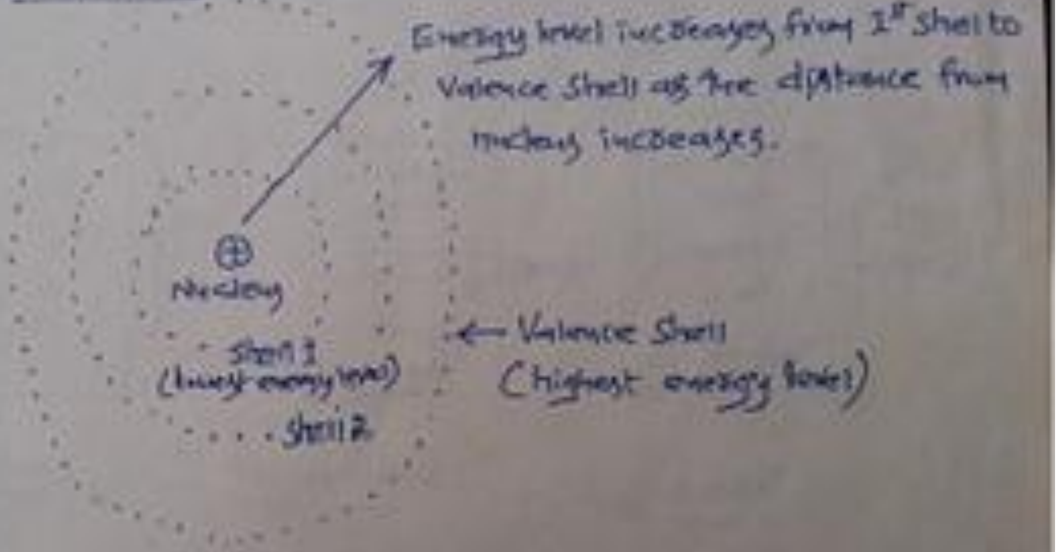
G.PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY, KURNOOL
(AUTONOMOUS)

Subject: BASIC ELECTRICAL & ELECTRONICS ENGINEERING
Subject Code: A30203_Part B : ELECTRONICS ENGINEERING
Branch: CSE
UNIT :1 INTRODUCTION TO SEMICONDUCTOR DEVICES

PN JUNCTION DIODE & ITS APPLICATIONS

Review of Semiconductor physics:-

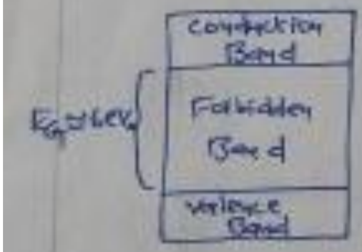
Structure of an atom:



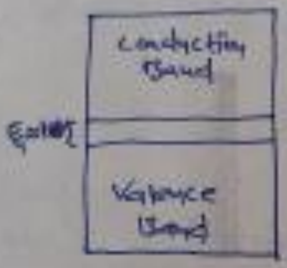
- The outermost shell is called Valence Shell and the electrons in this shell are called valence electrons.
- An electron which is not subjected to the force of attracti of the nucleus is called a 'free electron' such free electro are basically responsible to the flow of current.
- Sharing of valence electrons with other adjacent atoms is called 'covalent Bond'.
- Energy levels of various electrons present in 1st orbit, 2nd orbit, merge to form various "energy levels".

Energy Band Theory:-

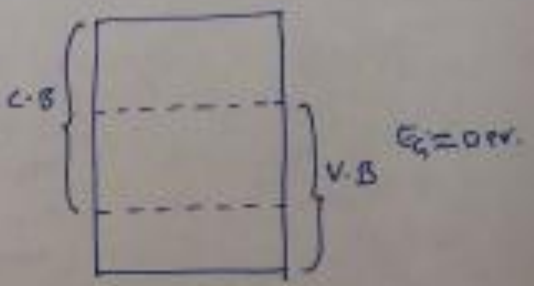
- The Energy band formed due to merging of Energy levels associated with Valence electrons i.e; electrons in the last shell is called "Valence band."
- The Energy band formed due to merging of energy levels associated with the free electrons is called "Conduction Band".
- The Energy gap which is present separating the conduction band and the Valence band is called "Forbidden band (or) Forbidden gap".



Insulator



Semiconductor



Conductor

Insulator	Semiconductor	Conductor
- Very poor conductor of electricity is called Insulator	- A substance whose conductivity lies in between Insulator & conductor is called a Semiconductor	- A very good conductor of electricity is called conductor
Ex:- Diamond carbon	Ex:- Graphite	Ex:- Metal

practical Semiconductors are:- Silicon & Germanium; GaAs

These are Insulators at low temperature.

At 0K ; E_g for Silicon is $E_g = 1.21eV$

for Germanium is $E_g = 0.785eV$

At 300K ; for Silicon $E_g = 1.1eV$

for Germanium $E_g = 0.72eV.$

Structure of Semiconductor Materials:-

Germanium atom   Silicon atom

- The process of loosing or gaining an electron, which converts electrically neutral atom to a charged ion is called "ionization".

Silicon is most widely used because:

1) Valence shell of silicon is 3rd shell, while Germanium is 4th shell.
2) Valence electrons of Germanium are ~~at~~ larger distance from nucleus and are loosely bound to the nucleus and can easily escape from the atom due to very small additional energy imparted to them. So at higher temperatures Ge atoms becomes unstable than silicon which can withstand at higher temperatures and is more stable.

Intrinsic Semiconductors

- The purest form of semiconductor is called an intrinsic semiconductor. The impurity content is very very small of the order of one part in 100 million parts of semiconductor.
- Intrinsic semiconductor behaves as a perfect insulator at absolute zero temperature.

- The concentration of free electrons and holes is always equal in an intrinsic semiconductor.

