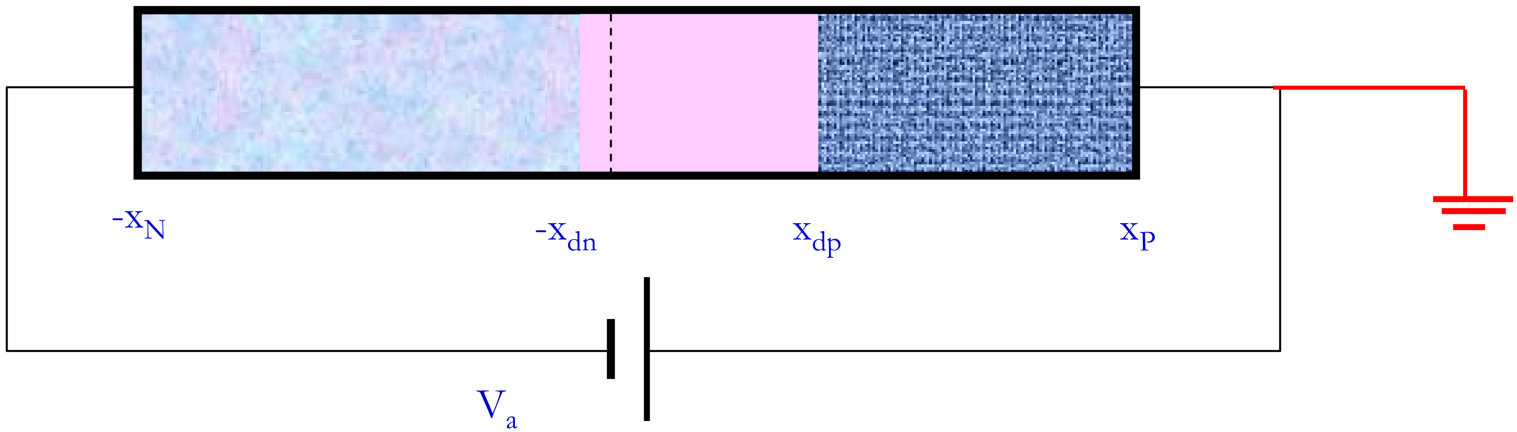
The np junction diode under bias

LECTURE 8

- *np*-junction under forward bias
- quasi-neutrality
- quasi-Fermi levels
- charge continuity equation
- master set of equations
- Shockley’s Law of the Junction
- Ideal diode Equation

