P-N JUNCTION DIODE & SPECIAL PURPOSE DIODES

★ **ACTIVE COMPONENTS :**

Components which supply energy in the circuit in the form of voltage or current, produce amplification & behave actively in the circuit.

→ Mostly behaviour is non-linear in nature.

→ External source is required for operation.

→ examples: transistor, operational amplifier, diodes, voltage sources etc.

★ **PASSIVE COMPONENTS :**

Components which consume energy in the circuit or store energy w/o producing any amplification.

→ examples: resistors, inductor, capacitor, potentiometer, switches etc.

★ **DRIFT CURRENT :**

When a voltage is applied to a semiconductor, the free e^- try to move in a straight line towards the positive terminal of the battery.

These free e^- collide with other atoms in the material along the way. Each time an e^- strikes an atom, it rebounds in a random direction but still the applied voltage makes the e^- drift towards the +ve terminal.

This current produced due to drifting of e^- is called drift current.

★ Drift current density for e^- : $\boxed{J_n = n_e q \mu_n E}$

★ Drift current density for hole : $\boxed{J_p = n_p q \mu_p E}$

& $\boxed{\mu_n = \frac{V_n}{E}}$

$v_n \rightarrow$ drift velocity of e^-

$E \rightarrow$ applied field intensity

$\mu_n \rightarrow$ mobility of e^- (in m^2/V-sec)

$q \rightarrow$ charge on $e^- = 1.6 \times 10^{-19}$ C

$n_e \rightarrow$ conc^n of e^-/m^3

DIFFUSION CURRENT:

piece of semiconductor → non-uniformly doped
One type of charge carriers occur at one end
Due to difference in concentration of charge carrier at the 2 ends
& due to repulsion b/w like charges, the charge carriers
move from region of high density to low density in turn
producing a current known as Diffusion Current.
The diffusion current continues till all the charge carriers
are evenly distributed throughout the material.

★ Diffusion Current Density: $\boxed{J_p = q D_p \frac{dp}{dx}}$

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

D_p & D_n are diffusion constants of holes & e^-
$\frac{dp}{dx}$ & $\frac{dn}{dx}$ are concentration gradients of holes & e^- respectively

★ **DIODE**: A two terminal electronic component that only conducts current in one direction (so long as it is operated within a specified voltage level).

INTRINSIC → pure semiconductor
EXTRINSIC → doped semiconductor

* p-type: HOLES (majority)
  Trivalent impurity

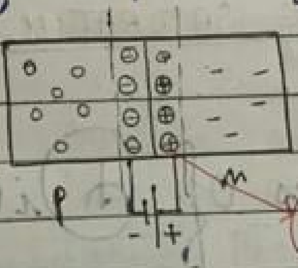
* n-type: ELECTRONS (majority)
  Pentavalent impurity

pn junction diode

In n-region, the holes diffusing from p-side recombine with free e^-. Due to additional positively charged holes, these atoms on n-side become +ve immobile ions just near the junction in n-region.

In p-region, the free e^- diffusing from n-side recombine with holes. Due to gain of e^-, these atoms become −ve immobile ions just near the junction in p-region.

As more holes diffuse to n-side, large immobile +ve charge accumulates near the junc^n on n-side. This +ve charge repels the holes & diffusion of holes from p-side stops.



Depletion region, depletion layer or space charge region

* Depletion region is depleted of mobile charge carriers.

★ Due to accumulation of positive & negative immobile ions at the junction, there exists a voltage across the depletion region known as barrier potential or junction potential.

0.7 V for Silicon   0.3 V for Germanium

★ BIASING: Applying external voltage to p-n junction diode

★ **FORWARD BIASING:** $\boxed{\text{+ve terminal}}$ of battery connected to $\boxed{\text{p-side}}$ & $\boxed{\text{−ve}}$ terminal to n-side.

→ Opposes potential barrier.

→ Width of depletion region ↓

→ Forward current is due to majority charge carriers.

* THRESHOLD VOLTAGE OR CUT-IN VOLTAGE: Voltage above which current flows in forward bias.

★ Reverse saturation current ↑ with ↑ in temperature. The rise is 7%/°C for both Germanium & silicon & approximately doubles for every 10°C rise in temperature.

★ REVERSE BIASING : $\boxed{+ve}$ of battery to $\boxed{n\text{-side}}$

$\boxed{-ve}$ of battery to $\boxed{p\text{-side}}$

→ supports potential barrier.

→ width of depletion layer increases.

