Given $E_F = E_V - 2kT$ on the P-side
$E_F = E_C - E_C/4$ on the n-side

Under equilibrium conditions, the fermi level is constant with position.

(b)

$$V_{bi} = \frac{1}{aV} \left[ (E_C - E_F)_P \text{ side} + (E_F - E_C)_n \text{ side} \right]$$
(Taken from eqs. 5.12)

$$E_{G1} = 1.12 eV$$

$$V_{bi} = \frac{1}{aV} \left[ \left( \frac{E_g}{2} + 2kT \right) + \left( \frac{E_g - E_g/4}{2} \right) \right]$$

$$= \frac{1}{aV} \left[ \frac{E_g}{2} + 2kT + \frac{E_g}{4} \right] = 0.89 V$$
(b) 

\[ V_{bi} = \frac{kT}{q} \ln \left[ \frac{n(x_{2i})}{n(-x_{2i})} \right] \]  

(from eqn 5.8)

for the specific case of a nondegenerately doped step junction where \( N_{A1} \) and \( N_{A2} \) are the \( P_1 \) side and \( P_2 \) side doping concentrations

\[ n(x_{2i}) = \frac{n_c^2}{N_{A2}} \]  

\[ n(-x_{2i}) = \frac{n_c^2}{N_{A1}} \]

Substituting (2) & (3) into (1) we get

\[ V_{bi} = \frac{kT}{q} \ln \left[ \frac{N_{A1}}{N_{A2}} \right] \]
(d) The depletion approximation introduces an idealization of the actual charge distribution. The approximation has two components that can be stated as follows:

1. The carrier concentrations are assumed to be
Negligible compared to the net doping concentration in a region $-x_p \leq x \leq x_n$.

(2) The charge density outside the depletion region is taken to be identically zero.

(c) No. The negative charge on the $x < 0$ portion of part (c) plot is caused by a depletion of hole on the higher-doped $N_A_1$ side of the junction, leading to a net charge associated with ionized acceptors. But the positive charge on the $N_A_2$ side of the junction cannot be attributed to ionized donors, since there is no donor doping. There is a hole concentration on the $x > 0$ side of the junction in excess of $N_A_2$. Since $P > N_A_2$ near the junction, we cannot invoke depletion approximation.
(a) \[ V_{bi} = \frac{KT}{qV} \ln \left( \frac{N_A N_D}{n_i^2} \right) = 0.614 \text{V} \] [from eqn 5.10]

(b) \[ X_P = \left[ \frac{2K_s E_0}{qV} \frac{N_D}{N_A(N_A+N_D)} \right]^{1/2} \] [from eqn 5.30b]
\[ X_P = 3.65 \times 10^{-5} \text{cm} \]

\[ X_m = \left[ \frac{2K_s E_0}{qV} \frac{N_A}{N_D(N_A+N_D)} V_{bi} \right]^{1/2} \] [from eqn 5.30a]
\[ X_m = 7.31 \times 10^{-5} \text{cm} \]
\[ \therefore W = X_P + X_m = 1.1 \times 10^{-4} \text{cm} \]

(c) \[ E(0) = -\frac{qV N_D}{K_s E_0} \cdot X_m = -1.12 \times 10^{-4} \text{V/cm} \] [from eqn 5.21 at \( x=0 \)]

(d) \[ V(0) = \frac{qV N_A}{2K_s E_0} \cdot X_P^2 = 0.205 \text{V} \] [from eqn 5.26 at \( x=0 \)]
Given $N_A = 10^{17}/\text{cm}^3$ on P-side
$N_D = 10^{15}/\text{cm}^3$ on n-side

(a) $V_{bi} = \frac{kT}{qN} \ln \left( \frac{N_A N_D}{n^2} \right) = 0.716 \text{V}$

(b) $x_p = \left[ \frac{2k_bE_0}{qN} \cdot \frac{N_D}{N_A (N_A + N_D)} \cdot V_{bi} \right]^{\frac{1}{2}} = 9.62 \times 10^{-7} \text{cm}$

(c) $x_n = \left[ \frac{2k_bE_0}{qN} \cdot \frac{N_A}{N_D (N_A + N_D)} \cdot V_{bi} \right]^{\frac{1}{2}} = 9.62 \times 10^{-5} \text{cm}$

$N = x_n + x_p = 9.72 \times 10^{-5} \text{cm}$
(c) \[ \varepsilon(0) = -\frac{qN_0}{k_s \varepsilon_0} x_n = -1.47 \times 10^4 \text{ V/cm} \]

(d) \[ V(0) = \frac{qN_A}{2k_s \varepsilon_0} x_p^2 = 0.205 \text{ V} \]

The solution is just a step function, not a cubic function as mentioned earlier.
The solution is just a superimposition of the step function solution for \( x < 0 \) and linearly graded function for \( x > 0 \).

Statement: The built in voltage of a pn junction vanishes at high temperatures.

\[
\text{high temperature } \Rightarrow \text{ intrinsic T-region}
\]

In the intrinsic T-region:

\[
\eta_e \gg \eta_d, \eta_A
\]

\[
\therefore \eta_m(x_n) = \eta_e, \quad \eta_p(-x_p) = \eta_e
\]

\[
\therefore V_{bc} = \frac{kT}{q} \ln \left[ \frac{\eta_m(x_n)}{\eta_p(-x_p)} \right]
\]

As \( T \uparrow \), \( V_{bc} \rightarrow \frac{kT}{q} \ln \left[ \frac{\eta_e}{\eta_e} \right] = 0 \)

Given \( \eta_A = 10^{17} / \text{cm}^3 \), \( \eta_d = 10^{15} / \text{cm}^3 \)

<table>
<thead>
<tr>
<th>( T )</th>
<th>( \eta_e / \text{cm}^3 )</th>
<th>( \eta_m(x_n) / \text{cm}^3 )</th>
<th>( P_p(-x_p) / \text{cm}^3 )</th>
<th>( \eta_p(-x_p) / \text{cm}^3 )</th>
<th>( V_{bc}(T) )</th>
<th>( \eta_A, \eta_D \text{ of } \eta_e(CT) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>300K</td>
<td>10^{10}</td>
<td>10^{15}</td>
<td>10^{14}</td>
<td>10^{8}</td>
<td>0.71</td>
<td>( \Rightarrow \text{ extrinsic} )</td>
</tr>
</tbody>
</table>
| 600K  | 6 \times 10^{15}| 6.5 \times 10^{15}| 10^{14}         | 3.6 \times 10^{14}| 0.15            | \{ \begin{align*}
\text{p-side } \eta_A > \eta_e & \Rightarrow \text{ ext.} \\
\eta_d \text{ ext./int.}
\end{align*} \}
| 900K  | 4 \times 10^{17}| 4 \times 10^{17} | 4.53 \times 10^{17} | 3.63 \times 10^{17} | 0.0009         | \{ \begin{align*}
\text{p-side } \eta_A > \eta_e & \Rightarrow \text{ ext.} \\
\eta_d \text{ ext./int.} & \Rightarrow \text{ int.}
\end{align*} \}

\[
\eta_p(-x_p) = \frac{\eta_e^2}{P_p(-x_p)}
\]