Drift Currents

Thermal Equilibrium

Rapid, random motion of holes and electrons at "thermal velocity" $v_{th} = 10^7$ cm/s with collisions every $\tau_c = 10^{-13}$ s.

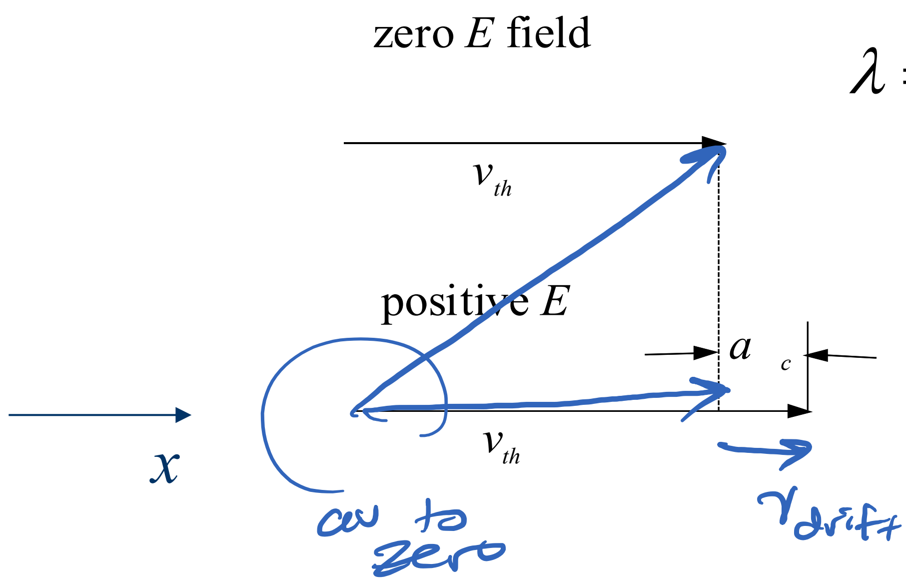
$$\tfrac{1}{2} m_n^* v_{th}^2 = \tfrac{1}{2} kT$$

Apply an electric field E and charge carriers accelerate … for τ_c seconds

$$\lambda = v_{th}\tau_c$$

$$\lambda = 10^7 \text{ cm}/s \times 10^{-13} s = 10^{-6} \text{ cm}$$

(hole case)



Drift Velocity and Mobility

For holes:

F = qE

$$v_{dr} = a \cdot \tau_c = \left(\frac{F_e}{m_p}\right)\tau_c = \left(\frac{qE}{m_p}\right)\tau_c = \left(\frac{q\tau_c}{m_p}\right)E$$

acceleration

Force/mass

$$v_{dr} = \mu_p E$$

mobility

For electrons:

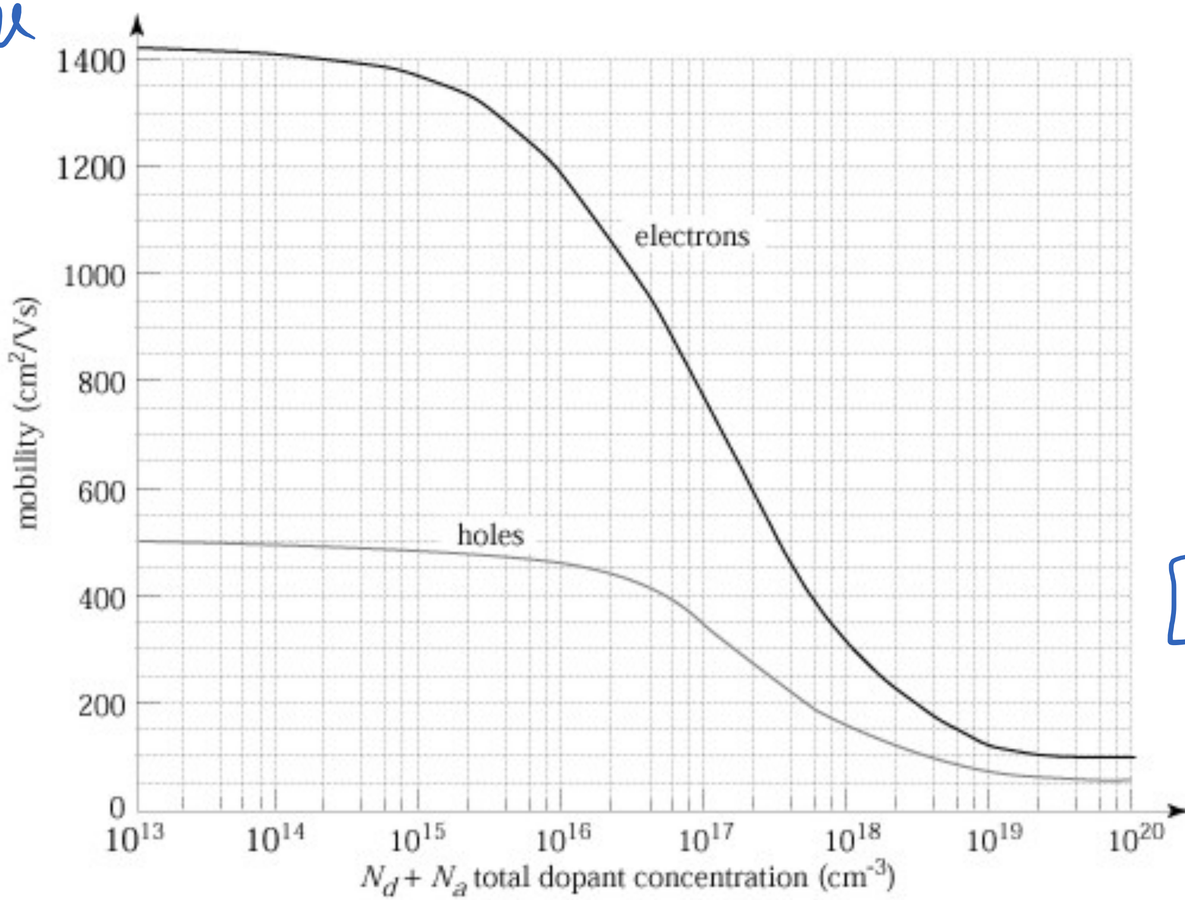
$$v_{dr} = a \cdot \tau_c = \left(\frac{F_e}{m_{\cancel{p}\,e}}\right)\tau_c = \left(\frac{-qE}{m_{\cancel{e}\,e}}\right)\tau_c = -\left(\frac{q\tau_c}{m_{\cancel{p}\,e}}\right)E$$

$$v_{dr} = -\mu_n E$$

Typo

Mobility vs. Doping in Silicon at 300 °K

μ



$v = \mu E$

$\mu = \frac{v}{E}$

$[\mu] = \frac{cm/s}{V/cm}$

$= \frac{cm^2}{V \cdot s}$

$N = N_d + N_a$

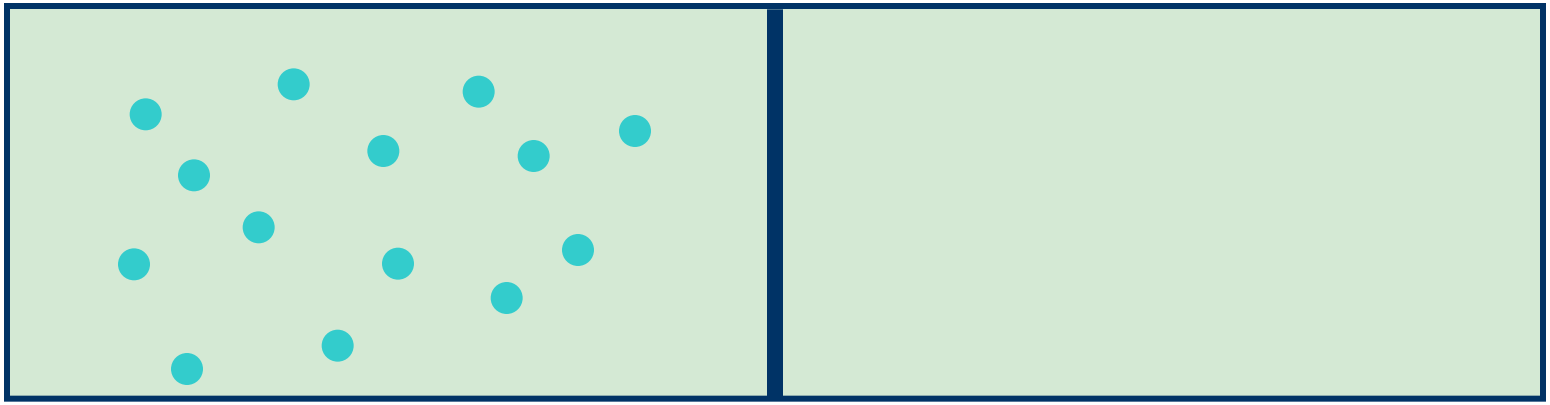
Typical values: $\mu_n = 1000$ $\mu_p = 400$

