Problem 5.1: (NMOS FET)

Suppose one is interested in obtaining and plotting the channel potential $V_{CS}(y)$ as a function of position $y$ inside the channel from the source end ($y = 0$) to the drain end ($y = L$). Suppose that one is operating in the linear (or the triode) regime: $V_{DS} < V_{GS} - V_{TN}$ in which the current is:

$$I_D = \frac{W}{L} \mu_n C_{ox} \left( V_{GS} - V_{TN} - \frac{V_{DS}}{2} \right) V_{DS}$$

a) Start from the current equation:

$$I_D = W \mu_n C_{ox} (V_{GS} - V_{TN} - V_{CS}(y)) \frac{dV_{CS}(y)}{dy}$$

and integrate the above equation from $y = 0$ to $y = y$. Solve the resulting equation for $V_{CS}(y)$ as a function of $y$ and plot (sketch) your answer for $0 \leq y \leq L$. Note that $V_{CS}(y = 0) = 0$ and $V_{CS}(y = L) = V_{DS}$.

b) The electric field is the derivative of the potential:

$$E_y(y) = -\frac{dV_{CS}(y)}{dy}$$

Find and plot (sketch) the electric field from $y = 0$ to $y = L$. Is the field constant/uniform? If not, explain why not (using physical rather than mathematical arguments).

c) From your answer in part (b), find the magnitude of the field at the Drain end ($y = L$) when $V_{DS}$ approaches $V_{GS} - V_{TN}$ from below and the current approaches:

$$I_D = \frac{W}{2L} \mu_n C_{ox} (V_{GS} - V_{TN})^2$$

Explain your answer (using physical rather than mathematical arguments).
Problem 5.2: (A NFET former exam problem)

A NFET (of unknown gate material) has the $I_D - V_{DS}$ curve shown below for $V_{GS} = 4 \, \text{V}$ and $V_{BS} = 0 \, \text{V}$. The threshold voltage $V_{TN}$ of the device is 1 V when $V_{BS} = 0 \, \text{V}$.

Assume:
- $W = 25 \, \mu\text{m}$
- $L = 10 \, \mu\text{m}$
- $\varepsilon_{ox} = 3.45 \times 10^{-13} \, \text{F/cm}$
- $t_{ox} = 10^{-6} \, \text{cm}$
- $\lambda_n = 0$
- $N_d = 10^{17} \, 1/\text{cm}^3$

a) What is the drain-to-source voltage at which the device saturates when $V_{GS} = 4 \, \text{V}$?

b) What is the electron mobility (cm$^2$/V-s) in the channel?

c) What is the inversion layer sheet charge density (in C/cm$^2$) in the FET channel at the source end when $V_{GS} = 4 \, \text{V}$ and $V_{DS} = 1 \, \text{V}$ and $V_{BS} = 0 \, \text{V}$?

d) What is the inversion layer sheet charge density (in C/cm$^2$) in the FET channel at the drain end when $V_{GS} = 4 \, \text{V}$ and $V_{DS} = 1 \, \text{V}$ and $V_{BS} = 0 \, \text{V}$?

e) For the same bias conditions as in parts (c) and (d), what is the drift velocity of electrons (cm/s) near the source end?

f) For the same bias conditions as in parts (c) and (d), what is the drift velocity of electrons (cm/s) near the source end?

g) What is the inversion layer sheet charge density (in C/cm$^2$) in the FET channel at the source end when $V_{GS} = 4 \, \text{V}$ and $V_{DS} = 5 \, \text{V}$ and $V_{BS} = 0 \, \text{V}$?

h) What is the inversion layer sheet charge density (in C/cm$^2$) in the FET channel at the drain end when $V_{GS} = 4 \, \text{V}$ and $V_{DS} = 5 \, \text{V}$ and $V_{BS} = 0 \, \text{V}$?
i) Now suppose $V_{GS} = 4 \, V$ and $V_{DS} = 5 \, V$ and $V_{BS} = -5 \, V$. Find the FET current (in Amps).