Name: ______________________________ (please print)

Signature: ___________________________

ECE 3455
Exam 2
April 21, 2007

Exam duration: 90 minutes

- You may have one 8 ½ x 11 in. "crib" sheet, written on both sides, during the quiz. You may have any calculator you choose, but no computers. No other notes or materials will be allowed.
- Show all work necessary to complete the problem on these pages. A solution without the work shown will receive no credit.
- Show units in intermediate and final results, and in figures.
- If your work is sloppy or difficult to follow, points will be subtracted.

This exam has 8 pages, including the cover sheet. Raise your hand if you are missing a page.

1 ________________/35

2 ________________/35

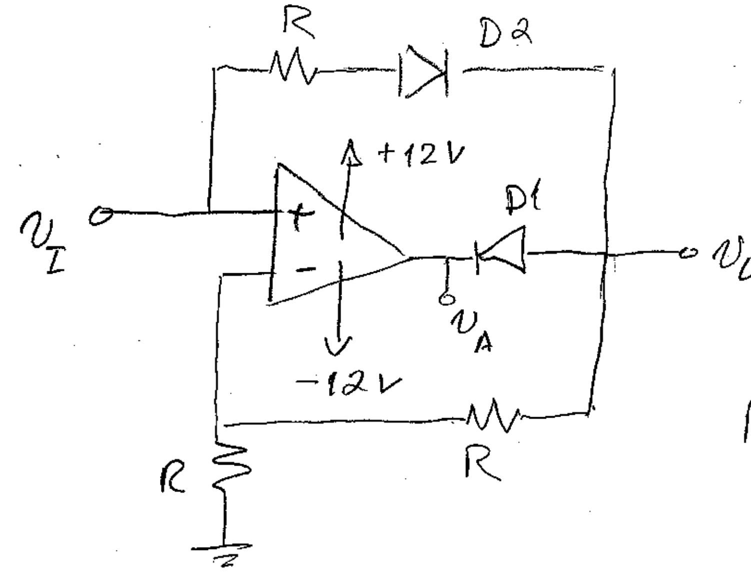
3 ________________/30

Total ________________/100

1. **(35 points)** In the circuit below, the diodes have a threshold voltage of 0.7 V, $r_D = 0$, and $I_S = 0$. The op amp is ideal.

i) Find v_O for $v_I = +2$ V.
ii) Find v_O for $v_I = -2$ V.

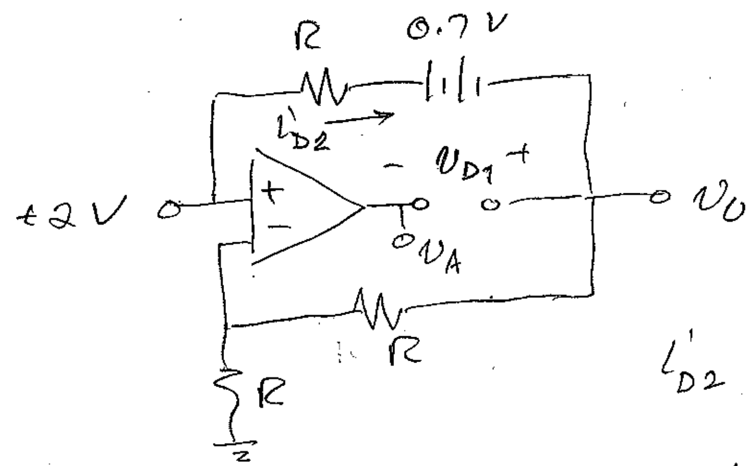
Be sure to prove that the diodes are in the regions you assume them to be in.



$R = 1000\ \Omega$

$v_I = 2V$: v_A will want to go positive so guess D1 OFF, D2 ON.

+15



We do not have negative feedback $\Rightarrow v_A = 12\ V$

$i_{D2} = \frac{2-0.7}{3R} = 0.433\ mA$

$\therefore v_O = 2R\, i_{D2} = 0.867\ V$

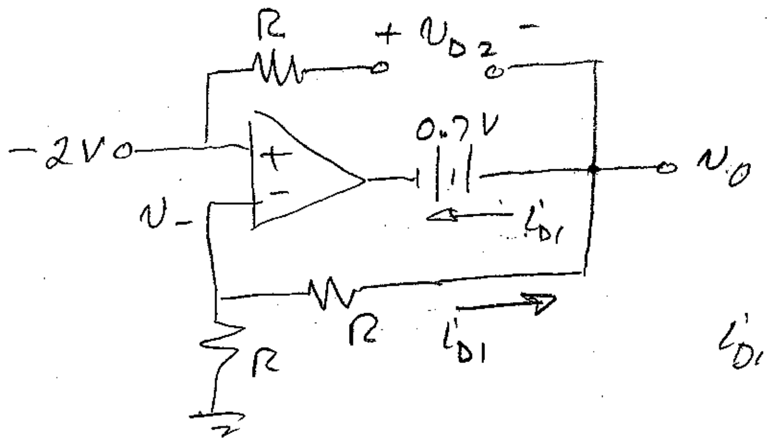
Room for extra work

Diode check: D2 $i_{D2} > 0$ $\Rightarrow$ OK

D1 $v_{D1} = v_O - v_A = -11.1\ V$ $\Rightarrow$ OK.

