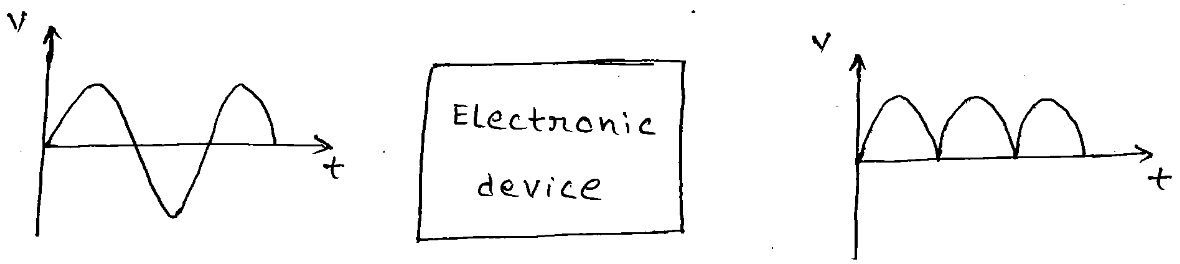
Electronics : The branch of Engineering which deals with current conduction through a vaccum or gas or semi conductor is known as Electronics.

Electronic Device : An electronic device is that in which current flows through a vaccum or gas or semi conductor.

Applications of Electronics :-

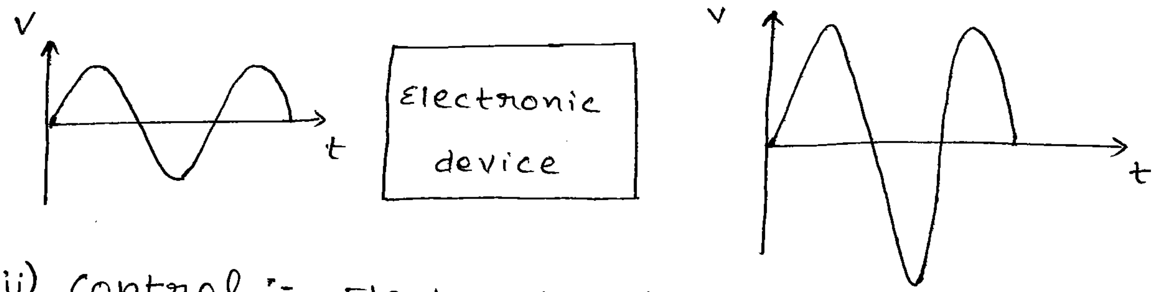
The Electronic devices are capable of Performing the following functions

i) **Rectification** : The conversion of a.c in to d.c is called rectification. Electronic devices can convert a.c power in to d.c power with very high efficiency. This d.c supply can be used for charging storage batteries, field supply of d.c generators etc.



(ii) **Amplification** :- The process of raising the strength of a weak signal is known as Amplification.

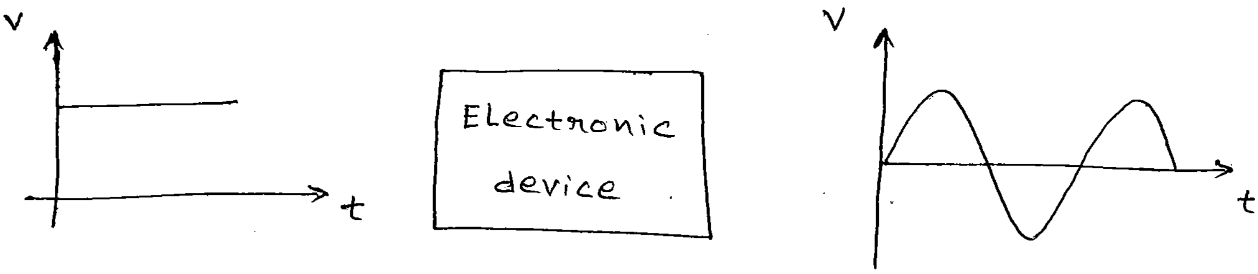
Ex. Radio's, Televisions



iii) <u>Control</u> :- Electronic devices find wide applications in automatic control.

<u>Ex</u> speed of a motor, voltage across a refrigirator etc

iv) <u>Generation</u> :- Electronic devices can convert d.c power in to a.c power of any frequency. when performing this function, they are known as oscillators.



v) <u>conversion of Light in to Electricity</u> :- Electronic devices can convert Light in to Electricity. This conversion of light in to electricity is known as photo Electricity. <u>ex</u> Burglar alarms etc

vi) <u>conversion of Electricity in to Light</u> :- Electronic devices can convert electricity in to Light. This valuable property is utilised in television and radar.

Generally materials are classified in to 3 types

i) Insulators

ii) Metals

iii) Semiconductors

i) Insulators :- A very poor conductor of Electricity is called an Insulator

Ex wood, glass, Diamond, Mica etc

ii) Metals :- An Excellent conductor is a metal. Ex : copper, Alluminium etc

iii) Semi Conductor :- A material whose conductivity lies between that of conductors and insulators is called semi conductors.

Ex: Silicon and Germanium.

Structure of an Atom :-

→ All the protons and neutrons are bound together at the centre of an atom, which is called nucleus, while all the electrons are moving around the nucleus

→ the electrons are arranged in the different orbits at fixed distances from the nucleus

→ In general, an orbit or a shell can contain a maximum number of $2n^2$ electrons, where 'n' is the number of the shell.

→ Each shell has energy level associated

→ Closer the shell to the nucleus, more tightly it is bound to the nucleus and posesses Lower energy level.

→ The outermost shell is called valence shell and the electrons in this shell are called valence electrons.

→ The valence electrons revolving in the outer most shell are said to be having highest energy level

→ The amount of energy required to extract the valence electron from the outer shell is very less

→ An electron which is not subjected to the force of attraction of the nucleus is called a free electron. Such free electrons are basically responsible to the flow of current.

→ more the number of free electrons better is the conductivity of the metal.

Energy band theory :-

A material can be placed into insulators, conductors and semiconductors depending upon its energy band structure.

The energy band diagram consists of three bands

(1) valence band (2) conduction band (3) Forbidden band

(1) Valence band :- The valence electrons possess highest energy level. when such electrons form the covalent bonds due to the coupling between valence electrons of adjacent atom, the energy band formed due to merging of energy levels associated with the valence electrons. ie. electrons in the last shell is called the valence band

(2) conduction band :- valence electrons form the covalent bond and are not free, but when certain energy is imparted to them they become free.

The energy band formed due to merging of energy levels associated with the free electrons is called conduction band.

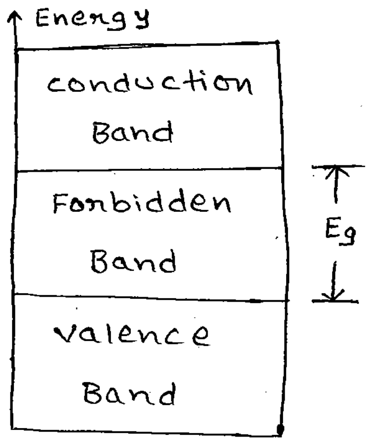
under normal conditions, the conduction band is empty and once energy is imparted the valence electrons jump from valence band to conduction band and become free.

(3) Forbidden band :-

while jumping from valence band to Conduction band the electrons have to cross an energy gap

The energy gap which is present separating the conduction band and the Valence band is called forbidden band or forbidden energy gap.

Insulators :- The energy band diagram of a insulator is shown in figure below.



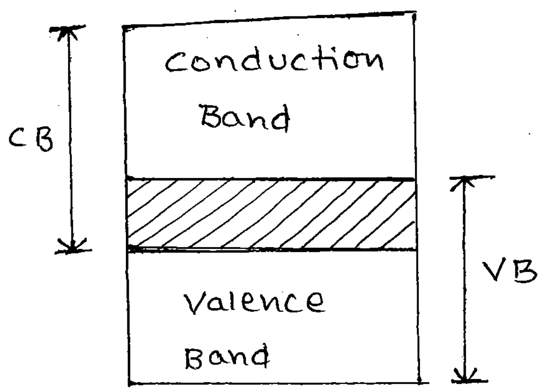
The valence band is fully filled and conduction band is almost empty and forbidden gap is more approximately of about 7eV

For a diamond, the forbidden gap is about 6eV

conduction is impossible in insulators even by applying additional energy.

