Fall 2013 HW #5

4.3

$\varepsilon_s = 11.7 \times 8.854 \times 10^{-12}\ \text{F/m}$

$N_B = 10^{15}\ \text{cm}^{-3} = 10^{22}\ \text{m}^{-3}$

$X_d \approx \sqrt{\frac{2\varepsilon_s}{qN_B}(0.75\text{V})} = 311\ \text{nm}$

$C_s = \frac{\varepsilon_s}{X_d} = 3.33 \times 10^{-4}\ \text{F/m}^2$

4.9

- For $V_{gs} = 0V$, $V_{gs} < V_{TN}$, so the mosfet is in cutoff. Therefore $i_D \approx 0A$.
- for $V_{gs} = 1V$, $V_{gs} - V_{TN} = 0.2V < V_{DS} = 0.25V$

Transistor is in saturation.

$$i_D = \frac{K_n}{2}(V_{gs} - V_{TN})^2$$

$$K_n = K_n'\left(\frac{W}{L}\right) = 200 \times 10^{-6}\left(\frac{5\mu}{0.5\mu}\right) = \boxed{2 \times 10^{-3}\ \text{A/V}^2}$$

$$i_D = \frac{2 \times 10^{-3}\ \text{A/V}^2}{2}(0.2)^2 = \boxed{40\mu A}$$

- for $V_{gs} = 2V, 3V$, $V_{DS} < V_{gs} - V_{TN}$, therefore mosfet is in linear (triode)

$$i_D = K_n(V_{gs} - V_{TN} - V_{DS}/2)V_{DS}$$

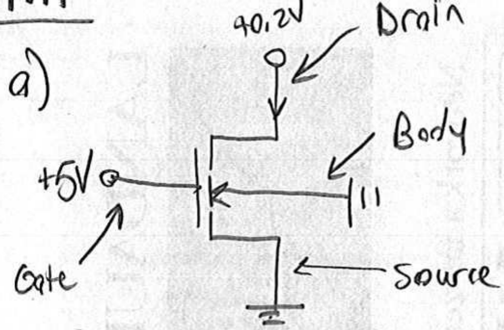
$$i_D = 2 \times 10^{-3}\ \text{A/V}^2\left(V_{gs} - 0.8V - \frac{0.25V}{2}\right)(0.25V)$$

$$\boxed{i_D = 537\mu A \quad \text{for } V_{gs} = 2V}$$

$$\boxed{i_D = 1.04 mA \quad \text{for } V_{gs} = 3V}$$

4.11

a)



The Source terminal is the one shorted to the body.

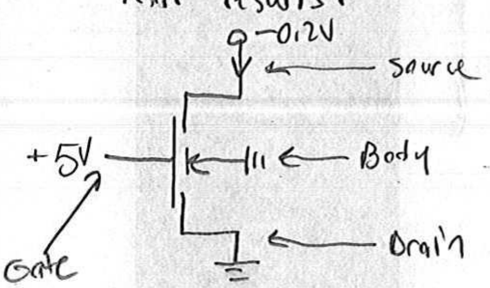
$V_{ds} = 0.2V < V_{gs} - V_T = 4.3V$, so linear operation

$$i_D = K_n\left(V_{gs} - V_T - \frac{V_{DS}}{2}\right)V_{DS}$$

$$= K_n\left(4.3V - \frac{0.2V}{2}\right)(0.2V)$$

$$\boxed{i_D = (0.84)K_n = (0.84)\underbrace{(100\times10^{-6}A/V^2)}_{K_n' \text{ from table}}\underbrace{\left(\tfrac{10}{1}\right)}_{\frac{W}{L}} = \boxed{840\mu A}}$$

b) Because there is a negative voltage on the top terminal, the source and drain are reversed. There is also a body bias that results.



- $V_{gs} = 5V - (-0.2V) = 5.2V$
- $V_{sb} = -0.2V$
- $V_{ds} = 0V - (-0.2V) = 0.2V$
- $V_{TN} = V_{TO} + \gamma\left(\sqrt{V_{SB} + 2\phi_F} - \sqrt{2\phi_F}\right)$

$$V_{TN} = (0.7V) + (0.75)\left(\sqrt{-0.2 + 0.6} - \sqrt{0.6}\right)$$

$$= 0.593V$$

i.e. transistor is in linear region

$$i_D = K_n\left(V_{GS} - V_{TN} - \frac{V_{DS}}{2}\right)V_{DS}$$

$$= (100\times10^{-6}A/V^2)\left(\frac{10}{1}\right)\left(5.2V - 0.593V - \frac{0.2V}{2}\right)(0.2V)$$

$$\boxed{= 901\mu A}$$

4.16

a) $i_D = K_n\left(V_{gs} - V_{TN} - \frac{V_{DS}}{2}\right)V_{DS}$

$\frac{1}{R_{on}} = \frac{i_D}{V_D} = K_n\left(V_{gs} - V_{TN} - \frac{V_{DS}}{2}\right) \approx K_n\left(V_{gs} - V_{tn}\right)$ for $V_{DS} \to 0V$