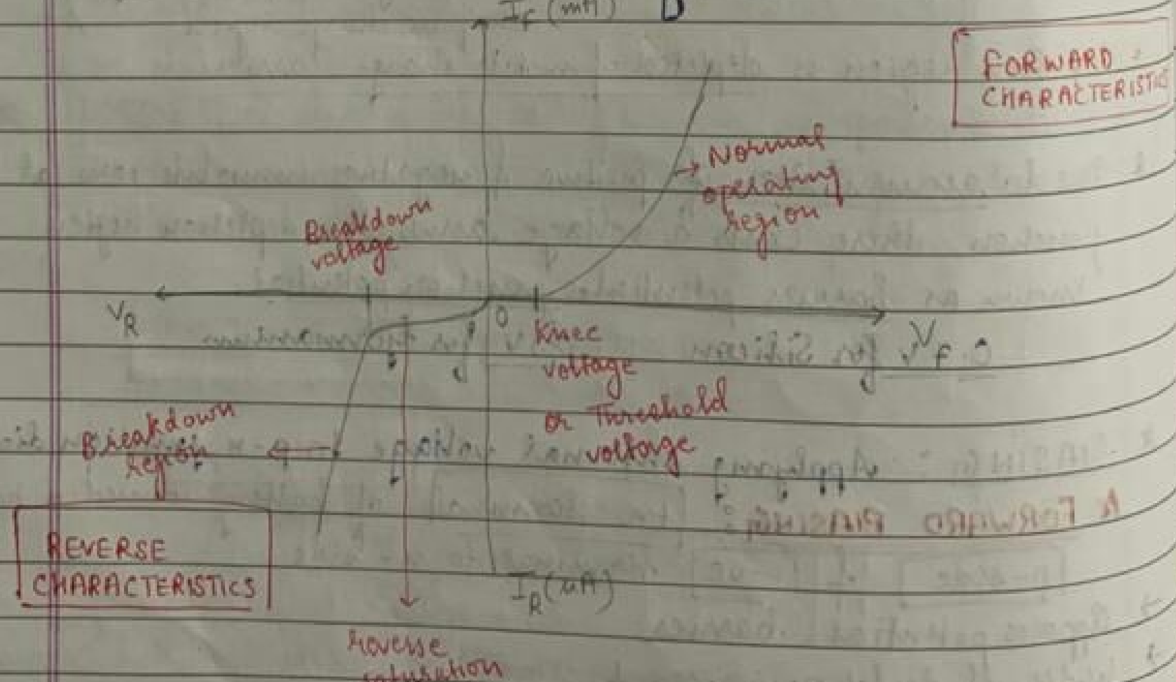
★ Due to increased barrier potential, free e^- on p-side are dragged towards +ve while holes on n-side are dragged towards negative of the battery.

This constitutes a current called <u>Reverse current</u> I_f flows due to ★ <u>minority charge carriers</u> & hence its magnitude is very small.

★ For constant temperature the reverse current is almost constant though applied reverse voltage is increased upto certain limit.

Hence it is called <u>REVERSE SATURATION CURRENT</u>.

★ V-I Characteristics of Diode



→ When forward voltage exceeds barrier potential, the current ↑ exponentially.

→ As the reverse voltage is ↑, reverse current ↑ initially but after a small voltage becomes constant, qual to reverse saturation current.

★ With ↑ in temperature, width of depletion layer ↓.

★ As temp is ↑, the forward current ↑ for a given value of forward voltage.

★ As temp. is ↑, the reverse current ↑.

★ Breakdown Voltage depends upon doping level.

AVALANCHE BREAKDOWN:

Minority charge carriers in the vicinity of depletion region get accelerated to very high kinetic energy & while moving keep colliding with other atoms, knocking out more charge carriers, hence multiplying the no of charge carriers

★ → On ↑ temperature, Breakdown Voltage ↑. ★{temp. coeff. is +ve}

Multiplication of charge carriers takes place due to collision with other atoms.

As temp ↑, atoms start vibrating, so due to ↓ in mean free path, e^- are not able to gain sufficient K.E & require more external voltage.

ZENER BREAKDOWN:

HEAVY DOPING → width of depletion region is less

↓

Depletion region will have more no of immobile ions.

Due to this strong electric field, many charge carriers are generated which are capable of crossing the junction & hence a heavy current flows in reverse direction.

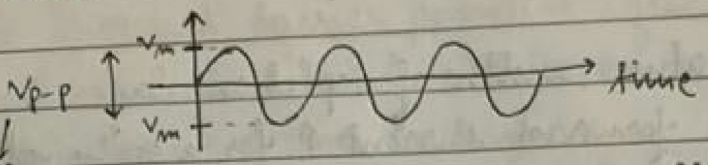
→ On ↑ temperature, breakdown voltage ↓.

★{Temperature coefficient is -ve}

Date

DIODE AS RECTIFIER

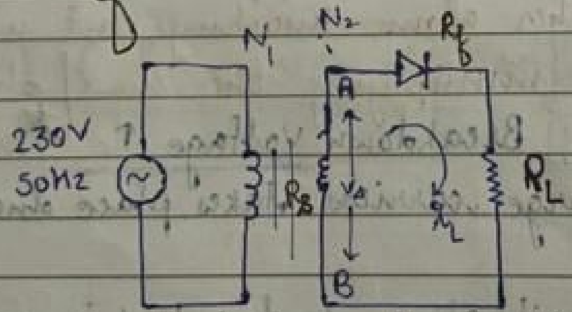
A rectifier is a device which converts a.c. voltage to pulsating d.c. voltage, using one or more p-n junction diodes.



$V_m \rightarrow$ maximum voltage or $V_p \rightarrow$ peak voltage

PULSATING DC

★ Half Wave Rectifier



A sinusoidal a.c voltage, having frequency of 50 Hz is applied to the rectifier circuit using suitable step-down transformer, with necessary turns ratio.

