EECS 2077
Semiconductor Devices

7 - BJT Intro and Switching　　　　Name:____________________________

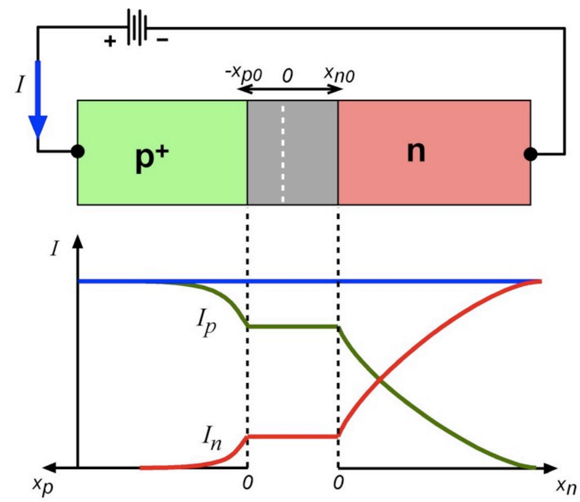
In-Class Problems

(1) For a PNP BJT, the emitter is typically p+ and the base lightly doped n-type. This is one of the factors that helps a small base current cause a large emitter-to-collector current. See the equations below for when we derived the diode current equation.

a) for the p+n diode parameters listed below, in forward bias, how many more holes are injected to the right vs. electrons injected toward the left? *Hint: just divide Jp/Jn, eliminate common terms, and give me the ratio between the two. Remember, it should show us LOTS of hole current vs. very small electron current (so we can get amplification).*

<u>p-side:</u>
$N_a = 10^{17}/cm^3$
$n_p = 2.25\times10^3/cc$
$D_n = 18\ cm^2/sec$
$L_n = 10^{-3}$ cm

<u>n-side:</u>
$N_d = 10^{15}/cm^3$
$p_n = 2.25\times10^5/cc$
$D_p = 25\ cm^2/sec$
$L_p = 10^{-2}$ cm

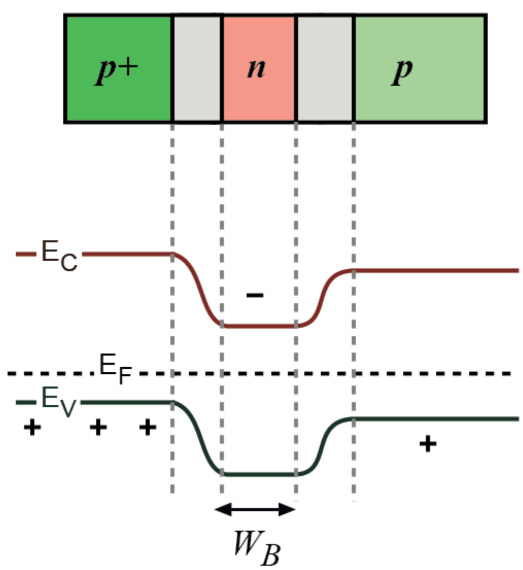


$$J_p(x_n = 0) = q\frac{D_p}{L_p}p_n(e^{qV/kT} - 1)$$

$$J_n(x_p = 0) = -q\frac{D_n}{L_n}n_p(e^{qV/kT} - 1)$$

Jp/Jn=100*(25/18)*(0.001/0.01) = 13.89, holes dominate!

(b) wait? We will take this same BJT problem next class, and calculate amplification factor and find out that it will be in the <u>hundreds</u>. How can that be then? For part (a) above, you will find Jn is only about 13X less than Jp, so that would be an amplification factor at best of 13? Right? What is going on?! See if you can figure it out. Look at the diagram below, the diagram is for diode with n and p regions that are LONG on both sides. *Hint, remember for a carrier to either drift, or <u>diffuse</u> over, it has to be roughly within a diffusion length of the depletion region (if not, it recombines before it can make it across). So for a BJT, in the base region, are we able to tap into all the electrons that coud diffuse over for a normal diode, or not? Often W_b is ~1 μm and L_n is often 100 μm or more!*



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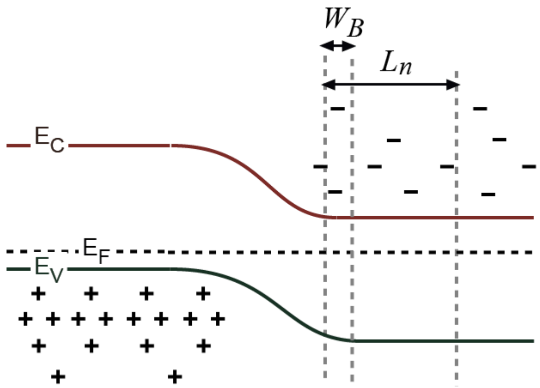


Answer: the number electrons available is truncated by Wb, so the ration of Jp to Jn for a BJT is actually MUCH MUCH larger!

