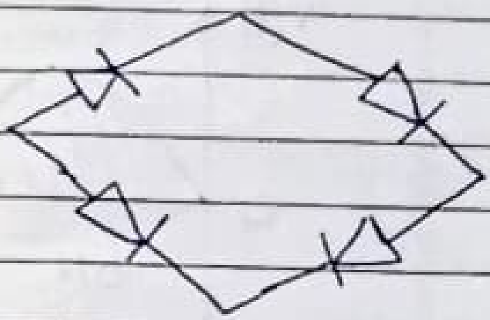
$V_D < V_T \longrightarrow$ off



☆ Diode Application:
1. rectifier
2. Clipper
3. Clamping
4. Voltage multiplier.

1. <u>Rectifier</u>: convert ac into dc.

- → Half wave rectifier
- → ~~Half~~ Full wave rectifier
  - ↓ Two diode rectifier
  - ↓ Bridge rectifier



<u>rectifier</u>: it is a semiconductor diode, used to convert AC into DC using the rectifier bridge application

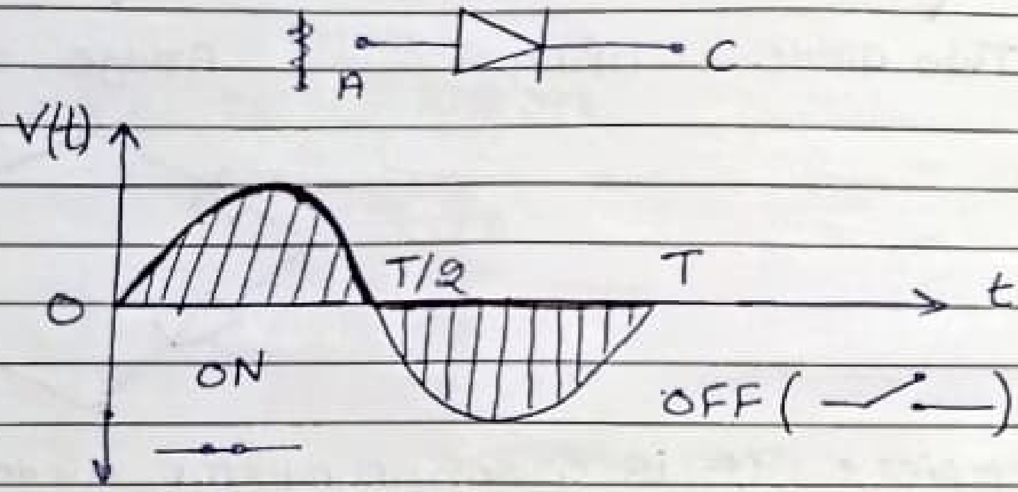
<u>Half wave rectifier</u>: a rectifier which ~~converts~~ conduct current of one direction and when input signal goes negative, it will not conduct the current, this is called half-wave rectifier.

<u>Full wave rectifier</u>: a full-wave rectifier diode circuit builds with four diodes, by this structure we can make both halves of the waves positive. For both positive and negative cycles of input, there is a ~~[illegible]~~ path ~~through~~ through the diode bridge.

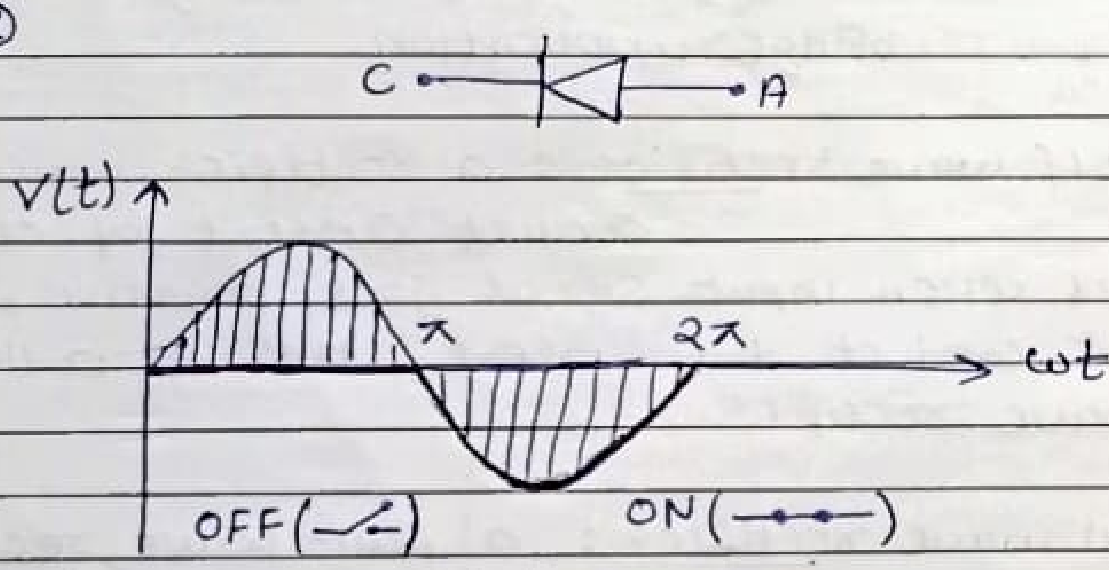
☆ How does a diode works :

