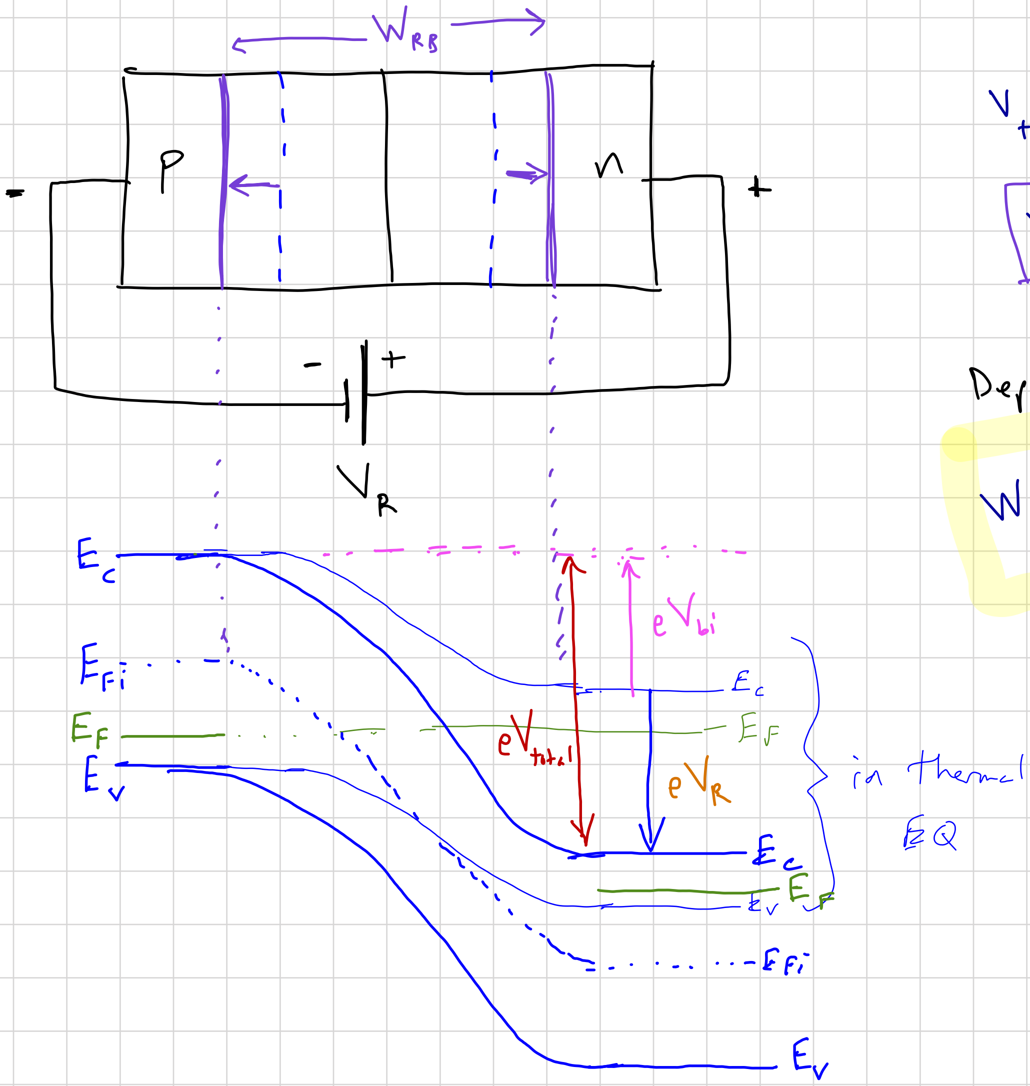
Lecture # 9

pn Junctions under bias

Applying a Reverse Bias



$$V_{total} = |\phi_{Fn}| + |\phi_{Fp}| + V_R$$

$$\boxed{V_{Total} = V_{bi} + V_R}$$

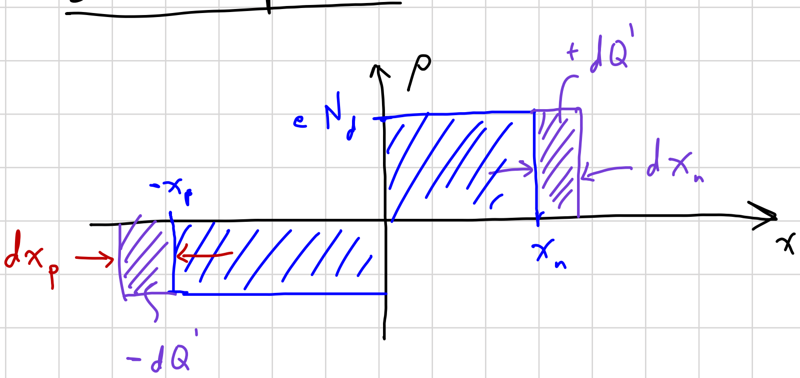
Depletion width has grown under V_R:

$$W_{RB} = \left[\frac{2\epsilon_s\epsilon_0}{e}\left(\frac{N_a+N_d}{N_aN_d}\right)(V_{bi}+V_R)\right]^{1/2}$$

Max E-field still occurs at metallurgical junction:

$$\mathcal{E}_{max} = \frac{-2(V_{bi}+V_R)}{W_{RB}}$$

Junction Capacitance



expansion of W with change in V_R (dV_R) yields a junction capacitance:

$$C' = \frac{dQ'}{dV_R} \quad (F/cm^2), \quad F = \frac{C}{V}$$

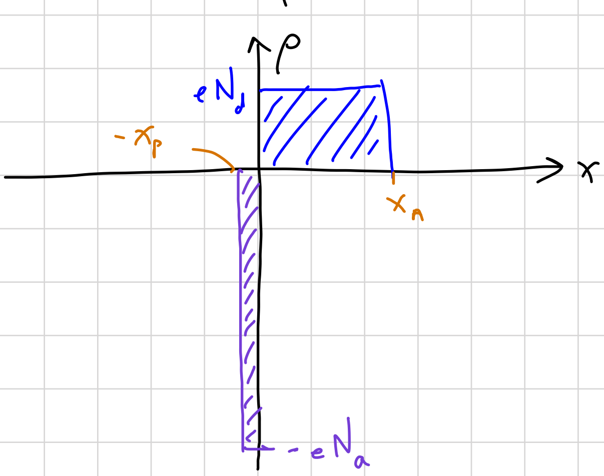
where:

$$dQ' = eN_d\,dx_n = eN_a\,dx_p$$

$$\therefore\ C' = \left[\frac{e\epsilon_s\epsilon_0 N_aN_d}{2(V_{bi}+V_R)(N_a+N_d)}\right]^{1/2}$$

