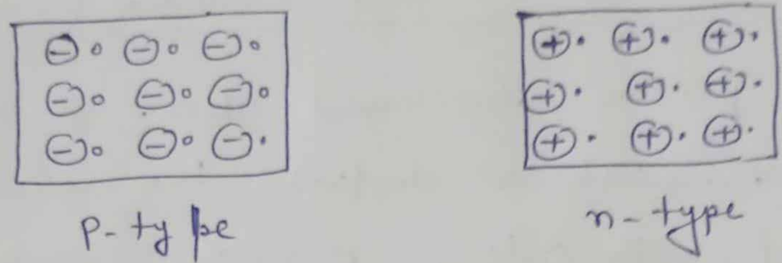
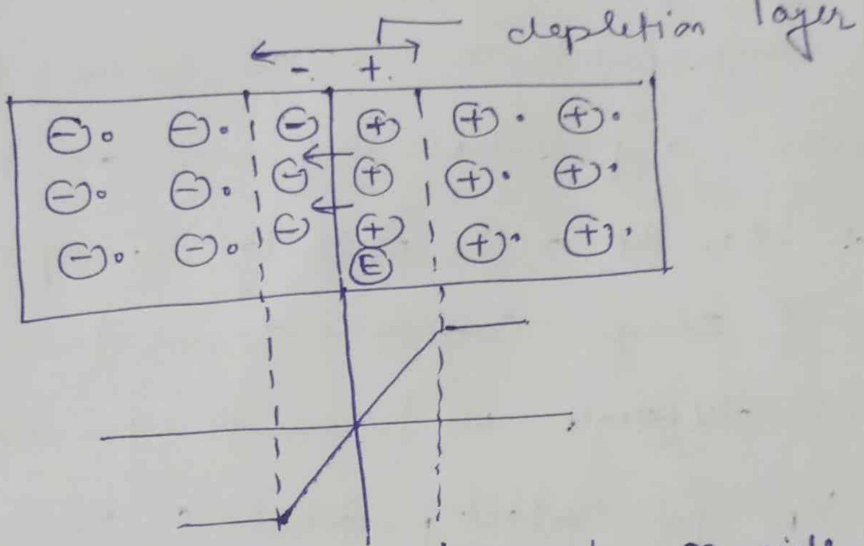
P-n Junction :- When a p type Semiconductor is joint with n-type semiconductor, the contact surface is called P-n junction. It is fabricated by a special technique.





- Holes starts to diffuse towards n-side and electrons start to diffuse towards p-side.
- Hence diffusion current will flow from left to right.
- Initially P-type & n-type, both are neutral. After diffusion of holes and electrons, an excess of +ve charge in n-region and -ve charge in P-region occurs, which creates an electric field exerts a force on electron and hole against their diffusion. ie e^- is pushed by potential barrier towards n-side and hole towards p-side, again a current will flow. and direction of this current is opposite to that of diffusion current called drift current (ie right to left)

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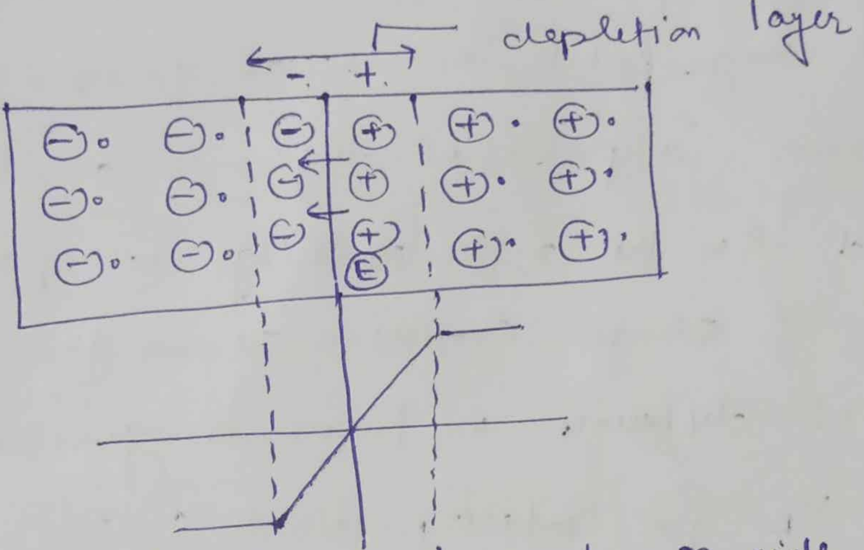
P-type n-type



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for unbiased diode

$$I_{diffusion} = I_{drift}$$

$$\therefore \boxed{I_{net} = 0}$$

Potential barrier at a p-n Junction

The diffusion process discussed above is a self-limiting process, which disturbs the electrical neutrality of both side. P-side acquires an excess of -ve charge while n-side an excess of +ve charge. This creates a potential difference at the junction. The P.d. has the right polarity to oppose further diffusion of charge carriers across the junction. This potential difference is known as junction potential barrier V_B for contact potential. (Its order is few tenths of a volts for most p-n junction).

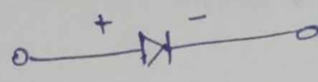
close the junction on either side of it, nearly all the mobile free charges diffuse to the other side and are immobilized there by recombination with the carriers of opposite polarity. Thus a narrow region exists at the junction which is depleted of all its mobile charge carriers. It is known as depletion region.

→ Its thickness depends upon the impurity concentration in the semiconductor and also on external voltage.

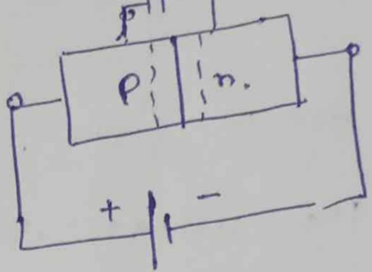
→ depletion region does not have any free charges. it behaves like a dielectric medium between two conducting regions. Thus : forms a capacitor. (≈ 10pF)

P-N- Junction diode

- The potential barrier is just sufficient to stop the movement of carriers across the junction.



(symbol).



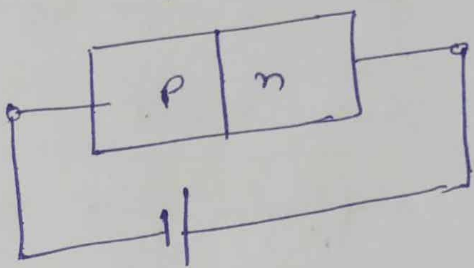
(forward biased)

- forward biased

In this Potential barrier is decrease

$I_{df} > I_{drift}$

⇒ I_{net} flow from P to n side



(Reverse biased).

- As forward bias voltage is increased, the current through the junction will increases. The increase in current is nearly exponential for the most part and it follows an equation known as diode equation

$$\boxed{I = I_s \left(e^{eV/k_BT} - 1\right)}$$

Where $I_s \rightarrow$ Saturation current under reverse biased

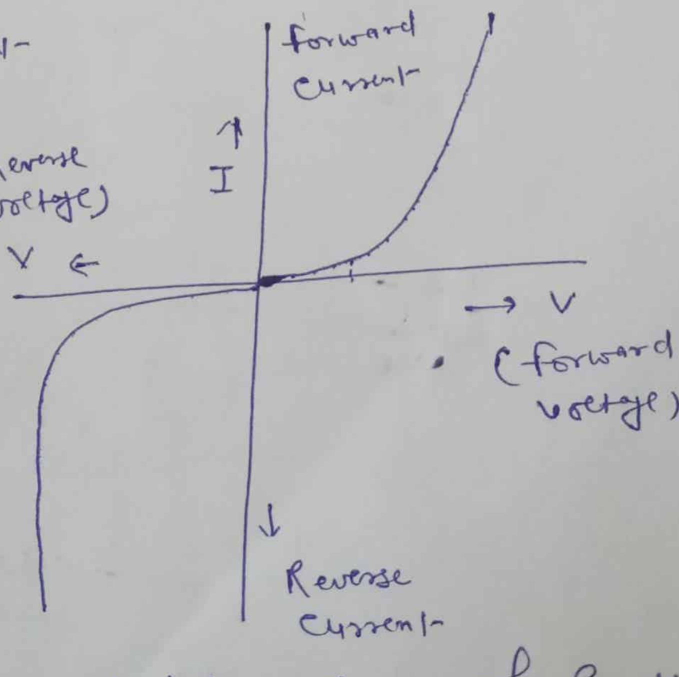
$e \rightarrow$ electronic charge

$V \rightarrow$ bias voltage (applied)

$\because \frac{k_BT}{e} \rightarrow$ has dimensions of voltage

$\frac{k_BT}{e} = V_T$ (voltage equivalent of tempr)

$\therefore\ I = I_s \left[e^{V/V_T} - 1\right]$



(Characteristic curve of P-n diode)

In forward bias, $V > V_T$

$\therefore e^{V/V_T} >> 1$

$\therefore \boxed{I = I_s e^{V/V_T}}$ or $\boxed{I = I_s\left[e^{\frac{V}{\eta V_T}} - 1\right]}$

As shown in figure, the diode current is negligible until the voltage exceeds a critical voltage (threshold voltage) [for Ge – 0.2 V, Si – 0.6 V]

