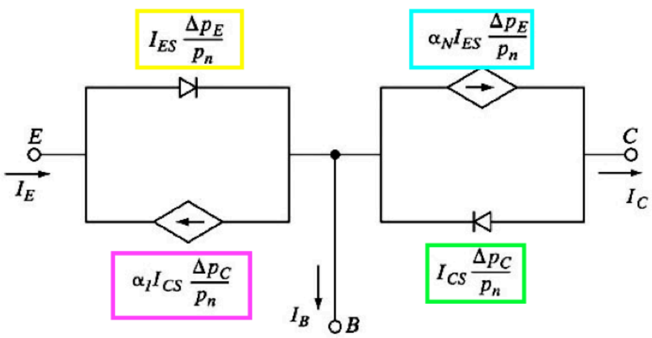
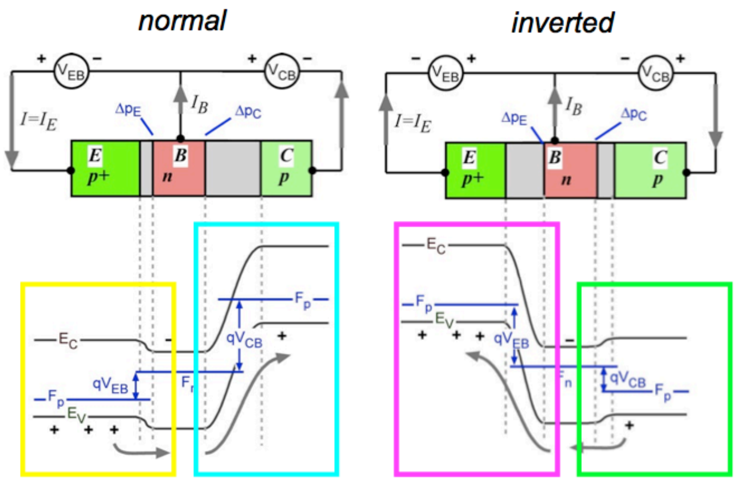
9 - BJT Coupled Diode

Name:______________________________

In-Class Problems

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



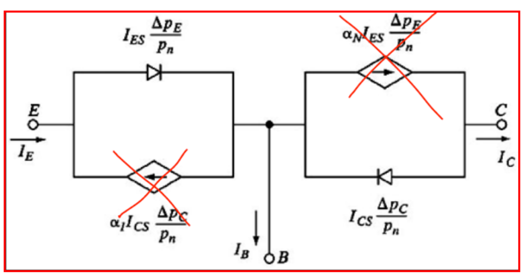


(1) First, some 'understanding / conceptual' questions for the coupled diode model….

(a) to what part of the BJT does the p_n belong to, E, B, or C?

Is holes in n-type material (minority carrier). So B!

(b) draw X's over, or just say, the components you would delete from the circuit if W_b became very large.



(c) TRUE or FALSE : The current sources represent a diode that is reversed biased, and simply capturing current sent to it across the base from a diode that is forward biased.

(d) TRUE or FALSE : a current source is an electronic component that delivers an electric current which is independent of the voltage across it, and that is why we use current sources in the coupled diode model when 'collecting' current.

(e) For the diodes in the model, circle or underline which type of current(s) that they practically represent:

recombination drift diffusion reverse saturation white-water rapids

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(f) For the current sources in the model, circle or underline which type of current(s) that they practically represent:

recombination   drift   diffusion   reverse saturation   white-water rapids without a paddle

(g) For the *base terminal* current, circle or underline which type of current(s) dominate in causing the required the base current:

recombination   drift   diffusion   reverse saturation   ouch, doorknob static-electricity shock

(h) If the BJT emitter and collector were both doped at the same level, and if we forward biased both the emitter-base and collector-base with the same voltage, the base current would be… (trust the model):

__ very large, two forward biased diodes feeding into the base!
__ medium, would have a concentration gradient across the base.
_X_ very small, no concentration gradient across the base, and base current would be limited to recombination.
__ can't tell, the model does not predict this at all…

(2) Now for a calculation problem, lets solve for ALL the values in the coupled diode model! Lets make it a bit simpler, just consider a symmetrical p⁺-n-p⁺ BJT and some key equations…