$\mu = \frac{q \tau_c}{m}$

Diffusion Currents

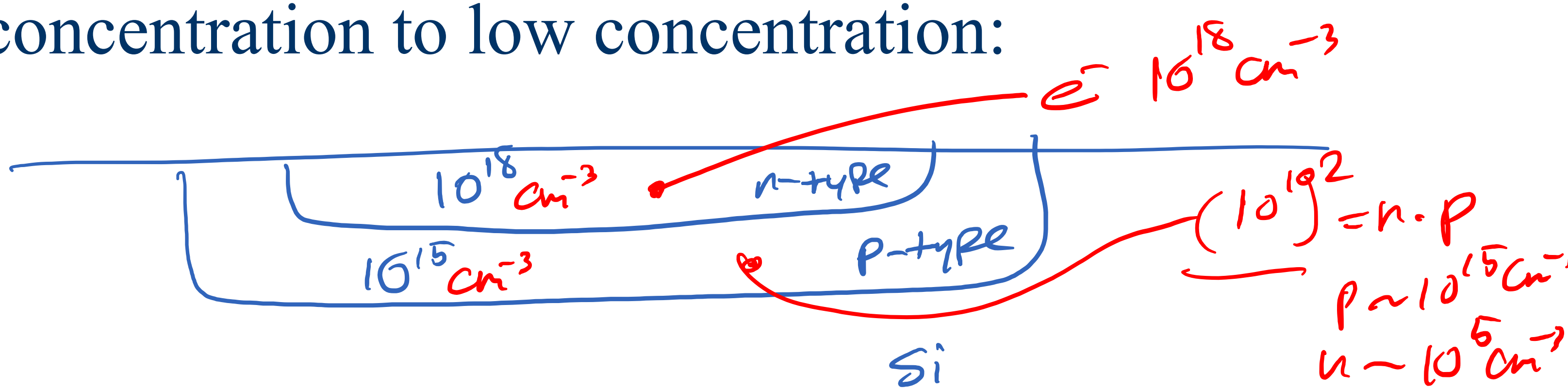
Diffusion

- Diffusion occurs when there exists a concentration gradient
- In the figure below, imagine that we fill the left chamber with a gas at temperate T
- If we suddenly remove the divider, what happens?
- The gas will fill the entire volume of the new chamber. How does this occur?



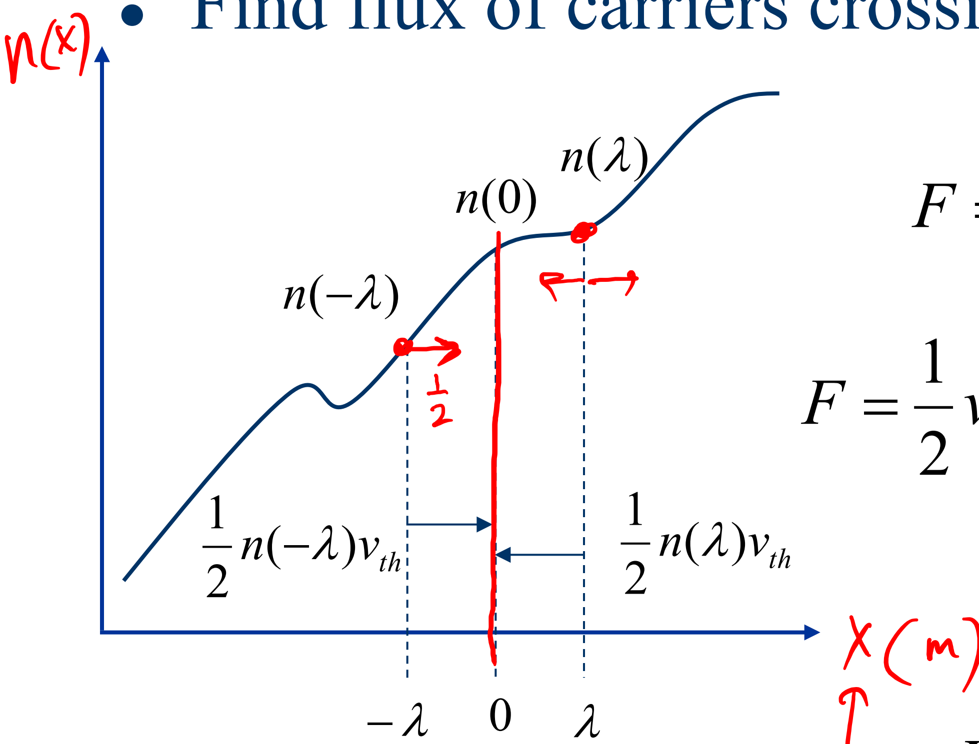
Diffusion (cont)

