ECE 3040B Microelectronic Circuits

Exam 2

March 20, 2003

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Print your name clearly and largely: Solutions

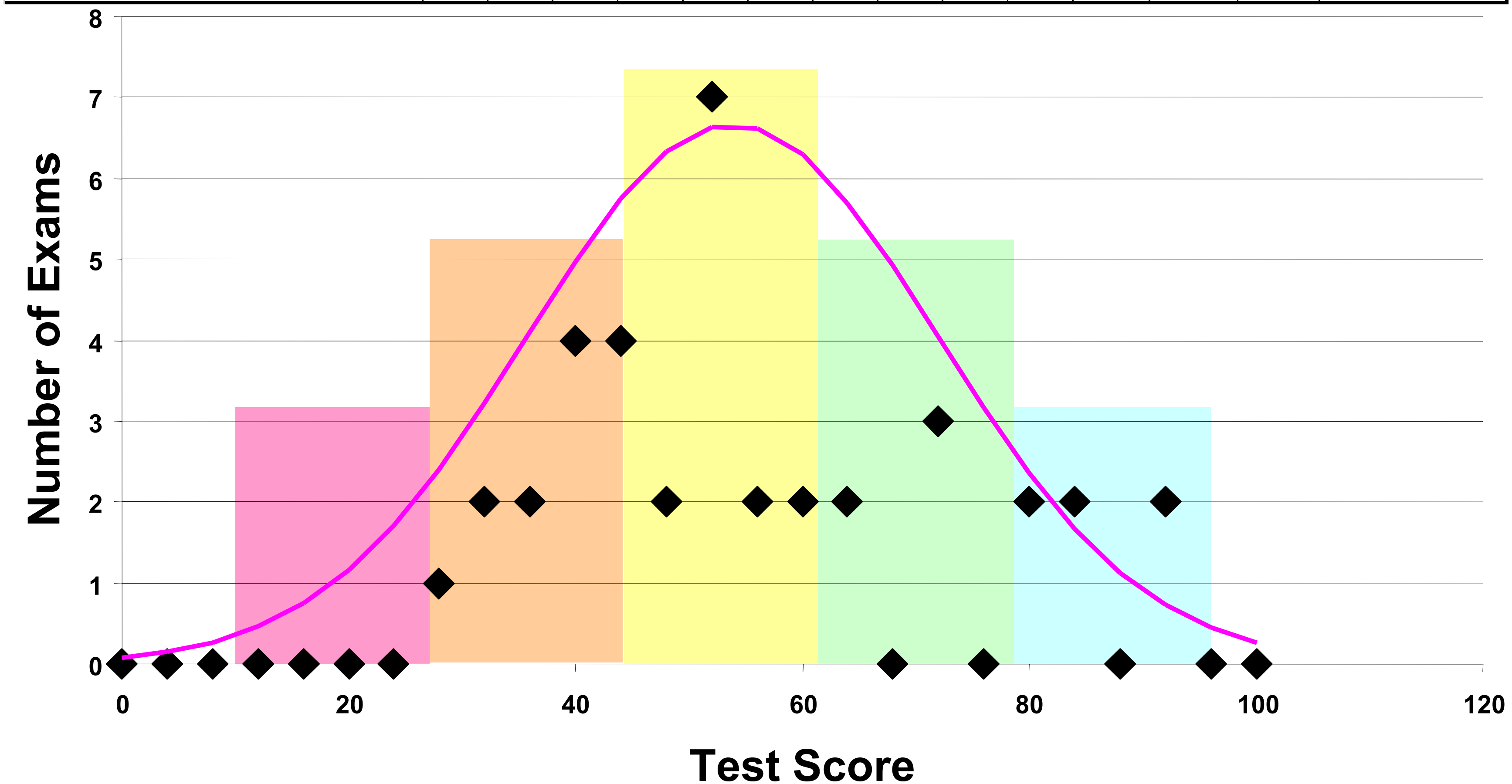
Instructions:
Read all the problems carefully and thoroughly before you begin working. You are allowed to use 1 new sheet of notes (1 page front and back), your note sheet from the previous exam as well as a calculator. There are 100 total points in this exam plus 10 points bonus (all or nothing, no partial credit). Observe the point value of each problem and allocate your time accordingly. SHOW ALL WORK AND CIRCLE YOUR FINAL ANSWER WITH THE PROPER UNITS INDICATED. Write legibly. If I cannot read it, it will be considered to be a wrong answer. Do all work on the paper provided. Turn in all scratch paper, even if it did not lead to an answer. Report any and all ethics violations to the instructor. Good luck!