Sec. 6.3

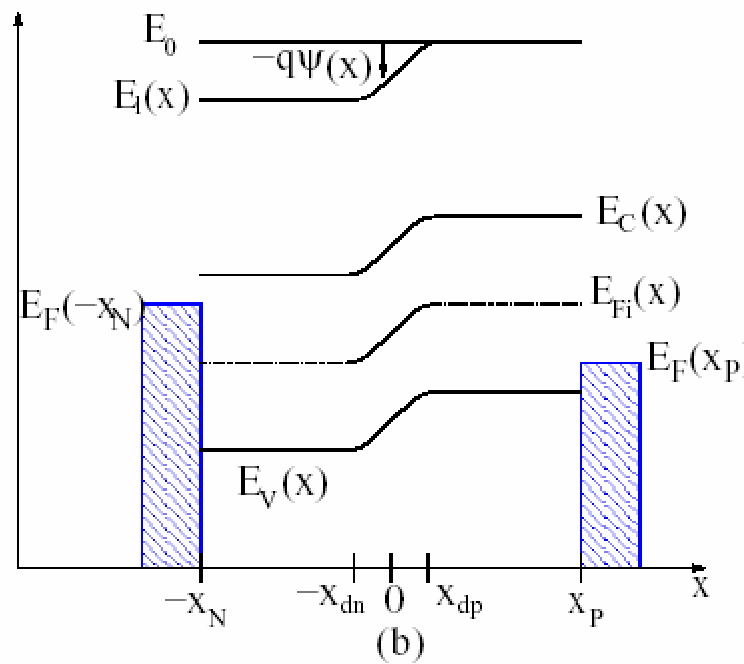
np-junction under bias



Note the polarity of V_a

$$\psi(-x_N) - \psi(x_P) = V_{bi} + V_a$$

$$E_F(-x_N) - E_F(x_P) = -qV_a$$

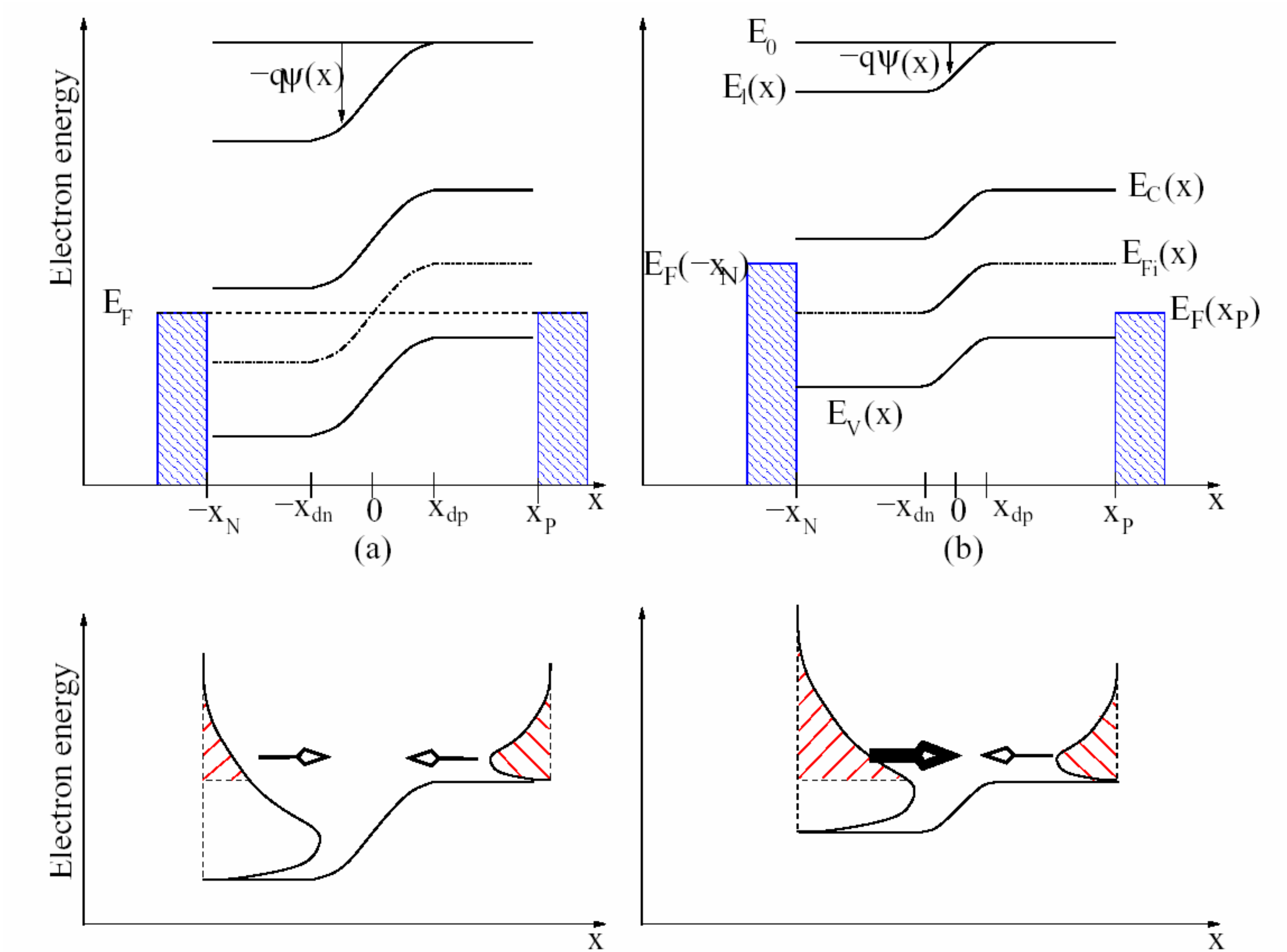


Can we assume that

$\psi(-x_{dn}) - \psi(x_{dp}) = V_{bi} + V_a$?

