NOTES: ①

* The most popularly used semiconductor is Silicon among other semiconductors such as Germanium. Silicon is abundant in nature and its properties when compared with Ge are more versatile for its use in semiconductor devices.
Crystal structure of Si → Diamond.

* Intrinsic semiconductor:
A perfect semiconductor crystal with no Impurities or lattice defect is called an Intrinsic Semiconductor. Here at 0K the valence band is filled with electrons and the conduction band is Empty.

At T = 300K $n = p$ = no. of holes = no. of electrons

$$n = p = n_i = 1.5 \times 10^{10}/cm^3 \text{ @ } 300K$$

The number (no.) of $\bar{e}$s at room temperature is too low for Electronic devices to operate properly so we need to Increase the temperature in order to Increase the concenteration of $\bar{e}$s but most of the time we operate devices at room temperature. So what we can do is that we can doped the semiconductor with group 13 or group 15 Impurities.

* Extrinsic Semiconductor:

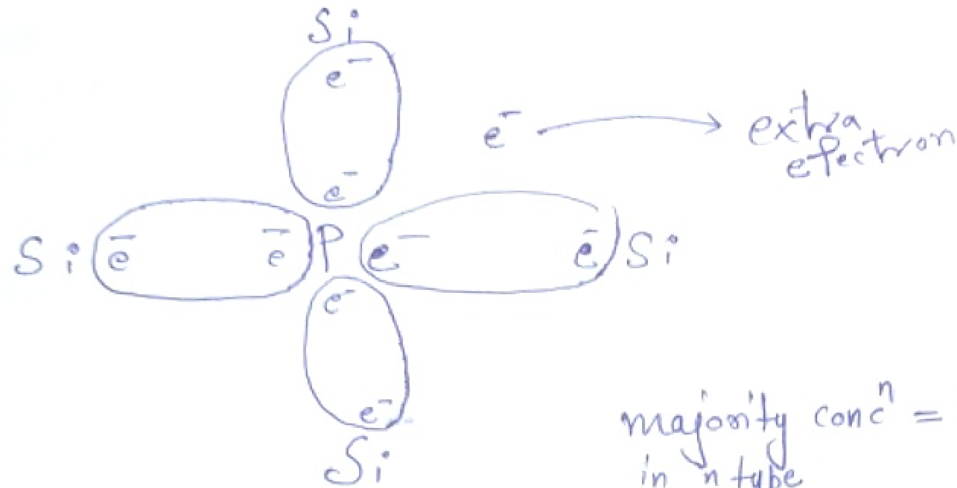
p-type

Here the Semiconductor is doped with group 13 Impurities such as Boron, Aluminium, Gallium etc
B, Al, Ga, In, Tl.

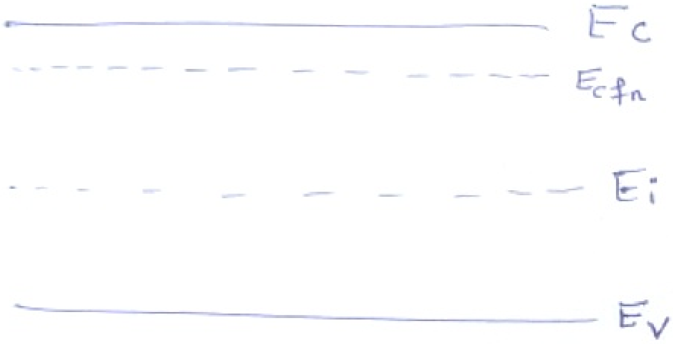
n-type

Here the Semiconductor is doped with group 15 Impurities such as phosphorus.

In n type S.C the $4e^-$s out of the $5e^-$s forms covalent bond with $4e^-$s of Si. The remaining $1e^-$ that is the $5^{th} e^-$ has a donor level close to the conduction band edge. The $5^{th} e^-$ contributes the increase in concentration of electron.