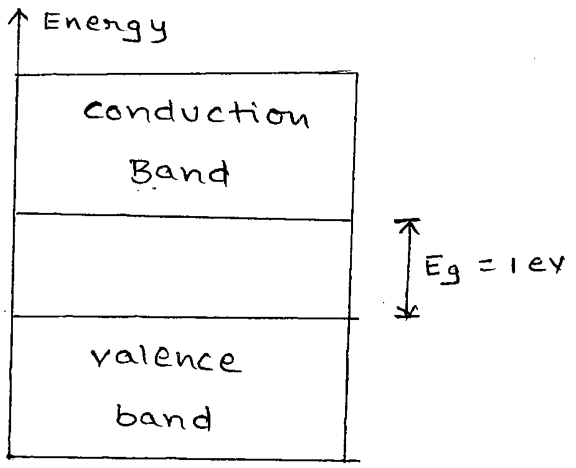
The resistivity of insulators is of the order of 10^7 ohm-meter.

Conductors : The energy band diagram of conductors is shown in figure below.



Here the valence band and conduction band overlap each other as shown in figure. As a result the electrons in the valence band can easily move in to the conduction band to make conduction easily. The resistivity is of the order of $10^{-8}\,\Omega\text{-m}$.

(3) Semi Conductors :- The energy band diagram of semi Conductors is shown in figure below.



Here the valence band is almost filled and conduction band is almost empty. The energy gap between valence band and conduction band is very small and is about 1eV.

The resistivity of semi Conductor is of the order of $10^{-4}\,\Omega\text{-m}$.

Hence smaller electric field is required to push the electrons from the valence band to the conduction band.

At low temperature, the valance band is completely full and conduction band is completely empty. therefore at low temperatures the

However even at room temperature, some of the valence electrons acquire thermal energy greater than Eg to overcome forbidden energy gap and jump in to the conduction band to make the conduction possible.

Hence as the temperature increases, the conductivity of semiconductor increases ie. resistance decreases. Therefore semi conductors have negative resistance temperature coefficient.

At 0°K, the forbidden gap for Germanium is

$$\boxed{E_g = 0.785\ eV}$$

and for Silicon (Si) is $\boxed{E_g = 1.21\ eV}$

The forbidden energy gap depends on temperature.

At Room temp ie 300°K

For Ge $E_g = 0.72\ eV$

For Si $E_g = 1.1\ eV$

<u>Commonly used Semi Conductors</u> :

There are many semi conductors available, but very few of them have a practical application in electronics. The two most frequently used materials are Germanium and Silicon. It is because the energy required to break their covalent bond (ie the energy required to release an electron from their valence bonds) is very small being 0.72 eV for Ge and 1.1 eV for Si

1) Germanium (Ge) :

The atomic number of Ge is 32. Therefore it has 32 protons and 32 electrons. Two electrons are in the first orbit; eight electrons in the second, 18 electrons in the third and 4 electrons in the outer (or) valence orbit.

It is clear that Ge atom has 4 valence electrons ie it is a tetravalent element. It is shown in fig (a)

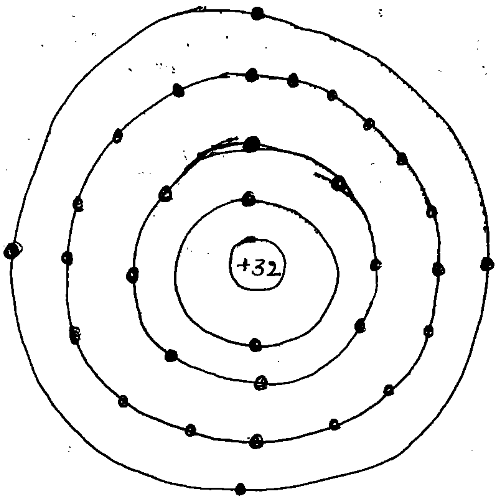


fig (a).

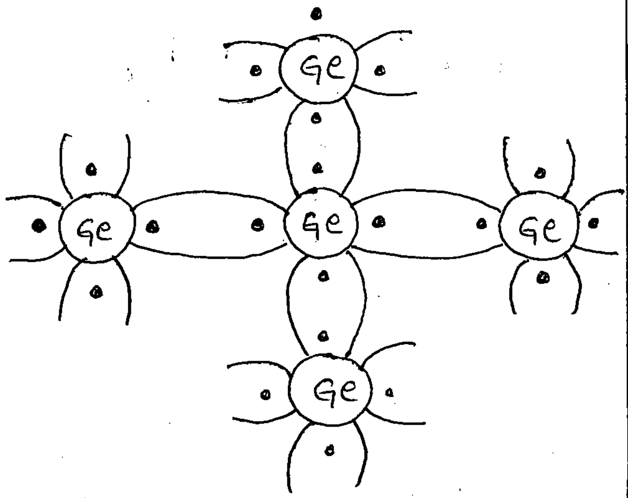


fig (b).

fig (b) shows how the various Germanium atoms are held through co-valent bonds. As the atoms are arranged in an orderly pattern, Ge has crystalline structure.

2) Silicon (Si) :- Silicon is an element ~~of~~ in most of the common rocks. Actually sand is silicon di oxide. And this is chemically reduced to silicon which is 100% pure for use as a semiconductor.

The atomic number of silicon is 14. Therefore it has 14 protons and 14 electrons. Two electrons are in the first orbit, eight electrons in the second orbit and four electrons in the ~~second~~ third orbit. This is shown in fig(a) below. It is clear that silicon atom has four valence electrons. ie. it is a tetravalent element.

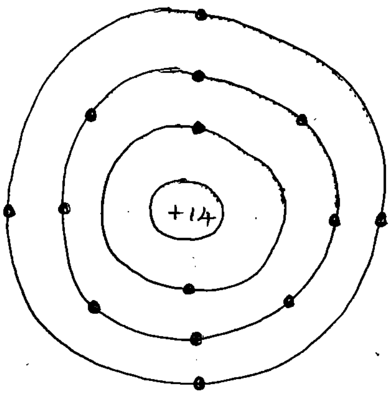


fig (a).

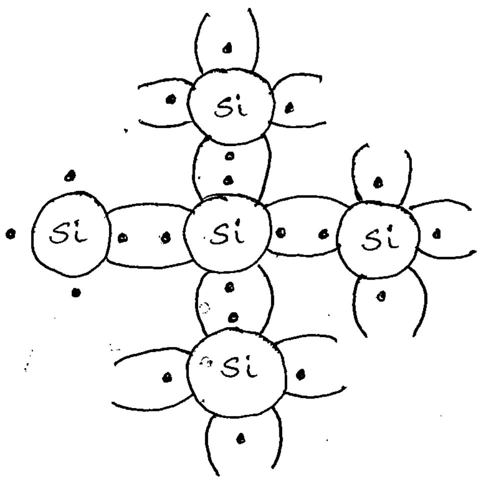


fig (b)

fig(b) shows how various silicon atoms are held through co-valent bonds. Like germanium, silicon atoms are also arranged in an orderly manner. Therefore silicon has crystalline structure.

<u>Classification of semi conductor materials</u> :-

Semi conductor materials are classified into two types
1. Intrinsic semi conductors
2. Extrinsic semi conductors.

1) <u>Intrinsic Semi Conductor</u> :- A pure form of semi-conductor material is known as intrinsic semi conductor material.

when there are four electrons in the outermost orbit, the semi Conductor material is refered to as pure or intrinsic Semi Conductor.

In pure Semi Conductor, the number of holes is equal to the number of free electrons.

Even at room temperature, some of valence electrons may acquire sufficient energy to enter the conduction band to form free electrons under the influence of electric field, these electrons constitutes the electric current.

The current due to the movement of free electrons in the conduction band is an electron current.

A missing electron in the valance band leaves a vacant space there, which is known as a hole.

under the influence of electric field, the current due to the movement of holes in the valance band is a hole current.

Therefore the electron as well as hole current together constitutes the total current in an intrinsic Semi Conductor.

Extrinsic Semi Conductor :- The intrinsic semi conductor has little current conduction capability at room temperature. To be useful in electronic devices, the pure semi conductor must be altered so as to significantly increase its conducting properties. This is achieved by adding a small amount of suitable impurity to a semi conductor. It is then called impurity or Extrinsic semiconductor. so

Doped semiconductor material is called Extrinsic (impure) Semi Conductor.

The process of adding small amount of impurities to the pure form of semi Conductor in order to increase the conductivity of semi Conductor is Known as doping.

Depending upon type of impurities, there are two types of extrinsic semi Conductors

(1) N-type (2) P-type.

