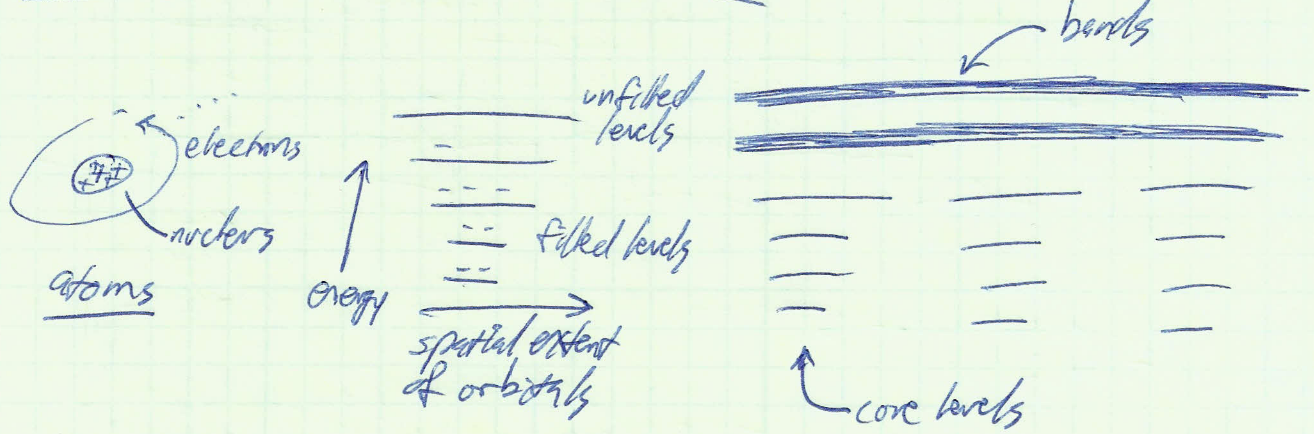
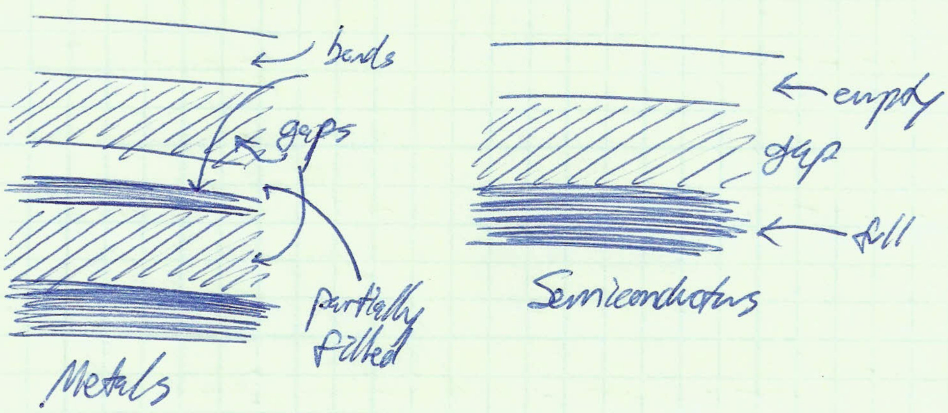
Diodes

Basic Semiconductor Physics

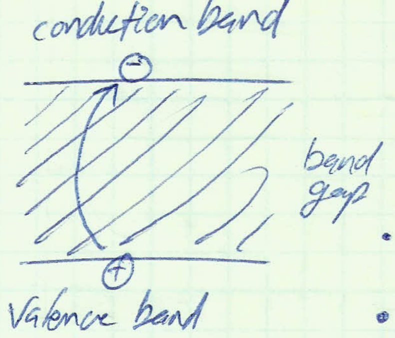


- Electrons in the atom can occupy discrete states
- In a solid crystal, the upper states merge into bands
- Properties of solids depend on these bands



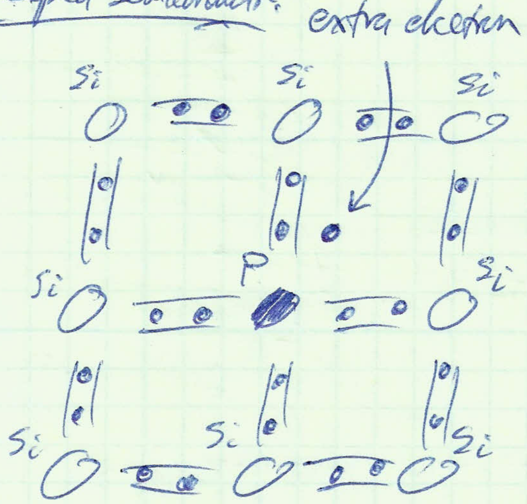
- Conducting current means electrons moving within the band
  - if the band is full, there is no net current

Most semiconductors are group IV : C, Ge, Si
or III-V : GaAs, InP, AlGaAs, GaN, etc.