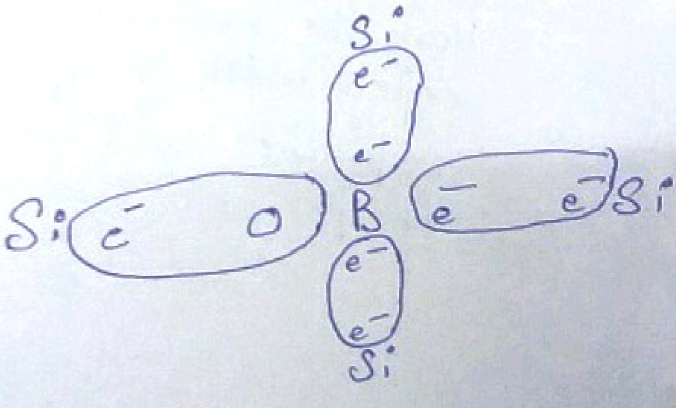


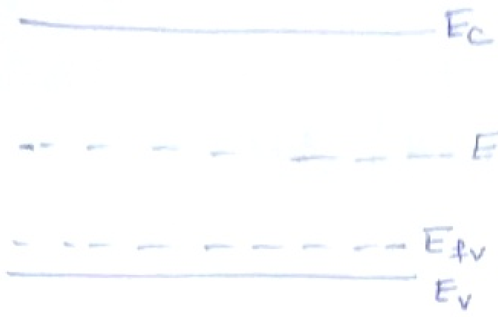
majority concⁿ = e^-s in n type



The fermi level lies close to conduction band in case of n-type S.conductor.

In p type S.C their remains one vaccancy since only $3e^-$s are their with p type Impurities so their is a need of 1 electron more so vaccancy is created.





The fermi level lies close to valence band as majority Conc^n is for holes in p type.

for Intrinsic Semiconductor:-

$$n = p = n_i$$

$$\boxed{np = n_i^2}$$

for n type:

$$\text{no. of } e^-\text{s} = n_i + N_D$$

Donor conc^n

@ room temp. we assume complete ionization so $n_i + N_D \sim N_D$.

$$\text{no. of holes} \times \text{no. of } e^-\text{s} = n_i^2$$

$$n_h \times (n_i + N_D) = n_i^2$$

$$\text{no. of holes} \times N_D = n_i^2$$

$$\text{no. of holes} = \frac{n_i^2}{N_D}$$

$$\boxed{\text{minority conc}^n \text{ (holes)} = \frac{n_i^2}{N_D}}$$

for p type:

(4)

$$n_i = n_i + N_A$$

$N_A \rightarrow$ Acceptor Impurities

$$\text{no. of holes} \times \text{no. of } e^-\text{s} = n_i^2$$

$$(n_i + N_A) \times n_{e^-} = n_i^2$$

$$n_i + N_A \sim N_A \quad \text{(@ 300k assuming complete Ionization)}$$

$$n_{e^-} = \frac{n_i^2}{N_A}$$

$$\boxed{\text{minority conc}^n \text{ (no. of } e^-\text{s}) = \frac{n_i^2}{N_A}}$$

* If both n type and p type doping is done in a Semiconductor than we have to identify what type of Semiconductor we get finally by solving

$N_D - N_A$ if $N_D \gg N_A$ [n type]

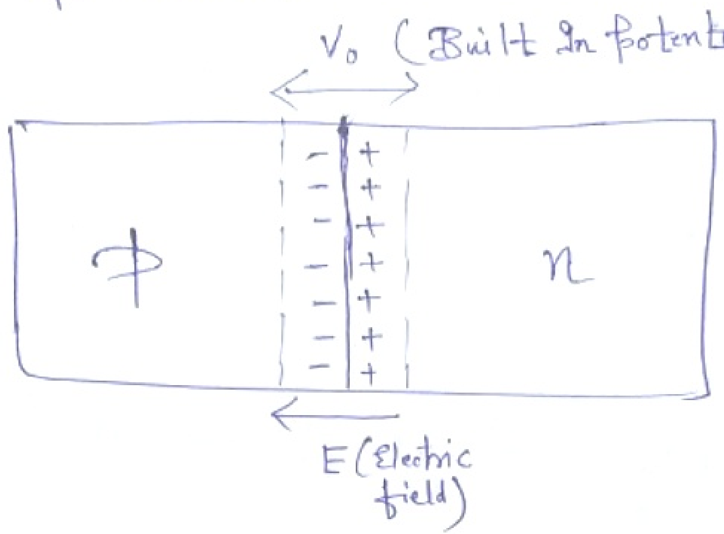
$N_A - N_D$ if $N_A \gg N_D$ [p type]