In reverse biased   Pb → Increase

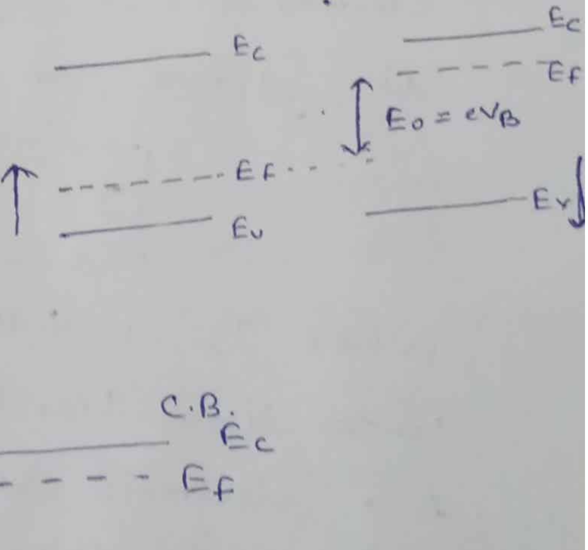
⇒ diffusion of $\bar{e}$ and hole is almost stopped

⇒ No current will flow

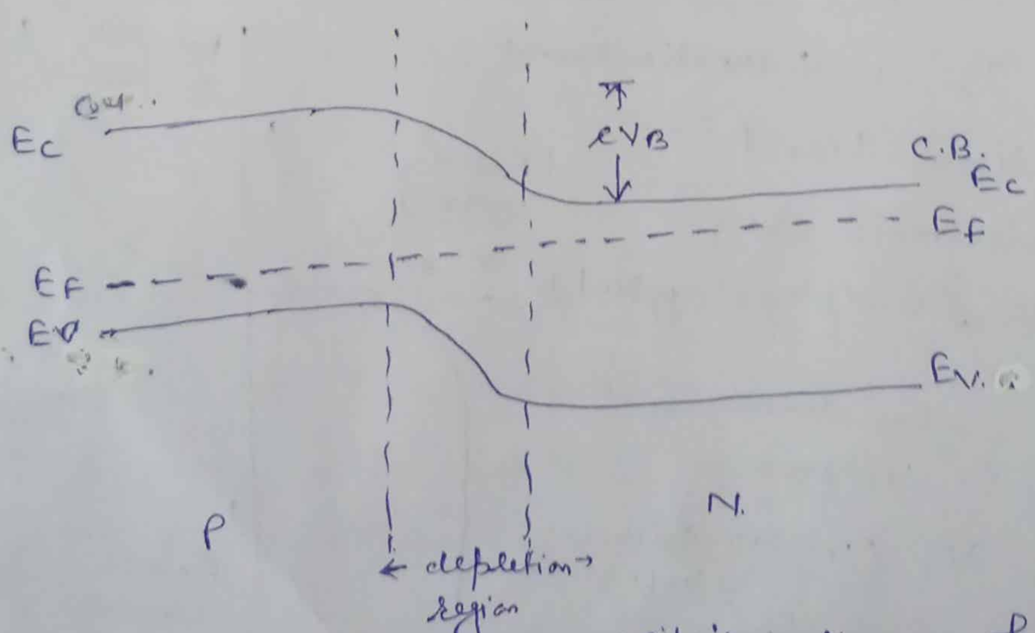
$\therefore I_{drift} > I_{diff}$.

$\eta = 1$ for Ge
$\eta = 2$ for Si
$\eta = 1$ (for small current)
$\eta = 2$ (large)

Biasing of P-N Junction

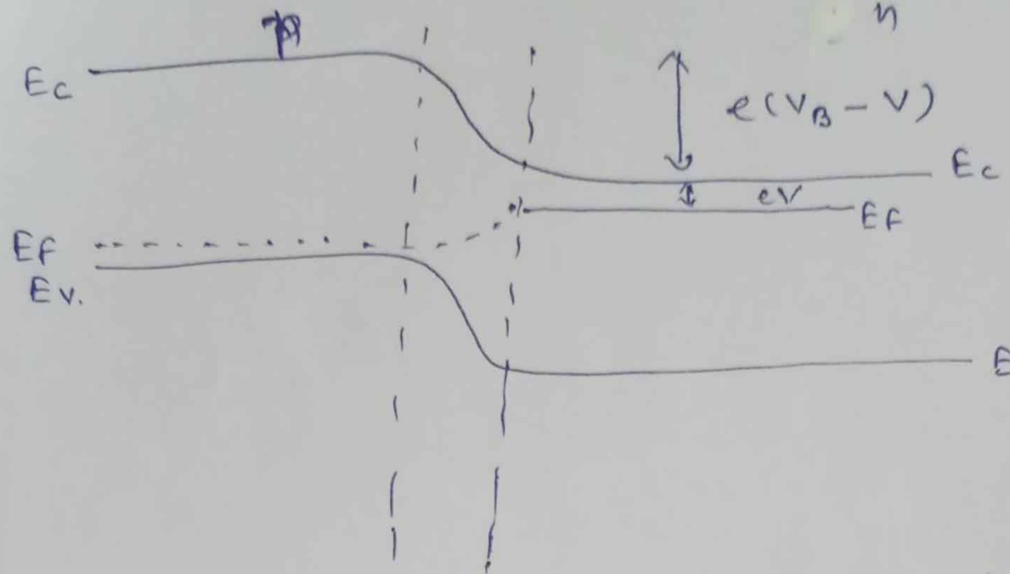


(a) Unbiased.



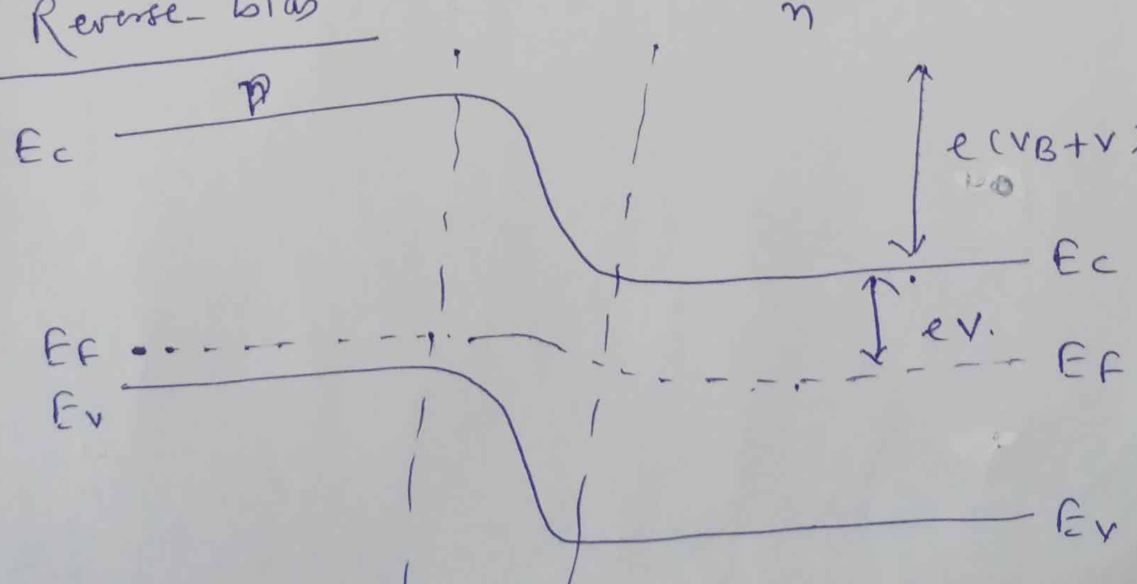
• When P-n junction is in equilibrium the no. of carriers diffusing from p to n is equal to carrier diffusing from N to P. Hence No current will flow.

(II) Forward bias.



- Energy of the electrons in n-region increased by an amount eV (V is applied voltage). Hence fermi energy level rises by eV. Potential barrier is decrease to $e(V_B - V)$. The net result is that the $\bar{e}$s crossing the junction from n-side can easily cross the junction. Since $\bar{e}$s in n-side are in majority, current across the junction increases.

(III) Reverse bias



- fermi level on n-side raising the height of barrier by $e(V_B + V)$ $\Rightarrow$ also increase depletion width too. So $\bar{e}$s crossing the junction will decrease. Hence, current is very much reduced in reverse biased.

TUNNEL DIODE :-

P-n junction diode having nearly zero breakdown voltage are known as Tunnel-diode.

OR

It is a p-n junction made from quite heavily doped s/c. Concentration required for this are of the order of 1 part in 10^3 while the concentration in normal diodes are of the order of 10^8.

This heavy doping produces some unusal effects, i.e.

1. It reduces the width of deplition layer. Deplition region in tunnel diode is 10^{-6} m, so that electron can tunnel directly.
2. It reduces the reverse breakdown voltage to a very small value (≈ zero) with result that diode appears to be broken down for any reverse voltage.
3. It produces a negative resistance section on V-I characteristics of diode.

