Electrical Properties Module

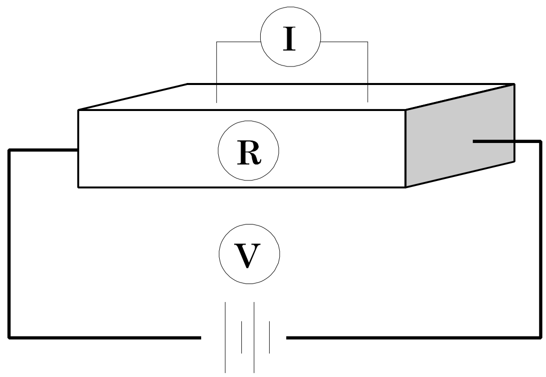
Outline

- Electrical Resistance
- Electrical Conductivity
    - Semiconductors
- Insulators
    - Capacitors

Electrical Current Flow

- Measured By Ohm's Law
  - Current (I) -Amps
  - Voltage (V) -Volts
  - Resistance (R) -Ohms

$$V = IR$$



Experience / Inference

- What Happens if
  - Length of Bar Increases?
  - Area Decreases?
- I (Current)
  - Decreases
- R (Resistance)
  - Increases
- Material Property
  - Resistivity

$$\rho = \frac{RA}{L}$$

  - Conductivity

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

Example

- Determine the Current Which Will Flow through 25m of Copper Wire (0.01 cm in diameter) When Subjected to 1mV.
- Determine
  - Resistivity
  - Resistance
  - Current Flow
- Resistivity
  - $\rho = 1.724 \times 10^{-10}\ \Omega\text{cm}$

Step Two

- Determine Resistance
- Resistivity
  - $\rho = 1.724 \times 10^{-10}\ \Omega\text{cm}$

$$\rho = \frac{RA}{L}$$

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

$$R = \frac{(1.724 \times 10^{-10}\,\Omega \cdot cm)(2500cm)}{(0.785 \times 10^{-4}\,cm^2)}$$

$$R = 0.005\Omega$$

Step Three

- Determine Current Flow
- Resistivity
  - $\rho = 1.724 \times 10^{-10}\ \Omega\text{cm}$
- Resistance
  - $0.005\ \Omega$

$$V = IR$$

$$I = \frac{V}{R}$$

$$I = \frac{0.001V}{0.005\Omega}$$

$$I = 0.2A$$

<u>Origin of Conductivity</u>

- Conductivity Depends On
  - Number of Free Carriers (n)
  - Charge of Carriers (q) 1.6×10^{-19}C
  - Mobility of Charge Carriers (μ)
- Number (n)
  - Depends on Fermi Energy
  - Temp Dependent
- Mobility (μ)
  - Velocity / Field Strength

$$\sigma = nq\mu$$

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

<u>Team Problem 3</u>

- Calculate the Voltage Required to Cause 10mA of Current to flow through resistors 2.5 cm long and with a cross sectional area of 3.5 cm^2, prepared from polycarbonate, germanium and gold
  - PolyCarbonate $\sigma = 5 \times 10^{-17}\ (\Omega\ cm)^{-1}$
  - Ge $\sigma = 2.3 \times 10^{-2}\ (\Omega\ cm)^{-1}$
  - Au $\sigma = 4.3 \times 10^{5}\ (\Omega\ cm)^{-1}$

1.4×10^{15} V
3.1 V
1.7×10^{-7} V

$$\sigma \equiv \frac{1}{\rho}$$

$$\rho = \frac{RA}{L}$$

Mobility

- As Temperature Increases Conductivity Decreases in Metals
- Decrease of Mobility Term
    - Lower Net Velocity
    - Thermal Vibrations Knock Electrons Off Track
    - Distance / Time Reduced

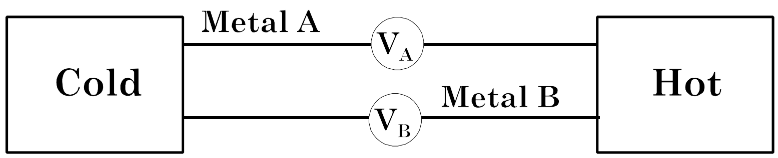
$$\mu = \frac{\bar{v}}{E}$$

$$\rho = \rho_{RT}\left[1 + \alpha\left(T - T_{RT}\right)\right]$$

In Copper ρ increases by 50% Between 25 and 200°C

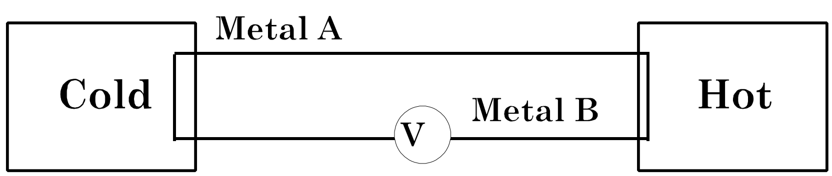
Two Different Wires

- Voltage Build Up Depends
  - on Material
  - on Temperature



Thermocouple

- Connect Two Wires and Measure Difference in Voltage



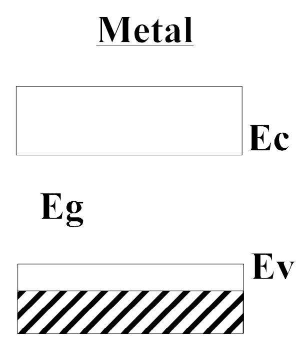
$V=V_A-V_B$

Band Theory of Materials

- Electrical Conduction Requires
  - Mobile Charge Carriers
- Ions in Solution
- Electrons
  - Available Energy States
  - Band Theory Correct
  - Sea of Electrons Incomplete