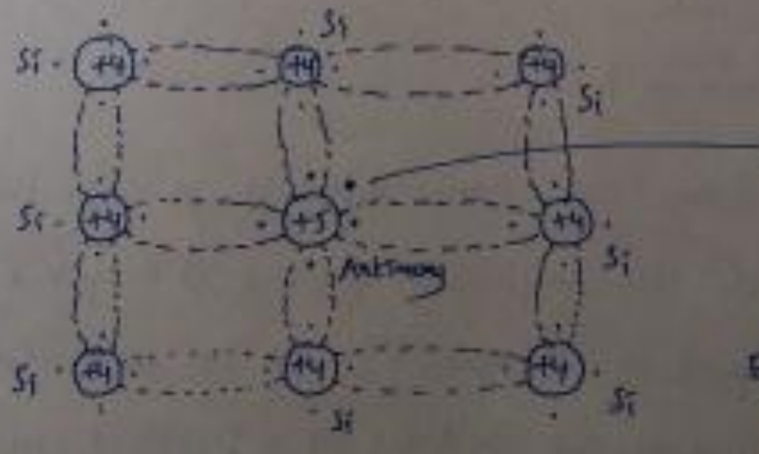
$$n = p = n_i \text{ (intrinsic concentration) } \text{number}/m^3 \text{ (or) } \text{number}/cm^3$$

Extrinsic Semiconductors:

- To a pure silicon, a small amount of impurity is added then it converts to Extrinsic semiconductor.
- Two types of impurities added are P-type and N-type.

N-type:

An atom with 5 valence electrons is called N-type impurity atom. All pentavalent impurities are Arsenic, Antimony, Bismuth, phosphorus. These atoms when doped with silicon atom four valence electrons occupy covalent bonds and the fifth will be nominally unbound and will be available as a carrier of current. These impurities donate excess negative electron carriers, and are therefore called as "donor" or "N-type" impurities.

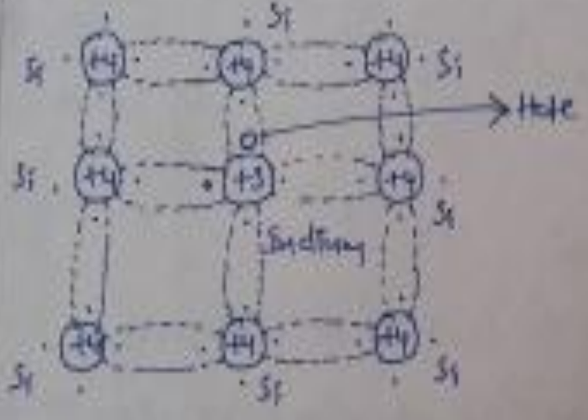


Silicon doped with Antimony pentavalent atom

Energy Band diagram

P-type:

- If a trivalent impurity atoms Boron, Alluminium, Indium, Gallium are added to an intrinsic semiconductor then a p-type semiconductor is formed.
- These impurities are also known as Acceptor or P-type impurities.
- These atoms when doped with silicon atom only three covalent bonds are filled and the vacancy that exists in the fourth bond constitutes a hole.



Silicon doped with trivalent Indium atom

Energy Band diagram

- Doping of an intrinsic semiconductor increases the conductivity.
- In a P-type material, the holes are the majority carriers and the electrons are minority carriers.
- In an N-type material, the electrons are majority carriers and the holes are minority carriers.

Fermi level :-

- The Fermilevel represents the energy state with 50% probability of being filled by an electron if no forbidden band exists.
- f(E) is called Fermi-Dirac probability function which specifies the fraction of all states at energy 'E' occupied under thermal Equillibrium conditions.

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

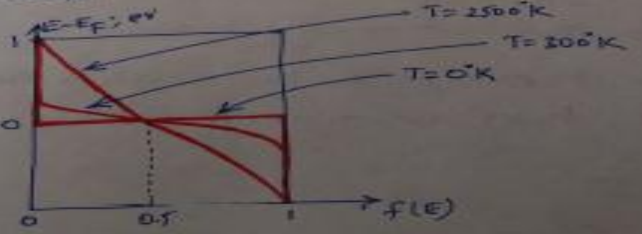
i) If $E=E_F$ then $f(E) = \frac{1}{1+e^{0}} = \frac{1}{2} = 0.5 = 50\%$ for any Value of temperature

ii) If $E>E_F$ then $f(E) = \frac{1}{1+e^{\infty}} = \frac{1}{1+\infty} = 0$

i.e; there is no probability of finding an occupied quantum state of energy greater than E_F at absolute zero temperature

iii) If $E<E_F$ then $f(E) = \frac{1}{1+e^{-\infty}} = \frac{1}{1+0} = 1$

i.e; All quantum levels with energies less than E_F will be occupied at $T=0°K$.



f(E) gives the probability that a state of energy 'E' is occupied

Fermilevel in an Intrinsic Semiconductor:

In Intrinsic Semiconductor; $n=p=n_i$

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

$p = N_v\, e^{-(E_F-E_v)/KT}$

N_c — Effective mass of electron

N_v — Effective mass of hole

∴ As $n=p=n_i$

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

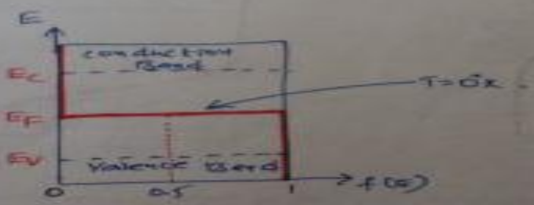
$$\ln \frac{N_c}{N_v} = \frac{E_c+E_v-2E_F}{KT}$$

$$E_F = \frac{E_c+E_v}{2} - \frac{KT}{2} \ln \frac{N_c}{N_v}$$

$\because N_c = N_v$

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

Hence the Fermi level lies in the center of the forbidden energy band.



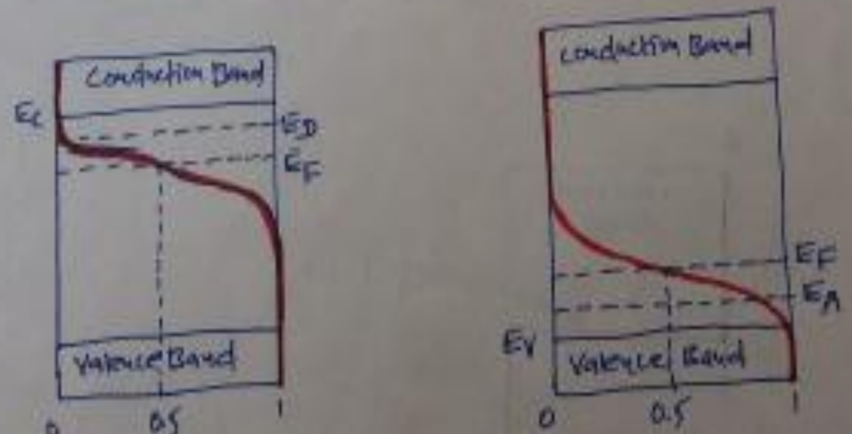
Energy Band diagram for an Intrinsic Semiconductor

Fermi level in Extrinsic Semiconductor:-

- The only parameter which changes by adding impurities is the Fermi level, E_F.

