# Diode Current Equation.

**Going to derive:** $I_D = I_0 \left( e^{V_D/V_T} - 1 \right)$

**Prerequisites**

How PN junction behaves
Diffusion mechanism.

**Derived:**

1) $V_0 = V_T \ln \left[ \frac{N_A N_D}{n_i^2} \right]$

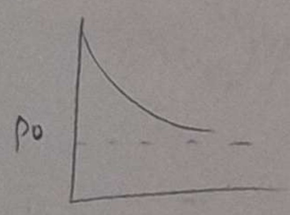
2) $P_p = P_n \, e^{V_0/V_T}$

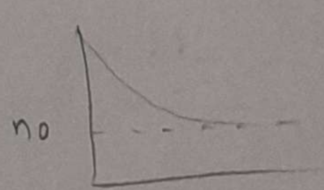
3) $n_n = n_p \, e^{V_0/V_T}$

4) $P(-x_{p0}) = P_n \, e^{V_0/V_T}$

5) $n(x_{n0}) = n_p \, e^{V_0/V_T}$

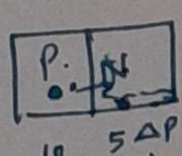
6) PN junction at equilibrium will not have any current flow.

7) 


→ low level injection

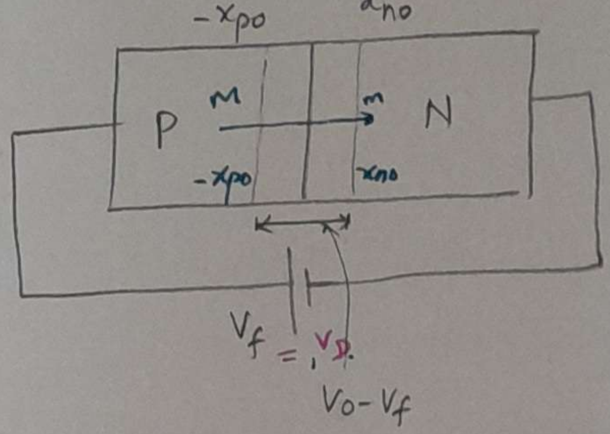
minority carrier << majority carrier




## Diode Current Equation

[Lect

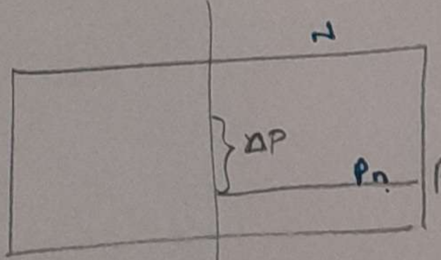
PN Jn in forward bias




When forward bias is applied. - Depletion layer is small

1) holes diffuse into n-region
2) After reaching n-region they become minority carriers.
3) Now, it is similar to that of low level injection
   - Extra minority carriers are generated in N-type semiconductor
   - follow exponential decay distribution.

[Formula]




holes in N-region:
$\Rightarrow P = \Delta P + P_n$

applied voltage '$V_D$'

$P = \Delta P + P_n$

under equilibrium.

from $P_p = P_n e^{V_B/V_T}$

$$P(-x_{po}) = P_n \, e^{V_B/V_T} \quad \text{—— (1)}$$

$$P(-x_{po}) = P(x_{no}) \cdot e^{\left(\frac{V_B - V_D}{V_T}\right)} \quad \text{—— (2)}$$

holes after diffusing into N-type SC they become minority carriers there. and follow an exponential decay.

