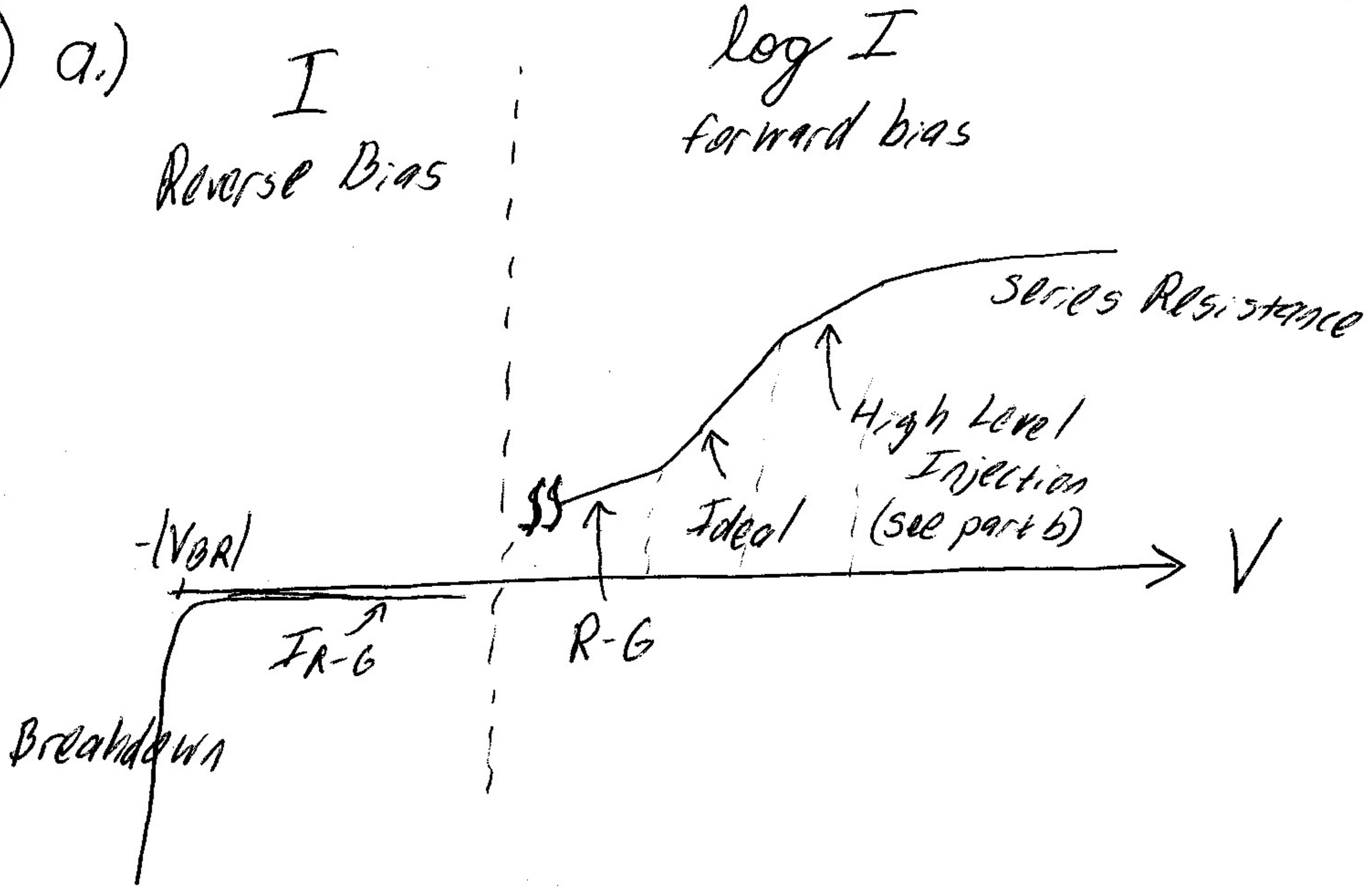
EE 3161

MIDTERM EXAM #2

SOLUTIONS

SPRING 2008

1. a.)



b.) Breakdown:

$$V_{BR} = \frac{N_A + N_D}{N_A N_D} \frac{\epsilon}{2q} \mathcal{E}_{cr}^2 \qquad \mathcal{E}_{cr} = 4\times10^5 \frac{V}{cm}$$

$$\boxed{V_{BR} = -18.3\,V}$$

I_{R-G} to Ideal:

$$qA \frac{n_i}{2\tau} W e^{qV_A/2kT} = q n_i^2 A\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right) e^{\frac{qV_A}{kT}}$$