FB → ON
RB → OFF

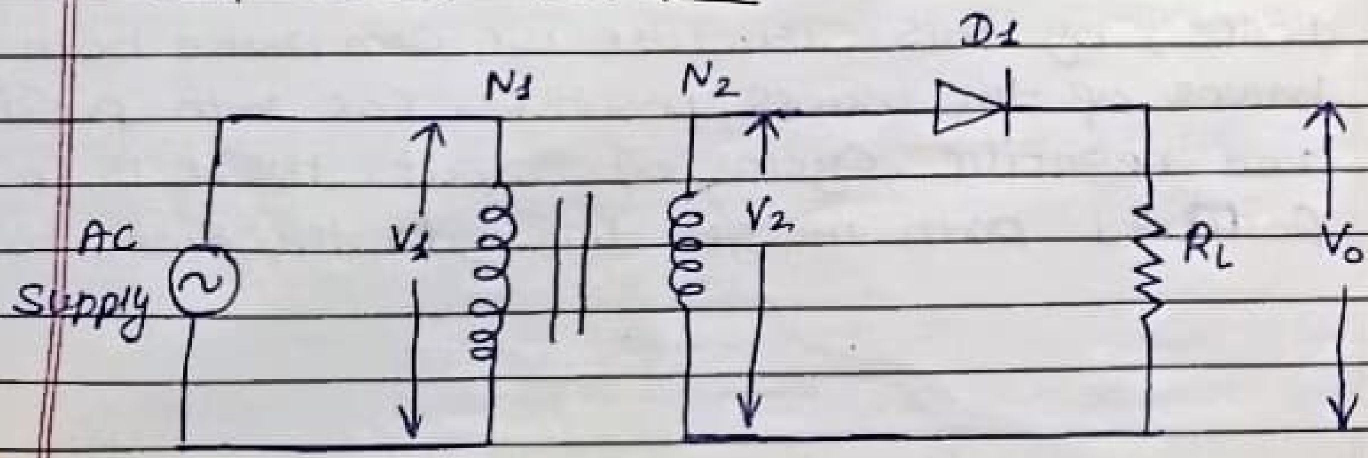
①



②



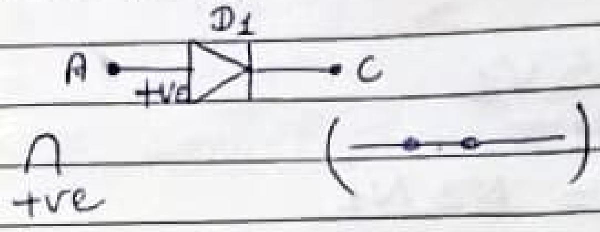
☆ Half wave rectifier :