(1) N-type Semi Conductor :-

When a small amount of pentavalent impurity such as Arsenic (As), Antimony (sb), Phosphorous, Bismuth etc is added to pure form of semi Conductor, it is Known as n-type semi Conductor. These pentavalent impurities are also called 'donar imprity atoms', because they donate or provide free electrons to the semi Conductor crystal.

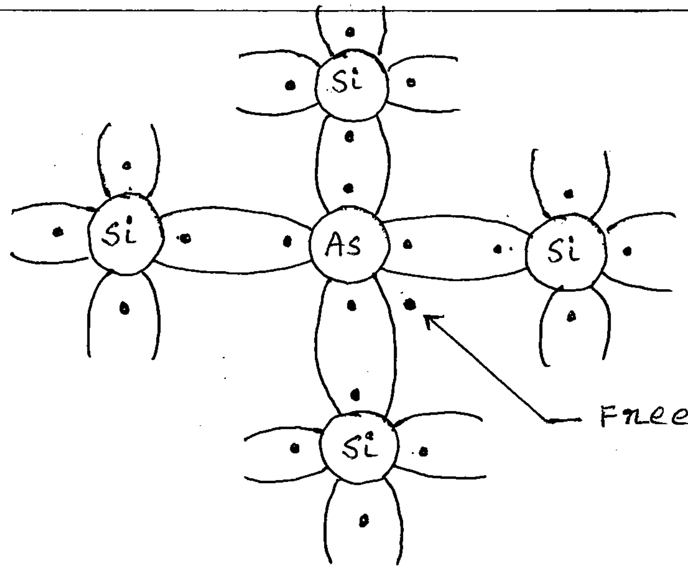


fig: Formation of covalent bonds in N-type semiconductor.

one donar impurity atom donates one free electron in N-type material. therefore free electrons are majority charge carriers in N-type semi conductors.

The following points may be noted carefully

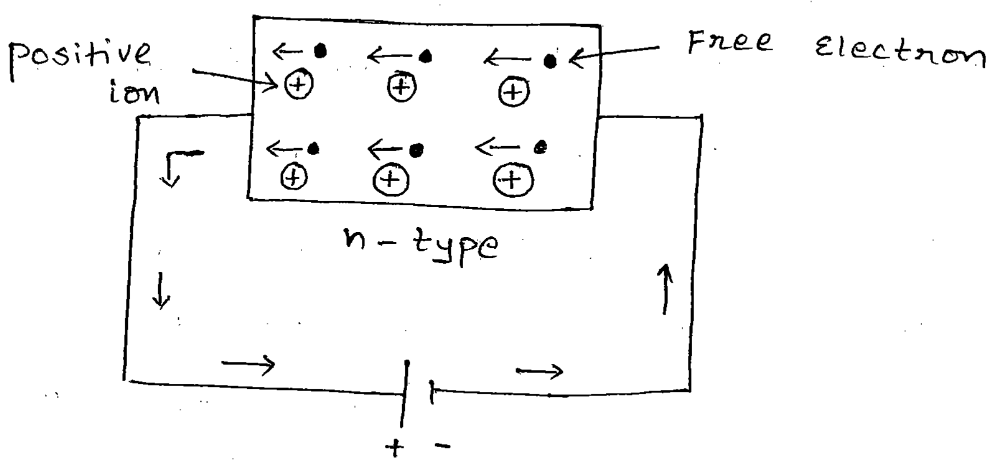
1) Many new free electrons are produced by the addition of pentavalent impurity.

2) Thermal energy at room temperature still generates a few electron-hole pairs. However the number of free electrons provided by the pentavalent impurity far exceeds the number of holes. It is due to this predominance of electrons over holes that it is called n-type semiconductor (n stands for negative). Here holes are the minority carriers.

n-type Conductivity :- The current conduction in an n-type semi conductor is predominantly by free electrons. when potential difference is applied across n-type semi conductor, the free electrons (donated by impurity) in the crystal will be directed towards the positive terminal, constituting electric current. so this type of conductivity is called n-type conductivity.

** The donor impurity atom donates one electron to the crystal and becomes "positive ion"

therefore n-type semi conductor cosists of free electrons and 'positive ion'



P-type semi Conductor :-

when a small amount of trivalent impurity such as Boron, Aluminium, Indium, Gallium is added to a pure semi conductor, It is called P-type semi conductor. These trivalent impurities are also called "Acceptor impurities".

one Acceptor impurity creates one hole in a P-type material, therefore the holes are majority charge carriers.

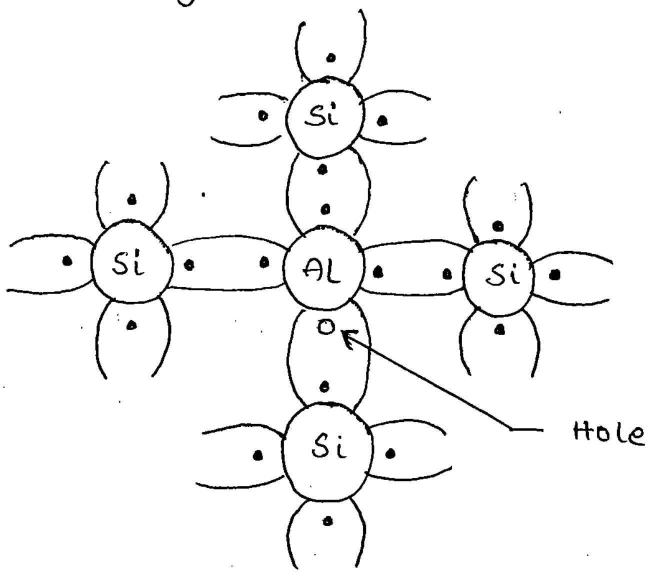
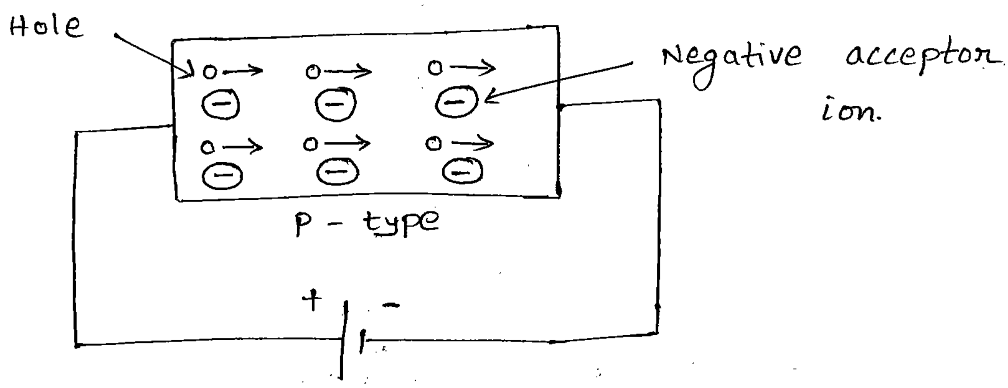


Fig: Formation of covalent bonds in P-type semi conductors.

Here fourth bond is incomplete, being short of one electron. This missing electron is called a hole. Therefore for each ~~gallium~~ AL atom added, one hole is created. A small amount of gallium provides millions of holes.

However, there are a few conduction band electrons due to thermal energy associated with room temperature. but the holes are far exceeds the number of electrons. because of this predominance of holes over free electrons, this type of semiconductor is called P-type semi conductor. (P stands for positive)

<u>P-type conductivity</u> :-



The current conduction in P-type Semi Conductor is predominantly by holes. when potential difference is applied to the P-type Semi Conductor, the holes are shifted from one covalent bond to another. As the holes are positively charged, they are directed towards the negative terminal, constituting hole current. so this type of conductivity is called P-type conductivity.

** The acceptor impurity atom is short of one electron, and becomes a negative ion.

Therefore P-type semi Conductor consists of <u>holes</u> and <u>Negative</u> <u>ions</u>.

Majority and minority carriers :-

In N- type Semi Conductor the majority Carriers are Electrons and the Minority carriers are the holes.