N-type: If a donor type impurity is added to the crystal, then at a given temperature all donor atoms are ionized and the first N_D states in the conduction band will be filled. Hence it is more difficult for the electrons from the valence band to bridge the energy gap by thermal agitation. Hence E_F must move closer to the conduction band to indicate that many of the energy states in that band are filled by donor electrons, and fewer holes exists in the valence band. This is shown in fig. below.

P-type:
- The same kind of argument leads to the conclusion that E_F must move from the center of the forbidden gap closer to the valence band for a P-type material. This is shown in fig. below.



(a) (b)

position of fermilevel in a) N-type Semiconductor

b) P-type Semiconductor.

Diffusion current :

Non uniform doped Semiconductor

Due to non uniform doping of a semiconductor there exists a force of repulsion between the charge carriers and move gradually i.e, diffuse from the region of high carrier density to low carrier density this process is called "Diffusion".
This movement of charge carriers under the process of diffusion constitutes a current called 'Diffusion current' and this exists without applying an external voltage.

- As the distance increases, the concentration of holes decreases which is shown in figure
- From the figure the slope of graph is the ratio of change in concentration to change in distance and is called "the rate of change of concentration (or) concentration gradient".

$$\text{concentration Gradient} = \frac{dP}{dx}.$$

- Diffusion current density is proportional to concentration gradient.

$$J_p \propto \frac{dP}{dx}$$

$$J_p = e D_p \frac{dP}{dx}$$

$$\boxed{J_p = -e D_p \frac{dP}{dx}} \quad \text{lly} \quad \boxed{J_n = e D_n \frac{dn}{dx}.}$$

D_p – Diffusion Constant of holes
D_n – " " electrons
e – charge of carrier

"–" negative sign is for because the slope $\frac{dP}{dx}$ is decreasing giving negative diffusion current.

Einstein's relation :

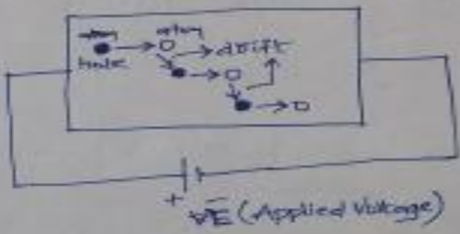
At a fixed temperature, the ratio of diffusion constant to the mobility is constant and this relation is called Einstein's relation.

$$\boxed{\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = V_T}$$

$$V_T = \frac{kT}{q} = \frac{1.38 \times 10^{-23} J/K \times 300K}{1.6 \times 10^{-19} \text{ coulombs}}$$

$$V_T = 26 \text{ mvolts}.$$

Drift current :



- The current produced due to bouncing of electrons or holes when it collides with an atom under the influence of an external electric field is called "Drift current".
- The Velocity with which electrons drift is called "Drift Velocity".
- Magnitude of drift Velocity is proportional to the electric field E.

$$v \propto E$$
$$v = \mu E \Rightarrow \mu = \frac{v}{E} = \frac{m/sec}{Volt/m} = \underline{\frac{m^2}{Volt\text{-}sec}}.$$

Drift current density due to electrons is $J_n = nev$ Amps/m²

$$\boxed{J_n = ne\mu_n E}$$
$$J_n = \sigma_n E$$

n – no. of free electrons / m³

e – charge of electron

μ_n – mobility of electrons

σ – conductivity.

Drift current density due to holes is $J_p = p.e.v$

$$\boxed{J_p = p.e.\mu_p E}$$
$$J_p = \sigma_p E$$

p – no. of holes per m³

μ_p – mobility of holes

$\sigma = \frac{1}{\rho}$ $(\Omega\text{-}m)^{-1}$

ρ – resistivity (Ω-m)

For an Extrinsic Semiconductor :

current density $J = (n\mu_n + p\mu_p) e \cdot E$ Amps/m²

$$J = \sigma E$$

conductivity $\boxed{\sigma = (n\mu_n + p\mu_p)e}$ $(\Omega\text{-}m)^{-1}$

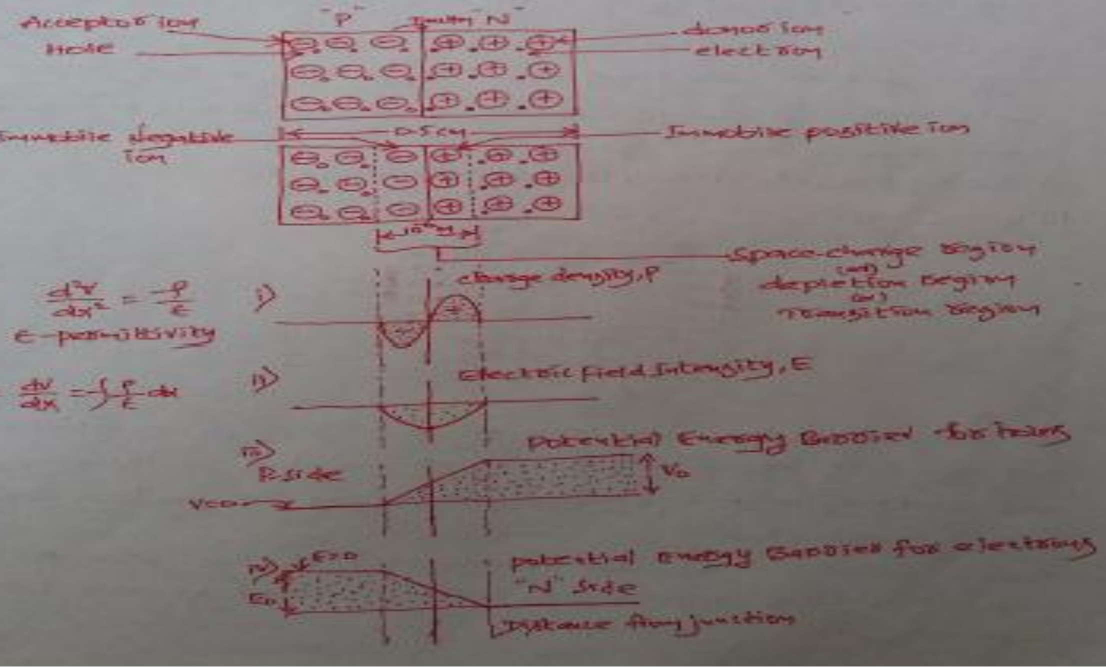
For an Intrinsic Semiconductor : $n = p = n_i$