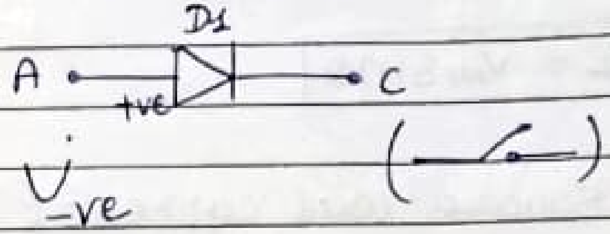
1) $N_1 > N_2$ or $N_2 > N_1$

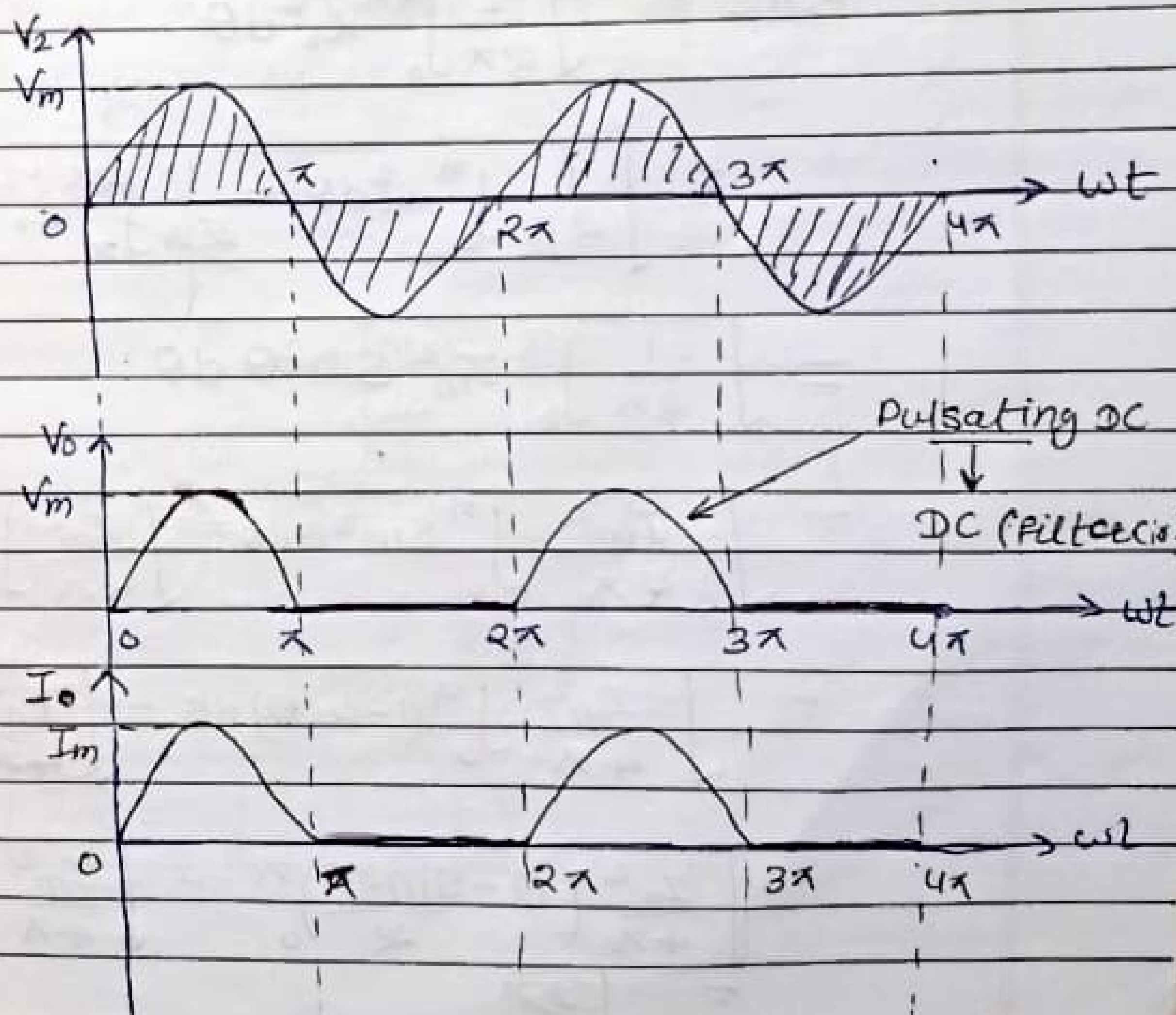
Step down Step up

2) +ve half cycle



3) −ve half ~~bo~~ cycle





→ let $V_1 = V_m \sin\omega t$

let $\omega t = \theta$

$$V_1 = V_m \sin\theta$$

→ $V_2 = \dfrac{N_2}{N_1} V_1$

if $N_2 = N_1$

$$V_2 = V_1 = V_m \sin\omega t = V_m \sin\theta$$

$$\boxed{V_2 = V_m \sin\theta}$$

Root mean square load current (I_{rms}) :

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_0^2 \, d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} i_0^2 \, d\theta + \cancel{\frac{1}{2\pi}\int_{\pi}^{2\pi} i_0^2 \, d\theta}^{\,0}}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2\theta \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\theta \, d\theta} = \sqrt{\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\theta}{2} \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\int_0^{\pi} (1-\cos 2\theta) \, d\theta} = \cancel{\sqrt{\frac{I_m^2}{4\pi}(\theta - \sin\theta)_0^{\pi}}}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^{\pi}} = \sqrt{\frac{I_m^2}{4\pi}(\pi - 0)}$$

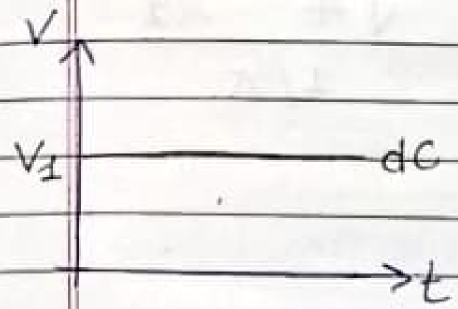
=

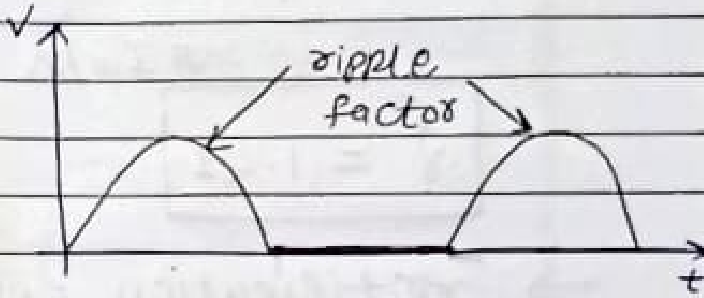
$$I_{rms} = \sqrt{\frac{I_m^2}{4\pi} \cdot \pi}$$

$$\boxed{I_{rms} = \frac{I_m}{2}}$$

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

☆ <u>Ripple factor:</u>





→ ripple factor is amount of ac signal present in dc.

$$\gamma = \frac{\text{o/p rms current}}{\text{o/p dc component (current)}}$$

$$= \frac{I_{ac}}{I_{dc}}$$

$$\boxed{I_{rms}^2 = I_{dc}^2 + I_{ac}^2}$$

$$\boxed{I_{ac}^2 = I_{rms}^2 - I_{dc}^2}$$

$$\boxed{I_{ac} = \sqrt{I_{rms}^2 - I_{dc}^2}}$$

$$\gamma = \frac{I_{ac}}{I_{dc}} = \frac{\sqrt{I_{rms}^2 - I_{dc}^2}}{I_{dc}}$$

where, $I_{rms} = \frac{I_m}{2}$; $I_{dc} = \frac{I_m}{\pi}$

$I_{rms}^2 = \frac{I_m^2}{4}$; $I_{dc}^2 = \frac{I_m^2}{\pi^2}$

$$\gamma = \frac{\sqrt{\frac{I_m^2}{4} - \frac{I_m^2}{\pi^2}}}{I_m/\pi} = \frac{\sqrt{\frac{1}{4} - \frac{1}{\pi^2}}}{1/\pi}$$

$$\boxed{\gamma = 1.21}$$

→ rectification efficiency:

$$\eta = \frac{\text{output dc power delivered}}{\text{AC input power}} = \frac{P_{dc}}{P_{AC}}$$