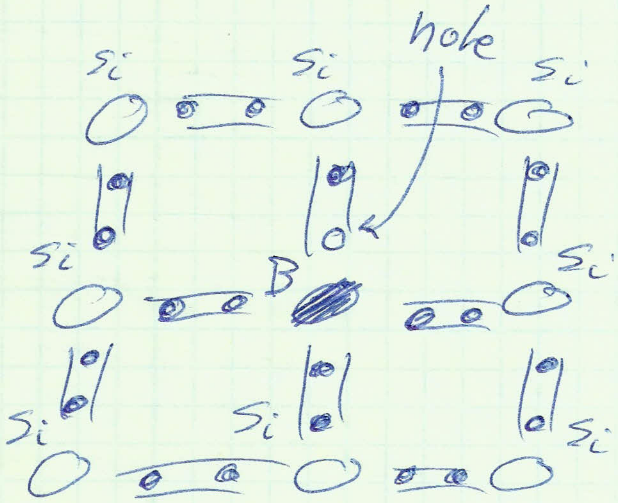
- Thermal excitation promotes some electrons from lower (valence) band to upper (conduction) band leaving a hole.
- Both electron and hole can move (conducts electricity)
- Carrier densities:
  - Metals $\sim 10^{28}-10^{29}\ cm^{-3}$
  - Semiconductors $\sim 10^{16}-10^{19}\ cm^{-3}$
  - Insulators $\sim 10^{7}\ cm^{-3}$

- Insulators are just like semiconductors, but with a much larger gap
- Doped semiconductors:



n-type semiconductor

Add group V elements



p-type semiconductor

Add group III elements

Thermal excitation of carriers

$n = p = n_i$ (in intrinsic - undoped - semiconductor)

$n_i = BT^{3/2} e^{-E_g/2kT}$ T = temperature

E_g ← band gap energy

B ← material-dependent constant

for any semiconductor (even doped) $n \cdot p = n_i^2$ ← equal numbers of electrons + holes

(in thermal equilibrium)

- Balance between thermal generation and recombination

Doped Semiconductors

N_D = density of donors
N_A = density of acceptors

for n-type:

$p_n n_n = n_i^2$, $n_n \simeq N_D \longrightarrow p_n \approx \frac{n_i^2}{N_D}$

for p-type

$p_p n_p = n_i^2$, $p_p \simeq N_A \longrightarrow n_p \approx \frac{n_i^2}{N_A}$

p_p ← majority carriers

n_p ← minority carriers

Current flow in Semiconductors

- Drift current - motion in response to electric field

$v_{p\text{-drift}} = \mu_p E$ ← electric field

μ_p ← mobility (material dependent)

$v_{p\text{-drift}}$ ← drift velocity of holes

$v_{n\text{-drift}} = -\mu_n E$

Drift Current - continued

$$J = q(p\mu_p + n\mu_n)E$$

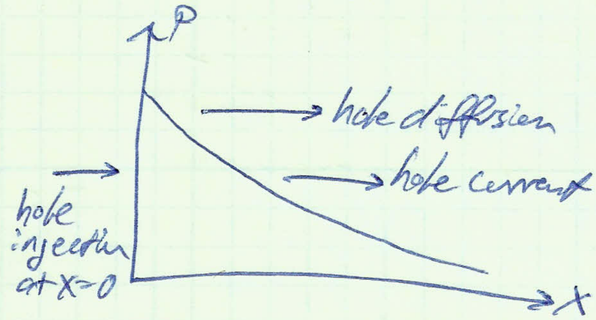
q — electronic charge; p, n — carrier densities

$$J = \sigma E \longrightarrow \sigma = q(p\mu_p + n\mu_n) \text{ conductivity}$$

- Diffusion current - motion due to concentration gradient

$$J_p = -qD_p \frac{dp(x)}{dx}$$

D_p — diffusion constant (material dependent)

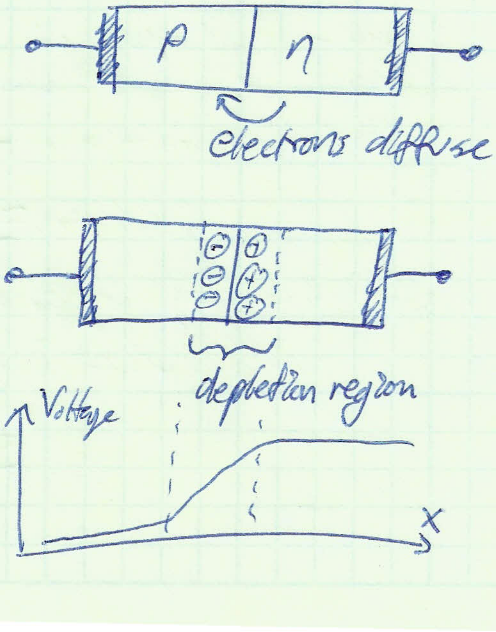


$$J_n = qD_n \frac{dn(x)}{dx}$$

Relationship between D and μ (not derived here) : $\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T = \frac{kT}{q}$

V_T — thermal voltage

Junction Diode:



Carriers diffuse to the opposite side and deplete majority carriers near the junction
- called "depletion region"
- creates "built-in voltage" that counters the flow of charge