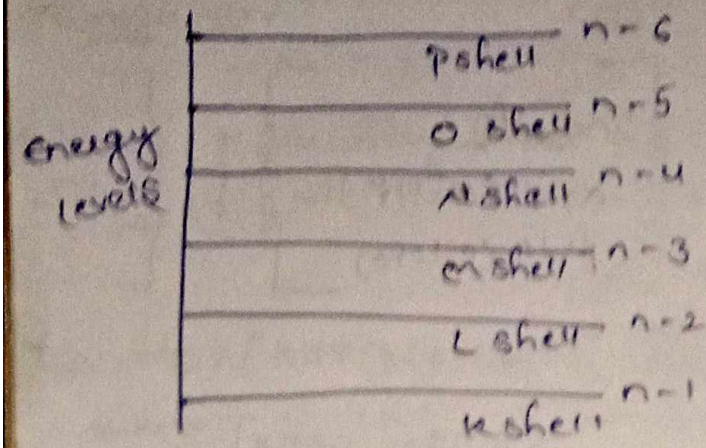
UNIT - I

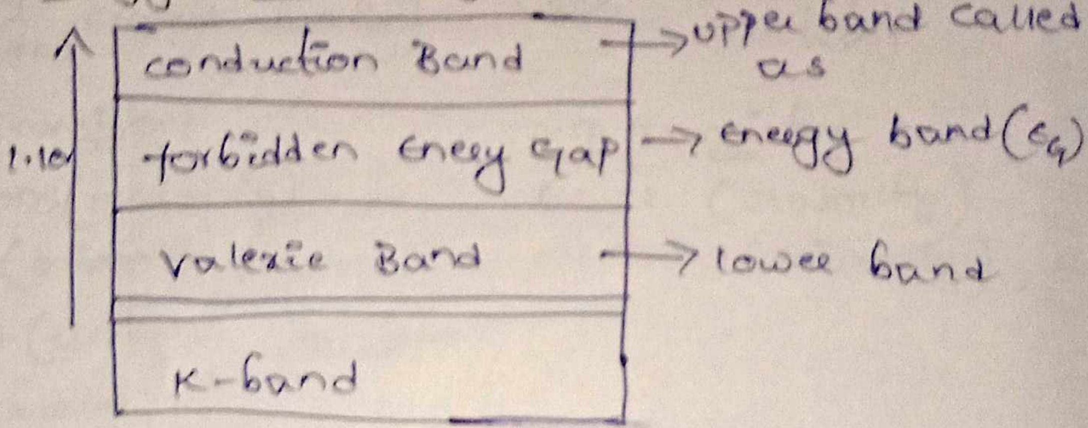
Semiconductor physics

fig - a: Different electron energy levels:-



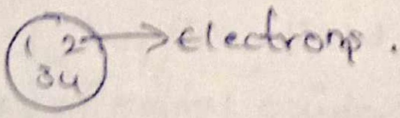
n -> no. of electrons.

fig - b: energy band diagram of silicon:-



orbit:-

- An orbit consists of same energy levels
- when the electrons have same energy levels then it produce valence electrons.



from fig-b:-

- If we want to move from valency band to conduction band. I have to gain 1.1ev.
- Similarly if we want to move from conduction band to valency band then we have to loose 1.1ev.

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3 materials

1) conductors
2) semi conductors
3) Insulators.

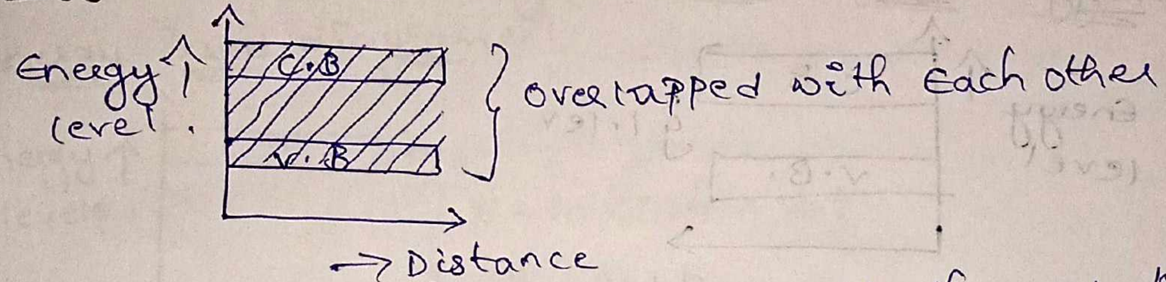
1) Conductors:
- single valency e^- in its outermost orbit.
- when we use single valency e^- then it can easily conducts with electric current

Example:

Gold, silver, copper, Aluminium.

- Resistance value is very small
- solids which contains metallic bands are called as metallic solids can be used.

Energy Band Diagram of conductor:



- we cannot produce energy gap b/w the conduction band and the valancy band because they are overlapped with each other.

Properties:-

1) It is rigid because it cannot be bend (or) cannot change out of shape.
alon-directional & crystaline in nature.
2) conductivity is good
3) low melting & boiling temperatures.

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2) semi conductors :-

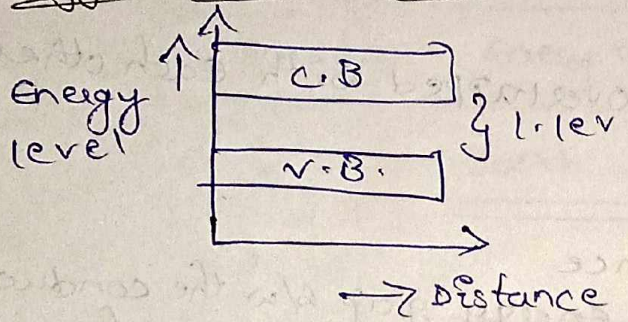
- semi conductors means it can be placed b/w conductor & insulator.
- contains 4 valency electrons in its outer most orbit.

Ex:
silicon(si), Germanium(Ge), Gallium(Ga) Arsenide(As)

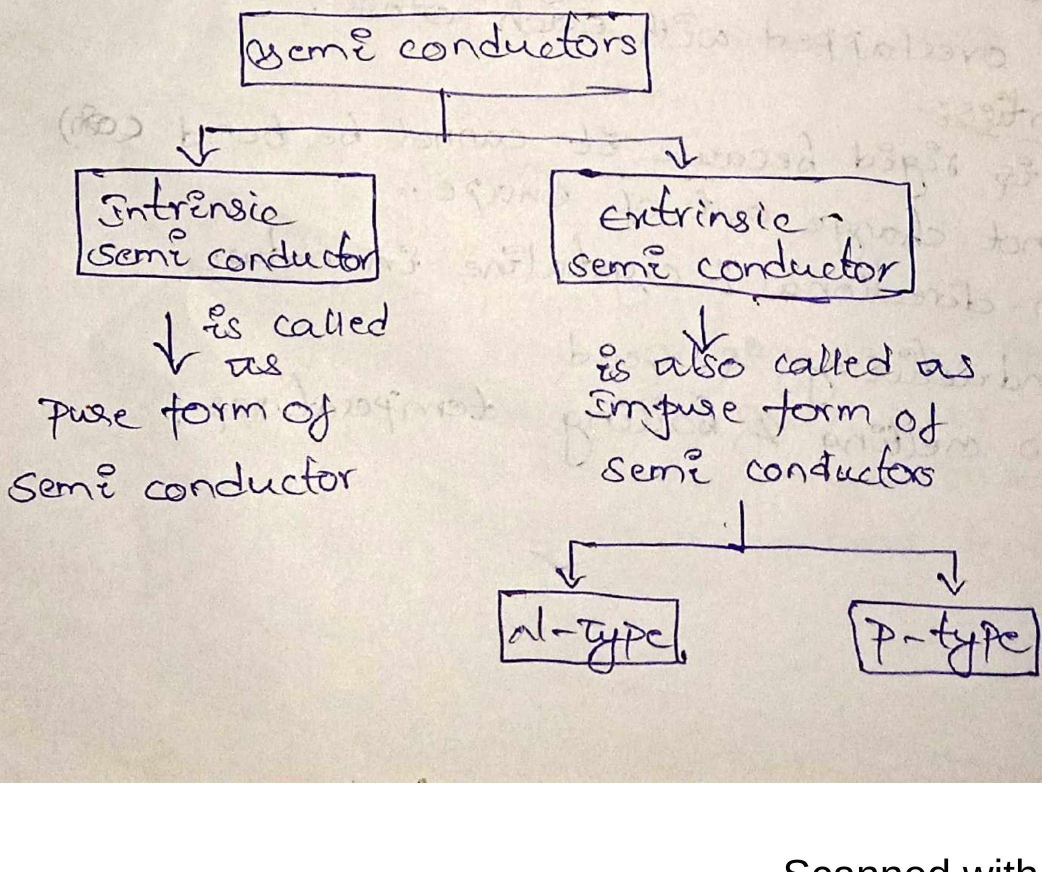
→ solids, liquids & Gaseous form of materials can be formed. These are formed then covalent compounds are formed.

- At 0K, electrons in convolation Band is empty, electron in valency band are completly filled. Then semiconductor acts as insulator.

Energy band diagram for semi conductor:



- semiconductors can be produce in two ways.



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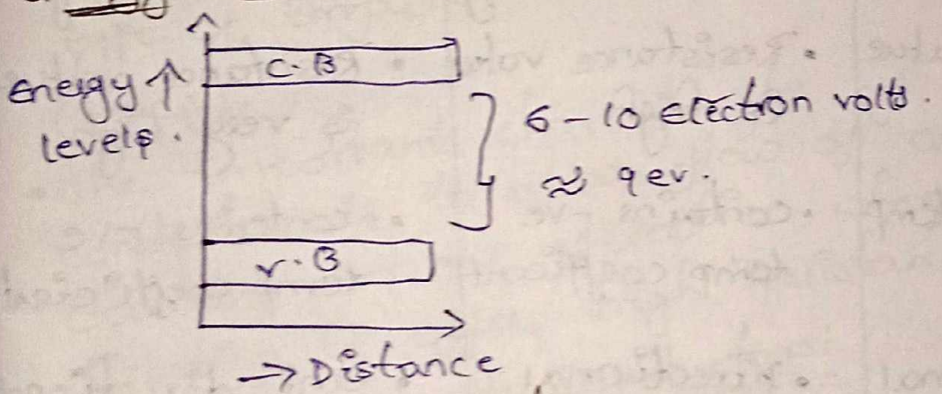
Properties for semi-conductors:-
- It is rigid, directional i.e. crystalline in nature
- conductivity is further ↑(increased) for doping of materials $\boxed{\text{adding}}$
- low melting of boiling temperature.

3) Insulators:-
- It is having 8 valency electrons in ints outermost orbit.

Examples:-
Paper, mica, sodium chloride
- It cannot conducts with electric current
- It contains -ve temperature coefficient.
- At 100°K, both electrons in conduction band and electrons in valency band are completly filled.

energy Band diagram:-



Properties for Insulators:-
- It is rigid, unidirectional & crystalline in nature
- conductivity is poor
- High melting of boiling temperature.

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comparision b/w conductors, semiconductors & Insulators.

conductor	semiconductor	Insulator.
• conducts easily with electric current	• conducts electric current less than conductor & greater than insulator	Does not conducts electric current.
• Have single valency in its outermost orbit	• Have 4 valency e's in its outermost orbit	Have 8 valency e's in its outermost orbit.
• energy gap is overlapped with each other	• contains energy gap of 1.1ev	contains energy gap of 6 to 10 ev (x9ev)
• metallic bonding	• covalent bonding	• Ionic bonding
• Resistance value is small	• Resistance value is high	• Resistance value is very high.
• contains +ve temp coefficienct	• contains -ve temp coeffecent	• contains -ve temp coefficient
• Non-directional	• Directional	• uni-directional
• Ex: Gold, silver, copper, alluminium, etc	• Ex: silicon(si), Germanium(Ge), Gallium Arsenide(GaAs)	• Ex: Paper, mica, sodium chloride

Semi conductors:-

semi-conductors are two types

1) N-type semi conductors

2) P-type

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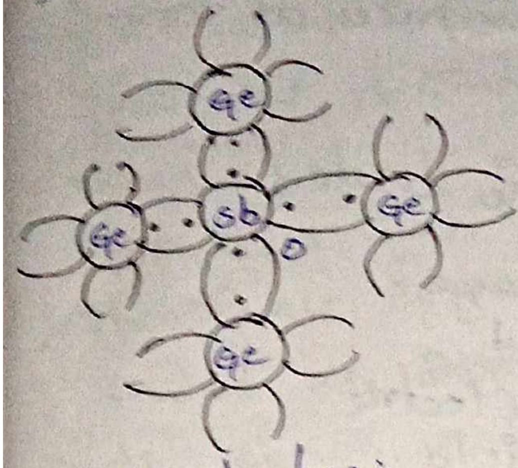
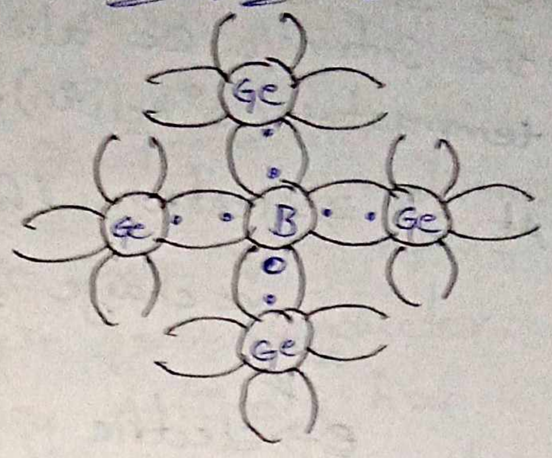
1) N-type sc:



2) P-type sc



semiconductors:

- It allows the flow in only one direction whereas in other direction it produces high resistance values
- semiconductors is produced by half-type of impurities with N-type (electrons) and other type of impurities in the form of P-type (holes).
- The important characteristic of any semiconductor is to allow flow of control of current in one direction, whereas in other direction it offers high. Resistance values.

Applications of semiconductors:

1) Radio
2) opto electronics
3) Industrial electronics
4) Power supplies
5) Television
6) Instrumentation.
7) computers

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1) Intrinsic sc:-

- The Intrinsic sc always produces at room temperature (0° kelvin).