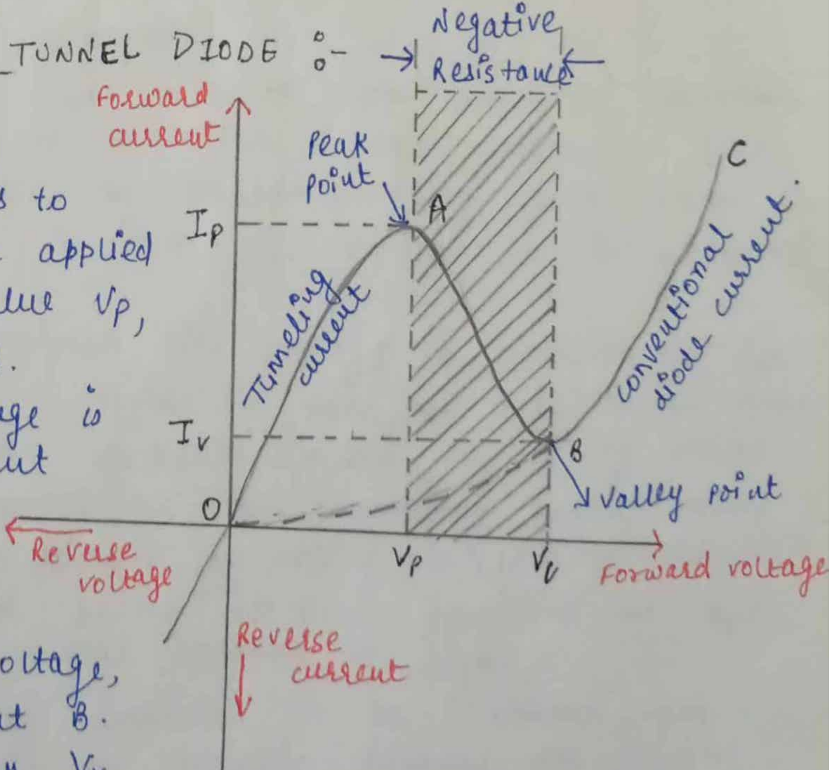
These diodes were discovered by Leo Easki in 1958 & hence it is also known as Easki Diode.

They are usually made of germanium or Gallium Arsenide because of high electron mobility & reasonable gap energy.

REPRESENTATION OF TUNNEL DIODE :-

OR

V-I CHARACTERISTICS OF TUNNEL DIODE :-



→ As soon as forward bias is applied, large current is produced. Current quickly rises to its peak value I_P when the applied forward voltage reaches a value V_P, which is shown by Point A.

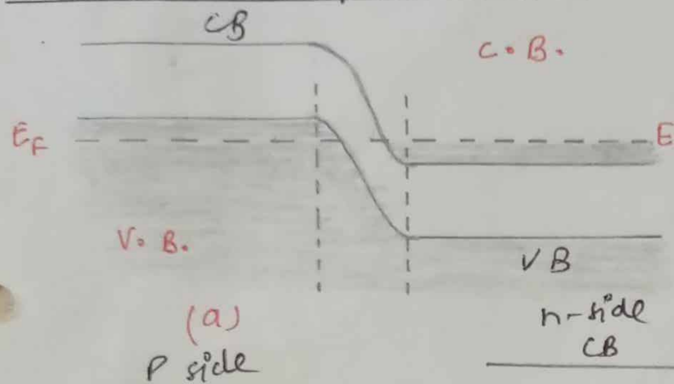
→ When the forward voltage is increased further, diode current start decreasing till it acheives its minimum value called valley current I_V, corresponding to valley voltage, V_V, which is shown by point B.

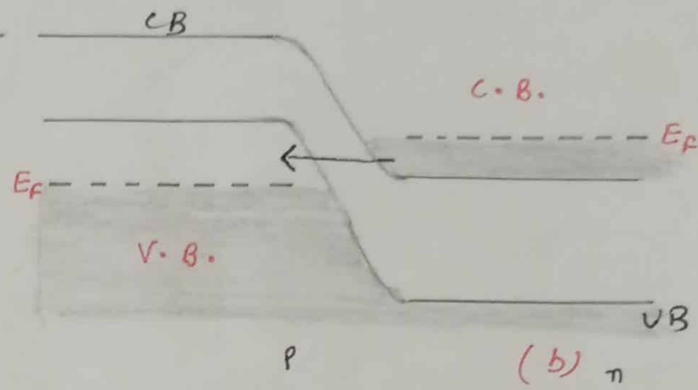
→ For voltage greater than V_V, current start increasing again as in ordainary junction diode.

In the region b/w A & B, current decreases with increasing applied voltage, OR Tunnel diode possess negative resistance in this region. It is a very useful property of diode i.e. instead of absorbing power, a negative resistance produces power. Such negative resistance produces oscillations in tank circuit by off setting losses in L & C components. Hence a tunnel diode is used as very high frequency oscillator.

This resistance increases as we go from A to B.

TUNNELING THEORY :-





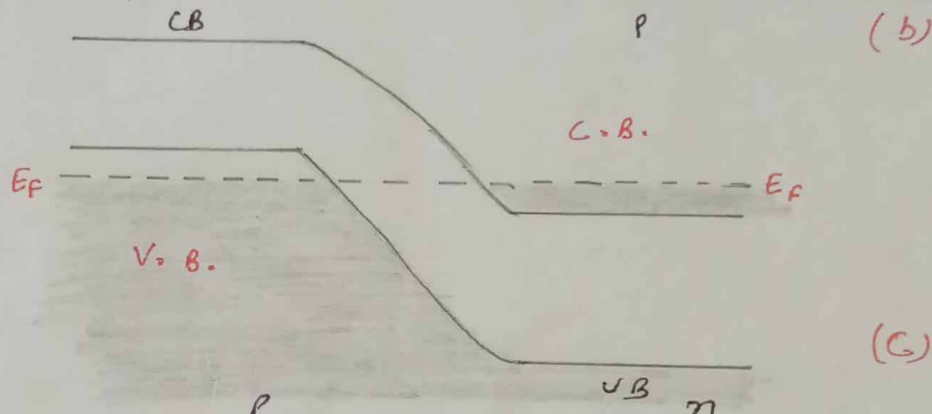


Fig. a :- When the bias is zero, corresponding to point O, it is observed that tunneling is zero, because the rate of electron tunneling is same in both direction & net current is zero. Or there is the same prob. of electrons going from states in C.B. of N-sides to states in V.B. of P-side as in opposite directions.

Fig. b :- When a small forward bias voltage is applied to the diode, the energy level in n-type s/c move up relative to those in P-type s/c. Now, all the electrons in C.B. see empty states just across the barrier & hence a large tunneling taken place, whereas the number of electrons tunneling in opposite direction is decreased. Hence there is a net electron flow to the left, which corresponds to conventional current to right.

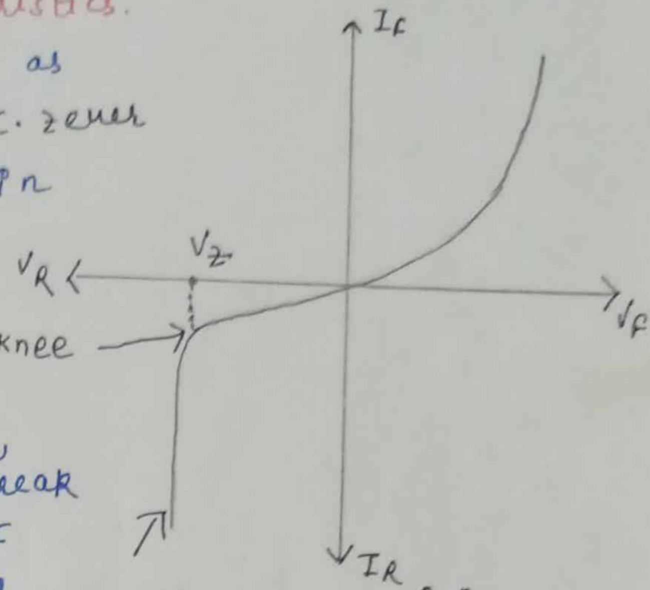
Fig. C :- As the applied voltage continues to be increased, the net current at certain voltage begins to decrease because the no. of empty states in P-side V.B. available for the electrons in N-side C.B. decreases. The net current is reduced almost to zero because electrons in N-side C.B. find no empty states into which they could tunnel directly.

With still higher applied voltage, the current follow the characteristics of an ordinary P-N junction diode. Net current is now due to diffusion of majority charge carriers ~~to~~ across the junction.

ZENER DIODE :-

When the reverse bias on a crystal diode is increased, a critical voltage called breakdown voltage is reached where the reverse current increases sharply to a high value. The breakdown region is the knee of reverse characteristics.

This breakdown voltage is also known as zener voltage {as American scientist C. Zener explain this} & the sudden increase in current is known as zener current.

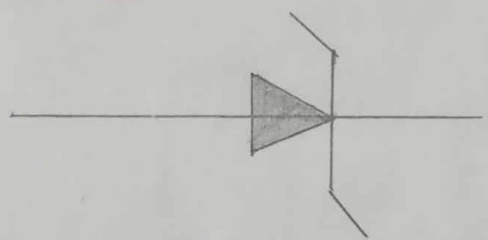


Reverse characteristics.

Breakdown voltage or zener voltage depends upon the amount of doping. If the diode is heavily doped, depletion layer will be thin & the break down of the junction will occur at lower reverse voltage. If the diode is lightly doped, breakdown voltage will be high.

"A properly doped crystal diode which has a sharp breakdown voltage is known as Zener Diode."

