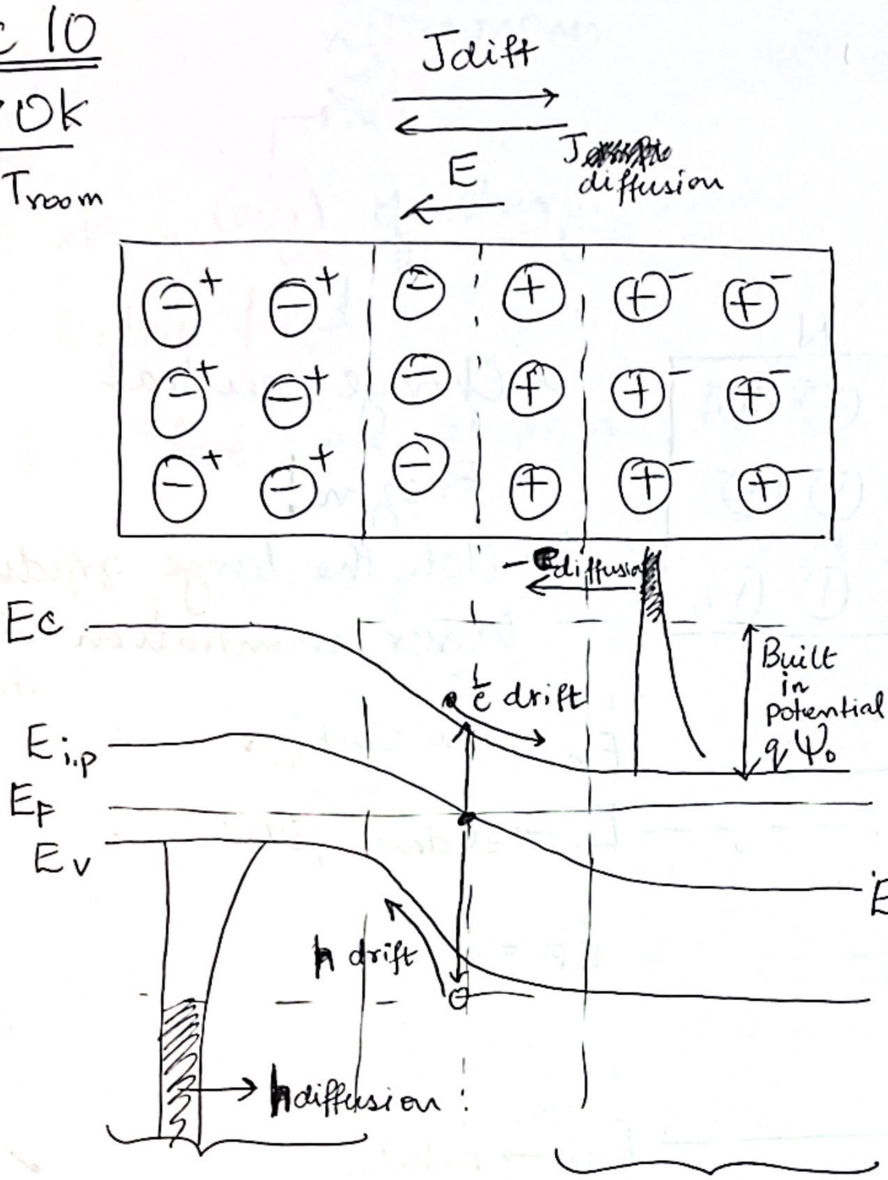
Lec 10

T > 0K

~~T~~ = T_{room}



$E_i > E_F$

$\Rightarrow$ p is large

$E_F > E_i$

$\Rightarrow$ n is large

> E reduces the diffusion current

> But E introduces a drift current from spontaneous eh pair generation.

> At thermal equilibrium $J_{drift} = J_{diffusion}$ & depletion region settles.

$\Rightarrow$ $\boxed{E_{Fermi} \text{ is constant across the diode.}}$

Otherwise net current would flow!

Another way to interpret is Ptype $\Rightarrow E_F \rightarrow E_V$ ntype $\Rightarrow E_F \rightarrow E_C$ at room temp. When they are connected E_F must be const. at thermal eq. $\Rightarrow$ bands must bend.

> These energy levels are for an electron.

