Problem 1: Graded by Prof. Fonstad

a)  
   i) A less than B, because K varies inversely with L.
   ii) A similar to B, because the threshold voltage does not depend on L.
   iii) A greater than B, because A has a smaller K and thus must be biased stronger.
   iv) A less than B, because $V_A$ is bigger for the longer device, and thus $g_o$ is smaller.
   v) A greater than B, because the area of the gate (WxL) is larger.
   vi) A similar to B, because $C_{gd}$ is proportional to the device width and that is the same in both devices.

b)  
   i) A less than B, because $I_{ES}$ is dominated by $N_{AB}$ and proportional to $1/N_{AB}$.
   ii) A similar to B, because $I_{CS}$ is dominated by $N_{DC}$ and that is the same in both devices. A less than B was also accepted.
   iii) A less than B, because the emitter defect increases with $N_{AB}$, and $\beta \approx 1/\delta_E$.
   iv) A similar to B, because $g_m = qI_c/kT$ and is the same for both devices.
   v) A less than B, because $V_A$ increases as the doping increases, and $g_o = I_c/V_A$
   vi) A similar to B, because $C_{\mu}$ is nominated by the collector doping, which is the same in both devices. A greater than B was also accepted.

c)  
   i) Essentially unchanged, because the sum of the n- and p-channel MOSFET gate areas is still $3W_{min}L_{min}$.
   ii) Decreased, because the p-FET is now narrower and delivers less current.
   iii) Increased, because the n-FET is now wider and can draw more current.
   iv) Essentially unchanged, because the static power is zero. (Trick question?)
   v) Essentially unchanged, because the logic HI voltage is still $V_{DD}$.
   iv) One increased, one decreased, because the nearly vertical portion of the transfer characteristic is no longer centered about $V_{DD}/2$.

Problem 2: Graded by Prof. Hoyt

a)  $\beta_F = i_C/i_B = 9.25 \text{ mA}/92.5 \mu\text{A} = 100$

b) $\delta_B = 0$, because the lifetime is infinite, meaning the minority carrier diffusion length is also infinite.

c) The factor in question appears in the emitter defect expression, and we can find the emitter defect because we know $\beta_F$ and $\beta_F \approx 1/\delta_{E'}$ when $\delta_B$ is negligible, as it is here:
\[ \beta_F \text{ and } \beta_p \approx 1/\delta_E = (D_e W_{e,\text{eff}} N_{DE})/(D_h W_{h,\text{eff}} N_{AB}) = (D_e/D_h) r, \text{ so } r = \beta_F (D_e/D_h) = 50 \]

d) Use the Gummel plot to find a value for \( I_{ES} \) and then use \( I_{ES} \) to find \( N_{AB} \):

\[ I_C \approx I_{ES} \exp \left( \frac{qV_{BE}}{kT} \right), \text{ and } I_{ES} \approx Aq_i^2 (D_e/W_{B,\text{eff}} N_{AB}), \]

so \( N_{AB} = Aq_i^2 (D_e/W_{B,\text{eff}} I_C) \exp \left( \frac{qV_{BE}}{kT} \right) = 1 \times 10^{17} \text{ cm}^{-3} \)

e) With the results of Parts (c) and (d), we find \( N_{DE} = r W_{B,\text{eff}} N_{AB}/W_{E,\text{eff}} = 1 \times 10^{19} \text{ cm}^{-3} \)

f) \[ n, p \]

\[ 1.45 \times 10^{15} \text{ cm}^{-3} \]

\[ 1.45 \times 10^{13} \text{ cm}^{-3} \]

\[ 10 \text{ cm}^{-3} \]

\[ n \]

\[ p \]

\[ \approx 0 \]

\[ 0.5 \] (\( w_B \))

\[ 1.5 \] (\( w_B + w_C \))

\[ n'(x) \]

\[ Q_{\text{diff}}(A) \]

\[ 0 \]

\[ w_B \]

g) \[ n'(x) \]

\[ Q_{\text{diff}}(B) = 2 Q_{\text{diff}}(A) \]

\[ 0 \]

\[ w_B \]

Problem 3: Graded by John Hennessey for Prof. Antoniadis

a) \( V_{FB} = -(\phi_{n^+} - \phi_p) = -[0.54 - (-0.3)] = -0.84 \text{ V} \)

b) \[ \phi(x) \]

Slight curvature (concave up)
c) \( x_p = x_A = (2 \varepsilon_{Si} \Delta \phi / q N_A)^{1/2} = 10 \text{ nm} \). We find \( \Delta \phi = 0.08 \text{ V} \).

The assumption is justified because the total potential change, which is \( |V_{FB}| \), is much greater than this value.

d) i) Electric field:

\[
\begin{align*}
E(x) &= E(0') E(0') = \varepsilon_{Si} / \varepsilon_{ox} = 3 \\
Q_n'/\varepsilon_{ox} &\quad Q_n'/\varepsilon_{si} \\
\text{Very small negative slope}
\end{align*}
\]

ii) Charge density:

\[
\begin{align*}
\rho(x) &= Q_n' \\
-x_M &\quad -x_{ox} &\quad 0 &\quad x_A &\quad x_B \\
-qN_A &\quad Q_p' \\
\end{align*}
\]

e) Neglecting \( qN_A x_A \) relative to \( Q_n' \) and \( Q_p' \), then \( Q_p' \approx Q_n' \). The situation looks like a parallel plate capacitor with two different dielectrics. The total potential drop from \( x = -x_{ox} \) to \( x = x_A \) is \( V_{FB} \) or 0.84 V. The drop across the oxide is \( Q_p' x_{ox} / \varepsilon_{ox} \) and that across the silicon is \( Q_p' x_{si} / \varepsilon_{si} \). Adding these together and setting them equal to \( V_{FB} \), we find

\[
Q_p' = V_{FB} / (x_{ox} / \varepsilon_{ox} + x_{si} / \varepsilon_{si}) = 3.5 \times 10^7 \text{ C/cm}^2
\]

f) The charge in the depleted lightly doped p-region is:

\[
-qN_A x_A = 1.6 \times 10^{19} \times 10^{15} = -1.6 \times 10^{30} \text{ coul/cm}^2
\]

This is much less than \( Q_p' \), so it neglecting it was a good approximation.
Average/Standard deviation:  

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<th>Problem 1</th>
<th></th>
<th>Problem 2</th>
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<th>Problem 3</th>
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Distribution to nearest 5:  
Find your face in this picture