$L_p \rightarrow W_N = 1\mu m$

$$D_p = \frac{kT}{q}\mu_p(3\times10^{16}) = .026\left(400\frac{V^2}{cm\text{-}s}\right) = 10.4\frac{cm^2}{s}$$

$$D_n = \frac{kT}{q}\mu_n(5\times10^{17}) = .026\left(390\frac{V^2}{cm\text{-}s}\right) = 10.1\frac{cm^2}{s}$$

$$L_n = \sqrt{D_n\tau_n} = 14.2\,\mu m$$

$$L_p = \sqrt{D_p\tau_p} = 14.4\,\mu m$$

$$V_A = \frac{2kT}{q}\ln\left[\frac{\frac{n_i}{2\tau}W}{n_i^2\left(\frac{D_n}{L_nN_A}+\frac{D_p}{N_DW_N}\right)}\right]$$

$$V_{bi} = \frac{kT}{q}\ln\frac{N_AN_D}{n_i^2} = .84V$$

$$W = \sqrt{\frac{2\epsilon}{q}V_{bi}\frac{N_A+N_D}{N_AN_D}} \approx .2\,\mu m$$

$\boxed{V_A = .29V}$ For I_{R-G} to I_{Ideal} transition

<u>I_{Ideal} to I_{HLI}:</u>

HLI starts at roughly

$$p_{no}e^{qV_A/kT} \approx \frac{1}{10}N_D$$

$$\frac{n_i^2}{N_D}e^{qV_A/kT} \approx \frac{1}{10}N_D$$

$$V_A = \frac{kT}{q}\ln\left(\frac{1}{10}\frac{N_D^2}{n_i^2}\right)$$

$$\underline{V_{A_{HLI}} : .71V}$$

Series Resistance

Note that if series resistance develops, it will be in the p-region because it is so much longer than the n-region

$$\rho = \frac{1}{q\mu N_A} = \frac{1}{q\,\mu_p(N_A = 5\times10^{17})\,N_A}$$

$$\rho = \frac{1}{(1.6\times10^{-19})(190)(5\times10^{17})}$$

$$\rho = .066\ \Omega\text{-cm}$$

$$R = \frac{\rho L}{A} = \frac{(.066)(.1cm)}{(10\times10^{-8}\,cm^2)}$$

$$\underline{R \approx 66\,k\Omega}$$

$$V_{SR} = IR$$

Let series resistance be appreciable when $V_{SR} \sim .1V$, or $I \approx 1.5\,\mu A$

$$q n_i^2\left(\frac{D_n}{L_n N_A} + \frac{D_p}{N_D W_n}\right)e^{qV_A/kT} = 1.5\,\mu A$$

$$V_{A\,junction} = \frac{kT}{q} \ln\left[\frac{1.5\mu A}{qn_i^2\left(\frac{D_n}{L_n N_A} + \frac{D_p}{N_D W_N}\right)}\right]$$

$$\boxed{V_{A\,junction} \approx .22V}$$

$\therefore$ Series Resistance starts to be a factor long before I_{Ideal} or I_{HLI} even starts. So these two regions are absent in this diode.

(2.) For this problem, I will assume a small area IC transistor ($A \sim 4\mu m^2$). In this case, if a concentration gradient develops between the two regions of the base, it will be eliminated by diffusion in a time short compared to τ_B. ($\tau \sim \frac{X^2}{2D} \sim \frac{(2\mu m)^2}{2(32\frac{cm^2}{s})}$ $\sim .6ns \ll \tau_B$). Therefore Q_B in both halves of the transistor is about the same.

CASE I

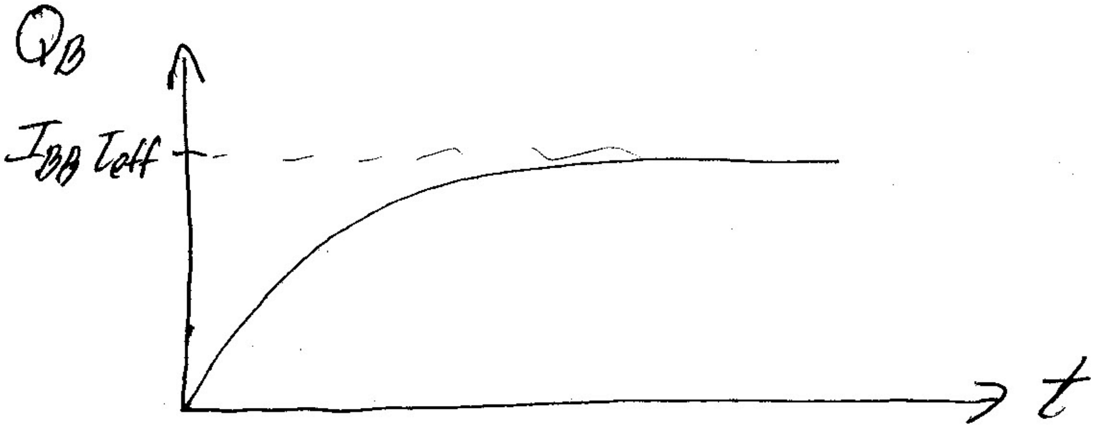
In steady state, $I_{BB} = \frac{Q_B}{\tau_B}$