At 0°K ⇒ electrons & holes are created.

electrons → -ve charge → add → E → electric field

holes → +ve charge → add → E → electric field.

- when we add electric field (E) to both +ves -ve charges it produced conduction current.

- $\boxed{\text{Total current in an intrinsic sc = sum of electrons ~~current~~ + sum of holes current}}$

2) Extrinsic sc:-

- At room temperature when we uses sc it produces contains poor conductivity.
- Due to poor conduction at room temperature, it is not useful for producing sc devices.

- Add No. of components to pure sc there is going to form of impure sc
- current conduction capability should increase to produce bigger sc
- Adding no. of components is called Doping.
- Extrinsic sc are two types

1) N-type sc:-

→ It is a donor atom.

→ It uses the Pentavalent impurities.

→ when pentavalent impurities is going to add with pure types of sc [like silicon, Germanium,

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Gallium Arsenide (GaAs) then it form n - type sc.

-> pentavalent impurities are Arsenic, bismath, phosphurus, Antimony.

-> when a small amount of pentavalent impurities such as Arsenic, bismath, Antimony, phosphurus is added to pure form of sc called as ~~ext~~ n - type semi-conductor.

-> As shown in the fig Antimony has 5 - valance electrons in its outermost orbit, where as germanium has 4 valence electrons in outermost orbit.

-> The corresponding 4 Ge atoms forms covalent bond with surrounding Antymony atoms.

-> But 1 Antimony atom is left free which gives raise to free electrons.

-> In n-type ~~sc~~ free electron is called as Donar atom [Donating electron in place of holes].

-> ∴ In ~~N~~- type sc majority carriers are e⁻ and minority carries are holes.

2) P - type sc :-

-> when a small amount of trivalent impurities such as Boron & Allumenium is added to pure form of sc called as intrinsic sc such as Ge, si, GaAs is called P - type sc

-> As show in the fig. Boron has 3 - valence electrons in its outermost orbit whereas

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Ge has 4 valence e^- in its outermost orbit

→ The corresponding 4 Ge atoms forms covalent bond with surrounding Boron atoms.

→ The 1 Boron atom which is left free is called as accepting atom means it is accepting more no. of holes in place of electrons.

→ ∴ In p-types sc holes are majority carriers and electrons are minority carriers.

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conductivity in a semi-conductor:-

Pure sc (Intrinsic sc)

no. of Electrons (n) = no. of holes (p)

- In a sc a problem which is occured is called "Thermal Agitation"

Thermal Agitation:-

when the both electrons and holes are combined because of thermal Agitations old electrons & holes pairs are disappear and creates new electrons & holes pairs (Re combination) is called thermal Agitation.

$$\begin{array}{cc} \text{electrons} & \text{holes} \\ \downarrow & \downarrow \\ -ve & +ve \end{array}$$

* During this recombination process charge particles are produce in the form of -ve & +ve

one in -ve is called as free e^- with mobilities μ_n

other in +ve is called as free holes with mobilities μ_p

↓

There we are going to apply to an electric field E. then current will be always in same direction.

Total current density in a sc

$$\boxed{J = J_n + J_p} \longrightarrow (1)$$

conduction current density.

J_n (conduction current density with respect to electrons)

$J_n = q n \mu_n E \rightarrow ②$

J_p (conduction current density with respect to holes)

$J_p = q p \mu_p E \rightarrow ③$

n = no. of free electrons / unit volume

p = no. of free holes / unit volume

μ_n = mobility of electrons, cm/v-s

μ_p = mobility of holes, cm²/v-s,

E = Electric field strength, v/cm.

q = charge of an electrons (columbs − 1.6×10^{-19})

By substituting ② & ③ in ①.

$J = q n \mu_n E + q p \mu_p E$

$J = q(n\mu_n + p\mu_p) E.$ → conductivity.

$\boxed{J = \sigma E} \rightarrow ④$. where $\boxed{\sigma = q(n\mu_n + p\mu_p)}$

Resistivity: (ρ)

- Reciprocal of conductivity is called Resistivity

$\boxed{\rho = \frac{1}{\sigma}}$

Intrinsic conductivity in a sc

n = p = n_i (intrinsic carrier concentration)

$\boxed{\sigma_i = q n_i (\mu_n + \mu_p)} \rightarrow ⑤$

extrinsic conductivity in a sc

N-type sc: $n >> p$

* extrinsic sc it produce only with help of charge carries

$\boxed{\sigma_E = q n \mu_n} \rightarrow ⑥$

it cannot produce any electric field only in intrinsic electric field is used.

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Intrinsic conductivity :-

σ_i = 5%/°c raise in temperature (when Germanium is used)

σ_i = 7%/°c raise in temperature (when silicon is used)

→ in intrinsic conductivity it increase 7% Raise in temperature when silicon used.

P-Type sc:

$p >> n$.

$\boxed{\sigma_E = q p \mu_p} \rightarrow (7)$.

Intrinsic conductivity in a sc

$\boxed{J = q n_i (\mu_n + \mu_p) E}$

Drift & Diffusion currents:-

* flow of charge produces the current produce in sc
* current is divided into two types (or)
  1) Drift
  2) Diffusion.

The net current which is flown across a sc material is divided into two type namely Drift & Diffusion current

* If I want short of Diffusion current is slow movement of air is called Drift current
* fast movement of air is called Diffusion current.

1) Drift current:-

Electric field produces pure form of semi-conductor material

• when a sc material is used in then it produces charge carriers & produce drift velocity (ϑ_d).

ϑ_d = product of mobility of charge carries & electric field field strength (ϵ)

$\vartheta_d = \mu \epsilon$.

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Holes(+ve) → move to -ve terminal

Electrons(-ve) → moves to +ve terminal.

* when we apply electric field apply to the pure sc material it produces the charge carriers in the form of drift velocity(v_d).

$$\boxed{J_n = q n \mu_n E \, A/cm^2} \rightarrow (1)$$

q = charge of an electrons

n = no. of free electrons / cm^3

μ_n = mobility of electrons / cm^3

E = Electric field strength / cm

$$\boxed{J_p = q p \mu_p E \, A/cm^2} \rightarrow (2)$$ [drift current density with respect to holes]

q = charge of an holes

n = no. of free holes / cm^3

μ_n = mobility of holes / cm^3.

Diffusion current: [The combined effect of charge carriers produces a current called diffusion current.]

* In a sc material charge carriers has an important property that it moves from higher concentration to lower concentration & vice versa

- Diffusion current depends on three factors:
  1) material of the sc [N type or P-type]
  2) Type of charge carrier [+ve charge (or) -ve charge].
  3) concentration gradient.

Diffusion current with respect to holes.

$$\boxed{J_p = -q D_p \cdot \frac{dP}{dx} \, A/cm^2} \rightarrow (3).$$

Diffusion current density with respect to electrons.

$$\boxed{J_n = q D_n \cdot \frac{dn}{dx} \, A/cm^2} \rightarrow (4)$$

$\frac{dn}{dx}$ → concentration coefficient w.r.t ē

D_p = Diffusion current with respect to holes
D_n = Diffusion " " " " electrons.

Total current in a SC:

Total current density in p-type SC

$$\boxed{J_p = q p \mu_p \epsilon - q D_p \frac{dP}{dx} \; A/cm^2} \rightarrow (5)$$

Total current density in N-type SC:

$$\boxed{J_n = q n \mu_n \epsilon + q D_n \frac{dn}{dx} \; A/cm^2} \rightarrow (6)$$

Einstein's Relationship of a semiconductor:

$$\boxed{\frac{D_p}{\mu_p} = \frac{D_n}{\mu_n} = \frac{KT}{q} = V_T} \rightarrow (7)$$

The relation which produced in the form of diffusion current and mobility.

K - BOLTZMAN constant.
T = Temperature
D_p = Diffusion coefficient with respect to holes.
V_T = cut-in voltage (or) Threshold voltage.
Intrinsic Si $D_p = 13 \; cm^2/s$.
$D_n = 34 \; cm^2/s$

In Intrinsic Ge, $D_p = 47 \; cm^2/s$
$D_n = 99 \; cm^2/s$

μ_p = mobility.
* The equation which relates between mobility μ and diffusion coeffecent D is called as Einstein Relationship of a SC.

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Problems:-

① The mobility of free electrons and holes in pure Germanium are $3800\ cm^2/v\text{-}s$ & $1800\ cm^2/v\text{-}s$ respectively the corresponding for pure silicon are $1300\ cm^2/v\text{-}s$ & $500\ cm^2$/ determine the values of intrinsic conductivity for both Germanium and silicon. $n_i = 2.5 \times 10^{13}\ cm^{-3}$ for Ge and $n_i = 1.5 \times 10^{10}\ cm^{-10}$ for silicon at Room temperature.

Sol:-

Ge:-

$\mu_n = 3800\ cm^2/v\text{-}s$

$\mu_p = 1800\ cm^2/v\text{-}s$

Si

$\mu_n = 1300\ cm^2/v\text{-}s$

$\mu_p = 500\ cm^2/v\text{-}s$

$n_i = 2.5 \times 10^{13}\ cm^{-3}$ for Ge

$n_i = 1.5 \times 10^{10}\ cm^{-10}$ for silicon.

for Germanium

$\sigma_i = q n_i (\mu_n + \mu_p)$.

$\sigma_i = (1.6 \times 10^{-19})(2.5 \times 10^{13})[3800 + 1800]$

$= 4 \times 10^{-6}[5600]$

$= 0.000004[5600]$

$= 0.0224\ S/cm$.

for silicon

$\sigma_i = q n_i (\mu_n + \mu_p)$

$\sigma_i = (1.6 \times 10^{-19})(1.5 \times 10^{10})[1300 + 500]$

$= 2.4 \times 10^{-9}[1800]$

$= 0.0000000024[1800]$

$= 4.32 \times 10^{-6}\ S/cm$.

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Mass-Action Law:

→ If a pure semiconductor is doped with N-type impurities the no. of electrons in the conduction band ↑es above a level & no. of holes in the valence band ↓es below a level, which would be available in intrinsic (pure) sc.

→ Similarly, ~~the no. of~~ if a pure sc is doped with P-type impurities, the no. of holes in the valence band ↑es above a level & no. of electrons in the conduction band ↓es below a level, which would be available in intrinsic (pure) sc.

→ This relation is known as Mass-Action Law & is given by $\boxed{n \cdot p = n_i^2} \rightarrow (1)$

where n is no. of free e's/unit volume, p is no. of holes/unit volume & n_i is the intrinsic ~~concentration~~ carrier concentration.

Charge densities in N-type & P-type sc's:

→ Law of mass action has given the relationship b/w free electron & hole concentration.

→ Let N_D be the concentration of donor atoms in N-type sc.

→ In order to maintain electronic neutrality,

• we have $n_N = N_D + P_N$

$$\boxed{n_N \approx N_D}$$

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→ Where n_N & P_N are $\bar{e}$ & hole concentration in N-type sc.

→ Value of P_N can be obtained from the relation of mass-action law as $P_N = \frac{n_i^2}{n_N}$

$$\therefore \boxed{P_N = \frac{n_i^2}{N_D}} \quad (\because n_N \approx N_D)$$

→ Similarly in a p-type sc, we have

$$P_P = N_A + n_P$$

$$\boxed{P_P \approx N_A}$$

Where N_A, P_P & n_P are concentrations of acceptor impurities of holes & $\bar{e}$'s resp in a p-type sc.

→ From Mass-action law, $n_P = \frac{n_i^2}{P_P}$

$$\therefore \boxed{n_P = \frac{n_i^2}{N_A}} \quad (\because P_P \approx N_A)$$

<u>Extrinsic Conductivity</u>:

→ Conductivity of a N-type sc is given by

$$\boxed{\sigma_N = q\, n_N \mu_N \approx q\, N_D \mu_n} \quad (\because n_N \approx N_D)$$

→ Conductivity of a p-type sc is given by

$$\boxed{\sigma_P = q\, P_P \mu_P \approx q\, N_A \mu_P} \quad (\because P_P \approx N_A)$$

∴ If $N_D >> N_A$, then the sc is converted from a p-type to N-type.

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→ If $N_A >> N_D$, then the sc. is converted from a N-type to P-type.

