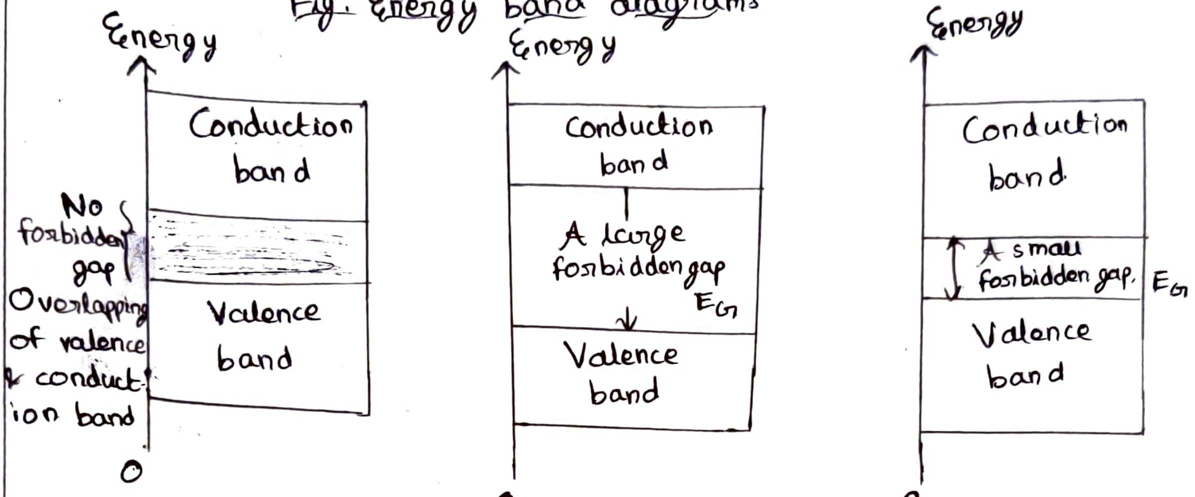
# UNIT-I
## P-N Junction Diode

**Classification of Materials based on Energy Band theory:-**

→ Based on the ability of various materials to conduct current, the materials are classified as (i) Conductors (ii) Insulators & (iii) Semiconductors.

Fig: Energy band diagrams




(a) Conductor (b) Insulator (c) Semiconductor

* (a) Conductors:-

A metal which is very good carrier of electricity is called conductor. Ex:- Copper, Aluminium

Conductor has large number of free electrons, so that it will conduct very easily.

Ex:- Copper has $8.5 \times 10^{28}$ free electrons per cubic metre which is a very large number. Hence copper is called good conductor.

In metals like copper, aluminium there is no forbidden gap between valence band & conduction band. The 2 bands overlap.

→ ∴ even at room temperature, a large number of electrons are available for conduction.

→ So without any additional energy, such metals contain a large number of free electrons & hence called as good conductors.

- Energy band diagram for a conductor is shown in fig (a).

* Insulators:-

→ Energy band diagram of insulator is shown in fig (b).

→ In insulators, there exist a large forbidden gap in between the conduction band & the valence band.

→ A very poor conductor of electricity is termed as insulator.

→ Ex:- Glass, Wood, Mica, diamond which does not conduct current.

→ Practically, it is impossible for an electron to jump from the valence band to the conduction band.

→ The forbidden gap is very wide, approximately of about 7ev is present in insulators.

→ For the diamond, the forbidden gap is about 6 ev.

→ Such materials conduction is rare & is called breakdown of an insulator. Paper is also the insulating material.

* Semiconductors:-

→ A metal having conductivity which is in between conductor & an insulator is called semiconductor.

Ex:- Silicon, Germanium

→ Semiconductor which does not conduct current at low temperatures, but as temperature increases, these materials behave as good conductors.

→ Forbidden gap in such materials is very narrow as shown in fig(c).

→ The forbidden gap is about 1eV.

→ At 0°K, the semiconductor materials behave as perfect insulators.

→ For silicon & germanium, the forbidden gap energy is given by,

~~$E_G = 1.21$~~ At room temperature,

For Germanium (Ge), $E_G = 0.72$ eV

For Silicon (Si), $E_G = 1.12$ eV

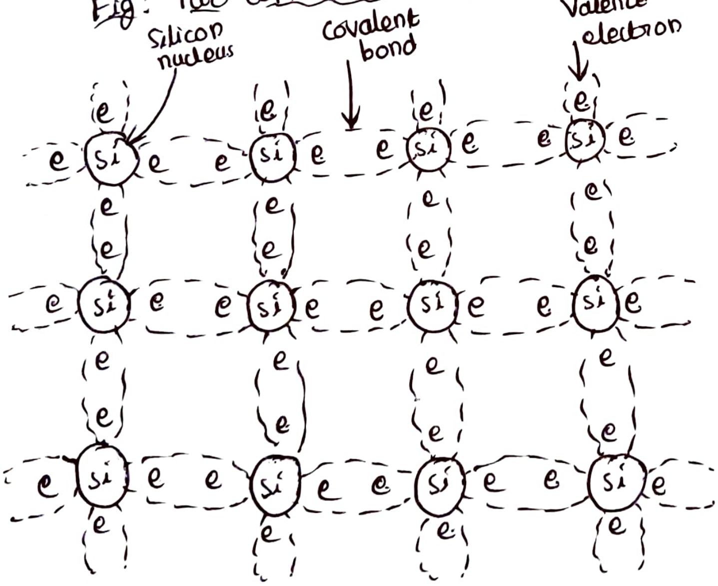
Intrinsic Semiconductors :-

→ A sample of semiconductor in its purest form is called an intrinsic semiconductor.

→ The impurity content in intrinsic semiconductor is very very small, of the order of one part in 100 million parts of semiconductor.

→ For achieving such a pure form, the semiconductor materials are ~~purely~~ carefully refined.

Fig: Two dimensional representation of silicon crystal

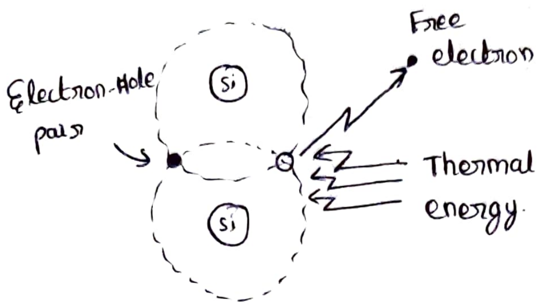



→ As shown in fig, the outermost shell of an intrinsic semiconductor like silicon has only 4 electrons.

→ As shown in fig (a), at room temperature, the number of valence electrons absorb the thermal energy, due to which they break the covalent bond & drift to the conduction band.

→ Such electrons become free to move in the crystal.

Fig (a) Breaking of covalent bond




Extrinsic semiconductors:-

→ In order to change the properties of intrinsic semiconductors, a small amount of some other material is added to it.

→ The process of adding other material to the crystal of intrinsic semiconductors to improve its conductivity is called doping.

→ The impurity added is called dopant.

→ Doped semiconductor material is called extrinsic semiconductor.

→ Depending upon the type of impurities, the 2 types of extrinsic semiconductors are 1) n-type & 2) p-type.

* Formation of p-type & n-type semiconductors:-

P-Type Semiconductor:-

→ When a small amount of trivalent impurity is added to a pure semiconductor, it is called p-type semiconductor.

→ The trivalent impurity has 3 valence electrons.

→ These elements are such as gallium, boron or indium.

