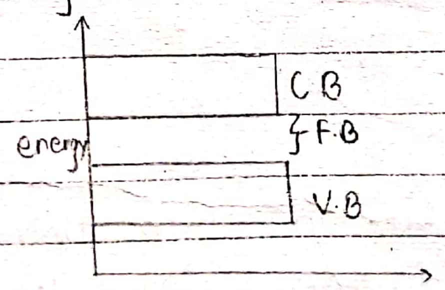
Semiconductors

* Energy bands in solids: The range of energy within which the electron can be found is called energy band. There are following 3 types of energy bands in solids;

(i) Valence band (V.B): The range of energy within which the valance electrons can be formed is called valence band.

(ii) Conduction Band (C.B): When the electrons of valence band gains energy then they jump from valence band to conduction band which are called conduction electrons or free electrons and are responsible for electrical conductivity. The range of energy with in which the conduction electrons can be found is called conduction band.

(iii) Forbidden Band (F.B)/Energy gap/ band gap: The gap of energy between valence band and conduction band is called forbidden band.



↳ On the basis of band theory, solids are classified in the following 3 classes;

(i) Conductor: Those solids in which the conduction band is overlap with the valence band and no forbidden band are called conductors. The electrons from valence band can easily jump to the conduction band and hence the electrical conductivity of conductor is very high.

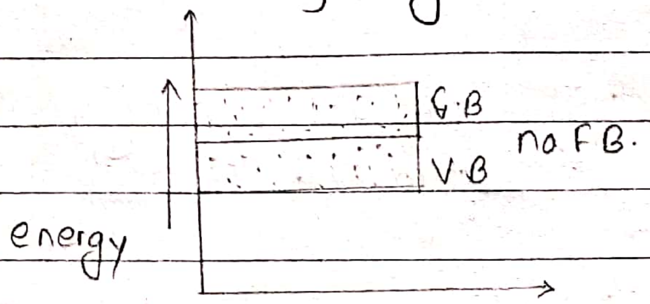


fig:- Energy bands in conductors.

(ii) Semiconductors: Those solids in which there is small energy gap between the valence band and conduction band (less than 3ev) are called semiconductors.

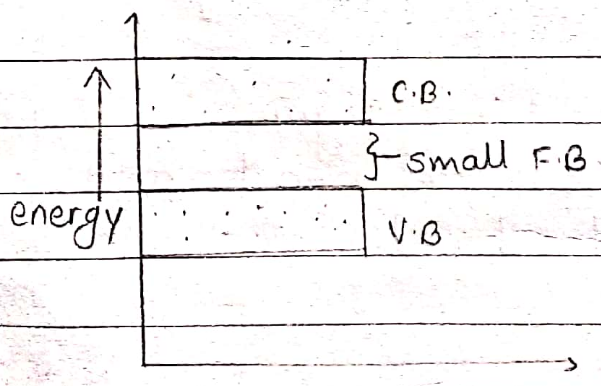


fig:- Energy band in semiconductors

(iii) Insulators: Those solids in which there is large energy gap between the valence band and the conduction band are called insulators.

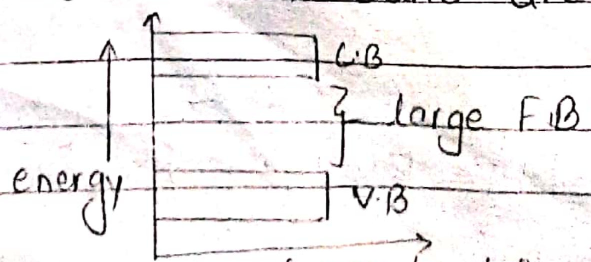


fig: Energy band in insulators.

* Semiconductors

Semiconductors are the materials having conductivity in between the conductor and the insulator. They are the materials having valency 4 and the atoms are covalently bonded. According to band theory, there is small energy gap (less than 3eV) in between the valence and the conduction band. For example; silicon (Si), Ge, etc. are semiconductors. For silicon, the band gap is 1.1eV and for Germinium, the band gap is 0.76 eV.

At absolute zero tempr, the conduction band is completely empty and valence band is completely filled. Therefore, at absolute zero tempr, the semiconductor acts ~~like~~ as insulator.

At room tempr, some of the electrons of valence band are gain thermal energy and jump from valence band to conduction band. Therefore, the semiconductors have small conductivity at room tempr. When the electrons from valence band are jump to conduction band then defficiency of electrons is created in ~~b~~ valence band which is called hole. Hole has positive charge.

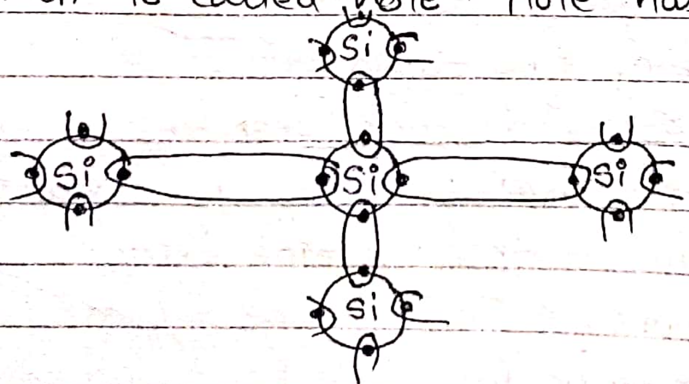


fig:- structure of silicon semiconductor crystal.

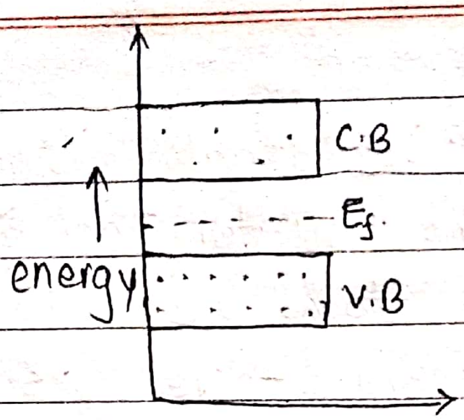


fig:- Energy level diagram for semiconductor.

* Types of semiconductor: There are following 2 types;
(i) Intrinsic semiconductor (Pure)
(ii) Extrinsic semiconductor (Impure)

(i) Intrinsic Semiconductor: A pure piece of semiconductor is called intrinsic semiconductor. In intrinsic semiconductor, the number of free ~~free~~ electrons in conduction band is equal to the number of holes in valence band.

(ii) Extrinsic semiconductor: When the pentavalent or trivalent impurity atoms are added (dopped) then extrinsic semiconductor is formed. The extrinsic semiconductors are of two types;
(a) N-type extrinsic semiconductor: When the pentavalent impurity atoms like: As, P, etc are added in entrinsic semiconductor then N-type extrinsic semiconductor is formed. In N-type semiconductor the no. of free electrons in conduction band is greater than the no. of holes in band. Therefore.

the free electrons are majority charge carriers and the holes are minority charge carriers.

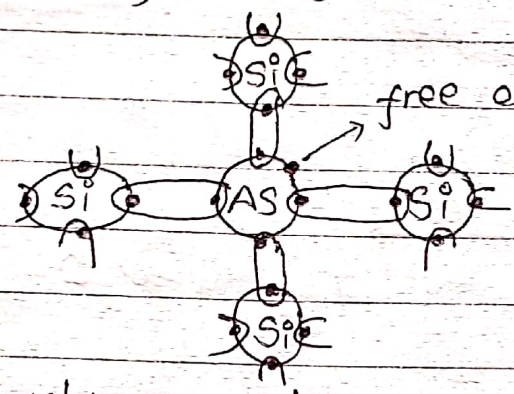
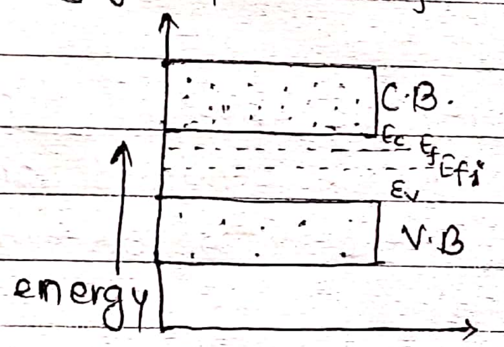


fig:- structure of N-type semiconductor crystal.



where, $E_{fi} = \frac{E_v + E_c}{2}$.

fig:- Energy level diagram for N-type semiconductor.