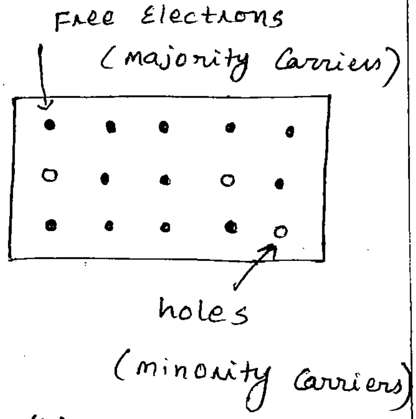
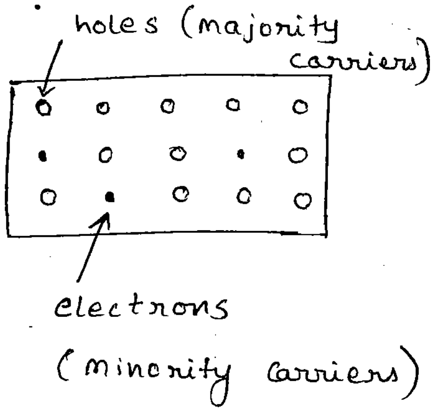


fig (i) N - type

In P- type Semi Conductor the majority carriers are holes and the minority Carriers are the electrons.

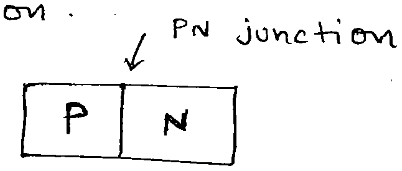


fig(ii) P - type

Qualitative theory of PN Junction (Formation of PN junction)

→ In a piece of semi conductor material, if one half is doped by P-type impurity and the other half is doped by N - type impurity, a PN junction is formed.

→ The plane dividing the two halves or zones is called PN junction.



→ P-type semi conductor consists of both holes and Negative acceptor ions (the acceptor impurity atom is short of one electron and becomes a negative ion)

→ The N-type semi conductor consists of both electrons and positive donor ion (The donor impurity atom donates one electron and becomes a positive ion)

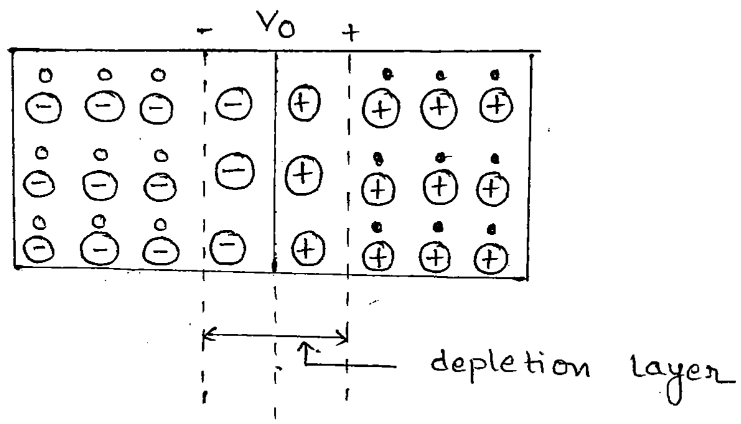
→ Here n-type material has a high concentration of free electrons while P-type material has high concentration of holes.

→ Therefore at the junction, there is a tendency for the free electrons to diffuse over to the P-side and holes to the N-side. This process is called diffusion.

→ As the free electrons move across the junction from n-type to P-type, Positive donor ions are uncovered. Hence a positive charge is built on the n-side of the junction.

→ At the same time, the free electrons cross the junction and uncover the negative acceptor ions by filling in the holes. Hence a net negative charge is established on P-side of the junction

→ Now positive charge on N-side repels holes to cross from P-type to n-type, and negative charge on P-side repels free electrons to enter from n-type to P-type. Thus barrier is set up against further movement of charge carriers. This is called potential barrier or barrier potential or junction barrier (V_0).



→ Barrier potential indicates the amount of voltage to be applied across the PN junction to restart the flow of electrons and holes across the junction

→ the barrior potential is expressed in Volts. Its value is called the height of the barrior.

→ the Magnitude of the barrior potential varies with doping levels and temperature.

→ The potential barrior can be increased or decreased by applying an external voltage.

→ The potential barrior is appronimately 0.7V for Si and 0.3 V for Ge at 25°C.

→ Inside the potential barrior, there is a positive charge on n-side and negative charge on P-side. This region is called <u>depletion</u> region or <u>space</u> <u>charge</u> <u>region</u>.

→ The thickness of this region is of the order of 10^{-4} cm (10^{-6} m = 1 micron)

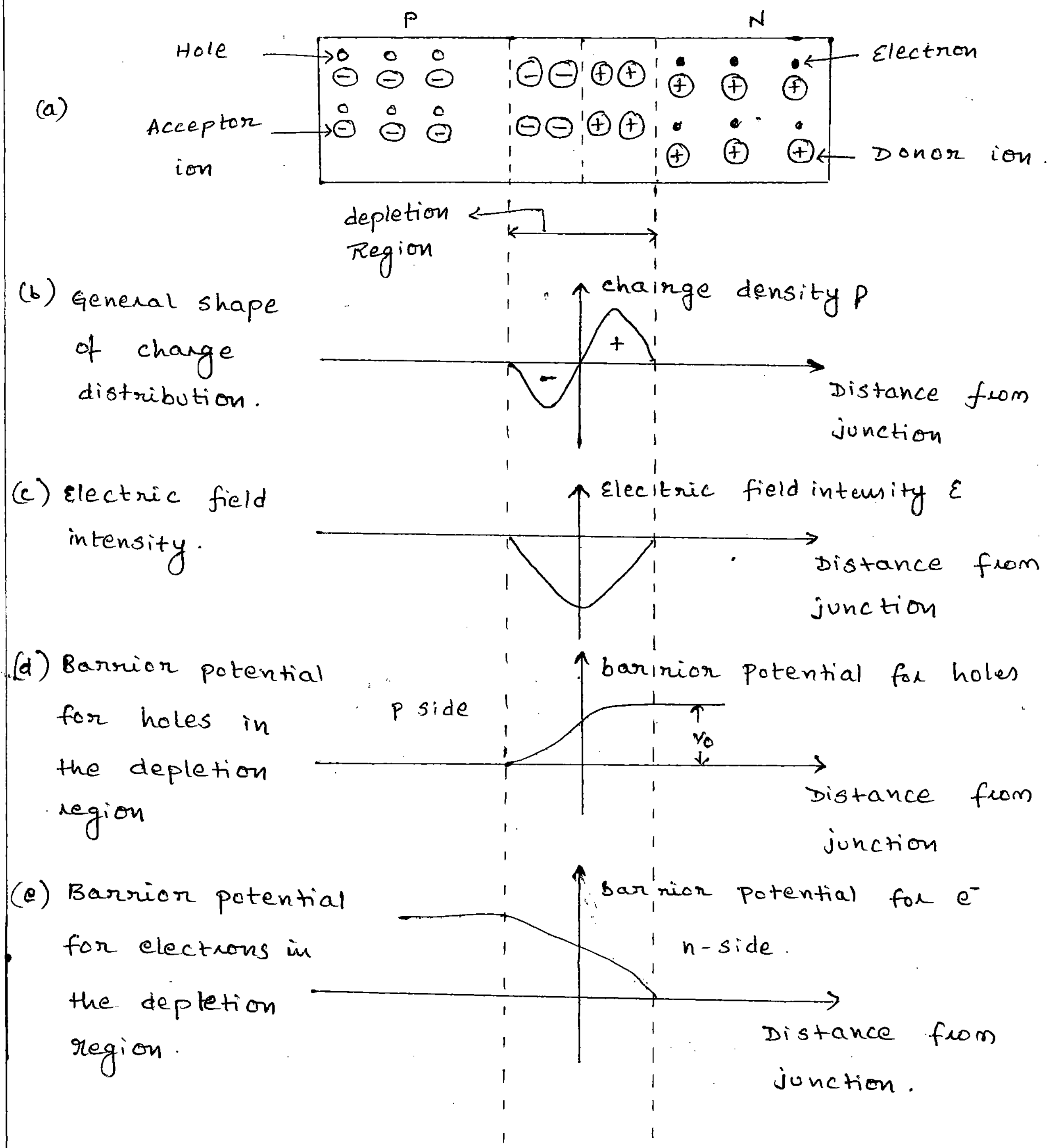
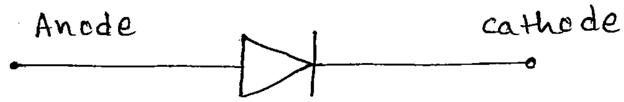


Figure: Formation of PN junction.

PN Junction as a Diode :-

The essential electrical characteristic of a PN junction is that it constitutes a diode which permits the easy flow of current in one direction and restricts the flow of current in opposite direction.

Diode Symbol : Diode symbol is shown in figure below.



