EE140 HW2

① $V_T = \frac{kT}{q}$ $T = -40$ to $+85\ C$

$T = -40$ $\frac{1.38 \times 10^{-23}\ J/K \cdot 233\ K}{1.6 \times 10^{-19}\ C} = 20.1\ mV$

$T = 85$ $\frac{1.38 \times 10^{-23}\ J/K \cdot 358\ K}{1.6 \times 10^{-19}\ C} = 30.9\ mV$

$\boxed{\Delta V_T = 10.8\ mV}$

② $I = 10uA$, $V_D = 600mV$ $I = I_S \exp\left(\frac{V_D}{V_t}\right)$

a) $I = I_s \exp\left(\frac{600mV}{V_t}\right) \exp\left(\frac{26mV}{V_t}\right) \approx 10uA \cdot e = \boxed{27\ uA}$

b) $I = I_s \exp\left(\frac{600mV}{V_t}\right) \underbrace{\exp\left(\frac{60mV}{V_t}\right)}_{\approx 10} = 10nA \cdot 10 = \boxed{100nA}$

c) $\frac{1\ nA}{10uA} = 10^{-4}$ 60mV decrease in V_D for every 10x reduction in I_D

$600mV - 4(60mV) = \boxed{360\ mV}$

d) PN junction temp coefficient is $-2mV/K$

$600\ mV + (-2mV/K)(-40 - 25) = \boxed{730\ mV}$

e) All diodes have $I_D = 10nA$ and thus $V_D = 600mV$

so $V_{total} = 10 \cdot 600mV$ $\boxed{V_{total} = 6V}$

f) Each diode has $\frac{1}{10}$ of $10nA$, so V_D drops by $60mV$

$\boxed{V_{total} = 540\ mV}$

(3) a) at $I = 0.1\ mA$ $V_{BE} \approx 610mV$

at $I = 1mA$ $V_{BE} \approx 670mV$ @ 25C

at $I = 10mA$ $V_{BE} \approx 730\ mV$

In both cases $\boxed{\Delta V_{BE} = 60mV}$ for $10\times$ I_C change

b) @ -40 C $\Delta V_{BE} \approx 50\ mV$

@ 125C $\Delta V_{BE} \approx 80\ mV$

c) Checking against #1, $\Delta V_{BE} = \ln(10) \cdot \frac{kT}{q}$

@ -40 C $\Delta V_{BE} = 46.3\ mV$

@ 125C $\Delta V_{BE} = 79\ mV$

} Pretty close to (b)

d) $I_C = 1mA$

$T = -40$	$V_{BE} = 790mV$	$\Delta V_{BE} = 130mV / 65K$
$T = 25$	$V_{BE} = 660mV$	
$T = 125$	$V_{BE} = 460mV$	$\Delta V_{BE} = 200mV\ / 100K$

For both cases, tempco is $-2mV/K$ as expected.

(4) a) $V_{GS} = 0.5V$, $V_{DS} = 0.5V$

NMOS:

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{0.72\ mA/um - 0.42\ mA/um}{0.1V} = 3\frac{mA}{V\,um}$$

$$r_o = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.6\ V - 0.4V}{.45\frac{mA}{um} - .42\frac{mA}{um}} \approx 6.7\ k\Omega \cdot um$$

$$A_v = -g_m r_o = -20.1\ V/V$$

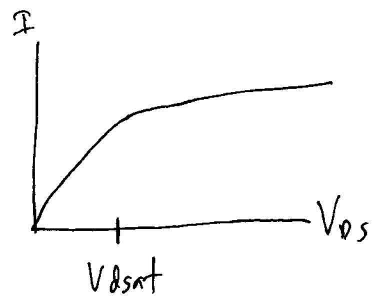
PMOS:

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}} = \frac{.67\ mA/um - .39\ mA/um}{0.1V} = 2.8\frac{mA}{V \cdot um}$$

$$r_o = \frac{\Delta V_{DS}}{\Delta I_D} = \frac{0.6V - 0.4V}{.4\frac{mA}{um} - .36\frac{mA}{um}} \approx 5k\Omega \cdot um$$

$$A_v = -g_m r_o = -14\ V/V$$

b)