After identifying the type we need to proceed further than $N_D - N_A$ or $N_A - N_D$ will be majority conc^n and $\frac{n_i^2}{(N_D - N_A)/(N_A - N_D)}$ will be minority conc^n.

PN Junctions:

Here seperate regions of p and n type Semiconductor materia brought together to form a junction. Before they are joined the n type material has large concentration of e^-s and has fewer holes vice versa for p type material.

PN Junc^n @ Equilibrium:

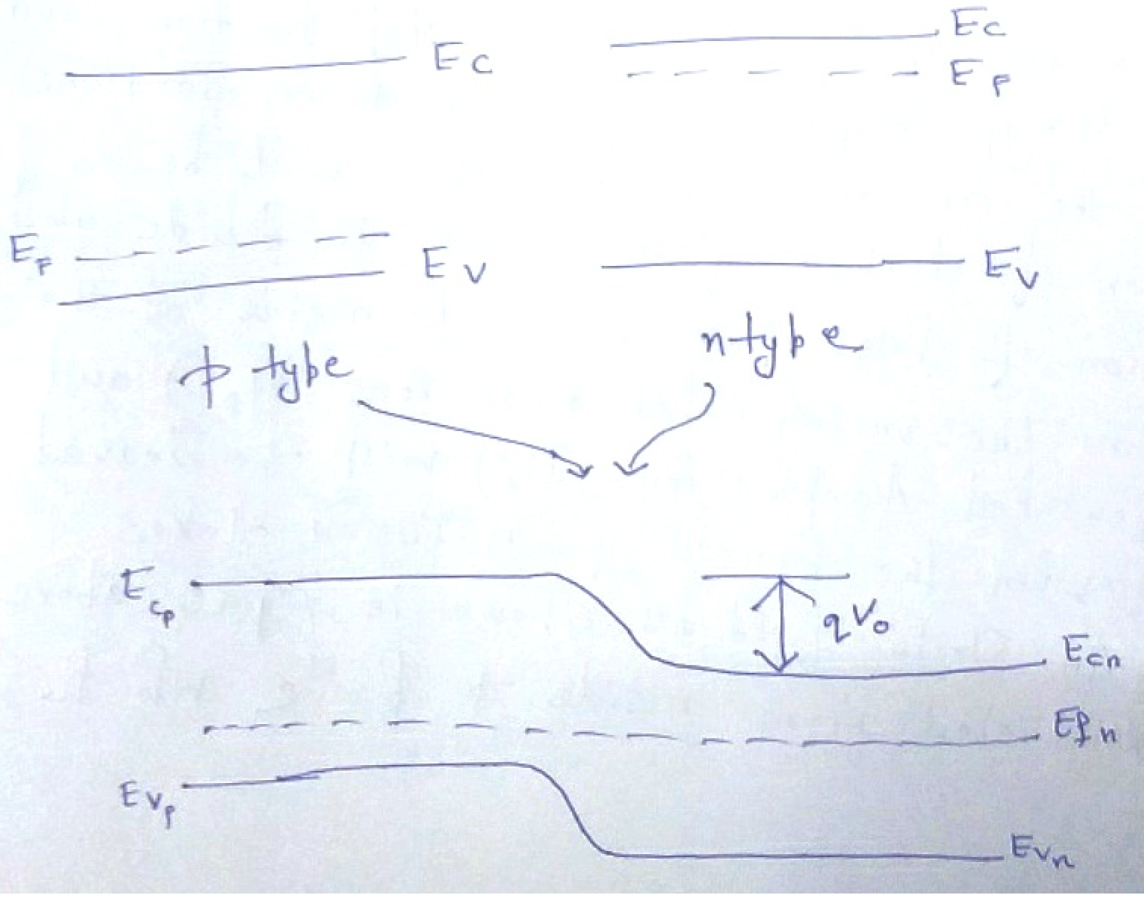


If we assume the function to be step function having p and n type doping uniform in their portions. Due to the concentration gradient their will be a diffusion of electrons from n side to p side and diffusion of holes from p side to n side of the Junction. The uncompensated donor ions (N_D^+) and uncompensated Acceptor ions (N_A^-) will be