Sec. 6.3

Forward-bias current

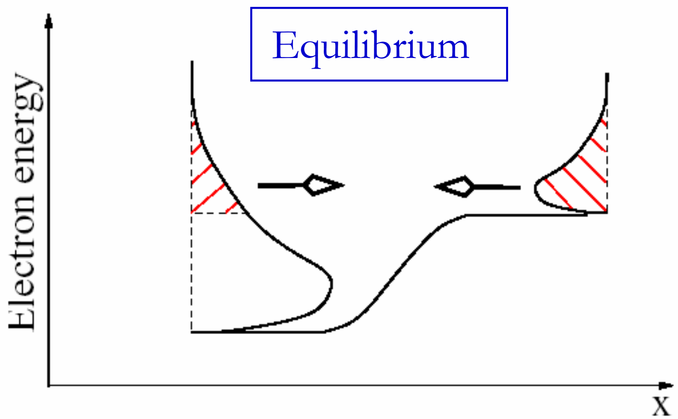


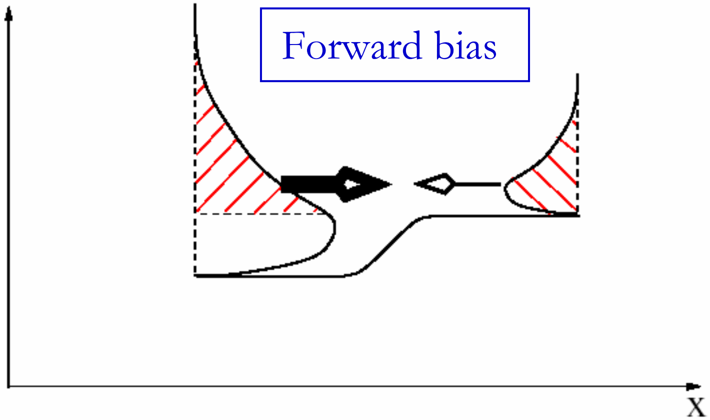
• Net current is due to e-injection into p-region.

Why has W shrunk?