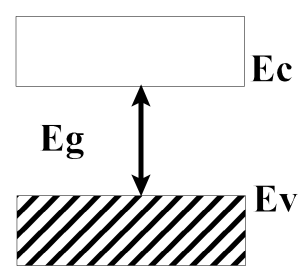
Band Diagram Metal

- Partially Filled Valence Band at 0K
- Electrons Require Little Energy to Conduct
- E_g Irrelevant
- Band Gap Differentiates Metal and Non-Metal



Band Diagram Non-Metal

- Filled Valence Band at 0K
- Electrons Require Large Energy to Conduct
- $E_g < 2.0$ eV
- $E_g > 2.0$ eV Insulator Arbitrary Definition Practical Definition



$k = 8.62 \times 10^{-5}$ eV/K

What Temperature Corresponds to a kT of 2eV?

Summary of Conductivity

- Designing for Electrical Conductivity Using Metals Requires Combining
  - Bulk Observations (Ohm's Law)
  - Atomic Level Understanding

$$\sigma = nq\mu$$

- Mobility
  - Impurities
  - Temperature Dependence

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

- Fermi Energy (Distribution)
  - Implications
  - Temperature Dependence

Determines n

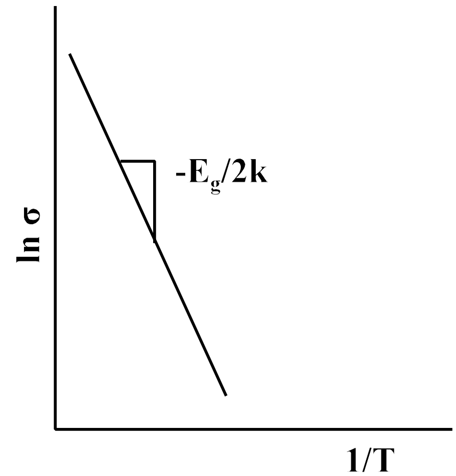
$$f(E) = \left[e^{\frac{E-E_F}{kT}} + 1 \right]^{-1}$$

<u>Temperature Dependent Conductivity</u>

- For Intrinsic Semiconductor
- Number of Charge Carriers
  - Those that jump the Band Gap

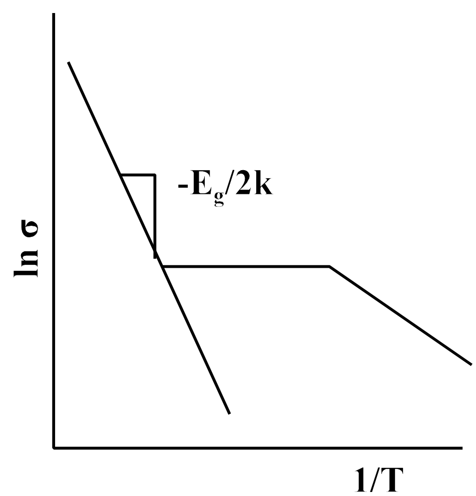
$$n_i = Ce^{-\frac{E_g}{2kT}}$$

$$\sigma = \sigma_0 e^{-\frac{E_g}{2kT}}$$



<u>Temperature Dependent Conductivity</u>

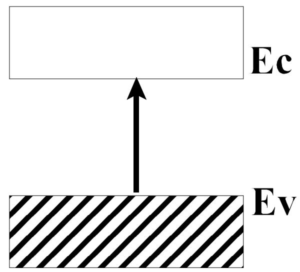
- For Extrinsic Semiconductor
- Three Temperature Ranges
  - Intrinsic (Very High T)
  - Exhaustion
  - Ionization (Very Low T)



Photoconduction

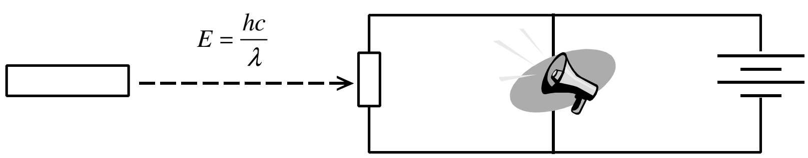
- Energy Required to Excite Electrons
- Light Can Supply This Energy

