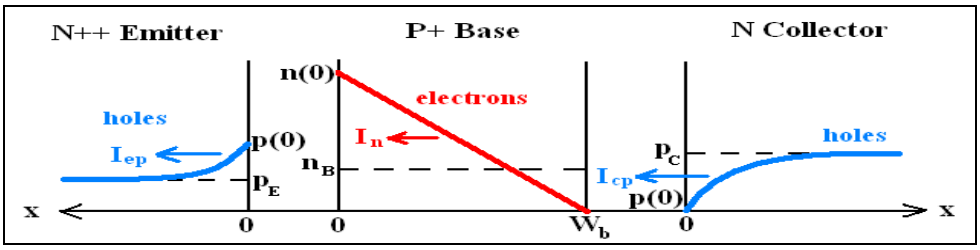
EE 330 Homework #4 Bipolar Junction Transistor Device Physics

1. The diagram below plots carrier profiles inside a Bipolar Junction Transistor (BJT). Use the diagram to answer the next several questions.



a. What type of BJT is shown: NPN or PNP?

b. Are the electrons shown in the base region majority or minority carriers?

c. Where do the electrons in the base region come from?

d. Are the holes in the emitter majority or minority carriers?

e. Where do the holes in the emitter come from?

f. The electron gradient shown in the base region causes electron diffusion. Do these electrons diffuse to the right or to the left in this diagram?

g. Which region do the diffusing electrons in the base region eventually end up at?

h. Why is the electron current I_n shown going to the left?

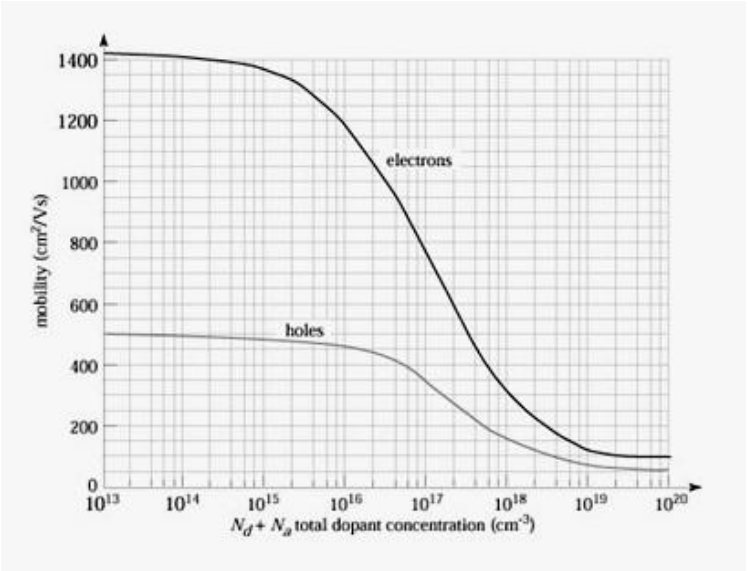
i. Using quantities shown in the diagram, write a simple expression for the *electron gradient* in the base.

2. Calculate the collector, base, and emitter currents and beta for a NPN BJT with the following specifications:

Emitter doping: 1E18 cm^{-3}
Base doping: 1E17 cm^{-3}
Collector doping: 1E16 cm^{-3}
Base width: 0.2 um
Emitter width: 1.0 um
V_{BE} = 0.7 volts
Junction area = 1000 um^2
Carrier lifetime = 10 us

Hints: Be sure to watch units (use cm). Use the plot shown and the Einstein Relation to calculate diffusivities.

Answer check: $I_C \approx 1.8$ mA $I_B \approx 6.9$ uA $I_E \approx 1.8$ mA $\beta \approx 260$



3. Calculate the current I_{CP} for the transistor described in Problem (2). Hint: See previous chapter lecture notes for the method of calculating diffusion length from the diffusivity and lifetime.

Answer check: 4×10^{-17} A

4. Calculate the base transit time τ_B for the BJT described in the last 2 questions. What is the speed of the electrons (in meters/second) as they move across the base region? Convert the speed to mph.