one-sided junctions

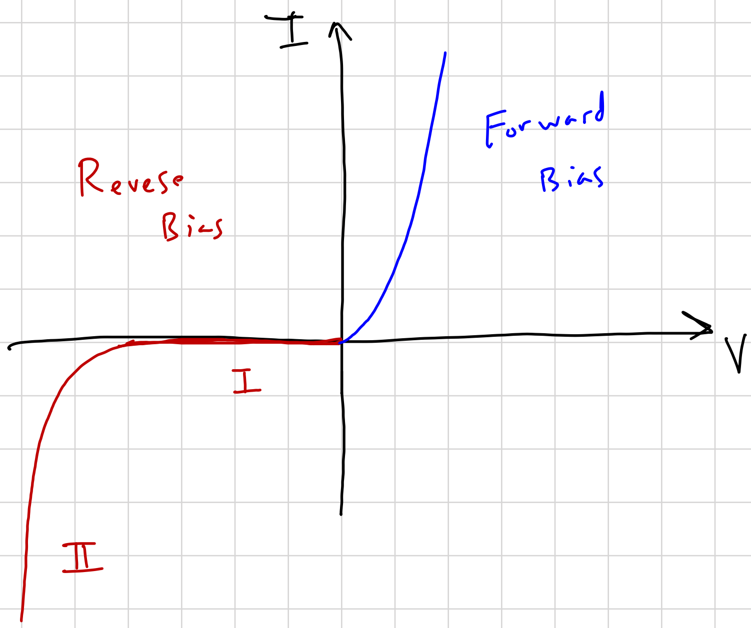
Example: p^+n heavy p-doping



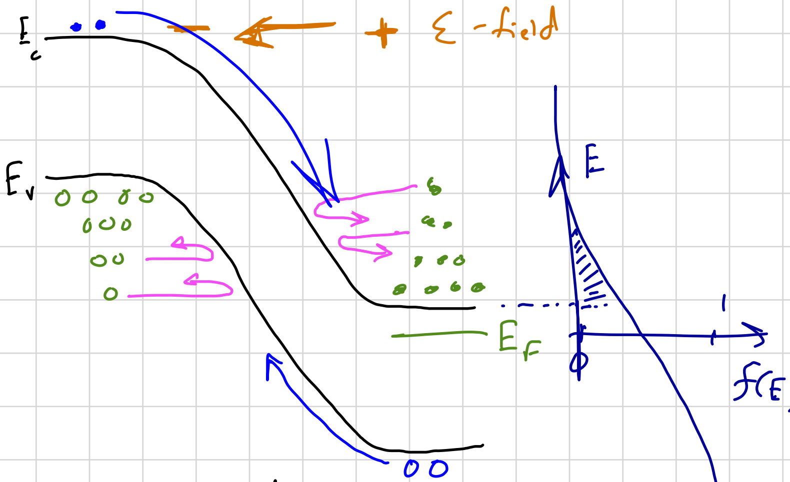
Can use this to approx. W since it will be $\sim x_n$:

$$W_{RB} \cong \left[\frac{2\epsilon_s\epsilon_0(V_{bi}+V_R)}{eN_d}\right]^{1/2}$$