$P_{dc} = I_{dc}^2 \cdot R_L$

$P_{ac} = I_{rms}^2 (R_F + R_L)$

R_F → forward resistance of diode

$$\eta = \frac{I_{dc}^2 \cdot R_L}{I_{rms}^2 \cdot (R_F + R_L)}$$

where $I_{dc} = \frac{I_m}{\pi}$; $I_{rms} = \frac{I_m}{2}$

$I_{dc}^2 = \frac{I_m^2}{\pi^2}$; $I_{rms} = \frac{I_m^2}{4}$

$$\eta = \frac{\frac{I_m^2}{\pi^2} \cdot R_L}{\frac{I_m^2}{4} \cdot (R_F + R_L)} = \frac{4}{\pi^2} \cdot \frac{R_L}{R_F + R_L}$$

$$\boxed{\eta = \frac{0.406 (R_L)}{R_F + R_L}}$$

If $R_F <<<< R_L$ then $R_F + R_L \approx R_L$

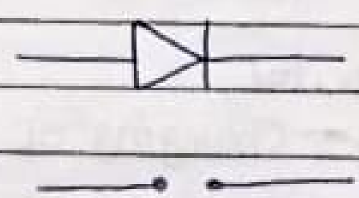
$$\eta = 0.406 \cdot \frac{R_L}{R_L} = 0.406$$

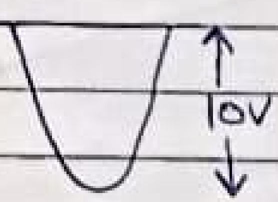
$$\boxed{\% \eta = 40.6 \%}$$

☆ <u>peak</u> <u>inverse</u> <u>voltage</u> (PIV) :

~~max~~ maximum voltage that appears across diode during the non-conducting condition.