Symbol of Zener Diode :-

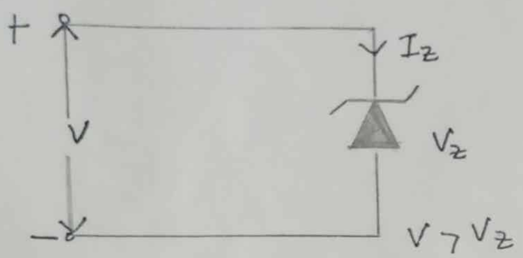


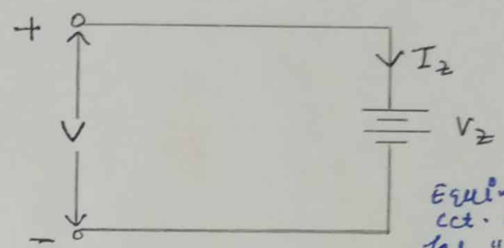
Properties of Zener Diode :-

1. A zener diode is an ordinary diode except that it is properly doped so as to have a sharp breakdown voltage.
2. A zener diode is always reverse connected i.e it is always reverse biased.
3. A zener diode has sharp breakdown voltage, called zener voltage V_Z.
4. When forward biased, its characteristics are similar to that of ordinary diode.
5. Zener diode is not immediately burnt just because it has entered the breakdown region. As long as the external cct. connected to the diode limits the diode current to less than burnt out value, the diode will not burn out.

Equivalent circuit of zener Diode :-

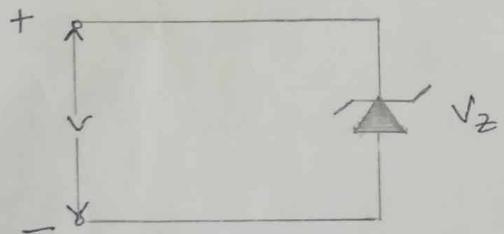
(i) "ON state" :- when reverse voltage across a zener diode is equal to or more than the breakdown voltage V_z, the current increases very sharply. Curve is almost vertical in this region, which indicates that voltage across zener diode is constant at V_z even though the current through it changes. ∴ in breakdown region, ideal zener diode can be represented by a battery of voltage V_z. Under such conditions, zener diode is said to be in "ON" state.

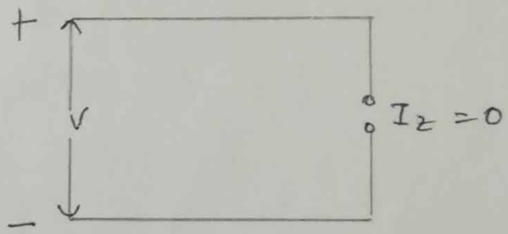




Equivalent cct. of zener for "ON" state

(ii) "OFF state" :- when the reverse voltage across the zener diode is less than V_z, but greater than 0V, the zener diode is in "OFF" state. Under such condition, the zener diode can be represented by an open circuit.





Equivalent cct. of zener for "OFF" state.

ZENER DIODE AS VOLTAGE STABILISER :-

Zener diode can be used as voltage stabiliser (regulator) to provide a constant voltage from a source whose voltage may vary over a sufficient range.

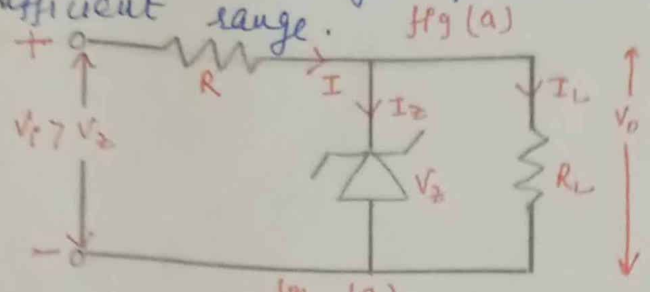
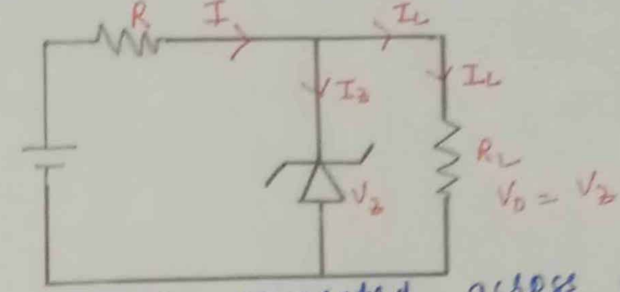


fig. (a)



Zener diode of zener voltage is reverse connected across the load R_L across which constant output is desired. The series resistance R absorbs the output voltage fluctuations so as to maintain constant voltage across load. Zener will maintain a constant voltage across load, so long as the input voltage does not fall below V_z. $(V_z) = E_0$

When the cct. is properly designed, the load voltage E_0 remains constant equal to V_z, even though input voltage & load resistance may vary over wide range.

Working of regulation can be understood in following two points.

When input is variable {i.e. E_i varies & R_L fixed} :- When the input voltage increases, since the zener is in the breakdown region zener diode is equivalent to a battery V_z. It is clear that the output voltage remains constant at $V_z = E_0$. Excess voltage is drop across series resistance R. This will cause an increase in value of total current I. At this zener current increases to maintain the excess current in R & hence load current remains constant. Thus the output voltage remains constant irrespective of the changes in input voltage.

When V_i increases, I & I_z increases but I_L remains fixed.

Then $E_0 = V_0 = \text{constant} = V_z$

Let $(V_i)_{min}$ & $(V_i)_{max}$ are the minimum & maximum output voltages for which output voltage is equal to V_z. (fig. b)

Calculation of $(V_i)_{min}$:- At this voltage, the zener turns in ON condition & voltage across load become equal to V_z.

i.e. $V_z = E_0 = V_0$

full ON state of zener $I_z \neq 0$

In OFF state of zener, $I_z = 0$, $I = I_L$

$$E_0 = V_Z = I R_L$$

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

$$\therefore \quad V_Z = \frac{(V_i)_{min}\, R_L}{R+R_L}$$

or $$\boxed{(V_i)_{min} = \frac{(R+R_L)}{R_L} \cdot V_Z}$$

Calculation of $(V_i)_{max}$:- At maximum input voltage, zener goes in deep breakdown & high current through zener flows.

$I_Z = \frac{E_0}{R_L}$ current through R, $I = I_Z + I_L$

since $I_L \left(= E_0/R_L = V_Z/R_L\right)$ is fixed, the value of I will be maximum when zener current I_Z is maximum.

$$\therefore \quad I_{max} = (I_Z)_{max} + I_L$$

Now,

$$E_i = E_0 + IR$$

since $E_0 (= V_Z)$ is constant, the input voltage will be maximum when I is maximum.

$$\therefore \quad (E_i)_{max} = E_0 + I_{max} R$$

or, $$\boxed{(E_i)_{max} = V_Z + I_{max} R}$$

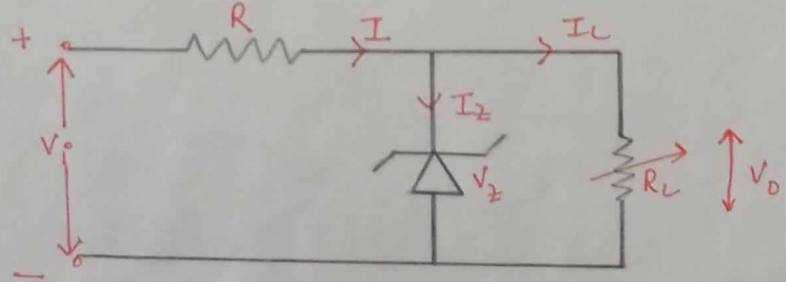
2) **when load is variable (V_i = constant, R_L = variable) :-** when load resistance decreases, the load current increases. The extra current can't come from the source. The additional load current will come from decrease in zener current I_Z. Thus output voltage stays at constant value V_Z.

when R decreases, then I_L increases.

$$\therefore \quad I = I_Z + I_L$$

& I is constant, then I_Z decreases so that $V_0 = V_Z$.

For a



for a definite range of R_L, the output voltage remains constant. (13)
Let $(R_L)_{min}$ & $(R_L)_{max}$ are the minimum & maximum value of load resistance for which output voltage is equal to zener voltage.

Calculation of $(R_L)_{min}$ & $(I_L)_{max}$:- Once the zener is in the ON state, load voltage $V_0 = V_Z$ is constant. As a result, when load resistance is minimum, load current will be maximum.

$(I_L)_{max} = \frac{V_0}{R_L}$, & zener current will have ~~maximum~~ minimum value, $I_Z = I - I_L$. Thus for constant o/p voltage, the zener should be in ON state.

$$V_0 = V_Z = \frac{R_L}{R + R_L} V_i$$

$$\frac{R + R_L}{R_L} = \frac{V_i}{V_Z}$$

$$\frac{R}{R_L} + 1 = \frac{V_i}{V_Z}$$

$$\frac{R}{R_L} = \frac{V_i}{V_Z} - 1$$

$$\frac{R}{R_L} = \frac{V_i - V_Z}{V_Z}$$

$$\boxed{(R_L)_{min} = \frac{R V_Z}{V_i - V_Z}}$$

This is the minimum value of load resistance, that will ensure that zener is in ON state. Any value of load resistance less than this value will result in a voltage E_0 across the load less than V_Z & the zener will be in OFF state.

