PURDUE UNIVERSITY DEPARTMENT OF PHYSICS

Physics 21900
General Physics II

Electricity, Magnetism and Optics
Lecture 7 – Chapter 16.1-4
Electric Current

Fall 2015 Semester

Prof. Matthew Jones

Reminder

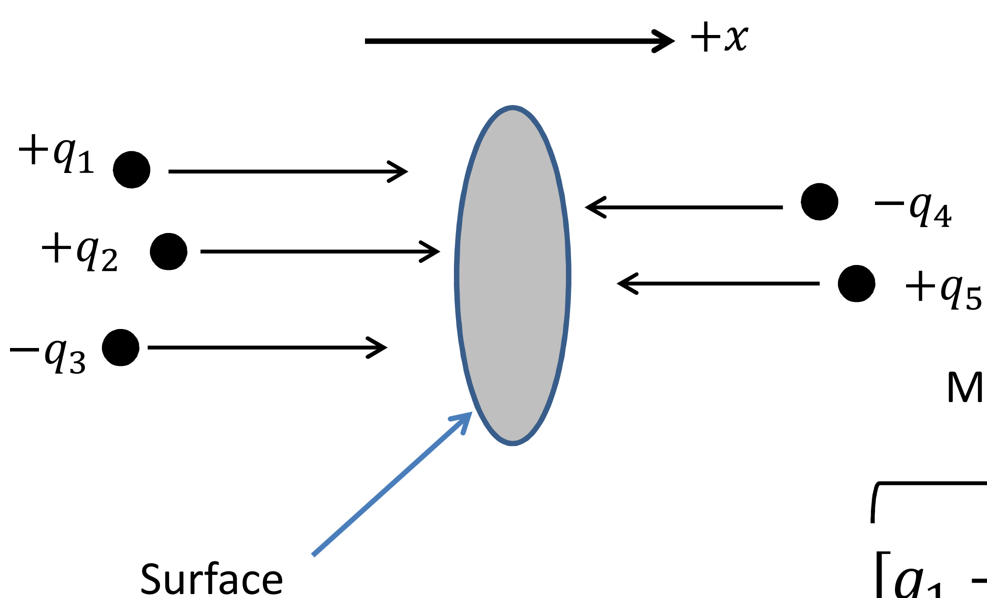
- The first mid-term exam will be on Thursday, September 24th.
- Material to be covered is chapters 14 and 15
  - Coulomb's law
  - Electric potential energy
  - Electric field
  - Electric potential
  - Capacitors

Electrodynamics

- So far we have studied electrostatics
  - Charges are unable to move
  - Charges have moved so that they are in a state of electrostatic equilibrium
- What happens when charge is allowed to move?
  - What rules govern the flow of charge?

Electric Current

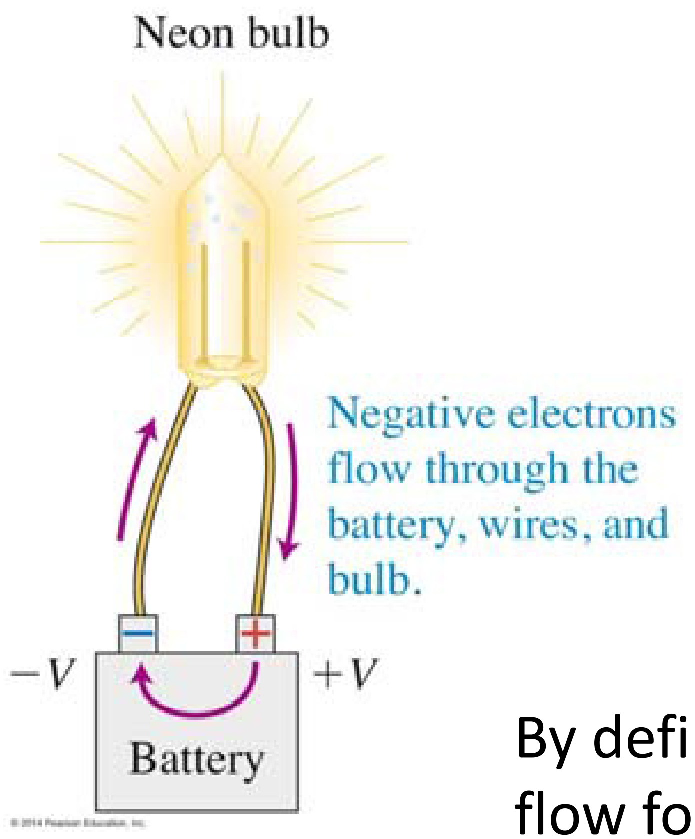
- We define the electric current I as the <u>rate</u> of flow of <u>net</u> charge through a surface.
  - The charge can be carried by anything that has a net charge: electrons, ions, molecules, particles, etc…