leaved behind when the process of Diffusion takes place. An Electric field as shown in figure above is established from n side to p side which has the potential to stop the further diffusion of holes or electrons. So a barrier commonly called as potential barrier of width W, Electric field E and with built in potential V_0 is established which stop the further diffusion and no net current flows across the junction.

→ Direction of diffusion of holes

← Direction of diffusion of electrons.

Energy band Diagram of PN Junction at Equilibrium:-



$$\boxed{V_o = \frac{kT}{q} \ln \frac{N_a N_d}{n_i^2}} \quad \text{— } 1$$

$$V_o = \frac{kT}{q} \ln \left(N_a \times \frac{N_d}{n_i^2} \right)$$

$P_p = N_a =$ hole conc^n @ p side

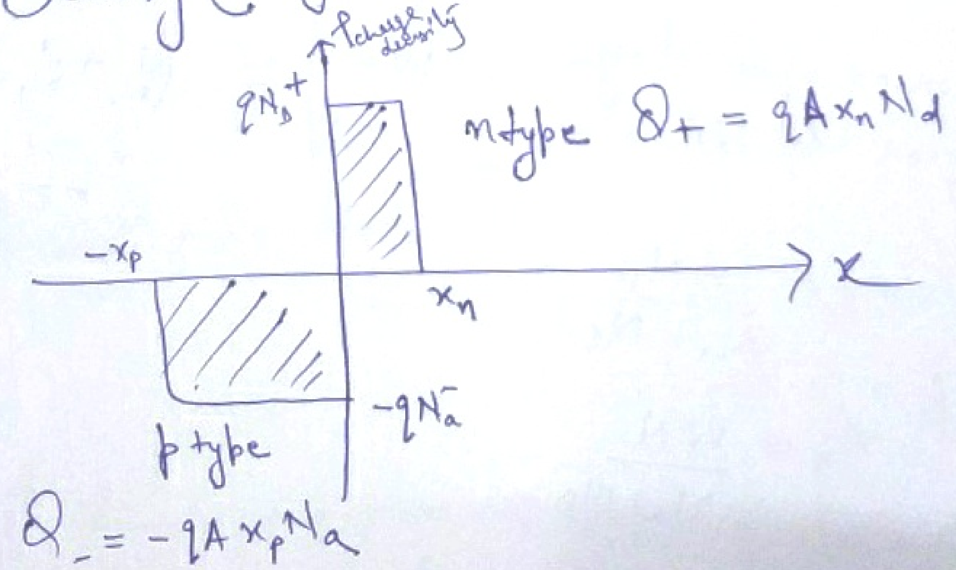
$P_n = \frac{n_i^2}{N_D} =$ minority hole conc^n @ n side

