8 - BJT Currents

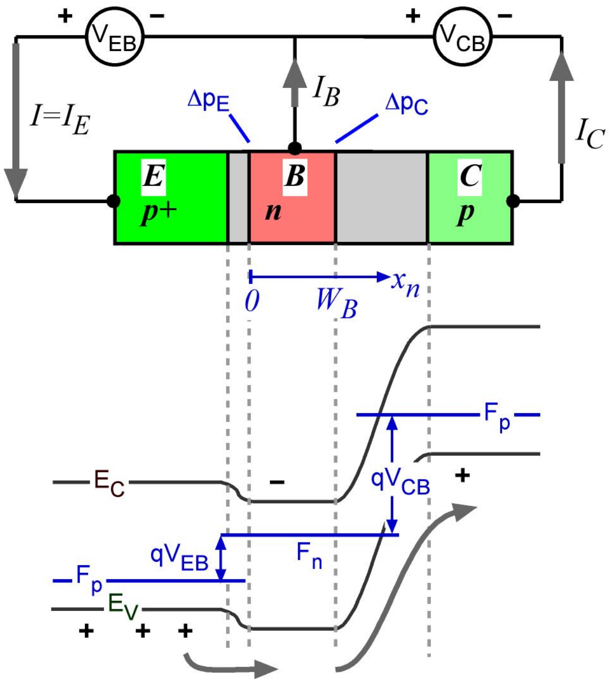
Name:______________________________

Agenda: (1) review the quiz / (2) 5 minutes minimum for lecture questions and review / (3) start the problems!

In-Class Problems

(1) See the equations below for the terminal currents of a PNP BJT.

(a) because all three current equations are similar you only have to choose one, for the one you choose, substitute in all the terms for Δp_E and write the resulting equation with blue marker for all terms that are part of I_0, green for all terms that are the rest of the standard diode equation (voltage dependence), and red for the terms that make this different than just a diode by accounting for current amplification.



$$\Delta p_E = p_n\left(e^{qV_{EB}/kT} - 1\right)$$

$$I_{Ep} \approx qA\frac{D_p}{L_p}\Delta p_E \,\mathbf{ctnh}\frac{W_b}{L_p}$$

$$I_C \approx qA\frac{D_p}{L_p}\Delta p_E \,\mathbf{csch}\frac{W_b}{L_p}$$

$$I_B \approx qA\frac{D_p}{L_p}\Delta p_E \,\mathbf{tanh}\frac{W_b}{2L_p}$$

$I_C = qA(D_p/L_p)*p_n(e^{qV/kT}-1)\mathrm{csch}(W_b/L_p)$

(b) rewrite the equation you chose above again, but for the case of an NPN BJT. Don't overthink this, I just want you to see that it is simple and that we don't have to re-derive everything for NPN. *Note, the current direction will change for NPN BJT but that is taken care of by 'q' (electrons vs. holes).*

$I_C = qA(D_n/L_n)*n_p(e^{qV/kT}-1)\mathrm{csch}(W_b/L_n)$

… note the q out front. For NPN the current is electrons, of negative charge, and therefore current flow direction is in the opposite direction.

… hey, what about the Q in the exponential? Does it change? Yes! But the emitter base voltage is reversed too for NPN, so the overall term in the exponent stays positive!

(c) All the semiconductor terms (D, L, p, etc), for which region of the BJT are they from, E, B, or C?

… all the terms are from the base, the region that makes a BJT a BJT! And, if emitter-base voltage is inside the equation, then that diode equation is for emitter-base, which is p+n and half of the Io terms (for the p+ side) can be neglected because they are very small.

(2) Some calculations, we will take it one step at a time…. consider a Symmetrical p+-n-p+ BJT:

N_D= $5\text{x}10^{14}$/cc
W_B= 0.01 x L_p (in the base)
V_{EC}= 10 V

$$qA\frac{D_p}{L_p}p_n = 0.2pA$$

$$I_{Ep} \approx qA\frac{D_p}{L_p}\Delta p_E \ \text{ctnh}\frac{W_b}{L_p}$$

$$I_C \approx qA\frac{D_p}{L_p}\Delta p_E \ \text{csch}\frac{W_b}{L_p}$$

$$I_B \approx qA\frac{D_p}{L_p}\Delta p_E \tanh\frac{W_b}{2L_p}$$

Keep your calculations simple using only the equations above and the diode equations! This will test if you really understand the above equations (more than just 'plug and chug' with equations).

The lecture slides have a lot of the information that you need (for example, same Wb/Lp ratio as that in slides, but note, the lecture video slides have an error as tanh($W_b/2L_p$) = 0.005, not 0.01 (I forgot to divide by 2).

(a) Calculate the excess of holes in the base at the edge of the EB depletion region for a forward bias of 0.3 V across the EB junction. *Hint, this is a simple equation, found on slide 4 and slide 19.*

p_n=$(1.5\text{x}10^{10})^2/5\text{x}10^{14}$=$4.5\text{x}10^5$/cc
Δp_E= p_n x e^(0.3/0.0259)=$4.5\text{x}10^{10}$ / cc

(b) Calculate the emitter current for a forward bias of 0.3 V across the EB junction. You can do this without the answer from (a) if you are smart about it! *Hint, I already calculated a lot of what you need in the information presented.*

From the lecture slides, ctnh part of I_E will be about 100, therefore.

Therefore I_E ~ 0.2pA x e^(0.3/0.0259) x 100 ~ 2.1 μA.

