Problem 1:

a) $P_n(x_n) = P_{no}\, e^{\frac{V_a}{V_T}} = \frac{n_i^2}{N_D} e^{\frac{V_a}{V_T}}$

$n_p(-x_p) = n_{po}\, e^{\frac{V_a}{V_T}} = \frac{n_i^2}{N_A} e^{\frac{V_a}{V_T}}$

$$\frac{P_n(x_n)}{n_p(-x_p)} = \frac{n_i^2}{N_D}\frac{N_A}{n_i^2} = \frac{N_A}{N_D} = \frac{10^{15}}{10^{16}} = 0.1$$

b) $J_p(x_n) = \frac{e D_p P_{no}}{L_p}\left(e^{\frac{V_a}{V_T}} - 1\right)$

$J_n(-x_p) = \frac{e D_n n_{po}}{L_n}\left(e^{\frac{V_a}{V_T}} - 1\right)$

$$\frac{J_p(x_n)}{J_n(-x_p)} = \frac{D_p}{D_n}\frac{L_n}{L_p}\frac{P_{no}}{n_{po}} = \frac{D_p}{D_n}\frac{L_n}{L_p}\frac{N_A}{N_D}$$

$$= \sqrt{\frac{D_p}{D_n}}\sqrt{\frac{\tau_n}{\tau_p}}\frac{N_A}{N_D} = \sqrt{\frac{\mu_p}{\mu_n}\frac{\tau_n}{\tau_p}}\frac{N_A}{N_D}$$

$$= \sqrt{\frac{400}{1000} \times \frac{10^{-6}}{10^{-7}}} \times \frac{10^{15}}{10^{16}} = 0.2$$

c) since $N_D \gg N_A$, $V_{BR} \simeq \frac{\epsilon_s \mathcal{E}_{cr}^2}{2eN_A}$

$$V_{BR} = \frac{11.7 \times 8.854\,10^{-14} \times (3\,10^5)^2}{2 \times 1.6\,10^{-19} \times 10^{15}} = 291\,V$$

d) $\delta n_p = n_{po}\left(e^{\frac{V_a}{V_T}}-1\right)e^{-x/L_n} \simeq n_{po}\, e^{\frac{V_a}{V_T}}\, e^{-x/L_n}$

$$\Delta n_p = A\int_0^\infty \delta n_p(x) = A\, n_{po}\, e^{\frac{V_a}{V_T}}\int_0^\infty e^{-x/L_n}$$

$$= A L_n n_{po} e^{V_a/V_T}$$

$L_n = \sqrt{D_n \tau_n}$; $D_n = \mu_n \frac{kT}{e} = .025 \times 1000 = 25$

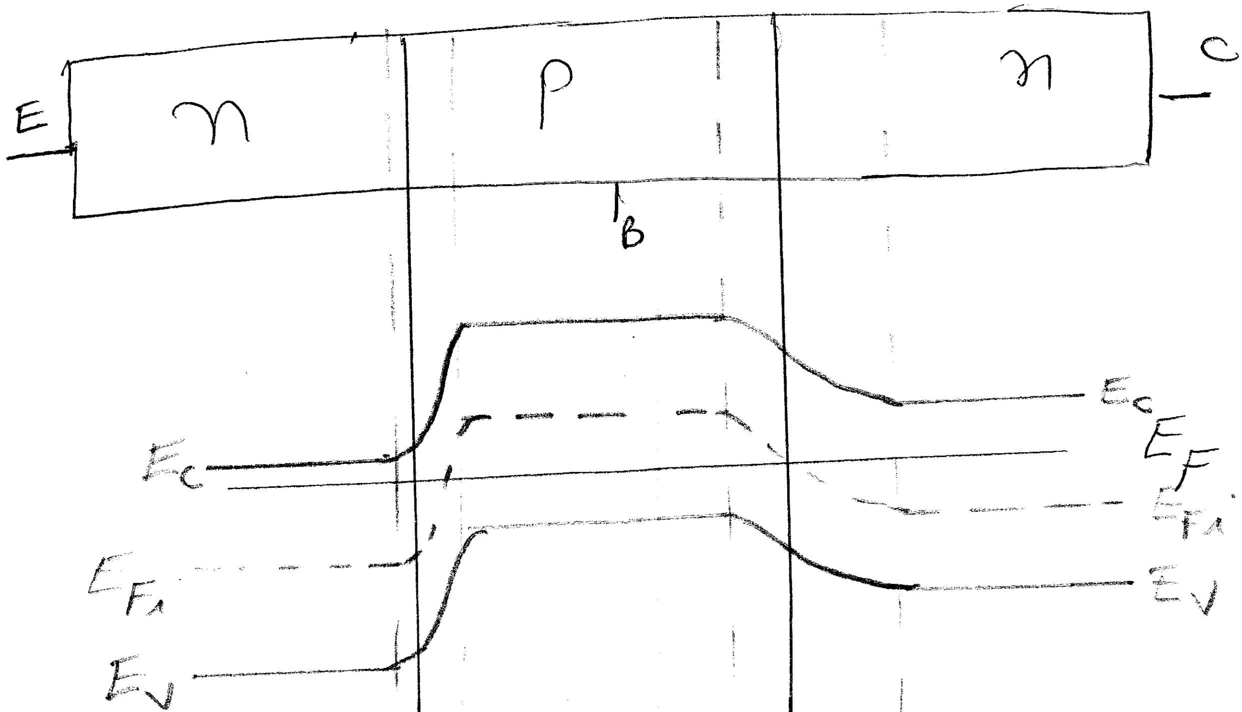
$L_n = \sqrt{25 \times 10^{-6}} = .05\ cm$; $n_{po} = \frac{(1.5\,10^{10})^2}{10^{15}} = 2.25\ 10^5\ cm^{-3}$