Secondary voltage, $\boxed{V_s = V_{sm} \sin \omega t}$

$V_{sm} \rightarrow$ max. secondary voltage

★ Turns ratio : $\boxed{\dfrac{N_2}{N_1} = \dfrac{V_{sm}}{V_{pm}} = \dfrac{V_{s(rms)}}{V_{p(rms)}}}$

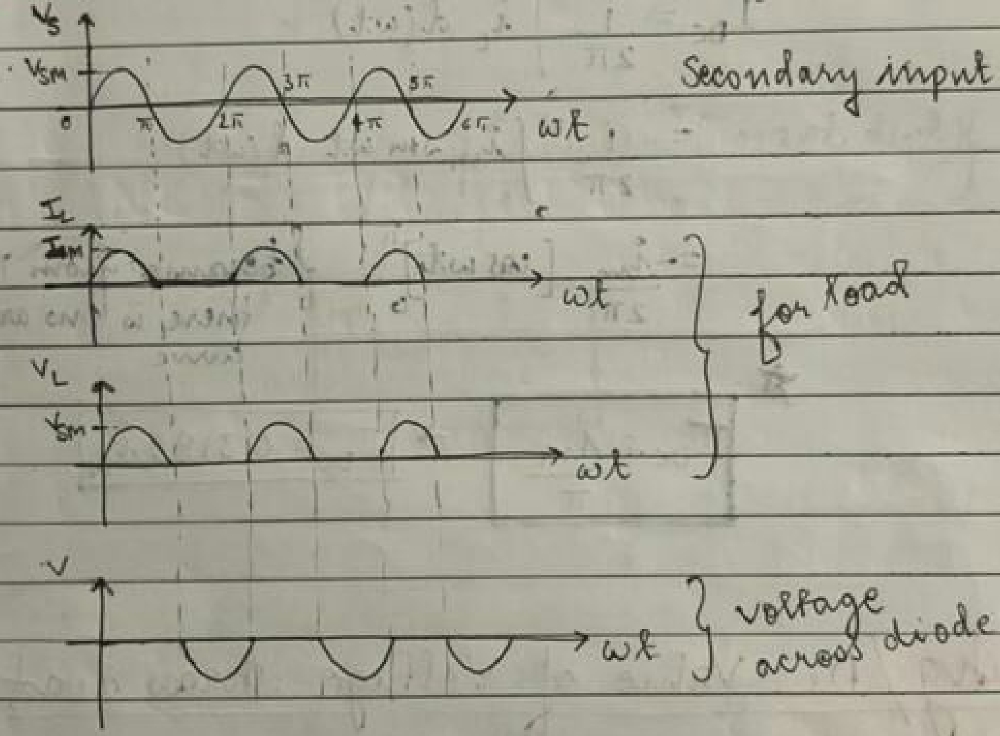
★ $\boxed{V_{s(rms)} = \dfrac{V_{sm}}{\sqrt{2}}}$

⟨2⟩

During +ve half cycle of input a.c. voltage, terminal (A) becomes +ve with respect to terminal (B). The diode is forward biased & current flows in the circuit in clockwise direction.

During -ve half cycle, terminal (A) is -ve with respect to terminal (B) & diode becomes reverse biased so no current flows through the circuit.

Thus, the load current is in the form of half sinusoidal pulses.



$$\boxed{i_L = i_M \sin \omega t}$$

$$\boxed{i_M = \frac{V_{SM}}{R_S + R_f + R_L}}$$

$R_S \rightarrow$ resistance of secondary winding of ~~diode~~ transformer
$R_f \rightarrow$ forward resistance of diode

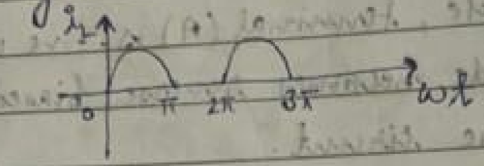
(i) PIV → Peak Inverse Voltage

Peak voltage that appears across diode in reverse biased condition.
The max. voltage that a diode can withstand in reverse condition w/o breaking down.

Here, $\boxed{PIV = V_{SM}}$

(ii) Avg Value / D.C value of current through load (I_{DC})

Avg. value = Area under curve / time period



Time period : 2π

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

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

$$= -\frac{i_m}{2\pi}\left[\cos \omega t\right]_0^{\pi}$$ {because from π to 2π there is no area under curve}

★ $\boxed{I_{DC} = \frac{i_m}{\pi}}$ → $\boxed{I_{DC} = 0.3185\, i_m}$

(iii) Avg / DC Value of Voltage Across Load

$$V_{DC} = I_{DC} \times R_L$$

$$= \frac{i_m}{\pi} \times R_L$$

$$= \frac{V_{sm}}{(R_s + R_f + R_L)\pi} \times R_L$$

$R_f + R_s \rightarrow$ very small

★ $\boxed{V_{DC} = \frac{V_{sm}}{\pi}}$

(vi) DC Power

Power available across load resistance

$$P_{DC} = V_{DC} \times I_{DC}$$

★ $$\boxed{P_{DC} = I_{DC}^2 \times R_L}$$

$$\boxed{P_{DC} = \left(\frac{I_m}{\pi}\right)^2 \times R_L}$$

(vii) AC Power

AC Power Input

★ $$\boxed{P_{AC} = I_{rms}^2 \times (R_s + R_f + R_L)}$$

(viii) Efficiency (η)

$$\eta = \frac{\text{output}}{\text{input}} = \frac{P_{DC}}{P_{AC}} = \frac{i_m^2/\pi^2 \times R_L}{i_m^2/4 \times (R_s + R_f + R_L)}$$