(b) P-type extrinsic semiconductor: When the trivalent impurity atoms like: Al, B, etc are added in intrinsic semiconductor then p-type extrinsic semiconductor is formed. In p-type semiconductor, the no. of holes in valence band is greater than the no. of free electrons in conduction band. Therefore, the holes are called majority charge carrier and free electrons are called minority charge carriers.

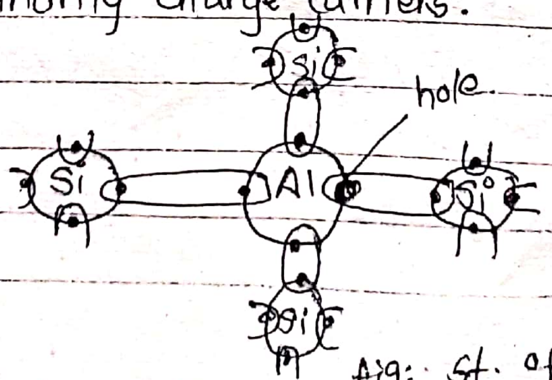


fig: St. of p-type semiconductor crystal

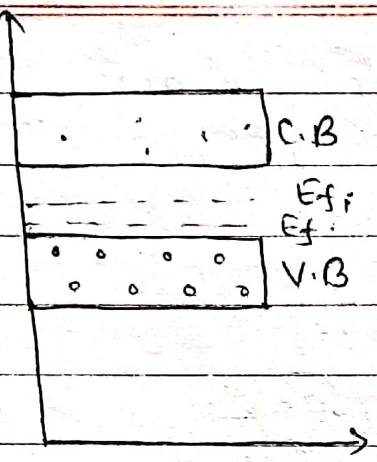


fig:- Energy level diagram for p-type semiconductor.

✓ * Carrier concentrations in semiconductor

(1) Carrier concentrations in intrinsic semiconductor: The carrier concentration of intrinsic semiconductor means the electrons and the holes concn in C.B and V.B respectively.

a) Electron concentration in intrinsic semiconductor
The concentration of electrons in conduction band is given by

$$n = \int_{E_c}^{\infty} g_e(E)\, f_e(E)\, dE$$

where,

$$f_e(E) = \frac{1}{e^{\left(\frac{E-E_f}{K_BT}\right)}+1}$$; is called fermi-Diracfunction

If $(E-E_f) >> K_BT$
then,

$$f_e(E) = e^{-\left(\frac{E-E_f}{K_BT}\right)}$$

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And, $D_e(E) = \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}(E-E_c)^{1/2}$ is called density of state. ($\because \hbar = h/2\pi$)

$$\therefore n = \int_{E_c}^{\infty} \frac{1}{2\pi^2}\left(\frac{2m_e}{\hbar^2}\right)^{3/2}(E-E_c)^{1/2} \cdot e^{-\left(\frac{E-E_f}{K_BT}\right)} \cdot dE$$

$$\text{or, } n = \frac{1}{2\pi^2}\left(\frac{2m_e K_BT}{\hbar^2}\right)^{3/2} e^{-\frac{(E_c-E_f)}{K_BT}} \int_{E_c}^{\infty}\left(\frac{E-E_c}{K_BT}\right)^{1/2} e^{-\left(\frac{E-E_c}{K_BT}\right)} \frac{dE}{K_BT}$$

~~or,~~

let, $\frac{E-E_c}{K_BT} = x$ In this case, $x = 0$ when, $E = E_c$

and $x = \infty$ when $E = \infty$

$\Rightarrow dE/K_BT = dx$

then,

$$n = \frac{1}{2\pi^2}\left(\frac{2m_e K_BT}{\hbar^2}\right)^{3/2} e^{-\frac{(E_c-E_f)}{K_BT}} \int_0^{\infty} x^{1/2} \cdot e^{-x} \cdot dx$$

$$\left[\int_0^{\infty} e^{-x} x^{n-1}\, dx = (n-1)\Gamma(n-1)\right]$$

Here, $\int_0^{\infty} e^{-x} \cdot x^{3/2-1}\, dx = \frac{1}{2}\Gamma\frac{1}{2} = \frac{1}{2}\sqrt{\pi}$

$$\therefore n = \frac{1}{2\pi^2}\left(\frac{2m_e K_BT}{\hbar^2}\right)^{3/2} \cdot e^{-\frac{(E_c-E_f)}{K_BT}} \times \frac{1}{2}\sqrt{\pi}$$

$$\text{or, } n = 2\left(\frac{m_e K_BT}{2\pi\hbar^2}\right)^{3/2} \cdot e^{-\left(\frac{E_c-E_f}{K_BT}\right)}$$

$$\therefore n = N_c\, e^{-\left(\frac{E_c-E_f}{K_BT}\right)} \quad \text{——— (1)}$$

where, $N_c = 2\left(\frac{m_e K_BT}{2\pi\hbar^2}\right)^{3/2}$.

The eq^n (1) is req^d expression for conc^n of electrons in the conduction band of intrinsic semiconductor.

b) Hole concentration in intrinsic semiconductor:

The hole concentration is given by

$$p = \int_{-\infty}^{E_v} D_h(E)\, f_h(E)\, dE \quad \text{--- (1)}$$

where, $f_h(E) = 1 - f_e(E)$, is the fermi-Dirac function for holes.

$$f_h(E) = 1 - \frac{1}{1 + e^{\left(\frac{E-E_f}{K_BT}\right)}}$$

$$f_h(E) = \frac{e^{\left(\frac{E-E_f}{K_BT}\right)}}{1 + e^{\left(\frac{E-E_f}{K_BT}\right)}}$$

If $E - E_f << K_BT$

Then,

$$f_h(E) = e^{\left(\frac{E-E_f}{K_BT}\right)}$$

Also,

$$D_h(E) = \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\right)^{3/2} \cdot (E_v - E)^{1/2}.$$

Using the values of $f_h(E)$ and $D_h(E)$ in eq^n (1) we get,

$$p = \int_{-\infty}^{E_v} \frac{1}{2\pi^2}\left(\frac{2m_h}{\hbar^2}\right)^{3/2} (E_v - E)^{1/2} \cdot \frac{e^{\left(\frac{E-E_f}{K_BT}\right)}}{\cancel{1 + e^{\left(\frac{E-E_f}{K_BT}\right)}}}\, dE$$

or, $$p = \frac{1}{2\pi^2}\left(\frac{2m_h K_BT}{\hbar^2}\right)^{3/2} \cdot e^{-(E_f - E_v)/K_BT} \int_{-\infty}^{E_v} \left(\frac{E_v - E}{K_BT}\right)^{1/2} e^{-(E_v - E)/K_BT} \frac{dE}{K_BT}$$

let, $\frac{E_v - E}{K_B T} = x$

then,

$$P = \frac{1}{2\pi^2}\left(\frac{2m_h K_B T}{\hbar^2}\right)^{3/2} \cdot e^{-(E_f - E_v)/K_B T} \int_0^\infty x^{1/2} \cdot e^{-x} dx$$

$$\left(\because \int_0^\infty e^{-x} x^{n-1} dx = \Gamma n\right)$$

$$\int_0^\infty e^{-x} x^{3/2-1} dx = \Gamma 3/2 = \frac{1}{2}\sqrt{\pi}$$

or, $$P = \frac{1}{2\pi^2}\left(\frac{2m_h K_B T}{\hbar^2}\right)^{3/2} \cdot e^{-(E_f - E_v)/K_B T} \cdot \frac{1}{2}\sqrt{\pi}$$

or, $$P = 2\left(\frac{m_h K_B T}{2\pi\hbar^2}\right)^{3/2} \cdot e^{-(E_f - E_v)/K_B T}$$

$$\therefore P = N_v e^{-(E_f - E_v)/K_B T} \quad \text{——— (2)}$$

where,

$$N_v = 2\left(\frac{m_h K_B T}{2\pi\hbar^2}\right)^{3/2}$$

The eqn (2) gives the concentration of holes in valence band of an intrinsic semiconductor.

