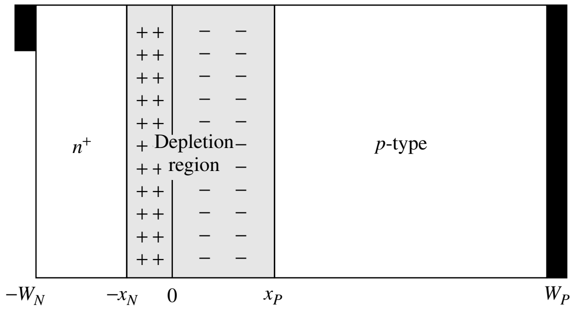

Figure 3.13 Simple solar cell structure used to analyze the operation of a solar cell. Free carriers have diffused across the junction ($x = 0$) leaving a space-charge or depletion region practically devoid of any free or mobile charges. The fixed charges in the depletion region are due to ionized donors on the n-side and ionized acceptors on the p-side

where ϕ is the electrostatic potential, q is magnitude of the electron charge, ε is the electric permittivity of the semiconductor, p_o is the equilibrium hole concentration, n_o is the equilibrium electron concentration, N_A^- is the ionized acceptor concentration, and N_D^+ is the ionized donor concentration. Equation 3.82 is a restatement of equation 3.70 for the given conditions.

This equation is easily solved numerically; however, an approximate analytic solution for an abrupt *pn*-junction can be obtained that lends physical insight into the formation of the space-charge region. Figure 3.13 depicts a simple one-dimensional (1D) *pn*-junction solar cell (diode), with the metallurgical junction at $x = 0$, which is uniformly doped N_D on the n-type side and N_A on the p-type side. For simplicity, it is assumed that the each side is nondegenerately doped and that the dopants are fully ionized.

Within the depletion region, defined by $-x_N < x < x_P$, it can be assumed that p_o and n_o are both negligible compared to $|N_A - N_D|$ so that equation (3.82) can be simplified to

$$\begin{aligned} \nabla^2\phi &= -\frac{q}{\varepsilon}N_D, \quad \text{for} - x_N < x < 0 \quad \text{and} \\ \nabla^2\phi &= \frac{q}{\varepsilon}N_A, \quad \text{for} \quad 0 < x < x_P \end{aligned} \tag{3.83}$$

Outside the depletion region, charge neutrality is assumed and

$$\nabla^2\phi = 0 \quad \text{for} \quad x \le -x_N \quad \text{and} \quad x \ge x_P. \tag{3.84}$$

This is commonly referred to as the *depletion approximation*. The regions on either side of the depletion regions are the quasi-neutral regions.

The electrostatic potential difference across the junction is the built-in voltage, V_{bi}, and can be obtained by integrating the electric field, $\vec{E} = -\nabla\phi$.

$$\int_{-x_N}^{x_P} \vec{E}\mathrm{d}x = -\int_{-x_N}^{x_P} \frac{\mathrm{d}\phi}{\mathrm{d}x}\mathrm{d}x = -\int_{V(-x_N)}^{V(x_P)} \mathrm{d}\phi = \phi(-x_N) - \phi(x_P) = V_{bi} \tag{3.85}$$