Emitter = Collector	Base	
$N_a = 10^{17}/cc$	$N_d = 10^{15}/cc$	
$\tau_n = 0.1\,\mu s$	$\tau_p = 10\,\mu s$	
$\mu_p = 200\ cm^2/V-s$	$\mu_n = 1300\ cm^2/V-s$	$A = 10^{-4}\,cm^2$
$\mu_n = 700\ cm^2/V-s$	$\mu_p = 450\ cm^2/V-s$	$W_b = 1\mu m$

$$p_n = n_i^2 / n_n \qquad D_p/\mu_p = kT/q \Rightarrow \quad D_p = \mu_p kT/q \qquad L_p = \sqrt{D_p \times \tau_p}$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{B\gamma}{1-B\gamma} \qquad \alpha = \frac{i_C}{i_E} = \frac{B i_{Ep}}{i_{En} + i_{Ep}} = B\gamma \qquad B = \operatorname{sec}h \frac{W_b}{L_p}$$

$$\gamma = \left[1 + \frac{L_p^n}{\mu_p^n}\frac{\mu_n^p}{L_n^p}\frac{n_n}{p_p}\tanh\frac{W_b}{L_p^n}\right]^{-1}$$

(a) Calculate p_n, Ies and Ics… Some hints are below…

- We have these equations… Need I_{ES}, I_{CS}. I can't just use the I_0 equation we learned for the regular diode, because these are NOT regular diodes! So what should we do?

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

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

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

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

- Easy! Just remove the voltage dependence part, and what is left, MUST be reverse saturation current…

$$I_{EN} = qA\frac{D_p}{L_p}\Delta p_E \ \mathrm{ctnh}\frac{W_b}{L_p}$$

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

$\therefore$ *in reverse bias:*

$$I_{ES} = I_{CS} = qA\frac{D_p}{L_p}p_n \ \mathrm{ctnh}\frac{W_b}{L_p}$$

Reminder, I_{ES} = I_{CS} because is symmetrically doped!

$$p_n = n_i^2/n_n = (1.5\times10^{10})^2/10^{15} = 2.25\times10^5 \ /cc$$

$$D_p/\mu_p = kT/q \quad \therefore \quad D_p = 450\times0.0259 = 11.66\,cm^2/s$$

$$L_p = \sqrt{D_p\times\tau_p} = \sqrt{11.66\times10\times10^{-6}} = 1.08\times10^{-2}\ cm$$

$$I_{ES} = (1.6\times10^{-19})(10^{-4})(11.66/1.08\times10^{-2})(2.25\times10^5)ctnh(10^{-4}/1.08\times10^{-2})$$

$$I_{ES} = I_{CS} = 4.2\times10^{-13}\ A$$

Note, if the BJT for this problem was NOT symmetrically doped, you would have to separately calculate Ics using its hyperbolic trig function instead.

~~(b) So at this point, the only things missing for the model are then the current transfer ratios! Calculate the current transfer ratios, and then go ahead and calculate amplification factor from that.~~

$$B = \sec h\frac{W_b}{L_p} = 0.99996$$

$$D_n = \mu_n\times kT/q = 18.13\ cm/s$$

$$L_n = \sqrt{D_n\times\tau_n} = 1.35\times10^{-3}\ /cm$$

$$\gamma = \left[1 + \frac{L_p^n}{\mu_p^n}\frac{\mu_n^p}{L_n^p}\frac{n_n}{p_p}\tanh\frac{W_b}{L_p^n}\right]^{-1}$$

$$\gamma = \left[1 + 0.124\times\tanh\frac{W_b}{L_p^n}\right]^{-1} = 0.99885$$

$$\alpha_N = \alpha_I = B\gamma = 0.99881$$

$$\beta = \frac{\alpha}{1-\alpha} = \frac{B\gamma}{1-B\gamma} = 832$$

~~*Note, if the BJT for this problem was NOT symmetrically doped, you would have to separately calculate the inverted mode current transfer ratio. Above, we pulled all the terms from the emitter-base for*~~

~~*normal mode, and for inverted mode, you would need to pull the terms from collector-base. Or, if you were smart, you could calculate it even more simply from:*~~ $\alpha_N I_{ES} = \alpha_I I_{CS}$

(3) True or false, for a PNP BJT setup for normal amplification. Circle or underline your answer.

