Homework 10

1) $N_D = 10^{16}$ donors/cm^3 $\quad N_A = 10^{15}$ acceptors/cm^3 $\quad V_{CB} = -2V$ and $-10V$

$W_b = 1 \mu m \quad V_{bi} = 0.7V$

a) $X_d = \sqrt{\frac{2\varepsilon_s}{q}\cdot\frac{(N_A+N_D)}{N_A N_D}\cdot(V_{bi}+|V_{CB}|)} = \sqrt{\frac{2\cdot 11.7\cdot 8.85\cdot 10^{-14}}{1.602\cdot 10^{-19}}\cdot\frac{(10^{16}+10^{15})}{10^{16}\cdot 10^{15}}\cdot(0.7+|-2|)} = 1.96\times10^{-4}$

$X_{n0} = \frac{N_A}{N_A+N_D}\cdot X_d = \frac{10^{15}}{10^{15}+10^{16}}\cdot 1.96\times10^{-4} = 1.78\times10^{-5}$

$0.178 \mu m$

$\boxed{X_{n0} = 1.78\times10^{-5}\text{ cm when } V_{CB} = -2V}$

$X_d = \sqrt{\frac{2\cdot 11.7\cdot 8.85\cdot 10^{-14}}{1.602\times10^{-19}}\cdot\frac{(10^{16}+10^{15})}{10^{16}\times10^{15}}\cdot(0.7+|-10|)} = 3.9\times10^{-4}$

$X_{n0} = \frac{10^{15}}{10^{15}+10^{16}}\cdot 3.9\times10^{-4} = 3.55\times10^{-5}$

$0.355 \mu m$

$\boxed{X_{n0} = 3.55\times10^{-5}\text{ cm when } V_{CB} = -10V}$

b) $V_{CB} = -2V \rightarrow W_b' = 1 - 0.178 = \boxed{0.822 \mu m}$

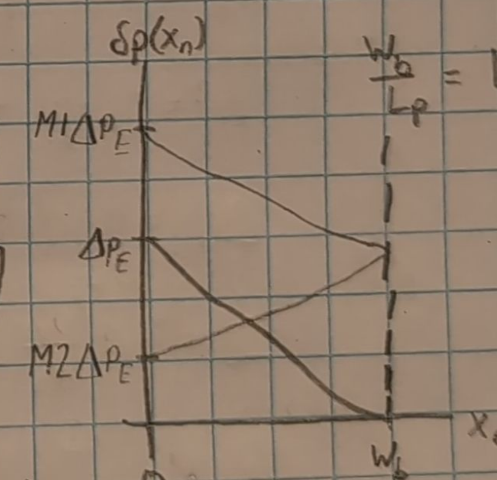
$V_{CB} = -10V \rightarrow W_b' = 1 - 0.355 = \boxed{0.645 \mu m}$

These reductions are significant

2) $\frac{W_b}{L_p} = 1$

$M_1 = \frac{e^{W_b/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}} = \frac{e^1}{e^1 - e^{-1}} = \boxed{1.15652}$

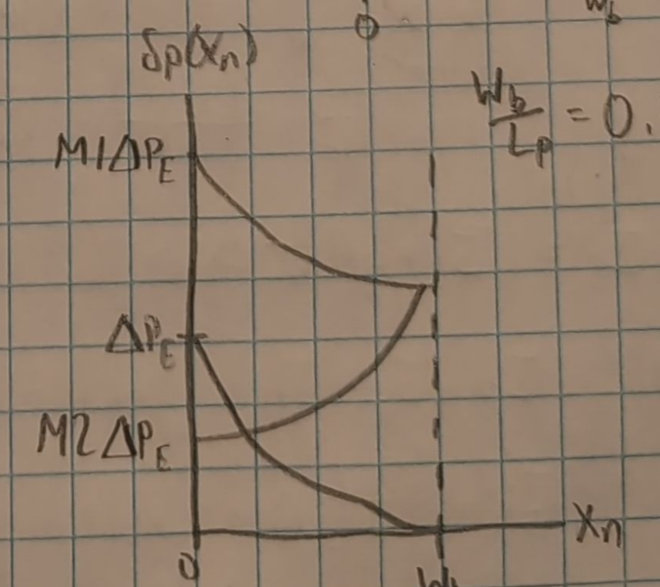
$M_2 = \frac{e^{-W_b/L_p}}{e^{W_b/L_p} - e^{-W_b/L_p}} = \frac{e^{-1}}{e^1 - e^{-1}} = \boxed{0.15652}$