$$V_o = \frac{kT}{q} \ln \frac{P_p}{P_n}$$

$$\frac{V_o q}{kT} = \ln \frac{P_p}{P_n}$$

$$\boxed{\frac{P_p}{P_n} = e^{qV_o/kT}} \quad \text{— } 2$$

Charge Density @ Junc^n :-

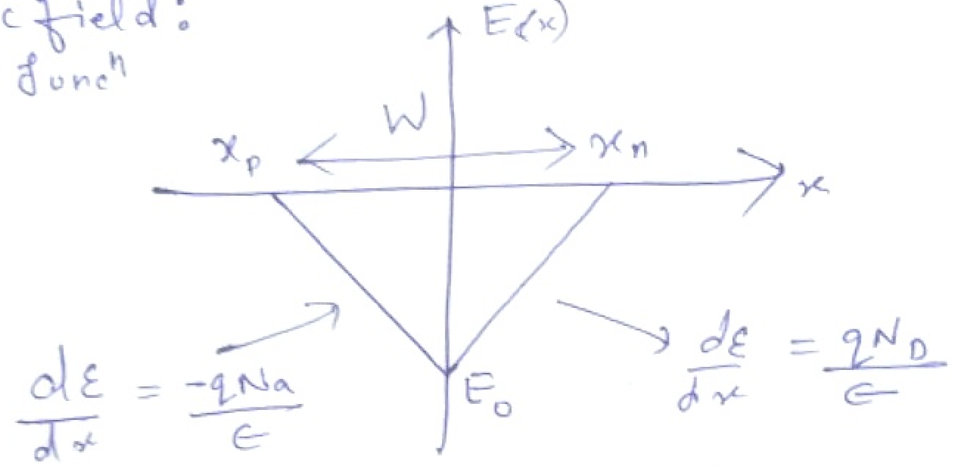


$Q_+ = Q_-$ [About the Junction]

$$\cancel{q}\cancel{A}\, x_p N_a = \cancel{q}\cancel{A}\, x_n N_D$$

$$\boxed{x_p N_a = x_n N_D} \quad -3$$

Electric field:
across junc^n



According to Poisson's Eq^n

$$\frac{dE}{dx} = \frac{qN_d}{\epsilon} \qquad 0 < x < x_n$$

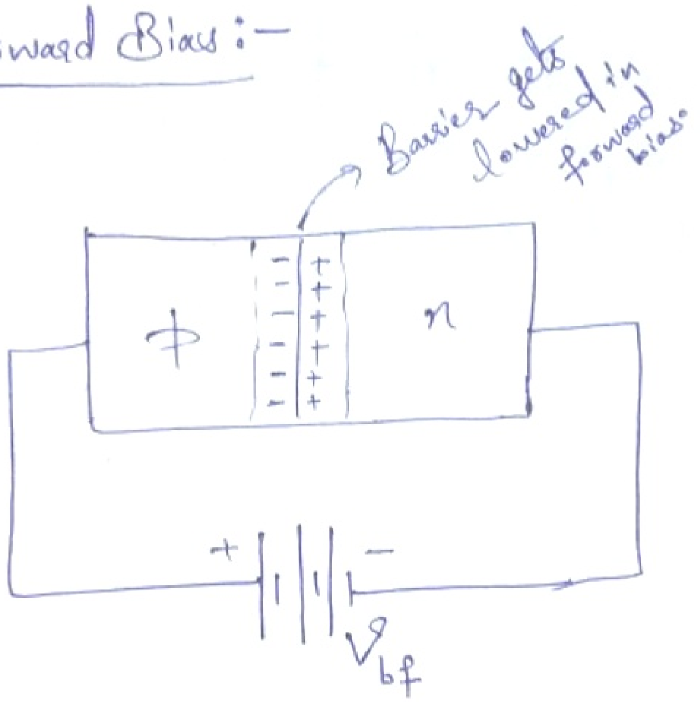
$$\frac{dE}{dx} = \frac{-q}{\epsilon} N_a \qquad -x_p < x < 0$$

Depletion or space charge region Width $= W = \sqrt{\frac{2\epsilon}{q}\left(\frac{1}{N_a} + \frac{1}{N_D}\right) V_0}$ — 4