★ $R_s + R_f \rightarrow$ very small

$$\rightarrow \boxed{\eta = \frac{4}{\pi^2} \approx 0.406 = 40.6\%}$$

(ix) Ripple Factor (γ)

(IX)

★ Lesser the ripple factor, closer the output would be to DC

★ I_{rms} = RMS value of total output current

I_{DC} = DC component present in output

I_{AC} = RMS value of AC component present in output

Ripple factor $\boxed{\gamma = \dfrac{\text{RMS value of AC component of output}}{\text{Average / DC component of output}}}$

★ $$\boxed{I_{rms} = \sqrt{(I_{AC})^2 + (I_{DC})^2}}$$

$$\rightarrow \gamma = \frac{\sqrt{(I_{rms})^2 - (I_{DC})^2}}{I_{DC}} = \sqrt{\left(\frac{I_{rms}}{I_{DC}}\right)^2 - 1}$$

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

★ $$\boxed{\gamma = 1.21 \text{ or } 121\%}$$

(X) Transformer Utilisation Factor

★ $\boxed{TUF = \dfrac{\text{DC Power delivered to load}}{\text{AC Power rating of transformer}}}$

★ $$= \frac{I_{DC}^2 \times R_L}{V_{rms} \times I_{rms}} = \frac{I_{DC}^2 \times R_L}{\frac{V_{sm}}{\sqrt{2}} \times \frac{i_m}{2}}$$

★ $$\boxed{TUF = 0.287 \text{ or } 28.7\%}$$

(xi) Voltage Regulation

It is the change in DC output voltage as the load changes from zero to maximum

$$\% \text{ Voltage Regulation} = \frac{(V_{DC})_{no\ load} - (V_{DC})_{full\ load}}{(V_{DC})_{full\ load}} \times 100$$

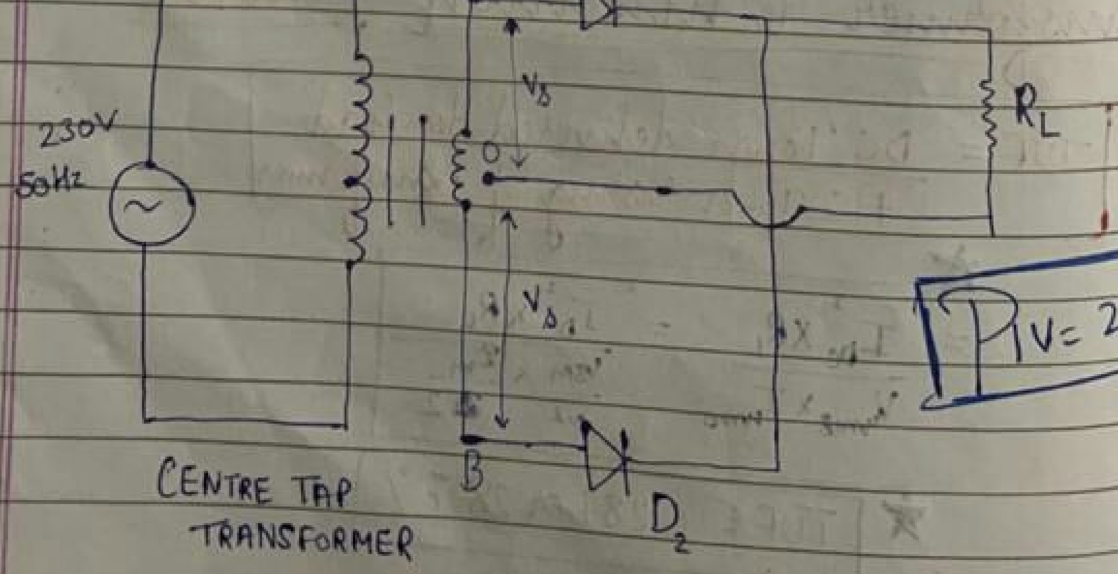
$$(V_{DC})_{NL} = \frac{V_{Sm}}{\pi} \qquad (V_{DC})_{FL} = \frac{I_m}{\pi} \times R_L$$

$$= \frac{V_{Sm} \times R_L}{\pi(R_s + R_f + R_L)}$$

★ $$\boxed{\% \text{ Voltage regulation} = \frac{R_s + R_f}{R_L} \times 100}$$

★ Full Wave Rectifier

① CENTRE TAPPED



$$\boxed{PIV = 2V_{SM}}$$

A sinusoidal a.c voltage is applied to the circuit through a step down transformer with suitable turns ratio

★ Due to center tapping the voltage gets divided into half

After stepping down, the voltage is $2V_s$ which gets divided into 'V_s' & 'V_s' due to center tapping.

