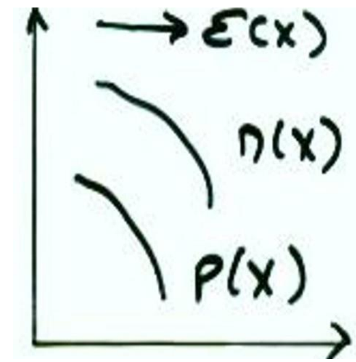
ECE 3030 Midterm 2 Review

1. (a) Optical Creation and Recombination

$\delta n = \delta p = g_{op}\ \tau$

$\delta n(t) = \Delta n\ e^{-t/\tau}$

$R = \delta n/\tau = \delta p/\tau$



1. (b) Diffusion Currents

$J_{diffusion} = -q\ D_p\ dp(x)/dx$ for holes

$J_{diffusion} = +q\ D_n\ d(n)/dx$ for electrons

1. (c) Drift: $J_{drift} = q\ (\mu_n n + \mu_p p)\ \mathcal{E} = \sigma\ \mathcal{E}$

1. (d) Total

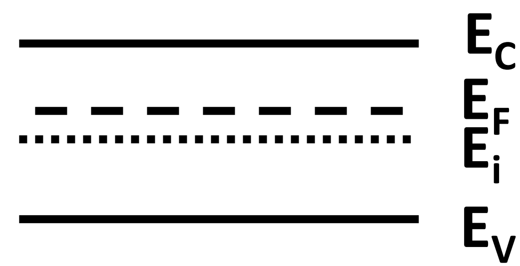
$J_p(x) = q\ \mu_p p(x)\mathcal{E}_x - qD_p\ dp(x)/dx$ for holes

$J_n(x) = q\ \mu_n n(x)\mathcal{E}_x + qD_n\ dn(x)/dx$ for electrons

2. Equilibrium Carrier Densities (without light)

$n_0 = n_i e^{(E_F - E_i)/kT}$

$p_0 = n_i e^{(E_i - E_F)/kT}$



Quasi—Fermi Levels F_n and F_p (with light)

