Chapter 18 Electrical properties

- Introduction
- Ohm's law
- Electrical conductivity
- Electronic and ionic conduction
- Energy band structures in solids
- Conduction in terms of band and atomic bonding atoms
- Electron mobility
- Electrical resistivity of metals
- Electrical characteristics of commercial alloys
- Intrinsic semiconductors
- Extrinsic semiconductors

Electrical conduction

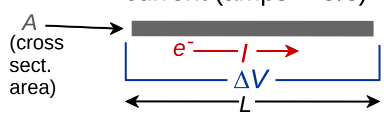
- Ohm's Law:

$$\Delta V = I\,R$$

voltage drop (volts = J/C) → ΔV; C = Coulomb

current (amps = C/s) → I

resistance (Ohms) → R



- Resistivity, ρ and conductivity, σ:
  - -- geometry-independent forms of Ohm's Law
  - -- Resistivity is a material property & is independent of sample

$$\frac{\Delta V}{L} = \frac{I}{A}\rho$$

E: electric field intensity → $\frac{\Delta V}{L}$

resistivity (Ohm-m) → ρ

J: current density → $\frac{I}{A}$

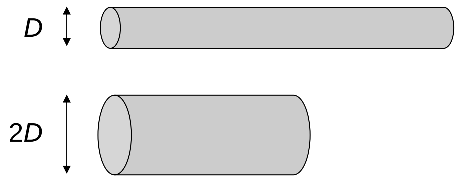
- Resistance:

$$R = \frac{\rho L}{A} = \frac{L}{A\sigma}$$

conductivity → $\sigma = \frac{1}{\rho}$

Electrical properties

- Which will conduct more electricity?



$$\rho = \frac{RA}{\ell} = \frac{VA}{I\ell}$$

- Analogous to flow of water in a pipe
- So resistance depends on sample geometry, etc.

Definitions

- Further definitions
  - $J = \sigma\, \varepsilon$ <= another way to state Ohm's law
  - $J \equiv$ current density $= \dfrac{\text{current}}{\text{surface area}} = \dfrac{I}{A}$ like a flux
  - $\varepsilon \equiv$ electric field potential $= V/\ell$ or $(\Delta V / \Delta \ell)$

$$J = \sigma\, (\Delta V / \Delta \ell)$$

Electron flux (J) conductivity (σ) voltage gradient ($\Delta V / \Delta \ell$)

Current carriers

- electrons in most solids
- ions can also carry (particularly in liquid solutions)

Conductivity: comparison

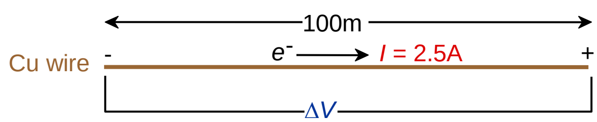
- Room T values $(\text{Ohm-m})^{-1} = (\Omega \cdot \text{m})^{-1}$

METALS	conductors	CERAMICS	
Silver	6.8×10^{7}	Soda-lime glass	10^{-10}-10^{-11}
Copper	6.0×10^{7}	Concrete	10^{-9}
Iron	1.0×10^{7}	Aluminum oxide	$<10^{-13}$

SEMICONDUCTORS		POLYMERS	
Silicon	4×10^{-4}	Polystyrene	$<10^{-14}$
Germanium	2×10^{0}	Polyethylene	10^{-15}-10^{-17}
GaAs	10^{-6}		
	semiconductors		insulators

Example: Conductivity problem

What is the minimum diameter (D) of the wire so that $\Delta V < 1.5$ V?

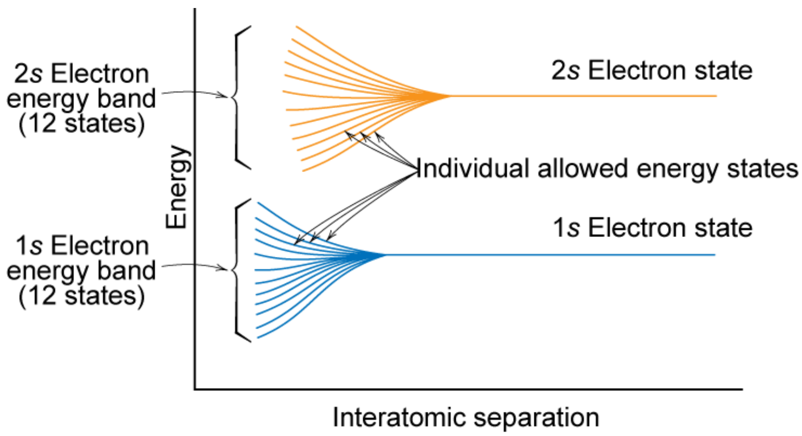


$$R = \frac{L}{A\sigma} = \frac{\Delta V}{I}$$

- L = 100m
- $A = \frac{\pi D^2}{4}$
- ΔV < 1.5V
- I = 2.5A
- σ = 6.07×10^{7} $(\text{Ohm-m})^{-1}$

