Example 4.2 An abrupt silicon ($n_i = 10^{10}$ cm$^{-3}$) p-n junction consists of a p-type region containing $10^{16}$ cm$^{-3}$ acceptors and an n-type region containing $5 \times 10^{16}$ cm$^{-3}$ donors.

a. Calculate the built-in potential of this p-n junction.

b. Calculate the total width of the depletion region if the applied voltage $V_a$ equals 0, 0.5 and -2.5 V.

c. Calculate maximum electric field in the depletion region at 0, 0.5 and -2.5 V.

d. Calculate the potential across the depletion region in the n-type semiconductor at 0, 0.5 and -2.5 V.

The built-in potential is calculated from:

$$\phi_i = V_i \ln \frac{P_nP_p}{n_i^2} = 0.0259 \ln \frac{10^{16} \times 5 \times 10^{16}}{10^{20}} = 0.76 \text{ V}$$

The depletion layer width is obtained from:

$$w = \sqrt{\frac{2\varepsilon_x}{q} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) (\phi_i - V_a)}$$

The electric field from

$$E(x = 0) = -\frac{2(\phi_i - V_a)}{w}$$

and the potential across the n-type region equals

$$\phi_n = \frac{qN_d x_n^2}{2\varepsilon_x}$$

where

$$x_n = w \frac{N_a}{N_a + N_d}$$

one can also show that

$$\phi_n = (\phi_i - V_a) \frac{N_a}{N_a + N_d}$$

This yields the following numeric values:

<table>
<thead>
<tr>
<th>$V_a$</th>
<th>$w$</th>
<th>$E$</th>
<th>$\phi_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 V</td>
<td>0.315 µm</td>
<td>40 kV/cm</td>
<td>0.105 V</td>
</tr>
<tr>
<td>0.5 V</td>
<td>0.143 µm</td>
<td>18 kV/cm</td>
<td>0.0216 V</td>
</tr>
<tr>
<td>-2.5 V</td>
<td>0.703 µm</td>
<td>89 kV/cm</td>
<td>0.522 V</td>
</tr>
</tbody>
</table>