*

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* Fermi-level in Intrinsic semiconductor

For intrinsic semiconductor, $n=p$

$$\therefore\ 2\left(\frac{m_e k_B T}{2\pi\hbar^2}\right)^{3/2} e^{-(E_c-E_f)/k_BT} = 2\left(\frac{m_h k_B T}{2\pi\hbar^2}\right)^{3/2} e^{-(E_f-E_v)/k_BT}$$

$$\text{or, } (m_e)^{3/2} = (m_h)^{3/2} \cdot e^{-\left(\frac{E_f-E_v}{k_BT}\right)+\left(\frac{E_c-E_f}{k_BT}\right)}$$

$$\text{or, } (m_e)^{3/2} = (m_h)^{3/2}\, e^{\left(\frac{E_v+E_c}{k_BT}\right)}\, e^{-2E_f/k_BT}$$

$$\text{or, } e^{2E_f/k_BT} = \left(\frac{m_h}{m_e}\right)^{3/2} e^{\frac{E_v+E_c}{k_BT}}$$

$$\text{or, } \frac{2E_{fi}}{k_BT} = \frac{E_v+E_c}{k_BT} + \frac{3}{2}\ln\left(\frac{m_h}{m_e}\right)$$

$$\text{or, } E_{fi} = \left(\frac{E_v+E_c}{2}\right) + \frac{3}{4}k_BT\ln\left(\frac{m_h}{m_e}\right) \quad \text{--- (1)}$$

where,

$E_f = E_{fi}$ is the fermi energy level for intrinsic semiconductor.

Since m_h is slightly greater than m_e.

At $T = 0\,K$,

$$E_{fi} = \frac{E_v+E_c}{2} \quad \text{--- (2)}$$

This shows that the fermi level lies exactly ~~between~~ midway between valence and conduction band as shown in the figure;

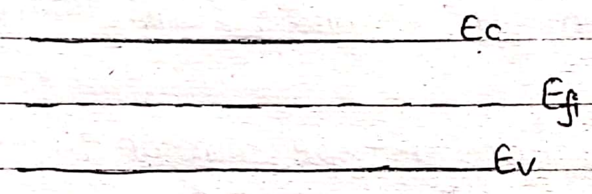


fig: Representation of fermi level for intrinsic semiconductor..

* Intrinsic carrier density

The intrinsic carrier density is given by

$$n_i^2 = n.p$$

$$\text{or, } n_i^2 = N_c N_v e^{-(E_c - E_f)/k_BT} . e^{-(E_f - E_v)/k_BT}$$

$$\text{or, } n_i^2 = N_c N_v e^{-(E_c - E_v)/k_BT}$$

$$\text{or, } n_i = \sqrt{N_c N_v} . e^{-(E_c - E_v)/2k_BT}$$

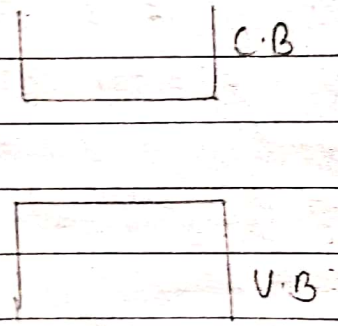
$$\text{or, } n_i = \sqrt{N_c N_v}\, e^{-E_g/2k_BT} \quad \text{—(1)}$$

where, $E_c - E_v = E_g$ is the energy gap.

This means the intrinsic carrier density depends exponentially on the ratio of energy gap to the thermal energy k_BT or the carrier density is independent to the fermi level but depends on the energy gap.

(2) Carrier concentration in extrinsic semiconductor

(a) Carrier concentration for N-type semiconductor. The Energy level diagram of N-type semiconductor is shown in the figure, ~~as the~~ As the tempr increases sum of the donor atoms get ionized and contribute electrons to the conduction band. Also, sum of the valence band electrons are jump in conduction band by creating holes in valence band.



let, Nd be the donor atoms per unit volumn with energy Ed. The concentration of electrons in conduction band is given by,

$$n = N_c e^{-\left(\frac{E_c - E_f}{K_B T}\right)} \quad \text{—— (1)}$$

If N_d^+ be the ionized donor atoms and p be the holes in valence band then,

$$n = N_d^+ + p \quad \text{—— (2)}$$

If the sufficient no. of donor atoms are ionized then, p can be neglected.

$$\therefore n = N_d^+ \quad \text{——— (3)}$$

where, $N_d^+ = N_d e^{-(E_f - E_d)/k_B T}$ ——— (4)

From eq^{n}s (1), (3) and (4) we get

$$N_c e^{-(E_c - E_f)/k_B T} = N_d e^{-(E_f - E_d)/k_B T}$$

or, $$\frac{N_d}{N_c} = e^{-(E_c - E_f)/k_B T + (E_f - E_d)/k_B T}$$

~~or~~, Taking ln on both sides.

$$\ln N_d - \ln N_c = -\frac{(E_c - E_f)}{k_B T} + \frac{(E_f - E_d)}{k_B T}$$

or, $$E_f = \frac{E_d + E_c}{2} + \frac{k_B T}{2} \ln\left(\frac{N_d}{N_c}\right) \quad \text{—— (5)}$$

This gives the position of fermi level at any temperature.
If T is very small,
then,

$$E_f = \frac{E_d + E_c}{2} \quad \text{——— (6)}$$

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(b) Carrier concentration for p-type extrinsic semiconductor

E_a = Energy level of acceptor
E_{fi} = fermi level energy of extrinsic semiconductor
E_f = fermi energy level of p-type semiconductor

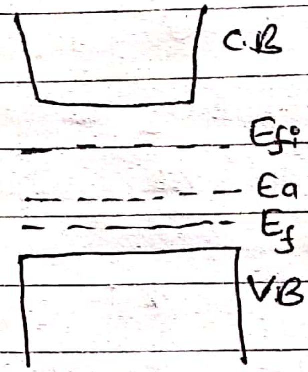

fig: Energy level diagram for p-type semiconductor.

The energy level diagram for p-type semiconductor is shown in the figure. The holes are created in valence band by following two ways:

i) Some of the electrons ~~are~~ jumps from V.B to C.B by gaining thermal energy.

ii) The acceptor atoms ~~are~~ accepts the electrons from valence band.

let n = number of electrons in C.B.
p = hole concentration in V.B
N_a = total acceptor concentration
N_a^- = ionised acceptor concentration.

In this case,

$$p = n + N_a^-$$

For p-type semiconductor,

$$p = N_a^- \quad \text{—— (1)}$$

(n can be neglected).

Here,

$$N_a^- = N_a e^{-(E_a - E_f)/k_B T}$$

And, $p = N_v e^{-(E_f - E_v)/k_B T}$

then, eq^n ① becomes,

$$N_v e^{-(E_f - E_v)/k_B T} = N_a e^{-(E_a - E_f)/k_B T}$$

$$\text{or, } N_v e^{-(E_f - E_v)/k_B T} = N_a e^{(E_f - E_a)/k_B T}$$

$$\text{or, } \frac{N_a}{N_v} = e^{-(E_f - E_v)/k_B T - (E_f - E_a)/k_B T}$$

$$\text{or, } \ln\left(\frac{N_a}{N_v}\right) = \frac{-(E_f - E_v)}{k_B T} - \frac{(E_f - E_a)}{k_B T}$$

$$\text{or, } \ln\left(\frac{N_a}{N_v}\right) = \frac{-2E_f + E_v + E_a}{k_B T}$$

$$\text{or, } \ln\left(\frac{N_a}{N_v}\right) = \frac{-2E_f}{k_B T} + \frac{E_v + E_a}{k_B T}$$

$$\text{or, } \frac{E_v + E_a}{k_B T} - \ln\left(\frac{N_a}{N_v}\right) = \frac{2E_f}{k_B T}$$

$$\text{or, } E_f = \frac{E_v + E_a}{2} - \frac{k_B T}{2} \cdot \ln\left(\frac{N_a}{N_v}\right). \quad \text{— ②}$$

At $T = 0K$,

$$E_f = \frac{E_v + E_a}{2} \quad \text{— ③}$$

This means the fermi level lie exactly in between valence and acceptor level.

