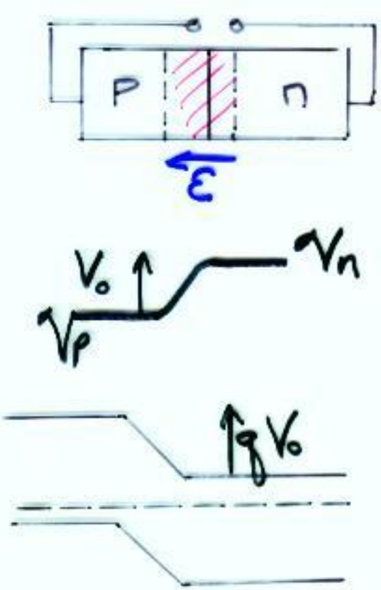
P-n Junctions with Forward & Reverse Bias

→ Effects of bias on the important junction parameters.

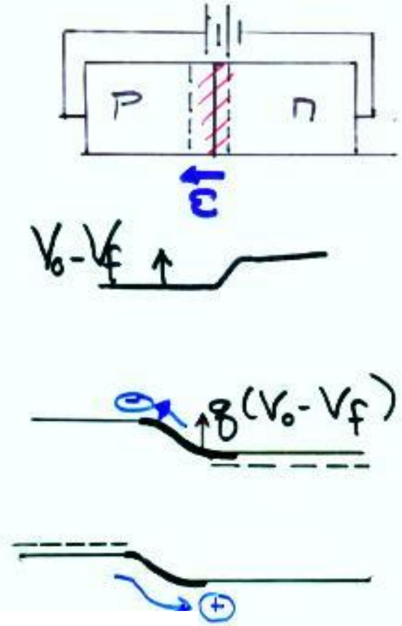
Assume that all Voltage V falls across transition region W.

- okay for "thin" transition region (compared to device area) and "highly doped" (low resistance of neutral semiconductor)

Equilibrium (V=0)

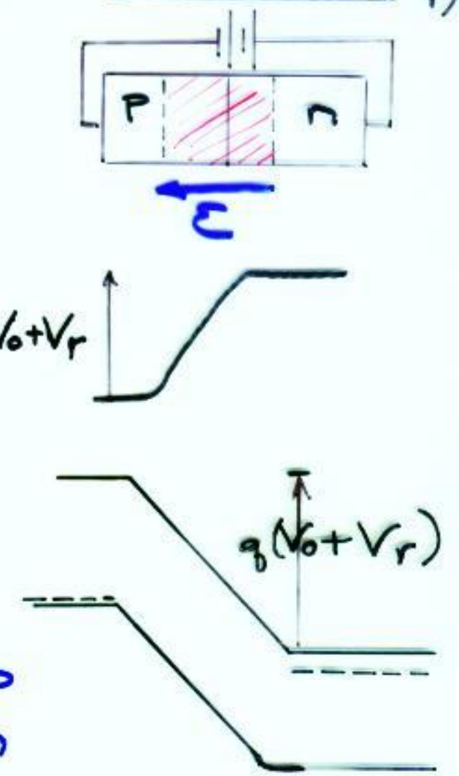


Forward Bias ($V=V_f$)

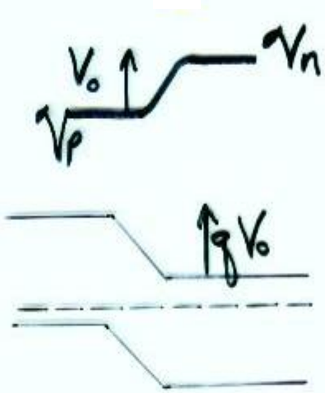


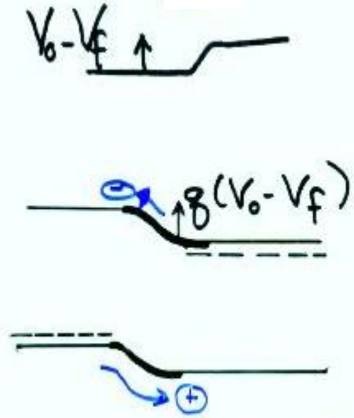
More electrons pushed n->p
More holes pushed p->n

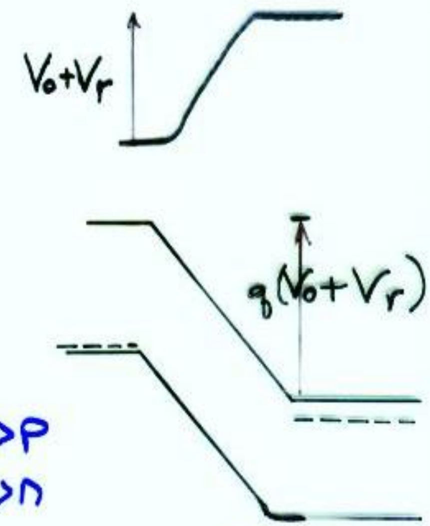
Reverse Bias ($V=V_r$)



