1) NMOS $(E_F = E_c)$ $\epsilon_{ox} = 3.9$, $\epsilon_s = 11.7$ $N_a = 10^{18}\ cm^{-3}$

$t_{ox} = 40Å = 4\times10^{-7}$ cm $W = 2L = 1\mu m = 10^{-4}$ cm

a) $V_{SB} = 0$

$C'_{ox} = \frac{\epsilon_{ox}\epsilon_0}{t_{ox}} = 8.6288 \times10^{-7}\ F/cm^2$

$\phi_F = \frac{kT}{q}\ln(N_a/n_i) = 0.4657 \Rightarrow (E_F < E_i) \Rightarrow \phi_F = -0.4657$

$Q'_B = -\sqrt{2\epsilon_s\epsilon_0 q N_a |V_{SB} - 2\phi_F|}$

$= -\sqrt{4qN_a\epsilon_s\epsilon_0|\phi_F|} = -5.5591\times10^{-7}\ C/cm^2$

$Q'_B/C'_{ox} = -0.64425$ V

$\phi_{ms} = \chi_s - (\chi_s + E_g/2 + |\phi_F|) = -(E_g/2 + |\phi_F|) = -1.0257\ V = V_{FB}$

$V_{th} = \phi_{ms} - 2\phi_F - Q'_B/C'_{ox}$

$= -1.0257 - (-0.9314) - (-0.64425)$

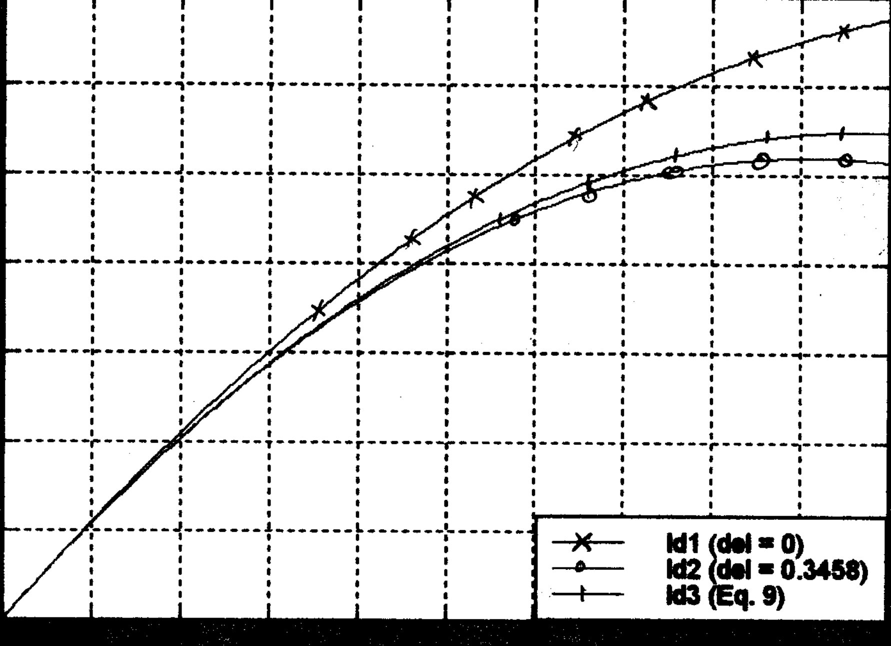
$= \boxed{0.55\ V}$

b) $\delta = \frac{1}{C'_{ox}}\left[\left|\frac{dQ'_B}{dV_{CB}}\right|_{V_{CB}=V_{SB}}\right]$

$= \frac{\sqrt{2q\epsilon_s\epsilon_0 N_a}}{2C'_{ox}\sqrt{|V_{CB} - 2\phi_F|}}$ Set $V_{CB} = 0$

$\delta = \frac{5.76\times10^{-7}}{16.6552\times10^{-7}} = \boxed{0.3458}$

c) See plots next page


Id1 (del = 0)
Id2 (del = 0.3458)
Id3 (Eq. 9)