Calculation of $(R_L)_{max}$ & $(I_L)_{min}$:- when load resistance is maximum, load current is minimum.

zener current, $I_Z = I - I_L$

when the zener is in ON state, I remains fixed.

{ since, voltage across R, $V_R = E_i - E_0$
& $I = V_R / R$, as E_i & E_0 fixed, I remains same }

i.e. when I_L is maximum, I_Z is minimum. OR when I_L is minimum, I_Z is maximum. If the maximum current that a zener can carry safely is $(I_Z)_{max}$, then

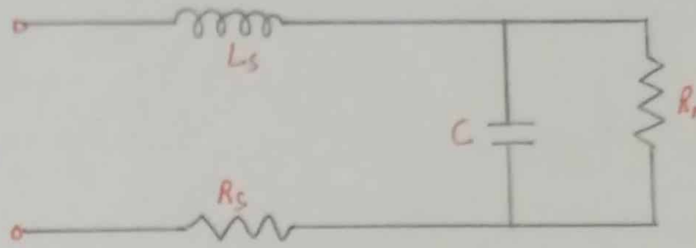
$$(I_L)_{min} = I - (I_Z)_{max}$$

$$\& \quad (R_L)_{max} = \frac{E_0}{(I_L)_{min}} = \frac{V_Z}{(I_L)_{min}}$$

If the load resistance exceed this max. value, the current through zener exceed $(I_Z)_{max}$ & device may burn out.

EQUIVALENT CIRCUIT OF TUNNEL DIODE :-

Capacitance & Resistance are junction diffusion capacitance (1 to 10 & negative resistance R_N resp.



Induction L_s is due to terminal leads (0.1 to 4 nH) & resistance R_s is due to leads, ohmic contact & s/c material (1 - 5 Ω)

These factors decides the frequency at which diodes may be used.

APPLICATIONS :-

Tunnel diode may be used as:

(1) Amplifier due to its negative resistance region.

(2) As tunnel diode oscillator due to its -ve resistance.

(3) It is used as ultra high speed switches.

ADVANTAGES :- Advantages of tunnel diode are :-

(1) Low cost.

(2) Low Noise.

(3) Simplicity.

(4) High speed of operation.

(5) Easy mode of operation.

(6) Low Power.

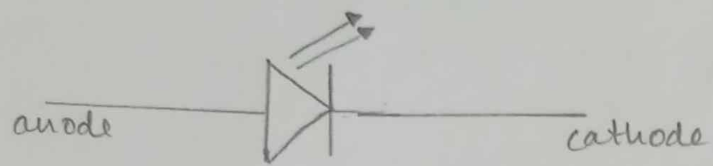
(7) Environmental Immunity.

DISADVANTAGES :-

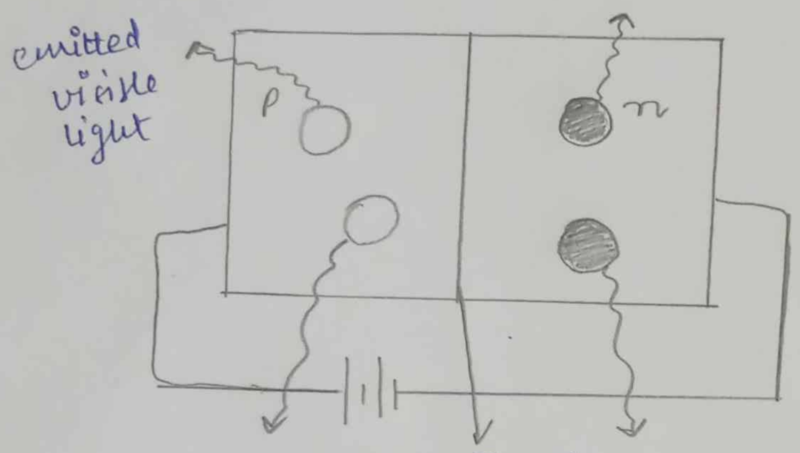
(1) Low output voltage swing.

(2) It can't provide isolation b/w i/p & o/p cct., being two terminal devices.

LIGHT EMITTING DIODE {LED}



It is a forward-biased p-n junction which emits visible light when forward current is made to flow in it.

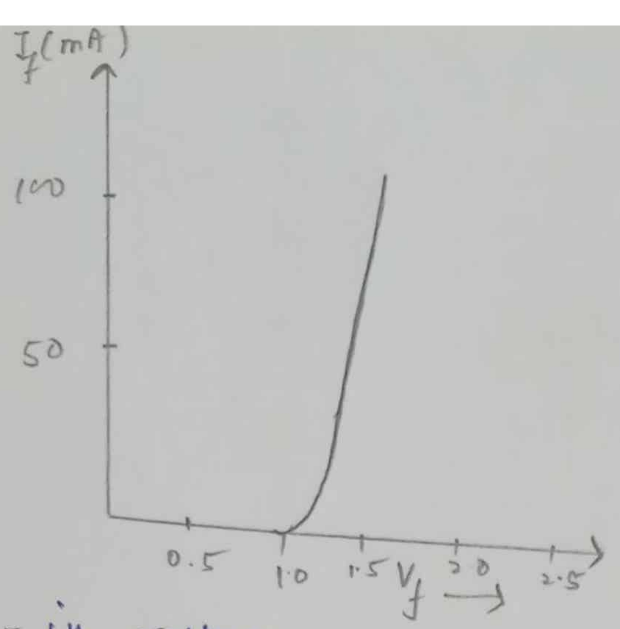


The light is emitted when e^- from n-side cross the junction and recombine with holes on p-side.

Explaination :- whenever an e^- recombine with a hole, it falls from C.B. to V.B. i.e. from higher energy state to lower energy state. The difference of energy is released in the form of heat or light.

In case of Si and Ge junctions, greater percentage of this energy is given up in the form of heat while a little amount in the form of light (which is insignificant)

But in S/C materials like Gallium Arsenide (GaAs), (GaAs-P) phosphide, most of the energy is given in the form of light.



cut-in voltage of LED is about 1.0 volt which is larger than ordinary diode. Hence p-n junction is forward biased, with a voltage greater than 1 volt, e^- hole recombination takes place.

In the recombination process, e^- release energy in the form of light.

Merits of LED over other types of lamps:-

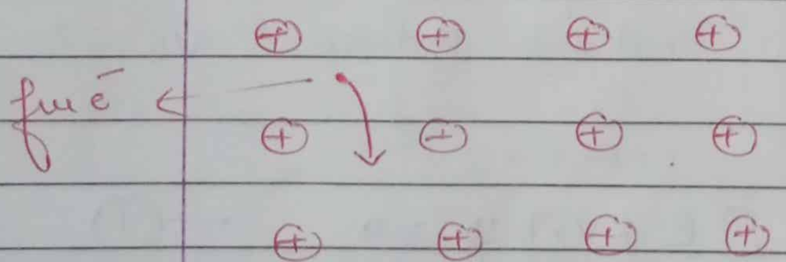
* Low working voltage and current.
* Less power consumption.
* Very fast action
* Small size and weight
* Emission of monochromatic light
* Extremely long life.

BAND Theory of solids

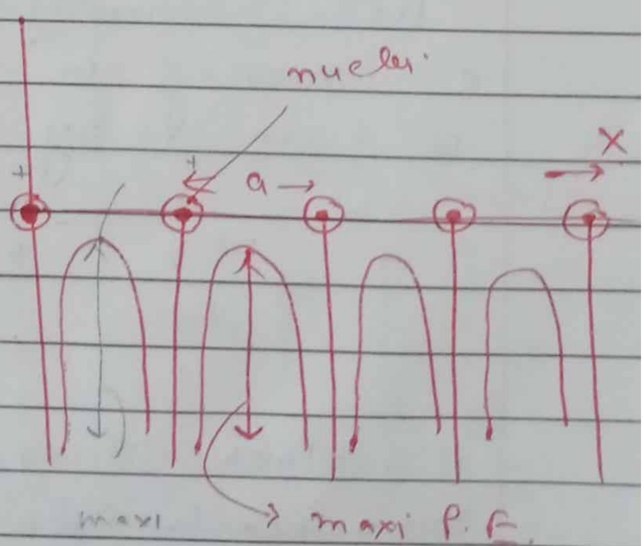
• free $\bar{e}$ theory could not explained that why some solids are good conductor, and some insulator and some semi-conductor. This can be explained on the basis of Band theory of solids.

• This theory of solids deals with the motion of $\bar{e}$s in solids.
• It explain conductivity of solids.
• On the basis of electrical conductivity the solids can be classified as conductors, semiconductors and insulators.

A crystalline solid consists of a lattice which is composed of a large no. of ion cores at regular intervals, and the conduction $\bar{e}$s that can move freely throughout the lattice. The conduction $\bar{e}$s move inside periodic +ve ion cores



(a) Motion of $\bar{e}$ in a crystal.



$$P.E = -\frac{Ze^2}{4\pi\epsilon_0 r}$$

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→ The potential of $\bar{e}$ at the positive ion site is zero and is maximum in between.