Sec. 6.4

Quasi-Fermi levels





The two flows are huge

The difference can be large but <<< huge

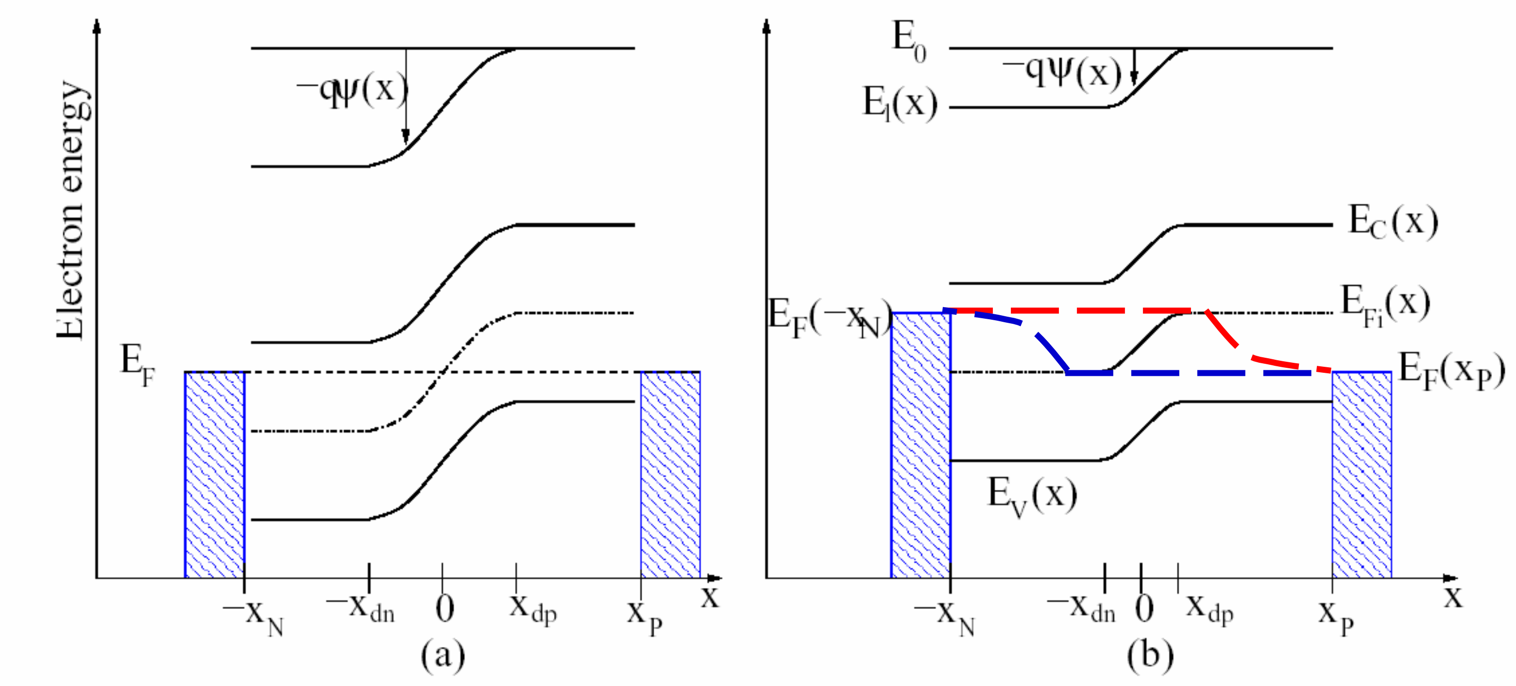
∴ we have a situation of quasi-

So, instead of THE Fermi-level, we define

$$
\begin{aligned}
n &= n_i \exp\left(\frac{E_{Fn} - E_{Fi}}{k_B T_L}\right) \\
p &= n_i \exp\left(\frac{E_{Fi} - E_{Fp}}{k_B T_L}\right)
\end{aligned}
$$

Sec. 6.3

Forward-bias current



Recall:

$$n = n_i \exp\left(\frac{E_{Fn} - E_{Fi}}{k_B T_L}\right)$$

$$p = n_i \exp\left(\frac{E_{Fi} - E_{Fp}}{k_B T_L}\right)$$

i.e., n,p are f(QFLs)
and, via E_{Fi}, f (ψ).

What are the red and blue dashed lines?

What is their separation in the depletion region?

What is happening at the contacts?

Can we solve for n and p?

So far we have 3 equations, but 5 unknowns !

$$\boxed{\begin{aligned} -\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\ J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\ J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \end{aligned}}$$

Present BC's are:

$n = n_0$ and $p = p_0$ at the ends (OHMIC CONTACT)