1-d)

i) $V_S = 0,\ V_B = 0,\ V_G = 3,\ V_D = 1$

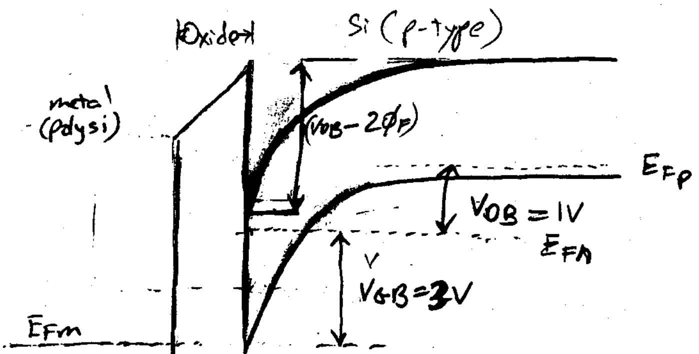
$$V_{DS,sat} = \frac{V_{GS} - V_{th}}{1+\delta} = \frac{3 - 0.55}{1.34} = 1.8205\ V$$

$V_{DS} < V_{DS,sat}$, $V_G > V_{th}$ $=$ $\boxed{\text{linear mode}}$

$$I_D = \frac{W}{L}\mu_n C_{ox}'\left[(V_{GS}-V_{th})V_{DS} - \tfrac{1}{2}(1+\delta)V_{DS}^2\right]$$

$$= 2(1350)(8.6\times10^{-7})\left[(1.82) - \tfrac{1}{2}(1.34)\right]$$

$$= \boxed{2.6737\ mA}$$



ii) $V_S = 0,\ V_B = 0,\ V_G = 3V,\ V_D = 3V$

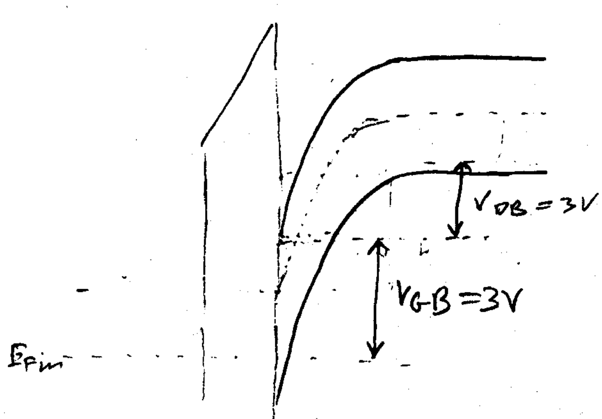
$$V_{DS,sat} = \frac{V_{GS} - V_{th}}{1+\delta} = 1.8205\ V$$

$V_{DS} = 3V > V_{DS,sat}$, $V_G > V_{th}$ $\Rightarrow$ $\boxed{\text{Saturation mode}}$

$$I_D = \frac{W}{L}\mu_n C_{ox}'\left[\frac{(V_{GS} - V_{th})^2}{2(1+\delta)}\right]$$

$$= 2(1350)(8.6\times10^{-7})\left[\frac{(1.82)^2}{2(1.34)}\right]$$

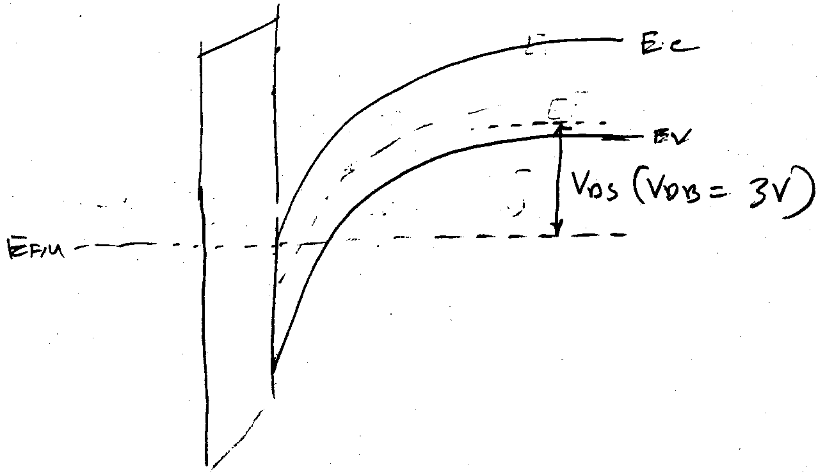
$$= \boxed{2.8687\ mA}$$



iii) $V_S = 0$, $V_B = 0$, $V_G = 0$, $V_D = 3V$

$V_G < V_{th} = \boxed{OFF}$

$\boxed{I_D = 0}$



2 a) Since V_{DS} (= -2V) is so close to V_{DS}^{sat} (= -2.01 V), only a small V_{SB} is enough to have the drain end no longer inverted.