Problems

(1) A sample of Si at a given temp T in intrinsic condition has a resistivity of 25×10^4 Ω-cm. The sample is now doped to the extent of 4×10^{10} donor atoms/cm³ and 10^{10} acceptor atoms/cm³. find the total conduction current density if an electric field of 4v/cm is applied across the sample. Given that $\mu_n = 1250$ cm²/v-s, $\mu_p = 475$ cm²/v-s at the given temp.

sol:-

$$\boxed{\sigma_i = q n_i (\mu_n + \mu_p)}$$

$$\Rightarrow \sigma_i = q n_i (\mu_n + \mu_p) = \frac{1}{25\times10^4} = 400\ \Omega\text{-cm}$$

$$\therefore n_i = \frac{\sigma_i}{q(\mu_n+\mu_p)} = \frac{1}{25\times10^4 \times 1.6\times10^{-19}(1250+475)}$$

$$\Rightarrow n_i = \frac{1}{4\times10^{-14}\times1725} = \frac{1}{6.9\times10^{-11}} = 1.45\times10^{10}$$

$$\therefore \boxed{n_i = 1.45\times10^{10}\ \text{cm}^{-3}}$$

Net donor density $N_D(=n) = 4\times10^{10} - 10^{10} = 3\times10^{10}$

$$\boxed{N_D = 3\times10^{10}\ \text{cm}^{-3}}$$

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$$\boxed{p = \frac{n_i^2}{N_D}} = \frac{(1.45\times10^{10})^2}{3\times10^{10}} = \frac{2.1025\times10^{20}}{3\times10^{10}}$$

$$= 0.7\times10^{10}$$

$$\therefore \boxed{p = 0.7\times10^{10}\ cm^{-3}}$$

$$\sigma = q(n\mu_n + p\mu_p)$$

$$\Rightarrow \sigma = 1.6\times10^{-19}(3\times10^{10}\times1250 + 0.7\times10^{10}\times475)$$

$$\Rightarrow \sigma = 1.6\times10^{-19}(3.75\times10^{13} + 3.325\times10^{12})$$

$$\Rightarrow \sigma = 1.6\times10^{-19}(4.0825\times10^{13}) = 6.532\times10^{-6}$$

$$\therefore \boxed{\sigma = 6.532\times10^{-6}\ s/cm}$$

$\therefore$ Total current density is given by $\boxed{J = \sigma E}$

$$\Rightarrow J = 6.532\times10^{-16}\times4 = 26.128\times10^{-6}$$

$$\therefore \boxed{J = 26.128\times10^{-6}\ A/cm^2}$$

2. find the concentration (densities of holes & e^{-}'s in N-type Si at 300°K, if the conductivity is 300 s/cm. Also find these values for p-type Si. Given that for Si at 300°K, $n_i = 1.5\times10^{10}/cm^3$, $\mu_n = 1300\ cm^2/V\text{-}s$, & $\mu_p = 500\ cm^2/V\text{-}s$

sol:- a. concentration in N-type Si :

conductivity of an N-type Si is given by $\boxed{\sigma = qn\mu_n}$

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$\Rightarrow$ Concentration of $\bar{e}$'s, $\boxed{n = \dfrac{\sigma}{q\mu_n}}$

$$\Rightarrow n = \frac{300}{1.6\times10^{-19}\times300} = \frac{300}{2.08\times10^{-18}} = 1.442\times10^{18}$$

$$\therefore \boxed{n = 1.442\times10^{18}\ cm^{-3}}$$

Concentration of holes, $\boxed{p = \dfrac{n_i^2}{n}}$

$$\Rightarrow p = \frac{(1.5\times10^{10})^2}{1.442\times10^{18}} = \frac{2.25\times10^{20}}{1.442\times10^{18}} = 1.56\times10^{2}$$

$$\therefore \boxed{p = 1.56\times10^{2}\ cm^{-3}}$$

b. Concentration in p-type Si:

Conductivity of a p-type Si is given by

$$\boxed{\sigma = pq\mu_p}$$

Concentration of holes is given by $\boxed{p = \dfrac{\sigma}{q\mu_p}}$

$$\Rightarrow p = \frac{300}{1.6\times10^{-19}\times500} = \frac{300}{8\times10^{-17}} = 3.75\times10^{18}$$

$$\therefore \boxed{p = 3.75\times10^{18}\ cm^{-3}}$$

Concentration of $\bar{e}$'s, $\boxed{n = \dfrac{n_i^2}{p}}$ $\Rightarrow n = \dfrac{(1.5\times10^{10})^2}{3.75\times10^{18}}$

$$\Rightarrow n = \frac{2.25\times10^{20}}{3.75\times10^{18}} = 0.6\times10^{2}$$

$$\therefore \boxed{n = 0.6\times10^{2}\ cm^{-3}}$$

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Drift & Diffusion Currents:

→ flow of charge, i.e current through a sc material are of two types, namely drift & diffusion.

→ The net current that flows through a PN Junction diode also has two components

(i) Drift current &

(ii) Diffusion current

(i) Drift current :– → Slow movement of air.

→ when an electric field is applied across the sc material, the charge carries attain a certain drift velocity V_d, which is equal to the product of mobility of charge carriers & applied electric field Intensity, E, As a result

→ The holes moves towards the –ve terminal of the battery & electrons moves towards +ve terminal of the battery,

→ This combined effect of movement of charge carriers constitute a current known as the drift current.

(or)

→ Drift current can be defined as the flow of electric current due to motion of charge carriers under the influence of external electric field.

→ Drift current density, J_n due to free $\bar{e}$'s is given by $\boxed{J_n = q n \mu_n E \quad A/cm^2}$

→ Drift current density, J_n due to ~~free e's~~ holes is given by $\boxed{J_n = q p \mu_p E \quad A/cm^2}$

where n = no. of free $\bar{e}$'s/ cubic. cm

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p = no. of holes / cubic cm. (cm^3)

μ_n = mobility of ē's in $cm^2/V\text{-}s$,

μ_p = mobility of holes in $cm^2/V\text{-}s$,

E = applied electric field strength in V/cm

q = charge of an ē = 1.6×10^{-19} columbs.

(ii) Diffusion Current:

→ In a sc material, the charge carriers have a tendency to move from the region of higher concentration to that of lower concentration of same type of carriers.

→ The movement of charge carriers takes place resulting in a current called as diffusion current.

→ Diffusion current depends on the material of the sc, type of charge carriers & concentration gradient.

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→ Diffusion current density due to holes, J_p is given by $\boxed{J_p = -q D_p \frac{dp}{dx} \; A/cm^2}$

→ D_n & D_p are diffusion coeff's in cm^2/s for $\bar{e}$'s & holes resp.

∵ Hole density $p(x)$ ↓es with ↑ing x as shown in fig (b), $\frac{dp}{dx}$ is −ve.

→ Diffusion current density due to free $\bar{e}$'s, J_n is given by $\boxed{J_n = q D_n \cdot \frac{dn}{dx} \; A/cm^2}$

→ Minus sign in the above eqn. is needed in order that J_p has a +ve sign in +ve x-direction.

→ Where $\frac{dn}{dx}$ & $\frac{dp}{dx}$ are concentration gradients for $\bar{e}$'s & holes resp.

Total current:

→ Total current in a sc is the sum of drift & diffusion current.

→ for a p-type sc, total current density is given by $\boxed{J_p = q p \mu_p E - q D_p \frac{dp}{dx}}$

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→ for a N-type sc, total current density is given by $\boxed{J_n = qn\mu_n E + qD_n \frac{dn}{dx}}$

Einstein Relationship for sc:

Equ which relates mobility (μ) and diffusion coeff D is known as Einstein relationship.

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

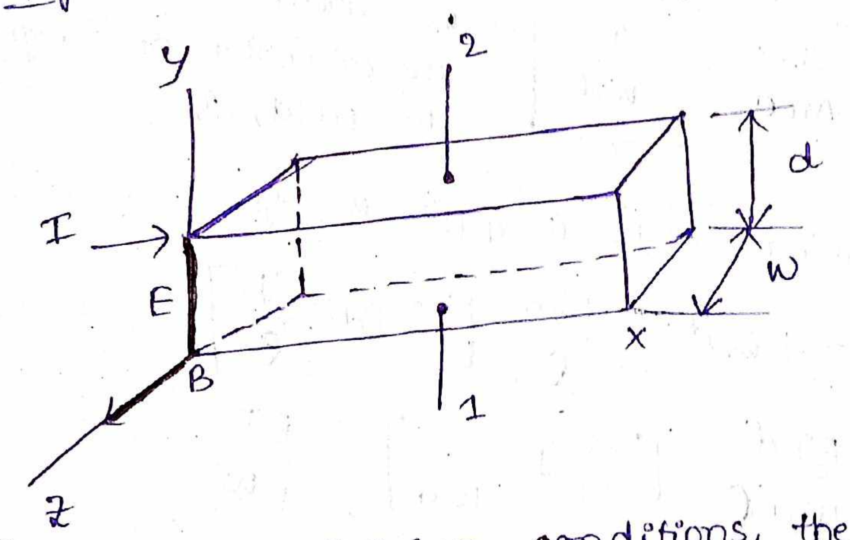
→ for an intrinsic sc, $D_p = 13\ cm^2/s$ & $D_n = 34\ cm^2/s$

→ for an intrinsic Ge, $D_p = 47\ cm^2/s$ & $D_n = 99\ cm^2$

Hall Effect:

→ When a transverse magnetic field B is applied to a specimen (thin strip of metal or sc) carrying current I, an electric field E is induced in the direction $\perp$ar to both I & B. This phenomenon is known as Hall Effect.

fig: Schematic diagram to observe the Hall Effect



→ Under equilibrium conditions, the E.F intensity E, due to hall effect must exert a force on

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the charge carrier q which balances the magnetic force i.e $\boxed{qE = Bqv_d}$

$$\Rightarrow \cancel{q}E = B\cancel{q}v_d$$

where v_d is drift velocity

$$\Rightarrow \boxed{E = Bv_d} \rightarrow ①$$

→ The Electric field intensity due to hall effect is given by $\boxed{E = \frac{V_H}{d}} \rightarrow ②$

where, d is the distance b/w surfaces 1 & 2

where, V_H is the Hall voltage b/w surfaces 1 & 2.

where, V_H is the Hall voltage b/w surfaces 1 & 2.

→ In a N-type sc, current is carried by $\bar{e}$'s, & these $\bar{e}$'s will be forced downwards side which becomes -ve ly charged w.r.t side 2.

→ Current density (J) is related to charge density(e) by $\boxed{J = e v_d}$

→ Current density (J) is related to current (I) by

$$\boxed{J = \frac{I}{Area} = \frac{I}{wd}}$$

w = width of the sc. in the direction of magnetic field, B.

→ By combining equ's ① & ②, we get

$$V_H = Ed = Bv_d d = \frac{BJd}{e} \quad \left[\because v_d = \frac{J}{e}\right]$$

$$= \frac{BI\cancel{d}}{w\cancel{d}e} \quad \left[\because J = \frac{I}{wd}\right] = \frac{BI}{ew}$$

$$\therefore \boxed{V_H = \frac{BI}{ew}} \rightarrow \text{Hall Voltage}$$

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→ Hall coefficient R_H is defined by $\boxed{R_H = \frac{1}{e}}$

$\therefore \boxed{R_H = \frac{V_H w}{BI}}$ $\therefore \boxed{V_H = \frac{R_H}{w} \cdot BI}$

→ R_H is +ve for p-type sc & R_H is -ve for N-type sc.

Advantages :-

→ Advantage of Hall effect is that they are non-contact devices with high resolution & small size.

Applications:

→ Hall effect is used to determine the carrier concentration (ni) & used to find whether a sc is N-type or p-type.

→ If terminal 2 becomes +vely charged w.r.t terminal, the sc must be N-type & is given by $\boxed{e = nq}$ where n is $\bar{e}$ concentration.

→ If terminal 1 becomes +vely charged w.r.t terminal 2, the sc must be p-type & is given by $\boxed{e = pq}$ where p is hole concentration.

→ Conductivity (σ) & mobility (μ) are related by the equ

$\Rightarrow \mu = \frac{\sigma}{e}$

$\boxed{\sigma = e\mu}$ (or) $\boxed{\mu = \sigma R_H}$

→ for N-type sc, $\boxed{\sigma = nq\mu_n \Rightarrow \mu_n = \frac{\sigma}{nq} = \sigma R_H}$

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→ for P-type SC, $\boxed{\sigma = pq\mu_p \Rightarrow \mu_p = \frac{\sigma}{pq} = \sigma R_H}$

→ It is also used in an instrument called Hall Effect Multiplier which gives o/p proportional to product of two i/p signals.

→ other applications are in measurement of velocity, RPM, sorting, limit sensing & non-contact current measurements.

Problems

1) An N-type sc has a Hall coefficent of 200 cm^3/c & its conductivity is 10 s/m find its electron mobility?

Sol: Given
$R_H = 200\ cm^3/c$, $\sigma = 10\ s/m$, $\mu_n = ?$

$\boxed{\mu_n = \sigma R_H} \Rightarrow \mu_n = 10 \times 200 = 2000$

$\boxed{\therefore \mu_n = 2000\ cm^2/v\text{-}s}$

2) the conductivity of an N-type sc is 10 s/m & its electron mobility is $50 \times 10^{-4}\ m^2/v\text{-}s$. Determine the e^- concentration!

Sol: Given $\sigma = 10\ s/m$, $\mu_n = 50 \times 10^{-4}\ m^2/v\text{-}s$

$n = ?$

w.k.t $\boxed{\mu_n = \frac{\sigma}{nq}}$

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e^- concentration $\boxed{n = \frac{\sigma}{\mu_n q}}$ $\Rightarrow n = \frac{10}{50\times10^{-4}}$

$\Rightarrow n = \frac{10}{50\times10^{-4}\times1.6\times10^{-19}}$

$= \frac{10}{8\times10^{-22}}$

$= 1.25\times10^{22}$

$= 12.5\times10^{21}$

$\boxed{n = 12.5\times10^{21}\ m^{-3}}$

3) A current of 20A is passed through a thin metal strip, which is subjected to a magnetic flux density of 1.2wb/m² the magnetic field is directed perpendicular to the current. the thickness of the strip in the direction of the magnetic field is 0.5mm. the Hall voltage is 60v. find the e^- concentration density.

Sol: Given $I = 20A$, $B = 1.2\ wb/m^2$, $V_H = 60v$

$w = 0.5mm$

$\boxed{n = \frac{BI}{V_H q w}}$ $n = \frac{1.2\times20}{60\times1.6\times10^{-19}\times0.5\times10^{-3}}$

$= \frac{24}{4.8\times10^{-21}} = 5\times10^{21}$

$\boxed{\therefore n = 5\times10^{21} m^{3}}$

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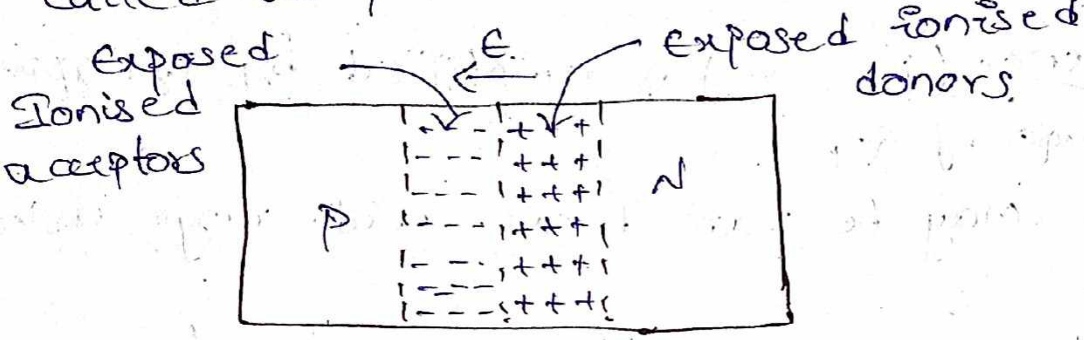
Theory of PN - Junction diode :

* In a SC material, if one half is doped by p-type impurity & other half doped by N-type impurity, a p-N Junction is formed.
* The plane dividing two halves or zones is called as pN-Junction.



fig(a):

→ As shown in fig-(a), N-type material has high concentration of free e's, while P-type material has high concentration of holes.