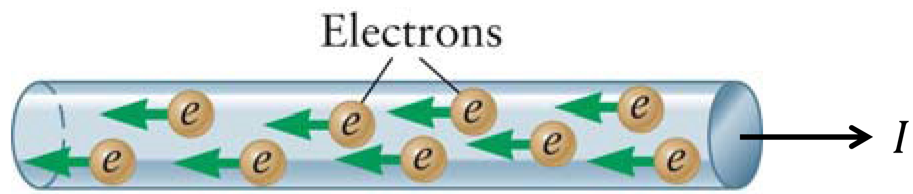


Mathematically, -q moving in the +x direction is equivalent to +q moving in the –x direction.

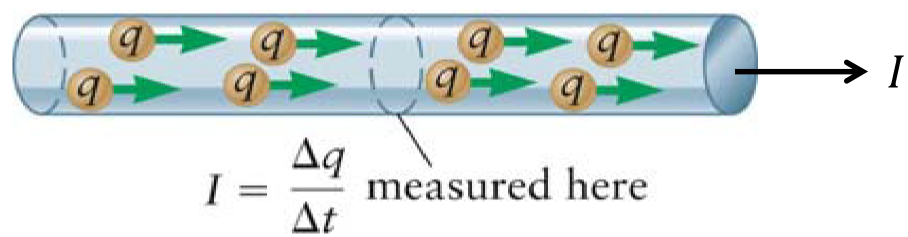
$$I = \frac{\overbrace{[q_1 + q_2 + (-q_3)]}^{\text{Moving right (+x)}} - \overbrace{[(-q_4) + q_5]}^{\text{Moving left (-x)}}}{\Delta t}$$

Current Flowing Through a Wire





Definition of **Conventional Current**

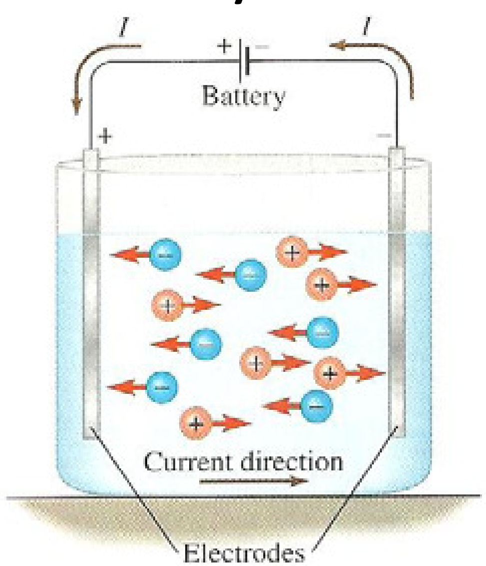


By definition, the direction of the current flow for either case is the same.