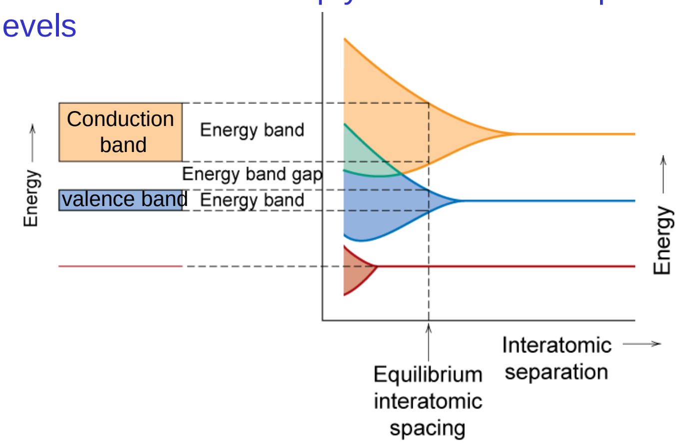
Solve to get $D > 1.87$ mm

Electronic band structures



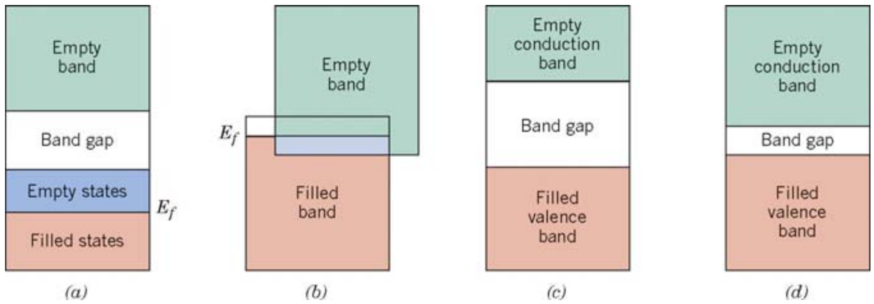
Band structure

- Valence band – filled – highest occupied energy levels
- Conduction band – empty – lowest unoccupied energy levels



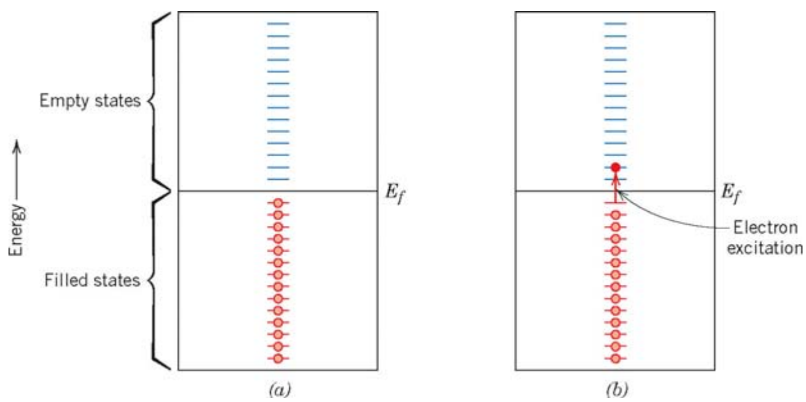
Various possible electron band structures

- Fermi energy E_f: the energy corresponding to the highest filled state at 0 K



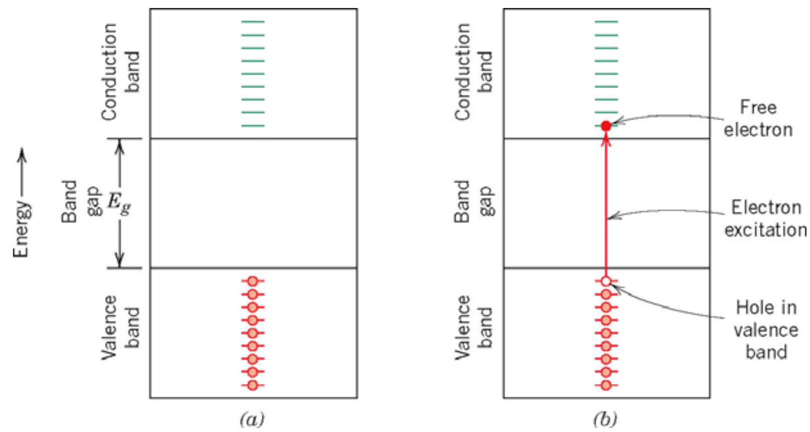
Metal (Cu) **Metal (Mg)** **Insulator** **Semiconductor**