→ As free e^-'s move across the junction from N-type to P-type, the donor atoms become +vely charged. Hence a +ve charge is built on the N-side of junction.

→ As holes move across the junction from P-type to N-type, the acceptor atoms become -vely charged. Hence a -ve charge is built on P-side of the junction.

→ ∴ An electrostatic potential difference is established b/w P&N regions, which is called potential barrier, junction barrier, diffusions potential or contact potential.

→ magnitude of contact potential (v_0) varies with doping levels & temp.

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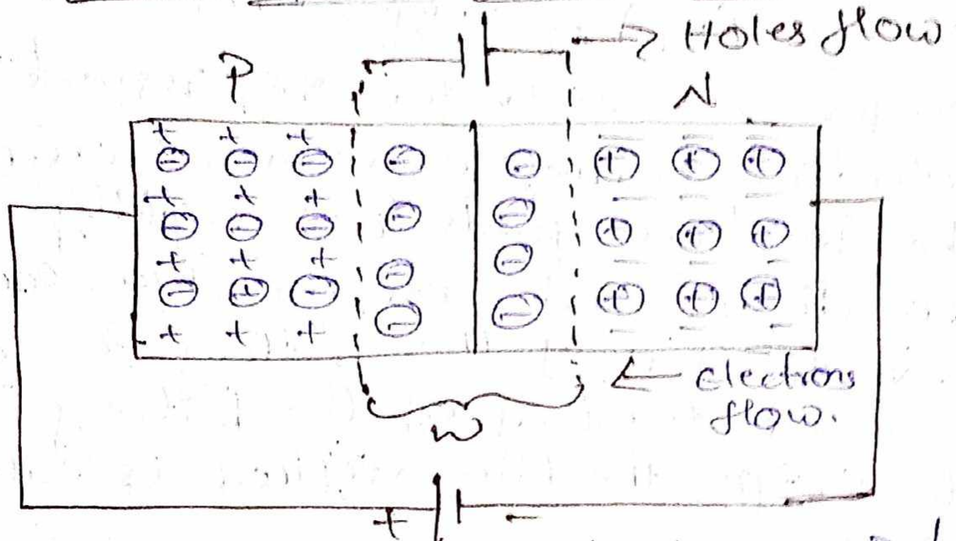
Vo is 0.3V for Ge & 0.6 to 0.72 v for si.

P-N Junction diode under forward Bias condition:

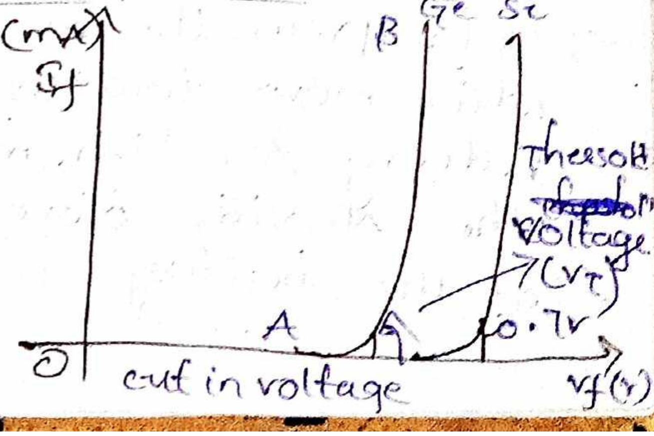
→ when +ve terminal of the battery is connected to P-type & -ve terminal of the battery is connected to N-type of the P-N junction diode, the bias applied is called as forward bias.

fig: P-N Junction diode under FB



* under FB condition, applied +ve potential repels the holes in P-type region so that holes moves towards the junction.
* Applied -ve potential repels the e⁻'s in N-type region so that e⁻'s moves towords the junction
* when the applied potential is more than internal barrier potential, the depletion region & internal barrier potential disappear.

V-I characteristics of P-N Junction diode:



→ As forward voltage (V_f) is ↑ed the forward current (I_f) is almost zero

→ for $V_f > V_0$, the potential barrier at the junction completly disappeas & holes cross the junction from p-type to n-type & the e^-'s cross the junction from n-type to p-type

→ As shown in the figure, cut-in-voltage (or) thersold voltage (V_T) is very small

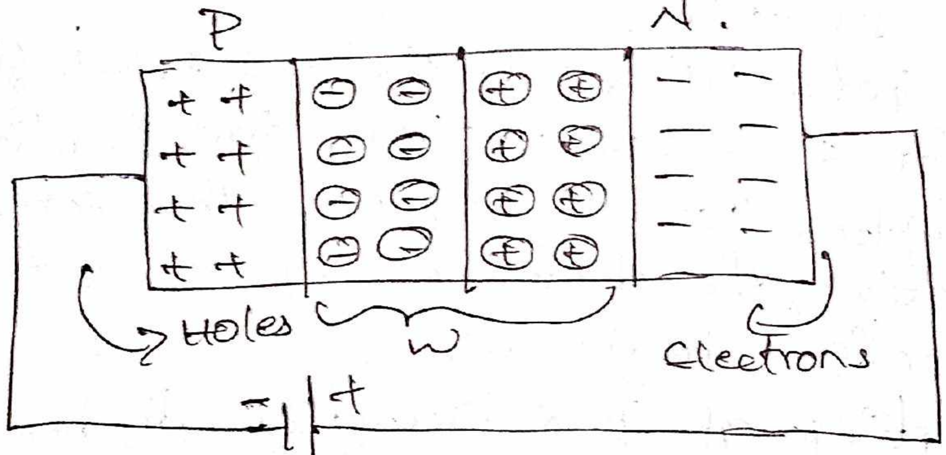
→ It is 0.3V for Ge & 0.7V for Si, respectively

→ At V_T, potential barrier overcomes & current through the junction starts to ↑ rapidly.

P-N Junction diode under Reverse Bias condition:

→ when the -ve terminal of the battery is connected to p-type & +ve terminal of the battery is connected to n-type, the bias applied is called as Reverse Bias.

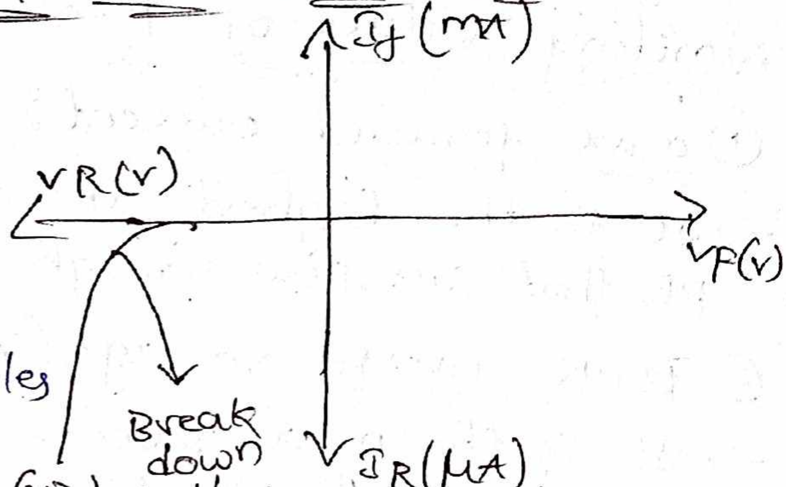
fig: P-N Junction diode under R.B



→ Holes from the majority carriers of the p-side which moves towords the -ve terminal of the battery & e^-'s from the majority carriers of the N-side moves towords the +ve terminal of the battery

→ Hence, width of the depletion region increased.
→ Hence, potential barrier is ↑ed which process the flow of majority carriers in both direction.

<u>V-I characteristics of P-N Junction diode</u> :-



* A very small current of the order of a few micro amperes flows under R.B as shown in the figure

→ under R.B condition, holes in the P-region are attracted towards -ve terminal of the battery & e^{-}'s in the N-region are attracted towards +ve terminal of the battery.
when it results in a current known as Reverse saturation current, I_R.
→ this leads to break-down voltage of the junction to very large reverse current.
→ Reverse voltage at which the junction break down occurs is known as Break-down voltage (VBD)

<u>P-N Junction diodes as Rectifier</u> :-
→ A P-N junction diode is a two terminal device
<u>i.e</u> polarity sensitive.
→ when the diode is FB, the diode conducts & allows current to flow through it without any resistance
<u>i.e</u> diode is ON.
→ when the diode is RB, the diode does not conduct & no current flows through it <u>i.e</u> diode is off

→ Ideal diode acts as a switch, either open or closed.

→ Ideal diode has zero resistance under FB & infinite resistance under RB

Limiting values of P-N junction diode:-

① max forward current:-

→ It is the highest instantaneous current under FB that can flow through the junction.

② Peak inverse voltage (PIV):-

→ It is the max reverse voltage that can be applied to the P-N junction.

→ If voltage across the junction exceeds PIV under R.B, the junction gets damaged.

③ max Power Rating

→ It is the max power that can be dissipated at the junction without damaging across the junction.

→ It is the product of voltage across the junction & current through the junction.

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UNIT - 1

Diode Applications

Rectifiers, filters & Regulators

* The circuits which converts a.c supply voltage into d.c supply voltage is called as the linear mode power (LMPS)
* The circuits which converts d.c supply voltage into d.c supply voltage is called as switched mode power supply (SMPS)

(i) LMPS : a.c/d.c power supply - converter

(ii) SMPS : a) d.c/d.c power supply - converter
b) d.c/a.c power supply - inverter.

* An a.c/d.c power supply converts a.c mains (230v, 50Hz) into required d.c voltages
* Dc/Dc power supplies (or) dc/dc converters are used in portable systems
* An inverter is a form of UPS (uninterrupted power supply) or SPS (stand by power supply) is very important and popular in computer systems.

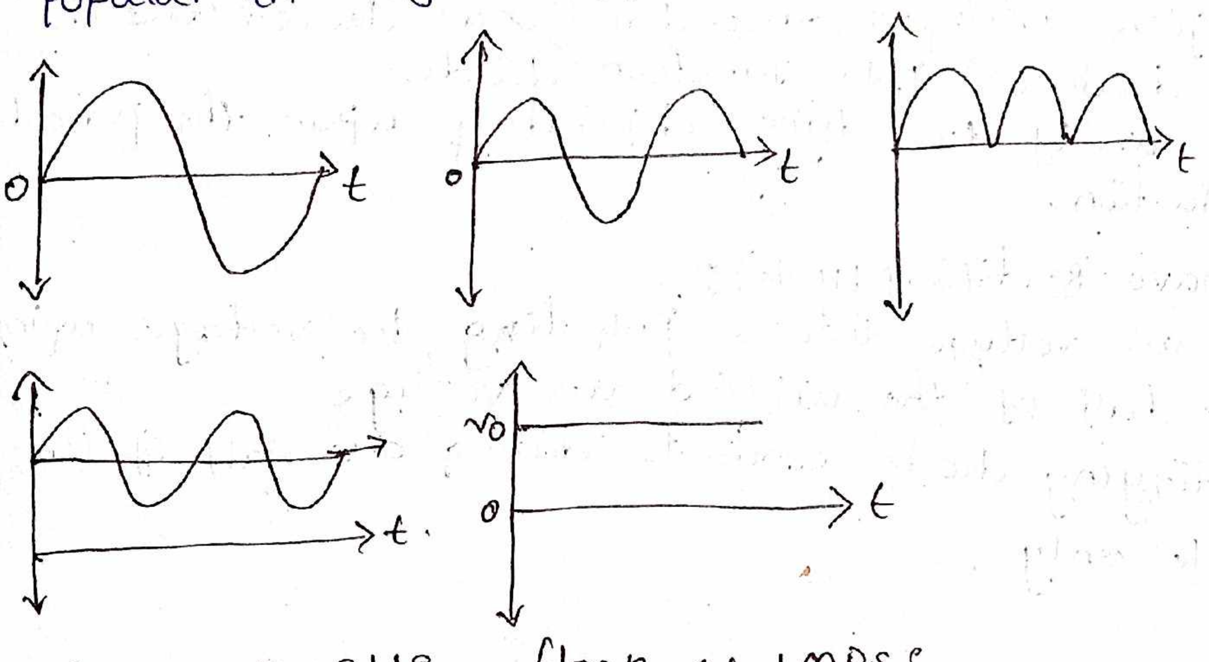
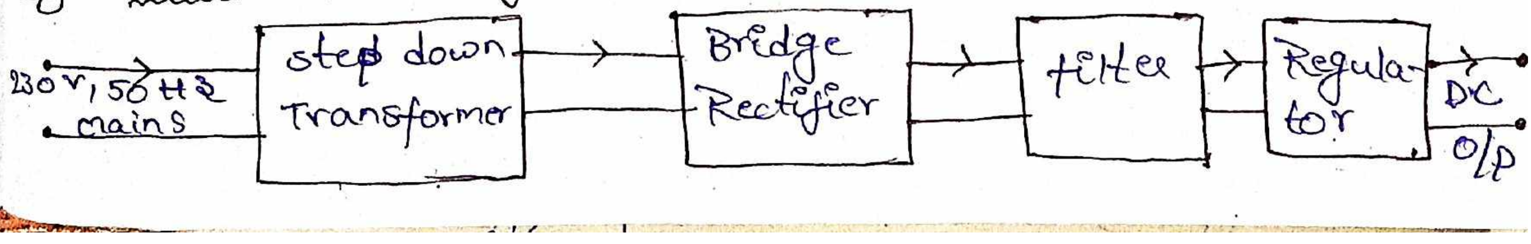


fig: Basic Building block of LMPS:



* Bi-directional a.c voltage is converted into a uni-directional Pulsating d.c voltage using a Rectifier.
* The unwanted ripple contents of pulsating d.c are Removed by filter to get pure d.c voltage.
* The o/p of filter is fed to a Regulator which give a steady dc o/p independent of load & i/p symbol/supply fluctuations.

Requirements of LMPS:-

(i) should be able to give minimum dc voltage at the rated current
(ii) Regulation of the power supply should be good.
(iii) a.c ripple should be low
(iv) power supply should be protected
(v) Response of power supply to temp changes should be minimum.

Rectifiers:-

* Rectifiers is used for converting a.c voltage into uni-directional d.c voltage.
* A rectifiers utilizes uni-directional device like a vaccum diode (or) PN - Junction diode
* Rectifier are of two types depending upon the period of conduction.

a) Half-wave Rectifier (HWR):-

* converts a.c voltage into a pulsating d.c voltage using only one half of the applied a.c voltage
* the Rectifying diode conducts during one half of the a.c cycle only.