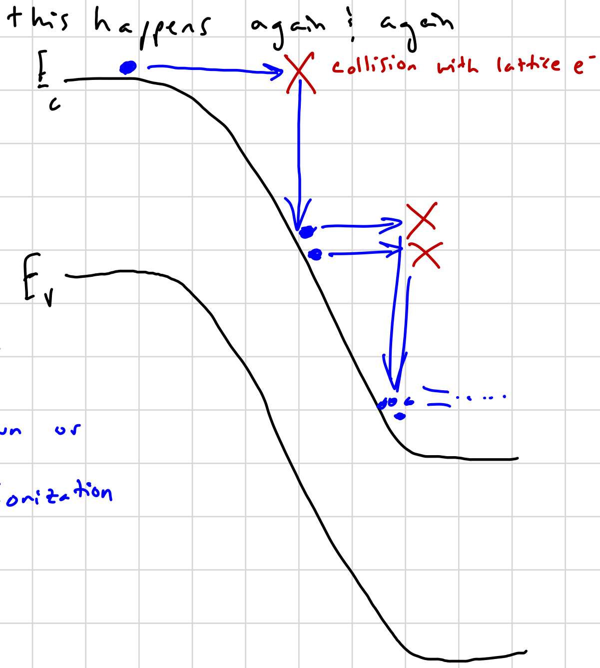
Junction Breakdown



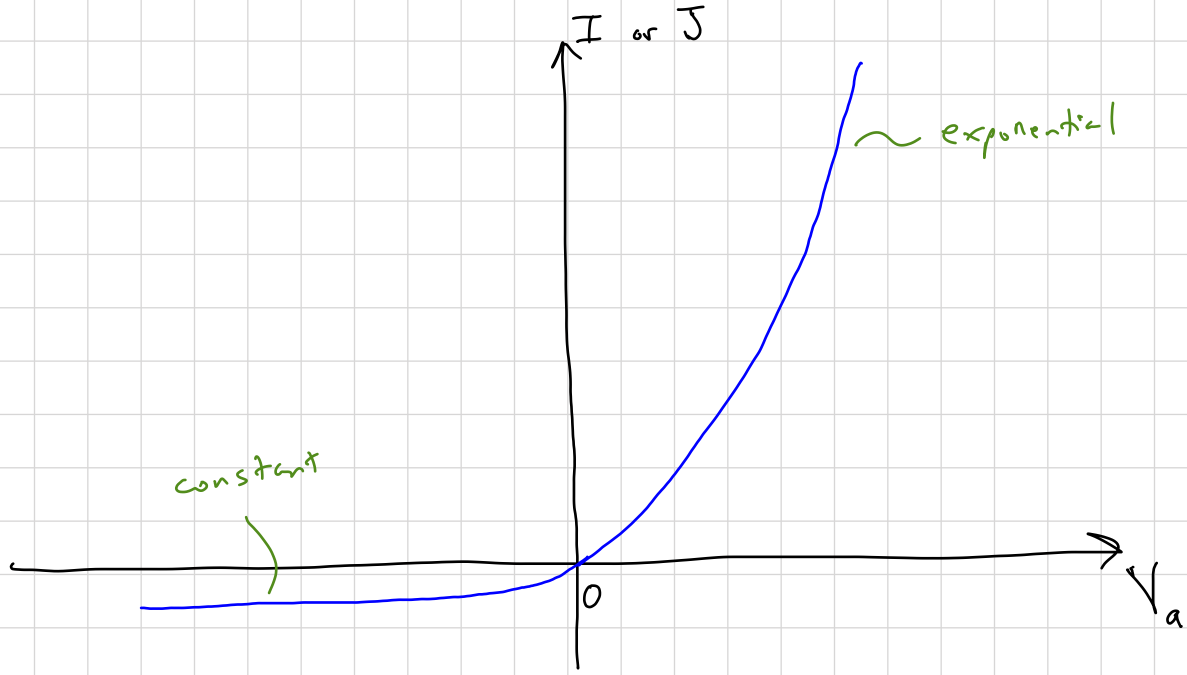
Region ①: No current (very small) from minority carriers



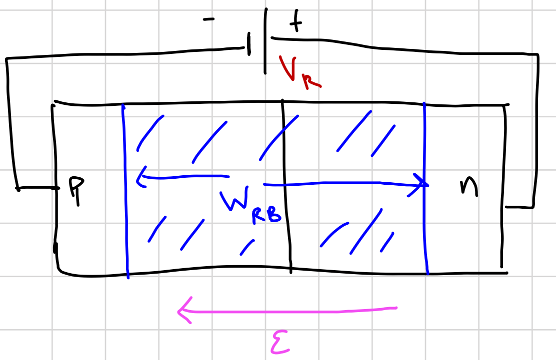
Region II: Breakdown, e^- collide with lattice e^-s, creating an e^- h^+ pair; this happens again & again

