# Drift, diffusion, mobility, diffusivity

## Einstein's Rel$^n$

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$$

Under thermal equilibrium check Einstein's Rel$^n$

$I = 0$ in thermal equilibrium

Detailed balance $\rightarrow$ $I_p = 0$, $I_n = 0$

$$I_p = A q p \mu_p \mathcal{E} - A q D_p \frac{dp}{dx} = 0$$

$$I_n = A q n \mu_n \mathcal{E} + A q D_n \frac{dn}{dx} = 0$$

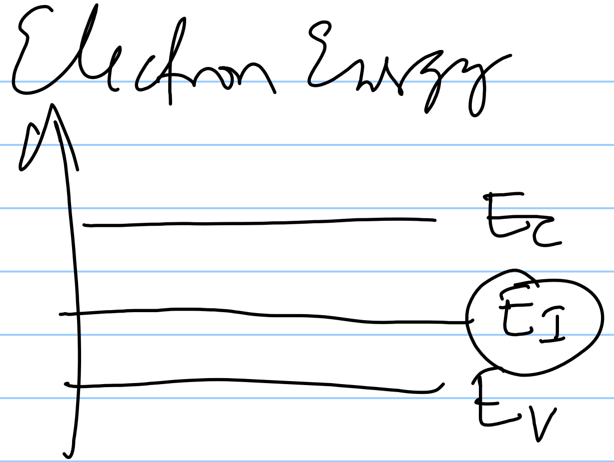
$$J_p = I_p / A, \quad J_n = I_n / A$$

$$I = I_p + I_n = 0$$

$$J_n = 0$$

$$q n \mu_n \mathcal{E} + q D_n \frac{dn}{dx} = 0$$

$$\mathcal{E}(x) = -\frac{dV(x)}{dx}$$




$$E_I = -qV_I$$

$$\frac{dE_I}{dx} = -q\frac{dV_I}{dx} = +q\mathcal{E}$$

$$\boxed{\mathcal{E} = \frac{1}{q}\frac{dE_I}{dx}}$$

$$J_n = 0 = qn\mu_n \frac{1}{q}\frac{dE_I}{dx} + qD_n\frac{d}{dx}\left\{n_i \exp\left(\frac{E_F - E_I}{kT}\right)\right\}$$

$$= n\mu_n \frac{d}{dx}E_I + \frac{nqD_n}{kT}\frac{d}{dx}(E_F - E_I)$$

$$0 = n\mu_n \frac{d}{dx} E_I + \frac{n}{kT} q D_n \frac{d}{dx}(-E_I)$$

$$\Rightarrow \mu_n = \frac{D_n}{\frac{kT}{q}} \Rightarrow \frac{D_n}{\mu_n} = \frac{kT}{q} = V_T$$

$$J_p = 0 \Rightarrow \frac{D_p}{\mu_p} = \frac{kT}{q} = V_T$$

$$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$$

$$J_n = n q \mu_n \mathcal{E} + q D_n \frac{dn}{dx}$$

$$J_n = n \mu_n \frac{d}{dx} E_I + q D_n \frac{d}{dx}[n]$$

$$n = n_i \exp\left(\frac{E_F - E_I}{kT}\right)$$

FERMI → IMREF level
quasi-Fermi level

Non-equilibrium condⁿ

quasi-Fermi level for electron ($E_{Fn}$)

quasi-Fermi level for hole ($E_{Fp}$)