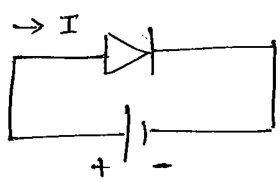
The P-type and n-type regions are referred to as Anode and Cathode respectively.
The Arrow in the symbol indicates the direction of easier conventional current flow.

Operation of PN junction Diode :

(1) **Forward Bias** :

→ When the positive terminal of the battery is connected to the P-type and the negative terminal of the battery is connected to n-type of PN junction diode, then the bias is said to be Forward bias.

→ A PN junction with forward bias is shown in figure below.



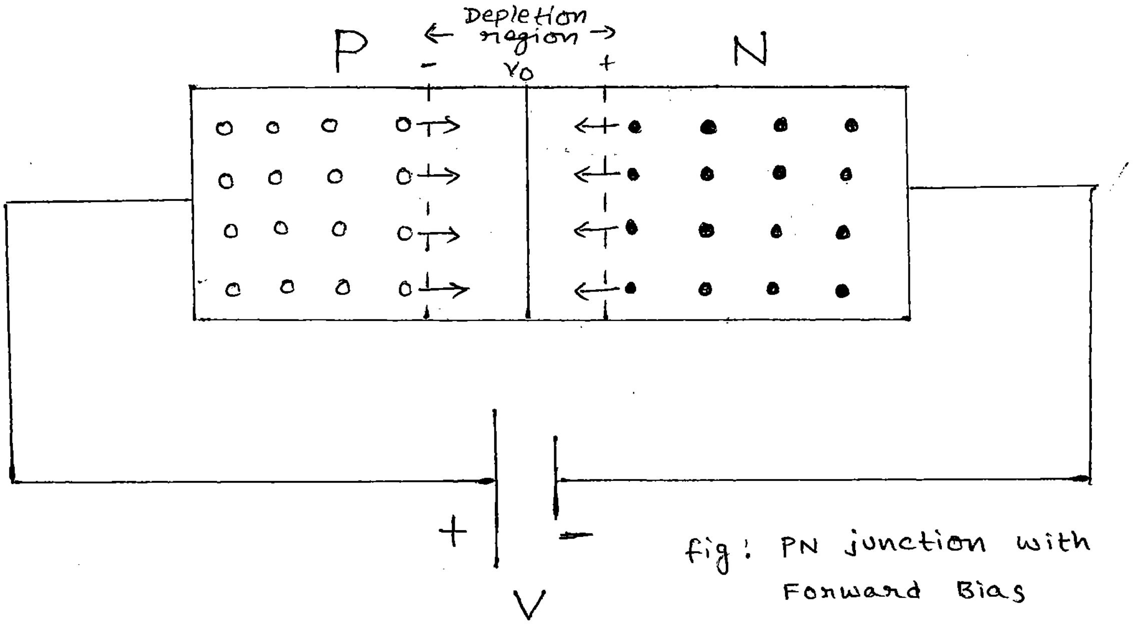


fig: PN junction with Forward Bias

→ when the PN junction is forward biased, as long as the applied voltage is less than the barrior potential there cannot be any conduction.

→ when the applied voltage becomes more than the barrior potential, the negative terminal of battery pushes the free electrons against barrior potential from n to p region. similarly positive terminal pushes the holes from p to n region. Thus holes get repelled by the positive terminal and cross the junction against the barrior potential, Electrons gets repelled by the negative terminal and cross the junction against the barrior potential. Thus the applied voltage overcomes the barrior potential. This reduces the width of the depletion region.

→ As forward voltage is increased, at a particular value the depletion region becomes very much narrow such that large number of majority charge carriers can cross the junction and these majority carriers can travel around the closed circuit and constitute a current called forward current.

→ The forward potential at which the potential barrior across the junction is completely eliminated and allows the current to flow through the junction is called cut-in voltage (or) threshold voltage of PN junction diode.

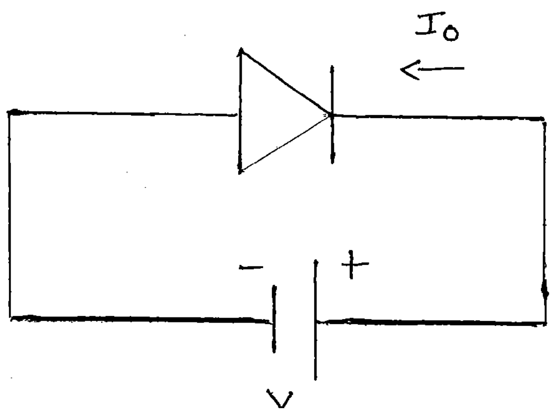
→ the cutin voltage for Ge is 0.3 V

→ the cut in voltage for Si is 0.7 V

(2) Reverse Bias :-

when the positive terminal of the battery is connected to the N type and the negative terminal of the battery is connected to the P type of the PN junction Diode, then bias is said to be 'Reverse Bias'.

A PN junction with reverse Bias is shown in figure below.



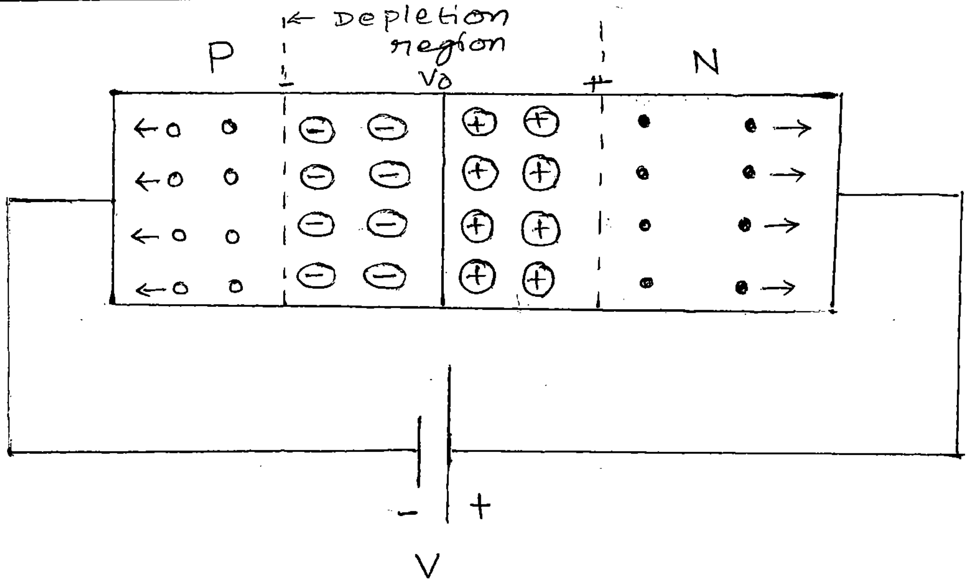


Fig: PN junction with Reverse Bias.

→ When the PN junction is reverse biased the negative terminal attracts the holes in the P-region, away from the junction, The positive terminal attracts the free electrons in the n-region away from the junction.

→ No charge carrier is able to cross the junction.

→ As electrons and holes both move away from the junction, the depletion region widens. Hence the resultant potential barrior is increased which prevents the flow of majority Carriers in both directions.

→ therefore, theoretically no current should flow in the external circuit. But in practice, a very small current of the order of a few micro Amperes flows under reverse biased condition.

→ Electrons forming covalent bonds of the semiconductor atoms in the P and N type regions may absorb sufficient energy from heat and light to cause breaking of some covalent bonds. Hence electron-hole pairs are continually produced in both the P regions.

→ under the reverse bias condition, the thermally generated holes in the P-region are attracted towards the negative terminal of the battery and the electrons in the N-region are attracted towards the positive terminal of the battery

→ consequently the minority carriers ie. electrons in the P-region, and holes in the n-region, wander over to the junction and flow towards their majority carrier side, giving rise to a small reverse current. this current is known as reverse saturation current I_0.

→ the Magnitude of reverse saturation current mainly depends upon junction temperature. because the Major source of minority carriers is thermally broken co-valent bonds.

→ As Already majority free Electrons from N-side are flowing towards ~~negative~~ positive terminal of battery, the newly Liberated electrons will also join with these majority electrons. thus a large number of free electrons are formed which is commonly called as an avalanche of free electrons. This leads to the breakdown of the junction leading to very large reverse current. The reverse voltage at which the junction break down occurs is known as Avalanche break down.