Separation $F_n – F_p$ = Departure from equilibrium

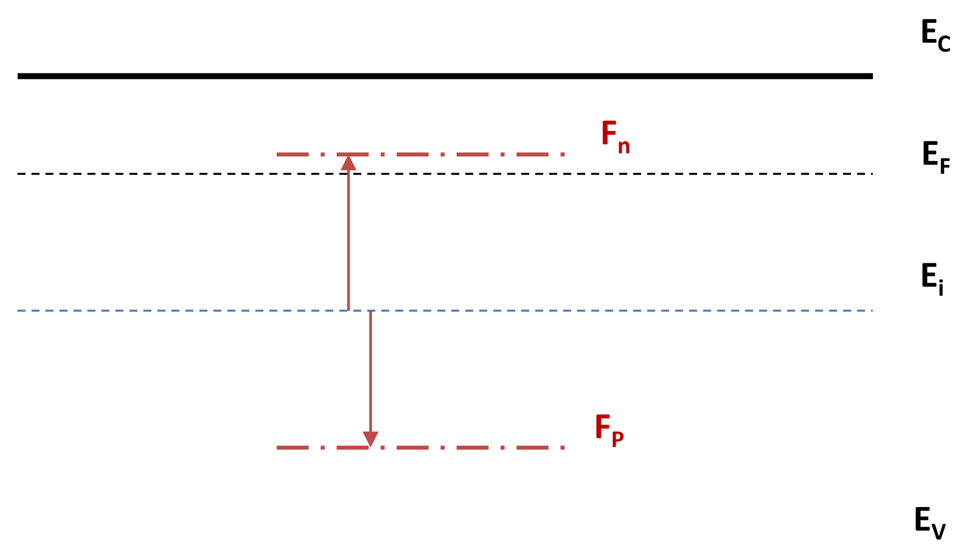
$n = n_i e^{(F_n - E_i)/kT}$

$p = n_i e^{(E_i - F_p)/kT}$

$n = n_o + \Delta n = n_o + g_{op}\tau$

$p = p_o + \Delta p = p_o + g_{op}\tau$

$J_n(x) = \mu_n n(x)\, dF_n/dx$

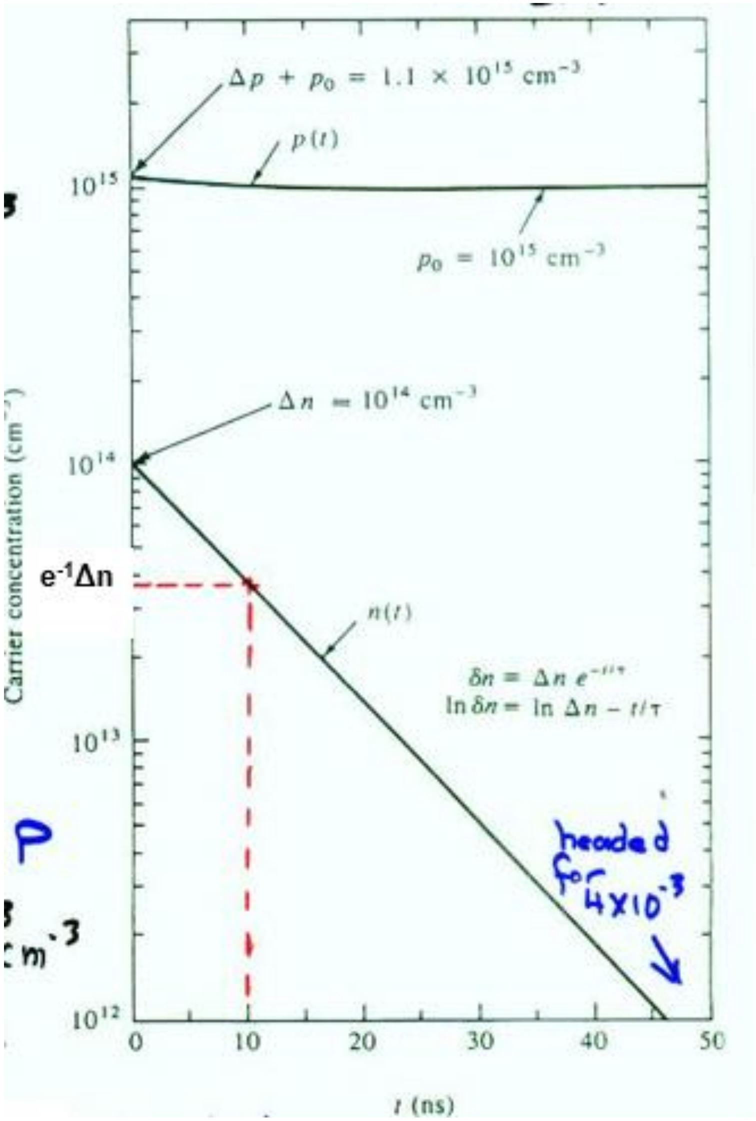


3. Excess Photogenerated Carrier Decay After Light

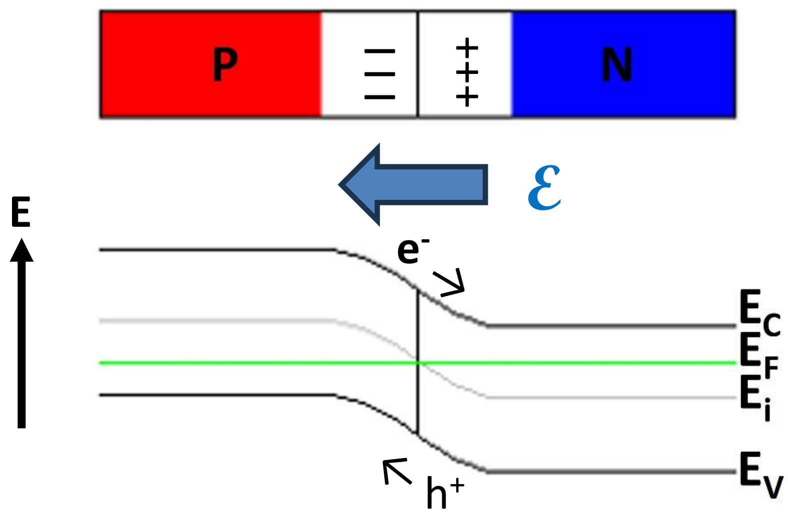
$n = n_o + \Delta n(t)$
$p = p_o + \Delta p(t)$

Minority carrier = n_i^2/Majority carrier
Minority carrier decay slope = $-1/\tau$

$J = \sigma\mathcal{E}$
Conductivity $\sigma = qn\mu_n + qpu_p$
$\Delta\sigma = qg_{op}(\tau_n\mu_n + \tau_p\mu_p)$