$$\Delta n_p = 10^{-5}\, cm^2 \times .05\, cm \times 2.25\, 10^5\, cm^{-3}\ e^{\frac{.5}{.025}}$$

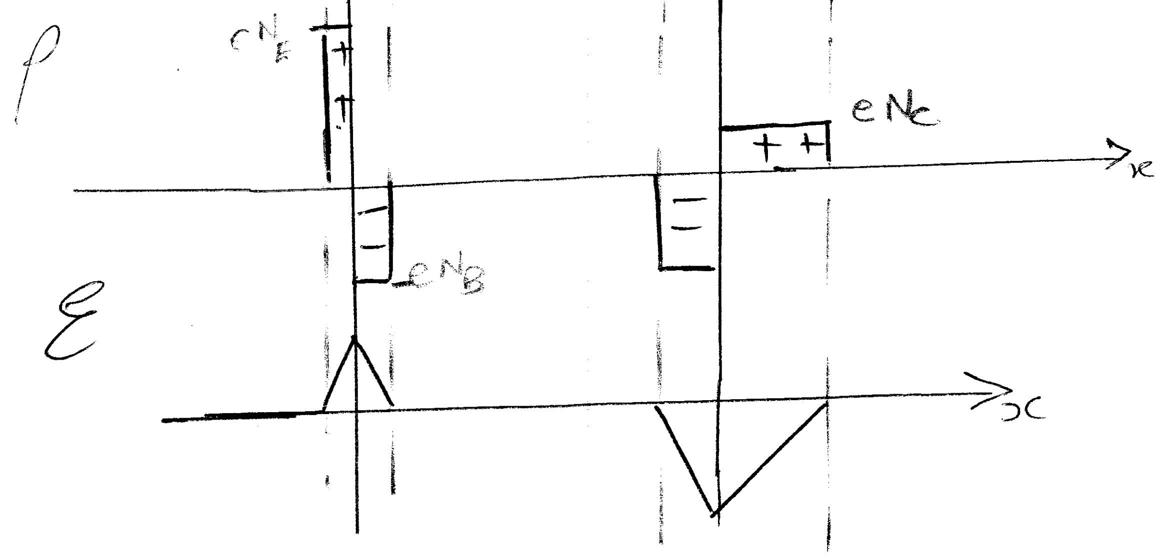
$\Delta n_p = 5.46\ 10^7$ ~~cm~~ . electrons

Problem 2:

a)



b)



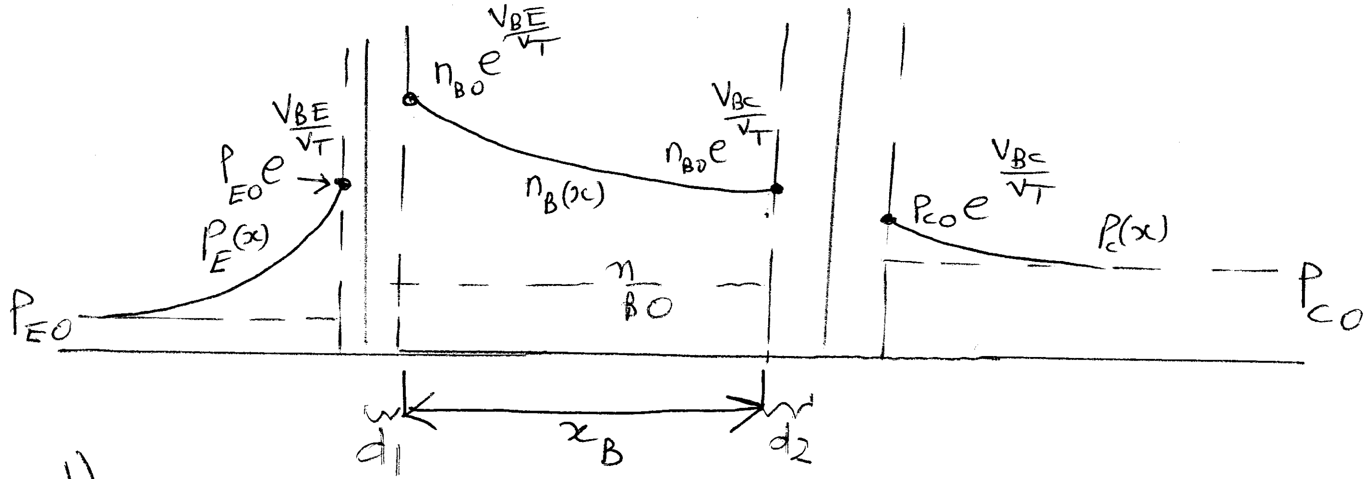
$$V_E - V_C = V_{bi}(B-E) - V_{bi}(B-C) = \frac{kT}{e}\ln\frac{N_E N_B}{n_i^2} - \frac{kT}{e}\ln\frac{N_B N_C}{n_i^2}$$