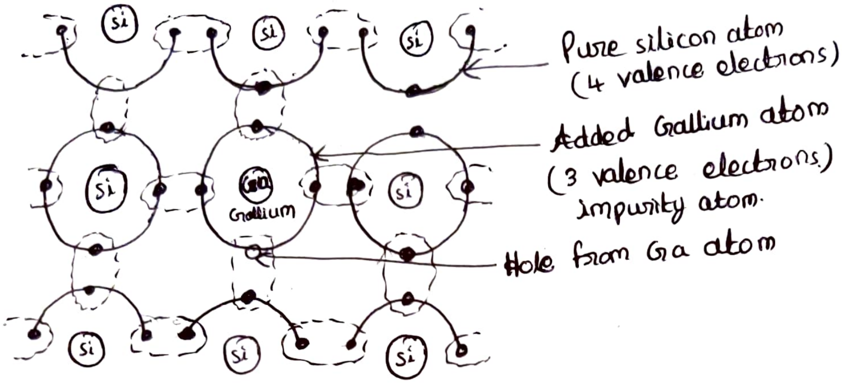
→ Such an impurity is called acceptor impurity.

→ Consider the formation of p-type material by adding gallium (Ga) in to silicon (si). Gallium atom has 3 valence electrons.

→ So Gallium atom fits in the silicon crystal in such a way that its 3 valence electrons form covalent bonds with the 3 adjacent one electron, the fourth covalent bond in the valence shell is incomplete.

⇒ The resulting vacancy is called a hole.

⇒ Such p-type material formation is represented in below fig.




⇒ Each gallium atom added in to silicon atom gives one hole.

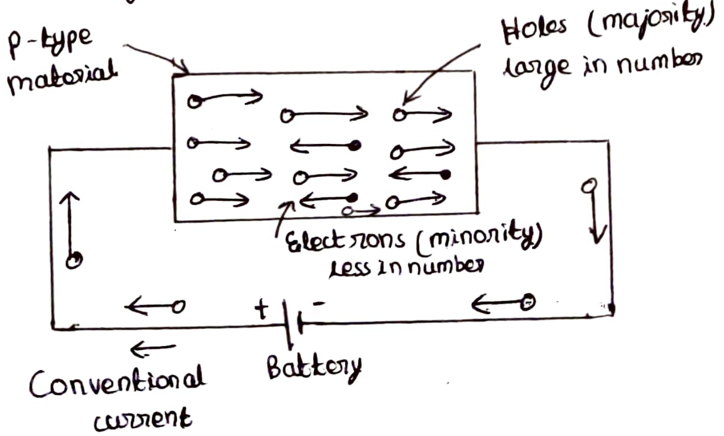
⇒ The number of such holes can be controlled by the amount of impurity added to the silicon.

⇒ As the holes are treated as positively charged, the material is known as p-type material.

⇒ Hole created due to added impurity is ready to accept an electron & is called acceptor impurity.

⇒ Thus even for a small amount of impurity added, large number of holes get created in the p-type material.

Fig: Conduction in P-Type Semiconductor



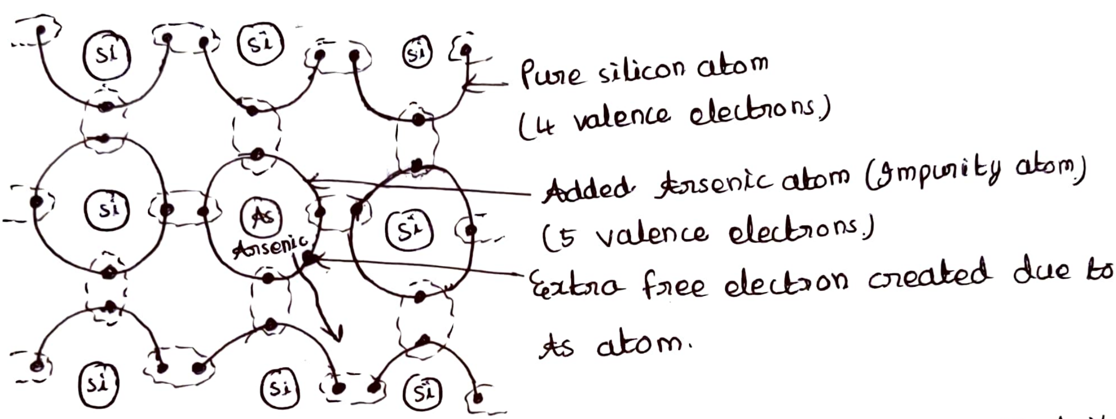
## n-Type Semiconductor:-

→ When a small amount of pentavalent impurity is added to a pure semiconductor, it is called n-type semiconductor.

→ The pentavalent impurity has 5 valence electrons.

→ Those elements are such as arsenic, bismuth, phosphorous & antimony. Such an impurity is called donor impurity.

→ Consider the formation of n-type material by adding arsenic (AS) in to silicon (si), as shown in below fig.




→ An Arsenic atom fits in the silicon crystal in such a way that its 4 valence electrons form covalent bonds with 4 adjacent silicon atoms. The 5th electron has no chance of forming a covalent bond

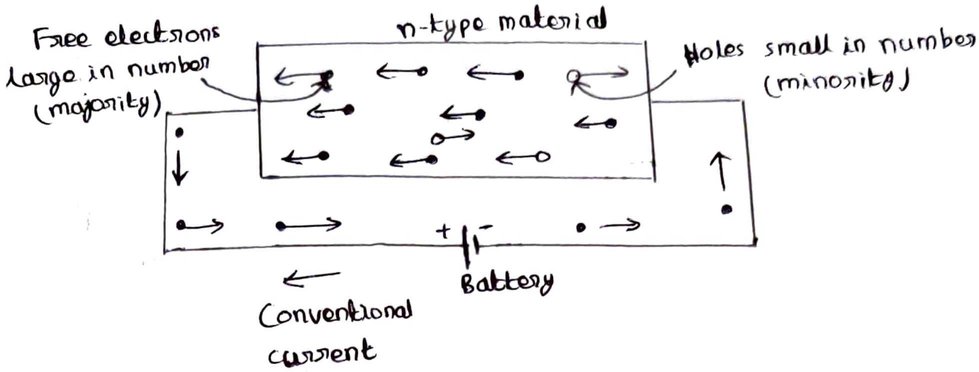
→ This spare electron enters the conduction band as a free electron

→ Such n-type material formation is represented in the arsenic atom added to silicon atom gives one free electron.

→ Since the free electrons have negative charges, the material is known as n-type material & an impurity donotes a free electron hence called donor impurity.

→ The free electrons are majority charge carriers

Fig: Conduction in n-type material




* Principle and operation of Diode:-

Definition:- A diode is the simplest semiconductor component. It is made of only 2 pieces from different semiconductor materials.

Diode Working Principle:-

Its function is to let electric current flow in one direction but to prevent flow in the opposite direction.

Fig (a) Two electrodes

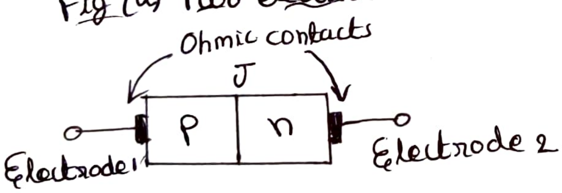
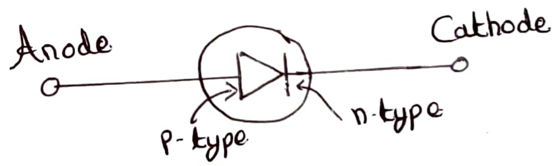



Fig (b) Symbol of a diode




P-n Junction diode:-

→ The p-n junction form a popular semiconductor device called p-n junction diode.

→ p-n junction has 2 terminals called electrodes, one each from p-region & n-region. Due to 2 electrodes it is called diode i.e di+electrode.

→ To connect the n & p regions to the external terminals, a metal is applied to the heavily doped n & p type semiconductor regions.

→ Such a contact between a metal & a heavily doped semiconductor is called ohmic contact.

→ Ohmic ~~con~~ contact has 2 properties,

(i) It conducts current equally in both the directions.

(ii) The drop across the contact is very small, which do not affect the performance of the device.

Biasing of p-n junction diode :-

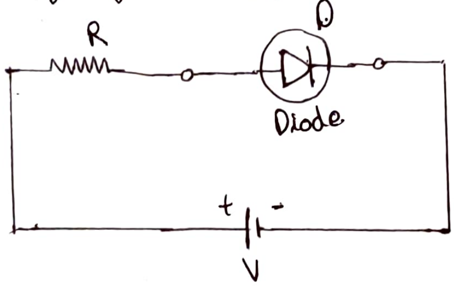
→ Applying external d.c voltage to any electronic device is called biasing.