$\psi(x_P) = 0$

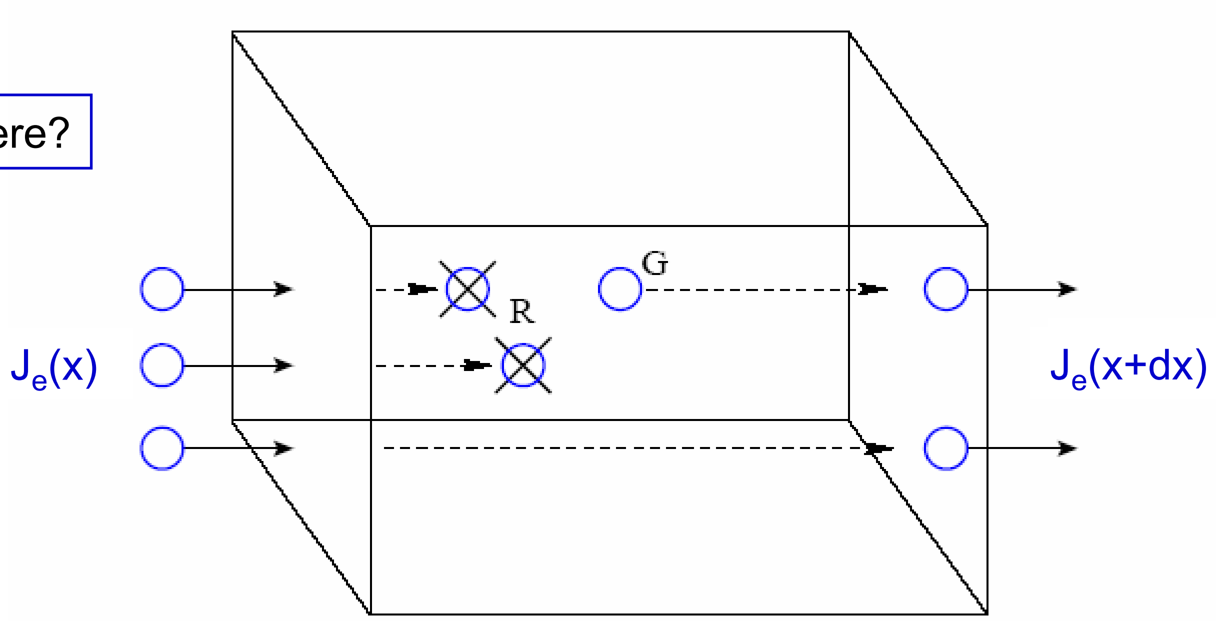
$E_{Fn}(-x_N) - E_{Fp}(x_P) = -qV_a$

2 more equations are needed, without introducing any more unknowns.

Sec. 5.2.2

Continuity of charge

What is happening here?



What is the equation for the continuity of charge?

$$\frac{\partial n}{\partial t} = \boxed{}$$

What are τ_e and L_e ?

$$\left\{\begin{array}{l} U \equiv R - G_{th} \\ U_e \equiv \dfrac{n - n_{0p}}{\tau_e} \\ L_e = \sqrt{D_e \tau_e} \end{array}\right.$$

Sec. 5.3

The master equation set

This is our version of (5.24)

$$\begin{aligned}
-\nabla^2\psi &= \frac{q}{\epsilon}[p - n + N_D - N_A] \\
J_e &= -qn\mu_e\nabla\psi + qD_e\nabla n \\
J_h &= -qp\mu_h\nabla\psi - qD_h\nabla p \\
\frac{\partial n}{\partial t} &= \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} \\
\frac{\partial p}{\partial t} &= -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h}\,.
\end{aligned}$$