Sign your name on **ONE** of the two following cases:

I DID NOT observe any ethical violations during this exam:

I observed an ethical violation during this exam:

Class Totals	#1	#2	#3	#4	#5	#6	#7	#8	#9a	#9b	#9c	#10-DC	#10-conv	#10-AC	Bonus a	Bonus b
Number of Tests=	37															
Point Value of problem=	5	5	5	5	5	5	5	5	9	6	5	15	10	15	10	5
Individual Problem Average=	51.5	35.2	49.7	90.9	54.5	69.1	69.1	50.3	39.7	56.1	26.7	40.2	43.0	32.5	3.0	12.1
Exam Average=	53.5															
Exam Standard Deviation=	17.7															
Exam Max=	91															
Exam Min=	26															



First 40% **Multiple Choice - Select the most correct answer(s)**

1.) (5-points) The concentration of minority carriers injected across a forward biased p-n junction…

a.) …increases exponentially as they move further away from the junction.
b.) …decreases exponentially as they move further away from the junction.
c.) ...is constant throughout the structure.
d.) …are blocked from crossing the junction by a large electric field.
e.) None of the above.

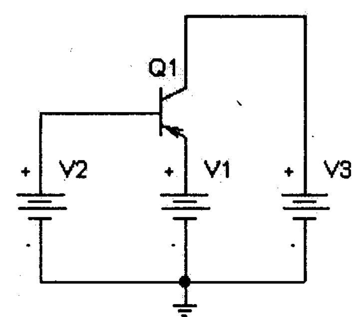
2.) (5-points) If the applied voltage of a forward biased p-n junction is increased from it's original value of (0.1 times V_{BI} where V_{BI} is the built in voltage) by 69.3% ...

a.) …the built in voltage is exceeded and the device will burn up.
b.) …the diode current will decrease by a factor of 2.
c.) …the diode current will increase by a factor of 2.
d.) …the diffusion capacitance will be decreased.
e.) both a and c

3.) (5-points) In a reverse biased p-n diode…

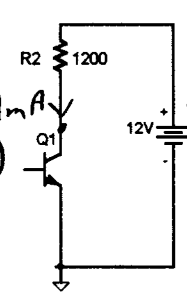
a.) …the small signal conductance is infinite.
b.) …the small signal conductance is zero.
c.) …the depletion capacitance is smaller than at zero bias
d.) …the depletion capacitance is larger than at zero bias
e.) both a and d
f.) both b and c

4.) (5-points) If an engineer wanted to bias this transistor into saturation mode, which of the following is true?



a. V3>V1 and V1>V3
b. V1>V2 and V3>V2
c. V2>V3 and V1>V3
d. V2>V1 and V2<V3
e. You cannot bias a transistor without resistors.

5.) (5–points) The power transistor in the circuit to the right is driven into cutoff and found to have a collector leakage current of 1 mA. What is the voltage on the collector, Vc referenced from ground?



1mA

$V_c = 12 - 1200(1e\text{-}3)$
$V_c = 10.8V$

a. 0V
b. 12V
c. 10.8 V
d. 1.2V
e. Not enough information given to solve.

6.) (5-points)
In a forward biased p-n junction:

a.) Most of the current is from drifting minority carriers.
b.) Most of the current is from diffusing majority carriers.
c.) The energy barrier for current flow is reduced.
d.) The energy barrier for current flow is enlarged.

7.) (5-points)
In a reverse biased p-n junction:

a.) Most of the current is from drifting minority carriers.
b.) Most of the current is from diffusing majority carriers.
c.) The energy barrier for current flow is reduced.
d.) The energy barrier for current flow is enlarged.