$v_I = -2V$: v_A will want to go negative so guess D1 ON, D2 OFF

+20



We do have negative feedback, so $v_- = -2\ V$

$i_{D1} = -\frac{v_-}{R} = \frac{2}{R} = 2mA$

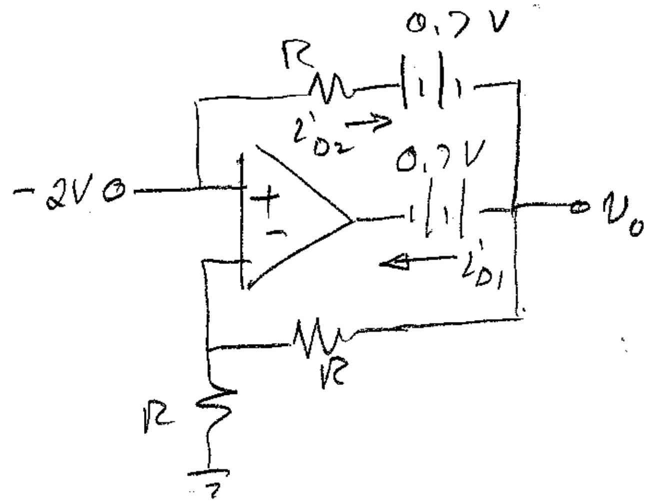
$v_O = -2 i_{D1} = -4\ V.$

Diode check: $i_{D1} = 2mA$ ✓

$v_{D2} = -2 - v_O = +2V$! WRONG GUESS !

Try again: (see pg. 2)

Room for Extra Work



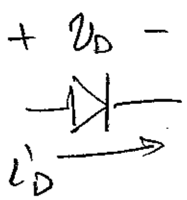
We still have negative feedback $\Rightarrow$ $v_o = -4V$.

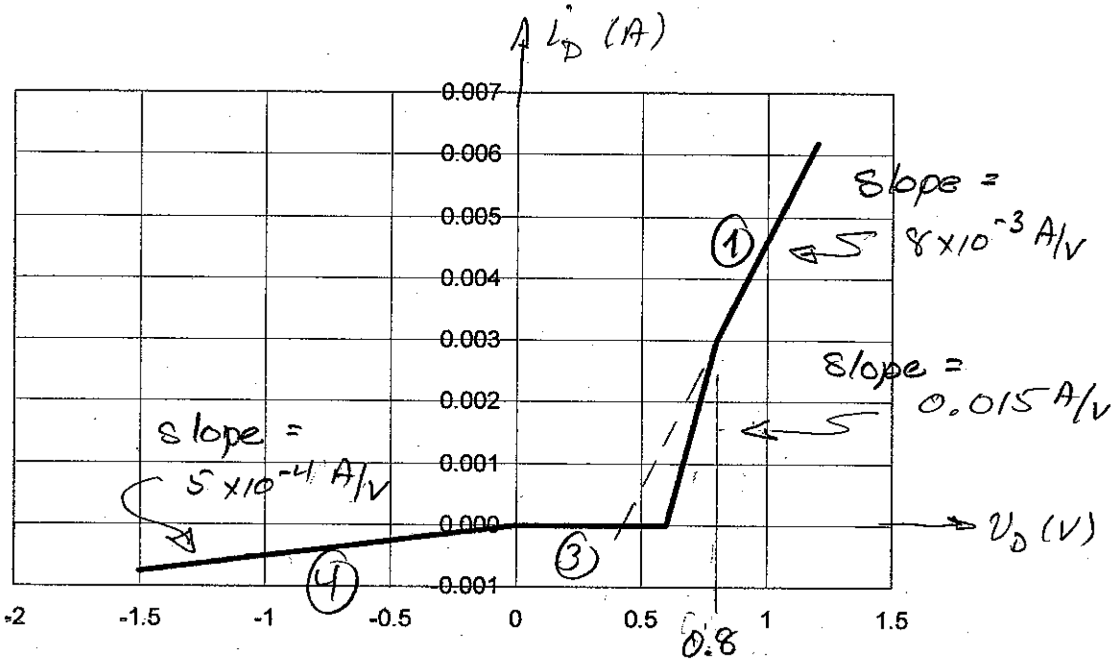
$$\therefore \quad i'_{D2} = \frac{-2 - 0.7 - (-4)}{R} = 1.3 \text{ mA} \checkmark$$