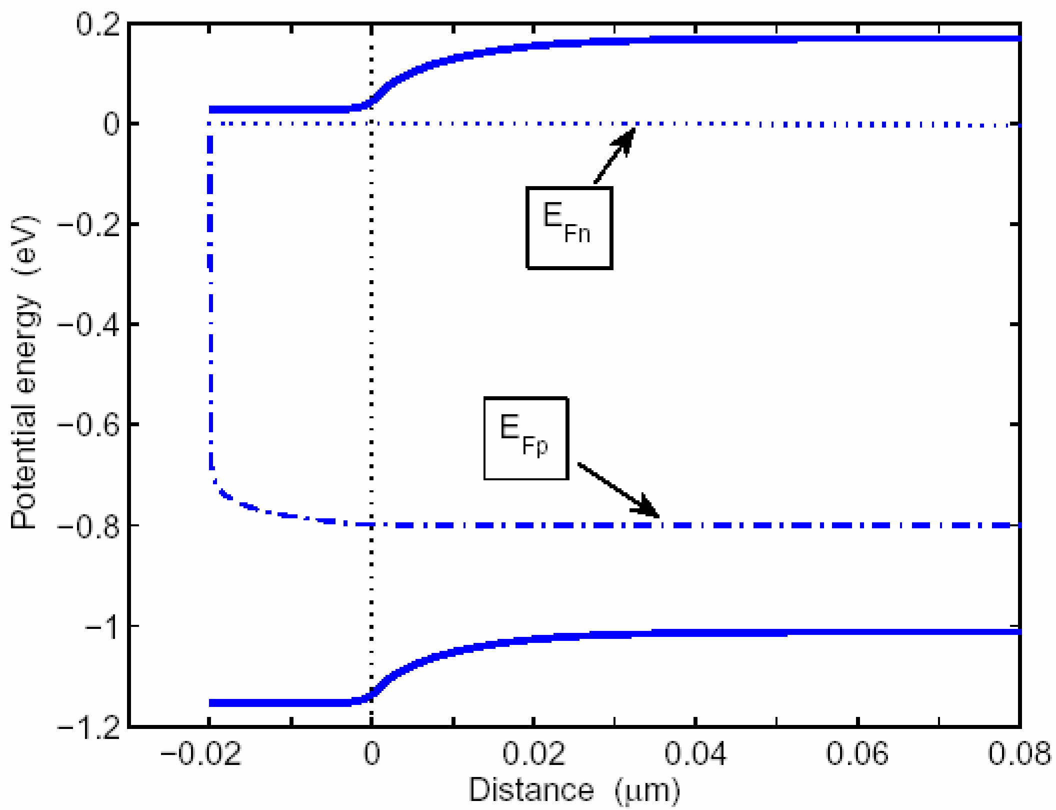
J's are f(n,p), so, essentially, we have

3 equations in 3 unknowns ;

solve numerically.