$$\frac{(1)}{(2)} \Rightarrow 1 = \frac{P_n}{P(x_{no})} \cdot e^{V_D/V_T}$$

$$\Rightarrow P(x_{no}) = P_n e^{\frac{V_D}{V_T}} \quad \text{—— (3)}$$

$$p(x_{no}) = \Delta p + P_n$$

$$\Delta p = P(x_{no}) - P_n$$

$$\Delta P = P_n e^{V_D/V_T} - P_n \quad \text{[From 3]}$$

So @ red
swp @ given

$$\Delta P = P_n \left[ e^{V_D/V_T} - 1 \right] \quad — (4)$$

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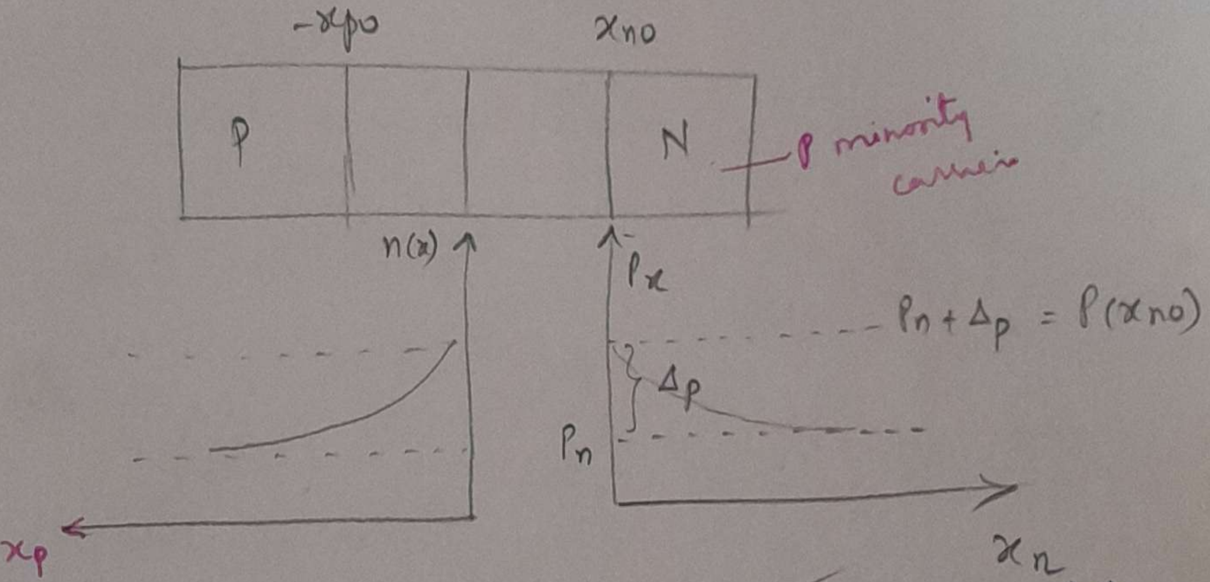
Similarly $$\Delta n = N_p \left[ e^{V_D/V_T} - 1 \right] \quad — (5)$$




~~Distribution of minority Carriers~~

~~$\Delta_n(x)$ $\delta_n(x) = \Delta p \, e^{-x/L_p}$~~

diffusion lengths of holes

$$\sqrt{D_p \tau_p} = L_p$$

In N-type

$$\Delta_p(x_n) \; \delta_p(x_n) = \Delta p \, e^{-x_n/L_p} \quad — (6)$$

$$\Delta_n(x_p) \; \delta_n(x_p) = \Delta n \, e^{-x_p/L_n} \quad — (7)$$

excess $\bar{e}$ concentration

Combining (4) and (6)

$$\Delta p(x_n)\ \delta_p(x_n) = P_n\left(e^{V_D/V_T}-1\right)\cdot e^{-x_n/L_p} \quad \text{— (8)}$$

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$$\Delta n(x_p)\ \delta_n(x_p) = N_p\left(e^{V_D/V_T}-1\right) e^{-x_p/L_n} \quad \text{— (9)}$$

The hole diffusion current density

$$J_p(x_n) = -q D_p \frac{dp}{dx}$$

excess hole distributions.

$$\Delta p(x_n)$$

$$= -q D_p \frac{d}{dx_n}\left[\delta p(x_n)\right] \quad \text{— (10)}$$

$e^{ax}$

$ae^{ax}$

The electron diffusion current density

$$J_n(x_p) = +q D_n \frac{d}{dx_p}\left[\delta n(x_p)\right] \quad \text{— (11)}$$

$$\frac{d}{dx_n}\left[\delta p(x_n)\right] = P_n\left(e^{V_D/V_T}-1\right)\left(-1/L_p\right) e^{-x_n/L_p} \quad \text{— (12)}$$

Combining (10) and (12)

$$J_p(x_n) = \frac{+q D_p P_n}{L_p}\left(e^{+V_D/V_T}-1\right) e^{-x_n/L_p}$$

$$I_p(x_n) = \frac{q D_p P_n}{L_p}\left(e^{+V_D/V_T}-1\right)\cdot e^{-x_n/L_p} \times A \quad \text{— (13)}$$

$=$

③

$$J_n(x_p) = q D_n n_p \left(e^{V_D/V_T} - 1\right) e^{-x_p/L_n} \cdot \left(-\tfrac{1}{L_n}\right)$$

$$I_n(x_p) = -Aq \frac{D_n}{L_n} n_p \left(e^{V_D/V_T} - 1\right) e^{-x_p/L_n} \quad \text{— (14)}$$

$$I_p = Aq \frac{D_p}{L_p} p_n \left(e^{V_D/V_T} - 1\right) e^{-x_n/L_p}$$

$$I_n = +Aq \frac{D_n}{L_n} n_p \left(e^{V_D/V_T} - 1\right) e^{-x_p/L_n}$$

$\xleftarrow{\quad}$ $e^-$ movement

$\xrightarrow{\quad}$ $I_n$ would be opposite to $e^-$ flow. and that's why it is

$-(e^- \text{ movement})$

$-(-Aq \cdots)$

$= +Aq \frac{D_n}{L_n} \cdots$

$$I = I_n + I_p$$

We need constant current

So, at $x_n = 0$ ; $x_p = 0$.

$$I_p = Aq \frac{D_p}{L_p} p_n \left(e^{V_D/V_T} - 1\right)$$

$$I_n = Aq \frac{D_n}{L_n} n_p \left(e^{V_D/V_T} - 1\right)$$

$$I = Aq\left(e^{V_D/V_T} - 1\right)\left[\frac{D_p}{L_p} p_n + \frac{D_n}{L_n} n_p\right]$$

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

Where $I_0 = I_s = qA\left[\frac{D_p}{L_p} \cdot p_n + \frac{D_n}{L_n} \cdot n_p\right]$

[minority carrier concentration]

$$= I_s \left[e^{V_D/\eta V_T} - 1\right]$$

when $V_D = \pm 1$