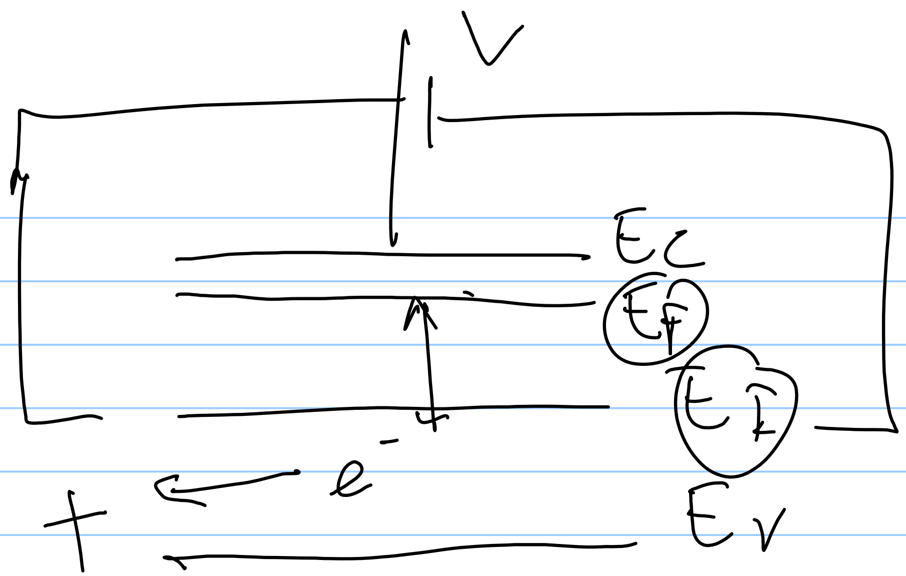
$F_n$, $F_p$

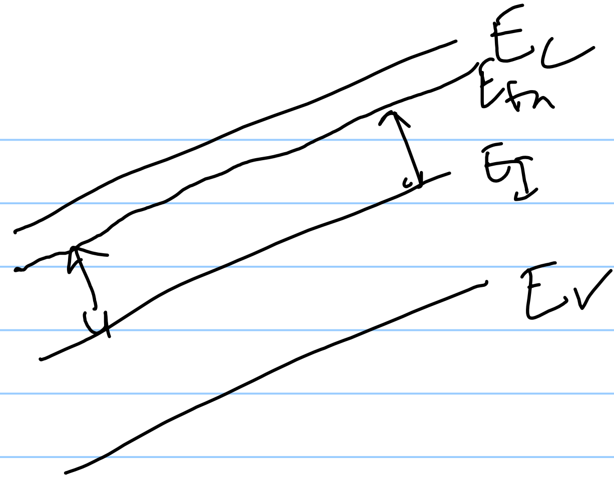
$$n = n_i \exp\left(\frac{E_{Fn} - E_I}{kT}\right)$$

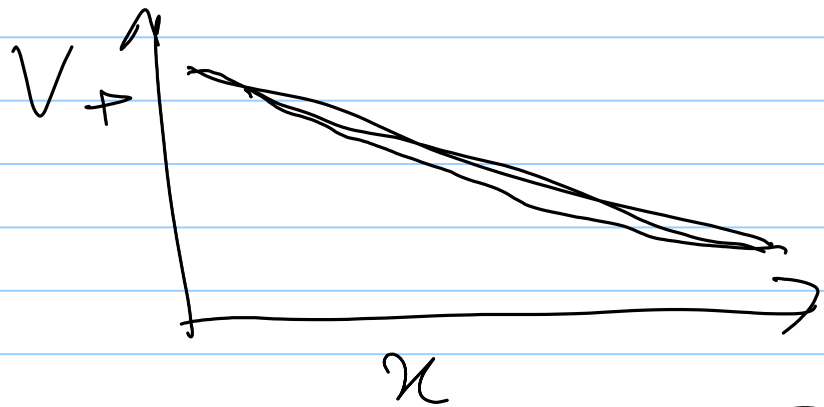
$$J_n = n\mu_n \frac{d}{dx}E_I + \frac{n}{kT} q D_n \frac{d}{dx}\left(E_{Fn} - E_I\right)$$