$\therefore$ current density $J = n_i (\mu_n + \mu_p) e E$ Amps/m²

$$J = \sigma E$$
$$\boxed{\sigma = n_i(\mu_n + \mu_p)e} \ (\Omega\text{-}m)^{-1}.$$

The P-N Junction :- [open circuit]

- Before the invention of diode there was vacuum diode which is bulky, costly and noisy. It takes more power and more time to start conducting because of thermionic emission and these limitations were solved by Semiconductor junction diode.
- If donor impurities are doped into one side and acceptor impurities into the other side of a single crystal silicon then a P-N Junction is formed which is shown in below figure.



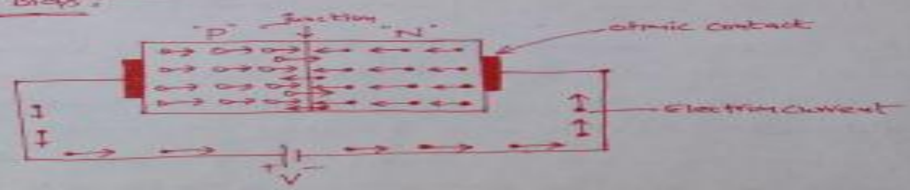
$$\frac{d^2V}{dx^2} = \frac{-\rho}{\epsilon}$$

ε-permittivity

$$E = \frac{dV}{dx} = -\int\frac{\rho}{\epsilon}dx$$

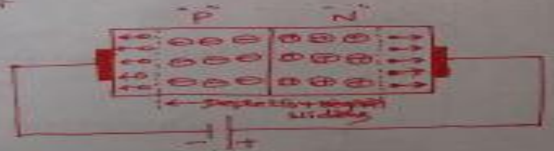
Biased P-N Junction:

Forward Bias:



- An External voltage applied with positive polarity to 'P'-type and negative polarity to N-type is called a Forward Bias.
- In a Forward Bias the holes cross the Junction from P-type to N-type and the electrons cross the junction in the opposite direc
These majority charge carriers travel around the closed circuit and large current flows.
- Forward biasing narrows the depletion region.

Reverse Bias:



- In Reverse bias the -ve terminal of battery is connected to 'p' side and +ve terminal to 'N' side of the junction. All holes in P-type and electrons in N-type move away from the junction resulting zero current flow
- A small current flows due to minority charge carriers present in 'p' and 'N' types and this current is called "Reverse Saturation current, I_0"

- The reverse current increase with increasing temperature and it is very small of the order of few micro amperes for Germanium and few nano amperes for silicon p-n Junction diodes.
- Reverse bias widens the depletion region.

The p-n Junction has two terminals called "electrodes", one each from p-region and N-region. Due to the two electrodes it is called "diode"

i.e; di+electrode = diode

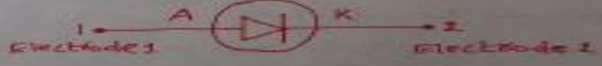
To connect N and P ~~terminals~~ regions to the external terminals, a metal is applied to the heavily doped N and P type semiconductor regions. Such a contact is called "Ohmic contact". It has an important property that

i) It conducts current equally in both the directions

ii) The drop across the contact is very small, which donot affect the performance of the device.

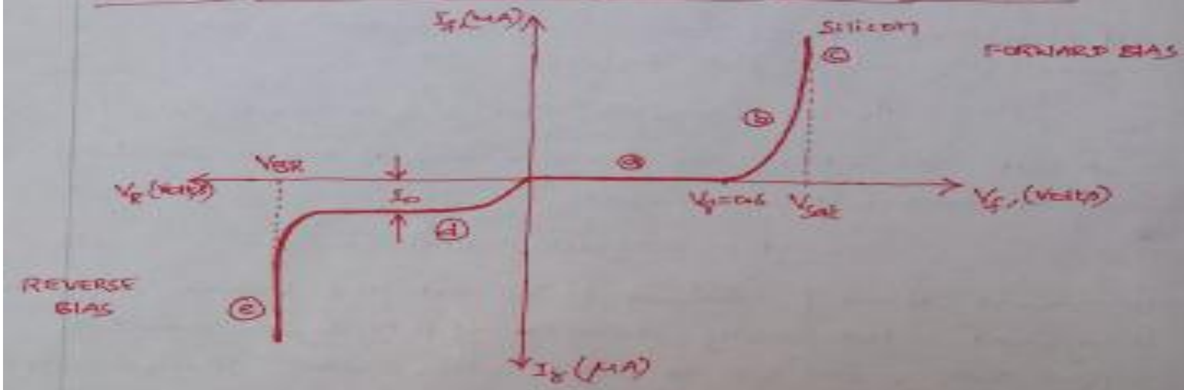
Thus ohmic contacts are used to connect 'N' and 'P' type regions to the electrodes.

Symbol :-



The arrowhead represents direction of hole current or conventional current.

Volt-Ampere (V-I) characteristics of P-N Diode :-



FORWARD BIAS :-

- The diode is forward biased if 'V' is positive, indicating that the 'p-side of the junction is positive with respect to N-side and the current flows from 'P' to 'N' side. For small range in Forward Voltage 'V' the current increases exponentially with voltage.
- There exists a "Cut-in" (or) "OFFSET" (or) "Break-point" (or) "Threshold Voltage", V_γ below which the current is very small (It is less than 1 percent of maximum rated value).

Beyond 'V_γ' the current rises very rapidly.

From the figure the cut-in voltage for

Germanium — $V_\gamma = 0.2V$
Silicon — $V_\gamma = 0.6V$

In Forward Bias from the figure:

ⓐ $V_a < V_\gamma$: As the applied potential is not sufficient to overcome the barrier, no current flows.