Units for current: $Ampere = \frac{Coulombs}{second}$

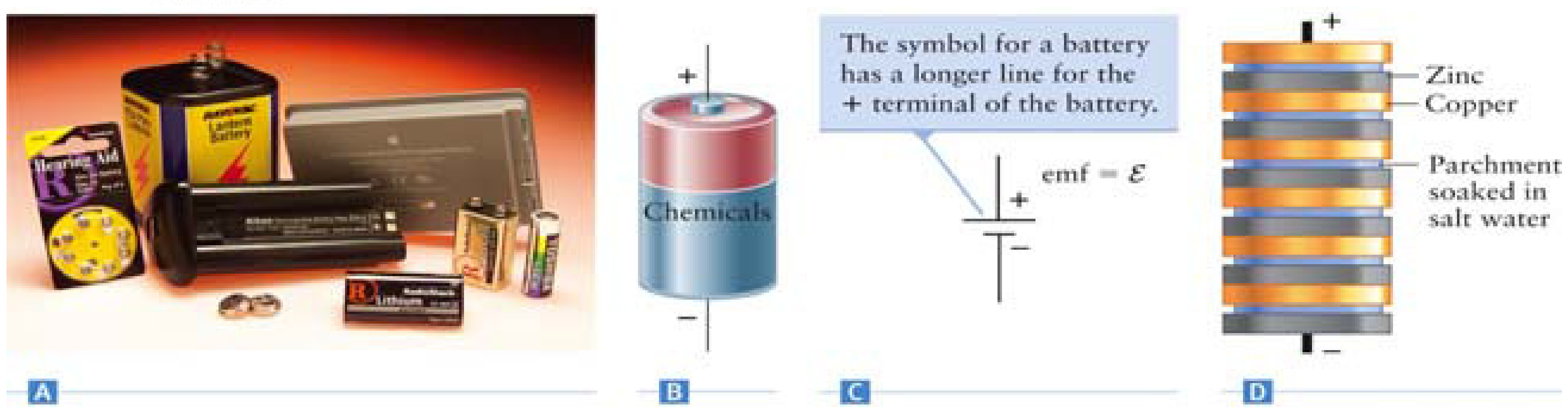
What Drives Current Flow?

You need an electrical potential difference, for example, a battery:

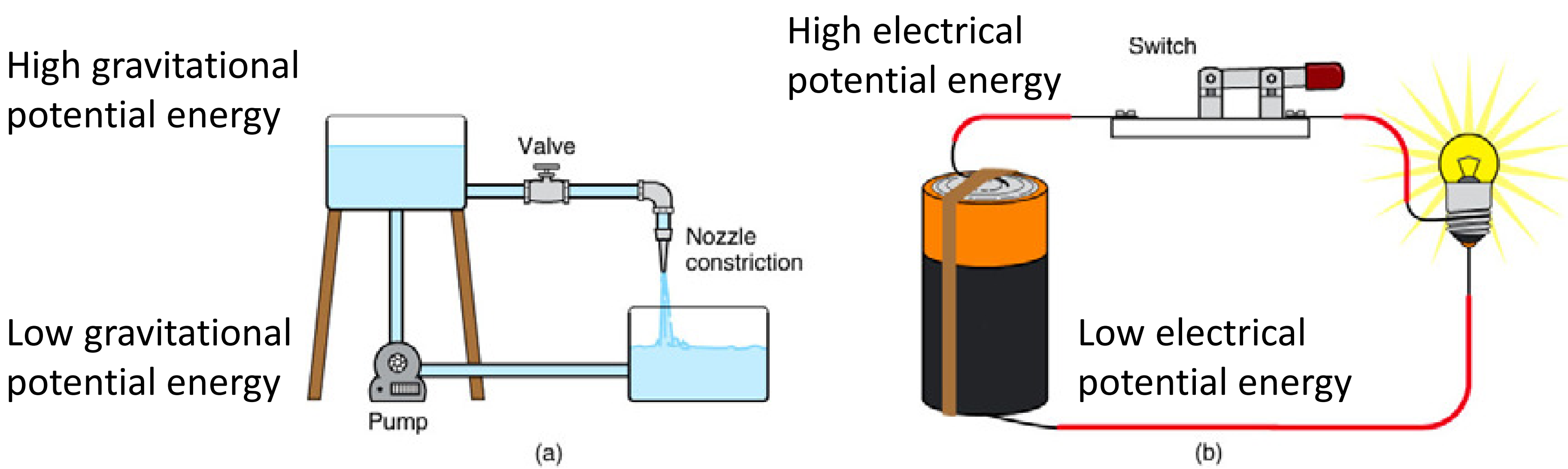


A potential difference develops across the terminals of a battery.