→ Under biased condition, p-n junction allows current flow only in one direction.

→ Depending on the polarity of the d.c voltage applied externally to it, the biasing is classified as (i) Forward biasing & (ii) Reverse biasing.

(i) Forward biasing of p-n Junction Diode :-

Fig: Symbolic representation




→ If an external d.c. voltage is connected in such a way that the p-region terminal is connected to the positive of the d.c voltage & the n-region is connected to the negative of the d.c. voltage, the biasing condition is called forward biasing.

Operation of forward biased diode :-

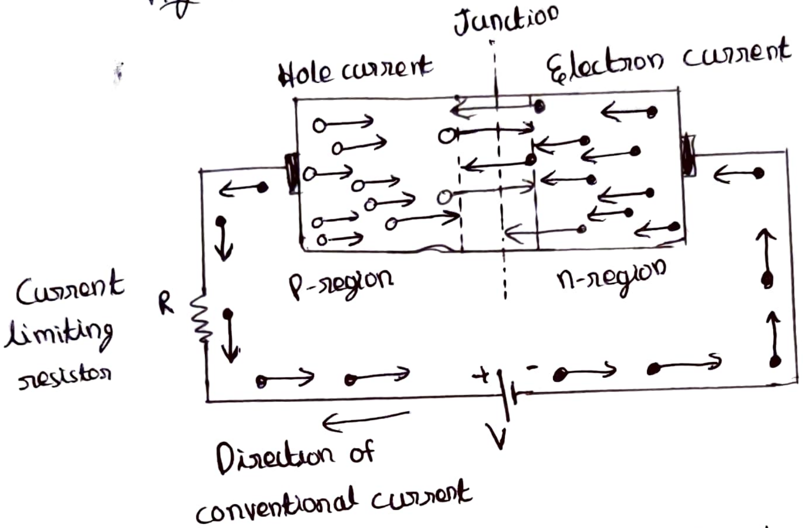
→ When the p-n junction is forward biased, as long as the applied voltage is less than the barrier potential, there cannot be any conduction.

→ When the applied voltage is more than the barrier potential, the negative terminal of battery pushes the free electrons against barrier potential from n to p region. ||ly positive terminal pushes the holes from p to n region. Thus holes get repelled by positive terminal & cross the junction against barrier potential.

→ Thus the applied voltage overcomes the barrier potential.

→ This reduces the width of depletion region

Fig: Forward current in a diode




→ At particular value of forward voltage, the depletion region becomes very much narrow, such that large number of majority carriers can cross the junction & constitute a current called forward current.

→ Once the conduction electrons enter p-region, they become valence electrons.

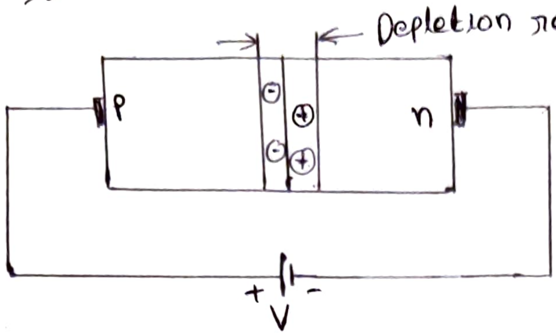
→ Then they move from hole to hole towards the positive terminal of the battery. The movement of valence electrons is nothing but movement of holes in opposite direction to that of electrons, in the p-region.

→ So current in p-region is the movement of holes which are majority carriers. This is the hole current.

→ The current in the n-region is the movement of free electrons which are majority carriers. This is the electron current.

→ Depletion region narrows due to forward bias voltage as shown in below fig.

Fig: Forward biased diode




→ Under the influence of applied forward bias voltage, the electrons get the energy equivalent to the barrier potential & while crossing the junction, electrons give up the amount of energy equivalent to the barrier potential.

→ Total voltage drop across a pn junction diode ($V_F$) is made up of

(i) Drop due to barrier potential.

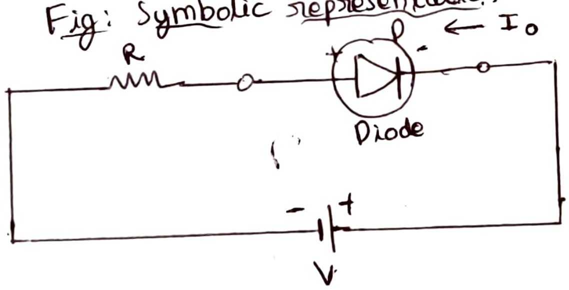
(ii) Drop due to internal resistance.

$V_F = 0.7V$ for Si

$V_F = 0.3V$ for Ge.

(ii) Reverse Biasing of p-n junction diode:-

Fig: Symbolic representation



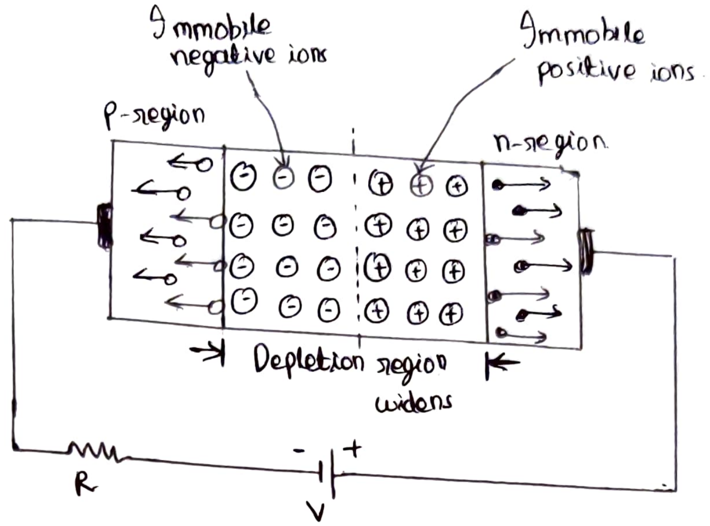

→ If an external d.c voltage is connected in such a way that the p-region terminal of a p-n junction is connected to the negative of the battery & the n-region terminal of a p-n junction is connected to the positive terminal of the battery, the biasing condition is called reverse biasing.

Operation of Reverse biased diode:-

→ when the p-n junction is reverse biased the negative terminal attracts the holes in the p-region, away from the junction. |||ly the positive terminal attracts the free electrons in the n-region away from the junction

→ As electrons & holes both move away from the junction, the depletion region widens.

Fig: Depletion region widens in reverse bias




→ As depletion region widens, barrier potential accross the junction also increases

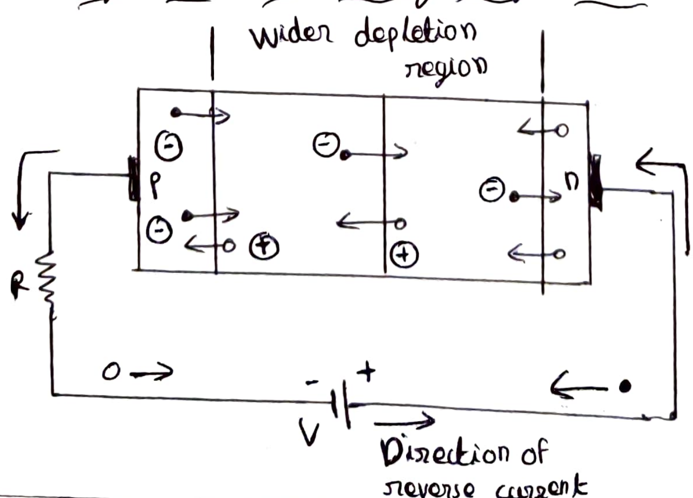
→ The polarities of barrier potential are same as that of the applied voltage.