4. P-N Junction

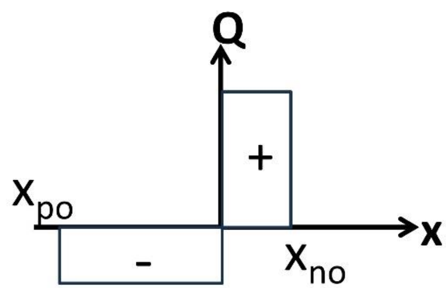


	Drift	Diffusion
p	←	→
n	→	←

Balance

Einstein Relation

$$D/\mu = kT/q$$



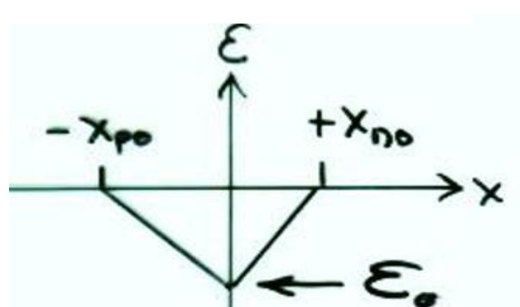
$$W = [(2\varepsilon V_0/q)(N_A^{-1} + N_D^{-1})]^{1/2}$$

$$\mathcal{E} = qN_A\, x_{p0}/\varepsilon = qN_D x_{n0}/\varepsilon$$

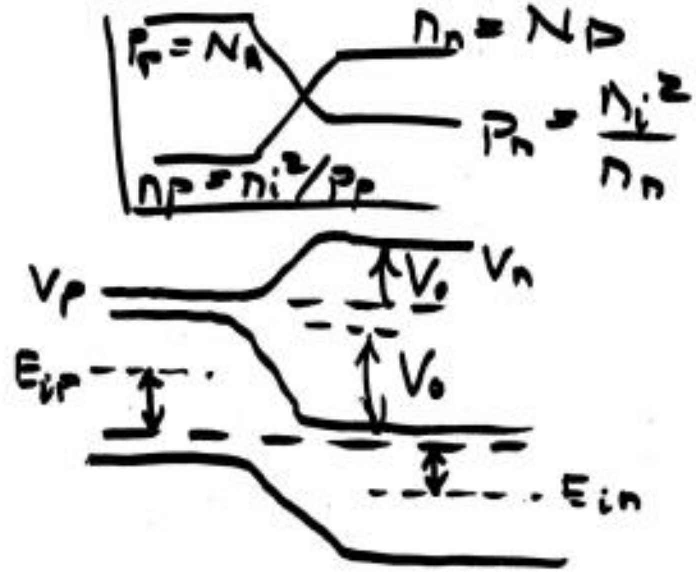
$$x_{n0} = N_A W/(N_A + N_D)$$

$$x_{p0} = N_D W/(N_A + N_D)$$

$$x_{n0}N_D = x_{p0}N_A$$



Contact Potential



$n_p p_p = n_i^2 = p_n n_n$
in equilibrium

$$V_0 = \frac{kT}{q} \ln \frac{N_A N_D}{n_i^2}$$

$$e^{qV_0/kT} = \frac{p_p}{p_n} = \frac{n_n}{n_p}$$

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also $p_p = n_i\, e^{(E_{ip} - E_F)/kT}$

$n_n = n_i\, e^{(E_F - E_{in})/kT}$ $\qquad E_{ip} - E_{in} = qV_0$

$L_n = [D_n\tau_n]^{1/2}$ $L_p = [D_p\tau_p]^{1/2}$

$J_p(x) = q\,\mu_p p(x)\mathcal{E}_x - qD_p\, dp(x)/dx$ for holes

$\delta p(x) = \Delta p\, e^{-x/Lp}$

$J_p(x) = -qD_p\, dp(x)/dx = -qD_p d\delta/dx = q(D_p/L_p)\Delta p e^{-x/Lp}$

$= q(D_p/L_p)\delta p(x)$ (so J in terms of excess charge)