→ Thus $\bar{e}$ is considered to be moving in a periodic potential as we have done in the electron theory

→ The motion of the electron in crystal is governed by Schrodinger equation. But in solid there are large no. of $\bar{e}$s so it is very difficult to solve Schrodinger equation for crystal.

→ We now describe the behaviour of the $\bar{e}$ in this potential using 1D approximation. This is done by finding the $\bar{e}$ wave function

BLOCH THEOREM

Let $V(x)$ denotes the P.E of an $\bar{e}$ in a linear lattice constant 'a' that $V(x) = V(x+a)$

The Schrodinger wave equation for an e^- moving in 1D constant potential V_0 is given by

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2}[E - V_0]\psi = 0 \quad \text{—} (1)$$

E – bloch observed that since potential is periodically, so, prob. of finding the e^- is also periodic and hence wavefunction

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is also periodic

i.e $$\boxed{\psi(x) = u_K(x)\, e^{iKx}} \quad -(II)$$

i.e product of plane wave e^{iKx} and periodic function $u_K(x)$

Where $$\boxed{u_K(x) = u_K(x+a)} \quad -(III)$$

$a \rightarrow$ Interatomic space

$u_K(x)$ depends on wave vector K and the periodicity of the ~~fun~~ potential

This theorem is known as Bloch theorem

Let us consider a linear chain of atoms of length L in 1D case with N be the no. of atoms in the chain, then

$$u_K(x) = u_K(x+Na) \quad -(IV)$$

$$\therefore \psi(x+Na) = e^{iK(x+Na)} \cdot u_K(x+Na)$$
$$= e^{iKNa} \cdot u_K(x)\, e^{iKx}$$
$$= \psi(x)\, e^{iKNa} \quad -(V)$$

Complex Conjugate

$$\psi^*(x+Na) = \psi^*(x) \cdot e^{-iKNa} \quad -(VI)$$

from (V) and (VI)

$$\psi(x+Na) \cdot \psi^*(x+Na) = \psi(x) \cdot \psi^*(x)$$
$$|\psi(x+Na)|^2 = |\psi(x)|^2 \quad -(VII)$$

$\Rightarrow$ e^- is not localized around ones particular atom and the prob. of finding the e^- is same throughout the crystal.

In equation. $e^{iKNa} = 1$

$$KNa = 2\pi n$$

$(\cos KNa + i \sin KNa) = 1$

$$K = \frac{2\pi n}{Na}$$

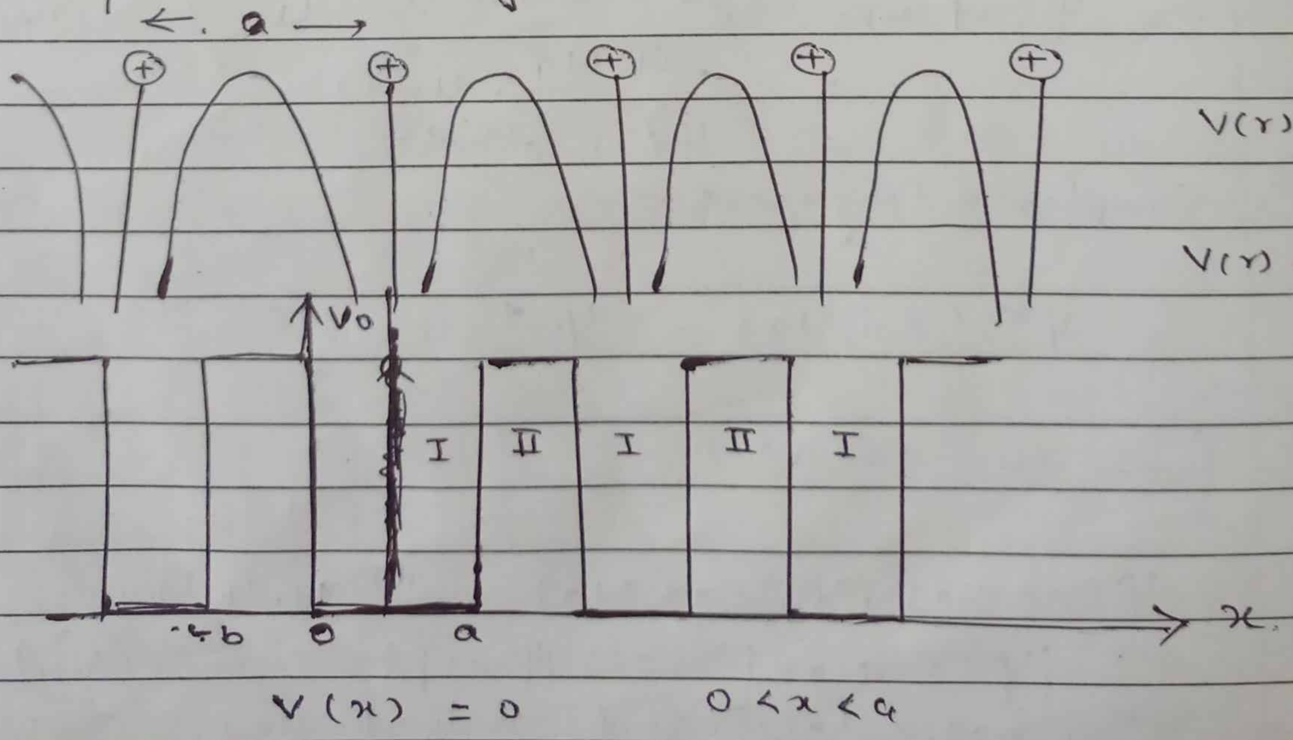
$$\boxed{K = \frac{2\pi n}{L}}$$

$L \rightarrow$ length of chain at atom

$n = \pm 1, \pm 2, \pm 3 \ldots$

Kronig - Penny Model.

To explain the behaviour of $\bar{e}$ in a solid under periodic potential. Kronig and Penny assumed that the potential energy of an $\bar{e}$ can be represented by periodic array of rectangular potential



$V(r) = \frac{-e^2}{4\pi\epsilon_0 r}$

$V(r) \propto \frac{1}{r}$

$$V(x) = 0 \qquad 0 < x < a$$
$$= V_0 \qquad -b < x < 0$$

Consider an array of square wells.
Schrodinger equations for an $\bar{e}$ in a crystal lattice is written as

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2} E\psi = 0 \quad \text{— (1) (I)}$$

$$\frac{d^2\psi}{dx^2} + \frac{2m}{\hbar^2} [E - V_0]\psi = 0 \quad \text{— (II) (II)}$$

$$\frac{d^2\psi}{dx^2} + \alpha^2\psi = 0 \quad \text{— (III)}$$

$$\frac{d^2\psi}{dx^2} - \beta^2\psi = 0 \quad \text{— (IV)}$$

Where $\alpha^2 = \frac{2m}{\hbar^2} E$ — (V)

$\beta^2 = \frac{2m}{\hbar^2} (V_0 - E)$ — (VI)

After applying boundary conditions and Bloch theorem, it turns out the following solution.

$$\boxed{\cos Ka = \frac{P \sin \alpha a}{\alpha a} + \cos \alpha a} \quad \text{— (VII)}$$

where $P = \frac{m V_0 ab}{\hbar^2}$ $\quad \because P \propto V_0 b$ = area P.

$P \rightarrow$ called scattering power of barrier.
$\Rightarrow$ It is a measure of the strength with which electron in a crystal are attracted to the ions in the crystal lattice sites.

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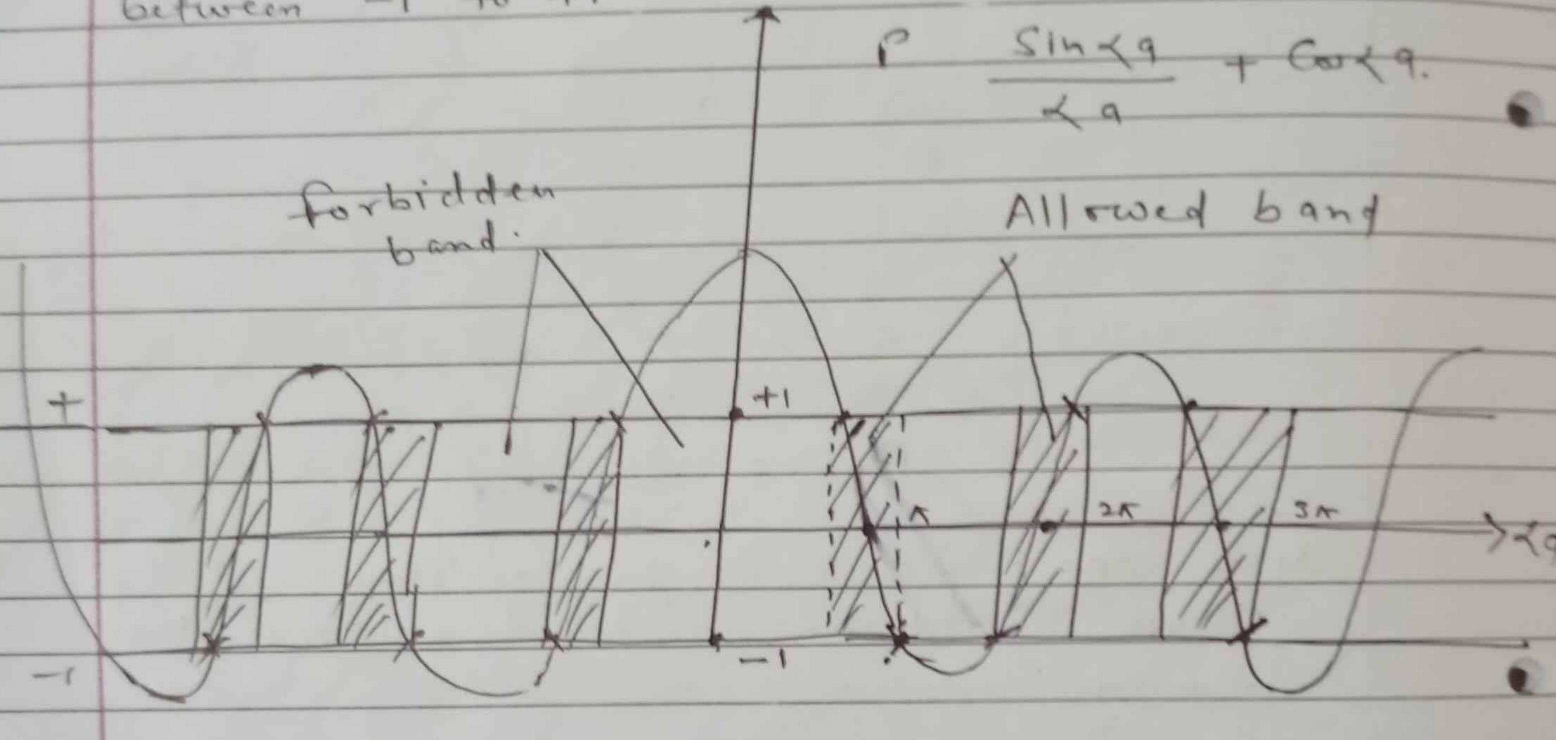
→ If P increase, the area of potential barrier increase and $\bar{e}$ is bound more strongly to a potential well

