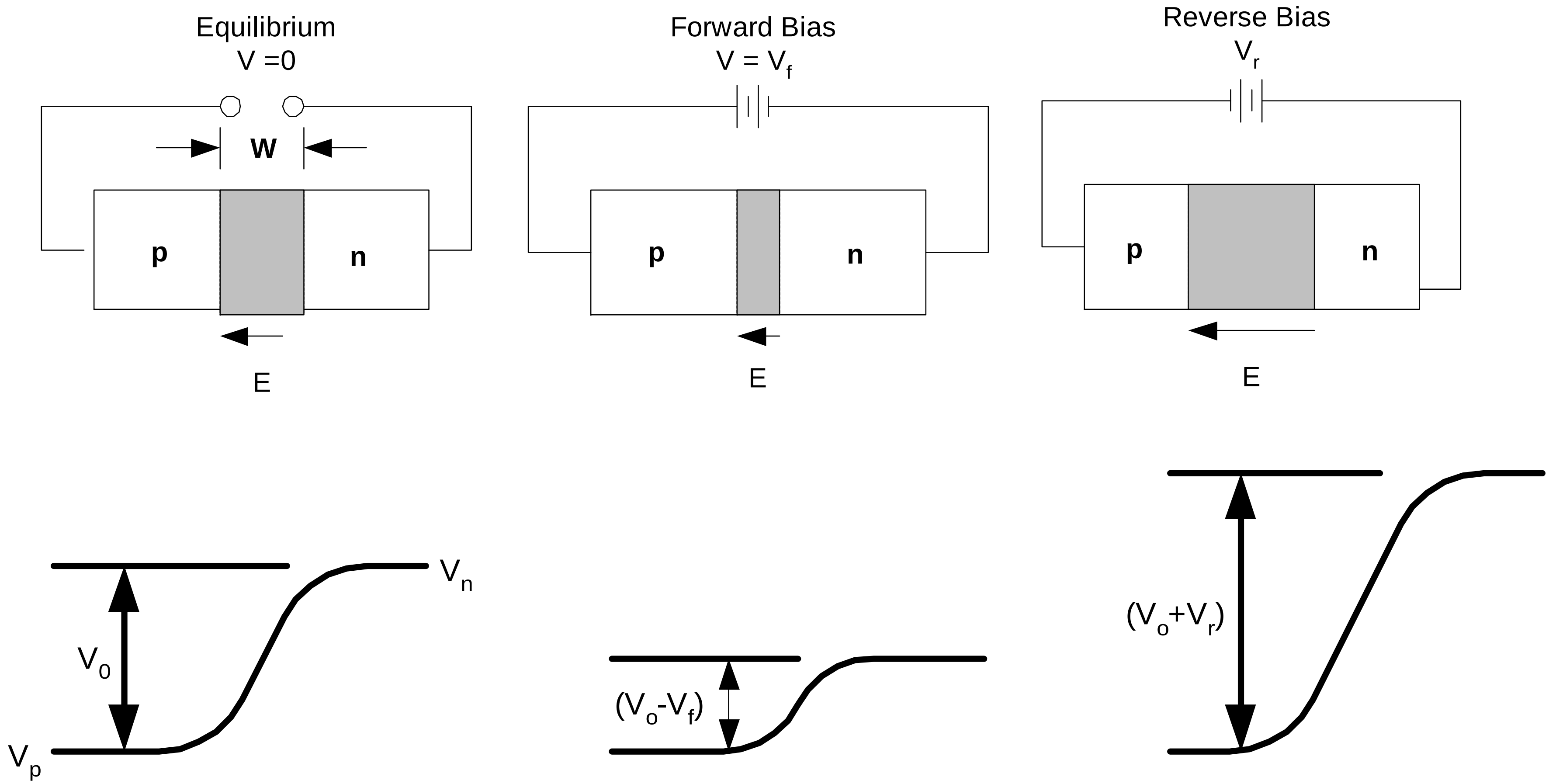
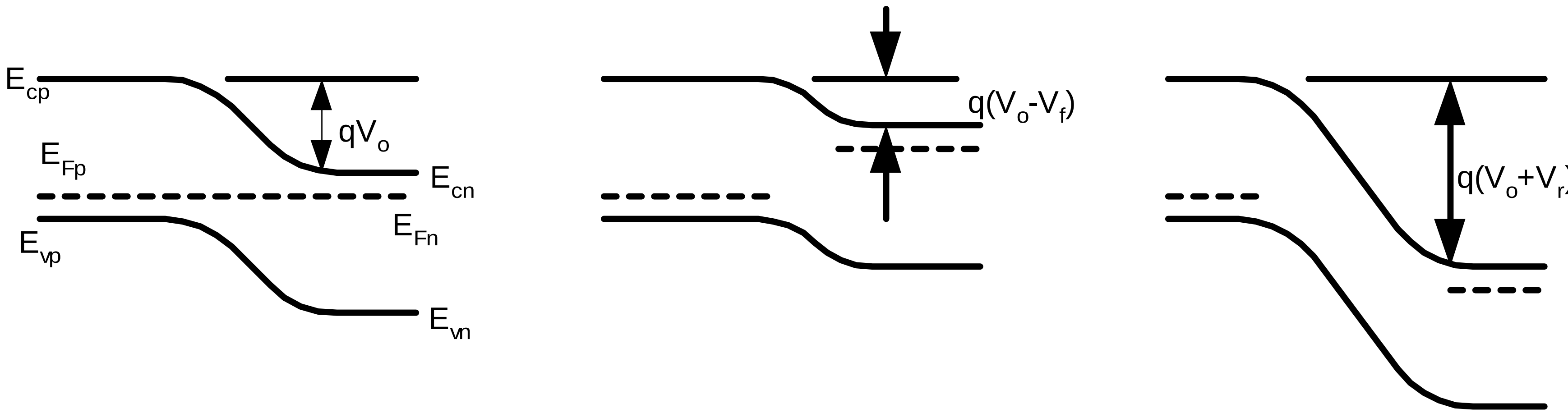
Non-equilibrium conditions in a pn junction