→ Due to increased barrier potential, the positive side drags the $e^-$'s from p-region towards the positive of battery. ||ly negative side of barrier potential drags the holes from n-region towards the negative of battery.

→ Thus reverse current (very small) flows due to minority charge carriers which are small in number.

→ The generation of minority charge carriers (also reverse current) depends on the temperature (thermal generation) & not on the reverse voltage applied.

Fig: Flow of minority charge carriers



→ Though the reverse saturation current ($I_o$) is not dependant on the applied reverse voltage, if reverse voltage is increased beyond particular value, large reverse current can flow damaging the diode called reverse breakdown.

Reverse breakdown of a diode takes place due to 2 effects.

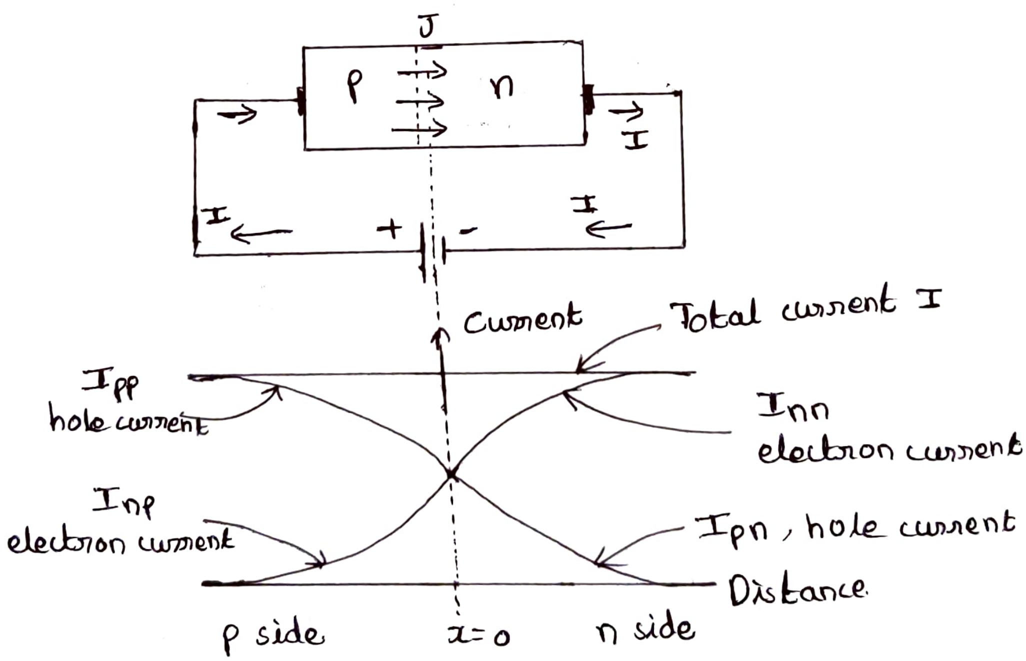
1) Avalanche effect 2) Zener effect

$I_o$ → For a constant temperature, the reverse current is almost constant though revese voltage is increased up to a certain limit.

* Current components in a p-n Diode :-

→ When a p-n junction diode is forward biased a large forward current flows due to majority carriers & the depletion region is very small.

Fig: Current components




→ In forward biased condition, holes from p-side get diffused in to n-side & electrons from n-side get diffused in to p-side.

→ On p-side, the current carried by electrons which is diffusion current due to minority carriers, decreases exponentially with distance measured from the junction. This current denoted as $I_{np}$.

→ Similarly holes from p side diffuse in to n-side carry current which decreases exponentially with respect to distance measured from the junction. This current is denoted as $I_{pn}$

→ If the distance is denoted as 'x', then

$I_{np}(x)$ = Current due to electrons in p side as a function of 'x'.

$I_{pn}(x)$ = Current due to holes in n side as a function of 'x'.

At $x=0$ (junction), the currents are $I_{np}(0)$ & $I_{pn}(0)$.

Hence the current at the junction, $I = I_{pn}(0) + I_{np}(0)$

→ As the entire circuit is a series circuit, the total current is maintained at 'I' independent of 'x'.

$I_{pp}(x)$ = Current due to holes in p side.

$I_{nn}(x)$ = Current due to electrons (majority carriers) in n-side.

On p side, $I = I_{pp}(x) + I_{np}(x)$.

On n side, $I = I_{nn}(x) + I_{pn}(x)$

→ As shown in figure, the current $I_{pp}$ decreases towards the junction, at the junction enters the n side & becomes $I_{pn}$ which further decreases exponentially. Similarly the current $I_{nn}$ decreases towards the junction & then $I_{np}$ further decreases exponentially.

→ In forward bias condition, the current enters the p side as a hole current & leaves the n side as an electron current, of the same magnitude.

→ Total forward current, I = sum of currents carried by electrons & holes

→ The proportion due to holes & electrons in constituting the current varies with the distance, from the junction.

* **Diode Equation:-**

→ The mathematical representation of V-I characteristics of diode is called diode current equation, given by

$$I = I_0\left[e^{V/\eta V_T} - 1\right] A$$

$I_0$ = Reverse saturation current in amperes.

$V$ = applied voltage, $\eta = 1$ for germanium diode
$= 2$ for silicon diode.

$V_T$ = voltage equivalent of temperature in volts.

$\eta$ = Emission coefficient or ideality factor that takes in to account, the effect of recombination taking place in the depletion region. The range of '$\eta$' is from 1 to 2.

→ The voltage equivalent of temperature ($V_T$) for a given diode at temperature 'T' is egiven by, $V_T = KT$ volts.

$K$ = Boltzmann's constant $= 8.62 \times 10^{-5}$ ev/°K.

$T$ = Temperature in °K.

At room temperature of 27°C i.e $T = 27 + 273 = 300°K$, $V_T = 26mV$.

The value of '$V_T$' is given by, $V_T = \frac{T}{\left(\frac{1}{K}\right)} = \frac{T}{\left(\frac{1}{8.62 \times 10^{-5}}\right)} = \frac{T}{11600}$

→ The diode current equation is applicable to all the conditions of the diode i.e unbiased, forward & reverse biased.

→ When unbiased, $V = 0$ hence we get,

$I = I_0\left[e^0 - 1\right] = 0\ A$ (no current through diode when unbiased

→ For forward biased, V must be taken positive & we get forward current, I as positive.

→ For reverse biased, 'V' must be taken negative, and we get reverse current, I as negative.

→ If both sides of diode current equation is divided by cross-sectional area, 'A' of the junction, $\frac{I}{A} = \frac{I_o}{A}\left[e^{V/\eta V_T} - 1\right]$

i.e $J = J_o\left(e^{V/\eta V_T} - 1\right)$ A/m² where J - Forward current density.
$J_o$ - Reverse saturation current density.

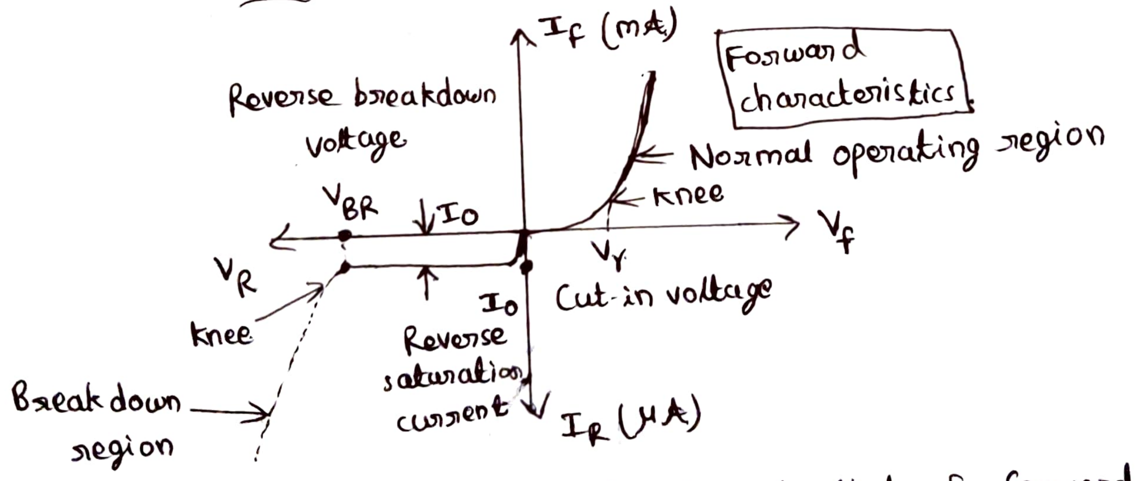
→ In forward biased condition, the bias voltage 'V' is considered positive, hence exponential index has positive sign, i.e $1 << e^{V/\eta V_T}$