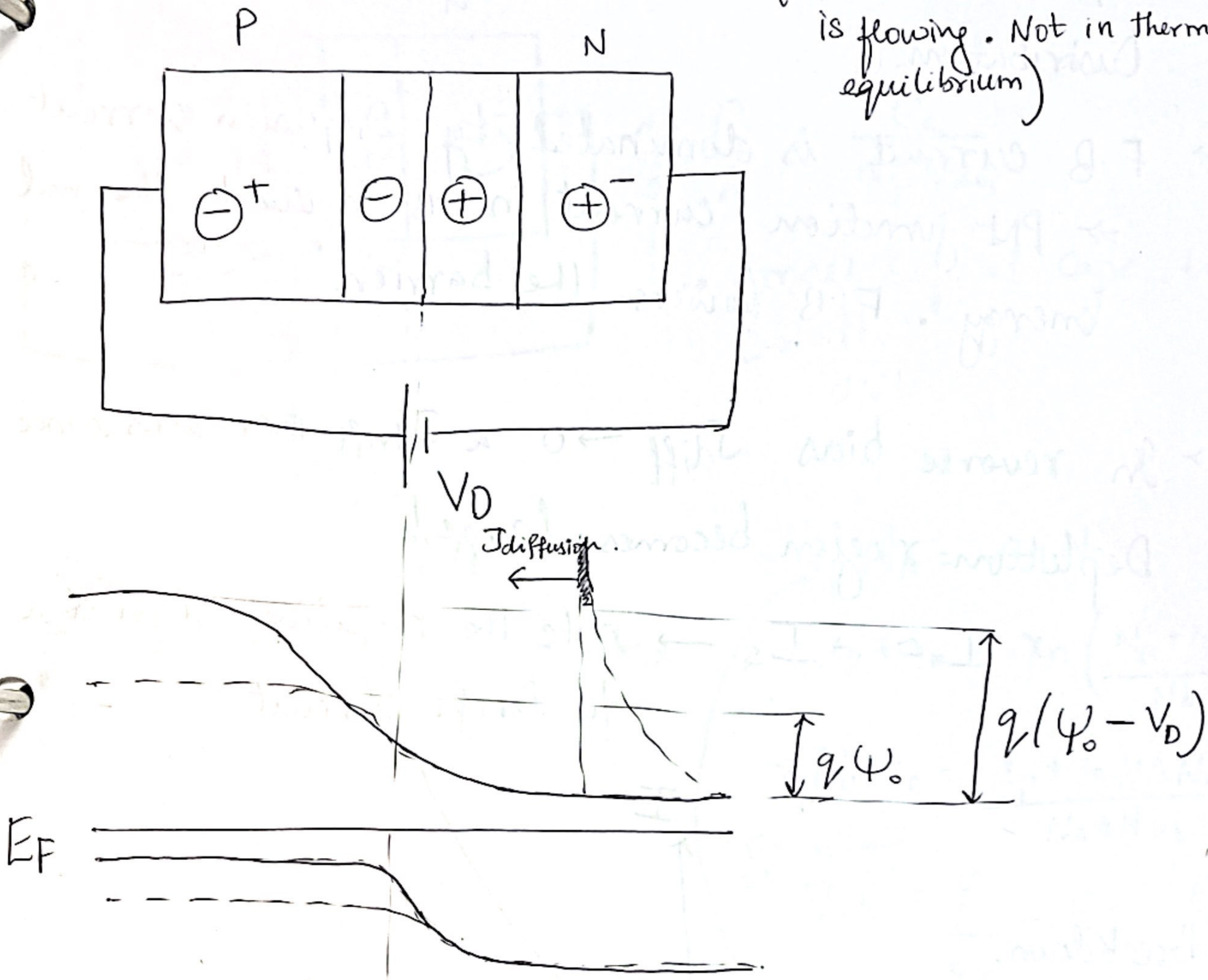
> $q\psi_0 = (E_{i,p} - E_F) + (E_F - E_{i,n})$. At room temperature

$n \simeq N_D \rightarrow$ no. of donors per unit volume. $p \simeq N_A \rightarrow$ no. of acceptors per unit vol.

$$\Rightarrow q\psi_0 = KT \ln\left(\frac{N_A}{n_i}\right) + KT \ln\left(\frac{N_D}{n_i}\right) \Rightarrow \boxed{\psi_0 = \frac{KT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)}$$

Effect of External Potential

(Note E_F is not defined (or constant) when current is flowing. Not in thermal equilibrium)