- A battery is an electrochemical device that converts **stored chemical energy** into **electrical energy**.
- EMF = Electro Motive Force = $\mathcal{E} = \Delta V$
- Work done by battery: $W = q\,\mathcal{E} = q\Delta V$



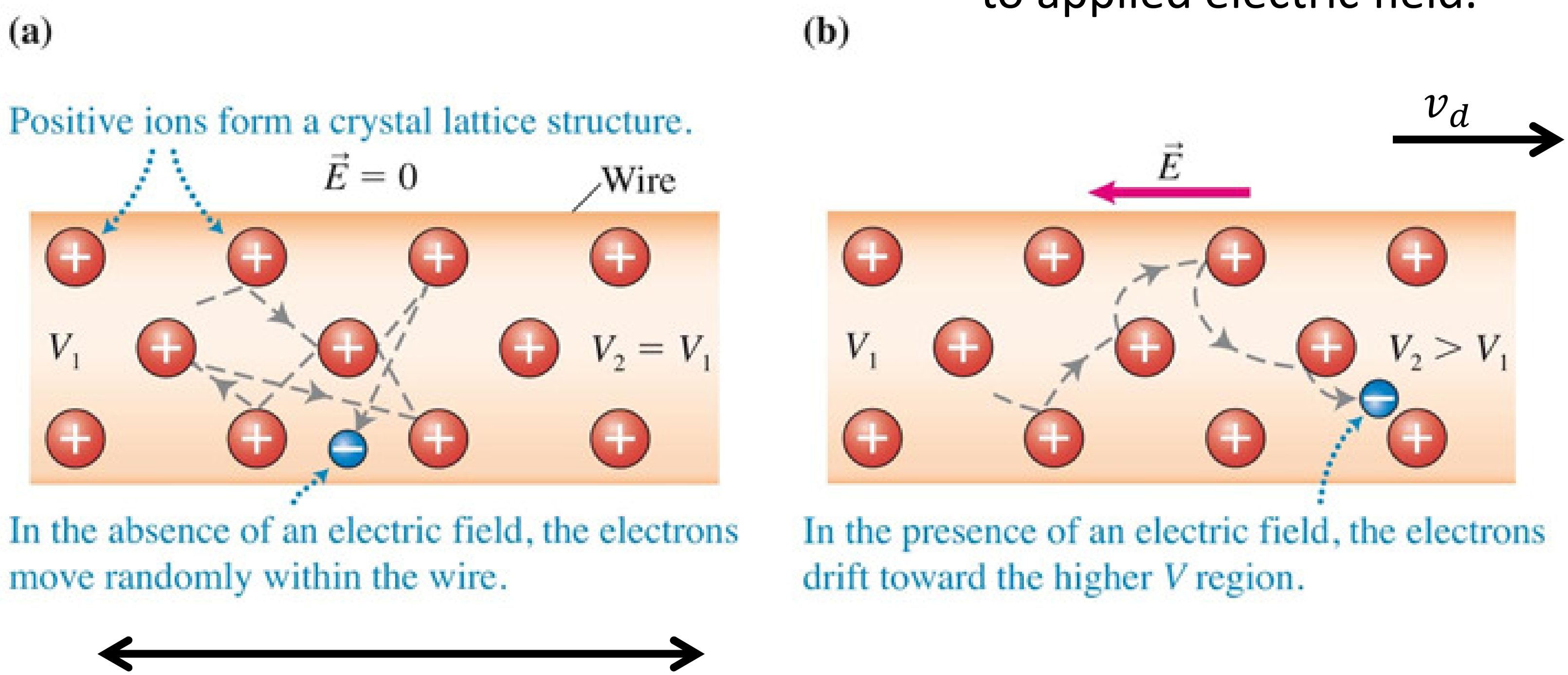
Analogy to Flowing Water



Resistance to flow: the ratio of the potential energy difference to the current flowing.