Conduction in terms of band and atomic bonding models



For a metal, occupancy of electron states (a) before and (b) after an electron excitation

Conduction in terms of band and atomic bonding models



For an insulator or semiconductor, occupancy of electron states (a) before and (b) after an electron excitation

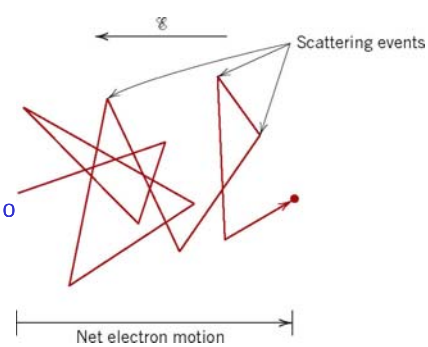
Electron mobility

- Drifting velocity: average electron velocity in the direction of the force imposed by the applied field

$$v_d = \mu_e \mathscr{E}$$

  - Electron mobility μ_e : an indication o the frequency of scattering events (m^2/V-s)

- The conductivity $\sigma = n|e|\mu_e$



Electrical resistivity of metals

- Mathiessen's rule

$$\rho_{totol} = \rho_t + \rho_i + \rho_d$$

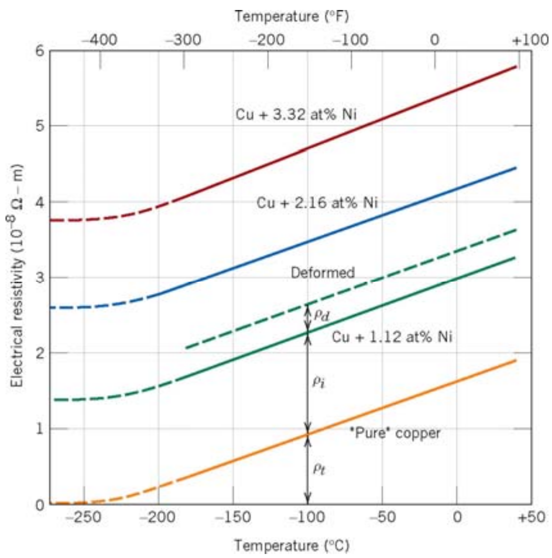
- Influence of T

$$\rho_t = \rho_0 + aT$$

- Influence of impurity

$$\rho_i = Ac_i(1-c_i)$$

- Influence of plastic deformation: increased numbers of electron-scattering dislocations

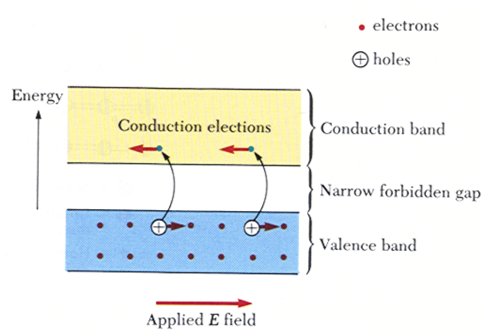


Intrinsic semiconductor

- Intrinsic semiconductor: its electrical behavior is based on the pure material

- Intrinsic semiconductor band structure

- A current arises from the flow of electrons and holes



Intrinsic semiconductor

- Elemental semiconductor
  - Group IVA, Si (Egap 1.1 eV), Ge (Egap 0.7 eV)

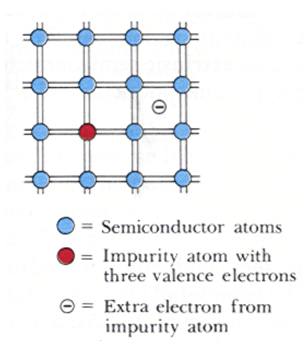
- Compound semiconductor
  - Group IIIA-VA, GaAs, InSb
  - Group IIB-VIA, CdS and ZnTe

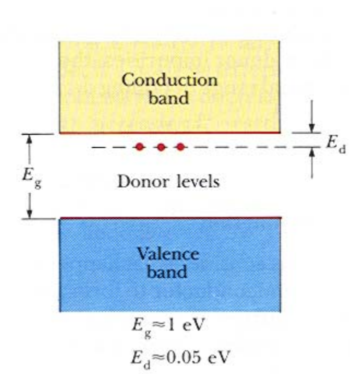
- Electric conductivity

$$\sigma = n|e|\mu_e + p|e|\mu_e$$

Extrinsic semiconductor

- The electrical behavior is determined by impurities.
- N-type semiconductor
  - Majority carrier: electrons
  - Minority charge carriers: holes





Extrinsic semiconductors(*cont.*)

- P-type semiconductor: trivalent substitutional impurities aluminum, boron, and gallium
  - Majority carrier: holes
  - Minority charge carriers: electrons