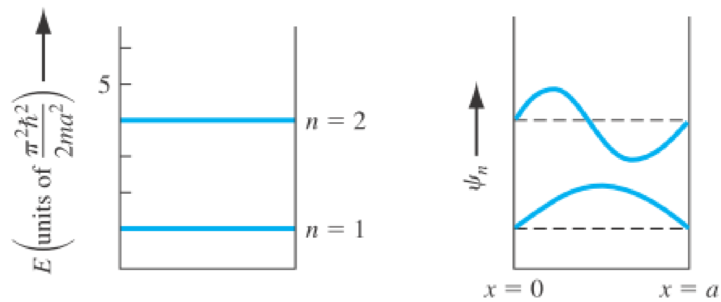
1.A. (8 points)

$$\psi(x) = \sqrt{\frac{2}{a}}\sin\left(\frac{n\pi x}{a}\right)$$

$$E_n(x) = \frac{\hbar^2 n^2 \pi^2}{2ma^2}$$



1.B. (8 points).

$$g_E(E)\,dE = g_k(k)\,dk$$

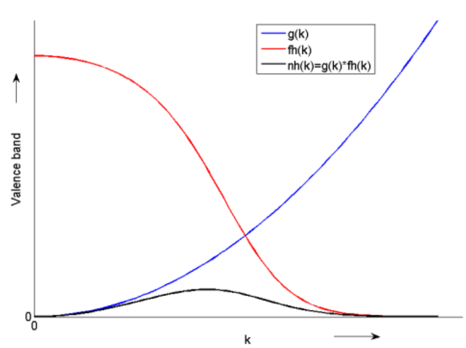
$$g_k(k) = \frac{k^2}{\pi^3}$$

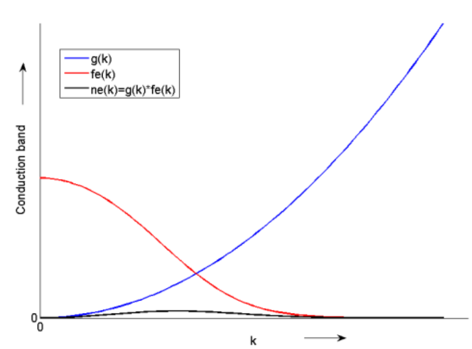
Assume conventional parabolic band structure:

$$E = E_C + \frac{\hbar^2 k^2}{2m^*} \qquad\qquad E = E_v - \frac{\hbar^2 k^2}{2m^*}$$

Fermi-Dirac of electrons in conduction band： $f_e = \dfrac{1}{1+\exp\left(\dfrac{E-E_F}{k_B T}\right)} = \dfrac{1}{1+\exp\left(\dfrac{E_C + \dfrac{\hbar^2 k^2}{2m^*} - E_F}{k_B T}\right)}$

Fermi-Dirac of holes in valence band： $f_h = 1 - f_e = 1 - \dfrac{1}{1+\exp\left(\dfrac{E_v - \dfrac{\hbar^2 k^2}{2m^*} - E_F}{k_B T}\right)}$





Question 2. (15 points)

$$J_{diff}(x) = -eD_p \frac{dp}{dx} = -\frac{eD_p}{L}\left(2\times10^{16}\left(1+\frac{x}{L}\right)\right)$$

$$J_{diff}(-6) = -\frac{\left(1.6\times10^{-19}\right)(10)}{12\times10^{-4}}\left(2\times10^{16}\left(1-\frac{6}{12}\right)\right) = \underline{-13.33\ \text{A/cm}^2}$$

Question 3. (16 points)

$$E_{F_i} - E_F = kT\ln\left(\frac{N_a}{n_i}\right) = 0.0259\ln\left(\frac{5\times10^{15}}{1.5\times10^{10}}\right) = \underline{0.33\ \text{eV}}$$

$$p = N_a + 0.1N_a = 1.1N_a$$

$$n = n_0 + 0.1N_a \simeq 0.1N_a$$

$$E_{Fn} - E_{Fi} = kT\ln\left(\frac{n}{n_i}\right) = 0.0259\ln\left(\frac{0.1\times5\times10^{15}}{1.5\times10^{10}}\right) = \underline{0.27\ \text{eV}}$$

$$E_{Fi} - E_{Fp} = kT\ln\left(\frac{p}{n_i}\right) = 0.0259\ln\left(\frac{1.1\times5\times10^{15}}{1.5\times10^{10}}\right) = \underline{0.33\ \text{eV}}$$

Question 4. (15 points)

$$V_B = \frac{\varepsilon E_{crit}{}^2}{2eN_B} = \frac{12.11\times8.85\times10^{-14}\times\left(4\times10^5\right)^2}{2\times1.6\times10^{-19}\times2\times10^{16}} = 26.79V$$

Question 5.