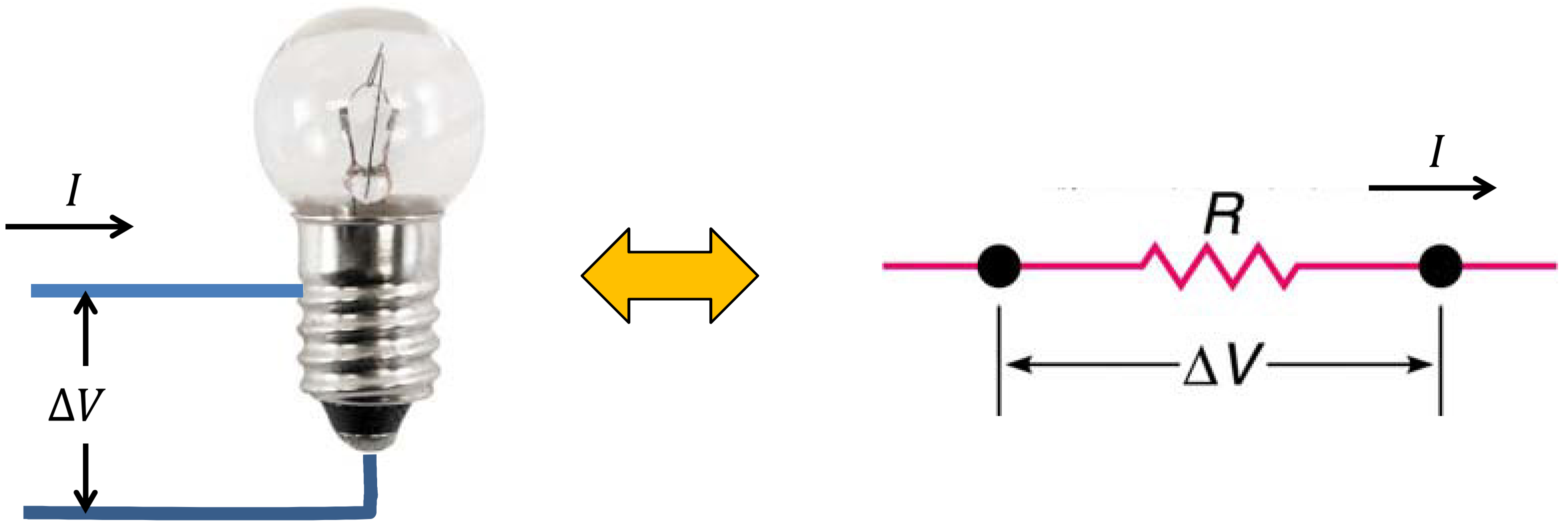
Microscopic Description

Net drift velocity of electron due to applied electric field.



Typical length scale:
a few nanometers
(1 nm = 10^{-9} m)

Ohm's Law



The current that flows is proportional to the potential difference across the device.