Vice Versa







More electrons pushed n->p
More holes pushed p->n

V_f opposes Built-In Field $\mathcal{E}$
so Net $\mathcal{E}$ decreases.
Lower barrier
so more diffusion

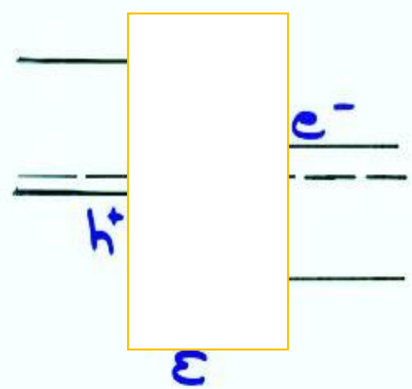
~ same drift since
few carriers available

Vice Versa

V_r adds to Built-In $\mathcal{E}$
so Net $\mathcal{E}$ increases
Higher Barrier
so Less Diffusion

~same drift

Particle Flow	Current	Type
h^+	J_p	Diffusion
h^+	J_p	Drift
e^-	J_n	Diffusion
e^-	J_n	Drift



Applied Bias Changes $\mathcal{E}$, so W changes too.

W with V_f since lower $\mathcal{E}$,

less + and - charges and therefore

less uncompensated acceptor and donor ions

in transition region.

W with V_r since higher $\mathcal{E}$, ...

Replace V_0 with $V_0 - V_f$ (forward bias)

or $V_0 + V_r$ (reverse bias)

in $$W = \left[\frac{2\epsilon V_0}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)\right]^{1/2}$$

$$x_{no} = \left[\frac{2\epsilon V_0}{q N_d}\left(\frac{N_a}{N_a + N_d}\right)\right]^{1/2}$$

$$x_{po} = \left[\frac{2\epsilon V_0}{q N_a}\left(\frac{N_d}{N_a + N_d}\right)\right]^{1/2}$$

$$W = \left[\frac{2\epsilon (V_0 - V_f)}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)\right]^{1/2}$$

$$W = \left[\frac{2\epsilon (V_0 + V_r)}{q}\left(\frac{1}{N_a} + \frac{1}{N_d}\right)\right]^{1/2}$$

Likewise, x_{no} and x_{po}.

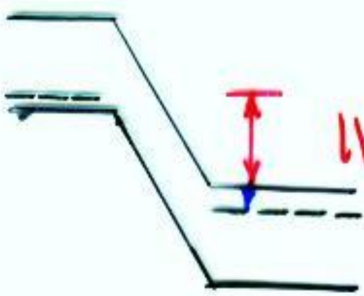
Separate Fermi Levels by $V_{applied}$.

$$|V_f| = \frac{|E_{Fn}-E_{Fp}|}{q}$$

Barriers get smaller

$E_{cp} - E_{cn}$ gets smaller

$E_{vp} - E_{vn}$ " "



$$|V_r| = \frac{|E_{Fp}-E_{Fn}|}{q}$$

Barriers get larger

$E_{cp} - E_{cn}$ gets larger

$E_{vp} - E_{vn}$ " "

Again → V_f opposes built-in field, $\mathcal{E}$ ____

so ____ diffusion current

(forward bias "fills in" much of the "uncovered" ionic charge)

→ V_r ____ to $\mathcal{E}$, so ____ diffusion current.

Drift currents ~ same, depends on availability of charges (low), supplied mainly by thermal / optical generation.

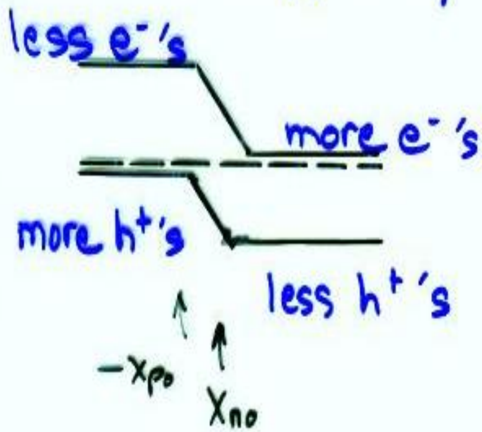
Bias Effect on Carrier Concentrations

Recall $\frac{p_p}{p_n} =$ at equilibrium

and $\frac{n_n}{n_p} =$

Eq. 3.25: $p_o = n_i e^{(E_i - E_F)/kT}$

If $(E_i - E_f)$ differs by V_0 from one side to the other, then p differs by $e^{qV_0/kT}$



equilibrium

(n and p concentrations in neutral regions)

With bias, $\dfrac{p(-x_{po})}{p(x_{no})} =$

Since E_F positions changed at edges of transition region. So n and p ratios change too.