$$J_{diff}\Big|_{V_0=0} \propto e^{\frac{-q\psi_0}{KT}}$$

$$J_{diff}\Big|_{V_D\neq 0} \propto e^{\frac{-q(\psi_0-V_D)}{KT}}$$

$\rightarrow$ Net current due to V_D

$$\propto e^{\frac{-q(\psi_0-V_0)}{KT}} - e^{\frac{-q(\psi_0)}{KT}}$$

$$\propto \left(e^{\frac{qV_D}{KT}}-1\right)$$

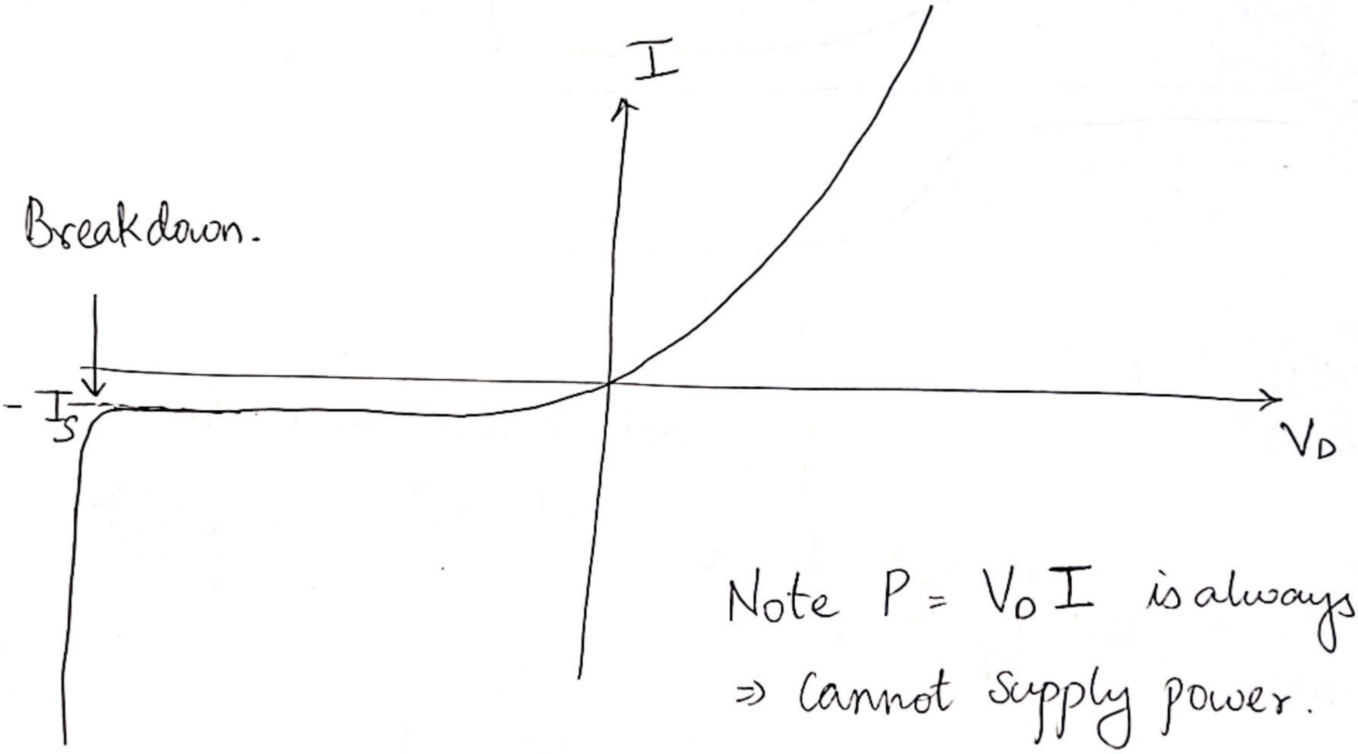
Also including holes we have $\rightarrow$ $\boxed{I(V_D) = I_S\left(e^{\frac{qV_D}{KT}}-1\right)}$

> Exponential dependance comes from Boltzmann Distribution.

> F.B current is dominated by Diffusion current
⇒ PN junction current in FB is due to thermal energy. F.B lowers the barrier.

