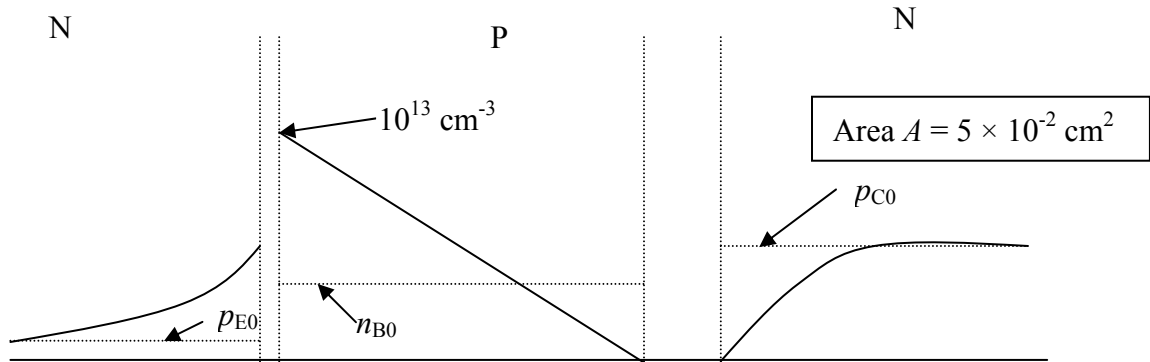


**ECSE-2210 Microelectronics Technology**  
**Class Activity 21 – Solution**

1. The figure below shows the minority carrier concentrations in the emitter, base and the collector region of an npn transistor. Answer the following questions. Most questions do not need any extensive calculations.



<u><b>Emitter</b></u>	<u><b>Base</b></u>	<u><b>Collector</b></u>
$p_{E0} = 10 \text{ cm}^{-3}$	$n_{B0} = 5 \times 10^3 \text{ cm}^{-3}$	$p_{C0} = 10^5 \text{ cm}^{-3}$
$L_E = 0.5 \text{ }\mu\text{m}$	$W_B = 0.8 \text{ }\mu\text{m}$	$L_C = 3 \text{ }\mu\text{m}$
$D_E = 5 \text{ cm}^2/\text{s}$	$D_B = 25 \text{ cm}^2/\text{s}$	$D_C = 10 \text{ cm}^2/\text{s}$
	$\tau_B = 10^{-7} \text{ s}$	

- a. Is the base-emitter junction forward-biased or reverse-biased? What is the voltage applied to the E-B junction?

Forward biased since the minority carrier concentration is higher than the equilibrium concentration at the depletion layer edges. From the figure it is seen that the minority carrier concentration in the base ( $n_B(0) = 10^{13} \text{ cm}^{-3}$ ), is higher than the equilibrium concentration  $n_{B0} = 5 \times 10^3 \text{ cm}^{-3}$ .

$$n_{B(0)} = n_{B0} \times \exp(q V_{BE} / kT)$$

$$10^{13} \text{ cm}^{-3} = 5 \times 10^3 \text{ cm}^{-3} \times \exp(V_{BE} / 0.0259 \text{ V})$$

$$V_{BE} = 0.0259 \times \ln(10^{13} / 5 \times 10^3)$$

$$V_{BE} = 0.555 \text{ V}$$

- b. Is the collector-base junction forward-biased or reverse-biased? Can we calculate the voltage applied to the C-B junction with the available data?

Reverse biased, as the concentration at the edge of the depletion region is much less than the equilibrium concentration. Calculating the voltage applied to the C-B junction is not possible, since we don't know the exact value of the carrier concentration at the C-B junction.

- c. What is the value of the collector current?

$$I_C = q A D_B [n_B(0) - 0] / W_B$$

$$I_C = \frac{1.6 \times 10^{-19} \times 25 \times 10^{13}}{0.8 \times 10^{-4}}$$

$$I_C = 25 \text{ mA}$$

- d. What is the value of the base current due to recombination in base? Call it  $I_{BR}$ .

$$I_{BR} = Q_B / \tau_B$$

$$I_{BR} = [q A n_B(0) W_B] / (2 \tau_B)$$

$$I_{BR} = \frac{1.6 \times 10^{-19} \times 5 \times 10^{-2} \times 10^{13} \times 0.8 \times 10^{-4}}{2 \times 10^{-7}}$$

$$I_{BR} = 32 \text{ } \mu\text{A}.$$

- e. What is the value of the base current due to the injection of holes into the emitter? Call it  $I_{BE}$ .

$$I_{BE} = [q A D_E p_{E0} \times \exp(qV_{BE}/kT)] / L_E$$

$$I_{BE} = \frac{1.6 \times 10^{-19} \times 5 \times 10^{-2} \times 5 \times 10 \times \exp(0.555/0.0259)}{0.5 \times 10^{-4}}$$

$$I_{BE} = 16 \text{ } \mu\text{A}.$$

- f. What is the value of the total base current?

$$I_B = I_{BR} + I_{BE} = 32 + 16 = 48 \text{ } \mu\text{A}$$

- g. What is the value of  $\beta_{dc}$  for this transistor?

$$\beta_{dc} = I_C / I_B$$

$$= 25 \text{ mA} / 48 \text{ } \mu\text{A} = 520$$

- h. What is the value of the electron component of the emitter current?

$$I_{EN} = I_C + I_{BR} = 25 \text{ mA} + 32 \text{ } \mu\text{A} = 25.032 \text{ mA}$$

- i. What is the value of the base transport factor?

$$\alpha_T = I_C / I_{EN} = 25 / 25.032 = 0.9987$$

- j. What is the value of the hole component of the emitter current?

This is the same as  $I_{BE}$

- k. What is the value of the emitter injection efficiency?

$$\gamma = I_{EN} / (I_{EN} + I_{EP}) = 25.032 \text{ mA} / (25.032 \text{ mA} + 16 \text{ } \mu\text{A}) = 0.9993$$

- l. Suppose the lifetime of minority carriers in the base is increased to  $2 \times 10^{-7}$  s. What will be the value of  $\beta_{dc}$  now?

$$I_{BR} \text{ will be reduced by a factor of 2: } I_{BR} = 32 \text{ } \mu\text{A} / 2 = 16 \text{ } \mu\text{A}.$$

New  $I_{BE}$  is the same as before and equal to  $16 \text{ } \mu\text{A}$ .

$$\text{Hence new } I_B = (16 + 16) \text{ } \mu\text{A} = 32 \text{ } \mu\text{A}.$$

$$\beta_{dc} = 25 / I_B = 25 \text{ mA} / (16 + 16) \text{ } \mu\text{A} = 780$$