$$\boxed{V_s = V_{SM} \sin \omega t}$$

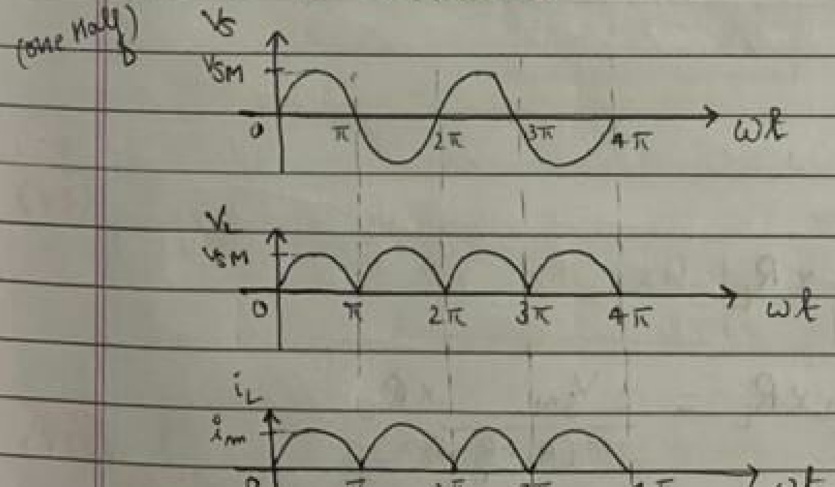
In the +ve half cycle of ac input voltage, terminal (A) is +ve & terminal (B) is -ve due to center tap transformer.

★ The diode D_1 will be forward biased & will act as closed switch; while diode D_2 will be reverse biased & will act as open switch.

In the -ve half cycle of ac input voltage, polarity is reversed A becomes -ve while B becomes +ve. $D_2 \rightarrow$ forward biased

$D_1 \rightarrow$ reverse biased

★ Load current flows in both half cycles of ac voltage & in the same direction.



$R_s \rightarrow$ resistance of half of secondary winding of transformer

★ $$\boxed{i_m = \frac{V_{SM}}{R_s + R_f + R_L}}$$

(i) PIV :

in first cycle, D_2 is reverse biased.
$\therefore V_{SM}$ across D_2 is PIV.

→ in second cycle or −ve half cycle of a.c. input voltage, D_1 is reverse biased.
$\therefore V_{SM}$ across D_1 is PIV.

(ii) I_{avg} or I_{DC} :

$$i_L = i_m \sin\omega t$$

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

$$= \frac{i_m}{\pi}\int_0^{\pi} \sin\omega t \cdot d(\omega t)$$

$$= \frac{-i_m}{\pi}\left[\cos\omega t\right]_0^{\pi}$$

★ $$\boxed{I_{avg} = \frac{2 i_m}{\pi} = 0.637\, i_m}$$

(iii) V_{avg} or V_{DC} :

$$V_{avg} = I_{avg} \times R_L$$

$$= \frac{2 i_m}{\pi} \times R_L = \frac{2 V_{SM}}{\pi (R_S + R_f + R_L)} \times R_L$$

★ $$\boxed{V_{avg} = \frac{2 V_{SM}}{\pi}}$$

⟨iv⟩ I_{rms}

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

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

$$= \sqrt{\frac{i_m^2}{2\pi}\int_0^{\pi}(1-\cos 2\omega t)\, d(\omega t)}$$

★ $$\boxed{I_{rms} = \frac{i_m}{\sqrt{2}}}$$

⟨v⟩ V_{rms}

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

$$= \frac{i_m}{\sqrt{2}} \times R_L = \frac{V_{sm}}{\sqrt{2}(R_s + R_f + R_L)} \times R_L$$

★ $$\boxed{V_{rms} = \frac{V_{sm}}{\sqrt{2}}}$$

⟨vi⟩ P_{DC}

★ $$\boxed{P_{DC} = I_{DC}^2 \times R_L}$$

⟨vii⟩ P_{AC}

★ $$\boxed{P_{AC} = I_{rms}^2 \times (R_s + R_f + R_L)}$$

(viii) Efficiency (η):

$$\eta = \frac{P_{DC}}{P_{AC}} = \frac{\left(\frac{2 i_m}{\pi}\right)^2 \times R_L}{\left(\frac{i_m}{\sqrt{2}}\right)^2 \times (R_S + R_f + R_L)}$$

$$= \frac{8}{\pi^2} \approx 0.81205$$

★ $\rightarrow \boxed{\eta \approx 81.205\%}$

(ix) Ripple Factor (γ):

$$\gamma = \frac{\text{RMS value of AC component of output}}{\text{DC component of output}}$$

$$\gamma = \frac{\sqrt{(I_{rms})^2 - (I_{DC})^2}}{I_{DC}}$$

$$\boxed{\gamma = 48.3\% \text{ or } 0.483}$$

(x) ★ Transformer Utilisation Factor:

$$TUF_{(HWR)} = 0.287$$

★ In full wave rectifier, the primary winding is supplying power to 2 half wave rectifiers

$\therefore$ For full wave rectifier $\quad TUF_{(Primary)} = 2 \times 0.287 = 0.574$

$$TUF_{(secondary)} = \frac{\text{DC Power given to load}}{\text{AC Power rating of Transformer}}$$

$$= \frac{i_{DC}^2 \times R_L}{\frac{V_{SM}}{\sqrt{2}} \times \frac{i_m}{\sqrt{2}}}$$

$= \frac{8}{\pi^2} = 0.8105$

$$\boxed{TUF_{rectifier} = \frac{TUF_{Primary} + TUF_{secondary}}{2}}$$

$$\boxed{TUF_{rectifier} = 0.693 \text{ or } 69.3\%}$$

(xi) Voltage Regulation:

Change in DC output voltage as load changes from zero to maximum.

$$\%\text{ Voltage Regulation} = \frac{(V_{DC})_{no\ load} - (V_{DC})_{full\ load}}{(V_{DC})_{full\ load}} \times 100$$

$$(V_{DC})_{no\ load} = \frac{2V_{SM}}{\pi} \qquad (V_{DC})_{full\ load} = \frac{2V_{SM} \times R_L}{\pi(R_s + R_f + R_L)}$$

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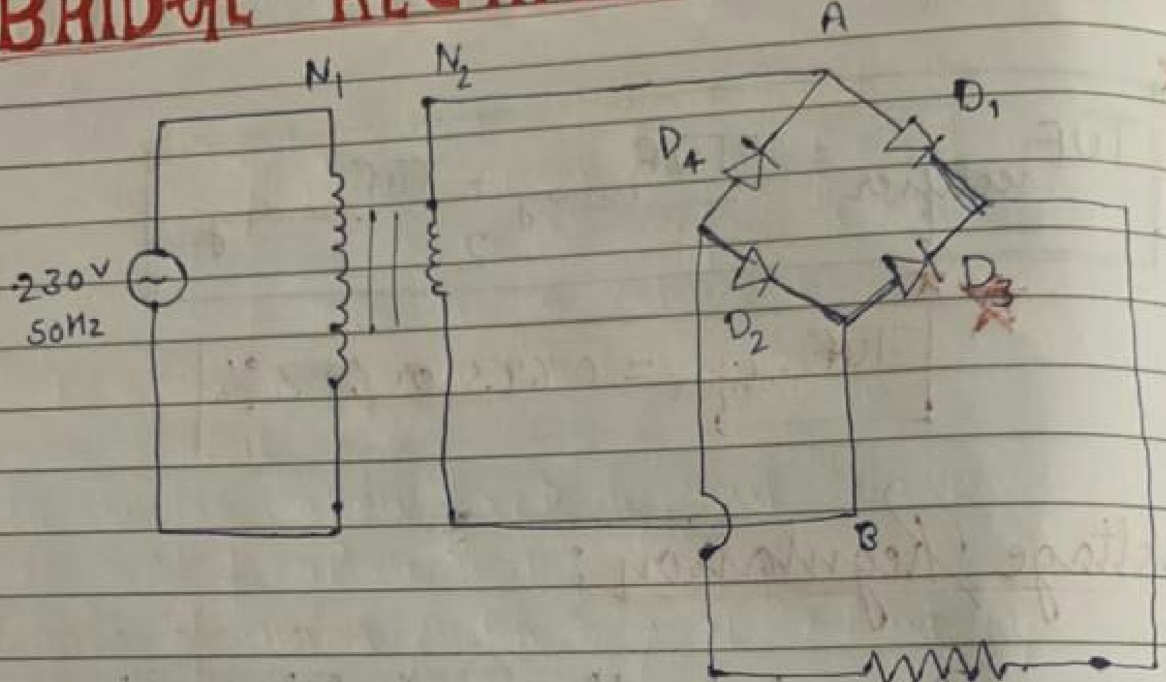
② BRIDGE RECTIFIER



★ For Bridge Rectifier, in each half cycle, 2 diodes conduct
R_f is replaced by $2R_f$.

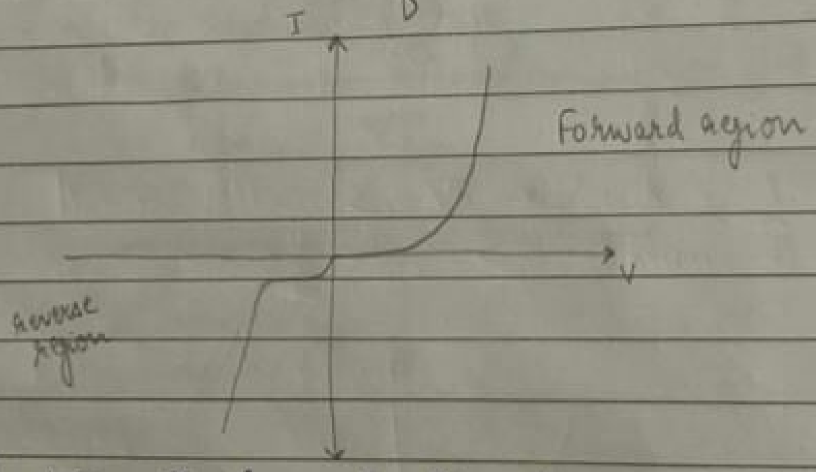
★ $$\boxed{i_m = \frac{V_{SM}}{R_s + 2R_f + R_L}}$$

$$\boxed{PIV = V_{SM}}$$

Light Emitting Diode

When the p-n junction is forward biased, the e^- & holes recombine & release energy in the form of light.
The free e^- lie in the conduction band
& holes lie in valence band.
In normal pn junction diode, this energy is released in the form of heat.
In the fabrication of LED, different semiconductor compounds like GaAs & GaP are used.
★ Energy of emitted photon is equal to band gap

V-I characteristics of LED



★ For LED, the forward voltage drop is larger than the p-n junction diode (1.8V to 3.5V)
w/o any resistor connected in series to the LED, it may get damaged due to the high current flowing through it

Longer leg → cathode → cup type structure

★ The graph of light output v/s wavelength is called Spectral response of LED.