Diode current Equation :-

If we consider the generation and recombination of carriers in the depletion region, the general equation of the diode current is approximately given by

$$I = I_0 \left[e^{V/\eta V_T} - 1 \right] \longrightarrow (8)$$

where I = diode current

I_0 = diode reverse saturation current at room temp

V = External voltage applied to the diode.

η = a constant [1 for Ge and 2 for Si]

$V_T = \frac{kT}{q} = \frac{T}{11600}$, volt equivalent of temp ie thermal voltage

where k = Boltzman's constant $(1.38 \times 10^{-23}\ J/K)$

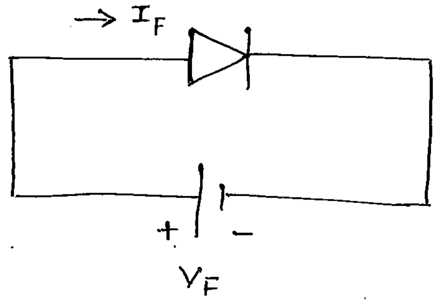
q = charge of the electron = 1.602×10^{-19} C

T = temperature of the diode junction (°K)

Volt - Ampere characteristics of a diode :-

(V-I characteristics)

(1) V-I characteristics in Forward bias condition :



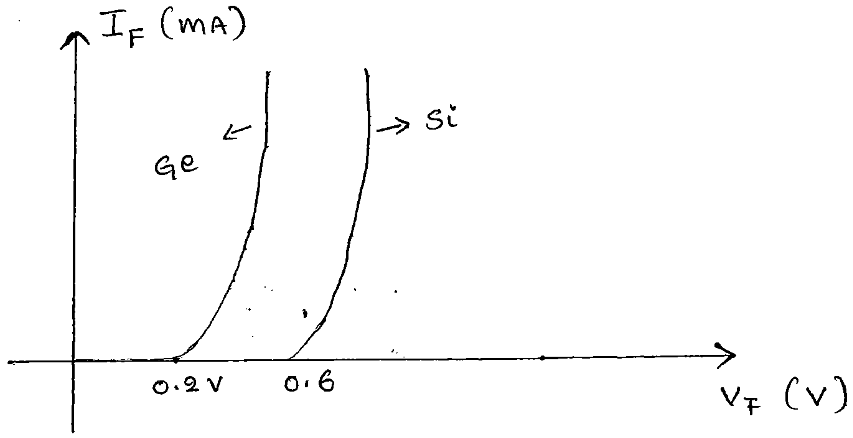
→ when a forward bias voltage V_F is applied to a PN junction diode, below the cut-in voltage V_γ, the diode will not conduct and the current flowing is very small. practically this current is assumed to be zero

→ The diodes will have a cut-in voltage or threshold voltage V_γ, below which current is very small, Beyond V_γ, the current rises very rapidly

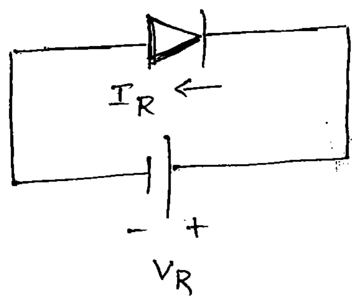
→ V_γ is approximately 0.2 V for Ge and 0.6 V for Si

→ As the forward biased voltage V_F is greater than the cut-in voltage V_γ, the potential barrior across the junction is completely eliminated and the current rises very rapidly.

→ The V-I characteristics under forward biased condition is shown in figure below.



(2) <u>V-I characteristics in Reverse biased condition:-</u>



When a PN junction diode is reverse biased, the negative terminal attracts the holes in the P-region away from the junction. The positive terminal attracts the free electrons in n-region away from the junction. No change carrier is able to cross the junction.

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

As depletion region widens, barrior potential across the junction also increases. The polarities of barrier potential are same as that of the applied voltage.

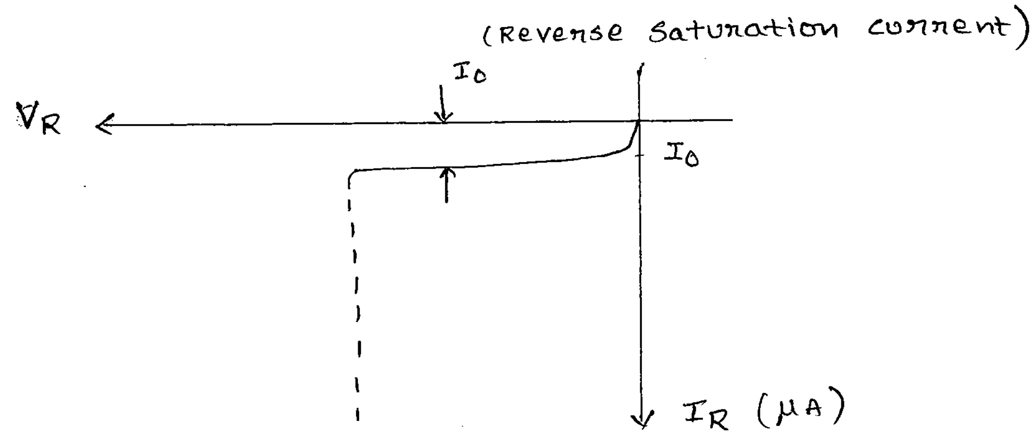
However a small reverse current called reverse saturation current I_0 flows across the junction due to the movement of minority charge carriers across the junction.

Reverse saturation current is very small of the order of few microamperes for Ge and few nanoamperes. for Si Pn junction diode.

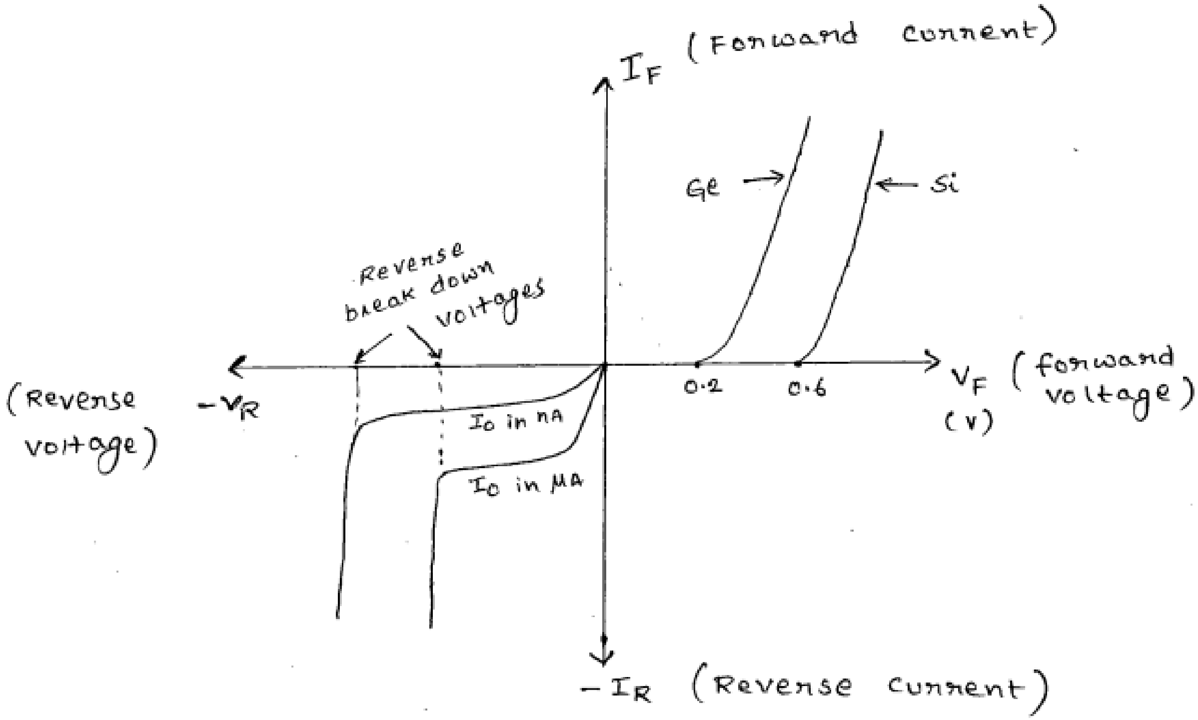
The generation of minority charge carriers depends on the temperature and not on the applied reverse bias voltage.

If the reverse bias voltage is increased beyond certain limit the junction breaks down and a very large reverse current flows.

The V-I characteristics under reverse biased condition for a Pn junction diode is shown in figure below.



The complete VI characteristics of a PN diode (Forward bias and Reverse bias) for both Ge and Si are shown in figure below.