(a) TRUE / FALSE : Cool device, because collector current changes proportionally (linearly) with change in base current.

(b) TRUE / FALSE : I_C plotted vs. V_{BE} should look like a diode plot because that is how holes are injected into the base.

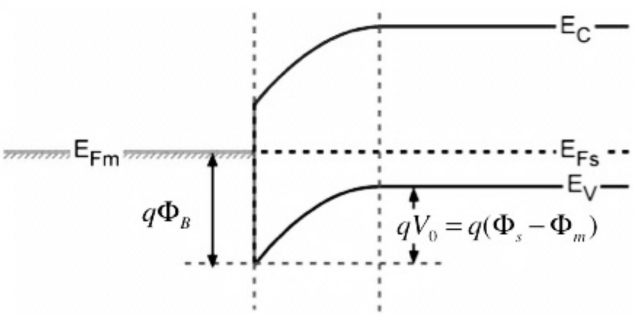
(c) TRUE / FALSE : If you double the amount of electrons *added* into the base (not the doped electrons), the collector current will also double. *Note, the doped electrons don't help increase the collector current because each doped electron already has an ionized positive phosphorus atom (no need for an additional hole).*

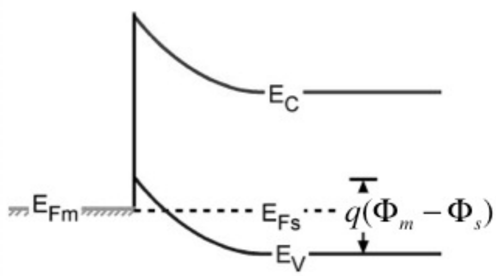
(d) TRUE / FALSE : Even though the BJT is an amplifier, the number of extra holes and electrons in the base are equal.

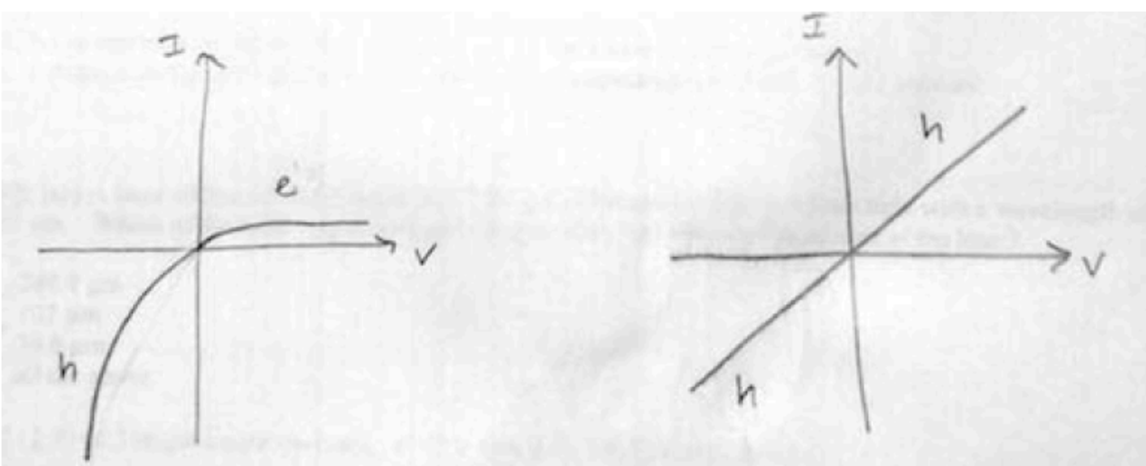
(e) TRUE / FALSE : If the hole lifetime in the base increases then the base current increases also.

(f) TRUE / FALSE : I_C saturation with increasing V_{CE} occurs because once you have the base-collector reverse biased the collector is all setup to collect holes as drift current.

(4) Some quick review… since many of you struggle w/ metal/semiconductor. Draw the IV diagram for both of these, with respect to voltage applied to the metal.







(5) A bit of review also. Determine the drain current for the mystery device shown in the circuit below. Determine the drain current for both Vg=0.5V and for Vg=1.0 V.

a) [10 pts] Determine the drain current for this first unknown device (below) for Vg=0.5V and for Vg=1.0 V.

10 mA   5 mA