in the n-type region. Δp_N and Δn_P are the excess minority-carrier concentrations. The minority-carrier lifetimes, τ_n and τ_p, are given by equation (3.48). For clarity, the capitalized subscripts, "P" and "N", are used to indicate quantities in p-type and n-type regions, respectively, when it may not be otherwise apparent. Lower-case subscripts, "p" and "n", refer to quantities associated with minority holes and electrons, respectively. Equations (3.76) and (3.77) thus each reduce to what is commonly referred to as the *minority-carrier diffusion equation*. It can be written as

$$D_p \frac{\mathrm{d}^2 \Delta p_N}{\mathrm{d}x^2} - \frac{\Delta p_N}{\tau_p} = -G(x) \tag{3.80}$$

in n-type material and as

$$D_n \frac{\mathrm{d}^2 \Delta n_P}{\mathrm{d}x^2} - \frac{\Delta n_P}{\tau_n} = -G(x) \tag{3.81}$$

in p-type material. For example, Δn_P is the minority electron concentration in the p-type material. The minority-carrier diffusion equation is often used to analyze the operation of semiconductor devices, including solar cells.

3.3 *PN*-JUNCTION DIODE ELECTROSTATICS

Where an n-type semiconductor comes into contact with a p-type semiconductor, a *pn*-junction is formed. In thermal equilibrium there is no net current flow and by definition the Fermi energy must be independent of position. Since there is a concentration difference of holes and electrons between the two types of semiconductors, holes diffuse from the p-type region into the n-type region and, similarly, electrons from the n-type material diffuse into the p-type region. As the carriers diffuse, the charged impurities (ionized acceptors in the p-type material and ionized donors in the n-type material) are uncovered – that is, no longer screened by the majority carrier. As these impurity charges are uncovered, an electric field (or electrostatic potential difference) is produced, which limits the diffusion of the holes and electrons. In thermal equilibrium, the diffusion and drift currents for each carrier type exactly balance, so there is no net current flow. The transition region between the n-type and the p-type semiconductors is called the *space-charge region*. It is also often called the *depletion region*, since it is effectively depleted of both holes and electrons. Assuming that the p-type and the n-type regions are sufficiently thick, the regions on either side of the depletion region are essentially charge-neutral (often termed *quasi-neutral*). The electrostatic potential difference resulting from the junction formation is called the *built-in voltage*, V_{bi}. It arises from the electric field created by the exposure of the positive and the negative space charge in the depletion region.

The electrostatics of this situation (assuming a single acceptor and a single donor level) are governed by Poisson's equation

$$\nabla^2 \phi = \frac{q}{\varepsilon}(n_o - p_o + N_{\mathrm{A}}^- - N_{\mathrm{D}}^+) \tag{3.82}$$