→ If $P \to 0$, the potential barrier become very weak i.e. 'e^-' becomes free.

The L.H.S of equ. (VII) have values between −1 to +1



→ A Consequence of this limitation is that only certain values of α $\left[\alpha = \frac{2\pi}{h} \sqrt{2mE} \right]$ are allowed. i.e. the energy spectrum consists of an infinite number of allowed bands separated by interval in which there are no energy levels

The allowed energy level boundaries correspond to the value of $\cos Ka = \pm 1$

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$$Ka = \pm n\pi$$

$$\boxed{K = \pm \frac{n\pi}{a}}$$

Case. I When $P \to 0$, then all the $\bar{e}$s are completely free to move in the crystal without any constraints.

$$\cos Ka = \cos \alpha a$$

$$\alpha = K$$

$$\alpha^2 = K^2 = \frac{2mE}{\hbar^2}$$

$$E = \frac{\hbar^2 K^2}{2m} = \frac{p^2}{2m}$$

$\because$ $p = \hbar K$

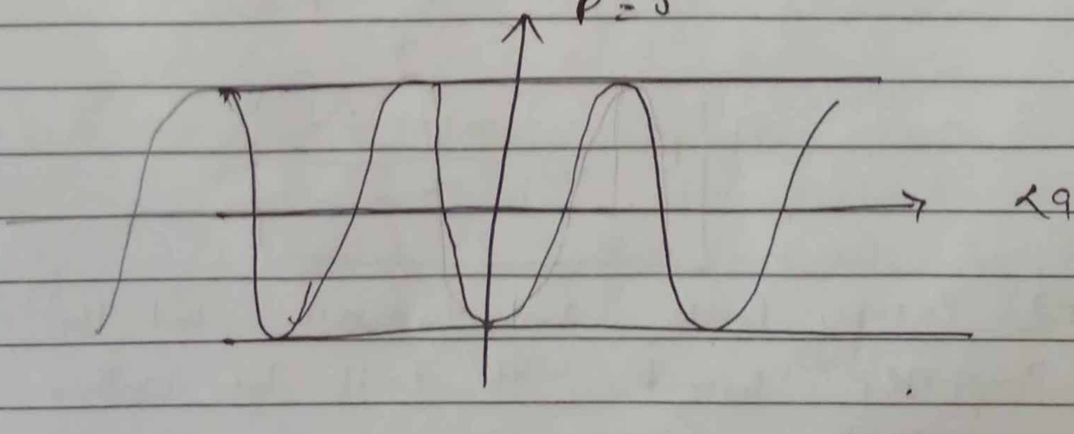
$$E = \frac{p^2}{2m}$$ (i.e. K.E. of free particle)

$\because$ $E =$ K.E

i.e. The energy corresponds to a Completely free particle

$\Rightarrow$ i.e a case of Conductor.

* Hence, no energy level exists that is all the energies are allowed to the electron



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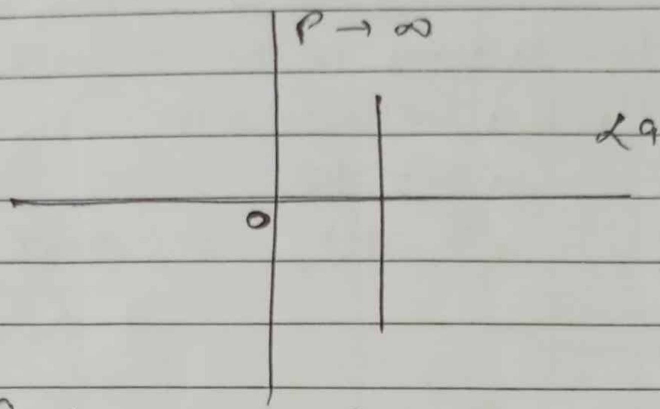
Case-2. When $P \to \infty$, the allowed energy band are infinitely narrow and the energy spectrum is a line spectrum



$$\therefore \cos ka = \frac{P \sin \alpha a}{\alpha a} + \cos \alpha a$$

$$\frac{\cos ka}{P} = \frac{\sin \alpha a}{\alpha a} + \frac{\cos \alpha a}{P}$$

$P \to \infty$

$$0 = \frac{\sin \alpha a}{\alpha a} + 0$$

$$\sin \alpha a = 0$$

$$\alpha a = \pm n\pi$$

$$\alpha = \frac{\pm n\pi}{a}$$

$$\alpha^2 = \frac{n^2\pi^2}{a^2}$$

$$= \frac{2m}{\hbar^2} E$$

$$\boxed{E = \frac{n^2\pi^2\hbar^2}{2ma^2}}$$

$\Rightarrow$ Energy levels are discrete and the e^- is completely bound. It will be within potential and move in one cell of width 'a'.

Effective Mass.

When $p \to 0$

we have

$$E = \frac{\hbar^2 k^2}{2m}$$

$$\frac{dE}{dk} = \frac{\hbar^2}{\cancel{2}m} \cdot \cancel{2}k = \frac{\hbar^2 k}{m}$$

$$\frac{d^2E}{dk^2} = \frac{\hbar^2}{m}$$

$$\boxed{m = \hbar^2 \left[\frac{d^2E}{dk^2}\right]^{-1}}$$

$$\boxed{m = \frac{h^2}{4\pi^2}\left[\frac{d^2E}{dk^2}\right]^{-1}}$$

Under periodic potential, the mass of the e^- is known as effective mass and represented by m^*

$$\boxed{m^* = \frac{h^2}{4\pi^2}\left[\frac{d^2E}{dk^2}\right]^{-1}}$$

This is a new concept and arises because of the interaction of e^- with periodic lattice.
If there is a strong binding force between the e^- the lattice, it will be difficult for the electron to move thereby acquired a large effective mass.

