At 300 K, a silicon npn bipolar junction transistor (BJT), with each region uniformly doped, has the following parameters:

$N_E = 1.6 \times 10^{18}$ cm^{-3}	$N_B = 3 \times 10^{16}$ cm^{-3}	$N_C = 2 \times 10^{15}$ cm^{-3}
$D_E = 7.5$ cm^2/sec	$D_B = 14$ cm^2/sec	$D_C = 11$ cm^2/sec
$\tau_{E0} = 10$ ns	$\tau_{B0} = 44$ ns	$\tau_{C0} = 90$ ns
$x_E = 0.9$ µm	$x_B = 0.7$ µm	$x_C =$ large

Also, $A_{BE} = 3 \times 10^{-3}$ cm^2, $x_{BE} = 7.6$ nm, $V_{BE} = 0.62$ V and $V_{CE} = 4.8$ V. Then:

a) Determine the thermal equilibrium minority carrier concentrations p_{E0}, n_{B0}, and p_{C0}.

b) Find the current densities J_{nE} and J_{pE} as well as the emitter current I_E. What fraction of I_E is due to electrons?

c) Find the current density constants J_{s0} and J_{r0}.

d) Find the approximate base transport factor α_T and emitter injection efficiency γ as well as the recombination factor δ.

e) Find the approximate common-base α and common-emitter β current gains.

f) Find the collector I_C and base I_B currents.

a) Per Table B.4, $n_i = 1.5 \times 10^{10}$ cm^{-3} @ 300K for Si

Per (4.43), $n_0 p_0 = n_i^2$

Emitter $n_0 = N_E$, $p_{E0} = \dfrac{(1.5\times10^{10})^2}{1.6\times10^{18}} \Rightarrow p_{E0} = 140{,}625$ cm^{-3}

Base $p_0 = N_B$, $n_{B0} = \dfrac{(1.5\times10^{10})}{3\times10^{16}} \Rightarrow n_{B0} = 7500$ cm^{-3}

Collector $n_0 = N_C$, $p_{C0} = \dfrac{(1.5\times10^{10})^2}{2\times10^{15}} \Rightarrow p_{C0} = 1.125\times10^{5}$ cm^{-3}

b) Per (12.34b), $J_{nE} = \dfrac{e D_B n_{B0}}{L_B}\left\{\dfrac{1}{\sinh(x_B/L_B)} + \dfrac{e^{V_{BE}/V_t} - 1}{\tanh(x_B/L_B)}\right\}$

b) cont. Page 504 of text, $L_B = \sqrt{D_B \tau_{B0}}$

$$L_B = \sqrt{14\times10^{-4}\,m^2/s\;44\times10^{-9}\,s} = 7.84857\times10^{-6}\,m$$

Per (7.10), $V_t = \frac{k_B T}{e} = \frac{8.617333\times10^{-5}\,eV/K\,(300K)}{e} = 0.025852\,V$

$$J_{nE} = \frac{1.6022\times10^{-19}(14\times10^{-4})7.5\times10^{9}}{7.84857\times10^{-6}}\left\{\frac{1}{\sinh(0.7/7.849)} + \frac{e^{\frac{0.62}{0.025852}}-1}{\tanh(0.7/7.849)}\right\}$$

$$\underline{\underline{J_{nE} = 6.27325\times10^{4}\,A/m^2 = 6.27325\,A/cm^2}}$$

Per (12.34a), $J_{pE} = \frac{e D_E p_{E0}}{L_E}\left(e^{V_{BE}/V_t}-1\right)\frac{1}{\tanh(x_E/L_E)}$