$J_n(x) = q\,\mu_n n(x)\mathcal{E}_x + qD_n\, dn(x)/dx$ for electrons

Quasi-Fermi Levels

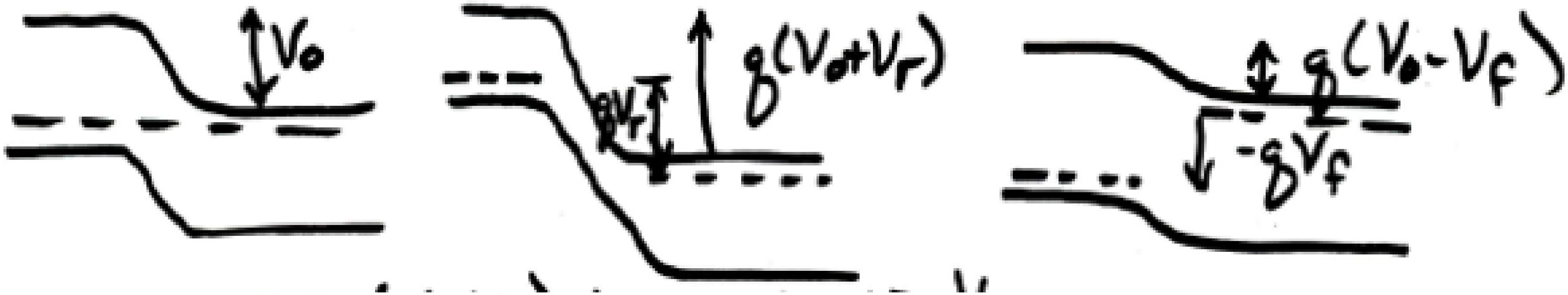
$J_n(x) = \mu_n n(x)\, dF_n/dx$

Any combination of change in n(x), p(x),x)/dp(x)/dx,
or dn(x)/dx results in a gradient of quasi-Fermi level and a current

Uses of $D/\mu = kT/q$ and $L = [D\tau]^{1/2}$

$L^2/D = \tau$ or $L^2/\tau = D$ or $D/L = L/\tau$ or $\mu = qD/kT$

5. PN Junction under Applied Voltage Bias

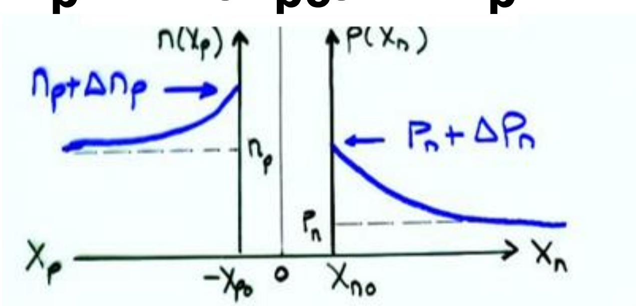


$$W = [2\varepsilon\,(V_0 - V_F)\,(N_A^{-1} + N_D^{-1})]^{1/2} \quad \text{(Forward)}$$

$$W = [2\varepsilon\,(V_0 - V_R)\,(N_A^{-1} + N_D^{-1})]^{1/2} \quad \text{(Reverse)}$$