$$I \propto \Delta V$$

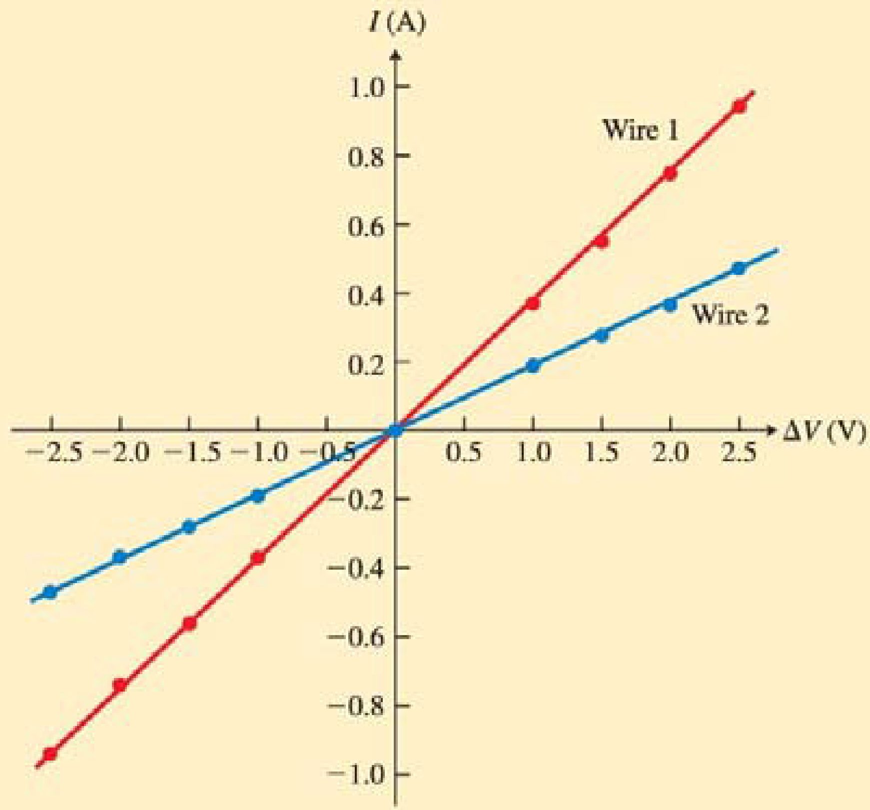
$$I = \Delta V / R \qquad R = \Delta V / I$$

Units for resistance: $Ohms = \dfrac{Volts}{Amperes}$

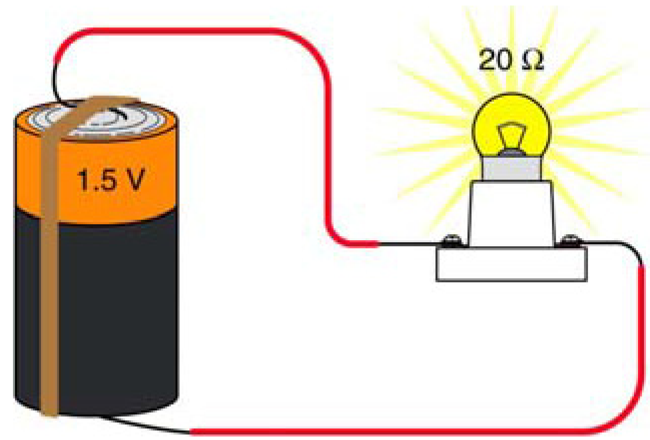
Ohm’s Law

Analysis

The graphs I versus ΔV for both resistive wires are straight lines that pass through the origin.



How much current will flow?

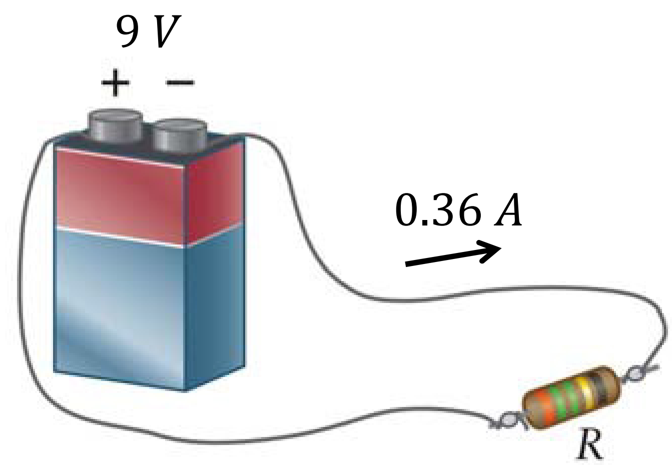


$$\mathcal{E} = I\,R$$

$$I = \frac{\mathcal{E}}{R} = \frac{1.5\ V}{20\ \Omega}$$

$$= 0.075\ A = 75\ mA$$

What is the electrical resistance?