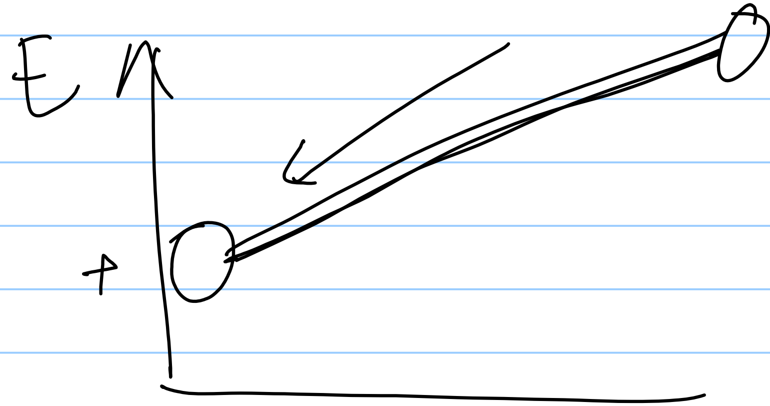
$$\Rightarrow \left[J_n = \frac{nq}{kT} D_n \frac{d}{dx}E_{Fn}\right] + \left[n\mu_n \frac{d}{dx}E_I - \frac{n}{kT} q D_n \frac{d}{dx}E_I\right]$$