Forward current equation, $I_f = I_o e^{V/\eta V_T}$

→ In reverse biased condition, the bias voltage 'V' is treated negative hence exponential index has negative sign, i.e. $e^{-V/\eta V_T} << 1$

Reverse current equation, $I_R \cong I_o(-1) \cong -I_o$ (Reverse saturation current)

V - I characteristics of p-n junction diode



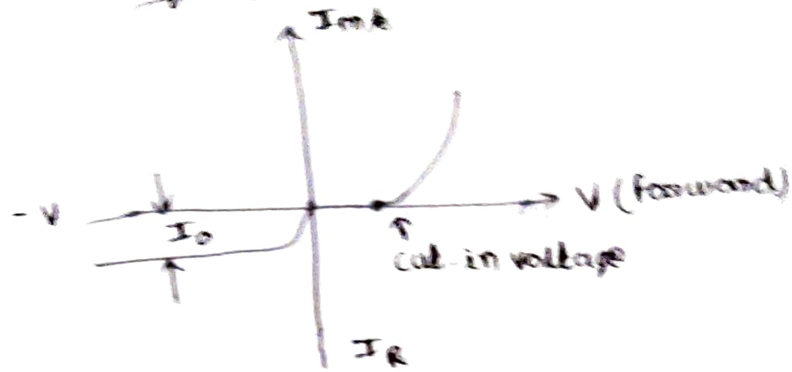

→ Reverse current flows in opposite direction to that of forward current.

→ Voltage equivalent of temperature, $V_T = KT$ is temperature dependant

→ Forward current depends on $I_o$ & $V_T$, hence entire V-I characteristics depends on the temperature.

→ Diode current equation is applicable to both forward & reverse biased conditions & describes the V-I characteristics of p-n junction diode

Fig: Cut-in voltage



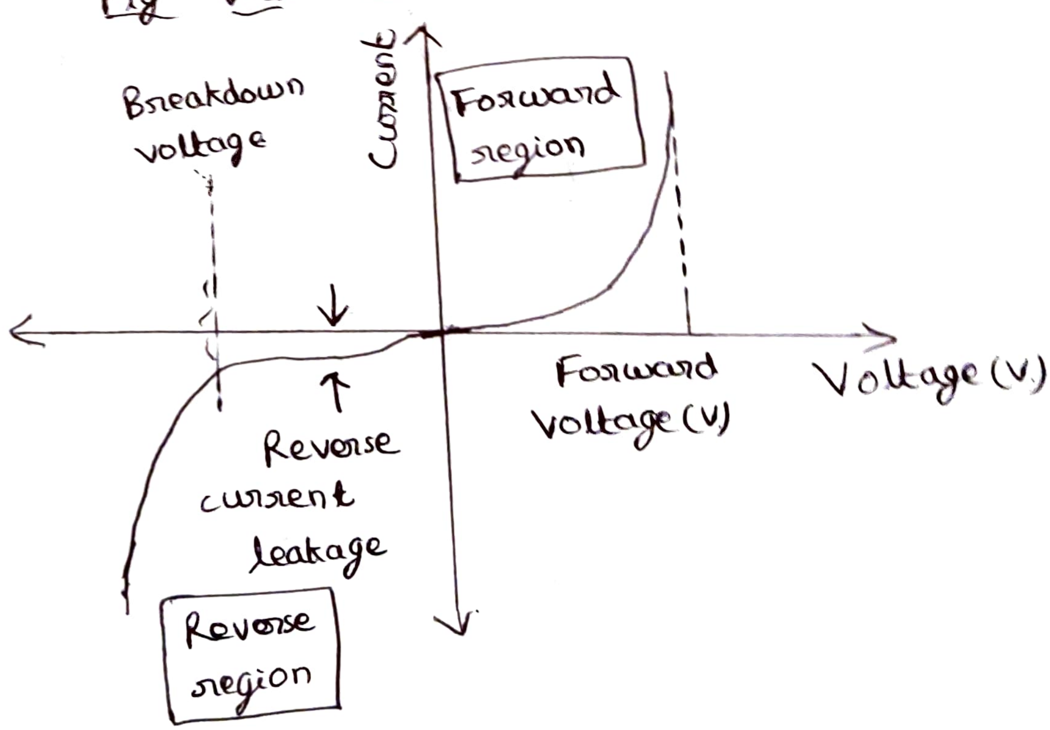

→ In the forward characteristics, the voltage at which the diode current starts increasing rapidly is called cut-in voltage, offset voltage, break point voltage or threshold voltage ($V_\gamma$).

$V_\gamma = 0.2$ for Germanium diode, $V_\gamma = 0.6V$ for silicon diode.

→ As temperature increases, more electron-hole pairs are generated & hence diode starts conducting at a lesser voltage. Thus cut-in voltage of diode decreases as temperature increases.

* Volt-Ampere characteristics:-

Fig: V-I characteristics of PN junction diode



V-I characteristics of PN junction diodes is a curve between the voltage and current through the circuit.

> Voltage is taken along the x-axis while the current is taken along the y-axis. With the help of curve shown in fig. there are 3 regions that diode works, they are (i) Zero Bias (ii) Forward bias (iii) Reverse bias.

(i) > When the PN junction diode is under zero bias condition, there is no external voltage applied i.e the potential barrier at the junction does not allow the flow of current.

(ii) When the PN junction diode is under forward bias condition, the P-type is connected to the positive terminal, while the n-type is connected to the negative terminal of the external voltage. In this condition, there is reduction in the potential barrier.

> At cut-in voltage ($V_\gamma$), the potential barrier decrease & there is a flow of current.

For silicon (si) diode, $V_\gamma = 0.7$ V

For Germanium (Ge) diode, $V_\gamma = 0.3$ V.

> Once the potential barrier is overcome by the diode, the external voltage increases and the curve is linear, the current increases slowly and the curve is non-linear.

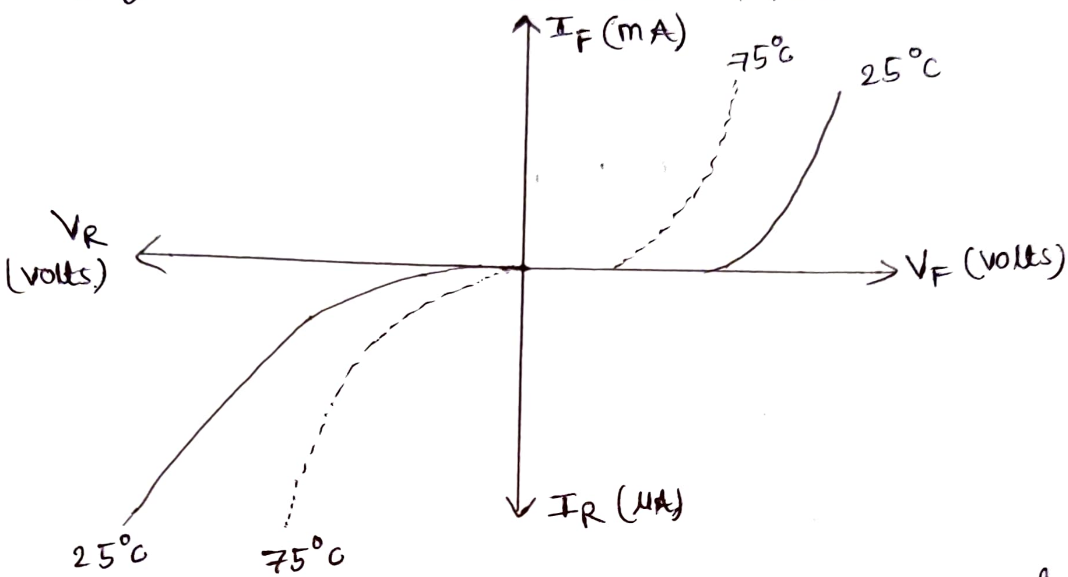
(iii) When the PN junction diode is under reverse bias condition, the P-type is connected to the negative terminal, while the n-type is connected to the positive terminal of the external voltage. In this condition, there is increase in the potential barrier.