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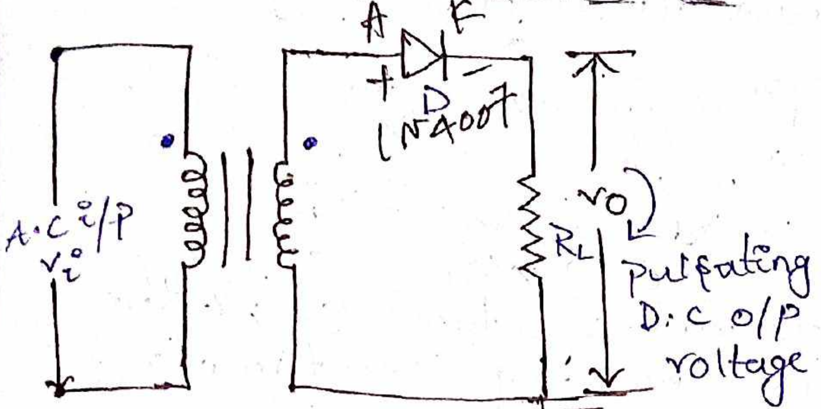
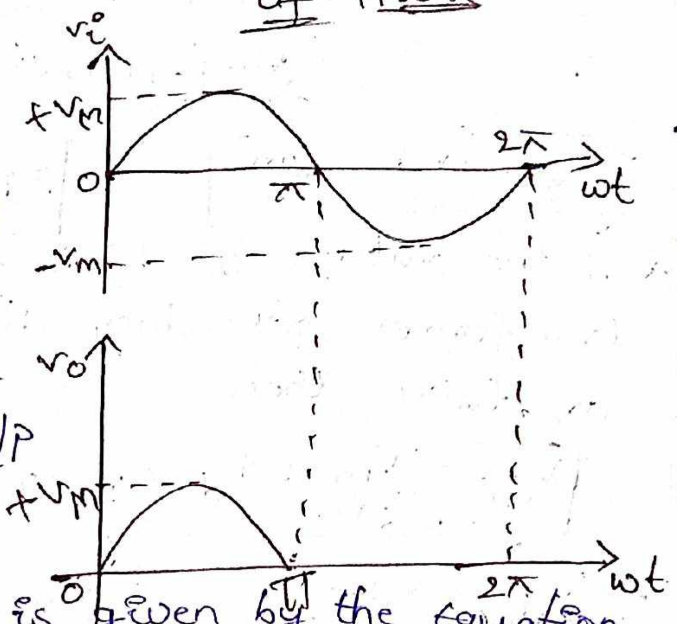
fig(a): Basic structure of HWR



fig(b): i/p & o/p wave forms of HWR



* fig(a) shows the basis circuit of HWR & fig (b) shows i/p & o/p wave forms of HWR
* Let v_i be the voltage to the primary of the transformer & is given by the equation

$\boxed{v_i = V_m \sin\omega t \; ; \; V_m >> V_\gamma}$ where V_γ cut in voltage of diode

* for an ideal diode, the forward voltage drop is zero
* During +ve half of the i/p signal, the anode of diode becomes more +ve w.r.t the cathode & hence D conducts.
* During -ve half of the i/p signal, the anode of diode becomes more -ve w.r.t the cathode & hence D doesn't conducts
* for an ideal diode, the impedence offered by the diode is infinity (∞). Hence, voltage drop across R_L is zero.

Ripple factor (Γ):-

* Ratio of rms value of a.c component to the d.c component in the o/p is known as ripple factor (Γ)

$$\Gamma = \frac{\text{rms value of a.c component}}{\text{d.c value of component}} = \frac{V_{r,rms}}{V_{dc}}$$

where $\boxed{V_{r,rms} = \sqrt{V_{rms}^2 - V_{dc}^2}}$ $\boxed{\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}}$

* V_{dc} is the average or d.c component of voltage across the load and is given by.

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V_{avg} (or) $V_{dc} = \frac{1}{2\pi}\left[\int_0^{\pi} V_m \sin\omega t \, d(\omega t) + \int_{\pi}^{2\pi} 0 \cdot d(\omega t)\right]$

$= \frac{V_m}{2\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{V_m}{\cancel{2}\pi} \times \cancel{2} = \frac{V_m}{\pi}$

$\therefore \boxed{V_{av} = V_{dc} = \frac{V_m}{\pi}}$ $\quad$ $\boxed{I_{dc} = \frac{V_{dc}}{R_L} = \frac{V_m}{\pi R_L} = \frac{I_m}{\pi}}$

* If the values of diode forward resistance (r_f) & the transformer secondary diode winding Resistance (r_s) are taken, then

$$\boxed{V_{dc} = \frac{V_m}{\pi} - I_{dc}(r_s + r_f)}$$

$\Rightarrow I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{V_m}{\pi(r_s + r_f + R_L)}$ $\quad$ $\boxed{I_{dc} = \frac{V_m}{\pi(r_s + r_f + R_L)}}$

* Rms voltage at the Load Resistance can be calculated as $\boxed{V_{rms} = V_m/2}$

$\therefore \Gamma = \sqrt{\left(\frac{V_m/2}{V_m/\pi}\right)^2 - 1} = \sqrt{(\pi/2)^2 - 1} = 1.21$

$\boxed{\Gamma = 1.21}$ $\quad$ $\left[\because V_{rms} = \left[\frac{1}{2\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \, d(\omega t)\right]^{1/2}\right.$

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

$\left. = V_m/2 \right]$

* Half wave rectifier is not practically useful in converting a.c into d.c

Efficiency (η):-

* The ratio of d.c o/p power to a.c i/p power is known as rectifier efficiency (η).

$$\therefore \boxed{\eta = \frac{\text{d.c o/p power}}{\text{a.c i/p power}} \times 100 = \frac{P_{dc}}{P_{ac}}}$$

$\therefore \eta = \frac{(V_{dc})^2}{R_L} \Big/ \frac{(V_{rms})^2}{R_L} \Rightarrow \eta = \frac{(V_m/\pi)^2}{(V_m/2)^2} = \frac{4}{\pi^2} \times 100$

$$\boxed{\eta = 0.406 = 40.6\%}$$

$$V_{rms} = \frac{1}{2\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t$$

$$= \frac{1}{4\pi} \int_0^{\pi} V_m^2 \sin^2 \omega t \quad]^{1/2}$$

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

$$= \frac{V^2 m}{4\pi} \left[\int_0^{\pi} \sin^2 \omega t \; d(\omega t) \right]^{1/2}$$

$$= \frac{Vm}{4\pi} \left[(1 - \cos^2 \omega t)_0^{\pi} \right]^{1/2}$$

$$= \frac{Vm}{4\pi} \left(1 - \cos 2\pi - \cos 2(0) \right]^{1/2}$$

$$= \frac{Vm}{4\pi} \left(\pi - \frac{\cos 2t}{2} \right)$$

$$\boxed{V_{rms} = \frac{Vm}{2}} \rightarrow (10)$$

$$\Gamma = \sqrt{\left(\frac{\frac{Vm}{2}}{\frac{Vm}{\pi}} \right)^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1}$$

$$\boxed{\Gamma = 1.21} \rightarrow (11).$$

a) efficiency: ...

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$\therefore$ $\boxed{\text{max efficiency of HWR is } 40.6\%}$

Peak Inverse voltage (PIV):

* maximum reverse voltage that a diode can withstand without damaging the junction.
* PIV voltage across a diode is the peak of the -ve half cycle.
* for HWR, $\boxed{\text{PIV is } V_m}$

Transformer utilisation factor (TUF):

$$\boxed{TUF = \frac{\text{dc power delivered to the load}}{\text{a.c rating of the secondary transformer}}}$$

$$\boxed{\therefore TUF = \frac{P_{dc}}{P_{ac\ rated}}}$$

* In HWR ckt, the rated voltage of the secondary transformer is $\boxed{V_m/\sqrt{2}}$
* But actual rms current flowing through the winding is only $\boxed{\frac{I_m}{2}}$ not $I_m/\sqrt{2}$

$$\Rightarrow TUF = \frac{I_m^2}{\pi^2} R_L \Big/ \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{\frac{V_m^2}{\pi^2} \times \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \times \frac{V_m}{2R_L}} = \frac{2\sqrt{2}}{\pi^2} = 0.287$$

$$\boxed{\therefore TUF \text{ of a HWR is } 0.287}$$

form factor:

$$\boxed{\text{Form factor} = \frac{\text{Rms value}}{\text{average value}}}$$

$$\Rightarrow \boxed{FF = \frac{V_m/2}{V_m/\pi}} \qquad \Rightarrow FF = \pi/2 = 1.57.$$

$$\boxed{\therefore \text{Form factor of HWR (FF)} = 1.57}$$

Peak factor:

$$\boxed{\text{Peak factor} = \frac{\text{Peak value}}{\text{rms value}}}$$

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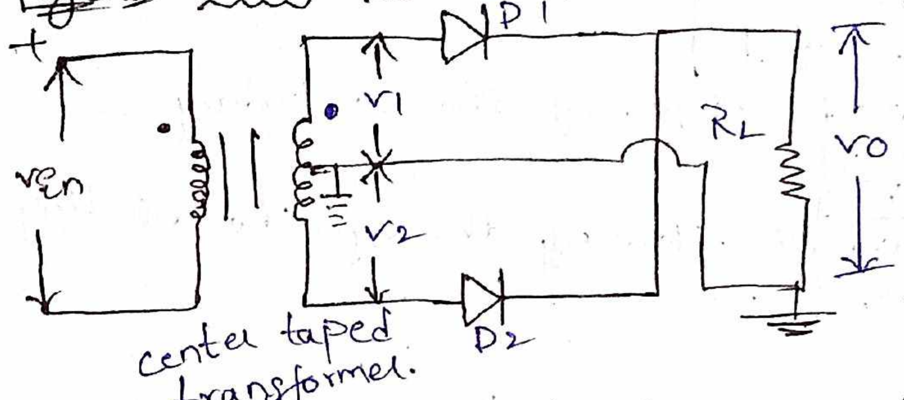
$\Rightarrow PF = \frac{V_m}{V_m/2}$ ∴ $\boxed{\text{peack factor of HWR} = 2}$

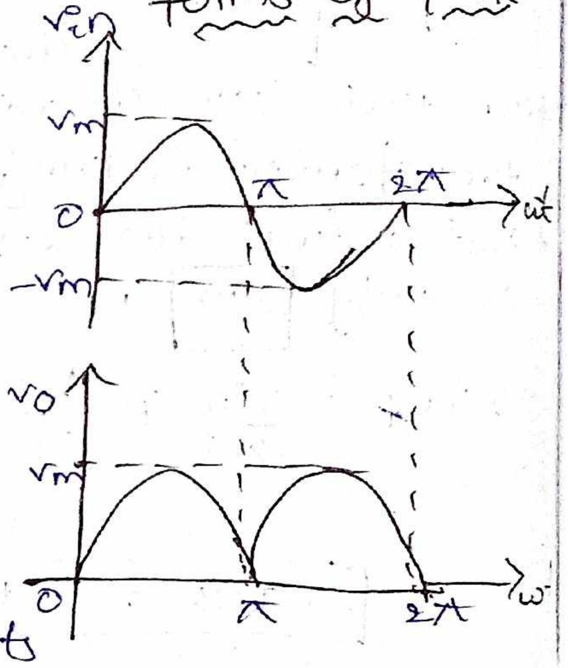
* Full-wave Rectifier :

* It converts an a.c voltage into a pulsating d.c voltage using both half cycles of applied a.c voltage.
* It used two diodes of which one conducts during one half-cycle while the other diodes conducts during other half-cycle of the applied a.c voltage.
* fig(a) shows the basic ckt of FWR & fig(b) shows the i/p & o/p wave forms of FWR

fig(a): Basic ckt of FWR



fig(b): i/p & o/p wave forms of FWR



* During +ve half of i/p signal, anode of diode D_1 becomes +ve and at the same time anode of diode D_2 becomes -ve. Hence D_1 conducts & D_2 does not conducts

∴ R_L flows through D_1.

* During -ve half of i/p signal, anode of diode D_1 becomes -ve & anode of diode D_2 becomes +ve. Hence D_1 does not conduct & D_2 conducts

∴ R_L flows through D_2

Ripple factor (Γ) (Gamma) $\boxed{\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}}$

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* Average voltage or d.c voltage across load resistance R_L is given by $V_{dc} = \frac{1}{\pi}\int_0^{\pi} V_m \sin\omega t \; d(\omega t)$

$$= \frac{V_m}{\pi}\left[-\cos\omega t\right]_0^{\pi} = \frac{V_m}{\pi} \times 2 = \frac{2V_m}{\pi}$$

$\therefore \boxed{V_{dc} = \frac{2V_m}{\pi}}$ $\therefore \boxed{V_{av} = V_{dc} = \frac{2V_m}{\pi}}$

$I_{dc} = \frac{V_{dc}}{R_L} \Rightarrow I_{dc} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}$ $\boxed{I_{dc} = \frac{2I_m}{\pi}}$

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

* If the diode forward resistance (r_f) & transformer secondary winding resistance (r_s) are taken, then

$$\boxed{V_{dc} = \frac{2V_m}{\pi} - I_{dc}(r_s + r_f)}$$

$$I_{dc} = \frac{V_{dc}}{(r_s + r_f) + R_L} = \frac{2V_m}{\pi(r_s + r_f + R_L)}$$

$$\boxed{\therefore I_{dc} = \frac{2V_m}{\pi(r_s + r_f + R_L)}}$$

* Rms value of voltage at R_L is given by

$$V_{rms} = \sqrt{\left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \; d(\omega t)\right]} = \frac{V_m}{\sqrt{2}}$$

$$\boxed{\therefore V_{rms} = V_m/\sqrt{2}}$$

$$\therefore \Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} = \sqrt{\left(\frac{V_m/\sqrt{2}}{2V_m/\pi}\right)^2 - 1} = \sqrt{\pi^2/8 - 1} = 0.482 \text{ (or) } 0.483.$$

$$\therefore \boxed{\Gamma = 0.482 \text{ (or) } 0.483}.$$

Efficiency (η):-

* Ratio of d.c o/p power to a.c i/p Power is known as rectifier efficiency (η).