$$\left[n\mu_n \frac{d}{dx}E_I - \frac{n}{kT} q D_n \frac{d}{dx}E_I\right] = 0$$




$$n = n_i \exp\left(\frac{E_{Fn} - E_i}{kT}\right)$$

$$J_n = \frac{nq}{kT} D_n \frac{d}{dx} E_{Fn} + ( - - - )$$

$$( - - - ) = 0$$

$$= \frac{nq}{kT} D_n \frac{d}{dx} E_F + ( - - - )$$

$$( - - - ) = 0$$

$$J_n = \frac{nq}{kT} D_n \, q \, \mathcal{E} + ( - - - - - )$$

$$( - - - - - ) = 0$$

$$\frac{q}{kT} D_n = \mu_n$$

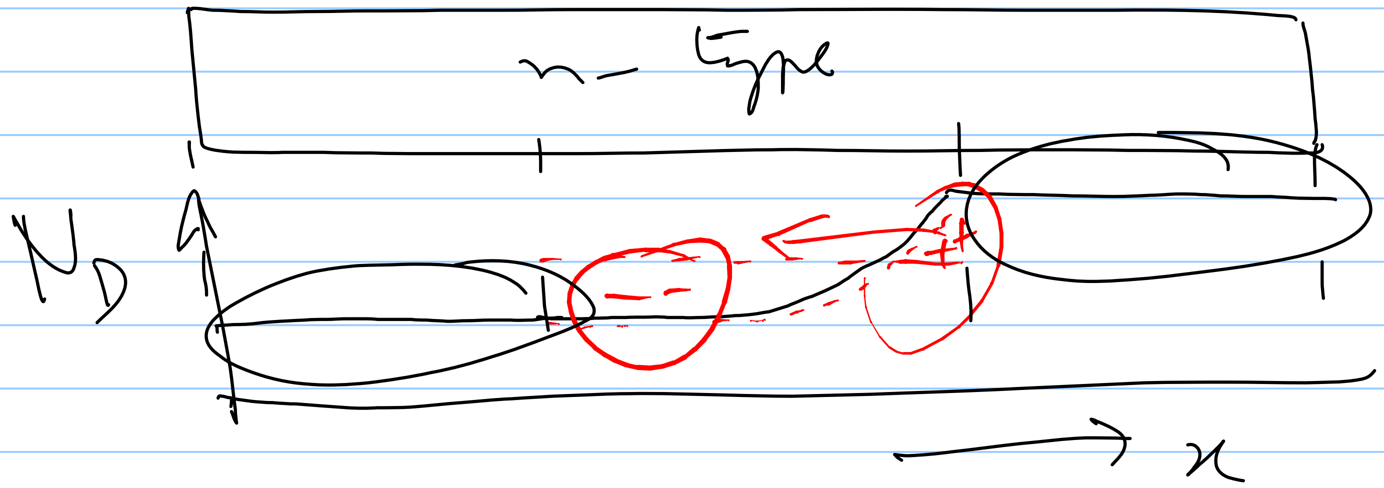
$$J_n = nq \mu_n \mathcal{E}$$

$$\mu_n = \frac{q D_n}{kT} = \frac{D_n}{V_T}$$

Einstein's Relⁿ holds in eqbᵐ & non-eqbᵐ cases

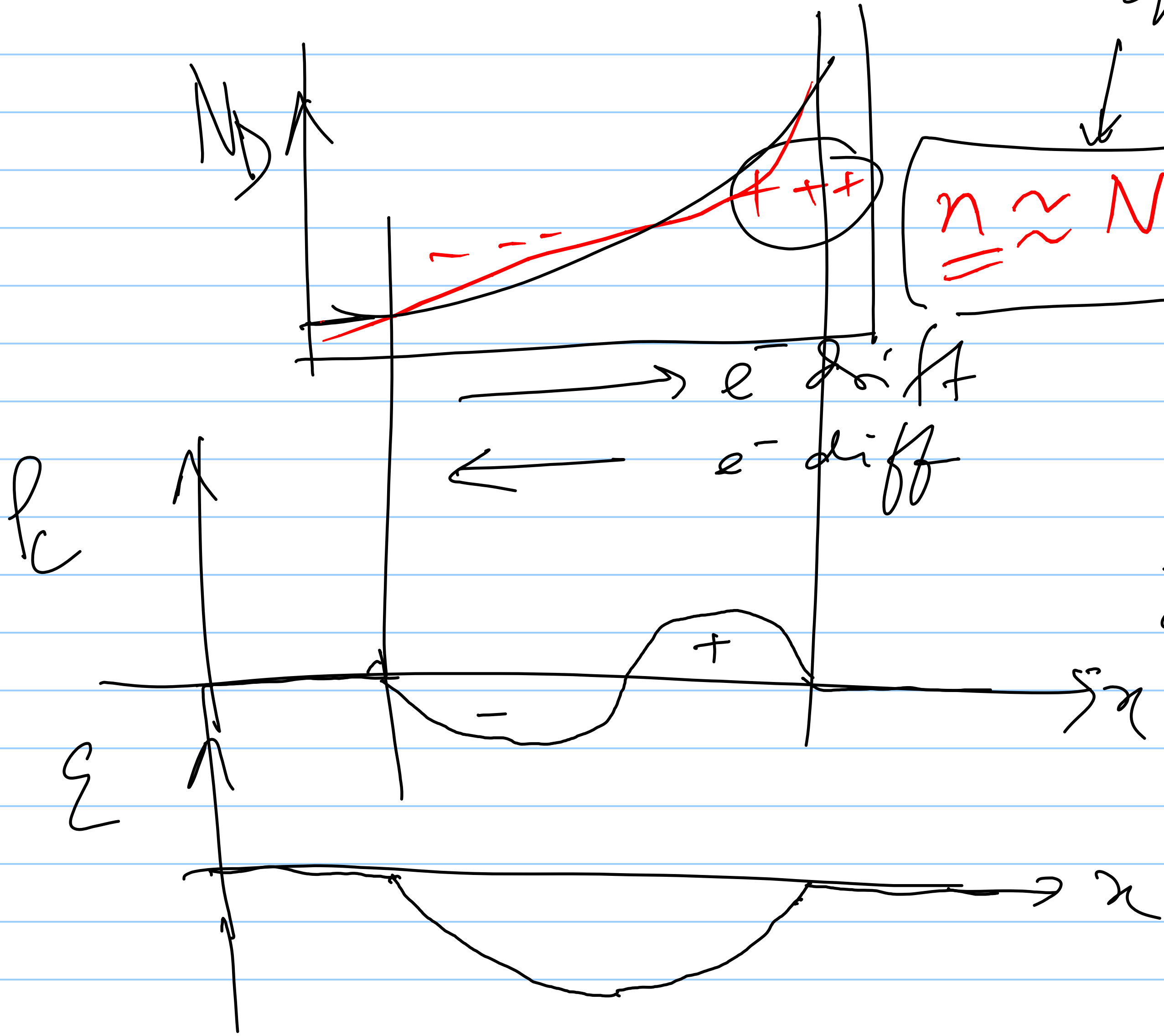
$$J_n = \frac{n}{kT} q D_n \frac{d}{dx} E_{Fn}$$