ⓑ $V_\gamma < V_a < V_{sat}$: For every increase in junction voltage the current also increases so it is almost a exponential relationship between 'V' and 'I'.

ⓒ $V_a \geq V_{sat}$: The carriers that are emitted due to external supply will collide with one another and create temperature. This temperature breaks the covalent bonds creating large amount of carriers which providing maximum current flow.

REVERSE BIAS:-

The diode is Reverse biased when 'p' side of the junction is negatively connected and 'N' side is positively connected.

From the figure:

ⓓ $V_a < V_{BR}$: The electric field gives emission but it is very small because it is due to minority carriers.

ⓔ $V_a \geq V_{BR}$: The carriers that are emitted due to electric field will collide and create secondary emission at very high voltage which is called Avalanche multiplication (or) carrier multiplication producing large reverse saturation current and the diode will spoil in this break down region due to large heat produced in the reverse bias.

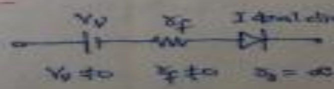
The dynamic reverse resistance is very high at the order of Mega ohms.

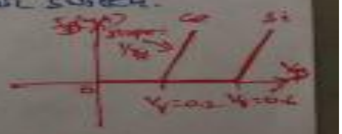
Ideal Versus practical Diodes:-

Ideal diode	practical diode
1) The cut-in voltage is zero since there is no barrier potential and small forward bias voltage causes conduction through the device	1) The cut-in voltage $V_\gamma = 0.2V$ for "Ge" and $V_\gamma = 0.6V$ for "Si". to overcome potential barrier across the junction.
2) The forward resistance is zero $R_f = 0$	2) Forward resistance is in the range of few tens of ohms. ; $R_f = 10\,\Omega$
3) The Reverse resistance is infinity $r_r = \infty$	3) Reverse resistance is in the range of mega ohms. ; $r_r = M\Omega$.
4) conducts in forward bias and does not conduct in Reverse bias	4) conducts in forward bias and a small reverse saturation current flows in Reverse bias for Ge → micro amps Si → Nano amps.
5) Ideal diode acts as a fast-acting electronic switch	5) This diode also acts as a fast-acting electronic switch.

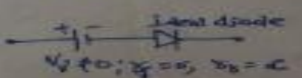
Diode Equivalent circuits:-

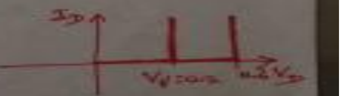
i) Piece wise linear model



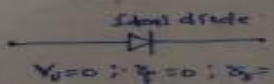


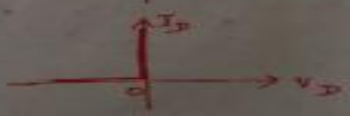
ii) Simplified model





iii) Ideal model

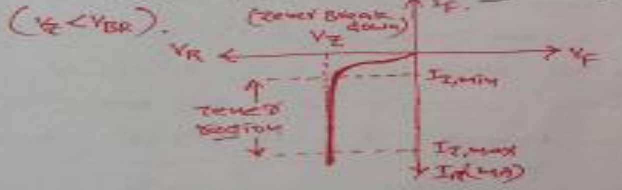


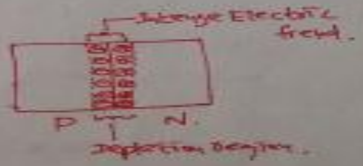


ii) Zener Breakdown:-

- When a P-N Junction is heavily doped the depletion region becomes narrow.
- In Reverse bias conditions, the electric field across the depletion layer is very intense. This intense field pulls the charge carriers out of valence bands of stable atoms easily.
- Under these circumstances the minority carriers constitute very large current and the breakdown is referred to as "Zener Breakdown".
- Thus the Zener Breakdown voltage decreases as the temperature increases this is called "Negative temperature coefficient".

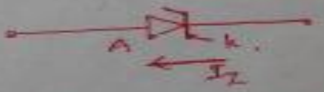
($V_Z<V_{BR}$).





Zener Diode characteristics:-

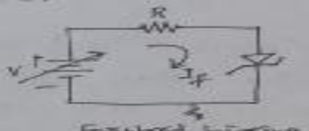
- Zener diode is a heavily doped PN junction semiconductor diode it is doped ~~with~~ at 10^4 parts 1 part of impurity.
- In 1934, a physicist carl Zener investigated the breakdown phenomenon.
- Zener diode is operated in "Reverse Breakdown Region".



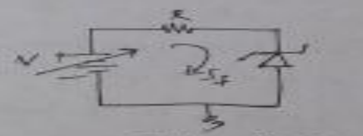
Zener diode Symbol

Forward bias:-

In forward bias the normal diode and zener diode operate in similar fashion.



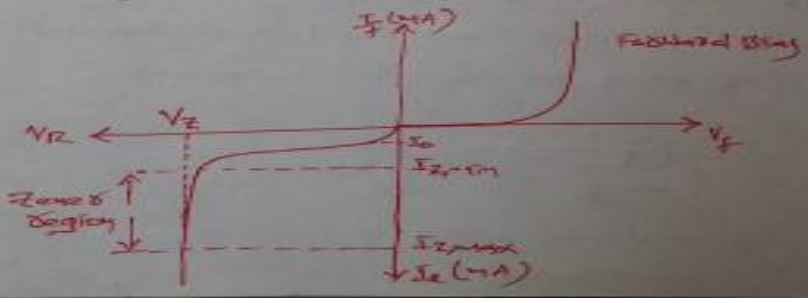
Forward biasing



Reverse biasing

Reverse bias:-

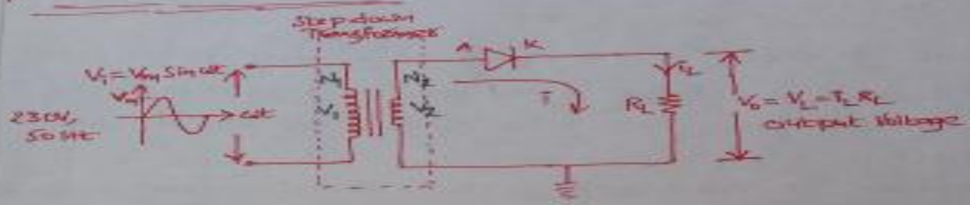
- In Reverse bias, the diode carries reverse saturation current, I_0 till $V_R < V_Z$. This current is very small in the order of few μA.
- At $V_R \geq V_Z$, current through Zener diode increases rapidly. The current corresponding to knee point which change from low value to large value is called "Zener Knee current" ($I_{Z,min}$).
- At this knee, a breakdown is said to occur in the device. The reverse voltage at which breakdown occurs is called "Zener breakdown voltage, V_Z".
- The maximum current a zener diode can carry safely is called "Zener maximum current, I_{Zmax}".
- Applications of zener diode are i) Voltage regulators ii) protection circuits iii) Voltage limiters.