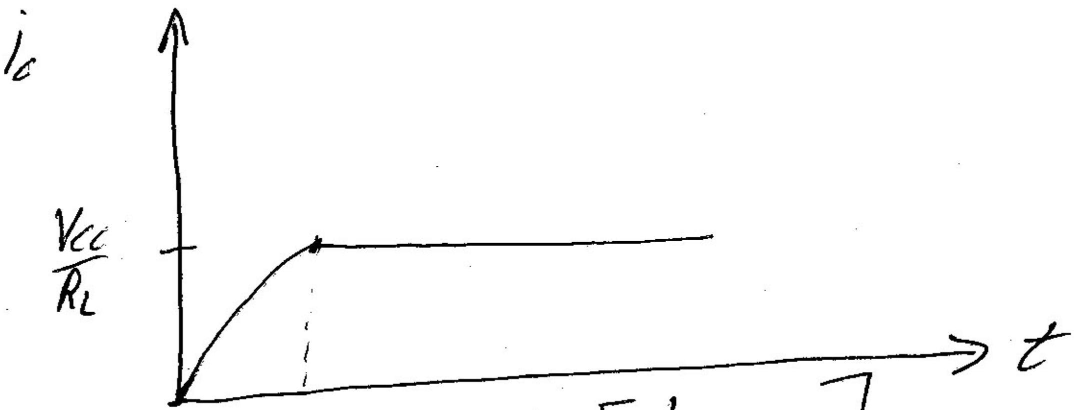
$$I_{BB} = \frac{q\left(\frac{A}{2}\right)W}{2\tau_{B1}}\Delta p_B(0,t) + \frac{q\left(\frac{A}{2}\right)W\Delta p_B(0,t)}{2\tau_{B2}}$$

$$I_{BB} = \frac{qAW\Delta p_B(0,t)}{2}\left[\frac{1}{2}\left(\frac{1}{\tau_{B1}} + \frac{1}{\tau_{B2}}\right)\right]$$

$$\therefore \frac{1}{\tau_{eff}} = \frac{1}{2}\left(\frac{1}{\tau_{B1}} + \frac{1}{\tau_{B2}}\right)$$

$$\underline{\tau_{eff} \approx .18\mu s}$$





$$\tau_r = \tau_{eff} \ln\left[\frac{1}{1-\frac{I_{CC}\,\tau_t}{I_{BB}\,\tau_{eff}}}\right]$$

$$\beta = \frac{\tau_{eff}}{\tau_t} \qquad \beta = \frac{.18\mu s}{\tau_t} \qquad \tau_t = \frac{W^2}{2D}$$

