April 18, 2001 - Quiz #2

problem	grade
1	
2	
3	
4	
5	
total	

Name: ______________________________

Recitation: ______________________________

General guidelines (please read carefully before starting):

- Make sure to write your name on the space designated above.
- **Open book**: you can use any material you wish.
- All answers should be given in the space provided. Please do not turn in any extra material. If you need more space, use the back page.
- You have **120 minutes** to complete your quiz.
- Make reasonable approximations and *state them*, i.e. quasi-neutrality, depletion approximation, etc.
- Partial credit will be given for setting up problems without calculations. **NO** credit will be given for answers without reasons.
- Use the symbols utilized in class for the various physical parameters, i.e. μ_n, I_D, E, etc.
- Every numerical answer must have the proper units next to it. Points will be subtracted for answers without units or with wrong units.
- Use $\phi = 0$ at $n_o = p_o = n_i$ as potential reference.
- Use the following fundamental constants and physical parameters for silicon and silicon dioxide at room temperature:

$$n_i = 1 \times 10^{10}\ cm^{-3}$$
$$kT/q = 0.025\ V$$
$$q = 1.60 \times 10^{-19}\ C$$
$$\epsilon_s = 1.05 \times 10^{-12}\ F/cm$$
$$\epsilon_{ox} = 3.45 \times 10^{-13}\ F/cm$$

1. *(25 points)* You are given a CMOS inverter with the following parameters:

$V_{Tn} = 0.5\ V$	$t_{ox} = 10\ nm$	$\mu_n = 400\ cm^2/V \cdot s$
$V_{Tp} = -1\ V$	$\lambda_n = \lambda_p = 0.1\ V^{-1}$	$\mu_p = 200\ cm^2/V \cdot s$
$V_{DD} = 5\ V$	$L_n = L_p = 1\ \mu m$	

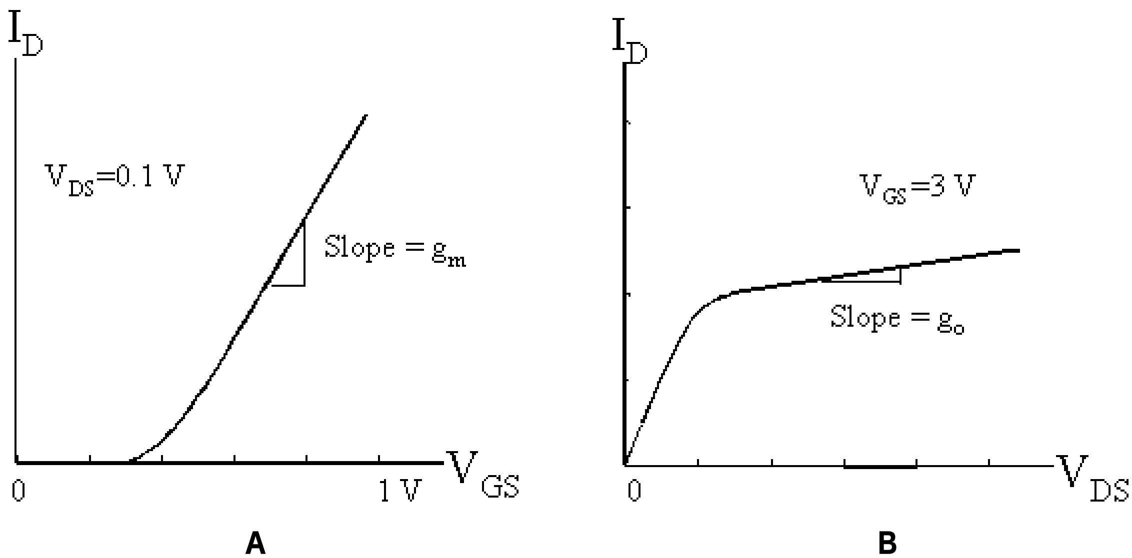
(1a) *(5 points)* Calculate the ratio W_p/W_n so that $V_M = 2.5\ V$.

(1b) *(5 points)* We want this inverter to have an average propagation delay $t_p = 1\ ns$ when driving a $C_L = 1\ pF$ capacitive load. Calculate W_n and W_p.