> Reverse saturation current flows in the beginning as minority carrie are present in the junction.

→ When the applied voltage is increased, the minority charges will have increased kinetic energy which affects the majority charges. At this stage diode breaks down & may also destroy the diode.

## * Temperature dependence :-

Fig: Characteristics of diode with respect to temperature




→ PN junction diode parameters like reverse saturation current, bias current, reverse breakdown voltage and barrier voltage are dependent on temperature.

→ Mathematically diode current is given by,

$$\cancel{I = I_0\left(e^{\frac{qV}{\eta KT}} - 1\right)}$$

$$I = I_S * (exp(V/(n * K * T/q)) - 1)$$

Hence from equation, we conclude that the current should decrease with increase in temperature, but exactly opposite occurs there are 2 reasons:

→ Raise in temperature generates more electron-hole pair thus conductivity increases & thus increase in current.

→ Increase in reverse saturation current with temperature offsets the effect of rise in temperature

→ Reverse saturation current ($I_s$) of diode increases with increase in the temperature, the rise is 7%/°C for both germanium & silicon

& approximately doubles for every 10°C rise in temperature.

→ Thus, if we kept the voltage constant, as we increase the temperature, the current increases.

→ Barrier voltage is also dependent on temperature, it decreases by 2 mV/°C for germanium and silicon.

→ Reverse breakdown voltage ($V_R$) also increases as we increase the temperature.

* Ideal versus practical:-

| Ideal diodes | Practical diodes |
| --- | --- |
| 1) Ideal diodes act as perfect conductor & ~~per~~ perfect insulator. | 1) Practical diodes cannot act as perfect conductor and perfect insulator. |
| 2) Ideal diode draws no current when reverse biased. | 2) Practical diode draws very low current when reverse biased. |
| 3) Ideal diode offers infinite resistance when reverse biased. | 3) Practical diode offers very high resistance when reverse biased. |
| 4) It cannot be manufactured. | 4) It can be manufactured. |
| 5) It has zero cut-in voltage. | 5) It has very low cut-in voltage. |
| 6) Ideal diode has zero voltage drops across its junction when forward biased. | 6) It has very low voltage drop across it, when forward biased. |
| 7) ~~Ideal diode acts as~~ perfect conductor ~~& perfect insulator.~~ | 7) |

* Static & dynamic resistances:-

A p-n junction diode allows electric current in one direction & blocks electric current in another direction. It allows electric current when it is forward biased & blocks electric current when it is reverse biased.

⇒ However, no diode allows electric current completely even in forward biased condition.

⇒ The depletion region present in a diode acts like barrier to electric current. Hence, it offers resistance to the electric current. Also, the atoms present in the diode provide some resistance to the electric current.

⇒ When charge carriers (free electrons & holes) flowing through the diode collides with atoms, they lose energy in the form of heat. Thus, depletion region & atoms offer resistance to the electric current

⇒ When forward biased voltage is applied to the p-n junction diode, the width of the depletion region decreases & there exist a then depletion regions and atoms in the diode offer some resistance to electric current called forward resistance.

⇒ When reverse biased voltage is applied to the p-n junction diode, the width of the depletion region increases & a large number of charge carriers (free electrons & holes) flowing through the diode is blocked by the depletion region. Hence only a small electric current flows due to minority carriers. Thus reverse biased diode offers large resistance to the electric current called reverse resistance.

The 2 types of resistances takes place in the p-n junction diode are:

(i) Forward resistance (ii) Reverse resistance.

⇒ The 2 types of resistance takes place in forward biased diode are;

(a) Static or DC resistance.

(b) Dynamic or AC resistance.

(a) Static or DC resistance:- (Refer page 14)

→ When forward biased voltage is applied to a diode that is connected to a DC circuit, a DC or direct current flows through the diode.

→ Direct current or electric current is the flow of charge carriers (free electrons or holes) through a conductor.

→ In DC circuit, the charge carriers flow steadily in single direction or forward direction.

→ The resistance offered by a p-n junction diode when it is connected to a DC circuit is called static resistance.

→ Static resistance is defined as the ratio of DC voltage applied across diode to the DC current or direct current flowing through the diode.

→ The resistance offered by the p-n junction under forward biased condition, $R_f = \frac{\text{DC voltage}}{\text{DC current}}$

(b) Dynamic resistance or AC resistance

→ The dynamic resistance is the resistance offered by the p-n junction diode when AC voltage is applied.

→ When forward biased voltage is applied to a diode that is connected to AC circuit, an AC or alternating current flows through the diode.

→ In AC circuit, charge carriers or electric current flows in both forward & reverse direction.

Dynamic resistance, $r_f = \frac{\text{Change in voltage}}{\text{Change in current}}$

## * Equivalent circuit:-

→ An equivalent circuit is a combination of elements properly chosen to best represent the actual terminal characteristics of a device, system, or in a particular operating region.

→ Once the equivalent circuit is defined, the device symbol can be removed from a schematic & equivalent circuit inserted in its place. The result is often a network that can be solved using circuit analysis techniques.

→ If we keep the diode operation away from the breakdown region, the curve is the piecewise linear. We can model the diode as a simple circuit element or combination of standard circuit elements.

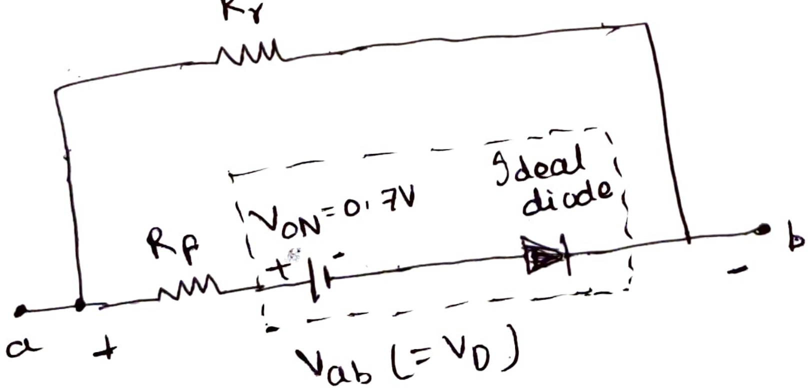
**DC Diode model:-** Here we take the ideal diode & the modifications that were required due to practical considerations.

Ideal diode:- $V_{ON} = 0$, $R_r = \infty$ & $R_f = 0$

i.e Ideal diode is short in forward bias.
open in reverse bias.

Practical diode (silicon):- $V_{ON} = 0.7V$, $R_r < \infty$ (several MΩ),
$R_f \cong r_d$ (< 50Ω).

Fig (a): Practical diode under d.c operating condition



→ Diode is a two-terminal device labeled as a & b with voltage $V_{ab}$ applied across the diode. a & b terminals are used to connect to other circuit elements.

→ We can define the operating region in forward or reverse bias.