(c) so now we have LOTS holes injecting from the p+ emitter into the lightly doped n-type base, and it required very few electrons to be injected from the base to the emitter. Next we need to add a collector and to have a narrow base (see diagram at right). As holes try to make it across the base to the collector, explain why we need to have a narrow base.

So they don't recombine with electrons as much, which reduces the needed Ib, and increases Ic/Ib (amplification). It's like a football player trying to run 10 yards vs. 100 yards without being tackled. The longer you go, the more tacklers you need to get through (tacker's being the same as an electron trying to recombine with the hole).

(d) for your answer to (c), does having a lightly doped base also help in the same way?

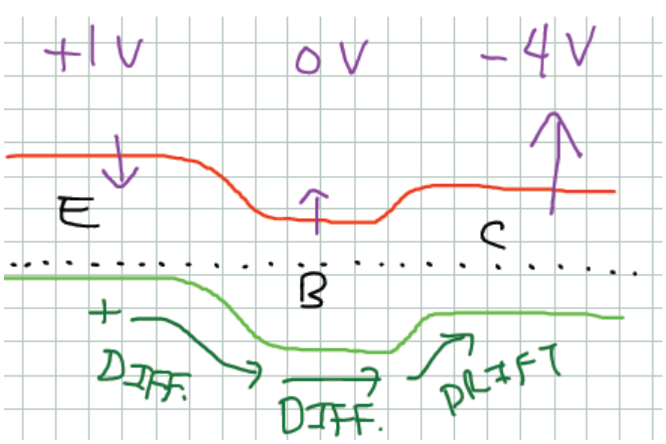
Yes! The analogy this time, is LESS football players trying to tackle you!

(2) Draw the band-diagram shown for question 1. Make sure the Fermi level positions are like that shown (represent the doping levels). Then…

(a) Label each region (emitter, base, and collector) using only these voltages as options (0V, +1V, -4V) as they would be under normal active mode (small base current being amplified into a large collector current). *The voltages are not in the right order above, you have to figure out the order!*

(b) Draw with up or down arrows, how the bands are relatively shifted by applied voltage.

(c) Lastly, label the three major drivers of hole current across the BJT as DIFFUSION or DRIFT. These regions are emitter-to-base, across the base, and base-to-collector. Make sure you understand why for each also!



(d) See the spec sheet I-V curves below. Why is I_C exponential vs. V_{BE}? The answer is simple. (ignore the temperature dependences, we will discuss that later).

Because it is a diode being turned on in forward bias, right?!

(e) See the spec sheet I-V curves below. For Ic vs. Vce, what is the amplification factor (Beta)? To be sure, pick 2 or 3 base-currents and collector currents to calculate Beta.

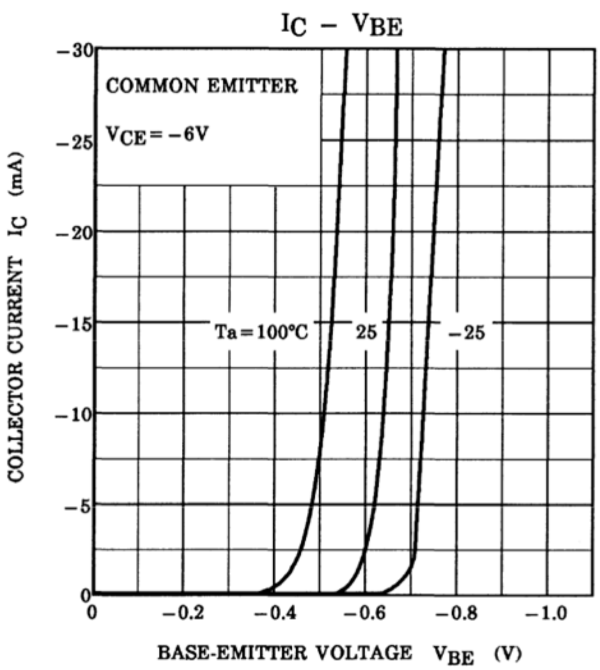
I'll measure at Vce = 4 V: 3.6 mA / 9 μA ~ 400 or so, 2 mA / 5 μA ~ 400 or so…