* Mobility: When an electric field e is applied to a material the charge carriers attain the velocity which is called drift velocity (V_d). The drift velocity is directly proportional to the applied electric field

i.e,

$$V_d \propto E$$

$$\text{or, } V_d = \mu E \quad \text{--- (1)}$$

where,

μ = proportionality constant called the mobility of the charge carriers.

$$\therefore \mu = \frac{V_d}{E} \quad \text{--- (2)}$$

* Photoconductivity: To measure the energy gap of the semiconductor, the semiconductor is eluminated with the photons of different frequencies. This optical absorption creates the extra electrons and hence the electrical conductivity of the semiconductor will be increased when the photons of suitable frequency are incident on it. This effect is called photoconductivity.

We have, the energy of photon is

$$E = h\nu \quad \text{--- (1)}$$

where, h is the planck's constant having value 6.62×10^{-34} JS.

and ν is the frequency of photon.

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I. Also,

$$E = \frac{hc}{\lambda} \quad \text{--- (2)} \quad \left(\because \nu = \frac{c}{\lambda}\right)$$

If λ_c be the wavelength of radiation (photon) when there is abrupt change takes place then,

Energy gap — $E_g = \frac{hc}{\lambda_c}$

for Si, $\lambda_c = 1.1 \times 10^{-6}$ m.

$$\therefore E_g = \frac{6.62 \times 10^{-34} \times 3 \times 10^{8}}{(1.1 \times 10^{-6})}$$

$$= 1.8 \times 10^{-19} \text{ J} \quad \text{for Si.}$$

$$\therefore E_g = 1.1 \text{ eV}.$$

* Metal-metal junction (contact potential)

Consider two metals 1 and 2 with work functions ϕ_1 and ϕ_2 ($\phi_1 < \phi_2$) respectively. When the two metals are far apart then their fermi levels are shown in the fig (a). If these metals ~~are~~ are placed in contact, the electrons are start to move from metal (1) to metal (2) because the metal '1' has high energy, until ~~p~~ both metals have the common fermi surface.

The metal 1 gets positive charge due to the loss of electrons and the metal 2 gets negative charge due to the gained of electrons a potential difference is created approach the metal-metal junction which is called contact potential. If V_c be the contact potential then

$$eV_c = \phi_1 - \phi_2$$

$$\Rightarrow V_c = \frac{\phi_1 - \phi_2}{e} \quad \text{--- (1)}$$

~~The e~~ where, $e = 1.6 \times 10^{-19}$ c is the charge of electron.

The eq^n (1) is required expression for contact potential.

* p-n junction and p-n junction diode

When a p-type and n-type semiconductors are suitably joined together then the common boundary between them is called p-n junction. The semiconductor device which is formed by the combination of p-type and n-type semiconductors is called p-n junction diode.

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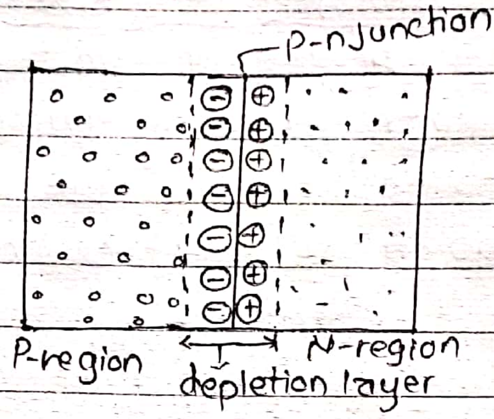
* Depletion layer



When a p-type and n-type semiconductors are kept in contact then a p-n junction is formed. The electrons from N-region are move ~~towards~~ P-region and hence the positive ions are created in N-region and negative ions are created in p-region around the p-n junction. These ions are attracted equally by both sides and hence they cannot move. This means a layer of immobile ions is formed around the p-n junction which is called depletion Layer (10^{-6} m)

The depletion layer is the insulating layer which prevents (deplets) the further diffusion of electrons and holes.

The electric potential is ~~set up~~ setup around the depletion layer which is called barrier potential and the electric field generated due to barrier potential is called barrier field.

(The thickness of depletion layer is about 10^{-6} m).

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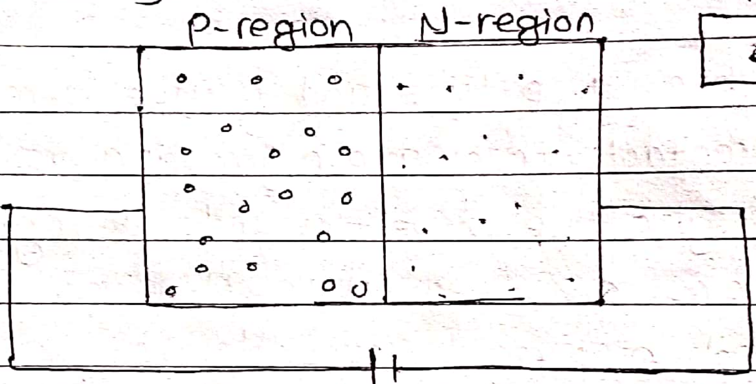
* Biasing of p-n junction Diode

If the pn-junction diode is connected with external source (Battery) then it is said to be baised. There are following two types of biasing of pn-junction diode;

(1) Forward biasing :



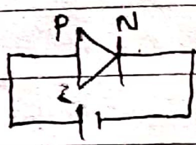


fig:- forward biasing of pn-junction diode.

If the positive terminal of battery is connected with p-region and the negative terminal of battery is connected with N-region of pn-junction diode then it is called forward biased.

In forward biasing,

→ The thickness of depletion layer is very small.
→ Forward resistance is very small.
→ Very high current flows through the diode.
→ Current flows due to majority charge carriers.

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<ii> Reverse biasing:

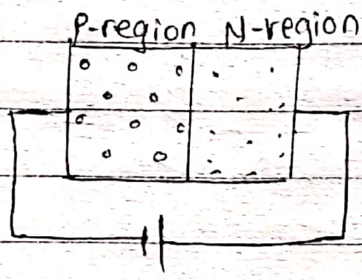


fig: Reverse biasing of pn-junction diode.

If the negative ~~termal~~ terminal of battery is connected with p-region and the positive terminal of battery is connected to N-region of pn-junction diode then it is called reverse biased.

In reverse biasing,
→ Thickness of deplection layer is very high.
→ Current flows due to minority charge carrier.
→ very small current flows through the diode.
→ forward resistance is very high

* Characteristics of pn-junction diode

The graphical relation between the applied voltage and current flowing through the diode is called characteristics of p-n junction diode. There are following two types of characteristics of p-n junction diode;

(I) Forward characteristics: The graphical relation between the forward voltage and forward current is called forward characteristics.

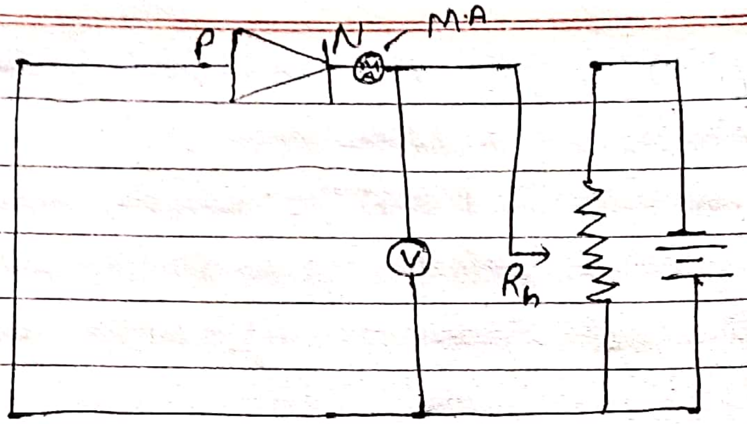


fig:- circuit diagram for forward characteristics of p-n junction diode.