$$\Delta p_n = p(x_{n0}) - p_n = p_n(e^{qV/kT} - 1)$$

$$\Delta n_p = n(x_{p0}) - n_p = n_p(e^{qV/kT} - 1)$$



$(n_p > p_n$ if $N_D > N_A)$

$$\Delta n(x_p) = \Delta n\, e^{-x_p/L_n} = n_p(e^{qV/kT} - 1)\, e^{-x_p/L_n}$$

$$\Delta p(x_n) = \Delta p\, e^{-x_n/L_p} = p_n(e^{qV/kT} - 1)\, e^{-x_n/L_p}$$

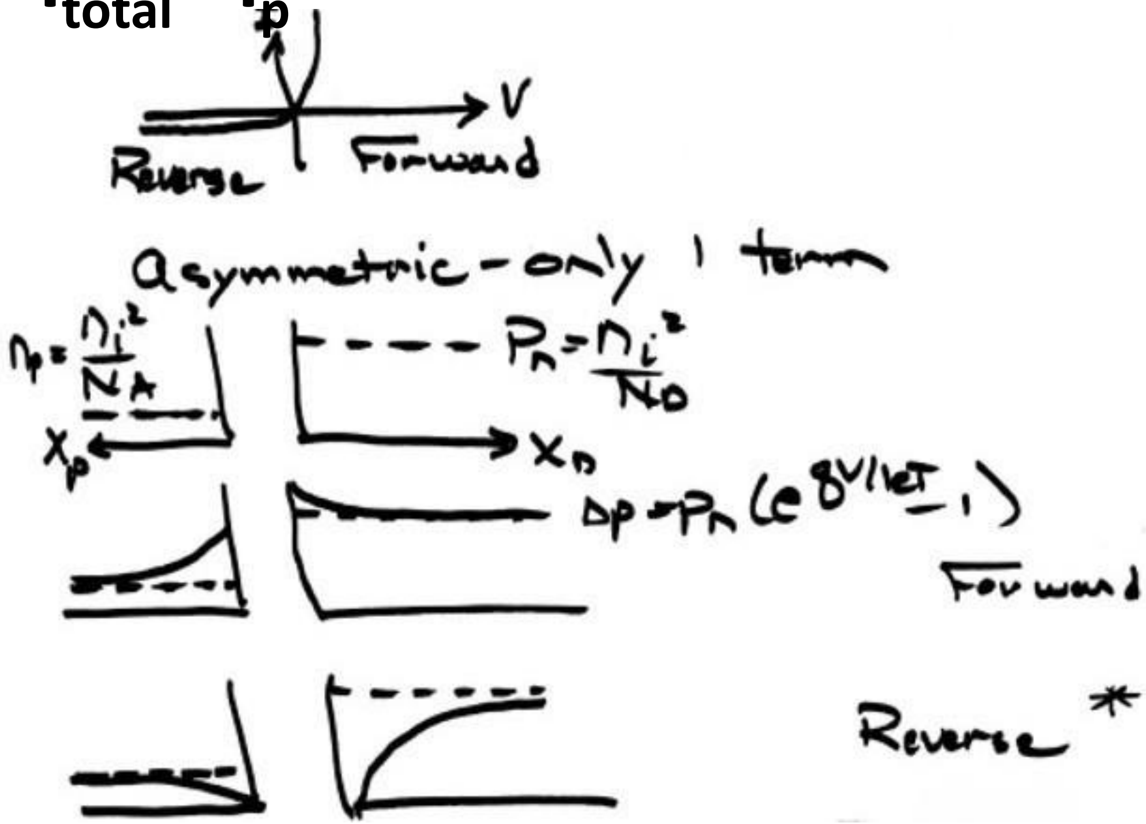
6. Currents: $I_{total} = I_p(x=0) + I_n(x=0)$

$= qA(D_p/L_p)\Delta p_n + qA(D_n/L_n)\Delta n_p = I_0\,(e^{qV/kT)} - 1)$

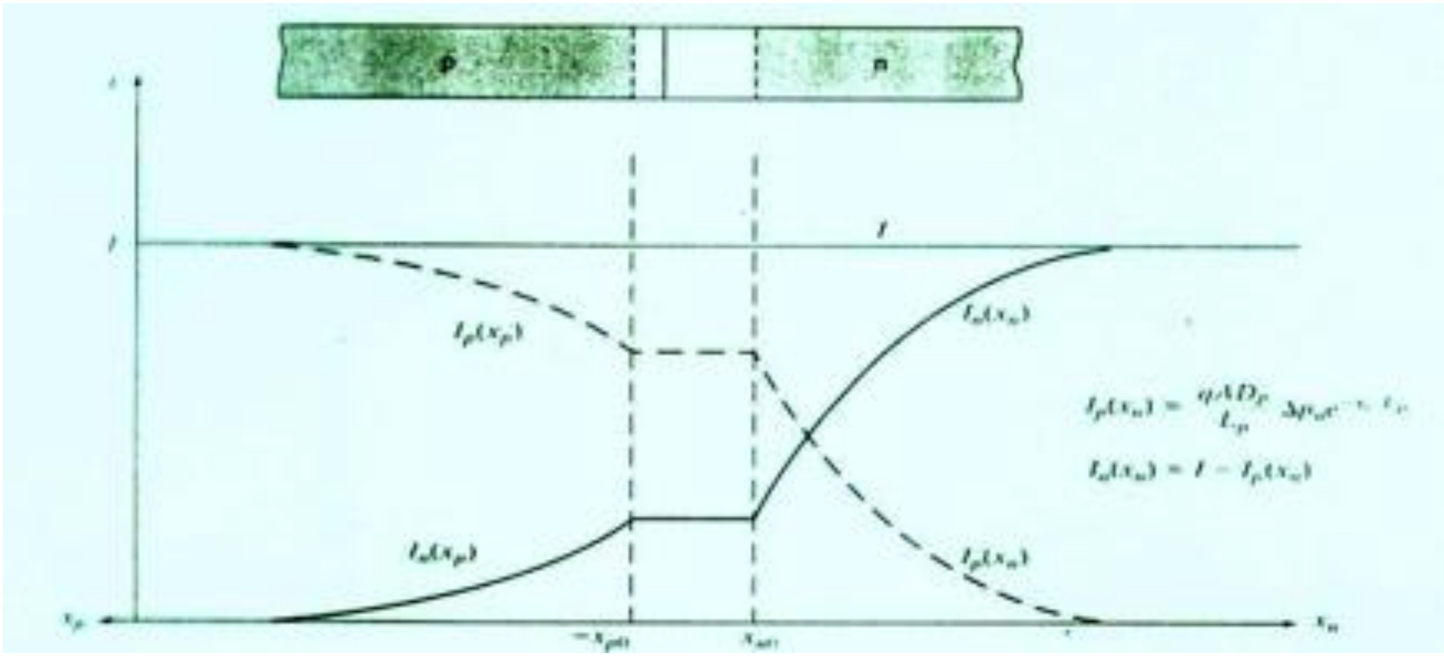
(The Diode Equation)