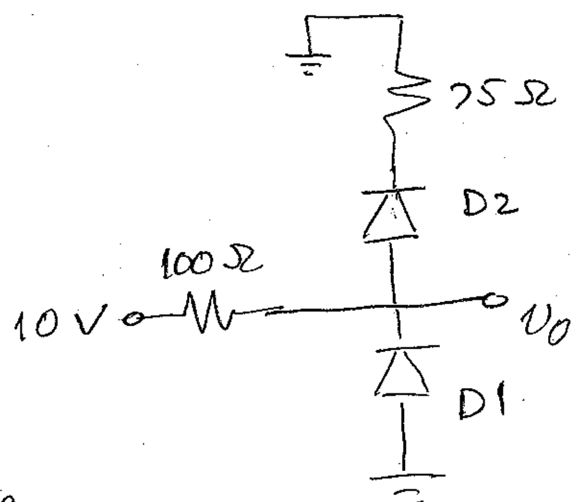
$$i'_{D1} = 1.3 \text{ mA} - \frac{v_o}{2R} = 1.3 \text{ mA} + 2 \text{ mA} = 3.3 \text{ mA} \checkmark$$

2. **(35 points)** The diodes in the circuit below are modeled with the "new and improved" diode model shown in the figure. The slopes of the straight lines are given in the figure.

Find v_O. Be sure to prove that the diodes are operating in the region you assume they are in.







Guess D1 region 4

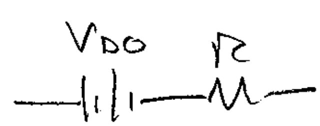
D2 region 1

Models:

D1 →

$R = 1/5\times10^{-4} = 2000\ \Omega$

D2 →



$R = 1/8\times10^{-3} = 125\ \Omega$

+7

+14

Room for extra work

What is V_{D0}? There are two methods: Either way, we have to extrapolate the line in region 1 back to the $i_D = 0$ axis.

1) Graphically: The graph shows the intercept is ~ 0.45 V.

2) Analytically: $y = mx + b$

m = slope = 8×10^{-3} so

$$i_D' = 8 \times 10^{-3} \cdot v_D + b$$

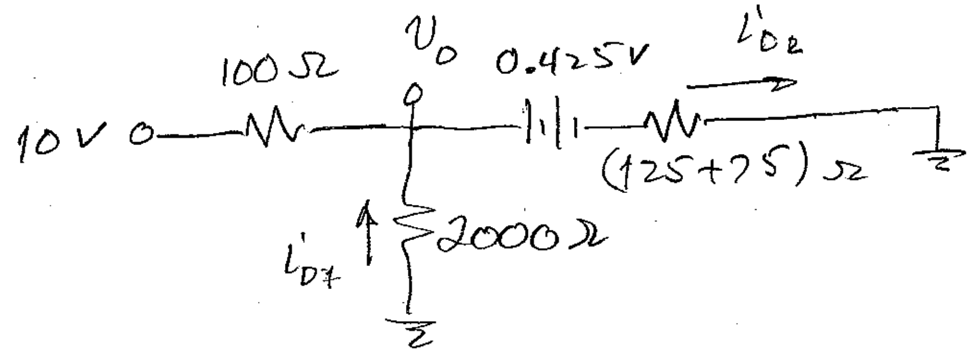
$$i_D' = 3\,mA \Rightarrow v_D = 0.8V$$

$$\Rightarrow b = 0.003 - 8 \times 10^{-3}(0.8) = -3.4 \times 10^{-3}\ A$$

So for $i_D' = 0$, $v_D = -b/8\times10^{-3} = 0.425\ V$

which is close to what we got above.

Test:



$$\frac{v_o}{2000} + \frac{v_o - 10}{100} + \frac{v_o - 0.425}{200} = 0$$

$$v_o + 20 v_o - 200 + 10 v_o - 4.25 = 0$$

$$31 v_o = 204.25$$

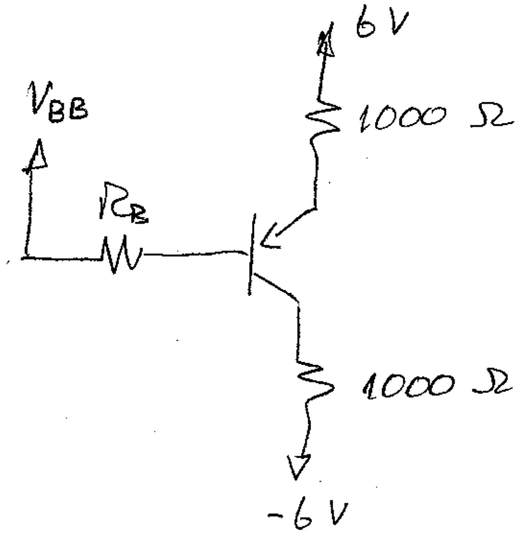
+4 $$v_o = 6.59 \text{ V}$$

Check:

+5 $$i_{D1} = \frac{-v_o}{2000} = -3.29 \text{ mA} \checkmark$$ (i_{D1} needs to be negative to be in region 4)

+5 $$i_{D2} = \frac{v_o - 0.425}{200} = 30.83 \text{ mA} \checkmark$$

3. **(30 points)** For the circuit below, choose values for V_{BB} and R_B so that the BJT is in the linear (active) region. As a constraint, it is given that V_{BB} cannot be larger than 6 V or less than – 6 V.

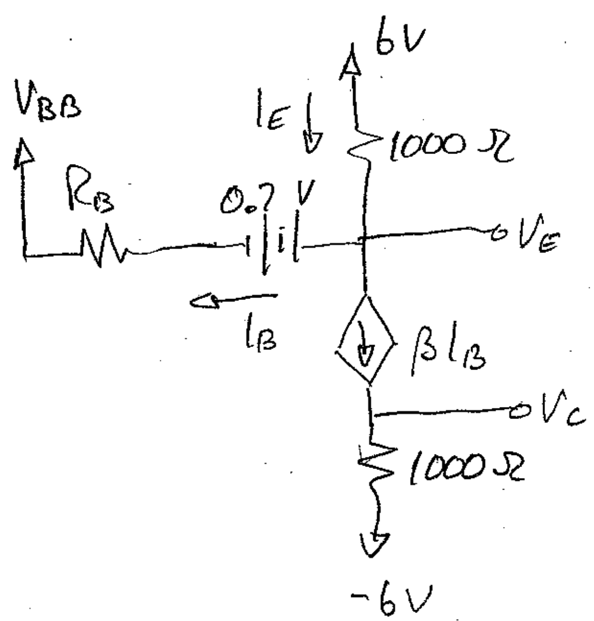


$\beta = 60$

$V_{CE,SAT} = -0.3\ V$

There are of course many possible solutions.

Let's set up a model:



For linear region we need

$V_C - V_E < -0.3\ V$

$V_C - V_E =$

$(1000\beta I_B - 6) -$

$(6 - 1000(\beta+1)I_B) < -0.3V$

$\Rightarrow\ 60000\ I_B + 61000\ I_B \ -12 < -0.3$

So $121000\ I_B < 11.7\ V$

$I_B < 96.7\mu A$

Room for extra work

Let's pick $I_B = 50\,\mu A$. Then

$$V_E = 6 - 61 I_B \cdot 1000 = 2.95\,V.$$

KVL: $-V_{BB} - I_B R_B - 0.7 + V_E = 0$

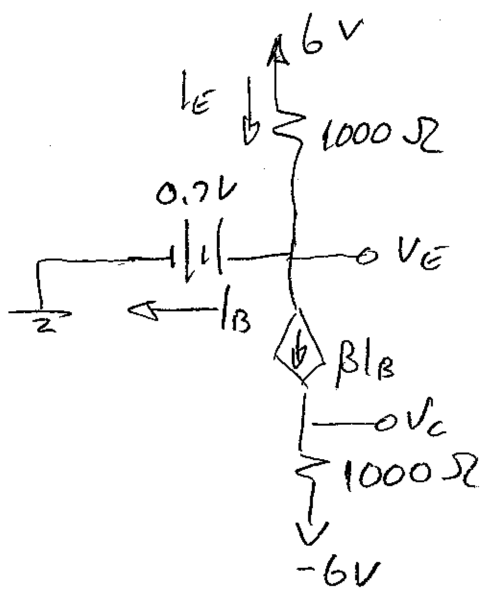
$$R_B = \frac{V_E - V_{BB} - 0.7}{I_B}$$

Clearly $(V_{BB} + 0.7)$ has to be less than V_E for R_B to be positive.

Choose $V_{BB} = 0 \Rightarrow R_B = \frac{2.95 + 0.7}{I_B} = 45\,k\Omega.$

Also $V_{CE} = -5.95\,V$

We could also have $V_{BB} = 0$, $R_B = 0$:



$$I_E = \frac{6 - 0.7}{1000} = 5.3\,mA$$

$$I_B = \frac{5.3\,mA}{\beta + 1} = 86.89\,\mu A$$

$$I_C = \beta I_B = 5.213\,mA$$

$$V_{CE} = (1000\,I_C - 6) - 0.7$$

$$= -1.49\,V$$