1) \[ V_{bi} = \frac{kT}{q} \ln \left( \frac{N_A N_D}{N_a^2} \right) = 0.716 \text{ V} \]

\[ X_p = \left[ \frac{2KsE_0 \cdot N_D \cdot V_{bi}}{q \cdot N_A (N_A + N_D)} \right]^{1/2} = 9.62 \times 10^{-7} \text{ cm} \]

\[ X_n = \left[ \frac{2KsE_0 \cdot N_A \cdot V_{bi}}{q \cdot N_D (N_A + N_D)} \right]^{1/2} = 9.62 \times 10^{-5} \text{ cm} \]

\[ W = X_n + X_p = 9.72 \times 10^{-5} \text{ cm} \]

\[ \varepsilon(x) = -\frac{qN_D}{KsE_0} X_n = -1.47 \times 10^4 \text{ V/cm} \]

\[ V(x) = \frac{q N_A}{2KsE_0} X_p^2 = 7.09 \times 10^{-3} \text{ V} \]

In problem 5.4, the widths of the n- and p-sides of the depletion region and the corresponding variation of the electrostatic variables are comparable reflecting the fact that \( N_A \approx N_D \).

Here with \( N_A \gg N_D \), we find the depletion region width and potential drop lie almost exclusively on the lightly doped n-side of the junction.

b) For band diagram, consider the Quasi-Fermi level, \( E_{Fp}, E_{Fn} \) first.

i) equilibrium state

ii) forward bias state \( (V_A > 0) \)

iii) reverse bias state \( (V_A < 0) \)
2) prob. 6.1 a~f)

a) Majority Carrier injection (diffusion) to the opposite side of the junction.
b) Minority carriers wandering into the depletion region and being accelerated (drifting) to the opposite side of the junction.
c) The reverse bias current is expected to be small because it arises from minority carriers which are few in number. The reverse bias current saturate because a small voltage all but eliminates majority carrier injection across the junction, and the remaining current due to minority carriers is independent of the applied voltage.
d) Generation and diffusion.

e) The primary reason is that $E 
eq 0$. Also, low level injection conditions seldom apply: $\delta n/\delta +$ thermal $R = -A \mu n/\xi n$ and $\delta p/\delta +$ thermal $R = -A \mu p/\xi p$
f) There is no a priori justification.

3) i) in the p-region: $p = N_a = 2 \times 10^{15}$ cm$^{-3}$
   
   \[ n = n_0 + \Delta n = G_L \cdot Z_n = 6 \times 10^{18} \times 10^{-4} = 6 \times 10^{14} \text{ cm}^{-3} \]
   
   \[ \Rightarrow F_p = E_2 - kT \ln \frac{n}{n_0} = E_2 - 0.20 \text{ eV} \]
   
   \[ F_n = E_2 + kT \ln \frac{p}{p_0} = E_2 + 0.17 \text{ eV} \]

   \[ \begin{array}{c}
   \hline
   E_c \\
   F_n \\
   - - - - - - E_2 \\
   F_p \\
   - - - - - - E_v \\
   \hline
   \end{array} \]

ii) in the n-region: $n = N_d = 4 \times 10^{16}$ cm$^{-3}$
   
   \[ p = G_L \cdot Z_p = 6 \times 10^{18} \times 10^{-4} = 6 \times 10^{15} \text{ cm}^{-3} \]
   
   \[ \Rightarrow F_n = E_2 + kT \ln \frac{n}{n_0} = E_2 + 0.40 \text{ eV} \]
   
   \[ F_p = E_2 - kT \ln \frac{p}{p_0} = E_2 - 0.17 \text{ eV} \]

   \[ \begin{array}{c}
   \hline
   E_c \\
   F_n \\
   - - - - - - E_2 \\
   F_p \\
   - - - - - - E_v \\
   \hline
   \end{array} \]
4)  
\[ I = qA \, N_a^2 \left( \frac{D_n}{L_n \, N_a} + \frac{D_p}{L_p \, N_d} \right) \left( e^{\frac{qV_a}{kT}} - 1 \right) \]
\[ = qA \left( \frac{D_n}{L_n} \cdot \frac{N_a^2}{N_a} + \frac{D_p}{L_p} \cdot \frac{N_a^2}{N_d} \right) \left( e^{\frac{qV_a}{kT}} - 1 \right) \]
\[ = qA \left( \frac{D_n}{L_n} \cdot n_{po} + \frac{D_p}{L_p} \cdot p_{no} \right) \left( e^{\frac{qV_a}{kT}} - 1 \right) \]

i) Without illumination case:
if \( T=300K, \, V_a>0.026, \) \( I \propto e^{V_a/0.026} \) \( \Rightarrow \) forward bias
if \( V_a<0.026, \) \( I = \text{constant}. \) \( \Rightarrow \) reverse bias.

\[ I \quad \vdash \quad V_a \]

ii) With illumination case:
if it's in forward bias, the curve is same as above case.
if it's in reverse bias, the value is negative constant but it's different from the above case.
because the minority carrier \( p_{no}, n_{po} \) is changed by illumination as prob. 3)

\[ I \quad \vdash \quad V_a \]

b) As \( T \) becomes very high, the intrinsic carrier concentration will become larger than the doping concentration, thus both the p & n material will become intrinsic and the diode will look like a simple resister.

\[ I \quad \vdash \quad V=IR \]

\[ 0 \quad \vdash \quad V \]
5) **a)** Approximately

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

This isn't perfect, because \( n_i = 10^{13} \text{ cm}^{-3} \) is technically degenerate.

\[ V_{bi} = 0.026 \ln \left( \frac{10^{18} \times 10^{15}}{(1.1 \times 10^{13})^2} \right) \]

\[ V_{bi} \approx 0.95 \text{ V} \]

**b)** Consider a simple pn junction

\[ X_p = \sqrt{\frac{2eV_{bi} N_d}{N_a (N_a + N_d)}} \]

\[ X_p = 3.5 \mu \text{m} \]

\[ X_n = \sqrt{\frac{2eV_{bi} N_a}{N_d (N_a + N_d)}} \]

\[ X_n = 3.5 \text{ Å} \]

So essentially, all the depletion width is in the lightly doped region and the width
in the heavily doped region is negligible.

1. For $V_a = 0 V$
   \[ W = (x_p + x_n + x_{n+p}) \]
   \[ \sim 0 \text{, } 2.5 \mu m \sim 0 \]
   \[ W \approx 2.5 \mu m \]

For $V_a = -5 V$
   \[ W = (x_{n+p}) + x_n + x_{n+p} \]
   \[ \sim 2.5 \mu m \sim 0 \]
   \[ W \approx 2.5 \mu m \]

2) For some reasons, essentially all the voltage drop is across the $p = 10^{-4}$ cm $\text{cm}^{-2}$ region.