(c) This should be real easy too (not require a ton of calculations): calculate the base current for a forward bias of 0.3 V across the EB junction. *Hint for one way to do this (there are two ways): calculate Beta using ratios of uncommon terms between Ic and Ib, and then if Ie and Ic are really close, just use amplification factor and Ie to calculate Ib. You will find a very large amplification factor, which means Ie and Ic are almost identical (Ib is really small).*

tanh($W_b/2L_p$) part of I_B will be about 0.005, therefore and amplification factor Ic/Ib of 20,000.

I_B =I_E /20,000 = 105 pA,, or do another way I_E ~ 0.2pA x e^(0.3/0.0259) x 0.005 ~ 105 pA

(d) This should be super easy: calculate the collector current for a forward bias of 0.3 V across the EB junction.

Should be about same as I_E since I_B is so small! I_E-I_B=I_C

(e) For the case described in (b) if we added one additional electron to the base, on average how many more holes would be in the base at any given time.

1, we need to maintain charge neutrality.

(f) For the case described in (b) and (c) if we added one additional electron to the base, and that electron had a lifetime of 10 μs, on average how many holes would be collected by the collector within 10 μs after the electron was added to the base. *This is also simple… (sort of, if you can see how to solve it).*

This is easy, this is the whole point of BJT amplification, 20,000 holes would get by before the electron recombined.

(g) Tougher question, for (f) how many holes need to be emitted? *I know it is close to the answer for (f), but give me the exact number so it shows me you understand how the BJT works.*

20000+1=20001, you need one more emitted hole to recombine with the one electron in the base..

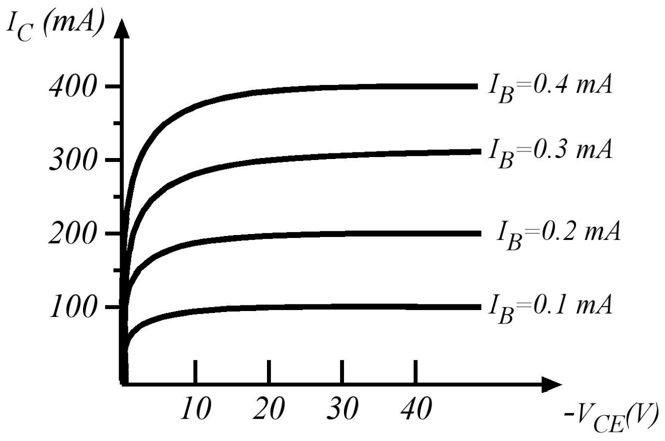
(h) In the lab, you measure that the maximum current you can obtain for this BJT is 1 mA. What is the output resistance of this BJT?

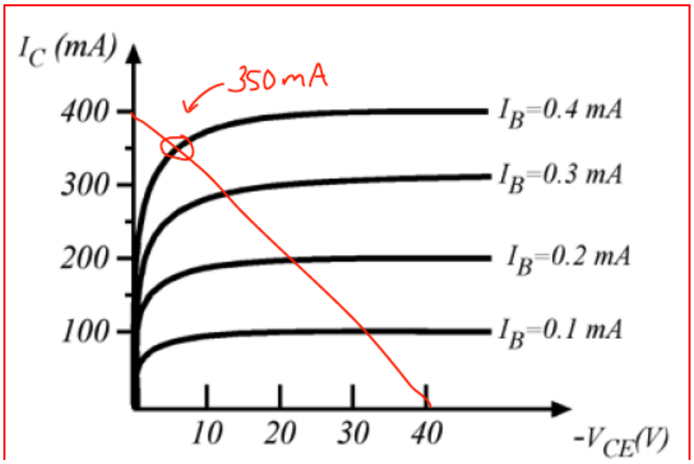
10V/1mA = 10,000 Ω

(i) In the lab, you cut the wire going to the base terminal. What will the voltage drop be across the base-collector region?

10V, there is no current flow so all the voltage must drop across the reverse biased BC junction.

(3) Consider the BJT with the following stand-alone Ic vs. Vce characteristic. Using load-line, graphically determine the collector current for a base current (I_B) of 0.4 mA. Assume the BJT externally is powered with 40 V power supply, and that the collector (which is the output of the device) has a resistance of 100 ohms.





(4) True or false, for a PNP BJT setup for normal amplification, assume an amplification factor of 100.

(a) [✓ TRUE] / FALSE : Collector current changes proportionally (linearly) with change in base current.

(b) [✓ TRUE] / FALSE : Hole drift across the base-collector increases exponentially with voltage across the emitter-base.

(c) TRUE / [✓ FALSE] : If 400 holes are collected, then we know that 400 holes are emitted.

(d) TRUE / [✓ FALSE] : At any given time, there will be 100 extra holes than electrons in the base .

(e) [✓ TRUE] / FALSE : IC saturation with increasing VCE occurs because once you have the base-collector reverse biased the collector is all setup to collect holes as drift current.

(5) For the diagram below, label the currents in order from LARGEST in magnitude to SMALLEST in magnitude. Just list them as numbers, such as 1,6,4,5,3,2. You may assume forward bias electron diffusion 5 is greater than reverse saturation electron and hole drift 6. If two currents are equal, you may note that by circling both of them in your answer. Note, only two of the currents are equal (the rest have a clear ordering).

Answer: 1, 2, 3=4, 6, 5 (5 is less than 6 because 6 is for pn and 5 is for p+n and Io goes down as doping increases)