$$= \frac{kT}{e}\ln\left(\frac{N_E}{N_C}\right) = .16\text{ V}$$

c) $V_{BE} = 0.7V \Rightarrow$ B-E is forward biased

$V_{CE} = 0.2V \Rightarrow$ C-B is forward biased

$\Rightarrow$ saturation region



d)

1) determine undepleted part of base x_B by subtracting the two depletion regions d_1 and d_2

2) assume $\delta n_B(x) \simeq n_B(x)$ is linear

$$\Delta n_B \simeq A \frac{\left(n_{B0}e^{\frac{V_{BE}}{V_T}} + n_{B0}e^{\frac{V_{BC}}{V_T}}\right) \times x_B}{2}.$$

Problem 3

a) $\phi_{ms} = \frac{E_g}{2e} - |\phi_{Fp}|$

$\phi_{Fp} = -\frac{kT}{e} \ln \frac{N_A}{n_i} = .025 \times \ln \frac{10^{16}}{1.5\,10^{10}} = -.335\,V$

$\phi_{ms} = \frac{1.12}{2} - .335 = .2247\,V$

b) At Threshold $\phi_s = 2|\phi_{Fp}| = .67\,V$

c) $x_{dT} = \left(\frac{4\epsilon_s|\phi_{Fp}|}{eN_A}\right)^{1/2} = \left(\frac{4 \times 11.7 \times 8.85\,10^{-14} \times .335}{1.6\,10^{-19} \times 10^{16}}\right)^{1/2} = 2.94\,10^{-5}\,cm$

$= .294\,\mu m \simeq .3\,\mu m$

d) Since $Q'_{ss} = 0$, $V_{FB} = \phi_{ms} = .2247\,V$

e) $V_{TN} = \frac{|Q'_{SD}(max)|}{C_{ox}} + \phi_{ms} + 2|\phi_{Fp}|$

$Q'_{SD}(max) = eN_A x_{dT} = 1.6\,10^{-19} \times 10^{16} \times 2.94\,10^{-5} = 4.7\,10^{-8}$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.854\,10^{-14}\,F/cm}{200\,10^{-8}\,cm} = 1.72\,10^{-7}$

$V_{TN} = .272 + .2247 + 2 \times .335 = 1.167\,V$

Problem 4

a) $\phi_{Fp} = \frac{kT}{e} \ln \frac{n_i}{N_A} = .025 \ln \frac{1.5 10^{10}}{10^{16}} = -.335V$

$\phi_{ms} = -\left(\frac{E_g}{2e} + |\phi_{Fp}|\right) = -\left(\frac{1.12}{2} + .335\right) = -.895V$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{3.9 \times 8.85 10^{-14}}{200 10^{-8}} = 1.72 10^{-7}$

$V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{C_{ox}} = -.895 - \frac{1.6 10^{-19} \times 2 10^{11}}{1.72 10^{-7}} = -1.08V$

$\gamma = \frac{\sqrt{2 \epsilon_s e N_A}}{C_{ox}} = \frac{\sqrt{2 \times 11.7 \times 8.85 10^{-14} \times 1.6 10^{-19} \times 10^{16}}}{1.72 10^{-7}} = .3347$

$V_{TN} = V_{FB} + 2|\phi_{Fp}| + \gamma \sqrt{2|\phi_{Fp}|}$

$V_{TN} = -1.08 + 2 \times .335 + .3347 \sqrt{2 \times .335} = -.136 V$

b) since $V_{TN} < 0 \Rightarrow$ depletion

c) $V_{DS}(sat) = V_{GS} - V_{TN} = 3 + .136 = 3.136$

since $V_{DS} = 2 < V_{DS}(sat) \Rightarrow$ linear region

$I_D = K_n \left[2(V_{GS} - V_{TN}) V_{DS} - V_{DS}^2\right]$

$K_n = \frac{W}{L} \frac{\mu_n C_{ox}}{2} = \frac{5}{1} \times \frac{1000 \times 1.72 10^{-7}}{2} = 4.3 10^{-4}$

$I_D = 4.3 10^{-4} \left[2(3.136) \times 2 - 4\right] = 3.67 10^{-3} A$

d) $\Delta V_T = 1 - (-.136) = 1.136$

Since $\Delta V_T > 0 \Rightarrow$ introduce acceptors

$$\Delta V_T = \frac{e D_I}{C_{ox}} \Rightarrow D_I = \frac{\Delta V_T \, C_{ox}}{e}$$

$$D_I = \frac{1.136 \times 1.72 \, 10^{-7}}{1.6 \, 10^{-19}} = 1.22 \, 10^{12} \ \frac{\text{atoms}}{\text{cm}^2}$$