$\frac{W_b}{L_p} = 0.1$

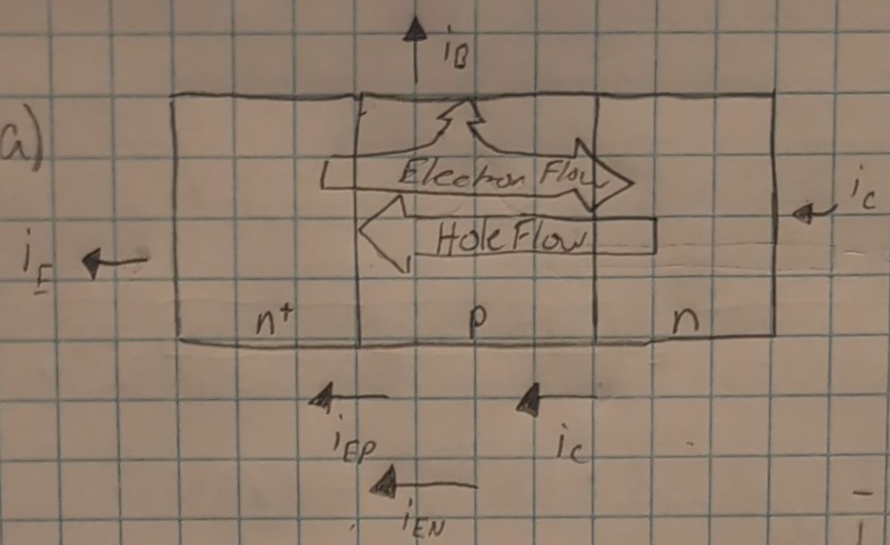
$M_1 = \frac{e^{0.1}}{e^{0.1} - e^{-0.1}} = \boxed{5.5167}$

$M_2 = \frac{e^{-0.1}}{e^{0.1} - e^{-0.1}} = \boxed{4.5167}$



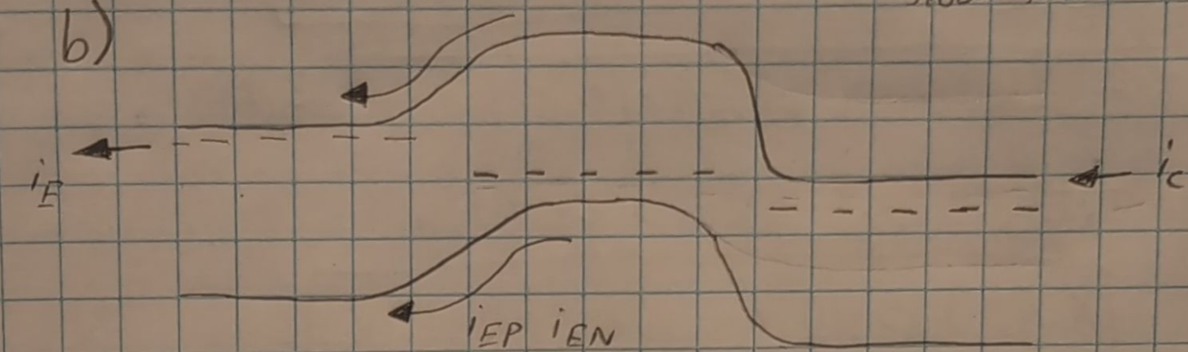
3)

a)



- Emitter and collector currents are reversed since npn causes electrons & holes to flow opposite of pnp.
- This is the same for base current since electrons flow from emitter to base.

b)



4) $A = 2\times10^{4}\ cm^2$ $W_b = 1\mu m$ $N_E = 10^{18}\ cm^{-3}$ $N_B = 10^{16}\ cm^{-3}$ $\tau_p = 1\mu s$

$\mu_p^n = 400\ cm^2/V\cdot s$ $\mu_n^p = 250\ cm^2/V\cdot s$ $\gamma = 1$ $V_{EB} = 0.6$

$n_i = 1.5\times10^{10}\ cm^{-3}$

a) Einstein Relation

$$D_p = \mu_p^n \cdot \frac{kT}{q} = 400 \cdot 0.0259 = 10.36\ cm^2/s$$

$$L_p = \sqrt{D_p \cdot \tau_p} = \sqrt{10.36 \cdot 10^{-6}} = 3.22\times10^{-3}\ cm$$

mass action law

$$n_i^2 = n_p \cdot p_n \rightarrow p_{no} = \frac{n_i^2}{N_B} = \frac{(1.5\times10^{10})^2}{10^{16}} = 2.25\times10^{4}\ cm^{-3}$$

$$\Delta p_c = p_{no}\left(e^{\frac{qV_{EB}}{kT}} - 1\right) = 2.25\times10^{4}\left(e^{\frac{0.6}{0.0259}} - 1\right) = 2.59\times10^{14}\ cm^{-3}$$

diffusion current equation

$$I_c = qA\frac{D_p}{W_b}\Delta p_N = q\cdot(2\times10^{4})\cdot\frac{10.36}{10^{-4}}\cdot(2.59\times10^{14}) = \boxed{8.597\ mA}$$