The circuit diagram for the study of forward characteristics of p-n junction diode is shown in above figure. In the figure V is voltmeter which measures the forward voltage, mA is milliameter which measures the forward current. R_h is rheostat with help of which the forward voltage can be changed.

When the forward voltage is zero, the forward current is also zero. If the forward voltage is increased initially the forward current remains zero and then increases gradually. At a certain value of forward voltage the forward current starts to increases sharply which is called knee voltage (V_K). The forward characteristics of p-n junction diode is shown in figure below;

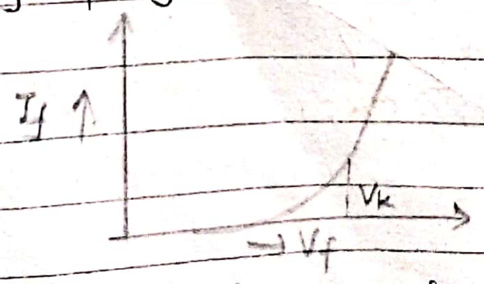


fig:- forward characteristics of p-n junction diode

[ii] Reverse Characteristics

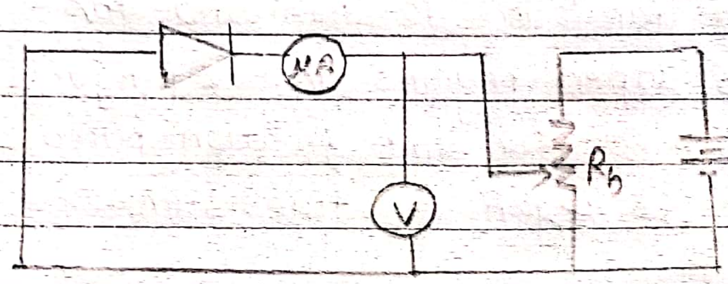


fig :- ckt diagram for the study of reverse characteristics.

The graphical relation between the reverse voltage and reverse current of a p-n junction diode is called reverse characteristics.

Above figure shows ~~the argument~~ arrangement for the study of reverse characteristics of p-n junction diode. Here, μA is microammeter which measures the reverse current and the the voltmeter V measures the reverse voltage.

If the reverse voltage is zero then the reverse current is also zero. If the reverse voltage is increased the reverse current increases gradually and then rapidly after a certain value of reverse voltage, which is called breakdown voltage (V_B).

* Bipolar Junction Transister (BJT)

A transister is semiconductor device having 3 doped regions and 2 p-n junctions. which is mainly used for amplification purpose. Following are the 3 regions of transister:-

i) Emitter (E): Emitter emits the majority charge carriers. Its doping level is highest and size is medium (larger than base and smaller than collector).

ii) Base (B): Base provides the path for the majority charge carriers emitted by emitter and collected by collector. Its doping level is ~~1st~~ least and size is smallest.

iii) Collector (C): The collector collects the majority charge carriers emitted by emitter and passed by base. Its size is largest and doping level is medium (greater than base and smaller than emitter).

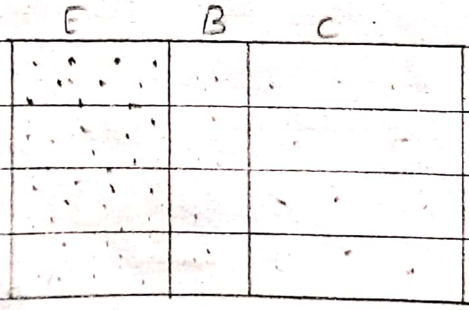


fig: Block diagram of transistor.

* Types of Transistor:

There are following two types of transistor;

(I) NPN-type transistor: If the emitter and collector are formed by N-type semiconductors and base is formed by P-type semiconductor then it is called NPN-type transistor.

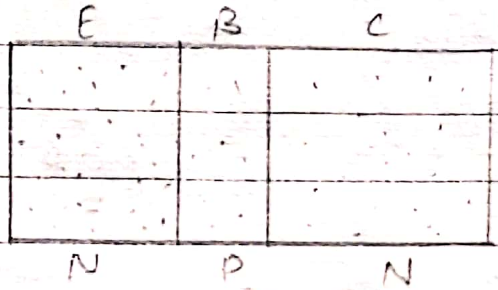
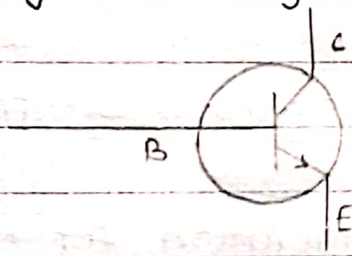


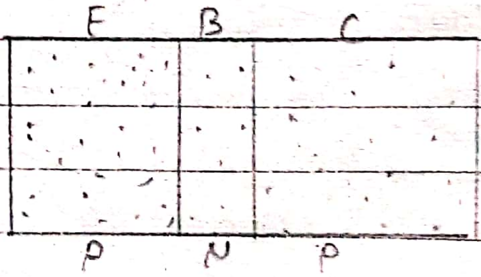
fig:- Block diagram of NPN-transistor.

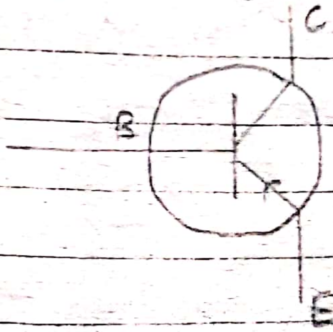


(Arrow pointing out)
(Not pointing in)

fig:- Electronic symbol of NPN-transistor.

(II) PNP-type transister: If the emitter and collector are formed by P-type semiconductors and base is formed by N-type semiconductor then it is called PNP-type transistor.





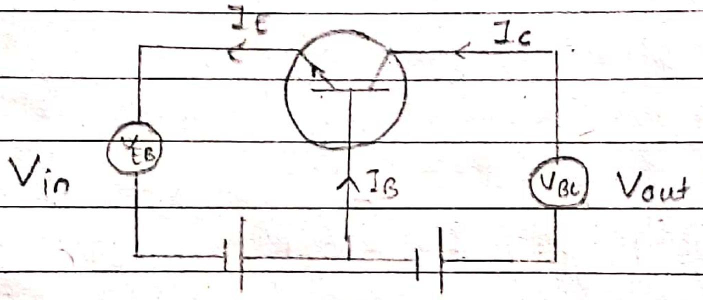
(Pointing In)

fig:- Block diagram of PNP transistor

fig: ~~Block diag~~ electronic symbol of PNP trancistor

* Configuration of Transistor : The ways by which a transistor can be connected with the external source is called configuration of Transistor. There are following 3 types of configuration of transistor.

(I) Common Base configuration :



E-B juction → forward
B-C junction → reverse
⇓
proper biasing

fig:- common Base configuration of NPN-type transistor.

The common base configuration for NPN-type transistor is shown in above figure. Here, the input is applied between the emitter and the base terminal and output is taken between collector and the base terminal.

(II) Common emitter (CE) configuration:

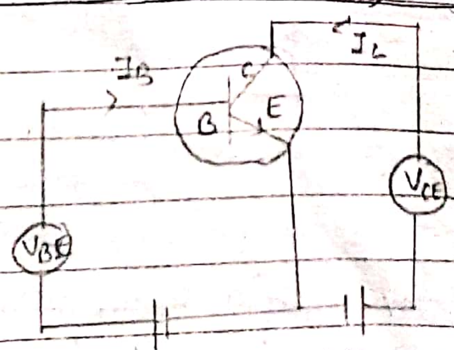


Fig:- common emitter configuration

(iii) Common Collector Configuration:

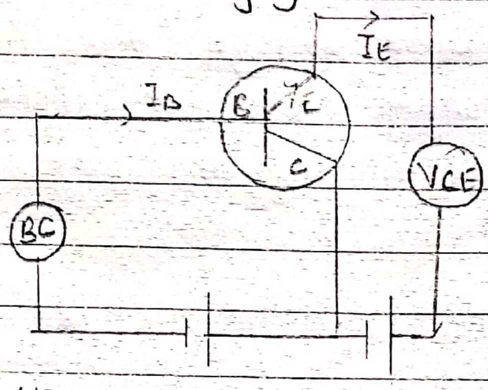
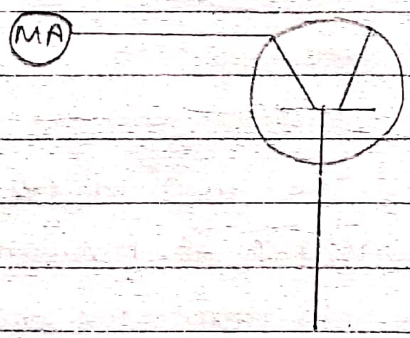


fig:- Common collector configuration of NPN - transistor.