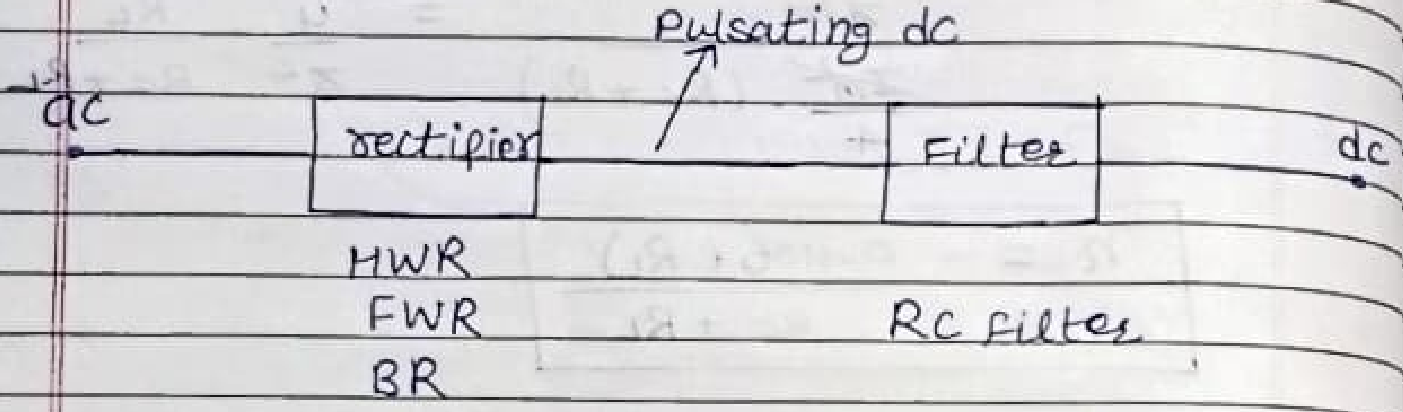
<u>R.B</u>



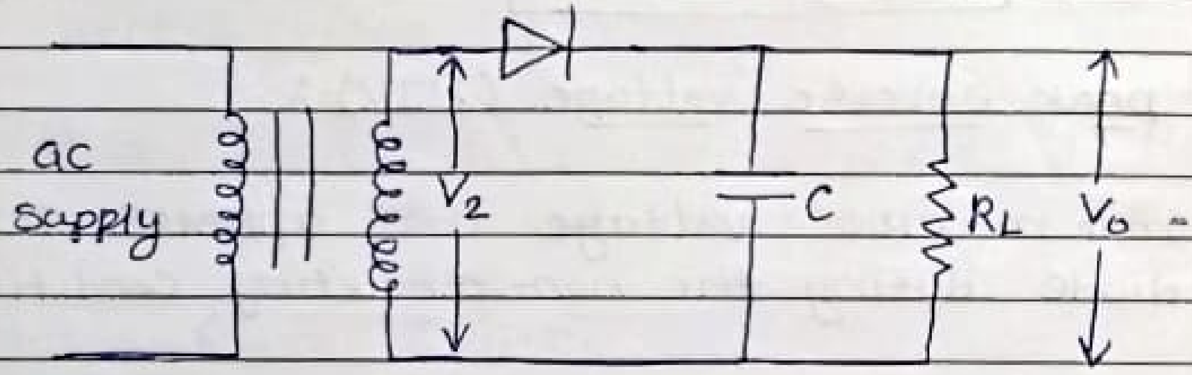


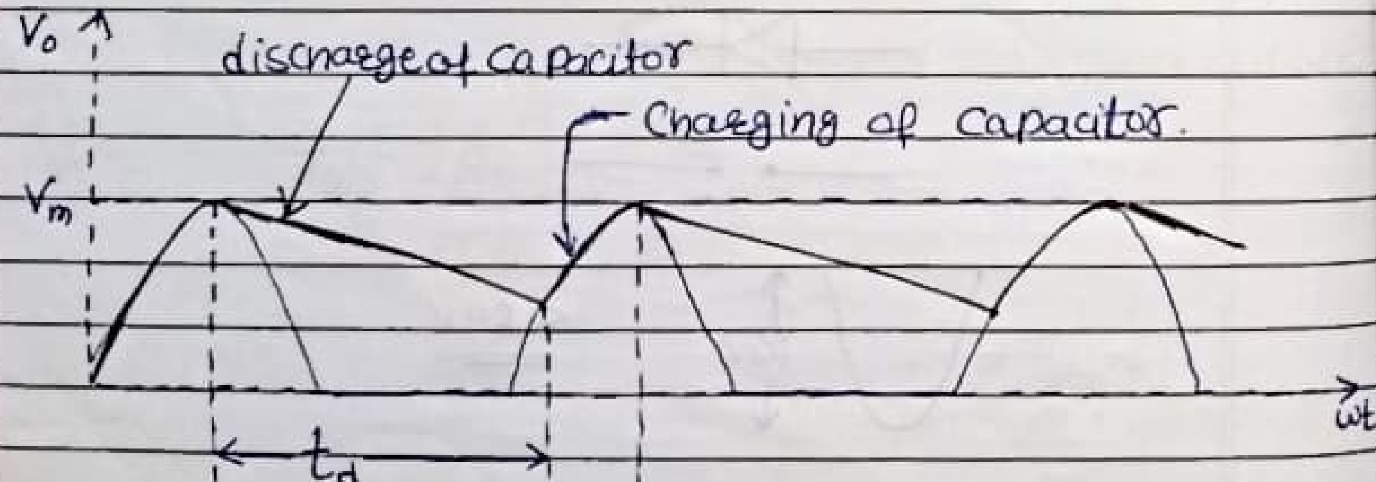
$\underline{\underline{< 10V}}$

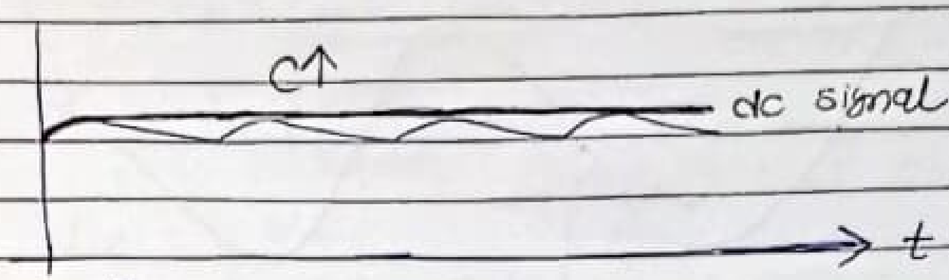
rectification:



★ RC Filter:



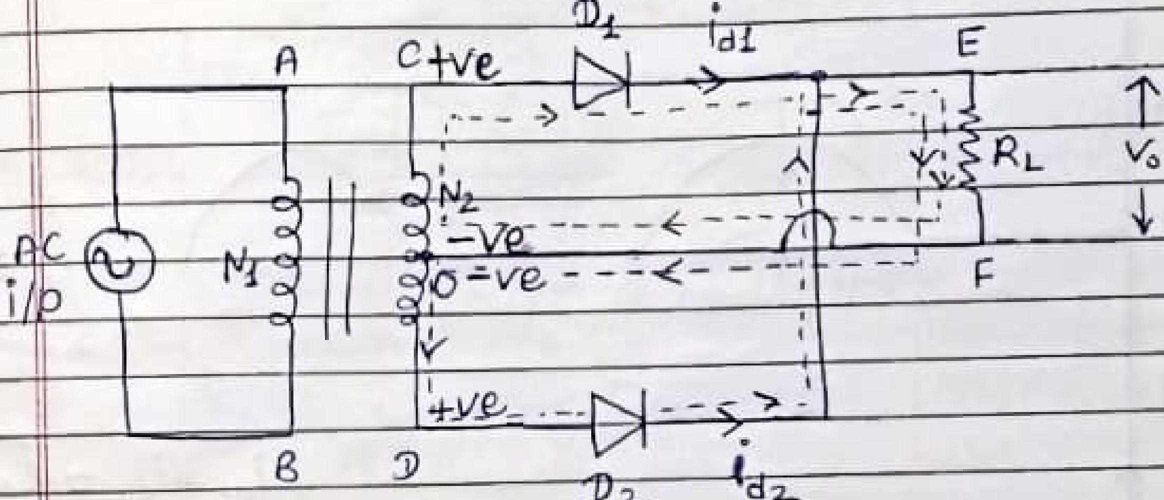


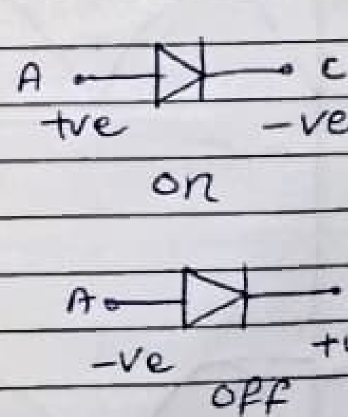


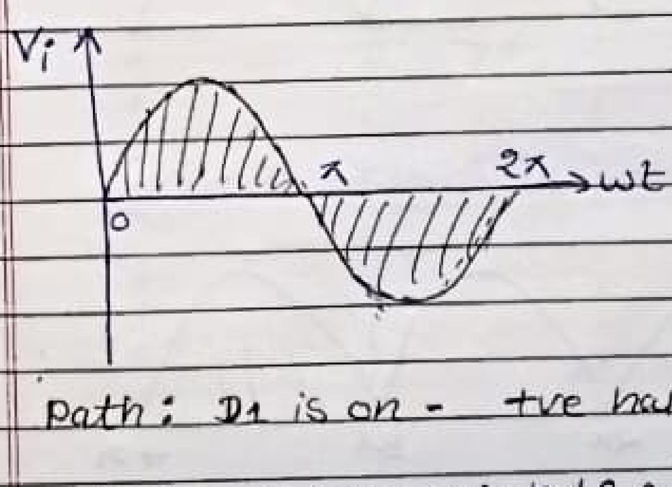
$$\gamma = \frac{V_{ac}}{V_{dc}} = \frac{1}{2\sqrt{3} f C R_L}$$