RECTIFIERS AND FILTERS

A Rectifier is a device which converts a.c voltage to pulsating d.c voltage using one or more P-N junction diodes.

I) Half-Wave Rectifier :-



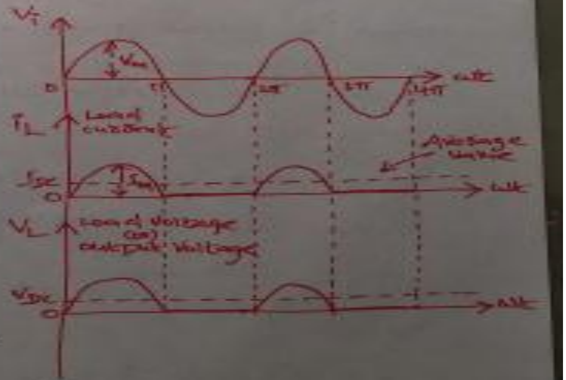
N_1 — primary winding
N_2 — secondary winding
V_2 — secondary voltage
V_1 — primary voltage

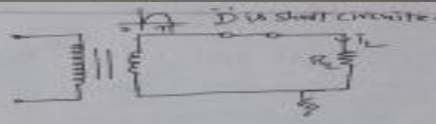
$$\boxed{\frac{N_2}{N_1} = \frac{V_2}{V_1}}$$

– A Transformer is a device which converts one form of current or voltage to other form without change in frequency.

i) For positive cycle :-

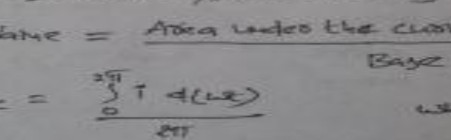
If positive cycle from 0 to π is given to input of diode then the diode is in forward bias condition and it is short circuited and current flows through the diode and through load resistance, R_L.
This current is represented in the wave-form from 0 to π duration and the load voltage also takes the same wave form since $V_L = I_L R_L$.

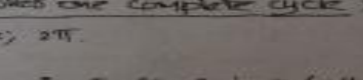




ii) For Negative cycle :-

– Negative cycle from π to 2π is given as input to the diode then diode 'D' is reverse biased and it is open circuited then zero current flows through the diode and through load resistance, R_L.
– This current is represented in the wave form from π to 2π duration and load voltage also takes zero voltage since $V_L = I_L R_L$.





– Hence the output is discontinuous in nature and it is called pulsating d.c.
– Hence it is necessary to calculate average value of load current and average value of output voltage.

i) Average or DC load current (I_{DC}) :-

Average or DC value is obtained by integration of alternating current

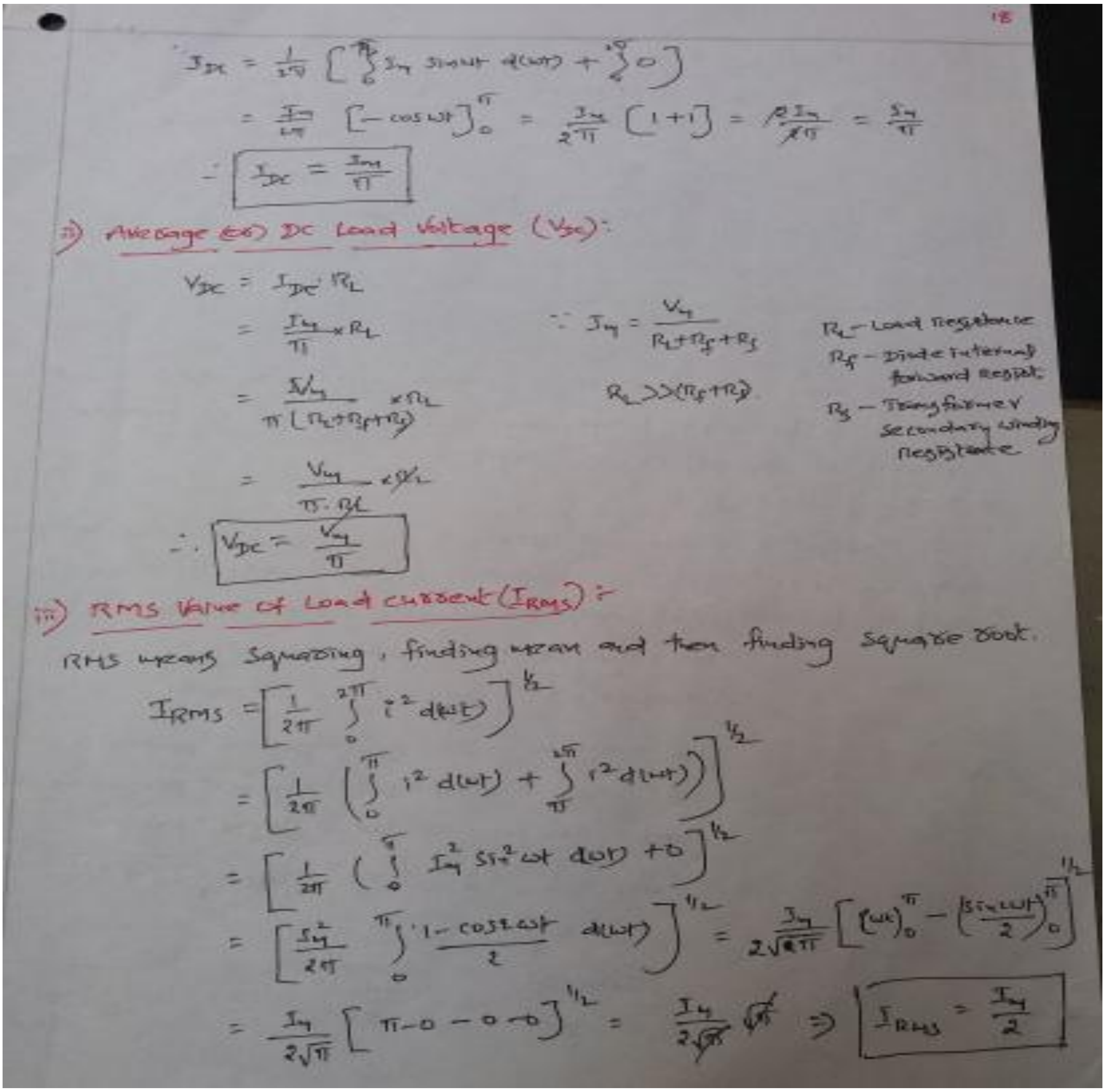
Average value = $\dfrac{\text{Area under the curve over one complete cycle i.e; } (0-2\pi)}{\text{Base, i.e; } 2\pi}$