(1c) *(10 points)* Estimate NM_L and NM_H for this inverter.

(1d) *(5 points)* Sketch and appropriately label the voltage transfer characteristics of this inverter.

2. *(20 points)* You are given the following I-V characteristics for a n-MOSFET with $t_{ox} = 10\ nm$, $W = 10\ \mu m$, and $L = 1\ \mu m$. The gate material is n$^+$-doped polysilicon. The body is tied up to the source.



In (A), $g_m = 1.4 \times 10^{-4}\ A/V$. In (B), $g_o = 5.7 \times 10^{-5}\ A/V$.

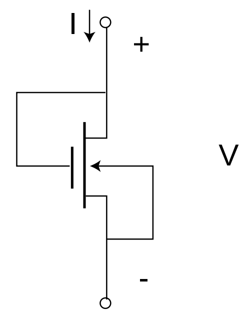
(2a) *(5 points)* From (A), estimate the threshold voltage, V_T.

(2b) *(5 points)* From (A), estimate the electron mobility, μ_n.

(2d) *(5 points)* Estimate the saturation voltage, V_{DSsat}, and the saturation current, I_{Dsat}, corresponding to the characteristics in (B).

(2e) *(5 points)* From (B), estimate the length of the channel pinch-off region, ΔL, at $V_{DS} = 4\ V$.

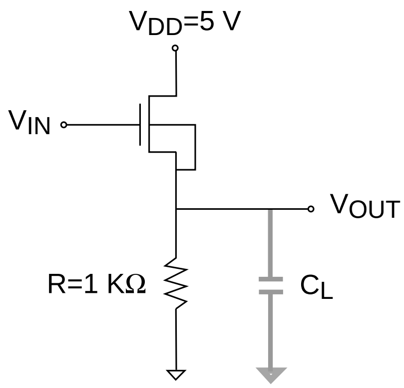
3. *(20 points)* An n-channel MOSFET is wired up in the form indicated below. This is an enhancement-mode device ($V_T > 0$). Neglect channel length modulation.



(3a) *(10 points)* In terms of usual MOSFET parameters, derive suitable equations for the I-V characteristics of the resulting two-terminal device. Sketch the I-V characteristics in a linear scale.

(3b) *(10 points)* Sketch a complete high-frequency small-signal equivalent circuit model for this two-terminal device for situations in which $V > V_T$. Express all small-signal elements in terms of those of the MOSFET, *i.e.*: as a function of g_m, g_o, C_{gs}, C_{gd}, C_{sb}, etc.

4. *(15 points)* An NMOS inverter with a resistor pull up was miswired and ended up as sketched below.



The parameters of the transistor are: $\mu_n C_{ox} = 50\ \mu A/V^2$, $W/L = 5$, and $V_T = 1\ V$. Neglect channel length modulation in this problem.

(4a) *(5 points)* For $V_{IN} = 0$, in what regime is the transistor biased? How much is V_{OUT}? *(numerical answer expected)*.

(4b) *(10 points)* For $V_{IN} = 5\ V$, in what regime is the transistor biased? How much is V_{OUT}? (you can leave the result in the form of an equation where V_{OUT} is the only unknown).

5. *(20 points)* In a certain pn junction diode at room temperature at a particular forward bias voltage, the current supported by hole injection into the n-side of the diode is 100 μA.

The quasi-neutral width of the n-side of the diode is $w_n - x_n = 1\ \mu m$. The hole diffusion coefficient is 10 cm^2/s. The pn junction area is 10 μm^2.

Make and state suitable approximations.

(5a) *(5 points)* Estimate the hole concentration at the space-charge region edge of the n quasi-neutral region. *(numerical answer expected).*

(5b) *(5 points)* Estimate the velocity at which holes are injected at the edge of the n quasi-neutral region *(numerical answer expected).*

(5c) *(5 points)* Estimate the hole flux arriving at the surface of the n quasi-neutral region. *(numerical answer expected).*

(5d) *(5 points)* Estimate the diffusion capacitance associated with hole storage in the n quasi-neutral region. *(numerical answer expected).*