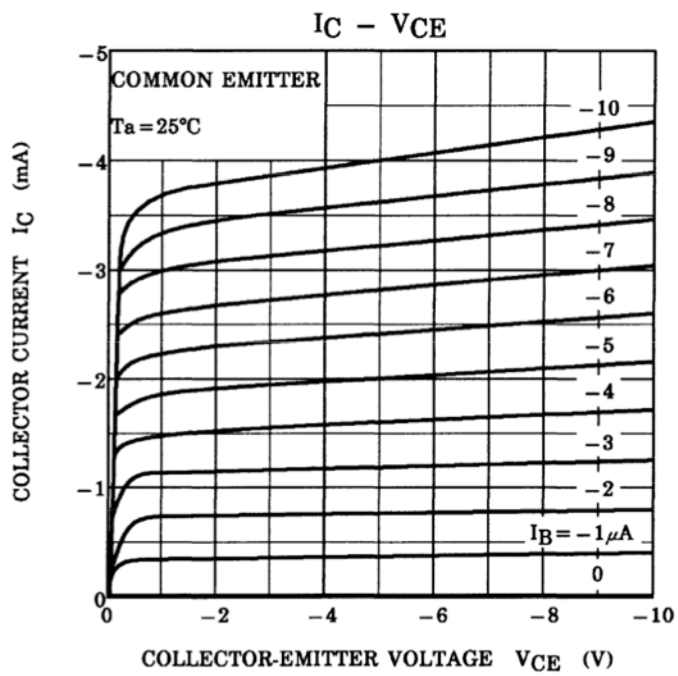
(f) See the spec sheet I-V curves below. As Vce is increased it takes a little bit (looks like ~0.5V) to get the BJT amplification going. Question: basically all the Vce voltage drop occurs where in the BJT? … and why is the collector current fairly constant as V_{CE} is further increased?

All Vce is applied across the base-collector. The base-collector is reverse biased, and reverse bias current is DRIFT and independent of voltage (so Ic is fairly constant with Vce).

(g) <u>Discover ahead for yourself!</u> Based on your answer to (f), that increasing Vce should increase the base-collector depletion region, right? An increasing depletion region should cut into the base and reduce Wb (the un-depleted width of the n-type base). So, if increasing Vce reduces Wb a bit, then why the slight positive slope for Ic vs. Vce?

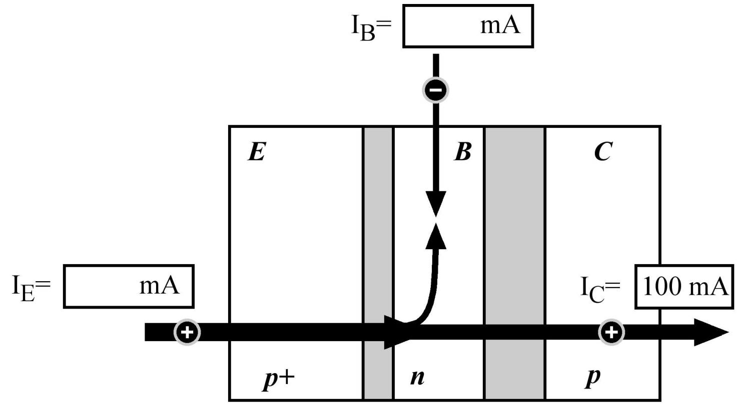
Increase Vce → Increase Vbc → Increase depletion width for bc (Wbc) → Reduce Wb → and a smaller Wb causes less holes to recombine w/ electrons in the base, which gives a larger Ic/Ib or a larger beta (amplification factor). So, the positive slope you see is the amplification factor increasing as you increase Vce!