$V_{DSAT} = V_{GS} - V_t$

Using $V_{GS} = 0.5$ NMOS curve, $V_{DSAT} \approx 0.3V$

so $V_{t,NMOS} \approx 200mV$

For PMOS, $V_{GS} = 0.5V$ $V_{DSAT} \approx -0.3V$ $V_{t,PMOS} \approx 200mV$

The difference in I_C for $V_{GS} = 0.5V$ to $V_{GS} = 0.6V$ is about the same as the change from $V_{GS} = 0.6V$ to $V_{GS} = 0.7V$ so they are probably velocity saturated.

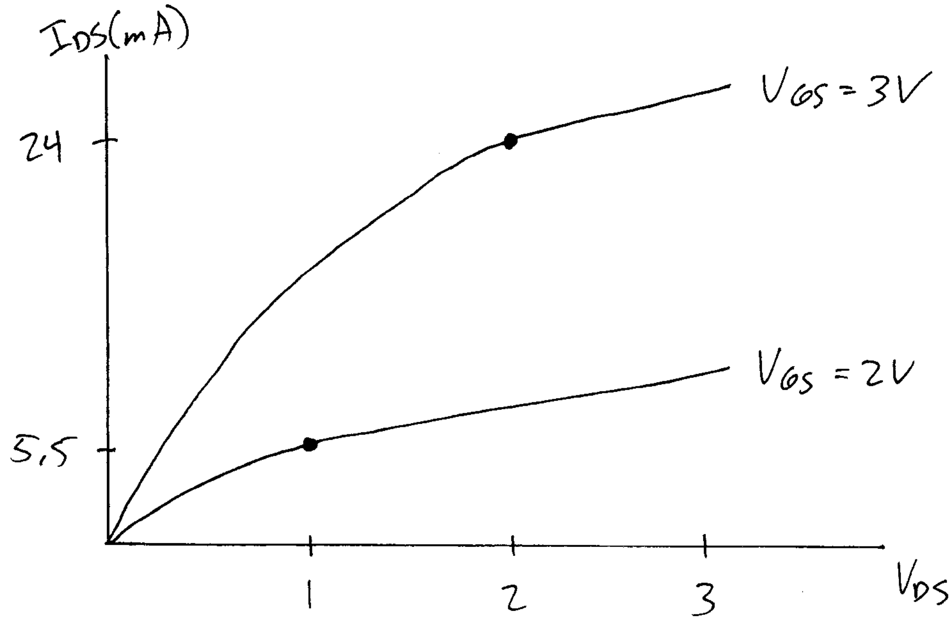
c) From Fig 6, slope looks like about $\frac{70\,mV}{decade}$

(Text says 65 mV/dec so graph estimate is close)