Based on linearized model $\delta = \left|\frac{\Delta V_{th}}{\Delta V_{CB}}\right| = 0.293$

The effective threshold voltage at drain is increased due to $V_{CB} = V_{DB}$. For the drain to be at the edge of strong inversion,

$$V_{GD} = V_T^{drain} \cong V_T\Big|_{V_{CB}=0} + \delta V_{DB}$$

$$-3 - (-2V) = -0.4V + \delta V_{DB} \Rightarrow V_{DB} = \frac{-0.6V}{\delta} = -2.05V$$

Since $V_{DS} = -2V$, $\underline{V_{SB} = -0.05V}$

More accurately, we can use full expression for $V_T(V_{CB})$ rather than linearized model.

$$V_T = V_{FB} - 2\phi_F - \frac{\sqrt{2K_S\epsilon_o q N_d |V_{CB} - 2\phi_F|}}{C_{ox}'}$$

$0.53V^{1/2}$ $\quad$ $0.81V$

$$V_T(V_{CB}=V_{DB}) - V_T(V_{CB}=0) = -0.6V = \frac{-\sqrt{2K_S\epsilon_o q N_d}}{C_{ox}'}\left(|V_{DB}-2\phi_F|^{1/2} - |2\phi_F|^{1/2}\right)$$

$$|V_{DB} - 2\phi_F| = \left(\frac{0.6}{0.53} + \sqrt{0.81}\right)^2 = 4.15 \Rightarrow V_{DB} = -4.15 + 0.81 = -3.34$$

$$\underline{V_{SB} = -1.34V}$$

2-e) $N' = 10^{12}\ cm^{-2}$

$V_T = -\frac{qN'}{C_{ox}} = +0.4642V$

$V_{T,new} = -0.4 + 0.4642V = \boxed{-0.8642V}$

$V_{D,sat,new} = \frac{V_{GS} - V_{T,new}}{1+\delta} = -1.66V$

$V_{DS} = -2V \not< V_{DS,sat,new} \Rightarrow$ $\boxed{\text{In Saturation Region}}$

3)

$\Delta L \ll L = 0.3\mu m$

$V_{DS} = V_{DS(sat)} + 0.5V \Longrightarrow V_{DS} - V_{DS(sat)} = 0.5$

$I_D = 1\mu A$ @ V_{DS}^{sat}

$Na = 2 \times 10^{17}$

$\Delta L = \sqrt{\frac{2\epsilon_s}{qNa}\left|V_{DS} - V_{DS(sat)}\right|}$

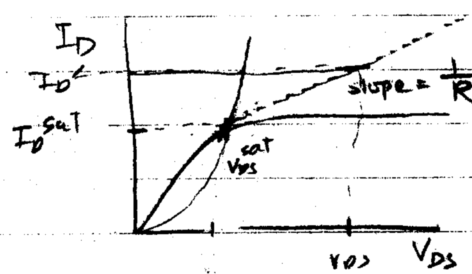
$\Delta L = \sqrt{\frac{2\times 11.7\times 8.85\times 10^{-14}}{1.6\times 10^{-19}\times 2\times 10^{17}}\left|0.5\right|} = 5.69\times 10^{-6}\ cm$

$= 0.0569\ \mu m$

$I_D' = \left(\frac{L}{L-\Delta L}\right) I_D$

$= \frac{0.3\ \mu m}{0.3\mu m - 0.0569\mu m}(1\mu A)$

$= 1.234\ \mu A$



$\text{slope} = \frac{I_D' - I_D}{V_{DS} - V_{DS(sat)}}$

$\frac{1}{R} = \frac{0.234\mu}{0.5}$

$\frac{1}{R} = 0.468\times 10^{-6}$

$R = \underline{2.14\ M\Omega}$