Problem :

A Silicon diode has a reverse saturation current of 7.12 nA at room temperature of 27°c. calculate its forward current if it is forward biased with a voltage of 0.7 V

Solution : Given data

$$I_0 = 7.12 \times 10^{-9} A, \quad V = 0.7 V$$

$$T = 27^\circ c = 300^\circ K, \quad \eta = 2 \text{ for Si}$$

$$V_T = \frac{KT}{q} = \frac{T}{11600} = \frac{300}{11600} \simeq 26 mV$$

According to diode current equation

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

$$I = 7.12 \times 10^{-9} \left(e^{0.7/(2 \times 0.026)} - 1 \right)$$

$$I \simeq 5 mA.$$

PROBLEM :

A Ge diode has a saturation current of 1 nA at 20°c. Find its current when it is forward biased by 0.4 V. Find the current in the same diode when the temperature rises to 110°c.

Solution : Given data

For Ge diode $\eta = 1$

$$I_{01} = 1 nA = 10^{-9} A$$

$$T_1 = 20^\circ C = 20 + 273 = 293^\circ K$$

$$V_T = \frac{T_1}{11600} = \frac{293}{11600} = 0.0252 V$$

$V = 0.4\,V \quad , \quad I = ?$

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

$$I = 10^{-9} \left(e^{0.4/(1 \times 0.0252)} - 1 \right)$$

$$I = 4.8 \text{ mA} .$$

If $T_2 = 110°c$ then $I = ?$

$$I_{02} = \left[2^{(T_2 - T_1)/10} \right] . I_{01}$$

$$I_{02} = 2^9 \times 10^{-9} = 512 \times 10^{-9} \text{ A} .$$

At $T_2 = 110°c = 110 + 273 = 383° K$

$$V_T = \frac{383}{11600} = 0.033\,V$$

$$I = I_{02} \left(e^{V/\eta V_T} - 1 \right)$$

$$I = 512 \times 10^{-9} \left(e^{0.4/(1 \times 0.033)} - 1 \right)$$

$I =$

<u>Problem</u>:

The diode current is 0.6 mA, when the applied voltage is 400 mv and 20 mA when the applied voltage is 500 mv. Determine η. Assume $\frac{KT}{q} = 25\,mV$

<u>Solution</u>: The diode current $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

$$0.6 \times 10^{-3} = I_0 \left(e^{\frac{400}{25\eta}} \right)$$

($\because$ neglecting 1)

Similarly $\quad 20 \times 10^{-3} = I_0 \left(e^{\frac{500}{25\eta}} \right)$

After simplifying $\eta = 1.14$.

Diode Resistance :-

(1) Forward resistance of a diode :

The resistance offered by the diode in forward biased condition is called forward resistance. The forward resistance is defined in two ways.

(i) Static or DC forward resistance (R_F)

(ii) Dynamic or AC forward resistance (r_f)

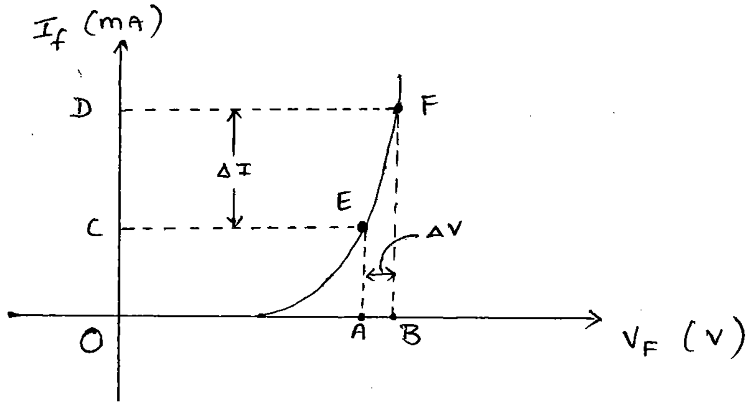


Fig: Forward characteristics of a diode.

(i) Static or DC forward resistance :-

The static or DC forward resistance R_F is defined as the ratio of the DC voltage applied across the PN junction to the DC current flowing through the PN junction.

$$R_F = \frac{\text{Forward dc voltage}}{\text{Forward dc current}} = \frac{OA}{OC} \text{ at point E}$$

ii) Dynamic or AC forward resistance :-

The resistance offered by the Pn junction under AC conditions is called dynamic or ac forward resistance and is denoted by r_f

→ The dynamic resistance is defined as the reciprocal of the slope of the V-I characteristics.

$$\text{ie} \quad r_f = \frac{dV}{dI}$$

The dynamic resistance is not a constant but depends upon the operating voltage.

From the diode current equation, we have

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

Differentiating the above equation w.r.t V, we get

$$\Rightarrow \frac{dI}{dV} = I_0 \left(e^{V/\eta V_T} \cdot \frac{1}{\eta V_T} - 0 \right)$$

$$\Rightarrow \frac{dI}{dV} = \frac{I_0 \, e^{V/\eta V_T}}{\eta V_T}$$

$$\Rightarrow \frac{dI}{dV} = \frac{I_0 + I}{\eta V_T}$$

For a forward bias, $I >> I_0$ and r_f is given approximately by

$$r_f = \frac{dV}{dI} \simeq \frac{\eta V_T}{I}$$

$$\therefore \boxed{r_f = \frac{\eta V_T}{I}}$$

→ The dynamic resistance varies inversely with current.

→ At room temperature and for $\eta = 1$

$$r_f = \frac{1 \times 26\,mV}{I}$$, where I is in mA. then

r_f will be in ohms (Ω)

For a forward current of 26 mA, the dynamic resistance is 1Ω.

From the above figure

$$r_f = \frac{\Delta V}{\Delta I} = \frac{1}{\Delta I/\Delta V} = \frac{1}{\text{slope of forward characteristics}}$$

→ Generally the value of r_f is very small of the order of few ohms in the operating region.

(2) <u>Reverse Resistance of a diode</u> :-

→ The resistance offered by the diode in reverse biased condition is called "<u>Reverse resistance</u>"

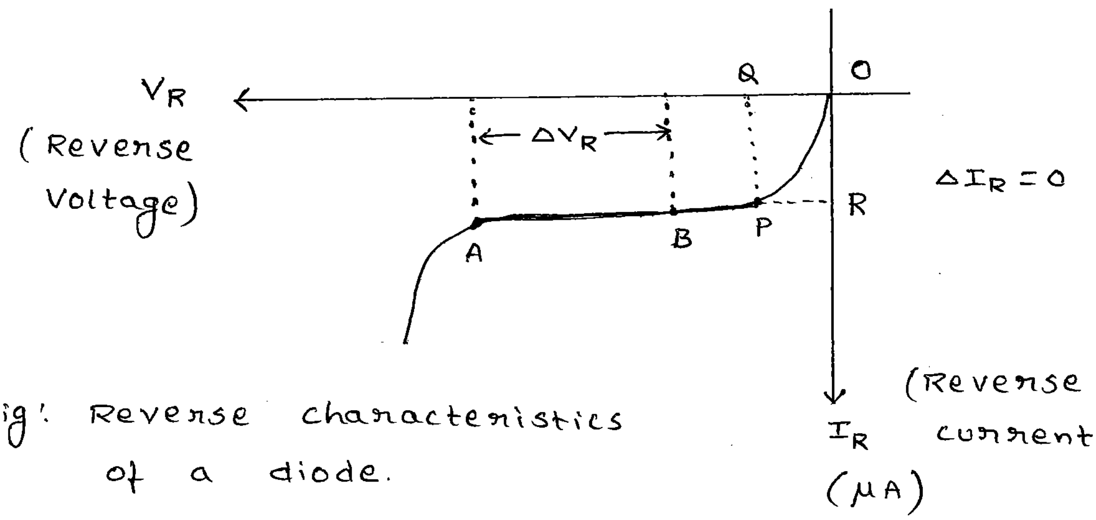


fig: Reverse characteristics of a diode.

The reverse resistance is defined in two ways

(i) static or DC reverse resistance (R_R)

(ii) dynamic or AC reverse resistance (r_r)

(i) Static reverse resistance (R_R) :-

The static reverse resistance R_R is defined as the ratio of applied reverse DC voltage to the reverse saturation current (I_0) flowing through the PN junction.

$$R_R = \frac{\text{Applied Reverse DC voltage}}{\text{Reverse Saturation current}} = \frac{OQ}{OR}$$

(at point P)

(ii) Dynamic reverse resistance (r_r) :

The reverse dynamic resistance r_r is defined as the ratio of incremental change in the reverse voltage applied to the corresponding change in the reverse current.

$$r_r = \frac{\Delta V_R}{\Delta I_R} = \frac{\text{change in reverse voltage}}{\text{change in reverse current}}$$

Problem :

A PN junction diode has a reverse saturation current of 30 μA at a temperature of 125°c. At the same temperature find the dynamic resistance for 0.2 V bias in forward and reverse direction.