Einstein

$$D_n = \mu_n^p \cdot \frac{kT}{q} = 250 \cdot 0.0259 = 6.475\ cm^2/s$$

mass action

$$n_{po} = \frac{n_i^2}{N_E} = \frac{(1.5\times10^{10})^2}{10^{18}} = 225\ cm^{-3} \qquad \Delta p_E = n_{po}\left(e^{\frac{qV_{EB}}{kT}} - 1\right) = 225\left(e^{\frac{0.6}{0.0259}} - 1\right) = 2.59\times10^{12}$$

diffusion current

$$I_E = I_c + qA\frac{D_n}{W_b}\Delta p_E = q(2\times10^{4})\cdot\frac{6.475}{10^{-4}}\cdot 2.59\times10^{12} = 5.37\mu A + 8.597\ mA = \boxed{8.651\ mA}$$

b)

$$I_B = I_E - I_C = 8.651 - 8.597 = \boxed{5.37\mu A}$$

$$I_B = qA\frac{D_p}{L_p}\left[(\Delta p_E + \Delta p_c)\tanh\frac{W_b}{2L_p}\right] = q(2\times10^{4})\frac{10.36}{3.22\times10^{-3}}\left[(2.59\times10^{14} + 2.59\times10^{12})\tanh\frac{10^{-4}}{2\times3.22\times10^{-3}}\right]$$

$$\boxed{I_B = 41.8694\ A}$$

makes no sense
probably did part a) wrong

5) $A = 10^{-4}\,cm^2$ $W_b = 2\times10^{-5}\,cm$ $N_{AE} = 5\times10^{18}\,cm^{-3}$ $N_{DB} = 10^{16}\,cm^{-3}$ $N_{AC} = 10^{15}\,cm^{-3}$

$\tau_n^E = 100\,ps$ $\tau_p^B = 2500\,ps$ $\tau_n^C = 2\,\mu s$ $\mu_n^E = 150$ $\mu_p^E = 100$

a) $\mu_n^B = 1500$ $\mu_p^B = 400$

$\mu_n^C = 1500$ $\mu_p^C = 450$

$$\beta = \frac{B\cdot\gamma}{1 - B\cdot\gamma}$$

$$B = \operatorname{sech}\frac{W_b}{L_p^B}$$

$$L_p^B = \sqrt{D_p^B\cdot\tau_p^B} = \sqrt{10.36\cdot 2.5\times10^{-9}} = 1.61\times10^{-4}$$

$$B = \operatorname{sech}\left(\frac{2\times10^{-5}}{1.61\times10^{-4}}\right)$$

$$D_p^B = \mu_p^B\cdot\frac{kT}{q} = 400\cdot 0.0259 = 10.36\ cm^2/s$$

$$B = 0.992334$$

$$L_n^E = \sqrt{D_n^E\cdot\tau_n^E} = \sqrt{3.885\times10^{-10}} = 1.97\times10^{-5}$$

$$\gamma = \left[1 + \frac{L_p^B n_n \mu_n^E}{L_n^E p_p \mu_p^B}\tanh\frac{W_b}{L_p^B}\right]$$

$$D_n^E = \mu_n^E\cdot\frac{kT}{q} = 150\cdot 0.0259 = 3.885$$

$$\gamma = \left[1 + \frac{(1.61\times10^{-4})(45)(150)}{(1.97\times10^{-5})(22500)(400)}\tanh\left(\frac{2\times10^{-5}}{1.61\times10^{-4}}\right)\right]$$

$$n_n = \frac{n_i^2}{N_A} = \frac{(1.5\times10^{10})^2}{5\times10^{18}} = 45$$

$$\gamma = 1.0007575287203$$

$$p_p = \frac{n_i^2}{N_D} = \frac{(1.5\times10^{10})^2}{10^{16}} = 2.25\times10^{4}$$

$$\boxed{\beta = 143.619}$$

b) $$\beta = \frac{\tau_p^B}{\tau_t}$$

$$\tau_t = \frac{W_b^2}{2D_p^B} = \frac{(2\times10^{-5})^2}{2\cdot 10.36} = 1.93\times10^{-11}$$

$$\beta = \frac{2.5\times10^{-9}}{1.93\times10^{-11}} = \boxed{129.534}$$

c) They're sorta close... $\Delta\beta = 14.085$ which is only 9.8%