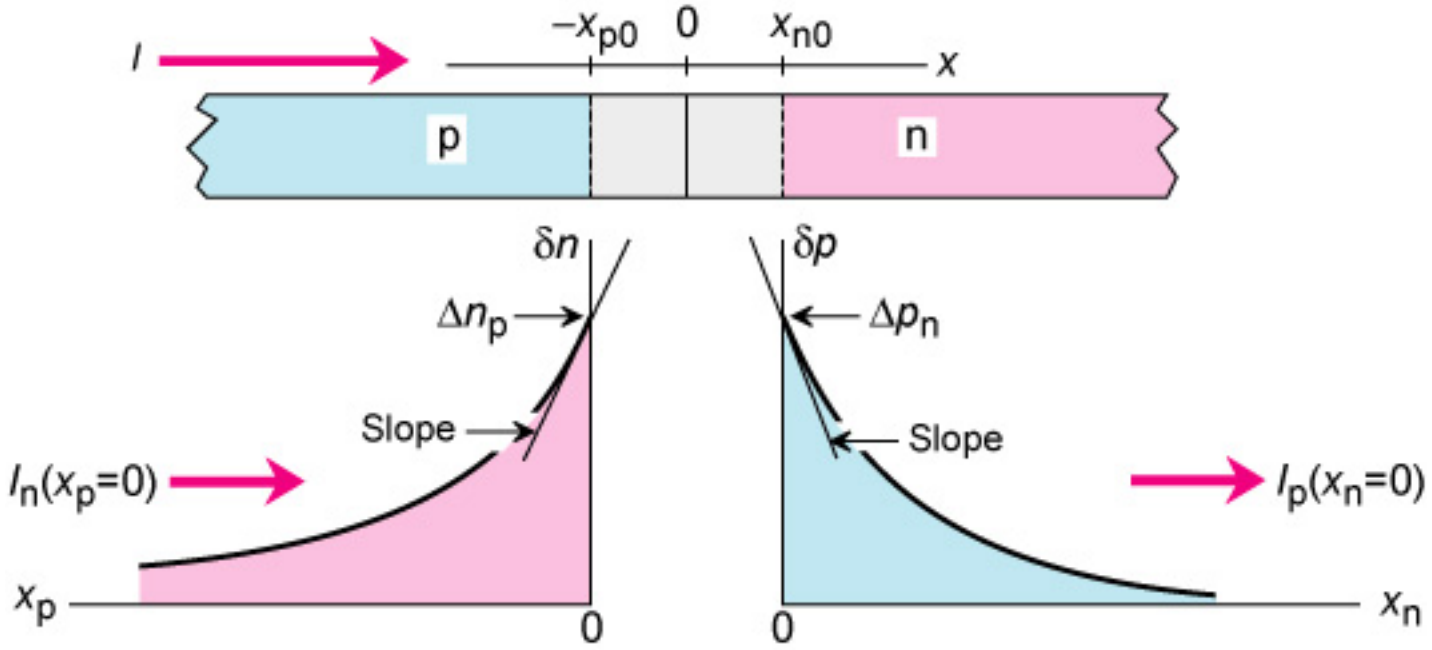
Summary of p-n junction theory

Diffusion theory

It is the purpose of this module to provide a concise summary of p-n junctions.