Solution : Given data

$$I_0 = 30\,\mu A = 30 \times 10^{-6} A$$

$$T = 125^\circ c = 125 + 273 = 398^\circ K$$

$$V = 0.2\ V$$

For Ge, $\eta = 1$, $V_T = \frac{T}{11600} = \frac{398}{11600} = 0.0343\,V$

we have $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

neglecting '1' we get

$$I = I_0 \; e^{V/\eta V_T}$$

differentiating w.r.t voltage (v)

$$\frac{dI}{dv} = \frac{I_0 \; e^{V/\eta V_T}}{\eta V_T}$$

$$\frac{dI}{dv} = \frac{I_0}{V_T} \; e^{V/V_T} \qquad [\because \eta = 1]$$

$$\frac{1}{r_f} = \frac{dI}{dv} = \frac{I_0}{V_T} \; e^{V/V_T} \qquad [\text{sub all the values}]$$

we get $\quad \therefore \; r_f = 3.36 \, \Omega$

|||ly $\quad \frac{1}{r_r} = \frac{dI}{dv} = \frac{I_0}{V_T} \; e^{-V/V_T}$

$\therefore \; r_r =$

Problem:

calculate the dynamic forward and reverse resistance of PN junction silicon diode when the applied voltage is 0.25 V at $T = 300^\circ K$ with given $I_0 = 2 \mu A$.

Solution: Given data

$I_0 = 2 \mu A$

$V = 0.25 \, V$

For Si, $\eta = 2$

At $T = 300^\circ K$

$V_T = 26 \, mV$

we have $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$

Neglecting '1' we get $I = I_0 \, e^{V/\eta V_T}$

$$\frac{dI}{dV} = \frac{I_0}{\eta V_T} \, e^{V/\eta V_T}$$

Forward resistance $r_f = \frac{dV}{dI} = \frac{\eta V_T}{I_0} \, e^{V/\eta V_T}$

$$r_f = \frac{2 \times 26 \times 10^{-3}}{2 \times 10^{-6}} \, e^{0.25/(2 \times 26 \times 10^{-3})}$$

$$r_f = 212.3 \, \Omega$$

For reverse resistance r_r use $V = -0.25\,V$

$$r_r = \frac{\eta V_T}{I_0} \, e^{-V/\eta V_T}$$ (After substituting all values)

$$r_r = 3.18 \, M\Omega$$

Problem:

The voltage across a silicon diode at room temp of $300^\circ K$ is $0.7V$, when $2mA$ current flows through it. If the voltage increases to $0.75V$, calculate the diode current assuming $V_T = 26\,mV$.

Solution: Given data $V = 0.7\,V$, $\eta = 2$ for Si, $V_T = 26\,mV$, $I = 2mA$.

Now $I = I_0 \left(e^{V/\eta V_T} - 1 \right)$ After substituting all values

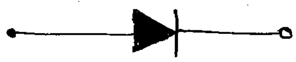
we get $I_0 = 2.84 \times 10^{-9}\,A$.

Now New voltage $V' = 0.75\,V$

$\therefore I' = I_0 \left(e^{V'/\eta V_T} - 1 \right) \Rightarrow I' = 5.23\,mA$ [After substituting all values]

Ideal versus practical diode :

Ideal diode :



1) the cut-in voltage is zero. Since for an ideal diode there is no barrior potential, thus any small forward bias voltage causes conduction through the device

2) The forward resistance is zero

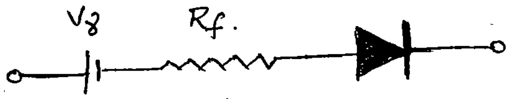
3) The reverse resistance is infinite

4) The diode readily conducts when forward biased and it blocks conduction when reverse biased.

5) The reverse saturation current I_0 is zero

6) The ideal diode acts as a fast acting electronic switch.

Practical Diode :-



1) There is a potential barrior across the junction, and this must be overcome before the diode can conduct.

2) the cut-in voltage or threshold voltage is approximately 0.2 V for Ge and 0.6 V for Si.

3) The forward resistance is in the range of few tens of ohms.

4) The reverse resistance is in the range of Mega ohms.

5) In forward bias condition, when the bias voltage is more than the cut-in voltage, the diode conducts.

6) The diode doesn't conduct when reverse biased. However a small reverse saturation current flows across the junction in the range of nano Amps for Si diode and micro Amps for Ge diode.

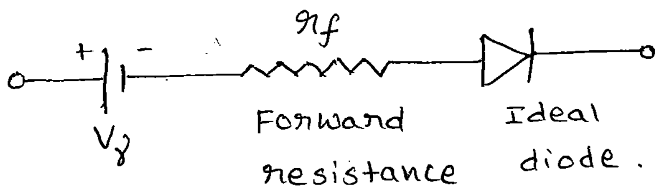
7) The diode also acts as a fast acting Electronic Switch.

<u>Diode Equivalent circuits</u> :-

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

→ A diode is replaced by a model with a battery equivalent to cut-in voltage of a diode, the forward resistance of a diode in series with an ideal diode.

→ the piece wise Linear equivalent circuit of a diode is shown in figure below.



Assuming $r_f = 0$, since for most applications, it is small to be ignored compared with resistance of other elements of the network.

→ Therefore the simplified equivalent circuit is as shown in figure below.

V_γ Ideal diode.

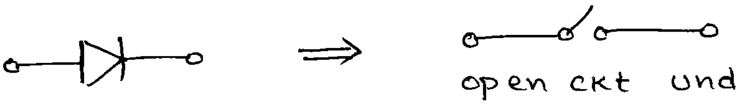
→ Asuming $V_\gamma = 0$ and $r_f = 0$, the equivalent circuit becomes the circuit model for an ideal diode.

Ideal diode

→ In forward biased condition the ideal diode acts as short circuit

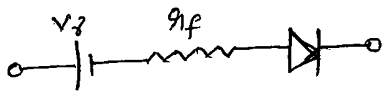
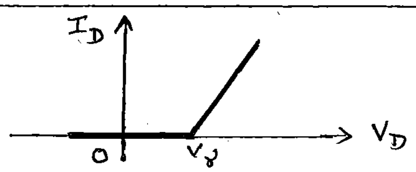
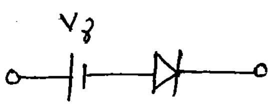
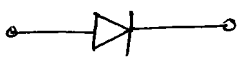
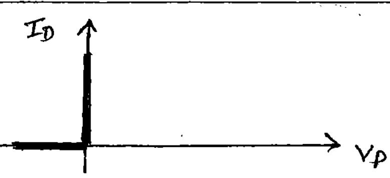
short ckt under forward bias

→ In Reverse bias condition the ideal diode acts as open ckt.



open ckt under Reverse bias.

Diode Equivalent circuits / models / V-I characteristics :-

S.NO	Type	Model	characteristics
1.	Piece wise Linear model	 $V_\gamma \neq 0$, $r_f \neq 0$, $r_r = \infty$	
2.	Simplified Model	 $V_\gamma \neq 0$, $r_f = 0$, $r_r = \infty$	
3.	Ideal Model	 $V_\gamma = 0$, $r_f = 0$, $r_r = \infty$	

PN diode Applications :-

An ideal PN junction diode is a two terminal Polarity sensitive device that has zero resistance when it is forward biased and infinite resistance when reverse biased. Due to this characteristic the diode finds a number of applications as follows.

1) Rectifiers in dc power supplies
2) Switch in digital logic circuits used in computers.
3) clamping networks used as dc restorer in TV receivers and voltage multipliers.
4) clipping circuits used as wave shaping circuits used in computers, radars, radio and TV receivers
5) Demodulation (detector) circuits.

→ The same PN junction with different doping Concentration finds special applications as follows

1) Detectors (PIN photo diode) in optical communication circuits.
2) Zener diodes in Voltage Regulators
3) Varactor diodes in tuning sections of radio and TV receivers
4) LED's in digital displays
5) LASER diodes in optical communication.
6) Tunnel diodes as a relaxation oscillator at Microwave frequencies.