**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 x $10^{16}$ 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 (4.2.1):

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

The depletion layer width is obtained from (4.3.17):

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

the electric field from (4.3.11):

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

and the potential across the *n*-type region equals

$$\phi_n = \frac{q N_d x_n^2}{2\varepsilon_s}$$

where

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

so that $\phi_n$ equals:

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

This yields the following numeric values:

| | $V_a = 0$ V | $V_a = 0.5$ V | $V_a = -2.5$ V |
|---|---|---|---|
| $x_d$ | 0.345 μm | 0.201 μm | 0.717 μm |
| $\mathcal{E}(0)$ | -44 kV/cm | -25 kV/cm | -91 kV/cm |
| $\phi_n$ | 0.126 V | 0.043 V | 0.543 V |