$$\mathcal{E} = I\,R$$

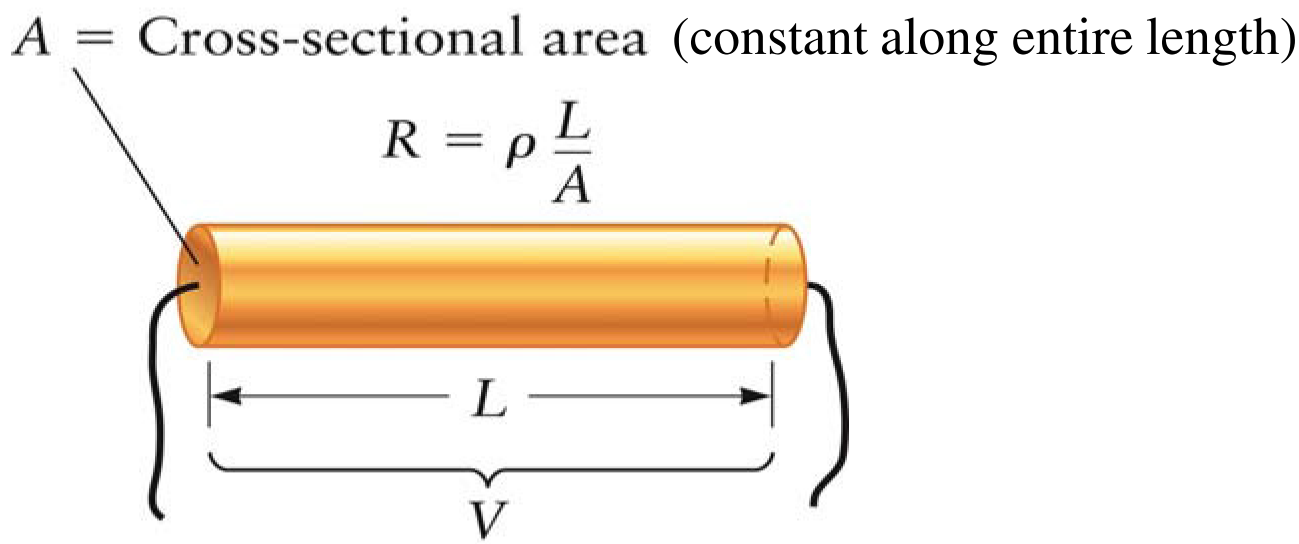
$$R = \frac{\mathcal{E}}{I} = \frac{9\ V}{0.36\ A}$$

$$= 25\ \Omega$$

Note that $\mathcal{E}$ is the potential difference of the voltage source.
V is the electrical potential across the device. In this case it is the same as $\mathcal{E}$.
I is the current through the device.

What determines R for a wire?

$$R \propto \frac{L}{A}$$



Units:

- Length, $L\ (m)$
- Area, $A\ (m^2)$
- Resistance, $R\ (\Omega)$
- Resistivity, $\rho\ (\Omega \cdot m)$

Note: resistance (R) and resistivity (ρ) are different!

Electrical Resistivity

Some materials, like metals, offer little resistance to current flow. Other materials, like plastic, offers high resistance to current flow.

Resistivity is used to quantify how much a given material resists the flow of current.