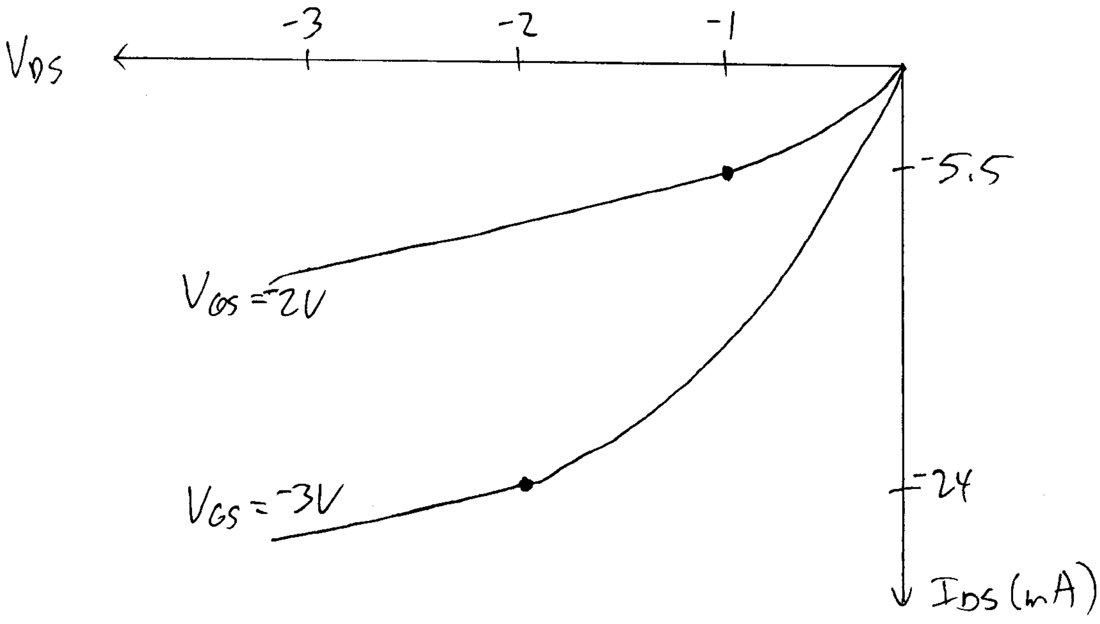
$$n = \frac{70}{60} = 1.17$$

Looks approximately same for NMOS/PMOS

(5)

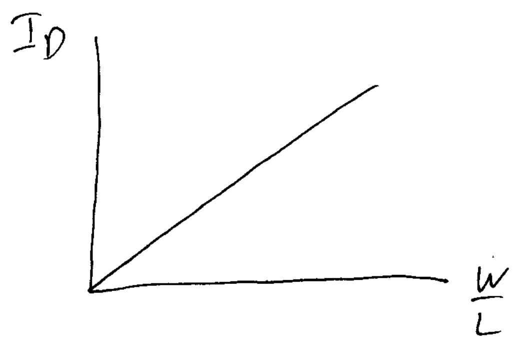


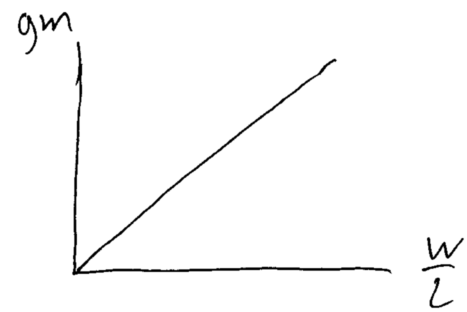
for $V_{GS} = 0V$, $V_{GS} = 1V$, $I_D = 0$



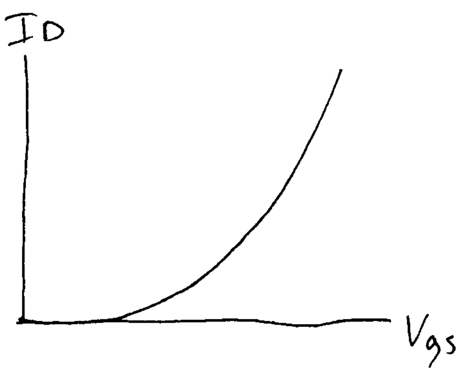
(6) $I_D = \frac{u C_{ox}}{2} \frac{W}{L} (V_{GS} - V_t)^2$

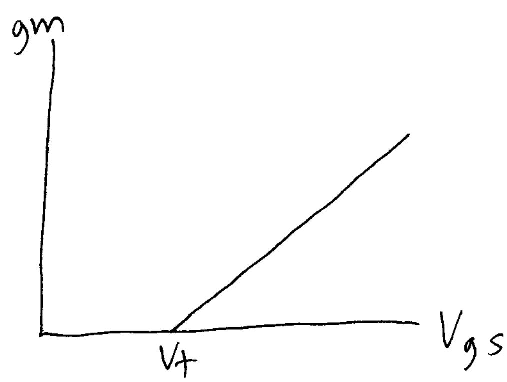
a) $g_m = \frac{2 I_D}{V_{GS} - V_t} = u C_{ox} \frac{W}{L} (V_{GS} - V_t)$