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$$\therefore \eta = \frac{\text{d.c o/p power}}{\text{a.c i/p power}} \times 100 = \frac{P_{dc}}{P_{ac}}$$

$$\Rightarrow \eta = \frac{(V_{dc})^2/R_L}{(V_{rms})^2/R_L} = \left[\frac{2V_m/\pi}{V_m/\sqrt{2}}\right]^2 = \frac{8}{\pi^2} = 0.812 \times 100$$

$$\boxed{\therefore \eta = 81.2\%}$$

$\therefore$ $\boxed{\text{max. efficiency of a FWR is } 81.2\%}$

Transformer utilisation factor (TUF):

* Average TUF in a FWR is determined by primary and secondary winding seperately and gives a value of 0.812

$$\boxed{\text{TUF of a FWR} = 0.693}$$

form factors:-

$$\boxed{\text{Form factor} = \frac{\text{rms value of o/p voltage}}{\text{avg value of o/p voltage}}}$$

$$\Rightarrow FF = \frac{V_m/\sqrt{2}}{2V_m/\pi} = \frac{V_m}{\sqrt{2}} \times \frac{\pi}{2V_m} = \frac{\pi}{2\sqrt{2}} = 1.11$$

FF of FWR = 1.11

Peak Factor:-

$$\text{peak factor} = \frac{\text{peak value of o/p voltage}}{\text{rms value of o/p voltage}}$$

$$\Rightarrow PF = V_m \Big/ \frac{V_m}{\sqrt{2}} = \sqrt{2} \qquad \boxed{\therefore \text{PF of FWR} = \sqrt{2}}$$

$$\boxed{\therefore \text{PIV for FWR is } 2V_m}$$

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1) Ripple factor (γ):

$$\gamma = \frac{\text{ratio of rms value of ac component}}{\text{dc value of component}} \quad \text{--- (2)}$$

$$\gamma = \frac{V_{r\,rms}}{V_{dc}}$$

where $V_{r,rms} = \sqrt{V^2_{rms} - V^2_{dc}}$

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} \quad \text{--- (3)}$$

→ Average or DC value of component flow across R_L is given by ;

$$V_{avg} \text{ (or) } V_{dc} = \frac{1}{\pi}\left[\int_0^{\pi} V_m \sin\omega t \, d(\omega t)\right].$$

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

$$= \frac{V_m}{\pi}\left[-\cos\pi + \cos 0\right]$$

$$= \frac{V_m}{\pi}\left[-(-1)+1\right] = \frac{2V_m}{\pi}$$

$$\boxed{V_{dc} = \frac{2V_m}{\pi}} \quad \text{--- (4)}$$

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

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

$$\boxed{I_{dc} = \frac{2I_m}{\pi}} \quad \text{--- (5)}$$

→ If diode contains both forward & secondary resistance is given by

$$\boxed{V_{dc} = \frac{2V_m}{\pi} - I_{dc}(r_s + r_f)} \quad \text{--- (6)}$$

$$I_{dc} = \frac{V_{dc}}{r_s + r_f + R_L}$$

$$I_{dc} = \frac{2V_m}{\ldots} \quad \text{--- (7)}$$

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

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

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

$$\boxed{V_{rms} = \frac{V_m}{\sqrt{2}}} \longrightarrow (8)$$

$$\rho = \sqrt{\left(\frac{\left(\frac{V_m}{\sqrt{2}}\right)}{\frac{2V_m}{\pi}}\right)^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{\rho = 0.483} \longleftarrow (9)$$

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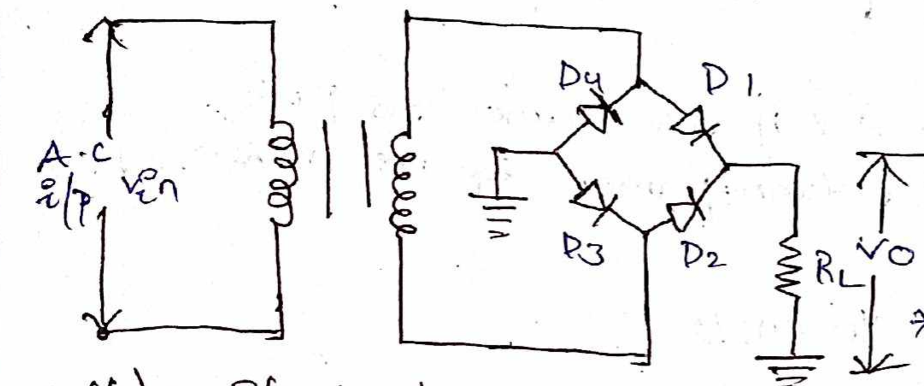
Bridge Rectifier:-

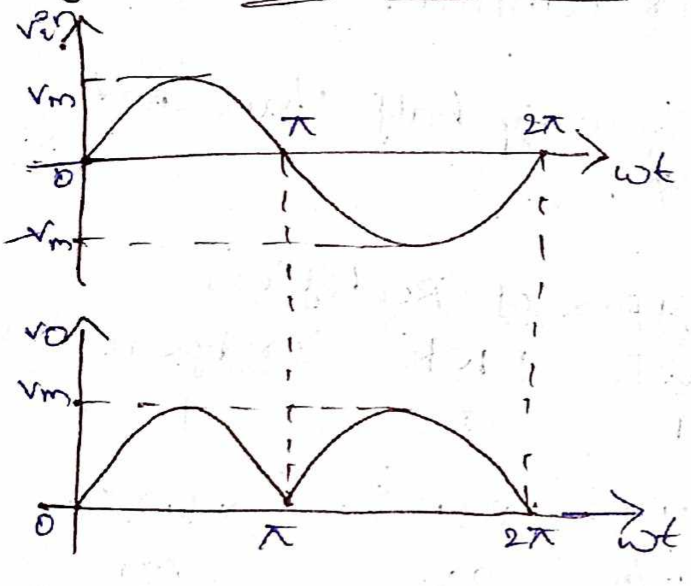
* Need for a center tapped transformer in a FWR is eliminated in the bridge rectifier
* Bridge rectifier has four diodes connected to form a bridge as shown in the fig (a)

fig(a): Bridge Rectifier:



* AC i/p voltage is applied to diagonally opposite ends of bridge
* RL is connected b/w other two ends of bridge
* During +ve half cycle of the i/p ac voltage diodes D_1 & D_3 conducts whereas diodes D_2 & D_4 doesnot conducts.
* conducting diodes D_1 & D_3 will be in series through RL
* During −ve half cycle of i/p a.c voltage, diodes D_2 & D_4 conducts where as diodes D_1 & D_3 does not conducts.

fig(b): I/p & O/p wave forms:



* conducting diodes D_2 & D_4 will be in series through RL
* then, a bi-directional wave is converted into a uni-directional one.

$$\boxed{V_{dc} = \frac{2V_m}{\pi} \ \& \ I_{dc} = \frac{V_{dc}}{R_L} = \frac{2V_m}{\pi R_L} = \frac{2I_m}{\pi}}$$

* If the values of transformer secondary winding resistance (r_s) & diode forward resistance (r_f) are taken, then

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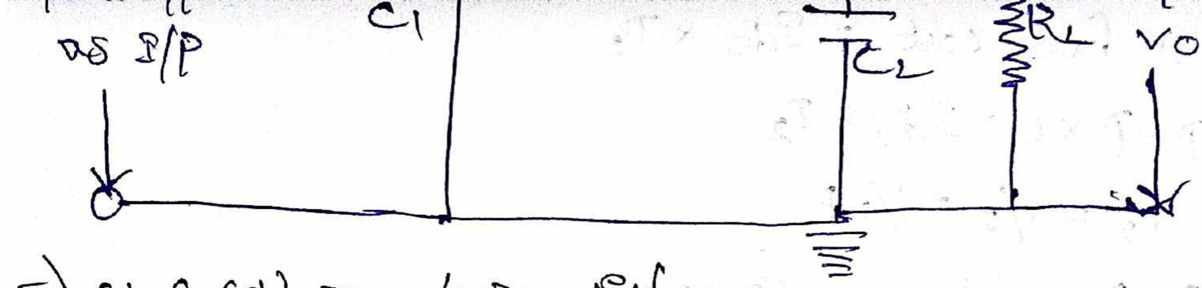
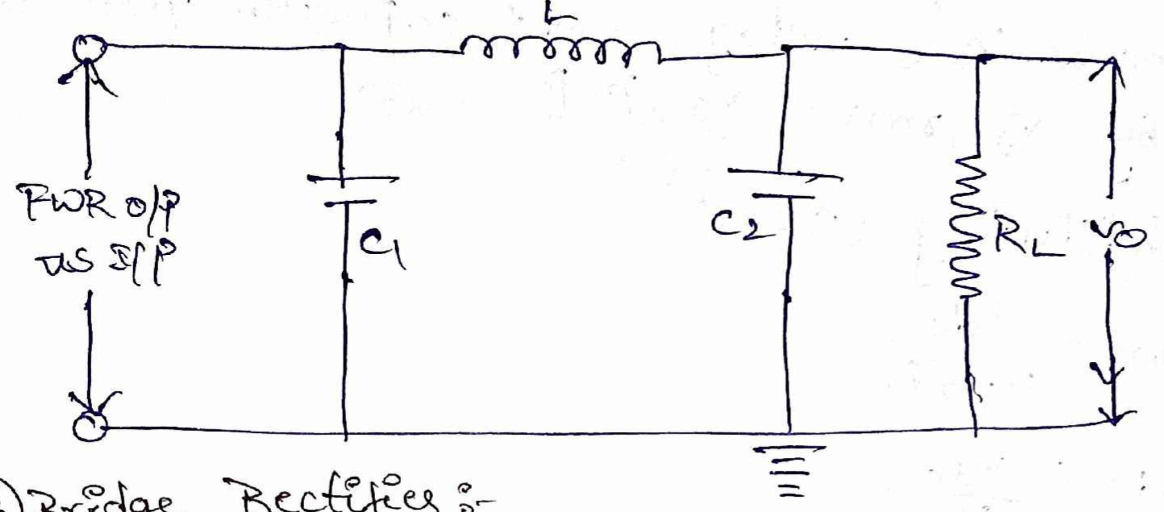


5) CLC (or) π – type filter



3) Bridge Rectifier :-

Diagram are already drawn

Let v_i be the i/p voltage to the primary of a transformer which is given by

$$\boxed{v_i = v_M \sin \omega t} \rightarrow (1)$$

where $v_m >> v_\gamma \rightarrow$ cut-in voltage

$v_\gamma = 0.3v$ for Ge

$v_\gamma = 0.6v$ for si

(1) Ripple factor:- (Γ)

$$\Gamma = \text{Ratio of } \frac{\text{rms value of a.c component}}{\text{d.c value of component}} \rightarrow (2)$$

$$\Gamma = \frac{v_{rms}}{v_{dc}} \rightarrow (3)$$

where $v_{r.rms} = \sqrt{v_{rms}^2 - v_{dc}^2} \rightarrow (4)$

substitute (4) in (1).

$$\Gamma = \frac{\sqrt{V_{rms}^2 - V_{dc}^2}}{V_{dc}}$$

$$\Gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1} \rightarrow (5)$$

Average (or) dc component across R_L is given by

$$V_{avg} \text{ (or) } V_{dc} = \frac{1}{\pi}\left[\int_0^{\pi} V_M \sin\omega t \, d(\omega t)\right]$$

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

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

$$\boxed{V_{dc} = \frac{2V_M}{\pi}} \rightarrow (6)$$

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

$$= \frac{2V_M}{\pi R_L}$$

$$\boxed{I_{dc} = \frac{2I_M}{\pi}} \rightarrow (7)$$

If diode contains both r_f & r_s are taken into consideration then

$$V_{dc} = \frac{2V_M}{\pi} - I_{dc}(r_s + r_f) \rightarrow (8)$$

$$I_{dc} = \frac{V_{dc}}{r_s + r_f + R_L}$$

$$I_{dc} = \frac{2V_m}{\pi(r_s + r_f + R_L)} \rightarrow (9)$$

$$V_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t \; d(\omega t)\right]^{1/2}$$

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

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

$$= V_m\left[\frac{1}{2\pi}(\omega t)_0^{\pi} - \left(\frac{\sin 2\omega t}{2}\right)_0^{\pi}\right]^{1/2}$$

$$\boxed{\therefore V_{rms} = \frac{V_m}{\sqrt{2}}} \rightarrow 10$$

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

$$\Gamma = \sqrt{\frac{\pi^2}{8} - 1}$$

$$\boxed{\Gamma = 0.482} \rightarrow (11)$$

(ii) efficiency (η):-

$$\eta = \frac{\text{dc o/p power}}{\text{ac i/p power}} \times 100 \rightarrow (12)$$

$$\eta = \frac{P_{dc}}{P_{ac}} \times 100$$

$$\eta = \frac{V_{dc}^2 / R_L}{V_{rms}^2 / R_L} \times 100$$

$$\eta = \frac{4V_m^2/\pi^2 \times \frac{1}{R_L}}{\frac{V_m^2}{2} \times \frac{1}{R_L}} \times 100$$

$$\eta = \frac{8}{\pi^2} \times 100$$

$$\boxed{\eta = 81.056\%} \rightarrow (13)$$

(iii) Peak Inverse voltage (PIV):-

$$\boxed{PIV = V_m} \rightarrow (14)$$

(iv) Transformer utilization factor (TUF):-

$$TUF = \frac{\text{d.c power delivered to the load}}{\text{a.c rated power}} \rightarrow (15)$$

$$TUF = \frac{P_{dc}}{P_{ac\ rated}}$$

$$TUF = \frac{V_{dc}^2 / R_L}{V_{rms} \times I_{rms}} := \frac{4V_m^2/\pi^2 \times \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}}$$

$$= \frac{4V_m^2 / \pi^2 \times \frac{1}{R_L}}{\frac{V_m}{\sqrt{2}} \times \frac{V_m}{\sqrt{2} R_L}}$$

$$= \frac{8}{\pi^2} = 0.812$$

$$\boxed{TUF = 0.812} \rightarrow (17)$$

(v) form factor (FF):

$$FF = \frac{\text{rms value}}{\text{Average value}} \rightarrow (18)$$

$$FF = \frac{\pi}{2\sqrt{2}} = 1.11$$

$$\boxed{FF = 1.11} \rightarrow (19)$$

(vi) Peak factor (PF):

$$PF = \frac{\text{Peak value}}{\text{rms value}} \rightarrow (20)$$

$$PF = \frac{V_m}{\frac{V_m}{\sqrt{2}}}$$

$$\boxed{PF = \sqrt{2} = 1.414} \rightarrow (21)$$

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comparision of Rectifiers

S.No	Parameters	HWR	FWR	BR
1	Diodes	1	2	4
2	V_{dc}	$\frac{V_m}{\pi}$	$\frac{2V_m}{\pi}$	$\frac{2V_m}{\pi}$
3	I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
4	Ripple factor(Γ)	1.21	0.482	0.482
5	efficiency (η)	40.5%	81.05	81.05%
6	PIV	V_m	$2V_m$	V_m
7	o/p frequency	f	2f	2f
8	TUF	0.286	0.693	0.812
9	form factor	1.57	1.11	1.11
10	peak factor	2	$\sqrt{2}$	$\sqrt{2}$
11	V_{rms}	$\frac{V_m}{2}$	$\frac{V_m}{\sqrt{2}}$	$\frac{V_m}{\sqrt{2}}$
12	I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$

$\boxed{V_{dc} = \frac{2V_m}{\pi} - I_{dc}(r_s + r_f)} \Rightarrow I_{dc} = \frac{2V_m}{\pi} = \frac{2V_m}{\pi(r_s+r_f+R_L)}$

$\boxed{I_{dc} = \frac{2V_m}{\pi(r_s+r_f+R_L)}}$

$\boxed{\text{max. efficiency of bridge rectifier is } 81.2\%}$

$\boxed{\text{Ripple factor } \Gamma = 0.48}$ $\boxed{PIV = V_m}$

Advantages:

(i) In the Bridge rectifier Γ & η are same as FWR.