Full wave rectifier :-

1) center-tapped :

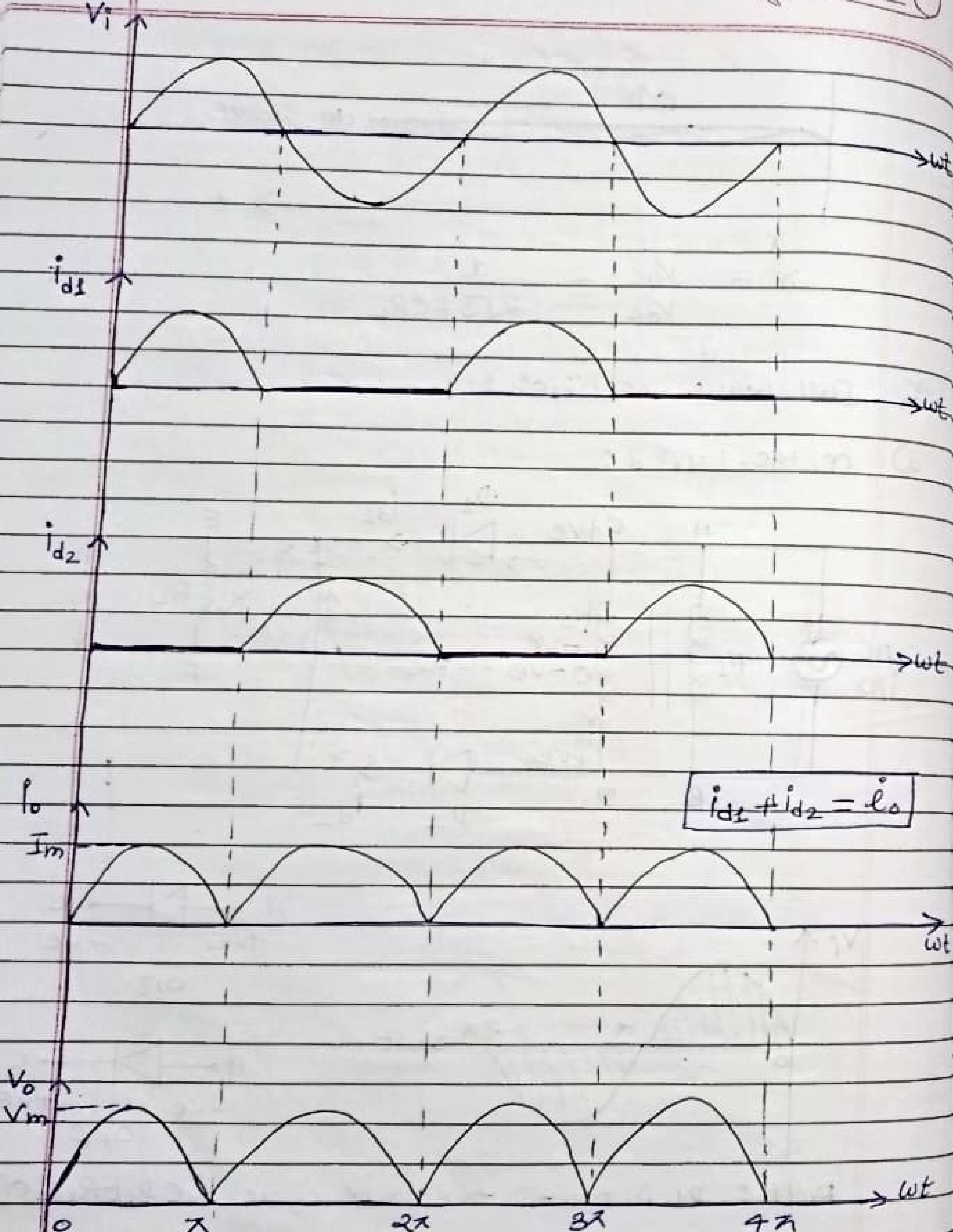






Path : D_1 is on - +ve half cycle ($C D_1 E R_L F O$)

Path : D_2 is on - -ve half cycle ($D D_2 E R_L F O$)



Vi
ωt
id1
ωt
id2
ωt
io
Im
id1 + id2 = io
ωt
Vo
Vm
ωt
0
π
2π
3π
4π

$V_i = V_m \sin wt = V_m \sin\theta$

$i_o = i_m \sin\theta$

$$I_m = \frac{V_m}{R_F + R_S + R_L}$$

R_L = Load Resistance
R_S = Secondary winding resistance
R_F = Forward diode resistance

Average current (I_{dc})

$$I_{dc} = \frac{\text{Area under the curve over the full cycle}}{\text{time period}}$$

$$= \frac{\int_0^{2\pi} i_o \, d\theta}{2\pi} = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin\theta \, d\theta$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} 2 I_m \sin\theta \, d\theta\right.$$

$$= \frac{1}{2\pi} \cdot 2 I_m (-\cos\theta)_0^{\pi} = \frac{I_m}{\pi}(1+1)$$

$$\boxed{I_{dc} = \cancel{2I_m}\ \frac{2 I_m}{\pi}}$$

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

$$\boxed{V_{dc} = \cancel{2I_m}\ \frac{2 I_m}{\pi} \cdot R_L}$$

RMS value of Current:

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_0^2 \, d\theta}$$

$$= \sqrt{\frac{1}{2\pi}\int_0^{2\pi} I_m^2 \sin^2\theta \, d\theta}$$

$$= \sqrt{\frac{I_m^2}{2\pi}\int_0^{2\pi} \left(\frac{1-\cos 2\theta}{2}\right) d\theta}$$

$$= \sqrt{\frac{I_m^2}{4\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^{2\pi}}$$