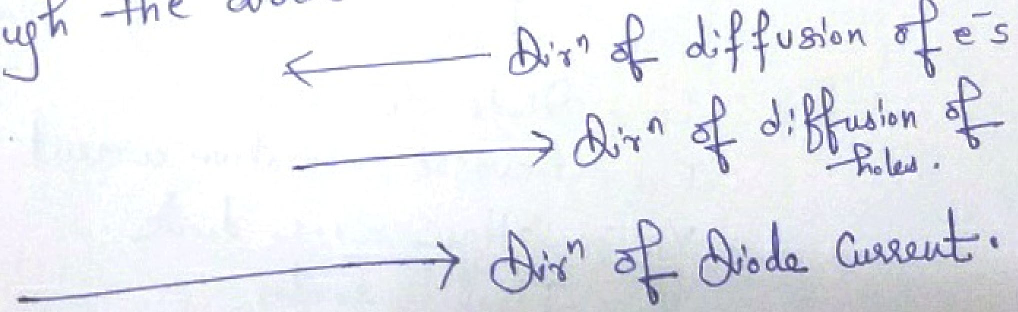
$$x_p = \frac{W N_D}{N_a + N_D}$$

$$x_n = \frac{W N_a}{N_a + N_D}$$

PN Junc^n @ forward Bias :-

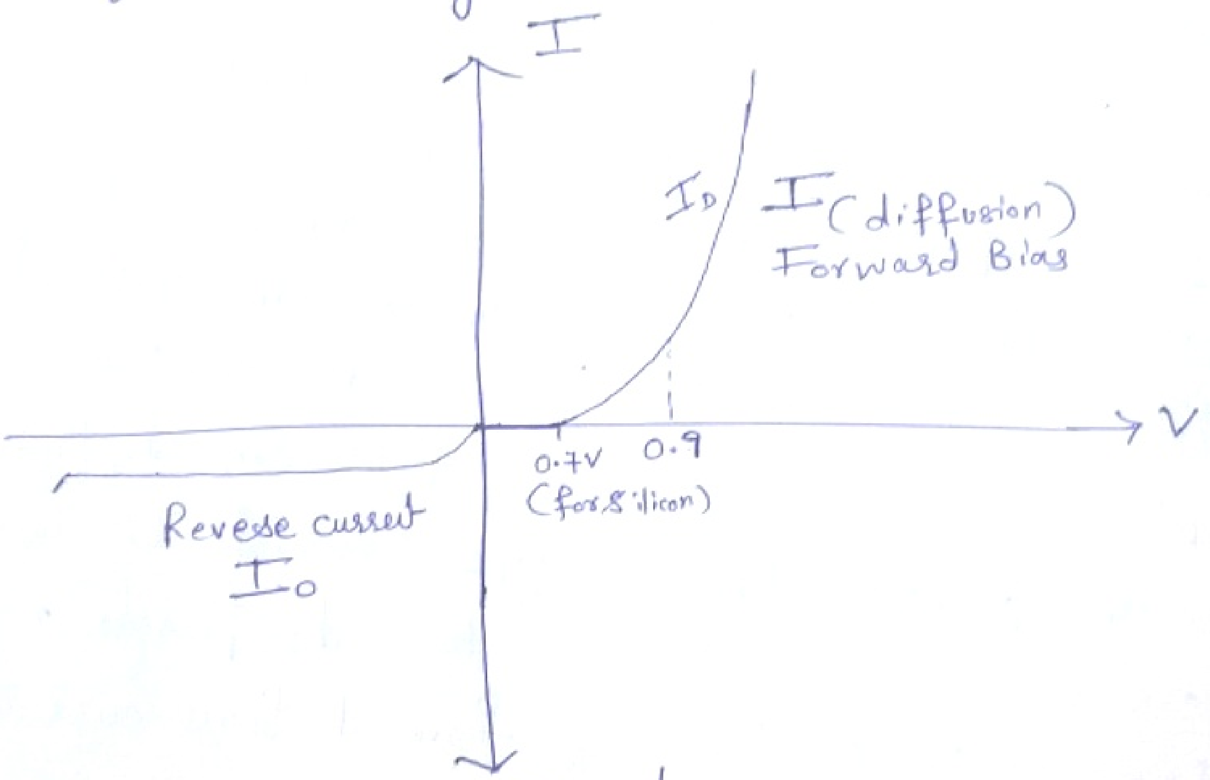


When p type is connected with positive potential and n type is connected with negative potential than the diode is said to be in forward bias. The voltage V_{bf} is applied in the direction opposite to the built in potential voltage to increase the rate of diffusion and lower the barrier. Due to the application of V_{bf} now more holes can diffuse to the phosphorus doped n type semiconductor and now more e^-s can also diffuse towards p side their will be a flow of forward bias current I_D through the diode.