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

where $i = I_m \sin\omega t$; $0 \le \omega t \le \pi$
$= 0$; $\pi \le \omega t \le 2\pi$
I_m is peak value of current

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

$$= \frac{1}{2\pi} \left[\int_0^{\pi} i \, d(\omega t) + \int_{\pi}^{2\pi} i \, d(\omega t) \right].$$



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$$I_{DC} = \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin\omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0\right]$$

$$= \frac{I_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{I_m}{2\pi}\left[1+1\right] = \frac{\cancel{2} I_m}{\cancel{2}\pi} = \frac{I_m}{\pi}$$

$$\therefore \boxed{I_{DC} = \frac{I_m}{\pi}}$$

ii) Average (or) DC Load Voltage (V_{DC}):

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

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

$$\because I_m = \frac{V_m}{R_L + R_f + R_s}$$

R_L – Load resistance

R_f – Diode internal forward resist.

R_s – Transformer secondary winding resistance

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

$$R_L >> (R_f + R_s)$$

$$= \frac{V_m}{\pi \cdot \cancel{R_L}} \times \cancel{R_L}$$

$$\therefore \boxed{V_{DC} = \frac{V_m}{\pi}}$$

iii) RMS Value of Load current (I_{RMS}):-

RMS means squaring, finding mean and then finding square root.

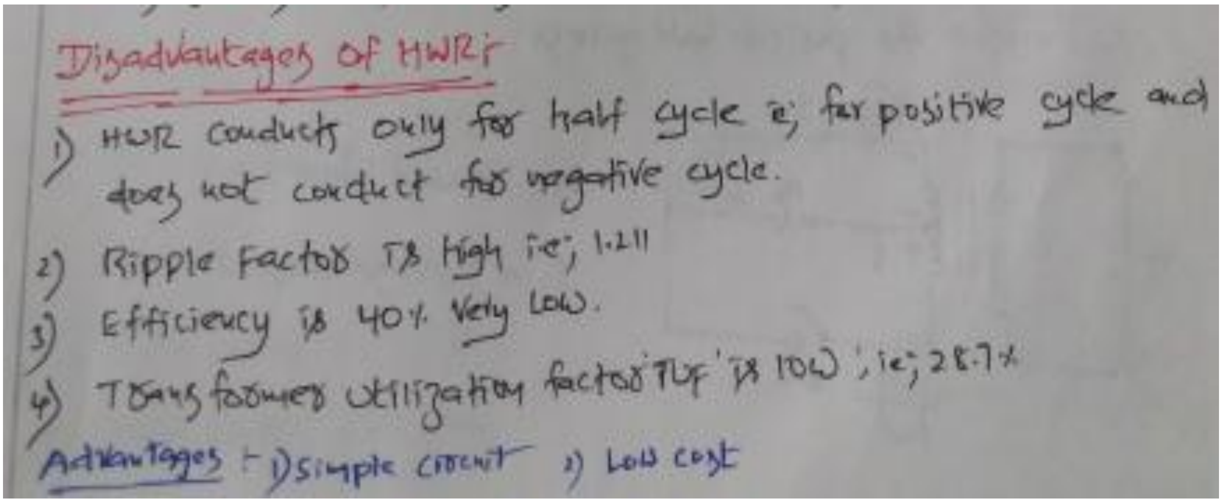
$$I_{RMS} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2 \, d(\omega t)\right]^{1/2}$$

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

$$= \left[\frac{1}{2\pi}\left(\int_0^{\pi} I_m^2 \sin^2\omega t \, d(\omega t) + 0\right)\right]^{1/2}$$

$$= \left[\frac{I_m^2}{2\pi}\int_0^{\pi} \frac{1-\cos 2\omega t}{2} \, d(\omega t)\right]^{1/2} = \frac{I_m}{2\sqrt{\pi}}\left[(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]^{1/2}$$

$$= \frac{I_m}{2\sqrt{\pi}}\left[\pi - 0 - 0 - 0\right]^{1/2} = \frac{I_m}{2\cancel{\sqrt{\pi}}}\cancel{\sqrt{\pi}} \Rightarrow \boxed{I_{RMS} = \frac{I_m}{2}}$$

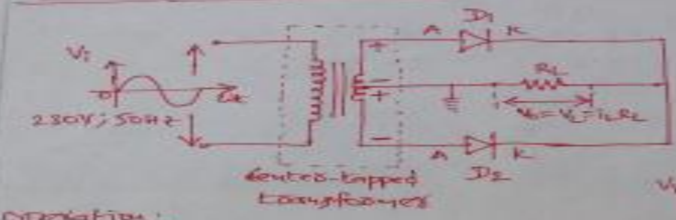


Disadvantages of HWR:-

1) HWR conducts only for half cycle i.e; for positive cycle and does not conduct for negative cycle.
2) Ripple Factor is high i.e; 1.21
3) Efficiency is 40% very low.
4) Transformer utilization factor TUF is low ; ie; 28.7%

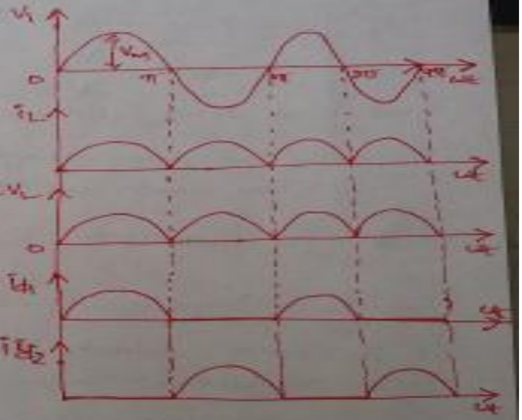
Advantages :- 1) Simple circuit 2) Low cost