(ii) Bulky center tapped transformer is not required.

(iii) PIV is V_m

(iv) TUF is high & ↑ to 0.812

Disadvantages:

(i) It requires four diodes as compared to two diodes for center - tapped FWR

(ii) PIV in a bridge rectifier is only half than that for a center tapped FWR.

-mparision of Rectifiers

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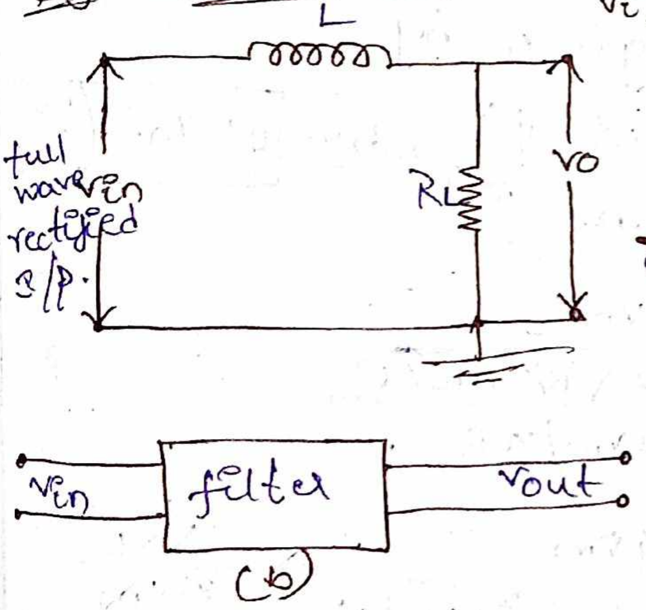
9	form factor	1.57	1.11	1.11
10	Peak factor	2	$\sqrt{2}$	$\sqrt{2}$

Filters:-

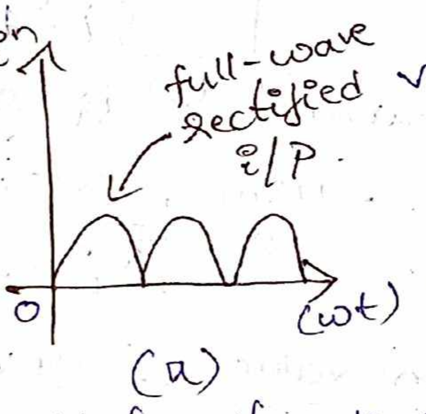
* o/p of a rectifier contains dc component as well as ac component.
* Filters are used to minimise the undesirable a.c i.e. leaving only the d.c component to appear at the o/p.
* o/p of a filter is not exactly a constant dc component, but it is also contains a small amount of a.c component
* filters are four types
  a) inductor filter
  b) capacitor filter
  c) LC/L-section filter
  d) CLC/π-type filter.

a) Inductor filter:-

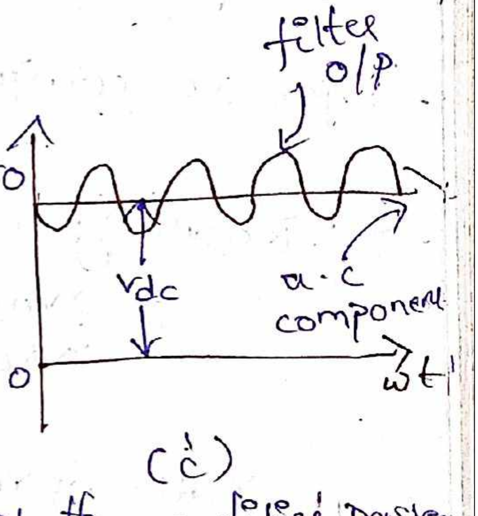
fig: concept filter:



(b)



(a)



(c)

* when the o/p of the rectifier passes through an inductor it blocks a.c component & allows only d.c component to reach the load

* Ripple factor of the inductor filter is given by.

$$\boxed{r = \frac{R_L}{3\sqrt{2}\,\omega L}}$$

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* It shows that Ripple factor (γ) will ↓ when L is ↑ed & R_L is ↓ed

* for analysing this filter for a FW, the fourier series can be written as $\boxed{V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{\pi}\left[\frac{1}{3}\cos 2\omega t + \frac{1}{15}\cos 4\omega t + \frac{1}{35}\cos 6\omega t + \cdots\right]}$

$\boxed{\text{D.C component is } \frac{2V_m}{\pi}}$

* Assuming 3rd and higher terms contribute little o/p the o/p voltage is $\boxed{V_0 = \frac{2V_m}{\pi} - \frac{4V_m}{3\pi}\cos 2\omega t}$

* Diode, choke & transformer resistance can be neglected since they are very small as compared with R_L

→ ∴ dc component of current $\boxed{I_m = \frac{V_m}{Z}}$

→ Impedence of series combination of L & R_L at 2ω is

$$Z = \sqrt{R_L^2 + (2\omega L)^2} = \sqrt{R_L^2 + 4\omega^2 L^2} \quad \therefore \boxed{Z = \sqrt{R_L^2 + 4\omega^2 L^2}}$$

→ for ac component $\boxed{I_m = \frac{V_m}{\sqrt{R_L^2 + 4\omega^2 L^2}}}$

→ ∴ Resulting current 'i' is given by

$$i = \frac{2V_m}{\pi R_L} - \frac{4V_m}{3\pi}\frac{\cos(2\omega t - \psi)}{\sqrt{R_L^2 + 4\omega^2 L^2}} \quad \text{where } \boxed{\psi = \tan^{-1}\left(\frac{2\omega L}{R_L}\right)}$$

$$\Rightarrow \Gamma = \frac{\text{Ratio of rms value}}{\text{dc value}} = \frac{\frac{4V_m}{3\pi\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}}}{2V_m/\pi R_L}$$

$$= \frac{\overset{2}{\cancel{4}}\cancel{V_m}}{3\cancel{\pi}\sqrt{2}\sqrt{R_L^2 + 4\omega^2 L^2}} \times \frac{\cancel{\pi} R_L}{\cancel{2}\cancel{V_m}}$$

$$= \frac{2}{3\sqrt{2}} \times \frac{1}{\sqrt{1 + \frac{4\omega^2 L^2}{R_L^2}}}$$

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→ If $\frac{4\omega^2L^2}{R_L^2} >> 1$, then expression for Γ is $\boxed{\Gamma = \frac{R_L}{3\sqrt{2}\omega L}}$

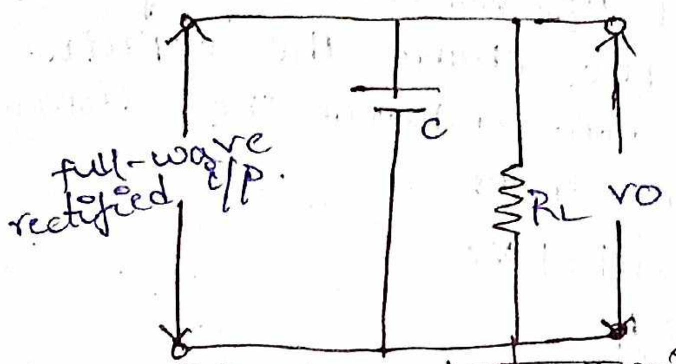
→ In case if R_L is ∞, i.e. o/p is open ckt, then Γ is $\Gamma = \frac{2}{3\sqrt{2}} = 0.471$ ∴ $\boxed{\Gamma = 0.471}$

→ this is slightly less than the value of 0.482

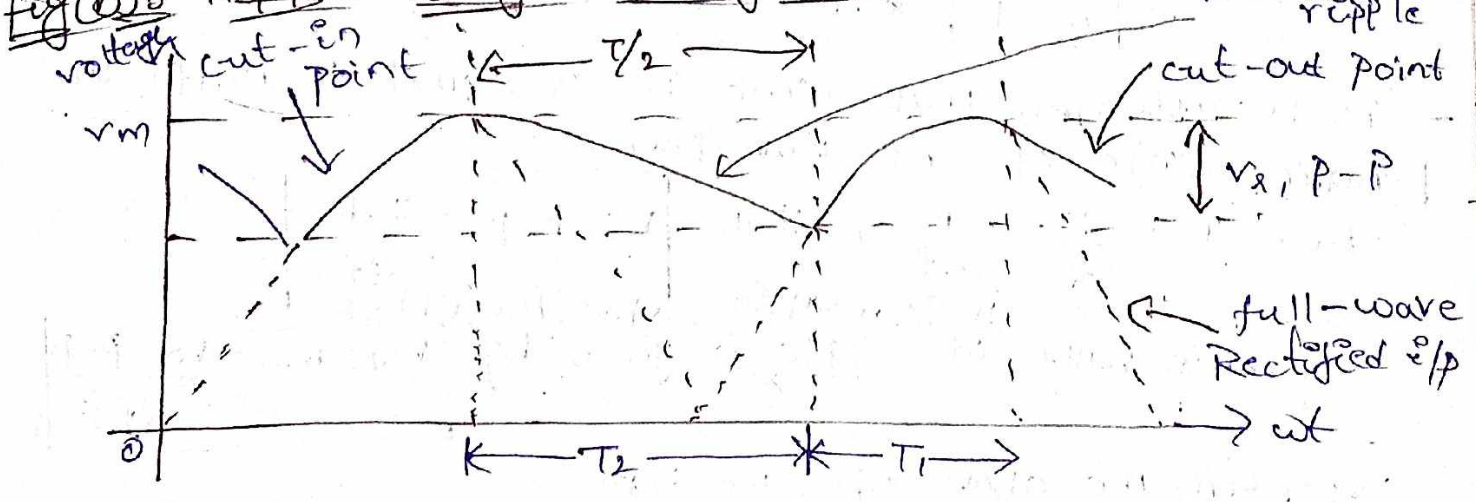
→ ∴ Inductor filter should only be used where R_L is small.

capacitor filters

fig(a):- ckt for capacitor filter:



fig(b):- Ripple voltage Traingular wave form



- An inexpensive filter for light loads is found in the capacitor filter which is connected directly across load is shown in fig (a)
- Property of a capacitor is that it allows ac component & blocks dc component
- During +ve half cycle, the capacitor charges upto the peak value of the transformer secondary

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Voltage V_m & try to maintain this value as the full wave i/p drops to zero

- Diode conducts for a period which depends on the capacitor voltage (equal to the load voltage)
- Diode will conduct when V_m becomes more than 'cut-in' voltage of the diode.
- Diode stops conducting when V_m becomes less than diode voltage. This is called 'cut-out' voltage
- Ripple voltage waveform with slight approximation can be assumed as triangular.
- From cut-in pt to cut-out pt, whatever charge the capacitor aquires is equal to the charge the capacitor has lost during the period of non-conductor, i.e., from cut-out pt to the next cut-in pt
- charge it has acquired $= V_{r,P-P} \times C$
- Charge it has lost $= I_{dc} \times T_2$

$$\therefore \boxed{V_{r,P-P} \times C = I_{dc} \times T_2}$$

- It is assumed that time T_2 is equal to half the periodic time of the waveform

i.e. $T_2 = \frac{T}{2} = \frac{1}{2f}$, then $\boxed{V_{r,P-P} = \frac{I_{dc}}{2fC}}$

in general for capacitor filter

$\therefore$ Rms value of ripple is given by $\boxed{V_{r,rms} = \frac{V_{r,P-P}}{2\sqrt{3}}}$

$\therefore$ From the above eqn, we have

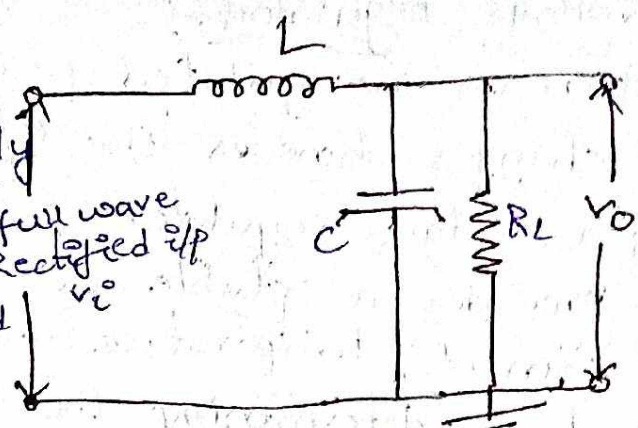
$$\boxed{V_{r,rms} = \frac{I_{dc}}{4\sqrt{3}fC}} = \frac{V_{dc}}{4\sqrt{3}fCR_L} \quad \left(\because \boxed{I_{dc} = \frac{V_{dc}}{R_L}}\right)$$

$$\boxed{r = \frac{V_{r,rms}}{V_{dc}} = \frac{1}{4\sqrt{3}fCR_L}} = \frac{1}{346.41 \times CR_L} = \frac{2.886 \times 10^{-3}}{CR_L}$$

- If $f = 50\,Hz$, C in μf & R_L in Ω $\therefore \boxed{r = \frac{2890}{CR_L}}$

- Ripple (r) may be ↓ed by ↑ing C or R_L or both with a ↑ in dc O/P voltage.