$I_p = qA(D_p/L_p)\, p_n(e^{qV/kT} - 1)\, e^{-xn/Lp}$

$I_n = I_{total} - I_p$



Currents



$$I_{total} = qA(D_p/L_p)\Delta p_n + qA(D_n/L_n)\Delta n_p$$

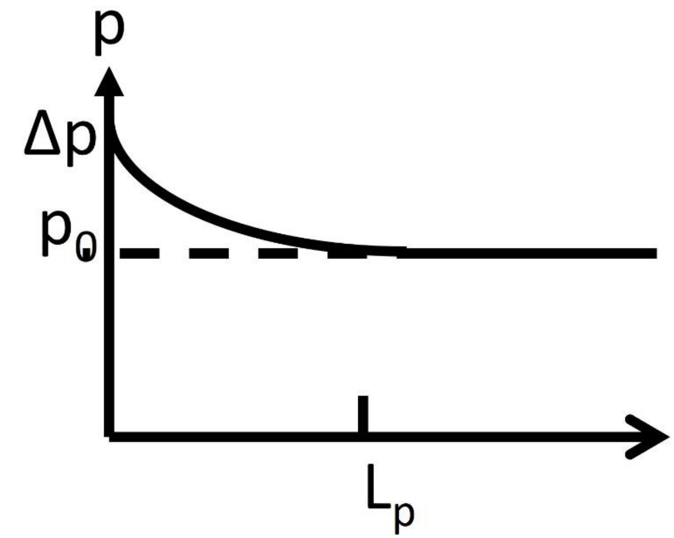
(Diode Equation)

$$I_p = qA(D_p/L_p)\, p_n(e^{qV/kT} - 1)\, e^{-x_n/L_p}$$

$$I_n = I_{total} - I_p$$

Injected Current

$I_p = -qAD_p dp/dx = qA(D_p/L_p)\Delta p e^{-x/L_p}$



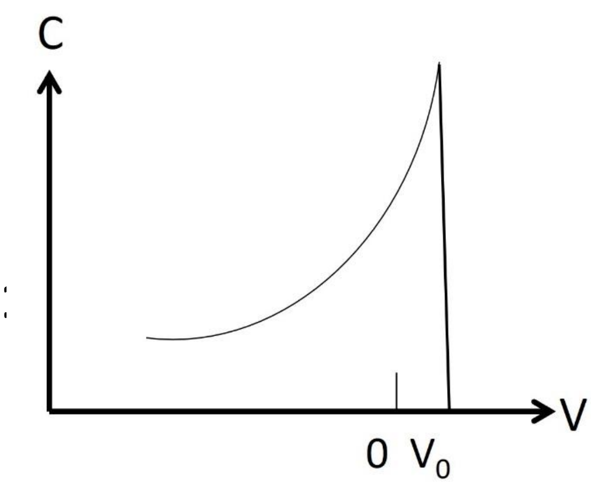
Stored Charge

$Q_p = -Q\ A\ \Delta p\ L_p = q\ A\ \Delta p\ L_p$

$\quad = q\ A\ L_p\ p_n(e^{qV/kT} - 1)$

(Area under curve = excess charge)

Capacitance



$C = (q/kT)\ Q_p$

$C_j = \varepsilon A/W$

$= \varepsilon A/[(2\epsilon\ (V_0 - V)/q)\ (1/N_A + 1/N_D)]$

Replacement Current

$I = Q_p/\ \tau$