(iv) I_{rms}

$$I_{rms} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi} i_L^2 \cdot d(\omega t)}$$

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

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

$$= \sqrt{\frac{i_m^2}{2\pi}\int_0^{\pi} \left(\frac{1-\cos 2\omega t}{2}\right) d(\omega t)}$$

$$= \frac{i_m}{2}\sqrt{\frac{1}{\pi}\left\{\int_0^{\pi} d(\omega t) - \int_0^{\pi} \cos 2\omega t \, d(\omega t)\right\}}$$

★ $$\boxed{I_{rms} = \frac{i_m}{2}}$$

(v) V_{rms}

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

$$= \frac{i_m}{2} \times R_L = \frac{V_{sm}}{(R_s + R_f + R_L) \times 2} \times R_L$$

★ $$\rightarrow \boxed{V_{rms} = \frac{V_{sm}}{2}}$$

Photodiode :

Photodiode is used in reverse bias mode → Reverse saturation current flows due to minority carriers → also known as $\boxed{\text{DARK CURRENT}}$

Whenever light of sufficient energy falls on photodiode, it can knock off the bound e^- of atoms in the depletion region.

Due to this, additional e^- hole pairs are created in the depletion region. Some of the pairs recombine with each other but the remaining can contribute in the flow of current.

In addition to small reverse current, photocurrent is also generated.

★ As the $\boxed{\text{intensity of light} \uparrow}$, $\boxed{\text{photocurrent also} \uparrow}$

★ Dark current should be as minimum as possible because this dark current will act as noise for generated photo current.

To generate photo current, the energy of incident photon should be sufficient enough.

For silicon → energy > 1.1 eV {greater than the band gap energy so that this incident light can generate e^- hole pairs}

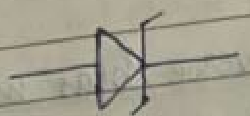
$$\text{Responsivity}(R) = \frac{I_p}{P}$$ unit : Ampere per watt

I_p → photocurrent
P → Incident light power

★ Reverse current is directly prop. to the intensity of light & is not dependent on reverse voltage.

★ Dark current flows even when no photons are entering the device.

ZENER DIODE



Zener Diode operates in reverse breakdown region

Zener Diodes are fabricated with precise breakdown voltage by controlling the doping level during manufacturing

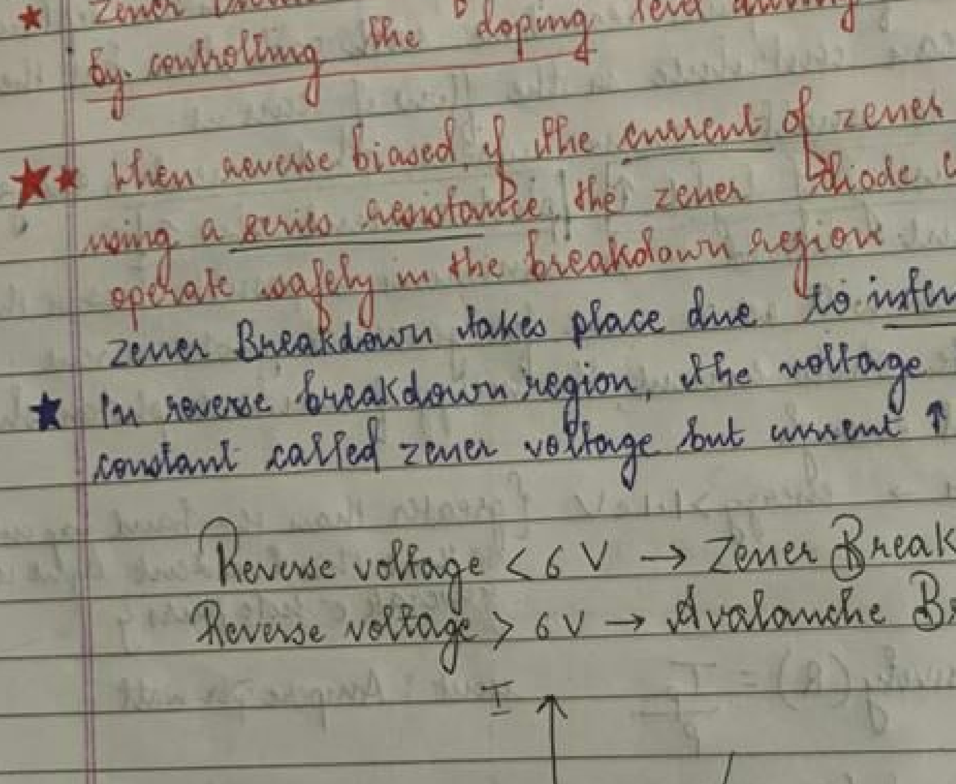
When reverse biased, if the current of zener diode is limited using a series resistance, the zener Diode continues to operate safely in the breakdown region

Zener Breakdown takes place due to intense electric field.