$W = .5\mu m$

$D = 32\ \frac{cm^2}{s}$

$\tau_t \approx 39ps$

$$\boxed{\beta \approx 4600}$$

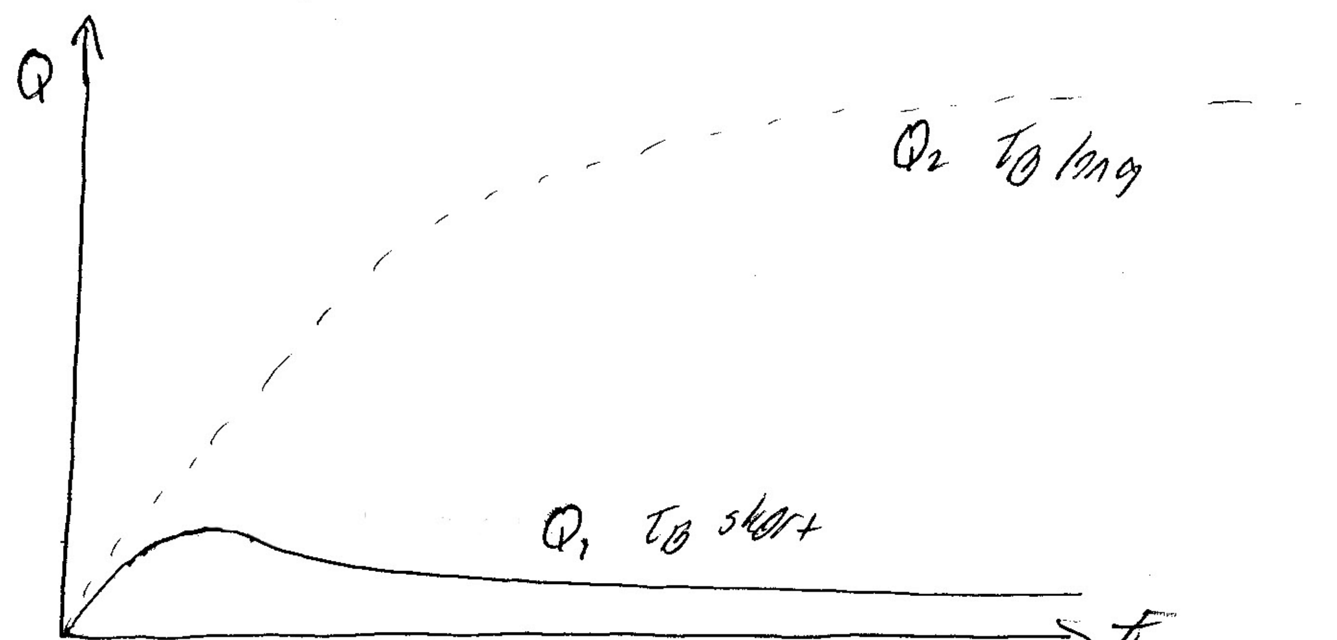
b.) I_{eff} replaces I_B

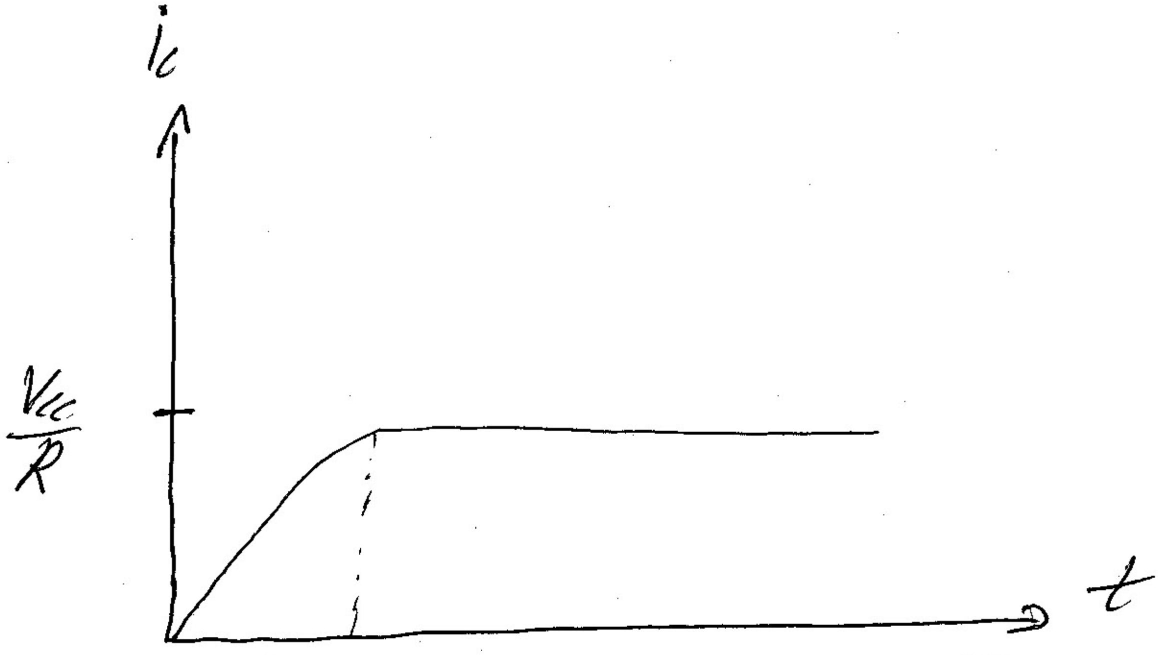
c.) A relative voltage drop would appear across the base, so the most transistor action would occur for the base regions nearest the contact. Further regions would have a more weakly biased BE junction.

CASE II

(2.) For a moderate to large area transistor the minority carrier diffusion time will be too slow to redistribute minority carriers in the base ($\tau \sim \frac{L_{base}^2}{2D}$) to keep $Q(x,t)$ the same in both halves of the BJT. However, the majority carriers <u>can</u> redistribute extremely quickly $\tau \sim \frac{\epsilon}{\sigma} \sim ps$, so the biases in each region are always constant.

$\therefore$ <u>The two BJTs can be treated separately but will enter saturation simultaneously.</u>





$$\approx \tau_{r_1} = \tau_{B_1} \ln\left[\frac{1}{1 - \frac{I_c \tau_t}{I_{BB} \tau_{B_1}}}\right]$$