Fig (b): Forward Biased dc Diode Model

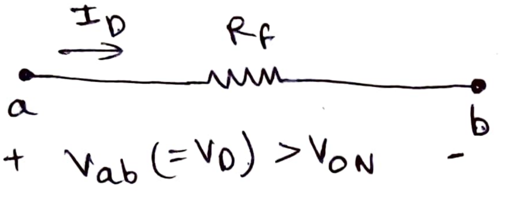
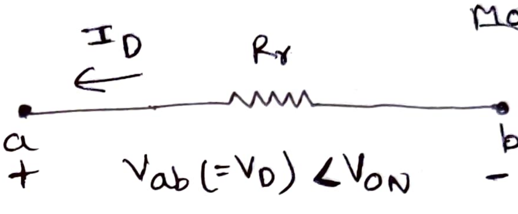



Fig (c): Reverse Biased dc Diode Model




→ For the forward biased region ($V_D \geq 0.7V$ for silicon), the ideal diode is a short & the terminal characteristics of fig(a) reduce to the parallel combination of $R_r$ and $R_f$. (fig b & c.)

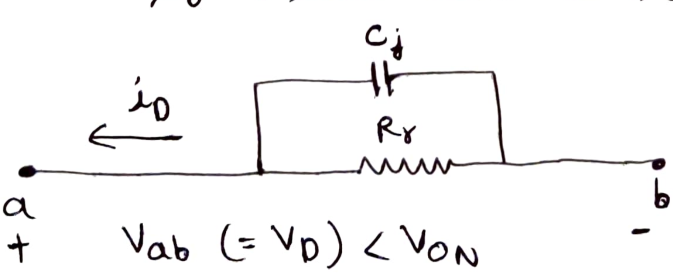
→ $\because R_r >> R_f$, $R_r \parallel R_f \approx R_f$.

→ For the reverse biased region ($V_D < 0.7V$ for silicon), the ideal diode is an open & the resistance between terminals 'a' & 'b' is $R_r$.

→ Diode characteristics in the forward & reverse bias are different.

AC Diode model:-

Fig (d): Reverse Biased ac Diode Model



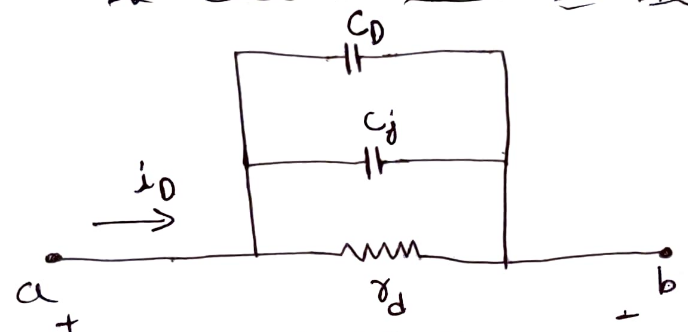

→ Whenever there is a charge separation, there is a capacitive effect.

→ Charge separation comes in the diode due to the depletion region that depends on the applied bias.

→ For the reverse bias, this introduces a junction capacitance ($C_j$) in parallel with the reverse bias resistance ($R_r$). (fig (d))

→ Current flows in different directions under ac operation. Since current is moving charge, ~~we~~ their is movement of charges in the semiconductor material. Charges can not move instantaneously, so there is a "charge storage" effect that leads to a diffusion capacitance ($C_D$).

Fig: Forward biased ac Diode Model




$V_{ab}$ ($= V_D$) $> V_{ON}$

→ The forward bias resistance is also a function of frequency, so the dynamic resistance ($r_d$) replaces the constant $R_f$ term.

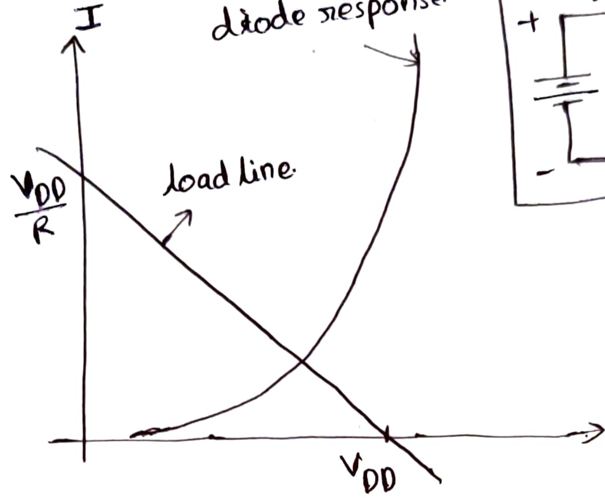
→ Diode is a nonlinear device that we cannot use circuit techniques (KCL, KVL etc) to analyze circuits containing diodes.

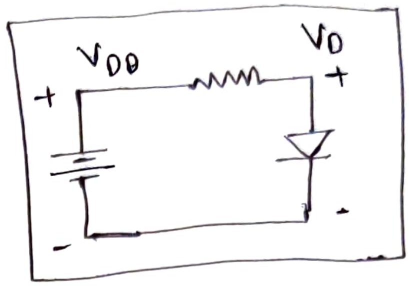
## * Load line analysis :-

→ In graphical analysis of nonlinear electronic circuits, a load line is a line drawn on the characteristic curve, a graph of the current vs. the voltage in a nonlinear device like a diode or transistor. It represents the constraint put on the voltage & current in the non-linear device by the external circuit.

→ The load line is a straight line that represents the ~~linear part~~ response of the linear part of the circuit connected to non-linear device

Fig: Diode load line. The curve shows the diode response ($I$ vs $V_D$), straight line shows the behaviour of the linear part of the circuit $I = ((V_{DD} - V_D)/R)$. The point of intersection gives the actual current & voltage




→ The points where the characteristic curve & the load line intersect are the possible operating point (Q point) of the circuit; at these points the current & voltage parameters of both parts of the circuit match.

→ The example at right shows how a load line is used to determine the current & voltage in a diode circuit.

→ The diode (non-linear device), is in series with a linear circuit consisting of a resistor, R & a voltage source, $V_{DD}$.

→ The characteristic curve (curved line), representing the current 'I' through the diode for any given voltage across the diode $V_D$, is an exponential curve.

→ The load line (diagonal line), representing the relationship between current & voltage due to kirchoff's voltage law applied to the resistor & voltage source, is $V_D = V_{DD} - IR$.

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→ Since the same current flows through each of the 3 elements in series, & the voltage produced by the voltage source & resistor is the voltage across the terminals of the diode, the operating point of the circuit will be at the intersection of the curve with the load line.

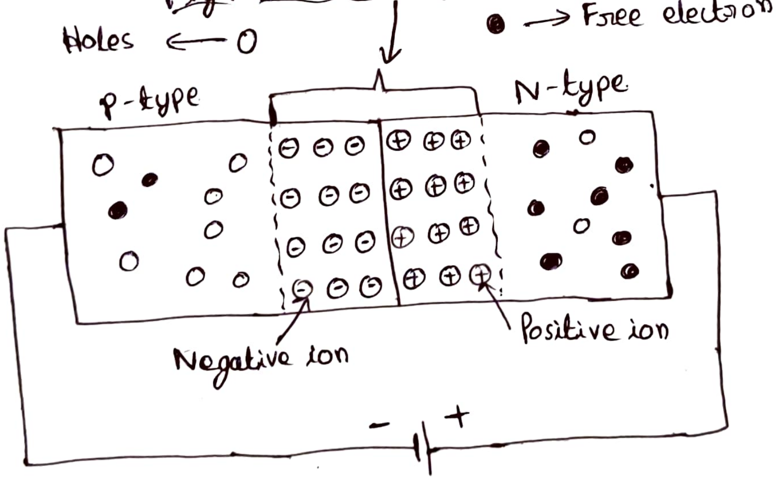
→ In a circuit with a 3 terminal device (transistor), the current-voltage curve of the collector-emitter current depends on the base current. It is shown on graph by a series of ($I_C - V_{CE}$) curves at different base currents.

→ A load line drawn on this graph shows how the base current will affect the operating point of the circuit.

* Transition and Diffusion Capacitances :-

Transition capacitance :-

Fig : Transition capacitance




→ When P-N junction is reverse biased the depletion region act as an insulator or as a dielectric medium & the p-type an N-type region have low resistance & act as the plates.

→ Thus this P-N junction can be considered as a parallel plate capacitor.