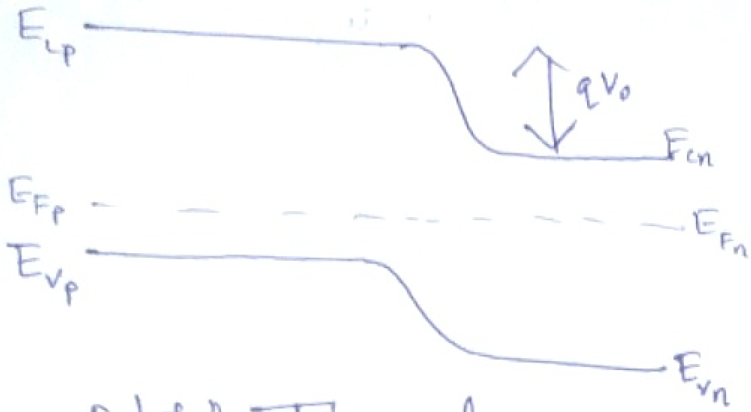
In case of reverse bias the p-type material is connected with negative terminal and n-type material is connected with positive terminal. In case of reverse bias the height of the depletion region increases and a very less amount of current known as reverse saturation current or dark current flows across the diode. (10)

So diode is a unidirectional device it allows the flow of current only in one direction.

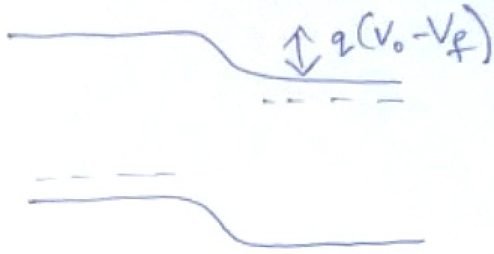


$$I_D = I_o\left(e^{qV_D/\eta KT} - 1\right)$$

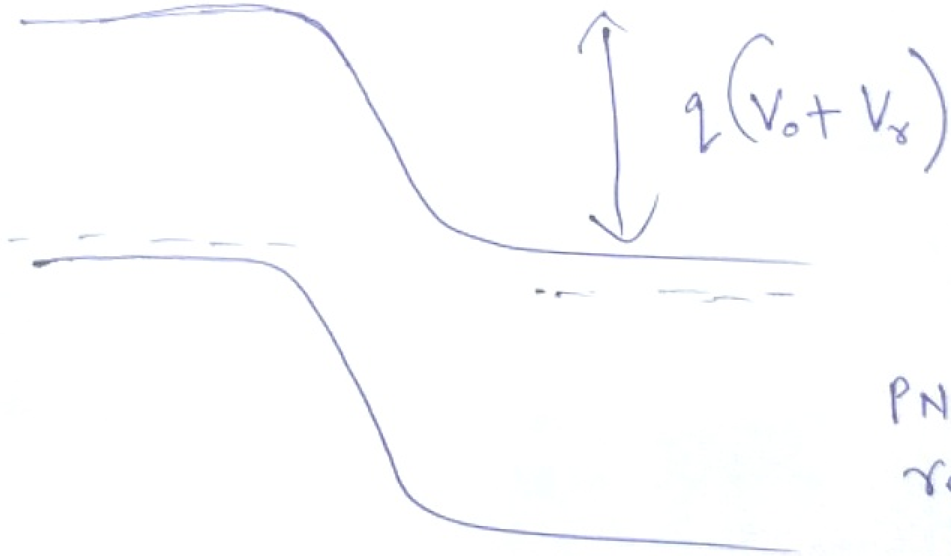
where I_D = Diode c/n current
I_o = Reverse saturation current
V_D = Voltage across diode
η = Ideality factor



PN Junc^n → Thermal Equilibrium



PN Junc^n @ Forward Bias.



PN Junc^n @ reverse Bias

Comparision of Energy Band Diagrams of PN Junc^n @ different states.