1) In a forward-biased NP junction under low-injection conditions, the QFL’s are approximately flat from the majority carrier region and then across the depletion region. As shown in the figure below for a long diode, the minority carrier QFL then decays linearly to the majority carrier QFL. Explain why the minority carrier QFL decays to the majority carrier QFL and why the decay is linear.

2) The diffusion capacitance is important for the a.c. response of a diode. Consider a P+N diode under forward bias. A common way to estimate the low-frequency diffusion capacitance is to make the "quasi-static" approximation:

\[ C_D = \frac{dQ_p(V_A)}{dV_A} \]

where \( Q_p(V_A) \) is minority carrier charge obtained from the d.c. solution and is given by

\[ Q_p(V_A) = \int_{x_p}^{x} \Delta p(x) \, dx \]

Compute the quasi-static diffusion capacitance for long P+N diode and compare it to the low-frequency diffusion capacitance as given by Pierret in SDF, eqn. (7.30b).

3) For a P+N diode, the forward biased current due to minority holes injected into a short N-type region is:

\[ J_p = q \frac{n_i^2 D_p}{N_A W_p} \left( e^{qV_A/k_BT} - 1 \right) \]
It is often the case, however, that the doping in the N-type region is not constant. Work out the current equation for a P+N diode with a non-uniformly doped N region by answering the following questions.

3a) Obtain an expression for the electric field, $E(x)$, assuming quasi-neutrality,
$$n(x) \approx N_D(x)$$

3b) Evaluate the hole current assuming the electric field from 3a) and show that the result is:
$$J_p(x) = -q \frac{D_p}{N_D(x)} \frac{d(N_p \Delta p)}{dx}.$$

3c) Explain why $J_p(x)$ is constant for a short N-type region.

3d) Using the results of 3b) and 3c), solve for $J_p$ in terms of $\Delta p(0)$ and $\Delta p(W_p)$.

3e) Compare the result to that of a uniformly doped region.

4) Consider an NPN BJT with the following parameters:
$$I_{E_n} = 1 \text{ mA} \quad I_{E_p} = 0.01 \text{ mA} \quad I_{C_n} = 0.98 \text{ mA} \quad I_{C_p} = 0.0001 \text{ mA}$$

4a) Determine the base transport factor, $\alpha_T$.
4b) Determine the emitter injection efficiency, $\gamma$
4c) Determine the currents, $I_E, I_C, I_B$
4d) Determine $\alpha_{DC}$.
4e) Determine $\beta_{DC}$.

5) Make sketches of the minority electron concentration in the base of an NPN BJT under the following conditions:

5a) Forward active region.
5b) Inverted active region.
5c) Saturation
5d) Cut-off
6) Consider the impact of changing some key BJT device parameters on some key figures of merit. For each of the 5 changes below, explain where the change increases, decreases, or has no effect on: i) the base transport factor, $\alpha_T$, ii) the emitter injection efficiency, $\gamma$, and iii) the current gain, $\beta_{dc}$.

6a) Increase the base width.
6b) Increase the base lifetime.
6c) Increase the base doping.
6d) Increase the emitter doping.