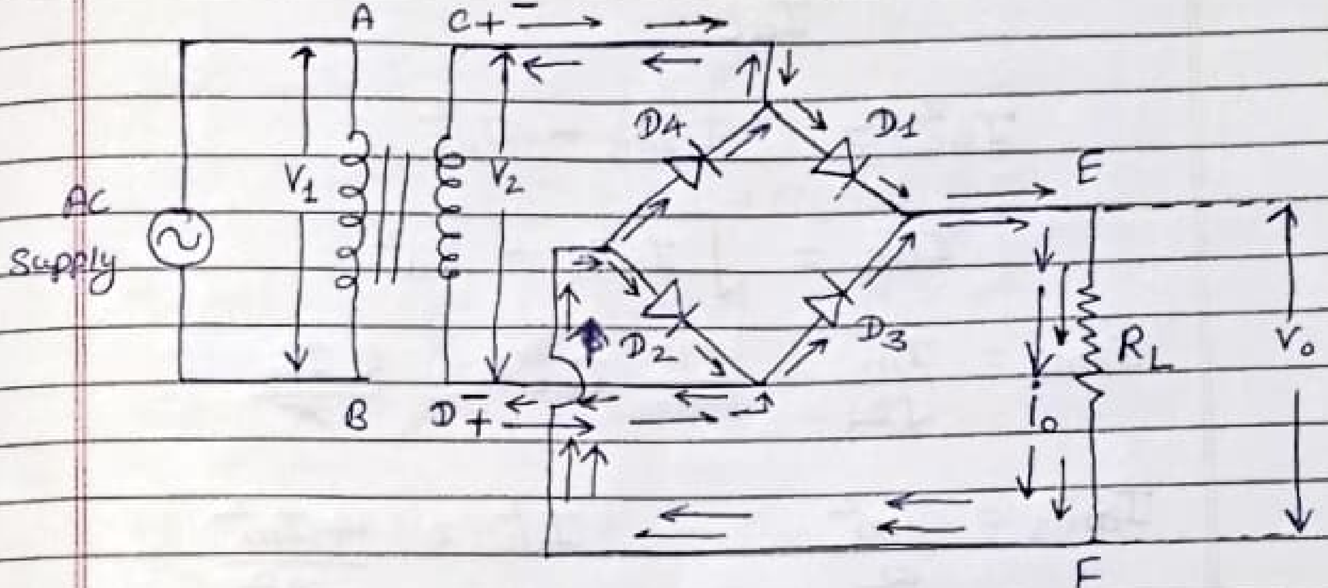
$$= \sqrt{\frac{I_m^2}{4\pi}(2\pi)} = \sqrt{\frac{I_m^2}{2}}$$

$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}}$$

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

$$\boxed{V_{rms} = \frac{I_m}{\sqrt{2}} \cdot R_L}$$

✱ Bridge wave Rectifier :



D1 is on = +ve half cycle [$C D_1 E R_L F D_2 D$]

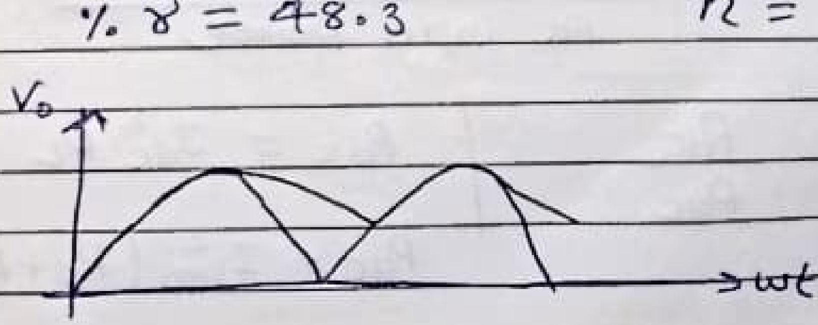
D3 is off = −ve half cycle [$D D_3 E R_L F D_4 C$]

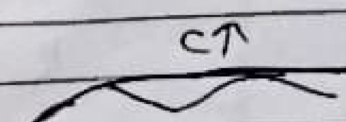
$$I_{dc} = \frac{2I_m}{\pi} \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$I_m = \frac{V_m}{R_F + R_L}$$

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

$$\% \gamma = 48.3 \qquad \eta = 81.2\%$$





$$\boxed{\frac{T}{2} = t_c + t_d}$$

Ripple factor:

$$\gamma = \frac{I_{ac}}{I_{dc}}$$

$$I_{ac}^2 = I_{rms}^2 - I_{dc}^2$$

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

$$I_{rms} = \frac{I_m}{\sqrt{2}} \qquad I_{dc} = \frac{2 I_m}{\pi}$$

$$I_{rms}^2 = \frac{I_m^2}{2} \qquad I_{dc}^2 = \frac{4 I_m^2}{\pi^2}$$

$$\gamma = \frac{\sqrt{\frac{I_m^2}{2} - \frac{4 I_m^2}{\pi^2}}}{2I_m/\pi} = \frac{\sqrt{\frac{1}{2} - \frac{4}{\pi^2}}}{2/\pi}$$

$$= \frac{\sqrt{0.5 - 0.405}}{0.6366}$$

$$\boxed{\% \gamma = 48.3 \%}$$

rectifier efficiency:

$$\eta = \frac{\text{DC power delivered to load}}{\text{AC input power}}$$

$$\eta = \frac{P_{dc}}{P_{ac}} \qquad P_{dc} = I_{dc}^2 R_L$$

$$P_{ac} = I_{rms}^2 (R_F + R_S + R_L)$$

$$\eta = \frac{P_{dc}}{P_{ac}} = \frac{I_{dc}^2 \cdot R_L}{I_{rms}^2 (R_F + R_S + R_L)}$$

$$= \frac{\left(\frac{4 I_m^2}{\pi^2}\right) \cdot R_L}{\frac{I_m^2}{2} (R_F + R_S + R_L)}$$