Diffusion theory



$$I_n(x_p = 0) = e\,A\,D_n \left.\frac{d\delta n}{dx_p}\right|_{x_p=0}$$

$$= -e\,A\,D_n \frac{\Delta n_p}{L_n}$$

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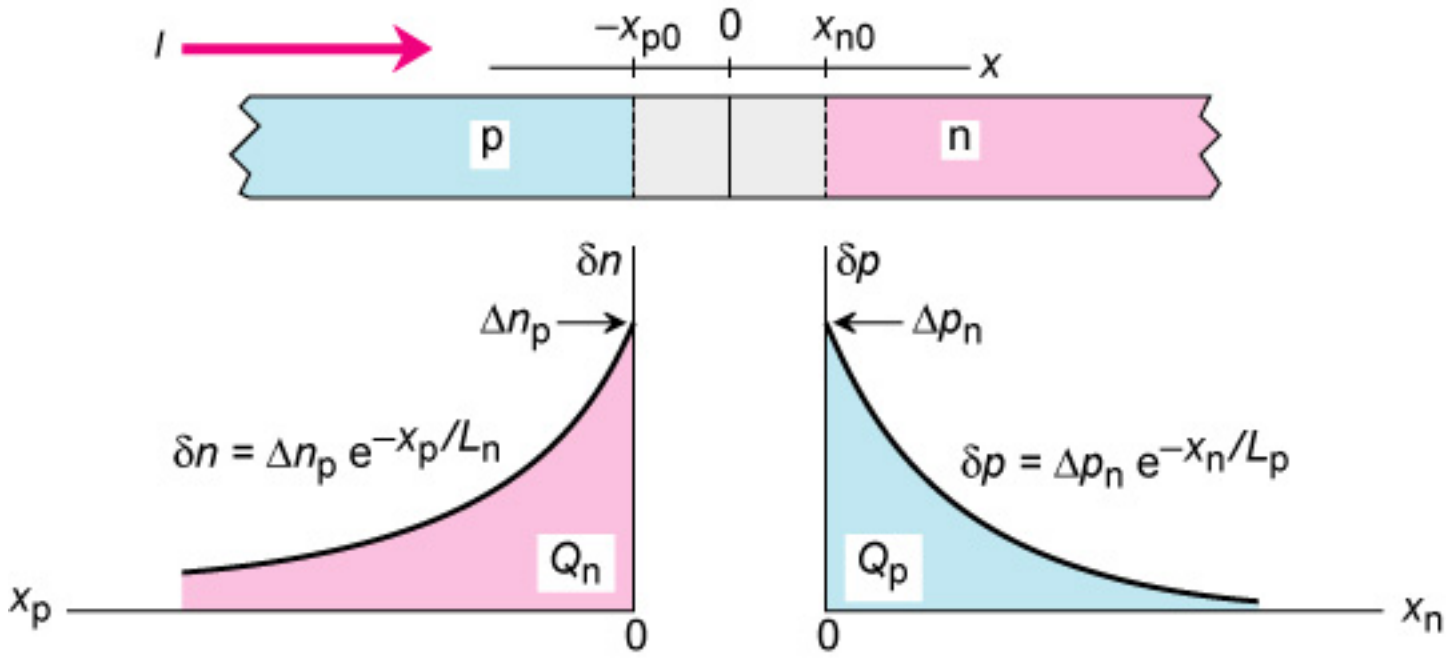
Interpretation:

- Currents are calculated from slope at edge of space-charge region
- Recall: Diffusion current density = $e\,D\,(dn / dx)$
- Also recall: $L_D = (D\,\tau)^{1/2}$

Charge control theory



$$Q_n = -eA\int_0^\infty \delta n(x_p)\,dx_p \qquad Q_p = -eA\int_0^\infty \delta p(x_n)\,dx_n$$

$$I_n(x_p=0) = \frac{Q_n}{\tau_n} = \frac{-eAL_n\,\Delta n_p}{\tau_n} \qquad I_p(x_n=0) = \frac{Q_p}{\tau_p} = \frac{eAL_p\,\Delta p_n}{\tau_p}$$

Interpretation:

- Currents are calculated from stored charge and minority carrier lifetime
- Recall: Current = Q / τ
- Also recall: $L_D = (D \tau)^{1/2}$
- Are currents derived by diffusion theory and charge control theory the same?

Shockley equation

$$
\begin{aligned}
I &= I_{\mathrm{p}}(x_{\mathrm{n}}=0) - I_{\mathrm{n}}(x_{\mathrm{p}}=0) \\
&= e\,A\left(\frac{D_{\mathrm{p}}}{L_{\mathrm{p}}}\,\Delta p_{\mathrm{n}} + \frac{D_{\mathrm{n}}}{L_{\mathrm{n}}}\,\Delta n_{\mathrm{p}}\right) \\
&= e\,A\left(\frac{D_{\mathrm{p}}}{L_{\mathrm{p}}}\,p_{\mathrm{n0}} + \frac{D_{\mathrm{n}}}{L_{\mathrm{n}}}\,n_{\mathrm{p0}}\right)\left(\mathrm{e}^{eV/kT}-1\right) \\
&= e\,A\left(\frac{L_{\mathrm{p}}}{\tau_{\mathrm{p}}}\,p_{\mathrm{n0}} + \frac{L_{\mathrm{n}}}{\tau_{\mathrm{n}}}\,n_{\mathrm{p0}}\right)\left(\mathrm{e}^{eV/kT}-1\right) \\
&= e\,A\left(\sqrt{\frac{D_{\mathrm{p}}}{\tau_{\mathrm{p}}}}\,\frac{{n_{\mathrm{i}}}^2}{N_{\mathrm{D}}} + \sqrt{\frac{D_{\mathrm{n}}}{\tau_{\mathrm{n}}}}\,\frac{{n_{\mathrm{i}}}^2}{N_{\mathrm{A}}}\right)\left(\mathrm{e}^{eV/kT}-1\right) \\
&= I_{\mathrm{s}}\left(\mathrm{e}^{eV/kT}-1\right)
\end{aligned}
$$

Interpretation:

- Celebrated Shockley equation is key equation of p-n junction diodes
- Shockley equation relates I-V to materials parameters

How would one design a p-n junction diode …

… with low saturation current?

… for high current densities?

… low capacitance?

… high frequency?

… large breakdown voltage?