8.) (5-points)
Decreasing the base width…

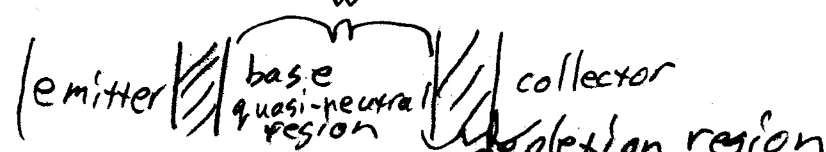
a.) …improves the common emitter current gain, β, but reduces the emitter injection efficiency, γ.
b.) … improves the common emitter current gain, β, improves the emitter injection efficiency, γ, but reduces the base transport factor α_T.
c.) … improves the common emitter current gain, β, improves the emitter injection efficiency, γ, improves the base transport factor α_T, but reduces the speed of the transistor.
d.) … improves the common emitter current gain, β, improves the emitter injection efficiency, γ, improves the base transport factor α_T, , improves the speed of the transistor but reduces the base-collector breakdown voltage.
e.) …is not a good idea because it can lead to a BJT with a poor self image.

20%

9.) (20-points) For the following questions concise answers are required. ***Points will be deducted for wordy or unclear statements***. In **3 short sentences or less**, using **simple** diagrams if necessary to explain, answer the following:

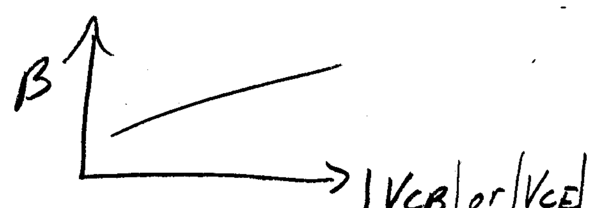
a.) (9 points) In a BJT, what is the "base width modulation effect"? Be sure your answer includes a description of which voltage change generates this effect.

As the magnitude of the reverse biased base-collector voltage, $|V_{CB}|$, increases, the increased depletion region consumes part of the base quasi-neutral region. This reduces the base " " " width, W.



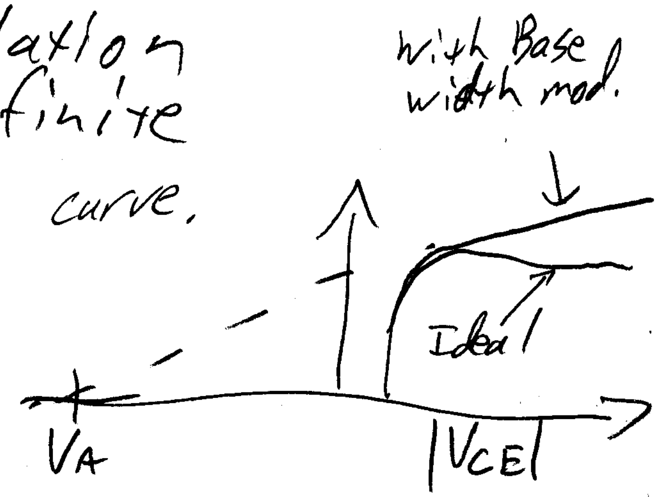
b.) (6 points) What consequence does this "base width modulation effect" have on the common emitter current gain, β?

A decreased W, resulting from a larger $|V_{CB}|$ results in a larger β $(\beta \propto \frac{1}{W})$. Thus, β becomes a function of $|V_{CB}|$