Sec. 6.4

Numerical solution



n/p diode

1E19/1E17 cm-3

0.02/2 micron

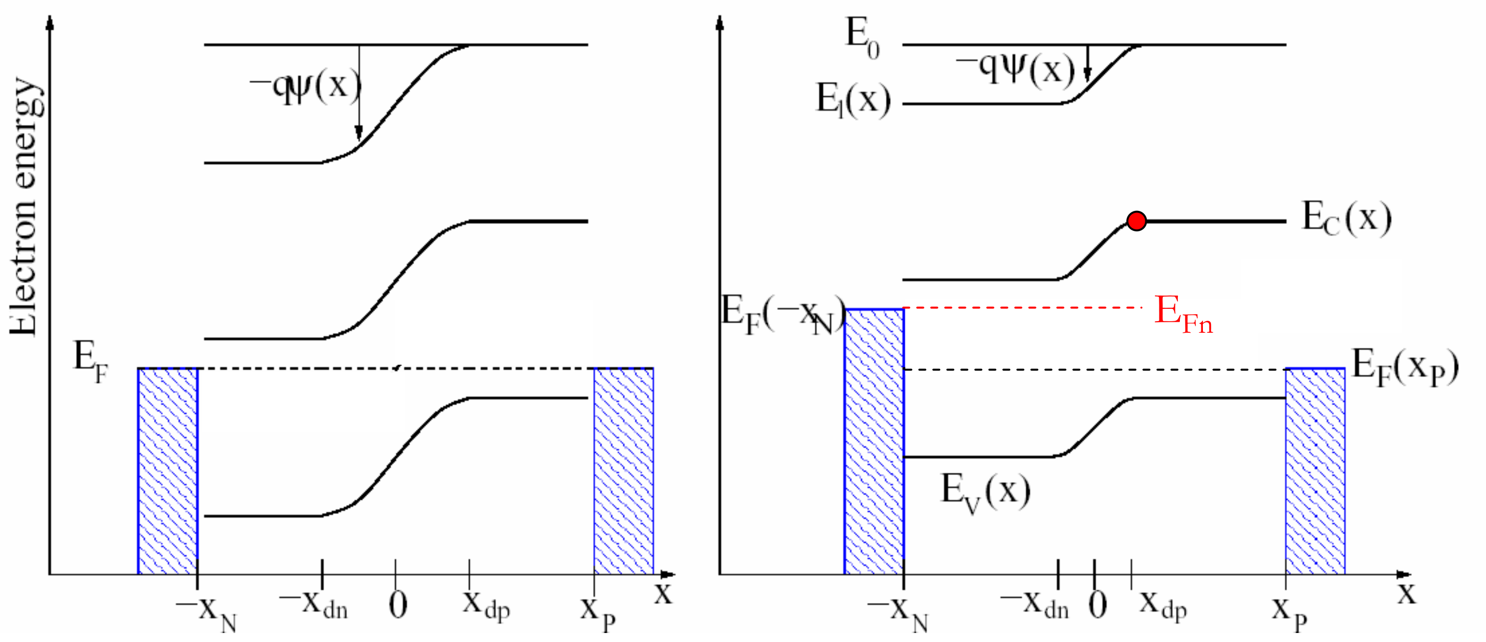
V_a=-0.8V

- Note at left contact
- Note across the space-charge region

What happens to the QFLs at x = 2 micron?

Sec. 6.5

Shockley's Law of the Junction

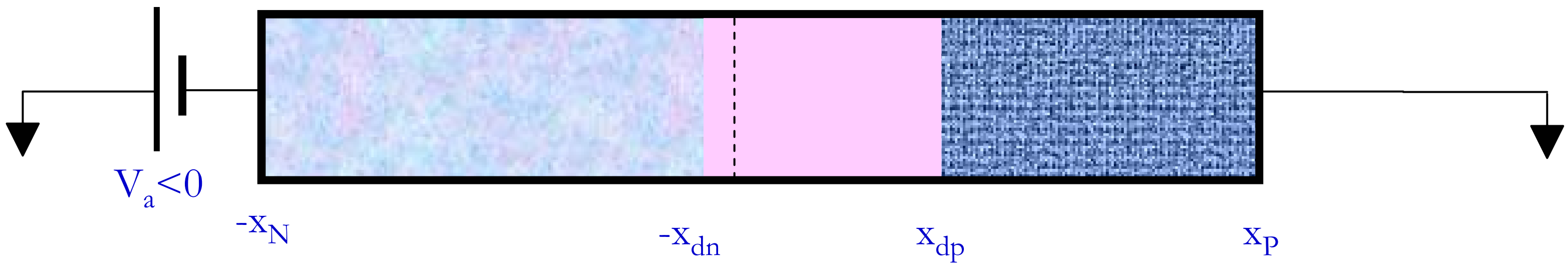


The constancy of the QFL across the SCR leads to a very useful BC:

$$n(x_{dp}) = \boxed{}$$

Sec. 6.6

The ideal-diode equation



- Pick a region in which to calculate the current.
- Why choose the *p*-type QNR for J_e ?
- Get the equations for this carrier from the Master Set

$$\begin{cases} \cancel{-\nabla^2\psi = \frac{q}{\epsilon}[p-n+N_D-N_A]} \\ J_e = \cancel{-qn\mu_e\nabla\psi} + qD_e\nabla n \\ \cancel{J_h = -qp\mu_h\nabla\psi - qD_h\nabla p} \\ \frac{\partial n}{\partial t} = \frac{1}{q}\nabla\cdot J_e - \frac{n-n_0}{\tau_e} \\ \cancel{\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla\cdot J_h - \frac{p-p_0}{\tau_h}}. \end{cases}$$

- Use General Solution

$$n(x) - n_{0p} = Ae^{x/L_e} + Be^{-x/L_e}$$

- Determine BC's

$$\begin{cases} n(x_P) \equiv n(\infty) = n_{0p} \\ n(x_{dp}) = n_{0p}e^{-V_a/V_{\text{th}}} \end{cases}$$

- Find n(x)
- Calculate $J_e(x_{dp})$

$$J_e(x_{dp}) = -qn_{0p}\left(e^{-V_a/V_{\text{th}}}-1\right)\cdot\frac{D_e}{L_e}$$