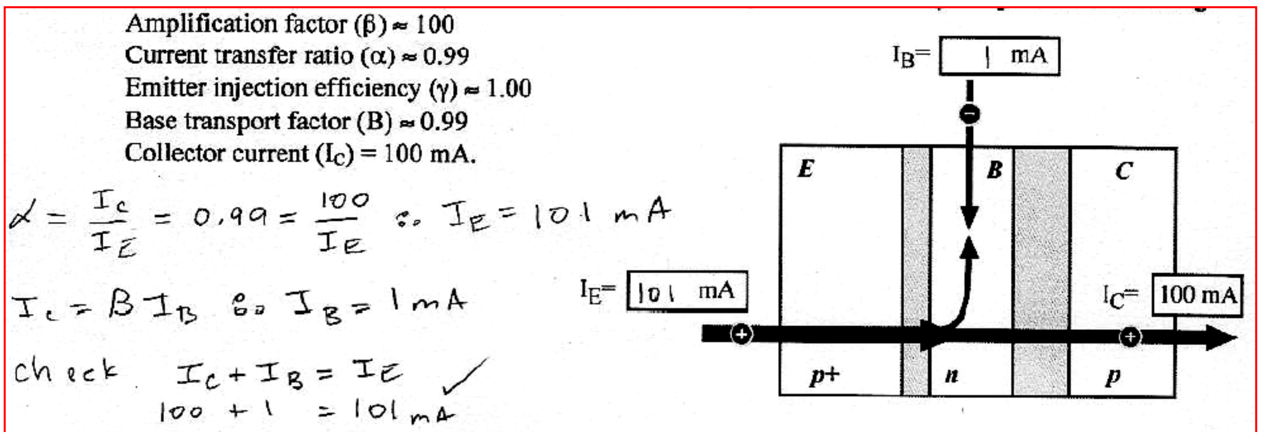


(3) Consider a PNP BJT. Calculate and label the magnitudes of each current component on the diagram given the following.

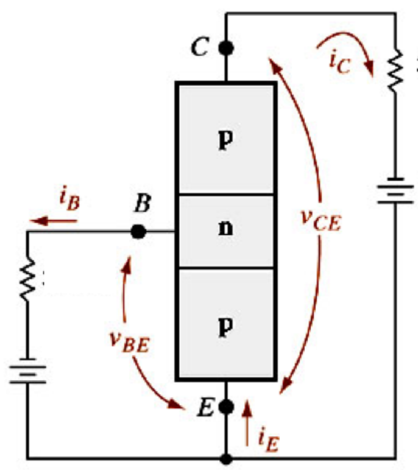
Amplification factor (β) ≈ 100
Current transfer ratio (α) ≈ 0.99
Emitter injection efficiency (γ) ≈ 1.00
Base transport factor (B) ≈ 0.99



Collector current (IC) = 100 mA.



(4) Draw a common emitter PNP BJT circuit (see image at right for an example), and for Vbe have a 10 kΩ resistor, and for Vce have a 500 Ω output resistance. Assume the amplification factor is 100. If we apply 1 V to forward bias the emitter base, and 20 V across the emitter and collector to setup the base-collector as reverse biased, what will the voltage drop be:



(a) across the output resistance;
(b) across the reverse biased based-collector.

Ib = 1V / 10E3 ohms, or 0.1 mA,

Therefore Ic = 0.01 A

Therefore votlage across output resistor is 500 ohm * 0.01 A or 5 V

Therefore the voltage drop across the base-collector is 15 V.

Interesting, that mean 150 mW are being consumed by the BJT (current x voltage across it). Make sure we cool it with a heat sink so it does not burn up!

(5) Drift vs. diffusion in a BJT! Circle or underline all that apply.

(a) type of current coming from the emitter: drift / diffusion / recombination
(b) type of current coming out the collector: drift / diffusion / recombination
(c) for a well designed BJT, dominates the base current: drift / diffusion / recombination
(d) drives emitter to collector current across the base: drift / diffusion / recombination

(6) Consider an NPN BJT biased such for normal operation (base current amplified into larger emitter to collector current). Assume the emitter is heavily doped and the base and collector lightly doped.

(a) [5 pts] draw a band diagram for an NPN BJT (not PNP like we did in class). Include Fermi levels and indicate voltage drops using the offsets between Fermi levels. Label the E, B, and C, regions.

(b) [5 pts] label the direction of emitter to collector current (remember e's move in opposite direction of current flow)

(c) [5 pts] for electron current, label where they are driven by a concentration gradient (CG), where they are driven by electric field (EF), and where it is caused by recombination (R).