LC Filter (or) L-section filter:

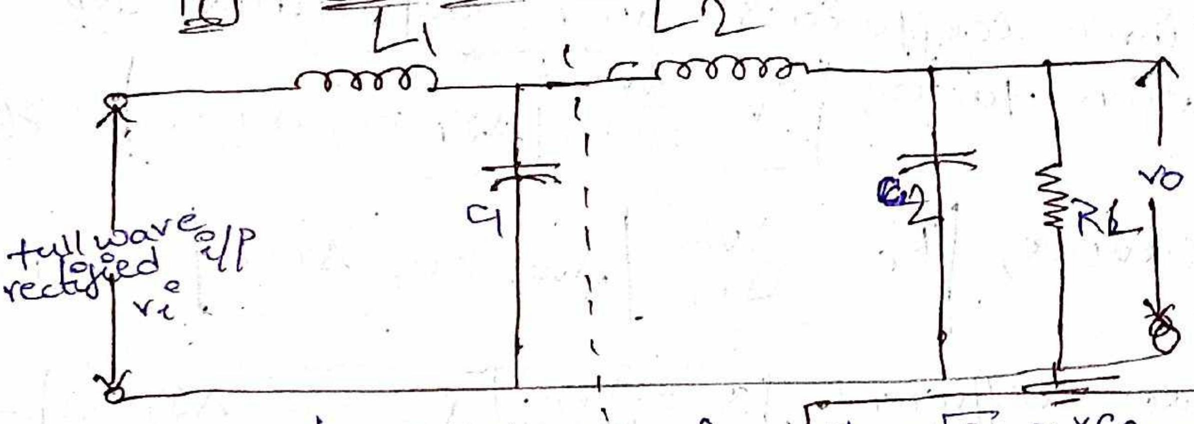


* wkt r is directly proportional to R_L in the induction filter & inversely proportional to R_L in the capacitor filter.
* If these two filters are combined LC filter (or) L-section filter is produced as shown in figure
* If the value of inductance is ↑ed, it ↑es the time of conduction
* At that point, one diode either D_1 or D_2 in FWR, will always be conducting.

multiple LC filters:-

* Better filtering can be achieved using two or more L-section filters as shown in the figure.

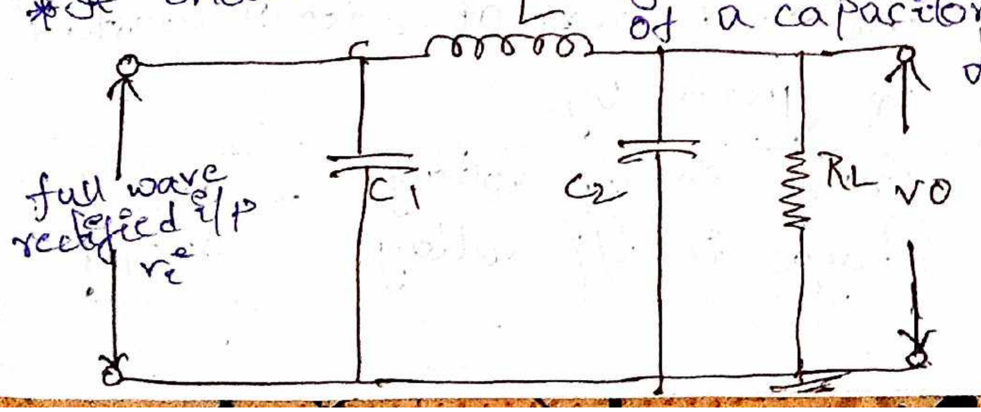
fig: multiple L-C filters:-



∴ Ripple factor is r given by $\boxed{r = \frac{\sqrt{2}}{3} \times \frac{X_{C_2}}{X_{L_2}} \cdot \frac{X_{C_1}}{X_{L_1}}}$

CLC or π-section filter:

* It shows CLC or π-type filter which basically consists of a capacitor filter followed by an LC section.



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Voltage Regulators:-

* In an unregulated power supply, the o/p voltage changes whenever the i/p voltage or load changes.
* A voltage regulator is an electronic circuit that provides a stable dc voltage independent of load current, temperature and a.c line voltage variants.

factors determining the stability:-

→ o/p dc voltage V_o depends on i/p unregulated dc voltage V_{in}, load current I_L & temperature T.

→ change in o/p voltage of power supply can be expressed as follows.

$$\boxed{\Delta V_o = \frac{\partial V_o}{\partial V_{in}} \Delta V_{in} + \frac{\partial V_o}{\partial I_L} \Delta I_L + \frac{\partial V_o}{\partial T} \Delta T} \rightarrow (1)$$

(or) $\Delta V_o = S_V \Delta V_{in} + R_o \Delta I_L + S + \Delta T \rightarrow (2)$

→ where three coefficients can be defined as i/p regulation factor, $\boxed{S_V = \frac{\Delta V_o}{\Delta V_{in}} \Big| \Delta I_L = 0, \Delta T = 0} \rightarrow (3)$

o/p resistance, $\boxed{R_o = \frac{\Delta V_o}{\Delta I_L} \Big| \Delta V_{in} = 0, \Delta T = 0} \rightarrow (4)$

Temperature coefficient, $\boxed{S_T = \frac{\Delta V_o}{\Delta T} \Big| \Delta V_{in} = 0, \Delta I_L = 0} \rightarrow (5)$

Line Regulation:-

→ change in o/p voltage for a change in line supply voltage keeping the load current & temp constant

→ line Regulation is given by

$$\boxed{\text{Line Regulation} = \frac{\text{change in o/p voltage}}{\text{change in i/p voltage}} = \frac{\Delta V_o}{\Delta V_{in}}}$$

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Load Regulation:

→ Load regulation is given by

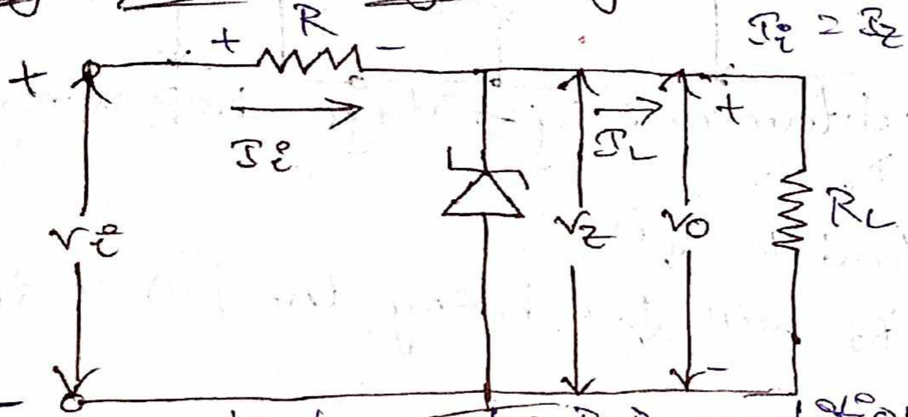
$$\boxed{\text{load regulation} = \frac{V_{no\,load} - V_{full\,load}}{V_{no\,load}}}$$

(or) $$\boxed{\text{Load Regulation} = \frac{V_{no\,load} - V_{full\,load}}{V_{full\,load}}}$$

(i) Zener Diode shunt Regulator:

fig: Zener voltage Regulator

$I_i = I_z + I_L$



→ A zener diode, under R.B condition can be used to regulate voltage accross the load.

→ under R.B condition, the voltage accross it is practically remains constant, even if current through it changes by large extents.

→ under normal conditions, i/p current $\boxed{I_i = I_z + I_L}$ → (9) flows through resistor R.

→ I/p voltage V_i can be written as

$$\boxed{V_i = I_i R + V_z = (I_z + I_L) R + V_z} \rightarrow 10.$$

→ As V_i ↑es, drop across resistor R will ↑ in $I_L + I_z$

→ As V_z is constant, voltage accross load will remain constant & hence I_L will be also constant.

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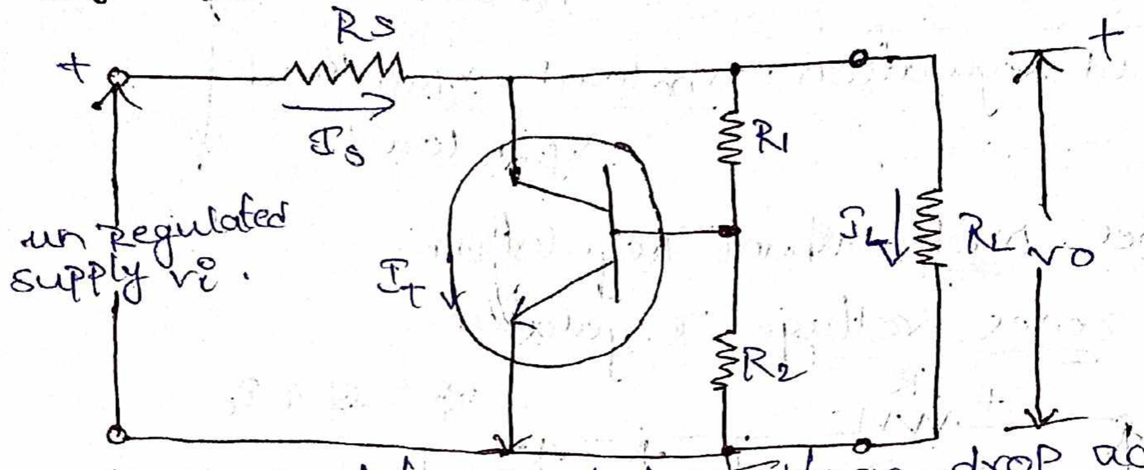
→ Zener diodes can be used as 'stand-alone' regul. ckts & also as reference voltage sources.

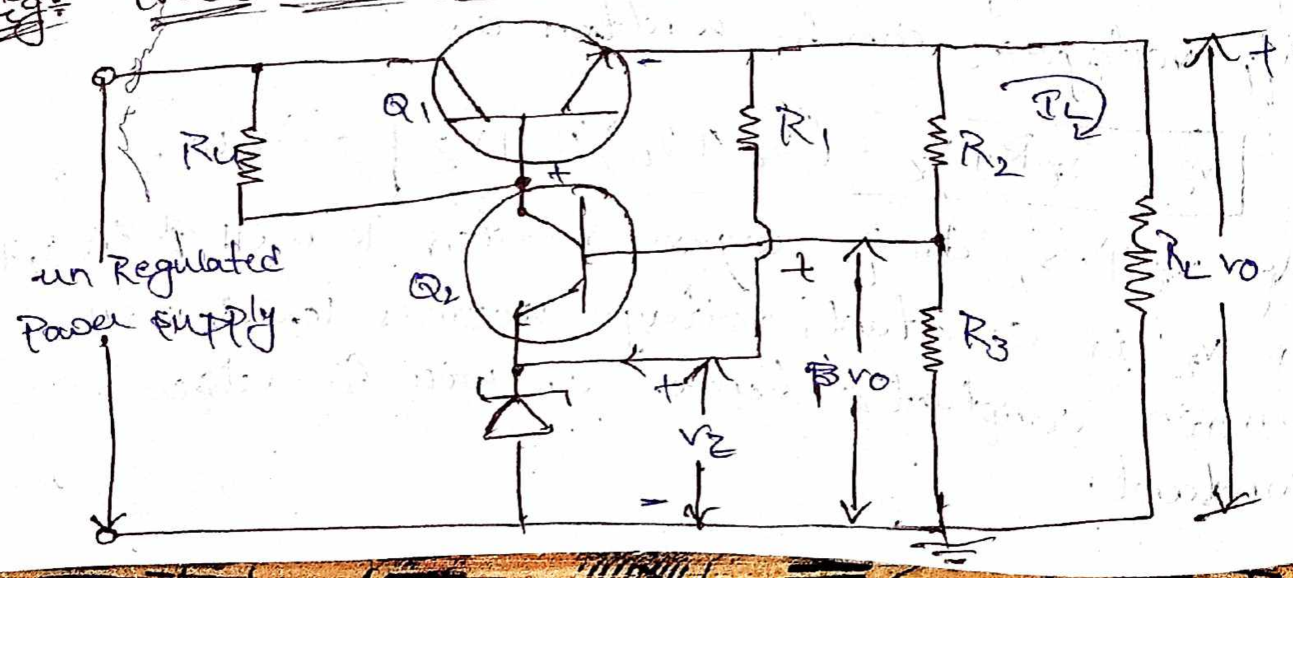
fig:- Transistor shunt Regulator



* o/p voltage is determined by ~~voltage~~ voltage drop across series resistor R_S.
* If I_L ↑es, V_O tend to ↓es.
* voltage across R_2 will ↓ reducing the F.B on the transistor
* for a given i/p voltage, o/p voltage remains constant. $\boxed{V_O = V_i - I_S R_S}$
* major drawback in this ckt is large amount of power dissipated in R_S.

(ii) Transistor series Regulator:-

fig:- Transistor series Regulators



* R_s is replaced by a transistor as shown in the above figure
* this circuit is more sensitive to voltage changes and provides better regulation
* Transistor Q_2 serves as a differential amplifier in which o/p voltage βV_o is compared with reference voltage V_Z
* the difference ($\beta V_o - V_Z$) is amplified by Q_2 & appears at the base of Q_1
* o/p voltage may be varied over wide range using R_2
* zener diode ~~of~~ and transistor Q_2 can be choosen because temp coefficents practically cancle with each other
* max dissipation in Q_1 takes place at high load currents ~~of~~ and low o/p voltage when using with a series regulator.
* major drawback of this ckt is voltage difference b/w i/p and o/p voltages.
* this can be overcomed to great extent by using thyristors.

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