All problems assume a silicon npn bipolar transistor. Given the following information:

\[ n_{B0} = \frac{n_i^2}{N_B} ; \quad V_t = 0.0259 \text{V} ; \quad p_{E0} = \frac{n_i^2}{N_E} ; \]

\[ V_{bi} = V_t \ln \frac{N_a N_d}{n_i^2} \]

\[ L_E = \sqrt{D_E \tau_{E0}} ; \quad L_B = \sqrt{D_B \tau_{B0}} \]

\[ \alpha_T = \frac{1}{\cosh \left( \frac{x_B}{L_B} \right)} ; \quad \gamma = \frac{1}{1 + \frac{p_{E0} D_E L_E \tanh \left( \frac{x_E}{L_E} \right)}{n_{B0} D_B L_B E_t \tanh \left( \frac{x_E}{L_E} \right)}} \]

\[ J_{s0} = \frac{q D_B n_{B0}}{L_B \tanh \left( \frac{x_E}{L_E} \right)} ; \quad \alpha = \gamma \alpha_T \delta ; \quad \beta = \frac{\alpha}{1 - \alpha} ; \]

\[ \delta = \frac{1}{1 + \frac{L_B}{J_{s0}} \exp \left( -\frac{V_{BE}}{kT} \right)} ; \quad q = 1.6 \times 10^{-19} \text{C} ; \quad p_{E0} = \frac{n_i^2}{N_E} \exp \left( -\frac{\Delta E_g}{kT} \right) ; \quad T = 300 \text{K} , \]

\[ \varepsilon_0 = 8.85 \times 10^{-14} \text{F/cm} ; \]

\[ \varepsilon_S = 11.7 \varepsilon_0 ; \quad E_g = 1.12 \text{eV} ; \quad N_E = 10^{18} \text{cm}^{-3} ; \quad N_B = 10^{16} \text{cm}^{-3} ; \quad D_E = 15 \text{cm}^2/\text{s} ; \]

\[ D_B = 8 \text{cm}^2/\text{s} ; \quad \tau_{E0} = 3 \times 10^{-7} \text{s} \]

\[ \tau_{B0} = 2 \times 10^{-7} \text{s} ; \quad x_E = 0.5 \mu\text{m} ; \quad x_B = 0.7 \mu\text{m} ; \]

\[ V_{BE} = 0.65 \text{V} ; \quad J_{r0} = 5 \times 10^{-8} \text{A/cm}^2 \]

\[ \Delta n_B(x) = \frac{n_{B0} \left[ \exp \left( \frac{2qV_{BE}}{kT} \right) - 1 \right] \sinh \left( \frac{2qV_{BE}}{kT} \right) - \sinh \left( \frac{x}{L_B} \right) }{ \sinh \left( \frac{x}{L_B} \right) } \]

\[ n_i = 1.5 \times 10^{10} \text{cm}^{-3} \]

1- What is the thermal equilibrium minority carrier hole concentration in the emitter without the band-gap narrowing effect?

2- What is thermal equilibrium minority carrier hole concentration considering the band-gap narrowing effect in the emitter as doping changes from 10^{18} \text{cm}^{-3} to 10^{19} \text{cm}^{-3}? (Assume band-gap change from 0.030 eV to 0.080 eV)

3- What is the thermal equilibrium carrier electron concentration in the base?

4- What is the excess carrier electron concentration in the base at x = 0? 

5- What is the emitter injection efficiency factor?

6- What is the base transport factor?

7- What is the reverse saturation current density?

8- What is the recombination factor?

9- What is the common-base current gain?

10- What is the common emitter current gain?