2) FULLWAVE RECTIFIER:-



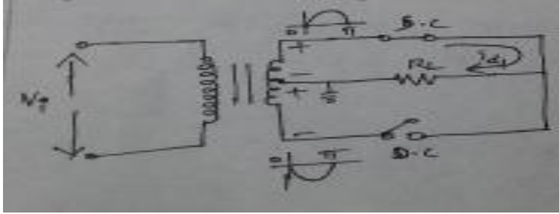
Operation:

i) For positive half cycle:-



- When positive half cycle from 0 to π duration is given as input to diode 'D1' then D_1 is forward biased and it is short circuited and current flows through the diode i.e; i_{d_1}.
- In the second half of the circuit a negative wave form is given as input to diode 'D_2' in the 0–π duration then 'D_2' is reverse biased it is open-circuited and zero current flows i.e; $i_{d_2} = 0$ in 0–π duration.
- Then current flowing through 'R_L' is i_{d_1} and voltage $V_L = i_L R_L$.

The circuit for positive half cycle is:

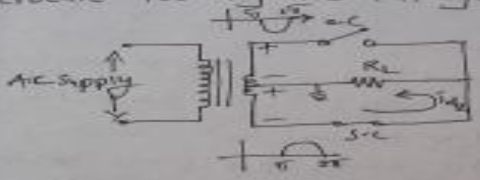


D_1 – Forward biased

D_2 – Reverse biased.

ii) For Negative half cycle:-

- When For negative half cycle from π – 2π duration is given as input to diode 'd1' then diode 'D_1' is reverse biased, open circuited and zero current flows through diode 'D_1'. i.e, $i_{d_1} = 0$.
- In the second half of the circuit, negative is converted to positive waveform from π–2π duration then diode 'D_2' is forward biased, short circuited and current flows through 'D_2'.
- The circuit for negative half cycle is:



D_1 – is forward biased

D_2 – is Reverse biased

i) Average or DC load current, I_{DC}:-

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

$i = I_m \sin\omega t ; \quad 0 \le \omega t \le \pi$

$= -I_m \sin\omega t ; \quad \pi \le \omega t \le 2\pi$

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

$$\boxed{I_{DC} = \frac{2I_m}{\pi}}$$

ii) $V_{DC} = \frac{2V_m}{\pi}$

iii) $I_{rms} = \frac{I_m}{\sqrt{2}}$

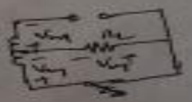
iv) Efficiency, η = 81.2%

v) Ripple factor, γ = 0.48

vi) Form factor, F.F = 1.11

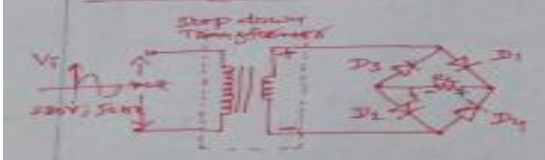
vii) peak factor, P.F = 1.414

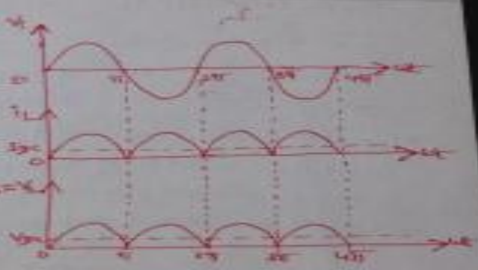
vii) PIV = $2V_m$



ix) TUF = 69.3%.

Bridge Rectifier:





output wave forms

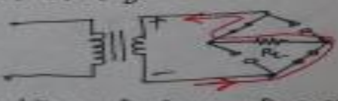
i) operation for positive half cycle:

During positive cycle from 0-π duration diodes D_1 and D_2 are forward biased and are short circuited. current flows through D_1 enters the load at positive terminal, leaving the load at negative terminal and then flows through diode D_2. During this cycle the diodes D_3 & D_4 are reverse biased and are open circuited and zero current flows through them.

current flow is represented by solid line.

ii) operation for Negative half cycle:

During negative half cycle the lower end of AC supply becomes positive diodes D_3 and D_4 become forward biased, current flows through D_4 enters the load at positive terminal, leaves the load at negative terminal and then flows through D_3. During this cycle the diodes D_1 & D_2 are reverse biased and zero current flows through them.



current flow is represented by solid line.

Thus the direction of flow of current through the load resistance R_L is same during both half cycles of the input supply voltage.

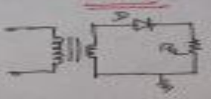
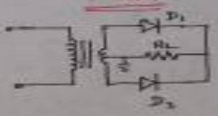
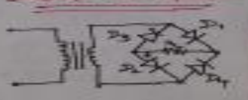
Advantages of Bridge Rectifier circuit:

i) No center-tapped transformer used
ii) Transformer is utilized effectively
iii) In High voltage applications it is used.

Disadvantage:

i) Use of four diodes as compared to two diodes in Full wave Rectifier.

Comparison of Rectifier Circuits:

	Parameter	HWR	FWR	BRIDGE RECTIFIER
1.	circuit			
2.	No. of diodes	1	2	4
3.	Average D.C current; I_{DC}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
4.	Average D.C. voltage; V_{DC}	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
5.	RMS current; I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
6.	D.c output power; P_{DC}	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4}{\pi^2} I_m^2 R_L$	$\frac{4}{\pi^2} I_m^2 R_L$
7.	A.c power input; P_{AC}	$\frac{I_m^2}{4}(R_f+R_s+R_L)$	$\frac{I_m^2}{2}(R_f+R_s+R_L)$	$\frac{I_m^2}{2}(2R_f+R_s+R_L)$
8.	Efficiency; η	40.6%	81.2%	81.2%
9.	Ripple Factor; γ	1.211	0.482	0.482
10.	~~Peak~~ Form Factor; F.F	1.57	1.11	1.11
11.	Peak factor; P.F	2	1.414	1.414
12.	PIV	V_m	$2V_m$	V_m
13.	TUF	0.287	0.693	0.812