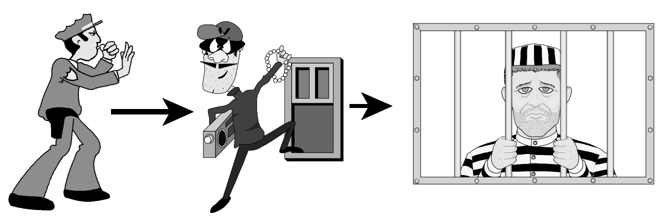
$$E = \frac{hc}{\lambda} = E_G$$



Burglar Alarm

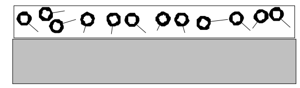
- Use Light as A Trigger



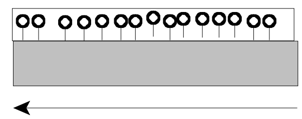


<u>Use of Insulators</u>

- Insulators Protect Us
  - Grab a Cord
  - Don't Die
  - That's Good
- Electrical Effect
  - Molecules May Respond to Voltage Difference
  - Hold Charge for Later Use



No Effect

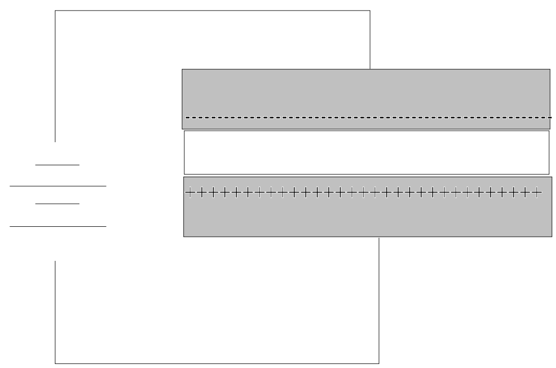


Response to Induced Electric Field

<u>Parallel Plate Capacitor</u>

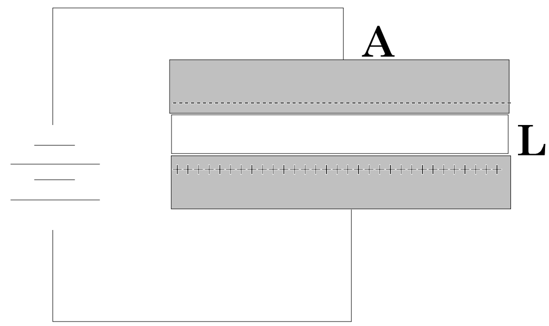
- Charge Build Up on Plates
- Definition of Capacitance

$$C = \frac{Q}{V}$$



Determination in Vacuum

- Based on Permitivity of Free Space



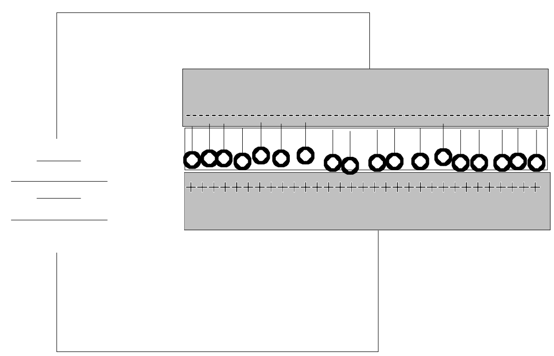
$$\varepsilon_0 = 8.85 \times 10^{-12} \frac{F}{m}$$

$$C = \varepsilon_0 \frac{A}{L}$$

A Capacitor Made of Two Plates 10cm^2 and separated by 0.1μm has a C=8.5x10^{-5}F. If 12V are applied a charge buildup of 0.001C will occur.

Insertion of Dieelectric Material

- Increases Capacitance
  - Allows For Orientation and Charge BuildUp
  - Dielectric Constant



$$\kappa = \frac{\varepsilon}{\varepsilon_0}$$

$$C = \varepsilon \frac{A}{L}$$

Frequency Dependence

- Capacitance Proportional to Polarizability
- Dipoles Must Respond to Electric Field
  - Orientation
  - Ionic/Atomic
  - Electronic

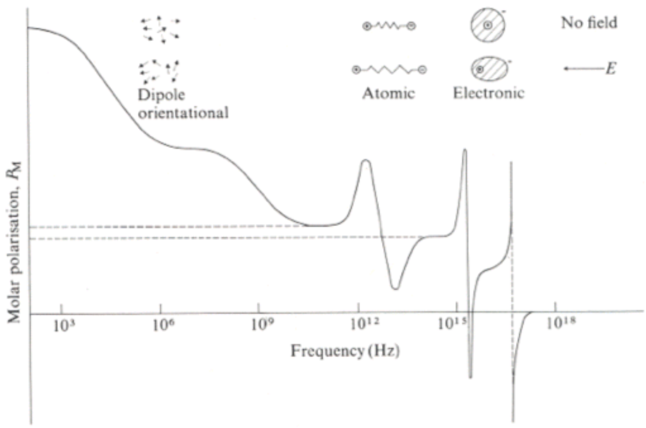


Fig. 2.2. Dispersion of molar polarisation in a dielectric (schematic).

Summary and Wrap-Up

- Electrical Resistance

- Electrical Conductivity
  - Semiconductors

- Insulators
  - Capacitors