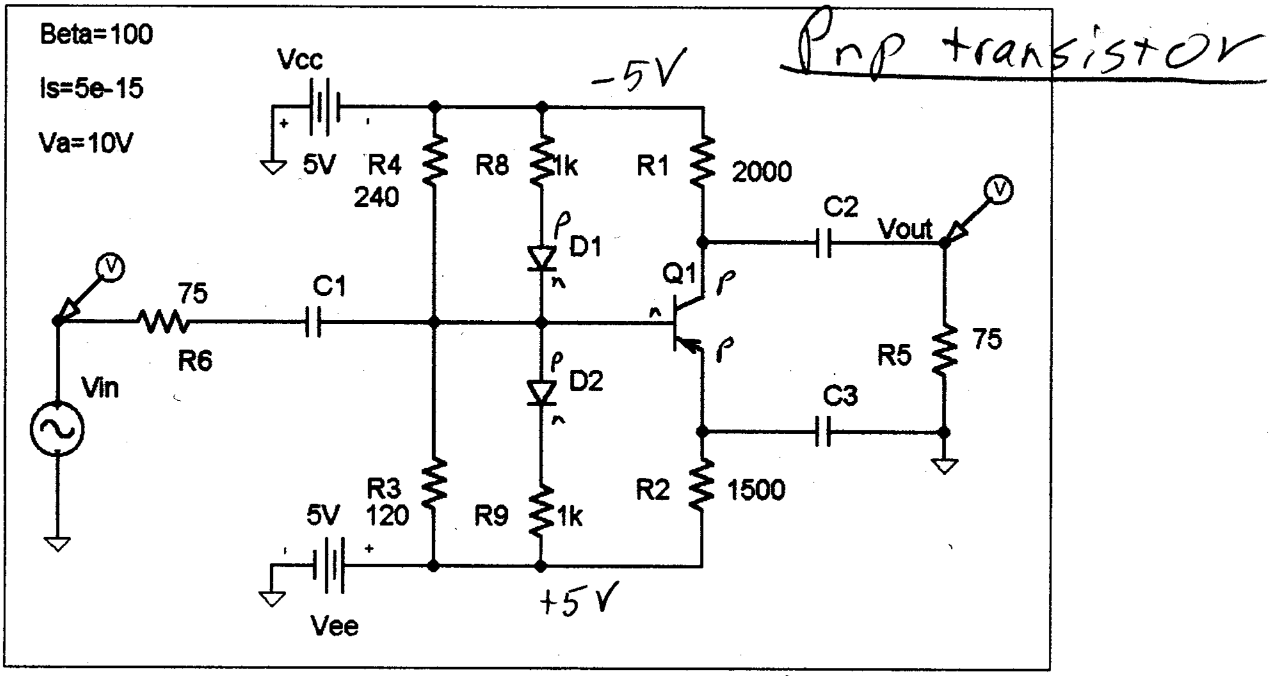
c.) (5 points) What consequence does this "base width modulation effect" have on the slope of the I_C vs V_{CE} current voltage characteristics?

The base width modulation effect results in a finite slope to the I_C vs V_{CE} curve. Thus, V_A is finite



(4^{th} Section - 40%) Pulling all the concepts together for a useful purpose:

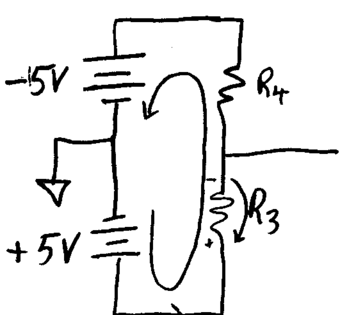
10.) (40-points) Given the following video amplifier circuit (takes a video signal from a 75 ohm transmission line represented by R6 and amplifies it into another 75 ohm transmission line represented by R5), what is the AC voltage gain, Vout/Vin? Assume: β_{DC}=100, Early voltage, V_A is 10V, turn on voltages for all forward biased junctions are 0.7 V, the saturation current, $I_S = I_o$=5e-15A for D1 and D2. You may assume all capacitors are very large values and are thus, AC shorts. Additionally consider the circuit to be operated at low frequencies where you can neglect all small signal capacitances. Also, neglect all resistances that result from quasi-neutral regions. *Hints: Use the CVD model for DC solutions.*



Small signal model of diodes are open circuits

Since D1 is in series with R8 and connects to −5V, D1 must be off.
Since D2 is in series with R9 and connects to +5V, D2 must be off.