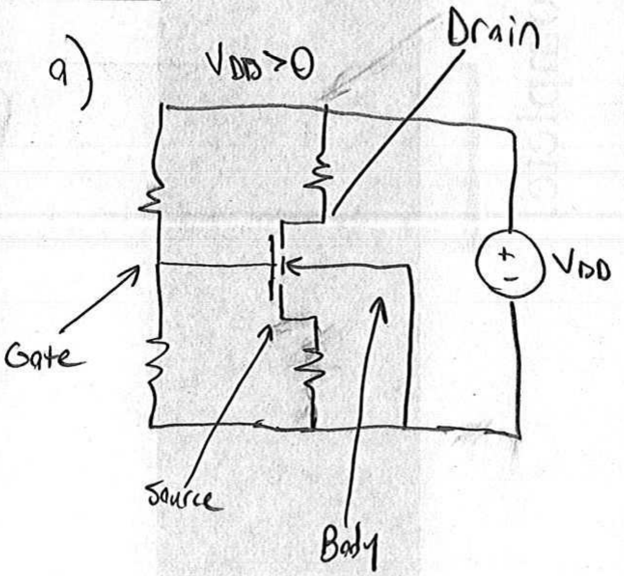
$\frac{1}{R_{on}} = K_n'\left(\frac{W}{L}\right)\left(V_{gs} - V_{TN}\right)$

$\left(\frac{W}{L}\right) = \frac{1}{R_{on}K_n'\left(V_{gs} - V_{TN}\right)} = \frac{1}{100\mu A/V^2\,(5V - 0.75V)\cdot(500\Omega)} = \boxed{4.7}$

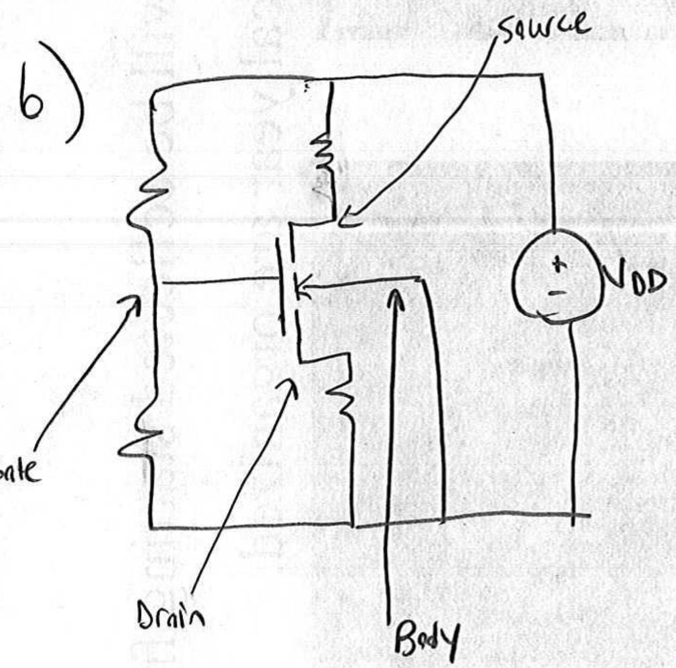
b) $\left(\frac{W}{L}\right) = \frac{1}{(500\Omega)(100\times10^{-6}A/V^2)(3.3V - 0.75V)} = \boxed{7.8}$

4.25

a)



b)



c) If R1, R2, R3, and R4 are chosen such that the transistor is on in part a, then most likely it will be off in part b because the gate will no longer be biased so that the transistor is on.

4.34

a) • For both transistors, $V_{GS} = V_{DS}$, therefore the transistors are in saturation for any V_{DS}, V_{GS}.

• Also, because the transistors are identical and current through them the same, the V_{DS} must be the same. Therefore the $V_{DS} = \frac{1}{2} V_{DD}$ for both transistors.

a) $i_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2 (1 + \lambda V_{DS})$

$i_D = \frac{1}{2}(100 \times 10^{-6} A/V^2)(10)(\frac{1}{2}(10) - 0.75)^2$

$\boxed{i_D = 2.13 mA}$

b) The current is simply twice of part A

$i_D = \frac{1}{2}(100 \times 10^{-6} A/V^2)(20)(\frac{1}{2}(10) - 0.75)^2$

$\boxed{i_D = 4.25 mA}$

c) $i_D = \frac{1}{2}(100 \times 10^{-6} A/V^2)(10)(\frac{1}{2}(10) - 0.75)^2(1 + (0.04)(\frac{1}{2}(10)))$

$\boxed{i_D = 2.55 mA}$

4.49

Saturation begins when $V_{ds} = V_{gs} - V_T$. Inspecting the figure, we see that saturation begins at the following V_{DS}, V_{gs} values

V_{gs}	V_{ds} (sat)
-2	-1.5
-3	-2.5
-4	-3.5
-5	-4.5

Therefore $\boxed{V_{TP} = -0.5V.}$

Because threshold voltage less than zero, the device is $\boxed{\text{enhancement mode}}$

To estimate K_p, we see $i_D \approx 4000\mu A$ for $V_{gs} = -5V$ in saturation.

$$i_D \approx \frac{1}{2} K_p (V_{gs} - V_{TP})^2$$

$$K_p \approx \frac{2 i_D}{(V_{gs} - V_{TP})^2} = \frac{2(4000 \times 10^{-6} A)}{(-5V - (-0.5V))^2} = \boxed{395 \mu A/V^2}$$

using K_p' from table 4.6

$$\frac{W}{L} = \frac{K_p}{K_p'} = \frac{395 \mu A/V^2}{40 \mu A/V^2} = \boxed{9.88}$$