For negligible changes in majority carrier concentration (low light levels / injection)

$$p(-x_{po}) = p_p$$

$$\frac{p_p / p_n}{p(-x_{po}) / p(x_{no})} = \frac{p_p / p_n}{p_p / p(x_{no})} = \frac{e^{qV_0/kT}}{e^{q(V_0-V)/kT}}$$

$$\frac{p(x_{no})}{p_n} = \boxed{}$$

Forward Bias V: $P(x_{no})$ increases over P_n: "Injection"

Reverse Bias V: $P(x_{no})$ decreases over P_n: "Extraction"

Forward Case: Excess carriers at edge of depletion region.

At x_{no}: $\Delta P_n = p(x_{no}) - P_n =$

At $-x_{po}$: $\Delta n_p = n(-x_{po}) - n_p =$

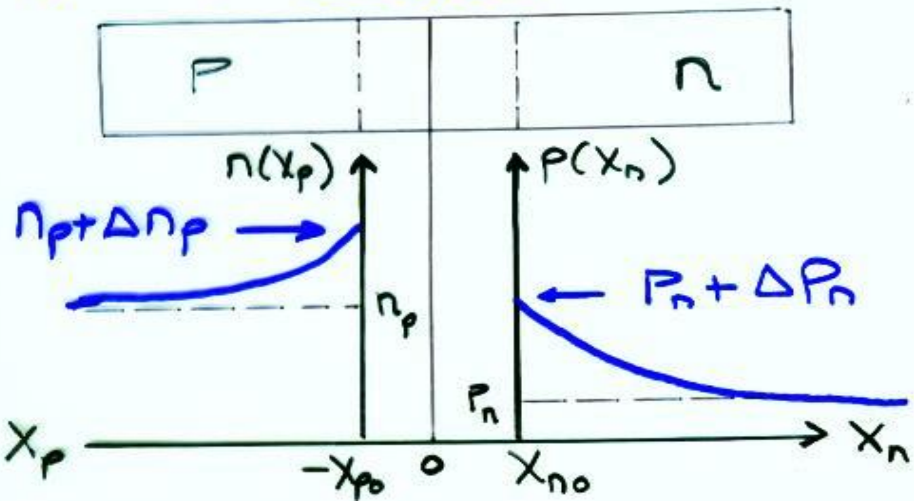
Why not excess carriers throughout neutral semiconductor?

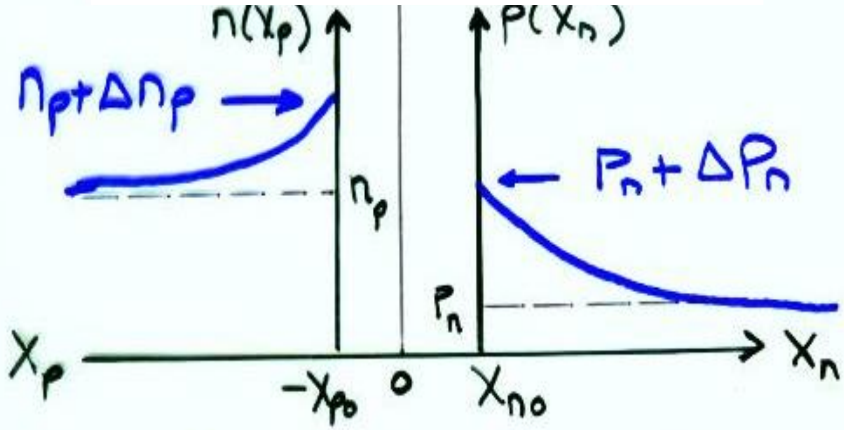
→

Injection produces excess ΔP_n at X_{no},
" " distribution in n-type side

$P(X_n)$ changes with X_n since, as they diffuse into the n-type bulk, they recombine.

$P(X_n)$ decreases with X_n.





Think of forward bias as "pushing out" majority carriers and "pulling in" minority carriers.

$p(x_n) = p_n + \Delta p_n$ for x_n at edge (i.e., x_{no})

$p(x_n) = p_n$ for x_n deep in bulk

similarly for $n(x_p)$

$p_n = \frac{n_i^2}{n_n} = \frac{n_i^2}{N_d}$ and $n_p = \frac{n_i^2}{p_p} = \frac{n_i^2}{N_a}$