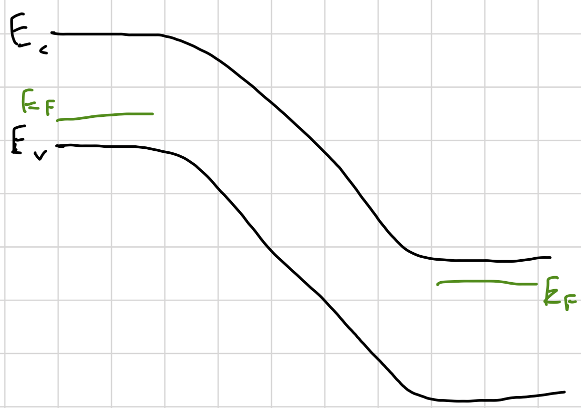


"Avalanche" Breakdown or Impact Ionization



Reverse-bias $(-V_a)$





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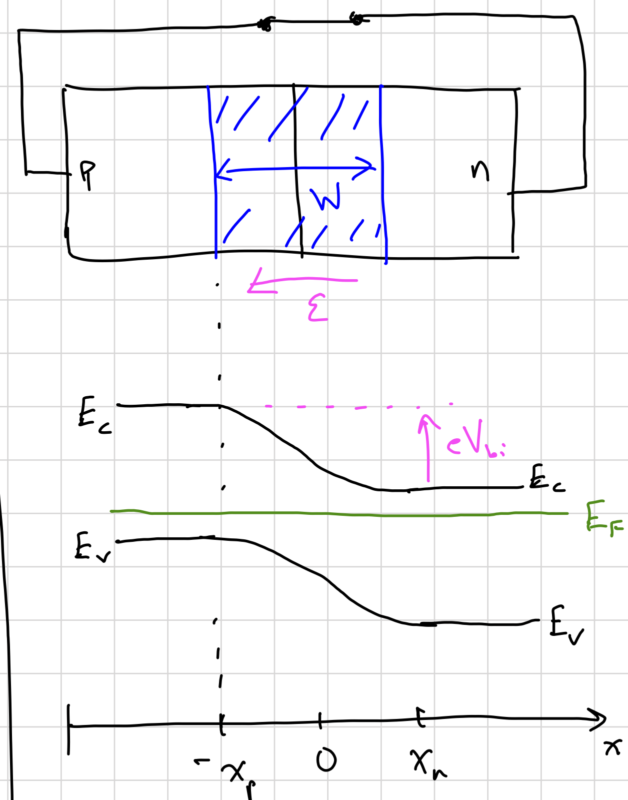
Zero-bias (thermal EQ)



$p_{po} = N_a$ $\qquad$ $n_{no} = N_d$

↳ p_p → majority carrier h^+ on p-region

n_n → majority carrier e^- in n-region

p_n → minority carrier h^+ in n-region

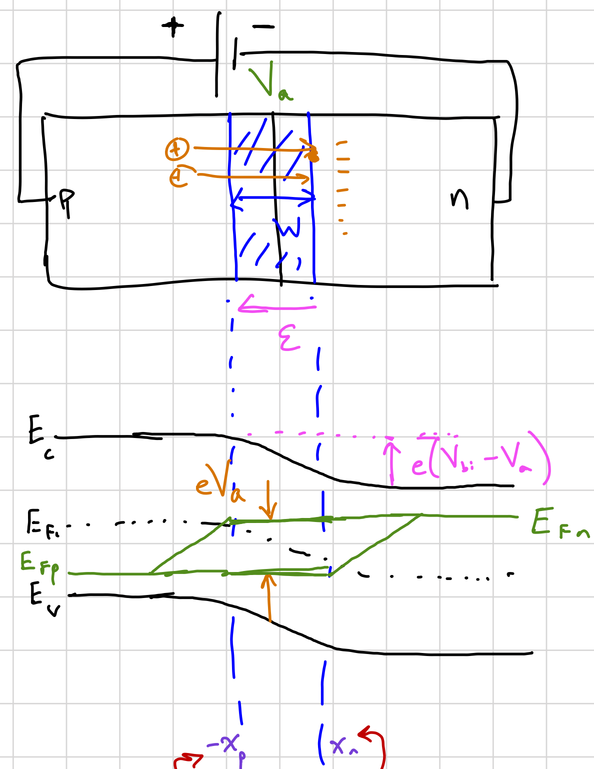
n_p → minority carrier e^- in p-region

$n_{po} = \frac{n_i^2}{N_a}$ $\qquad$ $p_{no} = \frac{n_i^2}{N_d}$

$$V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right)$$

$$n_{po} = n_{no} \exp\left(\frac{-eV_{bi}}{kT}\right)$$

Forward-bias $(+V_a)$



$n_p = n_{po} \exp\left(\frac{eV_a}{kT}\right)$ (used at $-x_p$)

$p_n = p_{no} \exp\left(\frac{eV_a}{kT}\right)$ (used at x_n)

Excess minority carrier concentrations:

$$\delta n_p(x) = n_p(x) - n_{po} = n_{po}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right] \exp\left(\frac{x_p + x}{L_n}\right)$$

mean free distance a minority carrier travels before recombining

$$\delta p_n(x) = p_n(x) - p_{no} = p_{no}\left[\exp\left(\frac{eV_a}{kT}\right) - 1\right] \exp\left(\frac{x_n - x}{L_p}\right)$$

$L = \sqrt{D\tau}$

$$E_{Fn} = E_{Fi} + kT \ln\left(\frac{n}{n_i}\right)$$

$$E_{Fp} = E_{Fi} - kT \ln\left(\frac{p}{n_i}\right)$$

$$n_p p_n = np = n_i^2 \exp\left(\frac{E_{Fn} - E_{Fp}}{kT}\right)$$