* Transistor characteristics

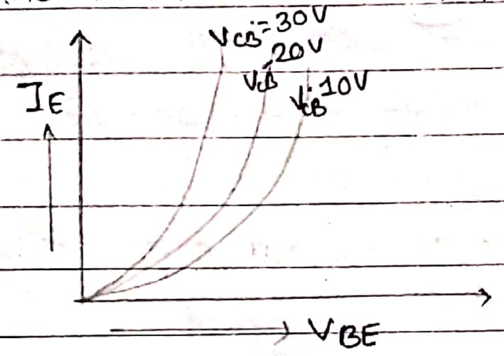
1) Common Base characteristics



The circuit diagram for common base characteristics of NPN type transistor is shown in above figure, where the base is common to bothe emitter and collector. Here the emitter base junction is forward biased with the battery V_{EE} and the collector-base junction is reverse biased with the battery V_{CC}. There are following 2 types of characteristics of common base characteristics;

1) <u>Input characteristics</u>

It is the graphical relation between the emitter current (I_E) and emitter-base voltage (V_{BE}) at constant collector-base voltage (V_{CB}). The input characteristic of CB configuration for NPN type transistor is shown in the figure.



The input resistance is,

$$R_I = \left(\frac{\Delta V_{BE}}{\Delta I_E}\right) \quad V_{CB} = \text{constant.}$$

II) <u>Output characteristic</u> : It is the graphical relation between I_C and V_{CB} at constant I_E. For common base configuration of NPN type transistor, the output characteristic is shown in the figure.

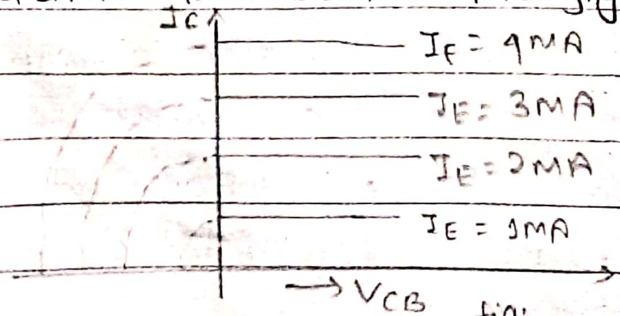


fig:-

The output resistance is

$$R_O = \left(\frac{\Delta V_{CB}}{\Delta I_c}\right) \quad V_{EB} \text{ is constant.}$$

(11) Common Emitter characteristics

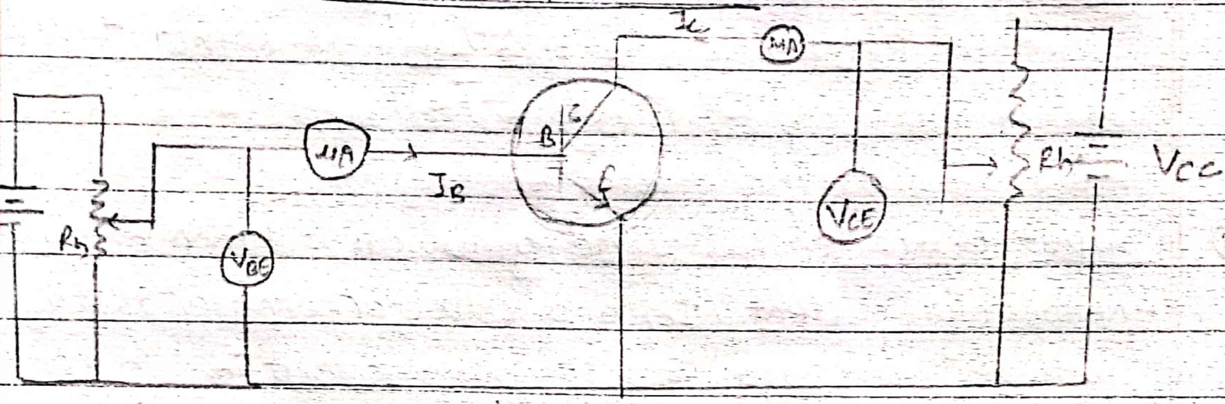


fig: ckt diagram for CE characteristics of NPN type transistor.

The circuit diagram for the study of common emitter characteristics is shown in above figure. The base-emitter voltage (V_{BE}) is read by a voltameter and the base current I_B by a microammeter (μA). The collector-emitter junction is reversed biased by the battery V_{CC}. The collector to emitter voltage V_{CE} is read by another voltmeter and the collector current I_C is measured by the milliammeter (mA).
There are following characteristics of common emitter configuration;

① **Input characteristics**: The graphical relation between the base current (I_B) and base-emitter voltage (V_{BE}) at constant V_{CE} is called the input characteristic of CE configuration. which is shown in the figure;

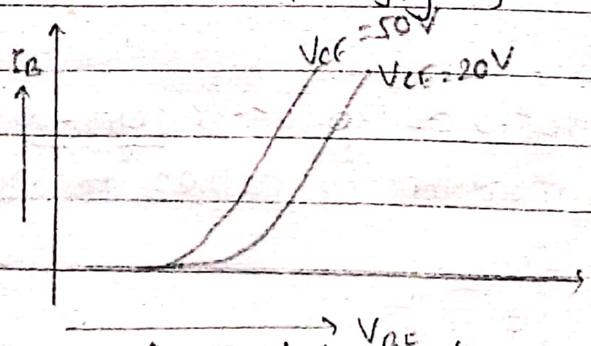


fig: Input characteristics of CE configuration.

Again,

Input Resistance $(R_I) = \left(\frac{\Delta V_{BE}}{\Delta I_B}\right)$ at constant V_{CE}.

(ii) Output characteristics: The graphical relation between the collector current (I_c) and collector-emitter voltage (V_{CE}) at constant I_B is called ouput characteristics of CE configuration.

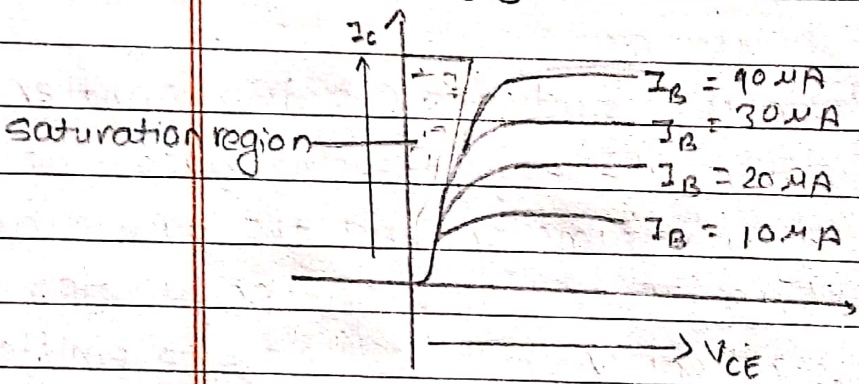


fig:- Output characteristics of CE configuration.

Again,

Output Resistance $(R_o) = \left(\frac{\Delta V_{CE}}{\Delta I_c}\right)$ at constant I_B.