Partial Answer check: 45,000 mph

5. Use the value of I_C calculated in Problem #2 along with τ_B to calculate the amount of minority carrier (electron) charge in the base of this BJT. How many electrons does this amount to?

Partial Answer check: 112,000 e^-

6. Calculate the transconductance g_m of the BJT described in Problem #2.

Answer check: 70 mA/V

7. A BJT with I_S = 5 fA (f = femto) is biased with V_{BE} = 0.7 volts. What is the value of collector current?

Answer check: 2.46 mA

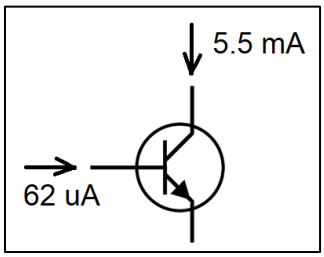
8. A BJT has a measured collector current of 120 uA at V_{BE} = 0.6 volts. What is I_S for this transistor?

Answer check: 1.14×10^{-14} A

9. A BJT with $I_S = 1 \times 10^{-14}$ A has I_C = 1 mA. What is the value of V_{BE}?

Answer check: 0.658 V

10. Measurements are recorded of the currents as shown in the diagram.



a. Is this an NPN or PNP transistor?

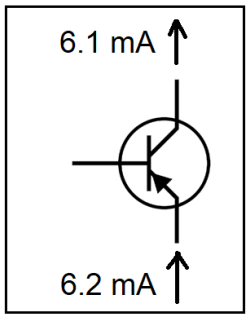
b. Calculate the emitter current.

c. Does emitter current flow into or out of this type of BJT?

d. Calculate beta.

e. Calculate alpha. **Answer check: 0.989**

11. Measurements are recorded of the currents as shown in the diagram.



a. Is this an NPN or PNP device?

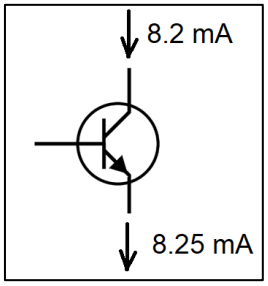
b. Calculate the base current.

c. Does base current flow into or out of this type of BJT?

d. Calculate beta. **Answer check: 61**

e. Calculate alpha.

12. Measurements are recorded of the currents as shown in the diagram.



a. NPN or PNP device?

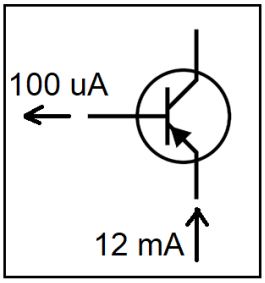
b. Calculate the base current.

c. Does base current flow into or out of this type of BJT?

d. Calculate alpha

e. Calculate beta **Answer check: 164**

13. Measurements are recorded of the currents as shown in the diagram.



a. NPN or PNP device?

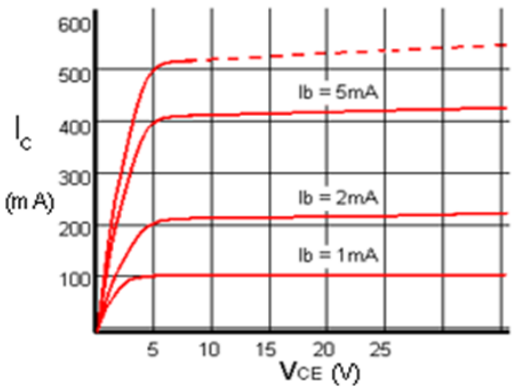
b. Calculate the collector current.

c. Does collector current flow into or out of this type of BJT?