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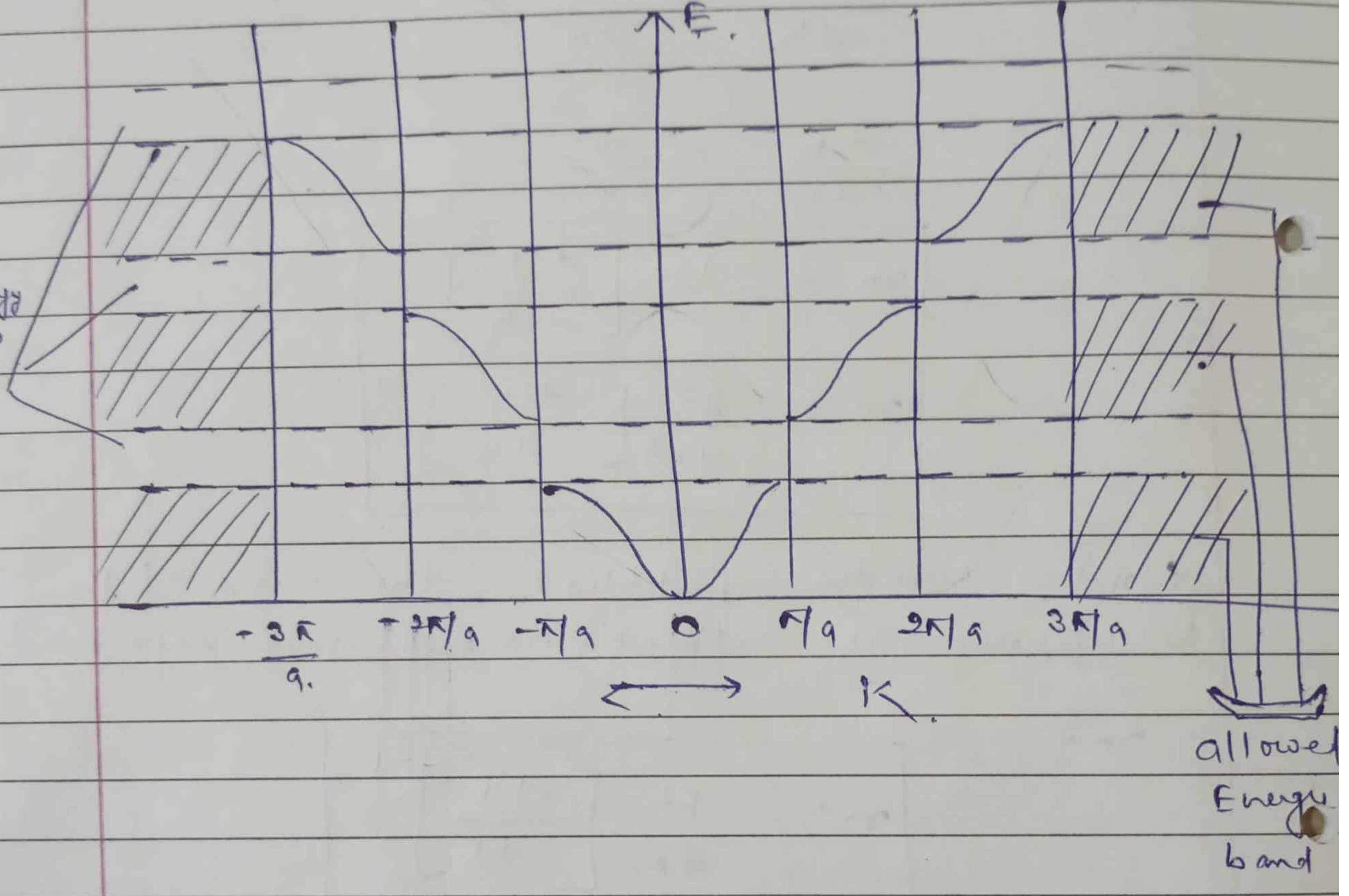
E-K Diagram

when $P \to 0$
we have

$$\boxed{E = \frac{\hbar^2 K^2}{2m}}$$



from fig it is clear that the energy of $\bar{e}$ is continuously increasing from $K = 0$ to π/a or zero extending from $k = -\pi/a$ to $+\pi/a$. The zone is called I Brillouin Zone.

After a break in energy values called forbidden region or band or zone, we get another allowed zone of energy values from ~~K~~ $= -\pi/a$ to $-2\pi/a$ and $+\pi/a$ to $+2\pi/a$. This zone is called second Brillouin Zone.

$\cos ka = \pm 1$
$ka = \pm n\pi$
$k = \pm n\pi/a = \pm\pi/a, \pm\frac{2\pi}{a}, \pm\frac{3\pi}{a}$

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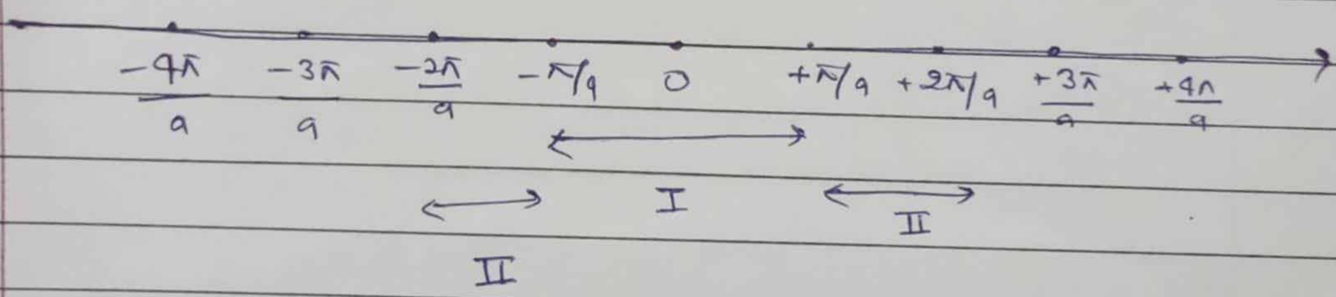
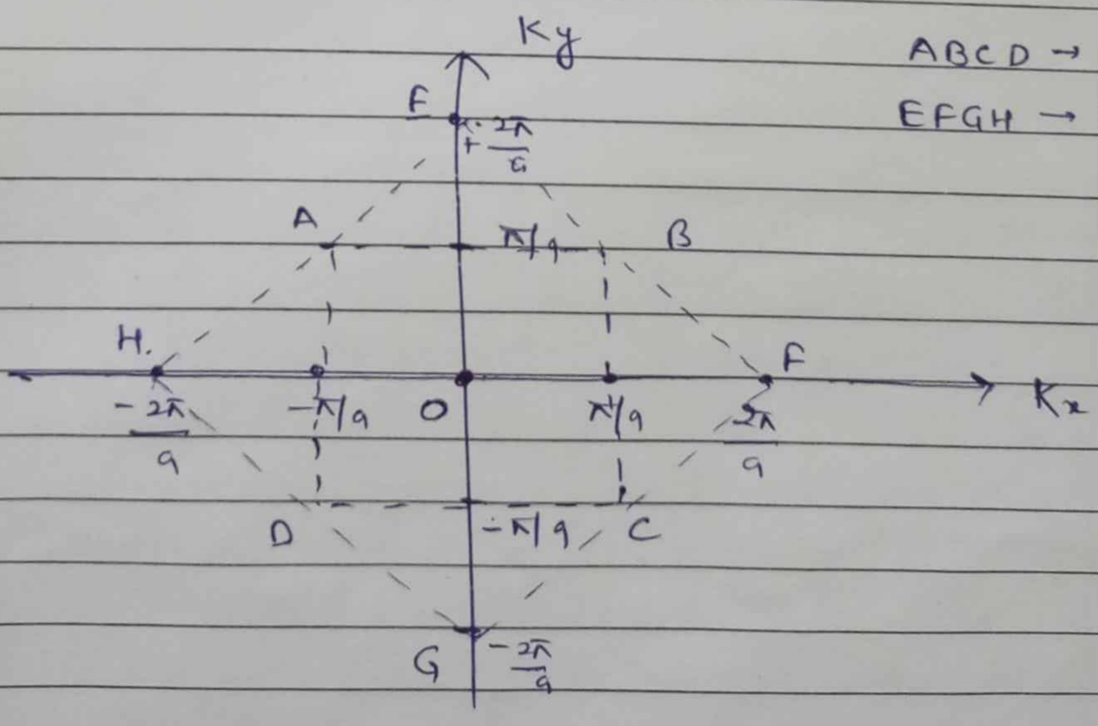
Brillouin Zones:-

(a) **Linear Lattice:-** In a 1D mono-atomic lattice a line representing the value of K is divided by energy discontinuities into segment of length as shown in figure. These line segments are known as Brillouin Zones.



(b) **Two - dimensional Lattice**



ABCD → I Brillouin
EFGH → II Brillouin
Zone.

PHOTODIODE :-

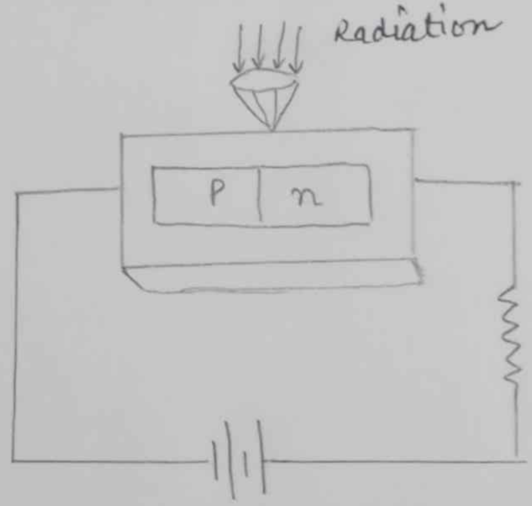
Two terminal device designed to respond to photon absorption are called photodiode.

Photodiode is a two terminal electronic device which when exposed to light the current starts flowing in the diode.

- It is operated in reverse biased mode only.
- It converts light energy into electrical energy.

Principle :- Principle of photodiode depends on the fact that output current of a reverse biased p-n junction changes considerably when the device is exposed to illumination.

Construction of Photodiode :-



symbol

A p-n junction photodiode is essentially a reverse biased diode with light permitted to fall on one surface of the device across the junction. The other sides being unilluminated. P-n junction diode is kept in a sealed plastic or glass casing. The cover is designed so that the rays are allowed to fall only on one surface across the junction. The remaining side of the casing are painted black to restrict the penetration of light rays.

Mechanism of operation :-

The junction of photodiode is illuminated by light source, the photons strike the junction surface. The photons impart their energy in the form of light to the junction. Due to which electrons from valence band get the energy to jump into conduction band and contribute to the current.

In this way, photodiode converts light energy into electrical energy.

- The current which flows in photodiode before light rays are incident on it is called dark current.

V-I characteristics of Photo-Diode :-