DC:



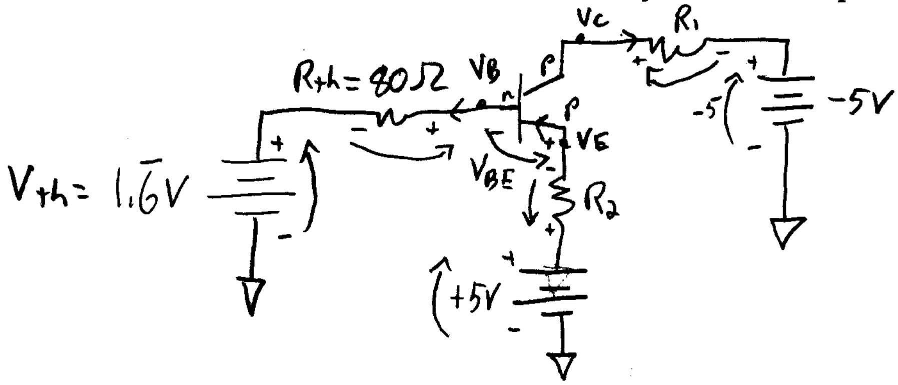
$R_{th} = R_4 \| R_3 = 80\,\Omega$

$V_{th} = 5V - IR_3$

$= 5V - (27.7e\text{-}3)120 = 1.\bar{6}\ V$

$I = \frac{10V}{R_4 + R_3} = 27.7mA$

Extra work can be done here, but clearly indicate with problem you are solving.



$$1.6\,V + I_B R_{th} + V_{BE} + I_E R_2 = 5V$$

$$I_B R_{th} + I_B(\beta+1)R_2 = 5V - 1.6 - 0.7$$

$$I_B = \frac{2.7V}{80 + 101(1500)}$$

$$\boxed{\begin{aligned} I_B &= 17.8\,\mu A \\ I_C &= \beta I_B = 1.78\,mA \\ I_E &= (\beta+1) I_B = 1.79\,mA \end{aligned}}$$

$V_B = 1.6V + (17.8\,\mu A)80\Omega$

$\boxed{V_B = 1.601V}$

$V_C = -5V + I_C R_1$

$= -5 + (1.78e\text{-}3)\,2000$

$\boxed{V_C = -1.44V}$

$V_E = 5V - I_E R_2$

$= 5V - (1.79e\text{-}3)1500$

$\boxed{V_E = 2.315V}$

Check: $V_E > V_B$ ✓
$V_C < V_B$ ✓ } Forward Active

pnp

Small Signal Parameters

$$g_m = \frac{I_C}{V_T} = \frac{1.78e\text{-}3}{0.0259}$$

$$\boxed{g_m = 0.0687\ \mho}$$

$$\beta = g_m r_\pi$$

$$\Rightarrow r_\pi = \frac{\beta}{g_m} =$$

$$\boxed{r_\pi = 1455\,\Omega}$$

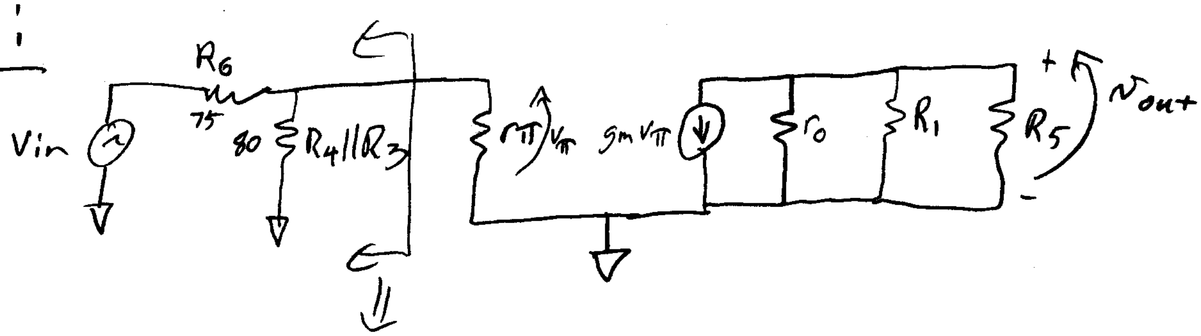
$$r_o = \frac{V_A + V_{EC}}{I_C}$$

$$= \frac{10 + (2.315 + 1.44)}{1.78e\text{-}3}$$

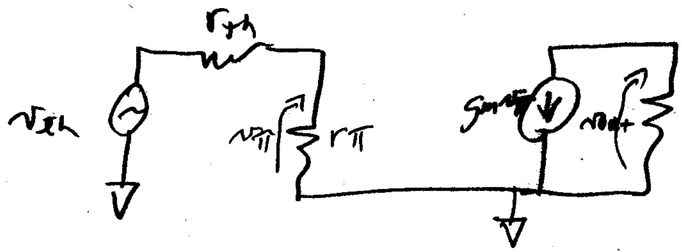
$$\boxed{r_o = 7{,}727\,\Omega}$$

Extra work can be done here, but clearly indicate with problem you are solving.