* α and β parameters

The ratio of collector current ~~and~~ to emitter current of a transistor is called α-parameter.

i.e, $\alpha = \frac{I_c}{I_E}$

The ratio of collector current ~~to~~ base current of a transistor is called β-parameter.

i.e, $\beta = \frac{I_c}{I_B}$

* Relation between α and β

For any transistor,

$$I_E = I_C + I_B \quad \text{——— (1)}$$

Dividing eqⁿ (1) by I_C.

$$\frac{I_E}{I_C} = 1 + \frac{I_B}{I_C}$$

or, $$\frac{1}{\alpha} = 1 + \frac{1}{\beta}$$

or, $$\frac{1}{\alpha} = \frac{\beta+1}{\beta}$$

or, $$\boxed{\alpha = \frac{\beta}{\beta+1}} \quad \text{——— (2)}$$

Also,

$$\frac{1}{\beta} = \frac{1}{\alpha} - 1$$

or, $$\frac{1}{\beta} = \frac{1-\alpha}{\alpha}$$

or, $$\boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{——— (3)}$$

The eqⁿs (2) and (3) are the relations between α and β parameters.

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* Field Effect Transistor (FET):
In field effect transistor, the current is conducted due to a single type of charge carriers or due to the effect of electric field. The FET are of 2 types;

1) Junction Field Effect Transistor (JFET): It is a 3 terminal semiconductor device in which the current conduction is either by electrons or holes. The current condition is controlled by means of an electric field between the gate and the conduction channel of the JFET.
There are following 2 types of JFET;

(a) N-channel JFET: It consists of an n-type silicon bar forming the conduction channel for the charge carriers. The p-n juction forming diodes are connected internally and a common terminal called gate is taken out from the p-region. The other 2 terminals source and drain are taken out from the bar

(b) P-channel JFET: It consists of a p-type silicon bar forming the conduction channel for the charge carriers. The p-n junction forming diodes are connected internally and a common terminal gate is taken out from n-region. The other two terminals source and drain are taken out from the bar.

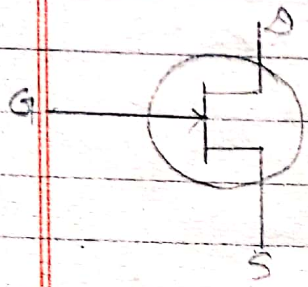


fig: N-Channel JFET

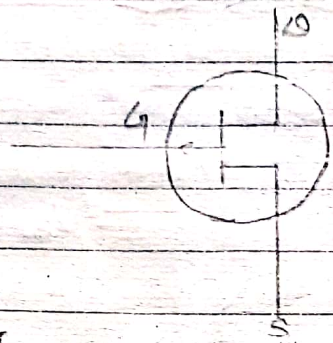


fig:- P-channel JFET

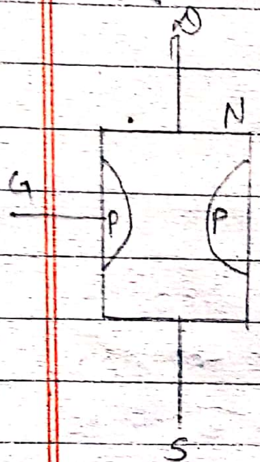


fig:- Block diagram of N-channel JFET.

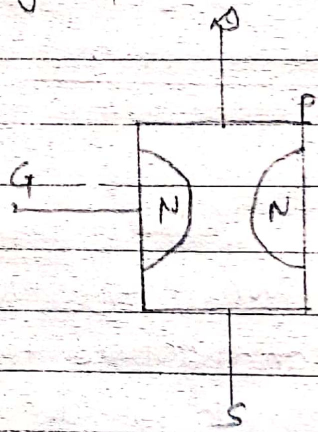


fig:- Block diagram of P-channel JFET

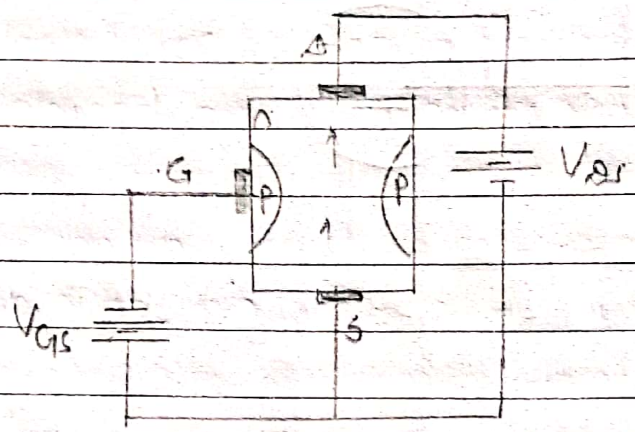
where,

Source → S

Drain → D

Gate → G

→ Working Principle of JFET



When the voltage V_{DS} is applied in the drain and source terminals and gate terminal, the depletion layers are established. The electrons flow ~~follow~~ ~~flow~~ from source to drain through the channels between the layers the width of depletion layers determines the width of the channel. And hence, the current conduction through the transistor.

When a reverse voltage V_{GS} is applied between the gate and source terminals, the width of depletion is increased which decreases the width of conduction channel and the current from source to drain decreases.

If the reverse voltage V_{GS} is decreased the width of depletion layer also decreases which increases the width of conduction channel. Hence, the current from source to drain increases.

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Therefore, the current from source to drain can be controlled by the application voltage on the gate terminal or the electric field. For this ~~region~~ reason, it is known as field effect transistor.

Hence, the JFET operates on the principle of that the width and the resistence of conduction channel can be varied by changing the reverse voltage V_{GS}

11) Metal oxide semiconductor field effect transistor (MOSFET):

MOSFET is another type of FET. It has two forms i.e. N-channel MOSFET and P-channel MOSFET. The P-channel MOSFET consists of two heavily dopped p-regions ~~different~~ diffused into N-type substrate whereas N-channel MOSFET consists of two heavily dopped N-type regions diffused into P-type substrate.

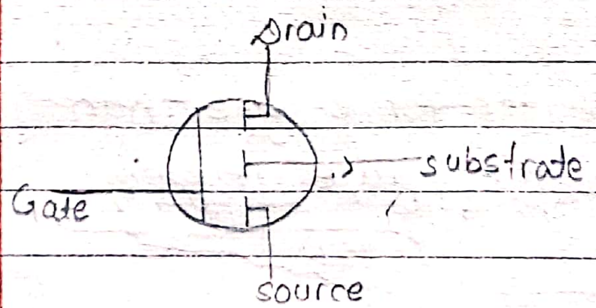


fig: P-channel MOSFET

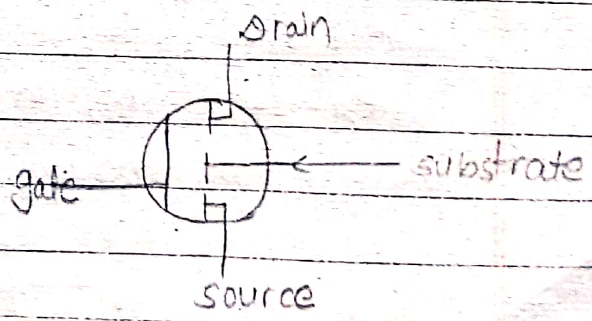


fig: N-channel MOSFET

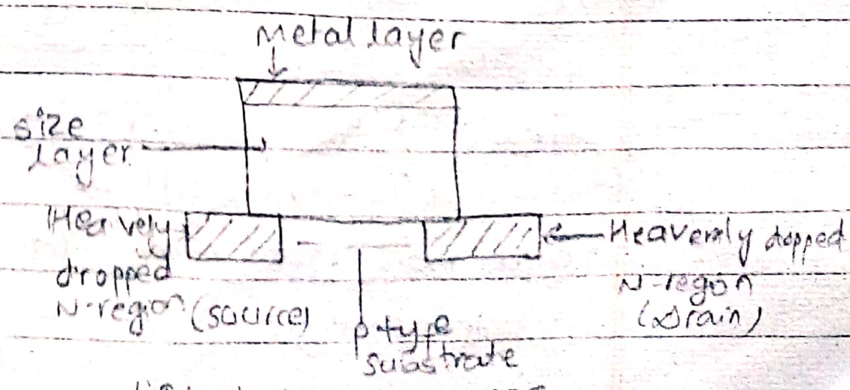


fig: N-channel MOSFET

* Current flow across p-n junction Diode

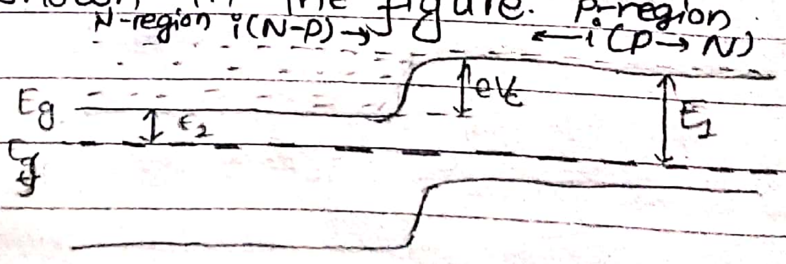
The flow of charge carriers (either electrons or holes) across the p-n junction diode can be explained by following two ways;