5.A. (10 points)

(a)(5 points)

$$J_S = en_i^2 \left(\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right)$$

$$= (1.6\times 10^{-19})\times(2.4\times 10^{13})^2 \times \left(\frac{1}{4\times 10^{15}}\sqrt{\frac{90}{2\times 10^{-6}}} + \frac{1}{2\times 10^{17}}\sqrt{\frac{48}{2\times 10^{-6}}}\right) = 1.568\times 10^{-4} A/cm^2$$

$$J_D = J_S \cdot \left[\exp(\frac{eV_a}{kT}) - 1\right]$$

$$= J_S \cdot (\exp(\frac{0.25}{0.0259}) - 1)$$

$$= 2.44 A/cm^2$$

$$J = J_D \bullet A = 2.44\times 10^{-4} A = 0.244 mA$$

(b)(5 points)

$$V_{bi} = V_T \times \ln(\frac{N_a N_d}{n_i^2}) = 0.0259 \times \ln\left(\frac{4\times 10^{15}\times 2\times 10^{17}}{\left(2.4\times 10^{13}\right)^2}\right) = 0.366V$$

$$W = \left\{\frac{2\varepsilon_S (V_{bi} + V_R)}{e} \cdot \frac{N_a + N_d}{N_a \cdot N_d}\right\}^{1/2} = 5.273\times 10^{-5} cm$$

$$J_{gen} = \frac{en_i W}{2\tau_0} = 5.062\times 10^{-5} A/cm^2$$

$$J_R = J_{gen} + J_S = 2.074\times 10^{-4} A/cm^2$$

$J = J_R \bullet A = 2.074\times 10^{-8} A \approx 0A,$ almost no current for reverse-biased voltage

5.B. (10 points)

The minority carrier electron distribution changes linearly with distance.

The minority carrier electron current density $J_n = \frac{eD_n n_{p0}}{W_p}\left[\exp(\frac{eV_a}{kT}) - 1\right]$

Question 6. (18 points)

6.A. (8 points)

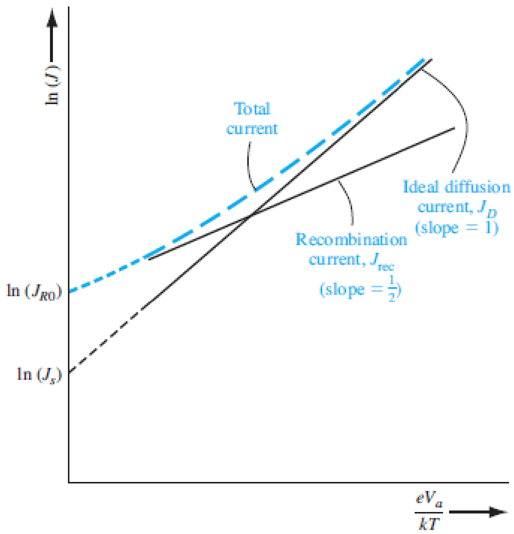


Figure 8.16 | Ideal diffusion, recombination, and total current in a forward-biased pn junction.

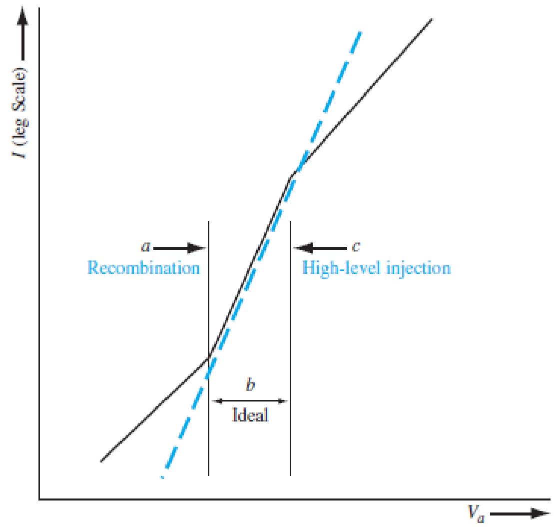


Figure 8.17 | Forward-bias current versus voltage from low forward bias to high forward bias.

6.B. (10 points)

$$V_{bi} = V_T \times \ln\left(\frac{N_a N_d}{n_i^2}\right) = 0.0259 \times \ln\left(\frac{4\times10^{16} \times 4\times10^{16}}{\left(1.5\times10^{10}\right)^2}\right) = 0.766V$$

$$J_S = en_i\left(\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right) = 2.686\times10^{-11}\,A/cm^2$$

$$J_D = J_S \cdot \exp\left(\frac{eV_a}{kT}\right)$$

$$J_{rec} = \frac{en_i W}{2\tau_0} \cdot \exp\left(\frac{eV_a}{2kT}\right), \text{ where } W = \left[\frac{2\varepsilon_S (V_{bi} - V_a)}{e} \cdot \frac{N_a + N_d}{N_a \cdot N_d}\right]^{1/2}$$

let $J_D = J_{rec}$ (solved graphically or by approximation)

$\Rightarrow V_a = 0.454V$