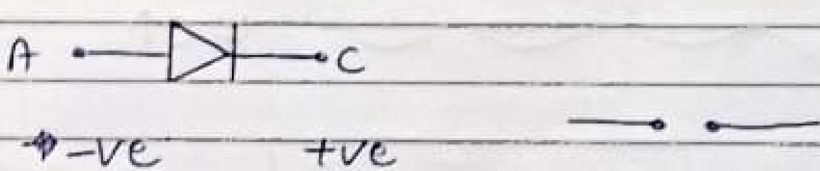
$$= \frac{8}{\pi^2} \cdot \frac{R_L}{R_F + R_S + R_L}$$

if $R_F + R_S <<< R_L$

~~to~~ then $R_F + R_S + R_L \approx R_L$

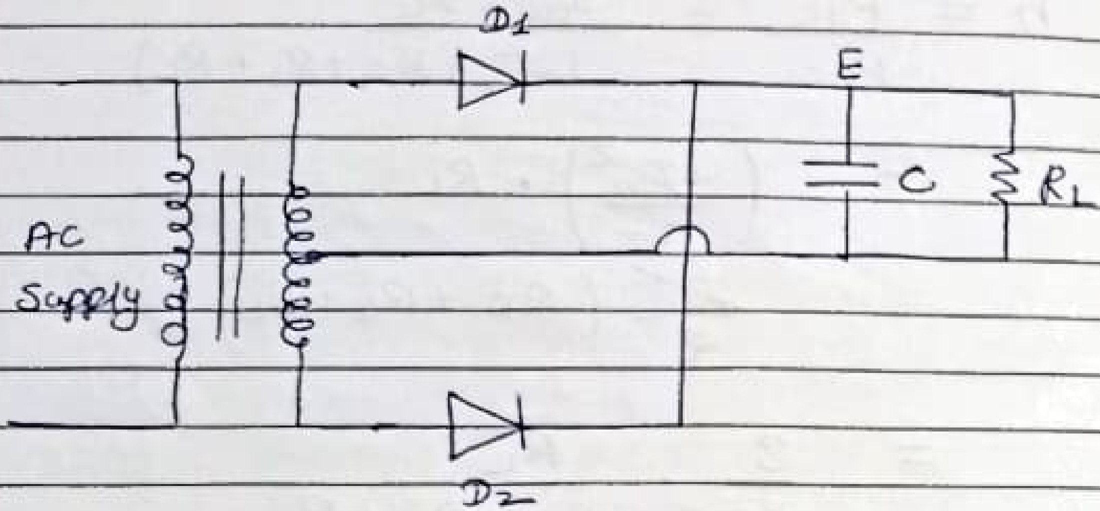
$$\eta = \frac{8}{\pi^2} \Rightarrow \boxed{\eta = 0.8105}$$

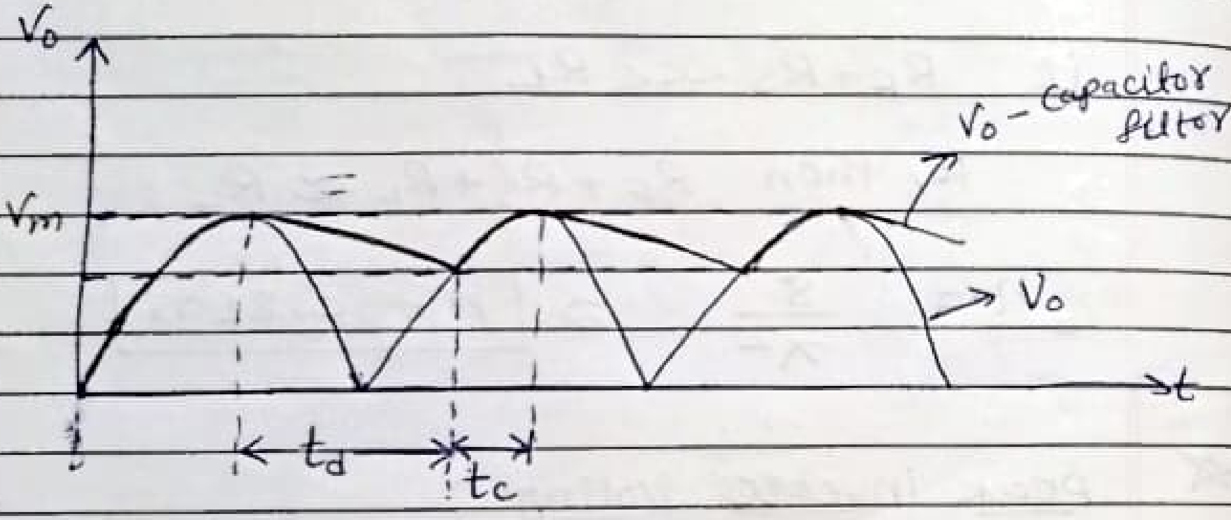
☆ peak inverse voltage:



$\boxed{PIV = 2V_m}$ FWR

Full wave rectifier with capacitor:





$$\boxed{\frac{T}{2} = T_c + T_d}$$

$$\gamma = \frac{1}{4\sqrt{3}\, f C \cdot R_L}$$