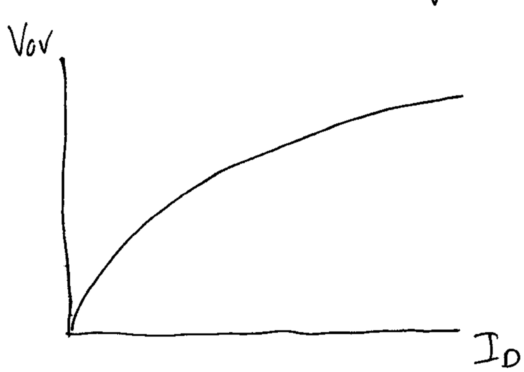


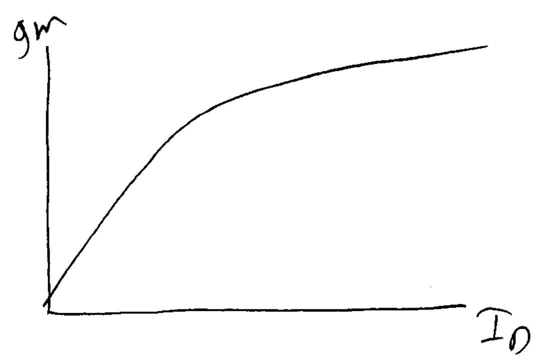
b)



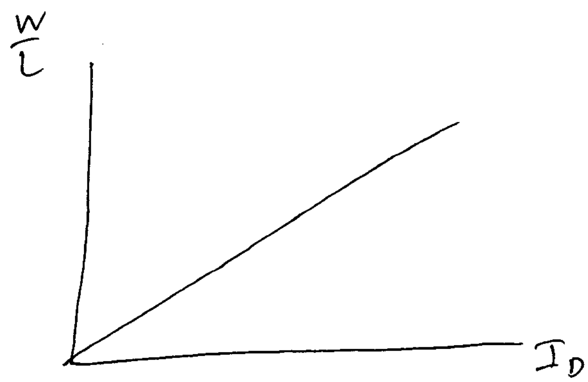


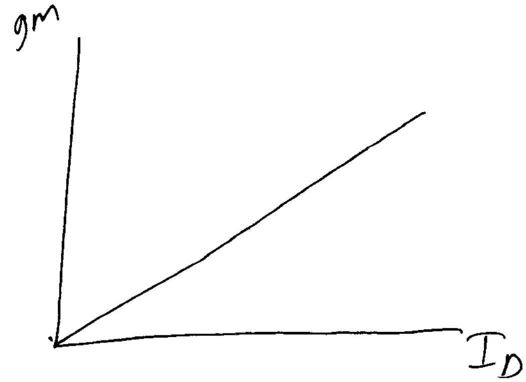
c) $V_{ov} = V_{GS} - V_t = \sqrt{\frac{2 I_D}{u C_{ox} \frac{W}{L}}}$ $\quad g_m = \sqrt{2 I_D \, u \, C_{ox} \frac{W}{L}}$





d) $\frac{W}{L} = \frac{2I_D}{u C_{ox} (V_{GS} - V_t)^2}$ $\qquad g_m = \frac{2I_D}{V_{GS} - V_t}$





HW2 Rubric
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1) 2 pts

2) 12 pts
-- 2 pts per part

3) 8 pts
-- a) 2 pts
-- b) 2 pts
-- c) 1 pt
-- d) 5 pts, 1 per question

4) 13 pts
-- a) 6 pts: 1 each for gm,ro,Av for both PMOS and NMOS
-- b) 5 pts: 1 pt for Vth for each (2 total), 2 pts for quad/velocity-sat, 1 pt for why
-- c) 2 pts: 1 pt each for NMOS and PMOS slopes

5) 6 pts
-- a) 1 pt per curve (2 curves, Vgs=0,1 are off), +1 getting vdsat in correct spot
-- b) 1 pt per curve (2 curves, Vgs=0,1 are off), +1 getting vdsat in correct spot

6) 8 pts
-- 2 pts per part for getting shape of curves correct (linear, quadratic, etc)

7) 5 pts
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54 pts total