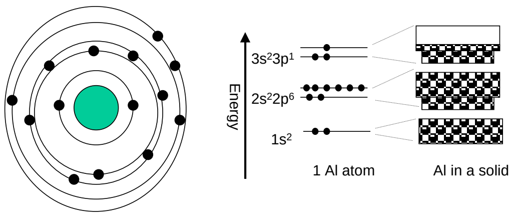
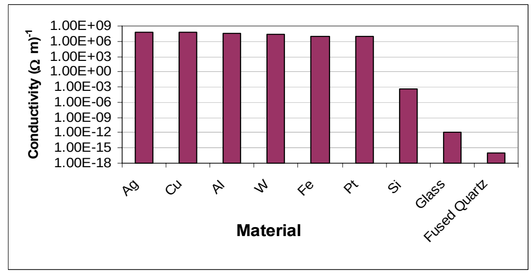
Class 3: Conductivity, Resistance, and Band Structures



PRIME Modules
Project-based Resources for Introduction to Materials Engineering

Metals, semiconductors, and insulators differ in conductivity



Silver is ~10^{24} times more conductive than quartz

[Fundamentals of Physics, Halliday & Resnick]

Electrical conductivity is the ability of a material to transmit electrons

The symbol for conductivity is the Greek letter sigma, σ

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

Resistivity, ρ, is the inverse of conductivity

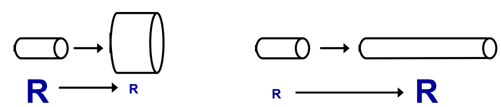
Conductivity and resistivity are material properties and are independent of sample size or shape

Conductance (G) and resistance (R) depend on the size and shape of the sample

$$R = \frac{1}{G} = \rho\frac{L}{A}$$

As length increases, resistance increases

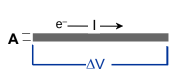
As cross sectional area increases, resistance decreases



Ohm's Law can be put into a geometry independent form using resistivity, not resistance

Ohm's Law: $\Delta V = I R$

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



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

E: Electric field intensity

J: Current density

ΔV = voltage drop (volts)

I = current (amps)

R = resistance (ohms)

L = length (m)

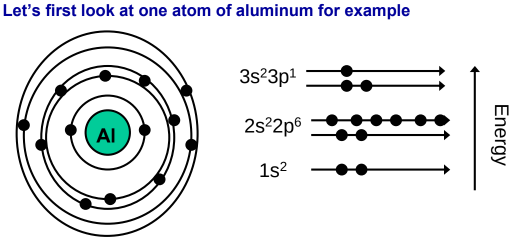
A = cross sectional area (m^2)

ρ = resistivity (ohm-m)

[Callister]

The atomic structure (especially the electrons) of metals makes them conductive

Let's first look at one atom of aluminum for example



Al has 13 electrons arranged around the nucleus

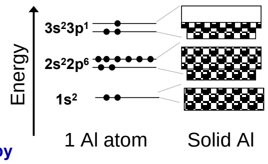
When aluminum atoms bond metallically, the electrons form energy bands

Solid Al has about 10^{22} atoms/cm^3

Atoms bond metallically and the electrons form an *electron sea*

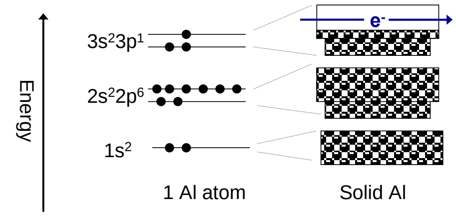
Electrons avoid having the same distinct energy levels as others nearby

The electrons form full and partially filled energy bands



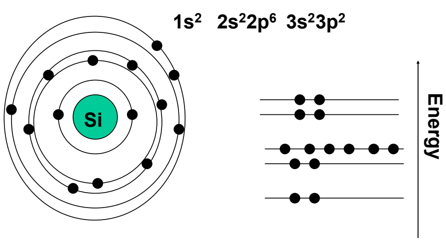
Partially filled or full energy bands overlapping empty ones allow metals to conduct

Electrons can freely pass through partially filled or overlapping energy bands



Semiconductors sometimes conduct elctricity, and sometimes they do not

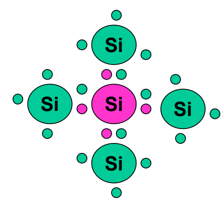
A lone silicon atom has 14 electrons, 1 more than aluminum



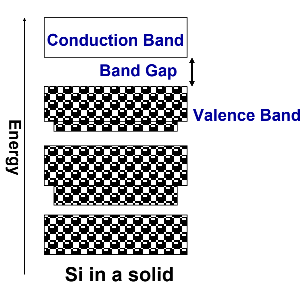
Silicon in a solid covalently bonds with other Si atoms to fill its valance shell

The silicon shares electrons to fill the outer 3s3p valence shell

Electrons are in a relatively stable state



Semiconductors can conduct when the electrons are excited and jump across the band gap



The outermost (valence) band of electrons is full

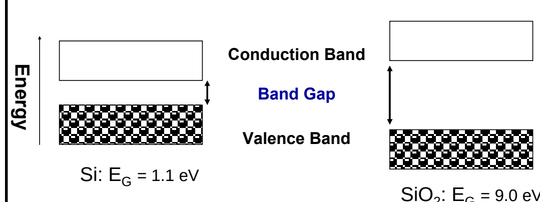
↓

There is room to conduct in the empty band above the valence

↓

To conduct, the electrons must be excited across the band gap

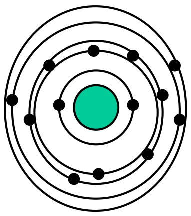
Insulators have a much larger band gap that electrons cannot normally cross

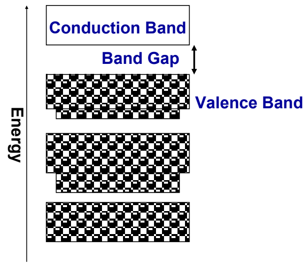


Under reasonable conditions, the electrons of an insulator cannot be excited from the valence to the conduction band

In summary, the atomic structure determines the conductivity

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





PRIME Modules
Project-based Resources for Introduction to Materials Engineering