1) For MOSFETs, we focus on understanding drain current. The gate current is taken to be negligibly small. For BJTs, we focus first on the collector current. For good BJTs, the base current is small, but not negligible. Before we discuss the base current, we focus on the collector current. We can understand the most important features of the common emitter collector current characteristic, $I_e(V_{BE}, V_{CE})$ or the common base collector current characteristic, $I_e(V_{BE}, V_{CB})$, by examining the minority carrier concentration in the base. Answer the following questions for an NPN BJT by providing a sketch of $Δn(x)$ in the base.

1a) Sketch $Δn(x)$ vs. $x$ for the forward active region of operation.
1b) Sketch $Δn(x)$ vs. $x$ for the saturation region of operation.
1c) Sketch $Δn(x)$ vs. $x$ for the reverse active region of operation.
1d) Sketch $Δn(x)$ vs. $x$ for the cut-off region of operation.

HINT: Begin with the Law of the Junction and assume a good transistor, which means the base is short compared to a minority carrier diffusion length.
HW Week 14 (continued)

2) The sketch below shows an NPN BJT. Assume that it is in the forward active region with $I_C = 1.23$ mA and $I_E = 1.27$ mA. Answer the following questions.

2a) What is the common emitter current gain, $\beta_{dc}$?
2b) What is the common base current gain, $\alpha_{dc}$?
2c) What is the base transport factor, $\alpha_T$?
2d) What is the emitter injection efficiency, $\gamma$?
2e) What is the emitter injection efficiency assuming that there is no recombination in the base?

3) The sketch below shows an NPN BJT biased in the forward active region with the four current components indicated. Assume:

\[
\begin{align*}
I_{En} &= 1.000 \text{ mA} \\
I_{Ep} &= 0.005 \text{ mA} \\
I_{Cn} &= 0.995 \text{ mA} \\
I_{Cp} &\approx 0
\end{align*}
\]

and answer the questions below.
HW Week 14 (continued)

3a) What is the emitter injection efficiency?
3b) What is the base transport factor?
3c) What is the common emitter current gain?
3d) What is the common base current gain?

4) The four current components for the two diodes in a PNP transistor are defined below. Assume that the base width is short (i.e. $W_B \ll L_n$) and that the transistor is biased in the forward active region with $V_{CB} = 0$. The common emitter current gain is $\beta_{dc} = 100$. Answer the following questions assuming that $I_{CP} = 10$ mA. Note that $V_{CB} = 0$ places the transistor on the borderline of the active and saturation regions. The behavior is continuous from one region to the next, so we can call this the active or saturation region. It is better to consider it to be the active region, because it takes a moderate forward bias on the base-collector junction to really get into the saturation region and see the collector current drop.

4a) What is $I_{Ep}$?
4b) What is $I_{En}$?
4c) What is $I_{Cn}$?
4d) What is the common base current gain, $\alpha_{dc}$?
HW Week 14 (continued)

5) Consider a bipolar junction transistor. All three regions (emitter, base and collector) are composed of the same semiconductor material (except for doping type/density). The excess minority carrier concentrations for a specific bias point are shown in the figure below – note that the scale is linear (although the concentrations near the CB junction are exaggerated for clarity). Assume that \( T = 300 \, \text{K} \) and that the base is doped at \( N_B = 1.0 \times 10^{17} \, \text{cm}^{-3} \) (\( N_B \) is either \( N_A \) or \( N_D \) you will need to figure out which.) The diffusion coefficients for electrons and holes are \( D_n = 20 \, \text{cm}^2/\text{s} \) and \( D_p = 10 \, \text{cm}^2/\text{s} \) respectively. Answer the following questions.

5a) What type of transistor is this? NPN or PNP? Explain how you know.
5b) What bias regime is illustrated in the figure?
5c) What is the doping density in the emitter (recall that \( N_B \) is given)?
5d) Which of the following best describes the base region? Explain your answer.
5e) What is the emitter injection efficiency (numerical answer)?
5f) What is \( \beta_{dc} \) for this transistor?