Per (12.18), $L_E = \sqrt{D_E \tau_{E0}} = \sqrt{7.5\times10^{-4}(10\times10^{-9})} = 2.7386\times10^{-6}\,m$

$$J_{pE} = \frac{1.6022\times10^{-19}(7.5\times10^{-4})1.40625\times10^{8}}{2.738613\times10^{-6}}\left(e^{\frac{0.62}{0.025852}}-1\right)\frac{1}{\tanh(0.9/2.7386)}$$

$$\underline{\underline{J_{pE} = 506.2738\,A/m^2 = 0.05062738\,A/cm^2}}$$

$$I_E = J_E A_{BE} = (J_{nE} + J_{pE})A_{BE}$$

$$= (6.27325 + 0.050627)3\times10^{-3} = 6.323877(3\times10^{-3})$$

$$\underline{\underline{I_E = 0.0189716\,A = 18.9716\,mA}}$$

$$\underline{\underline{frac_e = \frac{J_{nE}}{J_{pE}+J_{nE}} = \frac{62{,}732.5}{62{,}732.5 + 506.2738} = 0.991994 = 99.2\%}}$$

c) From (12.41) $J_R = \dfrac{e x_{BE} n_i}{2\tau_0} e^{V_{BE}/2V_t} = J_{r0} e^{V_{BE}/2V_t}$

Per (8.39), $\tau_0 = \dfrac{\tau_{p0} + \tau_{n0}}{2} = \dfrac{\tau_{B0} + \tau_{E0}}{2} = \dfrac{10 + 44}{2} = 27\,ns$

$$J_{r0} = \frac{1.6022\times10^{-19}(7.6\times10^{-9})(1.5\times10^{16})}{2(27\times10^{-9})}$$

$$\underline{\underline{J_{r0} = 3.38237\times10^{-4}\ A/m^2 = 3.38237\times10^{-8}\ A/cm^2}}$$

Per (12.43), $J_{s0} = \dfrac{e D_B n_{B0}}{L_B \tanh(x_B/L_B)}$

$$J_{s0} = \frac{1.6022\times10^{-19}(14\times10^{-4})(7.5\times10^{9})}{7.84857\times10^{-6}\tanh(0.7/7.84857)}$$

$$\underline{\underline{J_{s0} = 2.409634\times10^{-6}\ A/m^2 = 2.4096\times10^{-10}\ A/cm^2}}$$

d) Per Table 12.3

$$\alpha_T \simeq \frac{1}{1 + \frac{1}{2}(x_B/L_B)^2} = \frac{1}{1 + \frac{1}{2}\left(\frac{0.7}{7.84857}\right)^2}$$

$$\underline{\underline{\alpha_T \simeq 0.99604}}$$

$$\gamma \simeq \frac{1}{1 + \frac{N_B}{N_E}\frac{D_E}{D_B}\frac{x_B}{x_E}} = \frac{1}{1 + \frac{3\times10^{16}}{1.6\times10^{18}}\frac{7.5}{14}\frac{0.7}{0.9}}$$

$$\underline{\underline{\gamma \simeq 0.992248}}$$

d) cont. $\delta = \dfrac{1}{1 + \frac{J_{ro}}{J_{so}} e^{-V_{BE}/2V_t}}$

$\delta = \dfrac{1}{1 + \frac{3.38237 \times 10^{-4}}{2.409634 \times 10^{-6}} e^{\frac{-0.62}{2(0.025852)}}} \Rightarrow \underline{\underline{\delta = 0.999131}}$

e) Per Table 12.3

$\alpha = \gamma \alpha_T \delta = 0.992248(0.99604)0.999131$

$\underline{\underline{\alpha \simeq 0.98746}}$

$\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.98746}{1-0.98746} \Rightarrow \underline{\underline{\beta = 78.7334}}$

f) $\alpha = I_C/I_E$ (12.5) + $\beta = I_C/I_B$ (12.6)

$I_C = \alpha I_E = 0.98746(18.9716\ mA)$

$\underline{\underline{I_C = 18.7337\ mA}}$

$I_B = I_C/\beta = \dfrac{18.7337\ mA}{78.7334}$

$\underline{\underline{I_B = 2.37938 \times 10^{-4} A = 0.23794\ mA}}$