# Non-uniform Doping



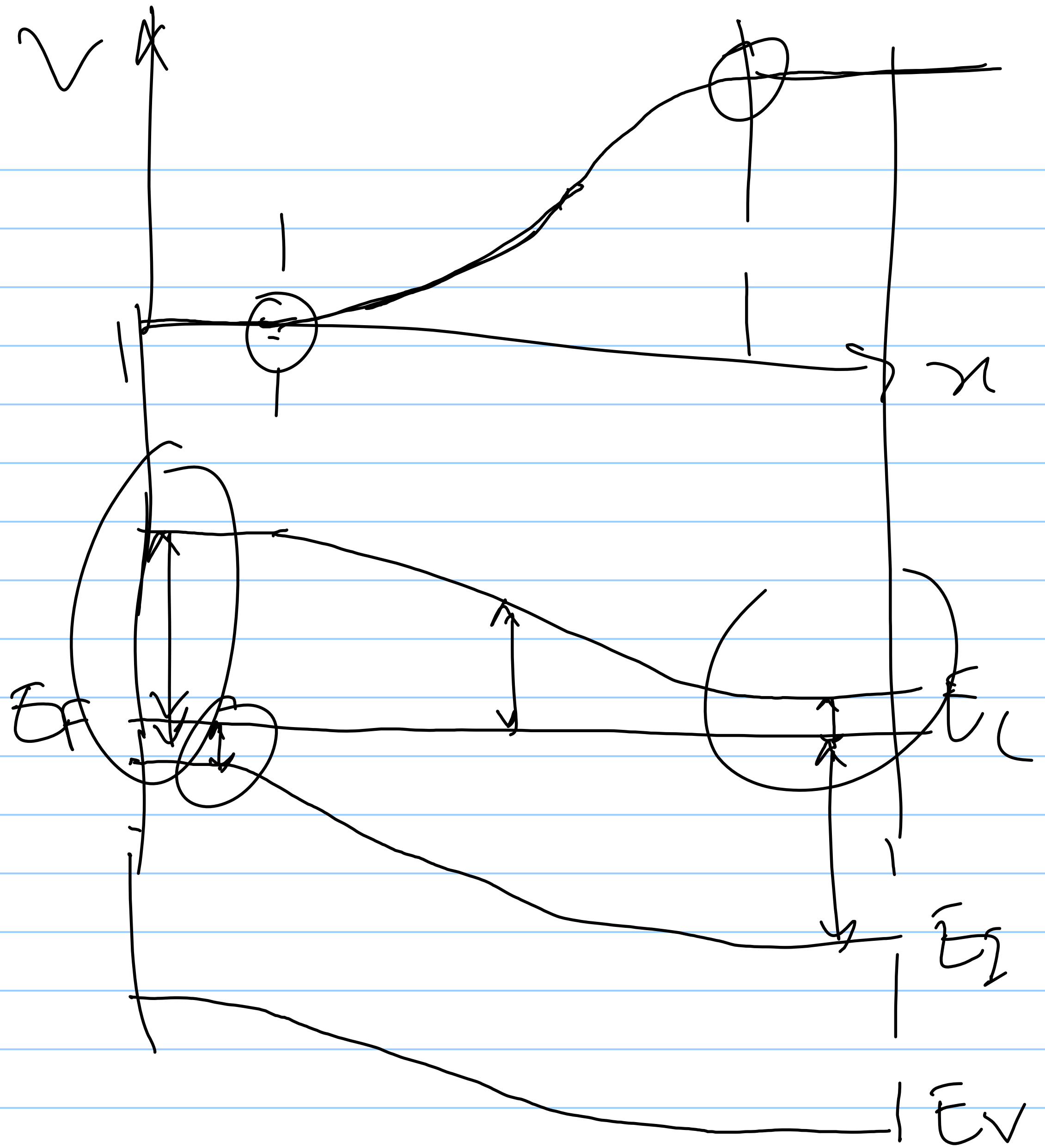
quasi-neutrality

$n \approx N_D$




$$\frac{d\mathcal{E}}{dx} = \frac{\rho_c}{\epsilon}$$

$$\mathcal{E} = -\frac{dV}{dx}$$


V
x
Ef
Ec
Ei
Ev