where G is the optical generation rate of electron–hole pairs. Thermal generation is included in R_p and R_n. The hole and electron current densities are given by

$$\vec{J}_p = -q\mu_p p\nabla(\phi - \phi_p) - kT\mu_p\nabla p \tag{3.73}$$

and

$$\vec{J}_n = -q\mu_n n\nabla(\phi + \phi_n) + kT\mu_n\nabla n. \tag{3.74}$$

Two new terms, ϕ_p and ϕ_n, have been introduced here. These are the so-called band parameters that account for degeneracy and a spatially varying band gap and electron affinity [14]. These terms were ignored in the preceding discussion and can usually be ignored in nondegenerate homostructure solar cells.

The intent here is to derive an analytic expression for the current–voltage characteristic of a simple solar cell, and so some simplifications are in order. It should be noted, however, that a complete description of the operation of solar cells can be obtained by solving the complete set of coupled partial differential equations, equations (3.70) through (3.74). The numerical solution of these equations is addressed later in this chapter.

3.2.9 Minority-carrier Diffusion Equation

In a uniformly doped semiconductor, the band gap and electric permittivity are independent of position. Since the doping is uniform, the carrier mobilities and diffusion coefficients are also independent of position. As we are mainly interested in the steady state operation of the solar cell, the semiconductor equations reduce to

$$\frac{\mathrm{d}\vec{E}}{\mathrm{d}x} = \frac{q}{\varepsilon}(p - n + N_\mathrm{D} - N_\mathrm{A}) \tag{3.75}$$

$$q\mu_p\frac{\mathrm{d}}{\mathrm{d}x}(p\vec{E}) - qD_p\frac{\mathrm{d}^2 p}{\mathrm{d}x^2} = q(G - R) \tag{3.76}$$

and

$$q\mu_n\frac{\mathrm{d}}{\mathrm{d}x}(n\vec{E}) + qD_n\frac{\mathrm{d}^2 n}{\mathrm{d}x^2} = q(R - G) \tag{3.77}$$

In regions sufficiently far from the *pn*-junction of the solar cell (quasi-neutral regions), the electric field is very small. When considering the minority carrier (holes in the *n*-type material and electrons in the *p*-type material) and low-level injection ($\Delta p = \Delta n \ll N_\mathrm{D}, N_\mathrm{A}$), the drift current can be neglected with respect to the diffusion current. Under low-level injection, R simplifies to

$$R = \frac{n_P - n_{Po}}{\tau_n} = \frac{\Delta n_P}{\tau_n} \tag{3.78}$$

in the p-type region and to

$$R = \frac{p_N - p_{No}}{\tau_p} = \frac{\Delta p_N}{\tau_p} \tag{3.79}$$