a) **Equilibrium currents across p-n junction:** We know that when the p-n junction is formed, a potential energy barrier i.e. eV_c is formed that stops the flow of majority carriers across the junction. At the junction equal amount of electrons and holes are continuously flow in the opposite direction show that the net flow will be zero. Here, we consider any flow of electrons in the conduction band of both N-type and p-type semiconductors. We know that no. of electrons N_e in conduction band is

$$N_e = N_c e^{-(E_g - E_f)/K_B T} \quad \text{---} ①$$

since,

$E_g - E_f$ is much greater for p-type than N-type as shown in the figure.



The electron current from p to N is $i(p \to N)$ will be proportional to the total no. of electrons in the p region. i.e the number of minority charge carrier

$\therefore\ i(P \to N) = A e^{-E_1/K_BT}$ —— (2)

where, A is constant and $E_1 = E_g - E_f$, of p-side.

In the N-side, there are large number of electrons (majority charge carriers) in the conduction band however only those having energy ~~greo~~ equal to or greater than the barrier energy ($|e|V_c$) will be able to cross the junction from N-side to p-side. The electron current $i(N \to P)$ associated with this flow will be proportional to the number of electrons in the N-region with energies greater than or equal to $|e|V_c$.

$\therefore\ i(N \to P) = A N_e f(E \geq |e|V_c)$ —— (3)

Here, $f(E \geq |e|V_c)$ is the fraction of those electrons with energies greater than or equal to ~~mode of~~ $|e|V_c$ which is given by.

$$f(E \geq |e|V_c) = e^{-|e|V_c/K_BT} \quad \text{—— (4)}$$

Again, putting $N_e = \frac{1}{4}\left(\frac{2m_e}{\pi\hbar^2}\right)^{3/2}(K_BT)^{3/2} e^{(E_f - E_g)/K_BT}$

$$\Rightarrow N_e \approx e^{-(E_g - E_f)/K_BT}$$

Eqn (3) becomes,

$$i(N \to P) = A e^{-(E_g - E_f)/K_BT} \cdot e^{-|e|V_c/K_BT}$$

$$i(N \to P) = A e^{-E_2/K_BT} \cdot e^{-|e|V_c/K_BT}$$

$$= A e^{-(E_2 + |e|V_c)/K_BT} \quad \text{—— (5)}$$

where, $E_2 = E_g - E_f$, for N-region.

Again,

We have, $E_1 = E_2 + |e|V_c$

$$i(N \to P) = Ae^{-E_1/k_BT} \quad \text{--- (6)}$$

from eqns (2) and (6), we get

$$i(P \to N) = i(N \to P) \quad \text{--- (7)}$$

Therefore, the flow of electron from N to P is equal to P→N thus the net current is zero. This is the condition of equilibrium current across the p-n-junction.

b) Diode Equation (Net flow of charge carries across the p-n junction diode):

When the external voltage (V) is applied across the diode, in the forward baised condition, the height of potential energy barrier at the p-n junction is $|e|(V_c - V)$. The net electron current from N-side to p-side will be

$$i = i(N \to P) - i(P \to N) \quad \text{--- (1)}$$

where,

$$i(N \to P) = Ae^{-[E_2 + |e|(V_c - V)]/k_BT} \quad \text{--- (2)}$$

and

$$i(P \to N) = Ae^{-E_1/k_BT} \quad \text{--- (3)}$$

is the flow of minority charge carriers from P to N.

Now, eqn (1) becomes.

$$i = Ae^{-[E_2 + |e|(V_c - V)]/k_BT} - Ae^{-E_1/k_BT}$$

we have,

$$E_2 + |e|V_c = E_1 = E_g - E_f$$

$$\therefore\ i = Ae^{-(E_2+|e|V_c-|e|V)/k_BT} - Ae^{-E_1/k_BT}$$
$$= Ae^{-(E_1-|e|V)/k_BT} - Ae^{-E_1/k_BT}$$
$$= Ae^{-E_1/k_BT}\, e^{|e|V/k_BT} - Ae^{-E_1/k_BT}$$
$$= Ae^{-E_1/k_BT}\left(e^{|e|V/k_BT} - 1\right)$$
$$i = i_0\left(e^{|e|V/k_BT} - 1\right) \quad \text{--- (4)}$$

where,
$$i_0 = Ae^{-E_1/k_BT}$$

This equation (4) is called diode equation.

* Conductivity of semiconductor (Electrical conductivity of semiconductor:

A semiconductor has two types of charge carriers. (i.e the electrons and holes). The total conductivity of semiconductor is the sum of the ~~fo~~ conductivity due to electrons and holes.

i.e,
$$\sigma = \sigma_e + \sigma_h \quad \text{--- (i)}$$

where,

σ_e = Conductivity of electrons

σ_h = conductivity of holes

The current carrying density for electrons and holes is given by,

$$\left.\begin{aligned} J_e &= \sigma_e E \\ \text{and, } J_h &= \sigma_h E \end{aligned}\right\} \text{--- (ii)}$$

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where, $J_e = \frac{I_e}{A}$ and $J_h = \frac{I_h}{A}$ current density and E is the electric field.

Again, the current density in terms of drift velocity (V_d) is

$$\left.\begin{array}{l} J_e = neV_{de} \\ J_e = ne\mu_e E \end{array}\right\} \text{—— (III)} \quad \left[\because \begin{array}{l} V_d \propto E \\ V_d = \mu E \end{array}\right]$$

$J = VenA$

$\frac{I}{A} = Ven$

$J = neV_d$

$J_e = neV_{de}$

$J_h = neV_{dh}$

where,

μ_e = the mobility of electron, n – no. of free electrons per unit volume.

Similarly, $J_h = peV_{dh}$

$$J_h = pe\mu_h E \quad \text{—— (IV)}$$

where, p = no. of holes per unit volume.

μ_h = mobility of hole.

Now, comparing eqn (II), (III) & (IV) we get,

$$\sigma_e E = ne\mu_e E$$

$$\text{or, } \sigma_e = ne\mu_e \quad \text{—— (V)}$$

And,

$$\sigma_h E = pe\mu_h E$$

$$\text{or, } \sigma_h = pe\mu_h \quad \text{—— (VI)}$$

Now, putting these eqn (V) & (VI) in eqn (I) we get

$$\sigma = \sigma_e + \sigma_h$$

$$\text{or, } \sigma = ne\mu_e + pe\mu_h$$

$$\text{or, } \sigma = e(n\mu_e + p\mu_h)$$

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At thermal equilibrium, for intrinsic semiconductor,

$$n = p = n_i$$

i.e. no. of holes = no. of electrons = no. of intrinsic carrier density

and,

$$n_i = \sqrt{N_c N_v}\; e^{-E_g/2K_BT}$$

Now,

$$\sigma = e(n_i \mu_e + n_i \mu_h)$$

$$\text{or,} \quad \sigma = e \cdot n_i (\mu_e + \mu_h)$$

$$\text{or,} \quad \sigma = e(\mu_e + \mu_h) \cdot \sqrt{N_c N_v} \cdot e^{-\frac{E_g}{2K_BT}} \quad \text{— (vii)}$$

This is the expression for conductivity of semiconductor.

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