- Infer $J_h(-x_{dn})$

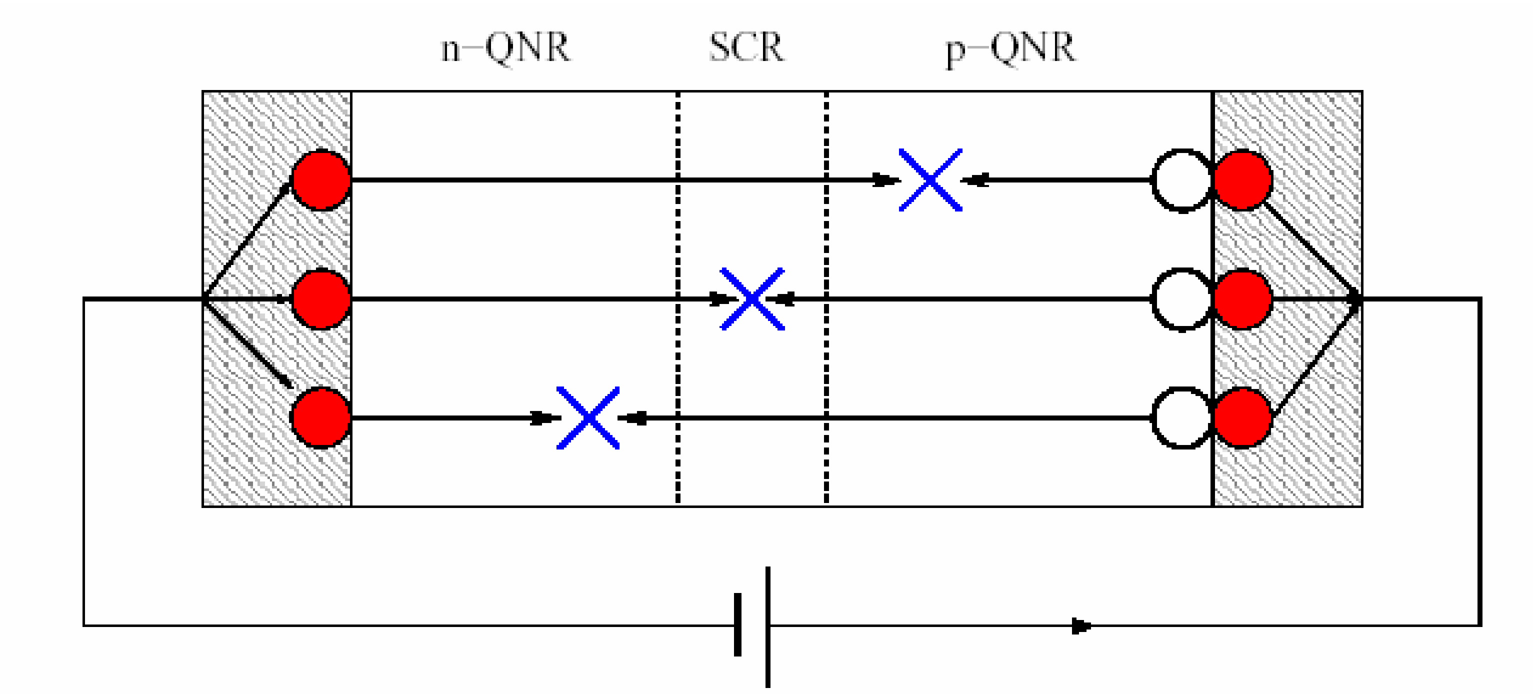
$$J_h(-x_{dn}) = -qp_{0n}\left(e^{-V_a/V_{\text{th}}}-1\right)\cdot\frac{D_h}{L_h}$$

- Sum the currents (is this OK?)

$$J = -q\left(n_{0p}\frac{D_e}{L_e} + p_{0n}\frac{D_h}{L_h}\right)\left(e^{-V_a/V_{\text{th}}}-1\right)$$
$$\equiv J_{00}\left(e^{-V_a/V_{\text{th}}}-1\right),$$

Sec. 6.6

Bipolar conduction



What is going on here?