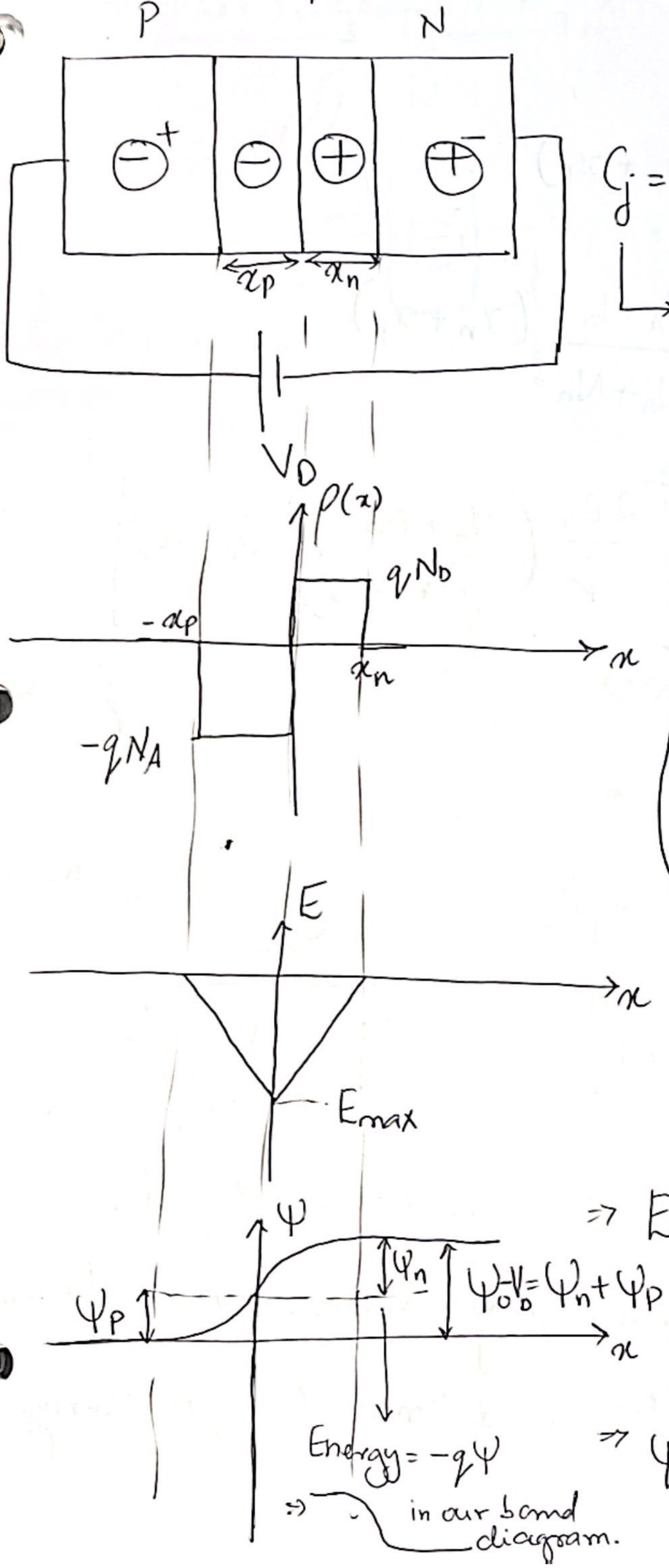
> In reverse bias $J_{diff} \to 0$ & J_{drift} increases since Depletion region becomes large!

$I \simeq -I_s \longrightarrow$ note the negative sign due to Drift current.



Note $P = V_D I$ is always true
⇒ Cannot supply power.

Junction Capacitance



$C_j = \frac{C}{A} = \frac{\epsilon_s}{x_p + x_n}$

↳ Small signal capacitance.

$C = \frac{dQ}{dV}$

$x_p N_A = x_n N_D$

$\Rightarrow x_p + x_n = x_n\left(\frac{N_A + N_D}{N_A}\right)$

$\Rightarrow N_D x_n = \frac{(x_p + x_n) N_A N_D}{N_A + N_D}$

Gauss Law

$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_s} \Rightarrow E = \int \frac{\rho}{\epsilon_s} dx$

$E_{max} = \frac{q N_A x_p}{\epsilon_s} = \frac{q N_D x_n}{\epsilon_s}$

$\Rightarrow E_{max} = \frac{q}{\epsilon_s}\left(\frac{N_A N_D}{N_A + N_D}\right)(x_n + x_p)$

$\vec{E} = -\nabla\psi$ → Potential.

$\Rightarrow \psi = -\int \vec{E}\, dx$

$$\psi_n = \frac{E_{max}\, x_n}{2} \quad ; \quad \psi_p = \frac{E_{max}\, x_p}{2}$$

$$\Rightarrow \psi_0 - V_D = \frac{E_{max}}{2}(x_n + x_p)$$

$$= \frac{q}{2\epsilon_s} \frac{N_A N_D}{N_A + N_D} (x_n + x_p)^2$$

$$\Rightarrow x_d \triangleq x_n + x_p = \left[\frac{2\epsilon_s}{q} \left(\frac{N_A + N_D}{N_A N_D} \right) (\psi_0 - V_D) \right]^{1/2}$$

$$\Rightarrow C_j = \frac{C}{A} = \frac{\epsilon_s}{x_d}$$

$$\Rightarrow C_j = \left[\frac{q\,\epsilon_s}{2\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(\psi_0 - V_D)} \right]^{1/2} = \frac{C_{j0}}{\left(1 - \frac{V_D}{\psi_0}\right)^{1/2}}$$

$C_{j0} \rightarrow$ C_j when $V_D = 0$.

- x_d is dominated by side that is lightly doped.
- $1/2$ comes from uniform doping profile. Linear profile $\Rightarrow 1/3$
- Doping profile in practice is estimated by measuring $C_j(V_D)$.