- The net motion of gas molecules to the right chamber was due to the concentration gradient
- If each particle moves on average left or right then eventually half will be in the right chamber
- If the molecules were charged (or electrons), then there would be a net current flow
- The diffusion current flows from high concentration to low concentration:



Diffusion Equations

- Assume that the mean free path is λ = $v_{th}\tau$
- Find flux of carriers crossing x=0 plane



not due to charge but due to direction

$$F = \frac{1}{2} v_{th}\left(n(-\lambda) - n(\lambda)\right)$$

$$F = \frac{1}{2} v_{th}\left(\left[\cancel{n(0)} - \lambda \frac{dn}{dx}\right] - \left[\cancel{n(0)} + \lambda \frac{dn}{dx}\right]\right)$$

$$F = -v_{th}\lambda \frac{dn}{dx}$$

gradient !

spatial

$$J = -qF = qv_{th}\lambda \frac{dn}{dx}$$

Einstein Relation

- The thermal velocity is given by kT

Thermal energy is driving motion

$$\tfrac{1}{2} m_n^* v_{th}^2 = \tfrac{1}{2} kT$$

Mean Free Time

time btwn collisions

$$\lambda = v_{th} \tau_c$$

$$v_{th} \lambda = v_{th}^2 \tau_c = kT \frac{\tau_c}{m_n^*} = \left(\frac{kT}{q}\right)\left(\frac{q\tau_c}{m_n^*}\right) = \frac{kT}{q}\mu$$

mobility

$$J = q v_{th} \lambda \frac{dn}{dx} = \cancel{q}\left(\frac{kT}{\cancel{q}} \mu_n\right)\frac{dn}{dx}$$

v_{th}^2 25mV

$$J = qD\frac{dn}{dx}$$

diffusion coefficient

$$D_n = \left(\frac{kT}{q}\right)\mu_n$$

diffusion ("small" currents) mobility (drift)

Total Current and Boundary Conditions

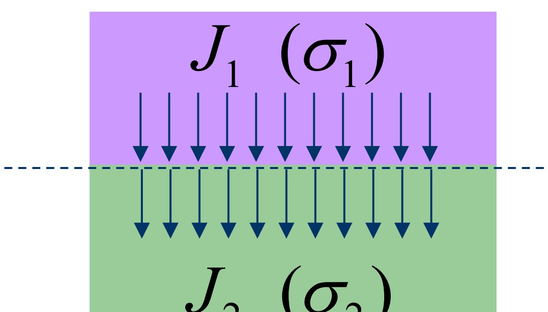
- When both drift and diffusion are present, the total current is given by the sum:

$$J = J_{drift} + J_{diff} = q\mu_{n/p} nE + qD_{n/p}\frac{dn}{dx}$$

electrons

holes

- In resistors, the carrier is approximately uniform and the second term is nearly zero
- For currents flowing uniformly through an interface (no charge accumulation), the field is discontinous



$$J_1 = J_2$$

$$\sigma_1 E_1 = \sigma_2 E_2$$

$$\frac{E_1}{E_2} = \frac{\sigma_2}{\sigma_1}$$

Reference

- Edward Purcell, *Electricity and Magnetism*, Berkeley Physics Course Volume 2 (2nd Edition), pages 133-142.