RESISTIVITIES ($\Omega \cdot m$), at 20° C

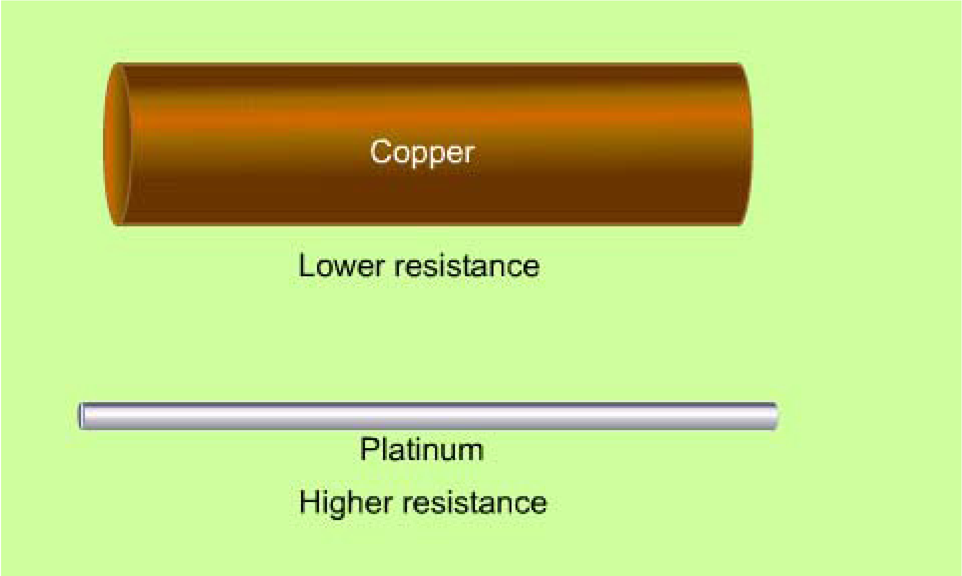
Conductors	
Silver	1.6×10^{-8}
Copper	1.7×10^{-8}
Aluminum	2.7×10^{-8}
Iron	9.6×10^{-8}
Platinum	10.5×10^{-8}
Nichrome	107.5×10^{-8}

Semi-conductors	
Carbon	3.5×10^{-5}
Silicon	2.5×10^{3}

Insulators	
Glass	10^{10} - 10^{14}
Rubber	1.0×10^{13}

Resistivity is a property of the material.

Resistivity / Resistance



Resistivity is an *intrinsic* property of the material.

Resistance depends on the resistivity of the material and its geometry.

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

American Wire Gauge (AWG)

Diameter: 2.053 2.588 3.264 4.115 6.544 8.251 mm

Determine the resistance of a 100 meter length of 12 AWG (2.052 mm diameter) sold wire made of the following materials:

a) Cu ($\rho = 1.70 \times 10^{-8}\ \Omega \cdot m$)
b) Al ($\rho = 2.65 \times 10^{-8}\ \Omega \cdot m$)
c) Fe ($\rho = 9.71 \times 10^{-8}\ \Omega \cdot m$)

$$Area = \pi R^2 = \pi\left(\frac{2.053\ mm}{2} \times \frac{1\ m}{1000\ mm}\right)^2 = 3.31 \times 10^{-6}\ m^2$$

$$R_{Cu} = \rho_{Cu}\frac{L}{A} = (1.70 \times 10^{-8}\ \Omega \cdot m)\frac{100\ m}{3.31 \times 10^{-6}\ m^2} = 0.514\ \Omega$$

$$R_{Al} = \rho_{Al}\frac{L}{A} = (2.65 \times 10^{-8}\ \Omega \cdot m)\frac{100\ m}{3.31 \times 10^{-6}\ m^2} = 0.801\ \Omega$$

$$R_{Fe} = \rho_{Fe}\frac{L}{A} = (9.71 \times 10^{-8}\ \Omega \cdot m)\frac{100\ m}{3.31 \times 10^{-6}\ m^2} = 2.93\ \Omega$$

Scaling Laws

- We don't like to do long numerical calculations. We are lazy and we make too many misteaks.
- It is easier to scale results that we already know.
- Example: What diameter of aluminum wire do we need to get the same resistance as 12 AWG copper wire of the same length?

$$A = \pi R^2 = \pi \frac{d^2}{4}$$

$$R = \rho_{Cu} \frac{L}{A} = \rho_{Al} \frac{L}{A'}$$

$$\frac{A'}{A} = \left(\frac{d'}{d}\right)^2 = \frac{\rho_{Al}}{\rho_{Cu}}$$

$$\frac{d'}{d} = \sqrt{\frac{\rho_{Al}}{\rho_{Cu}}} = \sqrt{\frac{2.65 \times 10^{-8}\ \Omega \cdot m}{1.70 \times 10^{-8}\ \Omega \cdot m}} = 1.24$$

$$d' = (2.052\ mm) \times 1.24 = 2.56\ mm$$

(roughly 10 AWG)