- Equilibrium, forward bias, reverse bias
- Carrier injection
- Calculating junction current
- Minority and majority currents
- Diode equation example

Equilibrium, forward bias, reverse bias



Equilibrium, forward bias, reverse bias



Equilibrium, forward bias, reverse bias

- Equilibrium
  - The Hole and electron drift and diffusion currents cancel each other out. No net current.
- Forward bias
  - The junction potential is lowered by an applied electric field.
- Reverse bias
  - The junction potential is increased by an applied electric field.

Equilibrium, forward bias, reverse bias

- Equilibrium
  - W does not change.
- Forward bias
  - W is smaller substitute (V_o-V) for V_o in equation for W.
- Reverse bias
  - W is larger substitute (V_o+V) for V_o in equation for W.

Equilibrium, forward bias, reverse bias

- Equilibrium
  - $E_{Fp}=E_{Fn}$ flat throughout .
- Forward bias
  - E_{Fp}(J) and E_{Fn} (J) are separated by $q(V_f)$ (J) .
- Reverse bias
  - E_{Fp}(J) and E_{Fn} (J) are separated by $q(V_r)$ (J) .

Equilibrium, forward bias, reverse bias

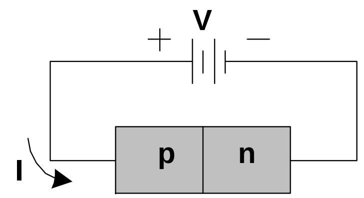
- Equilibrium
  - No net current .
- Forward bias
  - Diffusion current is increased because the barrier is lowered and thus more electrons and hole have enough energy to make it through the barrier. Electrons go from the n-side to the p-side. Holes go from the p-side to the n-side.
  - Drift current: small because this depends on the concentration of minority carriers. Thermally generated EHP's (within a diffusion length of W, are the only carriers that contribute to drift, thus independent of applied bias.

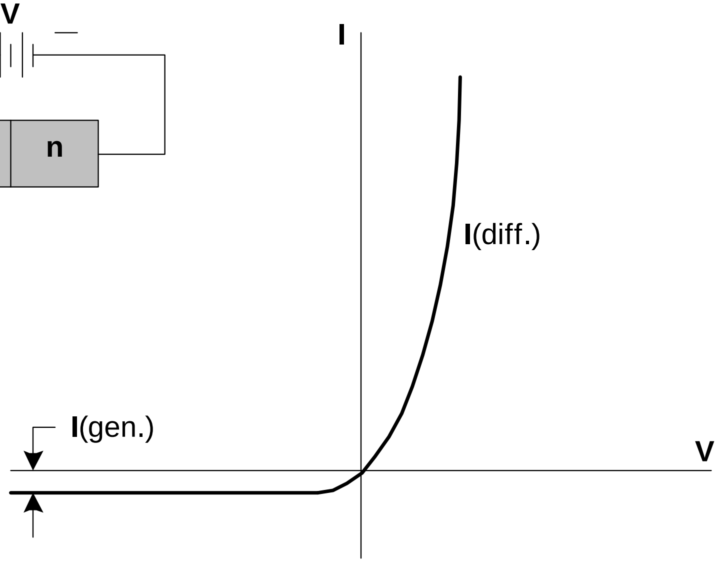
Equilibrium, forward bias, reverse bias

- Reverse bias
  - Diffusion current is decreased because the barrier is higher and thus less electrons and hole have enough energy to make it through the barrier. Electrons go from the n-side to the p-side. Holes go from the p-side to the n-side.
  - Drift current: small because this depends on the concentration of minority carriers. Thermal generated EHP's (within a diffusion length of W, are the only carriers that contribute to drift, thus independent of applied bias.