d. Calculate alpha **Answer check: 0.992**

e. Calculate beta

14. The plot shows a typical "family of curves" for a power BJT.



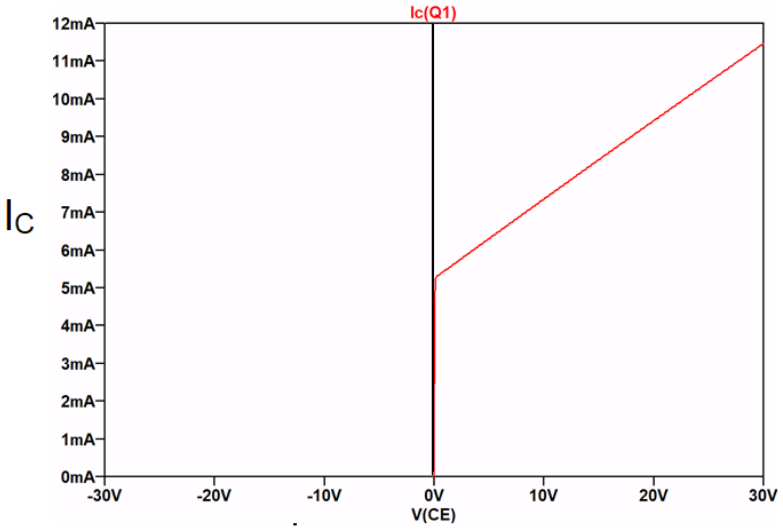
a. What is beta at I_B = 1 mA for this transistor?

b. What is beta at I_B = 5 mA and V_{CE} = 5 volts?
Answer check: 80

c. Estimate beta at I_B = 5 mA and V_{CE} = 1 volts. Why is beta lower at V_{CE} = 1 than at V_{CE} = 5?

d. Estimate beta at I_B = 5 mA and V_{CE} = 35 volts. Why is beta higher at V_{CE} = 35 than at V_{CE} = 5?

15. Shown is a plot of I_C vs. V_{CE} for a BJT that exhibits the Early effect.



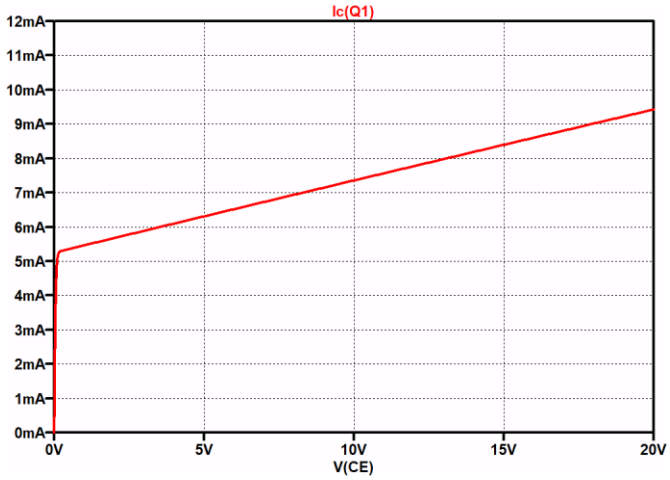
a. Estimate the Early voltage V_A by extrapolating the curve.

b. Estimate the transistor's output resistance Ro.

Answer check: 4.8kΩ

16. There is another way to determine the Early voltage V_A from the I_C vs V_{CE} plot using this formula:

$$V_A = \frac{I_{C0}}{m} \quad where \quad \begin{cases} I_{C0} = I_C \text{ at } V_{CE} = 0 \\ \text{m = slope of curve} \end{cases}$$



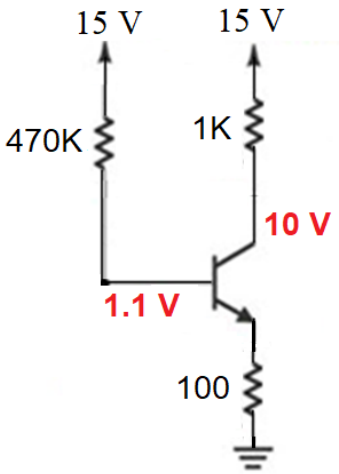
a. What is the value of I_{CO}?

b. Calculate the slope of the curve.

c. Calculate V_A.

d. How does V_A compare to the value obtained in the last problem?

17. This problem is a glimpse of what we will be doing next in this course. The circuit shown consists of a BJT, 3 resistors, and a 15V power supply. The voltages shown in red were measured with a voltmeter.



a. Calculate the collector current.

b. Calculate the base current.

c. Calculate the transistor's beta.

d. Calculate the emitter current.

e. Calculate the value of the voltage at the emitter terminal of the BJT.

f. Calculate V_{BE} **Answer check: 0.597**