AC:



$$v_{th} = v_{in} \frac{R_4 \| R_3}{R_4 \| R_3 + R_6} \qquad r_{th} = R_4 \| R_3 \| R_6 = 38.71\Omega$$



$R_L = r_o \| R_1 \| R_5 = 71.6\Omega$

$$\frac{v_\pi}{v_{th}} = \frac{r_\pi}{r_\pi + r_{th}} \qquad \frac{v_{out+}}{v_\pi} = -g_m R_L$$

$$\frac{v_{out+}}{v_{in}} \quad A_v = \left(\frac{v_{th}}{v_{in}}\right)\left(\frac{v_\pi}{v_{th}}\right)\left(\frac{v_{out+}}{v_\pi}\right)$$

$$= \left(\frac{R_4 \| R_3}{R_4 \| R_3 + R_6}\right)\left(\frac{r_\pi}{r_\pi + r_{th}}\right)\left(-g_m R_L\right)$$

$$= \left(\frac{80}{80+75}\right)\left(\frac{1455}{1455+38.71}\right)\left[(-0.0687)\ 71.6\ \Omega\right]$$

$$\frac{v_{out+}}{v_{in}} = (0.516)(0.974)(-4.92)$$

$$\boxed{\frac{v_{out+}}{v_{in}} = -2.47\ V/V}$$

Told in class: Room Temp.

Bonus (15 points total – NO PARTIAL CREDIT!!!!):

A MURB1620CT is a Silicon 200 Volt, 16.0 Amp fast power diode (switches in ~25.0ns) from Diodes Inc. The SPICE model parameters downloaded from the web are:

IS=3.19n, RS=3.67m, BV=200, IBV=5.00u, CJO=225p, M=0.333, N=1.59, TT=36.0n

When the diode is driven into forward bias to it's rated current of 16 amps, the voltage across the diode (often called the forward voltage drop), the voltage across the junction (V_D, V_A or junction voltage) and the voltage across the series resistance (drop across the contact + quasi neutral region) are 0.9785, 0.9198, and 0.0587 volts respectively.

a.) (10 points) What is the voltage across the diode (forward voltage drop), the junction voltage and the voltage across the series resistance (contact + quasi neutral region) when a Clemson engineer drives it beyond it's rated current, to 100 Amps in forward bias?

$I_s = 3.19e\text{-}9\ A$

$R_s = 3.67e\text{-}3\ \Omega$

$N = \eta = 1.59$

$I = I_s\left(e^{(V_D - IR_s/\eta V_T)} - 1\right)$ or in forward bias, $I \approx I_s e^{((V_D - IR_s)/\eta V_T)}$

$I = I_s e^{V/\eta V_T} e^{-IR_s/\eta V_T}$

$\boxed{IR_s = 0.367 \text{ volts}} \Longrightarrow$ Voltage across contact + quas.

so solving for V

$V_A = V_D - IR_s$

$V_A = 1.2868 - 0.367$

$\boxed{V_A = 0.9198\ V}$

voltage across junction

$V_D = \eta V_T \ln\left(\frac{I}{I_s e^{-IR/\eta V_T}}\right)$

$= 1.59(0.0259) \ln\left[\frac{100}{(3.19e\text{-}9)\, e^{-0.367/(1.59\times 0.0259)}}\right]$

$\boxed{V_D = 1.2868\ V} \Rightarrow$ forward Voltage drop (voltage circuit "sees")

b.) (5 points) What is it's current when reverse biased to it's maximum rated reverse bias voltage of 200 V?

$I \approx -I_s$

$\boxed{I = -3.19e\text{-}9 \text{ Amps}}$