Equilibrium, forward bias, reverse bias

- Equilibrium: I=I(Diff)-|I(gen)=0|
- Forward bias: $I = I_o(e^{qV/kT}-1)$
- Reverse bias: $I=I_o$





Carrier injection

- Minority carriers dominate

$$I = qA\left(\frac{D_p}{L_p}p_n + \frac{D_n}{L_n}n_p\right)\left(e^{qV/kT} - 1\right)$$

$$D_p = \frac{kT}{q}\mu_p,\ L_p = \sqrt{D_p\tau_p} \qquad p_n = \frac{p_p}{e^{qV_o/kT}} = \frac{N_a}{e^{qV_o/kT}}$$

$$D_n = \frac{kT}{q}\mu_n,\ L_n = \sqrt{D_n\tau_n} \qquad n_p = \frac{n_n}{e^{qV_o/kT}} = \frac{N_d}{e^{qV_o/kT}}$$

Calculating junction current

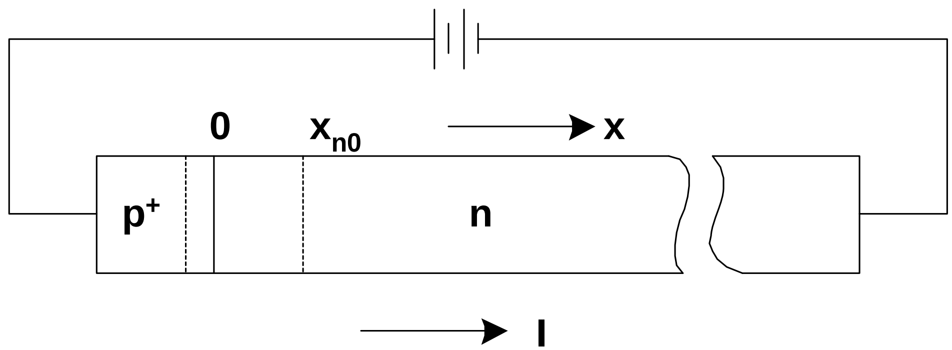
- The mobilities are for electrons in p-type material, and holes in n-type material. From figure 3-23 on page 99:
  - An electron in p-type Si material ($Na=10^{17}cm^{-3}$) would have a mobility of 1000 $cm^2/V\ s$
  - A hole in n-type Ge material ($Nd=10^{19}cm^{-3}$) would have a mobility of around 100 $cm^2/V\ s$

Calculating junction current

- Minority carrier lifetimes:

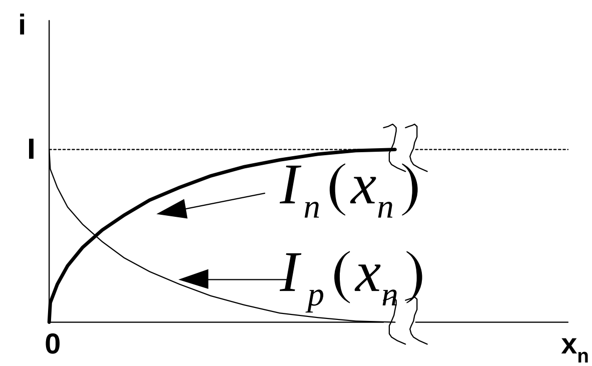
	τ_n	τ_p
Si	10×10^{-6} s	10×10^{-6} s
Ge	10×10^{-7} s	10×10^{-7} s
GaAs	1×10^{-9} s	1×10^{-9} s
ZnSe	1×10^{-9} s	1×10^{-9} s

Minority and majority currents



$$I_p(x_n) = \frac{qAD_p}{L_p}\Delta p_n e^{-x_n/L_p}$$

$$I_n(x_n) = I - I_p(x_n)$$



Numerical Example

- Continue with Silicon Example Igen.

$$\tau_n = \tau_p = 1 \times 10^{-6}\, s$$

Numerical Example

kT/q (V)	Si n_i (cm^{-3})	N_D (cm^{-3})	N_A (cm^{-3})	Vo(V)
0.025875	1.50E+10	1.00E+19	1.00E+16	8.73E-01

ε_r Si	ε_o F/cm^2	V Applied	T	x_p (cm)	x_n (cm)
11.90	8.85E-14	0.00E+00	300.00	3.3878E-05	3.3878E-08

W	Eo	Eo
3.39E-05	-5.15E+04	-5.15E+04

Numerical Example

Area cm^2	μ_n (cm^2/Vs)	μ_p (cm^2/Vs)	τ_n (s)	τp (s)
1.00E+00	1000	100	1.00E-06	1.00E-06

Dn (cm^2/s)	Dp (cm^2/s)	Ln (cm)	Lp (cm)
25.875	2.5875	0.00509	1.61E-03

ni^2/N_A (cm^{-3})	ni^2/N_D (cm^{-3})	Jn (A/cm^2)	Jp (A/cm^2)	Igen (A)
2.25E+04	2.25E+01	1.14E+08	3.62E+04	1.83E-11