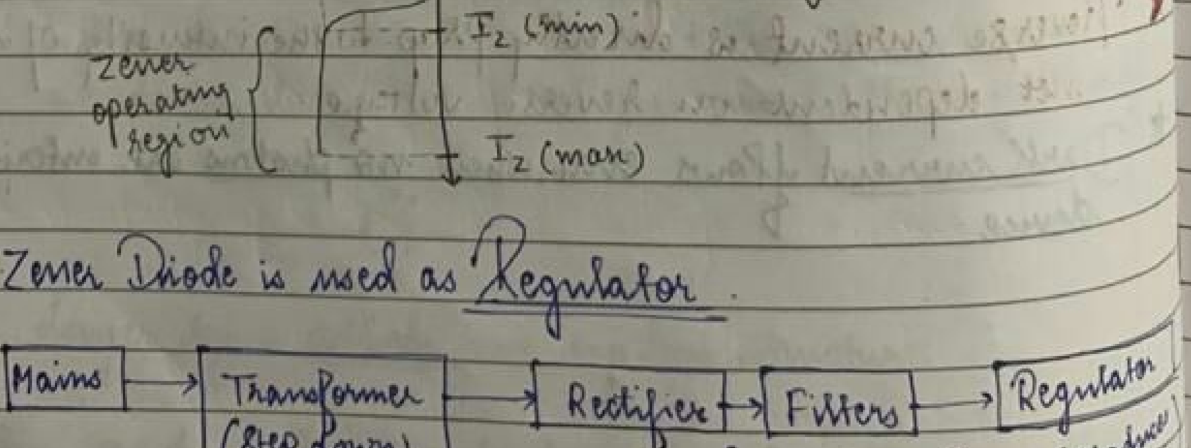
In reverse breakdown region, the voltage across it remains constant called zener voltage but current ↑ upto certain limit

Reverse voltage $< 6\,V$ → Zener Breakdown occurs

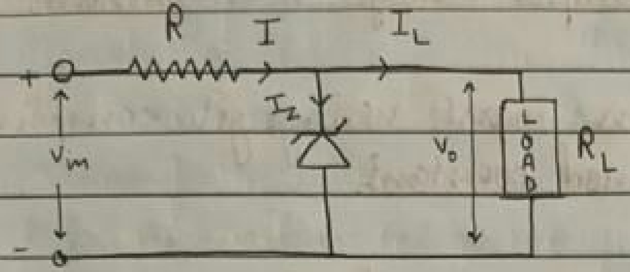
Reverse voltage $> 6\,V$ → Avalanche Breakdown



Zener Diode is used as Regulator.



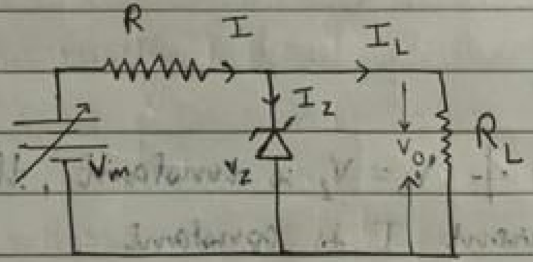
★ A voltage regulator circuit is designed to keep the output voltage of a power supply nearly constant under varying input voltage conditions & ~~output~~ varying load conditions



★ As long as the current through zener diode is between $I_{z\,min}$ & $I_{z\,max}$, the voltage across it is constant & equal to zener voltage.

★ As zener diode is connected in shunt with the load resistance the output voltage is equal to the zener voltage.

(i) Regulation with varying input voltage



$\boxed{V_0 = V_Z}$ $\boxed{I = I_Z + I_L}$

$$I = \frac{V_{in} - V_Z}{R}$$

Load current, $I_L = \frac{V_0}{R_L} = \frac{V_Z}{R_L}$

$\because$ V_Z & R_L (load resistance) are constant, I_L is also constant

if $V_{in} \uparrow$, then $I \uparrow$.

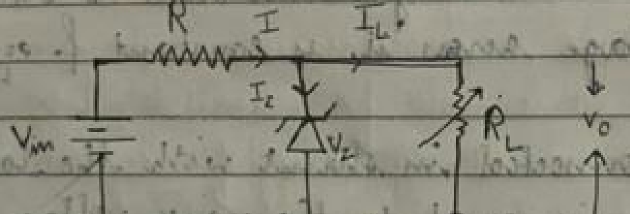
But I_L is constant $\therefore I_Z \uparrow$ to keep I_L constant

Similarly if $V_{in} \downarrow$ then $I_Z \downarrow$ to keep I_L constant

★ But in both cases, as long as I_Z is between $I_{Z\,min}$ & $I_{Z\,max}$, V_Z, i.e., output voltage, V_0 is constant.

Thus the changes in input voltage get compensated & output is maintained constant.

(ii) Regulation with varying load



The input voltage is constant while load resistance, R_L is variable

$$I = \frac{V_{in} - V_Z}{R}$$

As V_{in} is constant & $V_0 = V_Z$ is constant, then for constant R, the current I is constant

★ If R_L decreases $I_L \uparrow$ & to keep I constant, $I_Z \downarrow$

★ But as long as it is between $I_{Z\,min}$ & $I_{Z\,max}$ output voltage V_0 will be constant.

★ Similarly, if $R_L \uparrow$, $I_L \downarrow$ & to keep I constant, $I_Z \uparrow$ (less than $I_{Z\,max}$)

Thus, the changes in the load get compensated & output is maintained constant.