→ This junction capacitance is called as space charge capacitance or

→ The density of the charge carriers is high near the junction &

transition capacitance, denoted as $C_T$.

→ Since reverse bias causes the majority charge carriers to move away from the junction, so the thickness of the depletion region (W) increases with increase in reverse bias voltage.

→ Incremental capacitance, $C_T = dQ/dV$

$dQ$ → Increase in charge, $dV$ → Change or increase in voltage.

→ The depletion region increases with the increase in reverse bias potential, the resulting transition capacitance decreases.

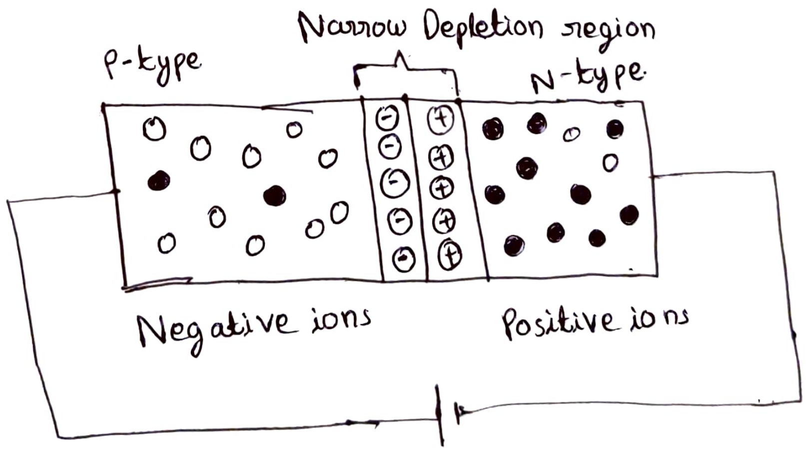
→ The formula for transition capacitance, $C_T = A\varepsilon/W$

A → Cross section area of the region, W → Width.

Diffusion capacitance:-

Fig: Diffusion Capacitance

- Occurs in forward biased diode - Storage capacitance, $C_D$.
- Due to stored charge of min. Electron & holes near dep. reg.




→ When the junction is forward biased, a capacitance comes into play, known as diffusion capacitance ($C_D$). $C_D >> C_T$

→ During forward biased, the potential barrier is reduced. The charge carriers moves away the junction & recombine.

→ The density of the charge carriers is high near the junction &

reduces or decays as the distance increases.

→ Thus in this case charge is stored on both side of the junction & varies with the applied potential. Change in charge with respect to applied voltage results in capacitance called diffusion capacitance ($C_D$).

→ $C_D = \tau I_D / \eta V_T$

$\tau$ → Mean life time of the charge carrier.

$I_D$ → Diode current

$V_T$ → Applied forward voltage.

$\eta$ → Generation recombination factor.

→ $C_D \propto I_D$

→ In forward bias, $C_D \gg C_T$ & thus $C_T$ can be neglected.

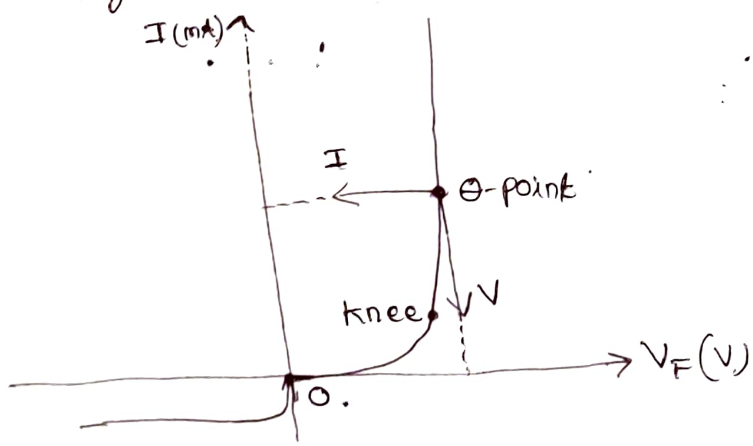
Refer these topics

* Static & dynamic resistances:-

(a) Static (or) DC resistance ($R_F$):- $R_F = \frac{V}{I}$

→ Static resistance is defined as the ratio of voltage to the current.

Fig: Static resistance




→ As shown in figure, $R_F$ at the operating (or) Q-point can be determined by using the corresponding values of 'V' & 'I'.

→ Below knee point, 'I' is low, i.e. $R_F$ is high ⇒ $\uparrow R_F = \frac{V}{I\downarrow}$

→ Above the knee point, 'I' is high, i.e. $R_F$ is low ⇒ $\downarrow R_F = \frac{V}{I\uparrow}$

→ $R_F$ is defined at a specific point.

(b) AC (or) Dynamic Resistance ($r_f$):- $r_f = \frac{\Delta V}{\Delta I}$

→ Dynamic resistance is defined as the ratio of change in voltage to the resulting change in current.

Fig:- Dynamic resistance

Fig (i)(a)

Fig (ia)

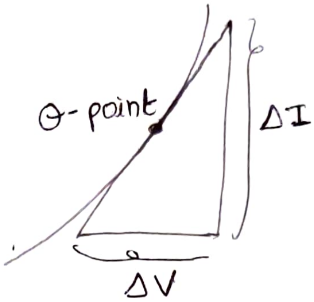
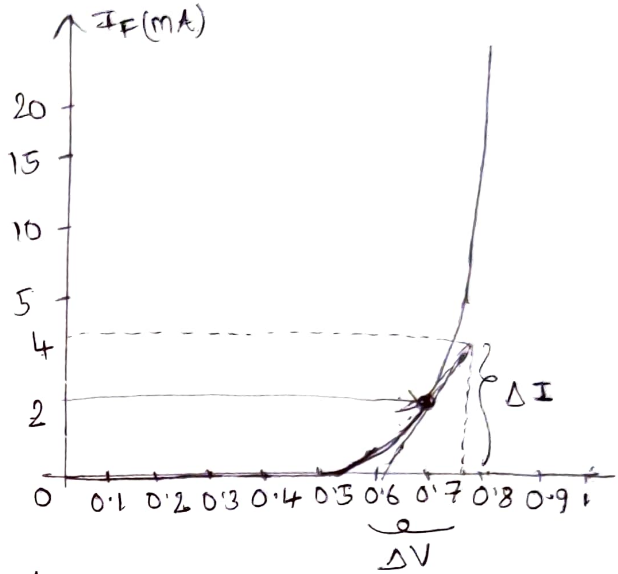



Fig (i b)




→ As shown in Fig (ia), a straight line drawn tangent to the curve through the quiescent point (Q-point) to determine the dynamic resistance for this region of the diode characteristics.

→ As shown in Fig (ib), for a small change in voltage, there will be a corresponding change in current, which is equidistant to either side of the Q-point.

→ The derivative of a function at a point is equal to the slope of the tangent line drawn at that point.

We know that, $I = I_0 \left( e^{V/\eta V_T} - 1 \right)$

Taking the derivative w.r.t the applied voltage, we get

$$\frac{dI}{dV} = \frac{d}{dV} \left[ I_0 \left( e^{V/\eta V_T} - 1 \right) \right]$$

$$= I_0 \left[ \frac{1}{\eta V_T} \cdot e^{V/\eta V_T} \right]$$

$$= \frac{I_0 \, e^{V/\eta V_T}}{\eta V_T} = \frac{I + I_0}{\eta V_T}$$

Generally, $I >> I_0$ i.e $\frac{dI}{dV} \simeq \frac{I}{\eta V_T}$

$\therefore \frac{dV}{dI} = r_j = \frac{\eta V_T}{I}$ i.e dynamic resistance varies inversely with current

where $V_T = T/11,600$, $V_T = 26\ mV$ at room temperature.

$\eta = 1$ for Ge & $\eta = 2$ for Si.

A.C resistance of a diode = $r_b$ (bulk resistance) + $r_j$ (junction resistance)

$r_b \rightarrow$ sum of ohmic resistances of the P- & N-type semiconductors.