# DEVIL PHYSICS
## THE BADDEST CLASS ON CAMPUS
### AP PHYSICS

# 18-1: The Electric Battery
# 18-2: Electric Current
# 18-3: Ohm’s Law: Resistance and Resistors
# 18-4: Resistivity

# Reading Activity Questions?

# Big Idea(s):

- Objects and systems have properties such as mass and charge. Systems may have internal structure.
- Interactions between systems can result in changes in those systems.
- Changes that occur as a result of interactions are constrained by conservation laws.

# Enduring Understanding(s):

- Electric charge is a property of an object or system that affects its interactions with other objects or systems containing charge.
- The electric and magnetic properties of a system can change in response to the presence of, or changes in, other objects or systems.

# Enduring Understanding(s):

- The energy of a system is conserved.
- Materials have many macroscopic properties that result from the arrangement and interactions of the atoms and molecules that make up the material.

# Essential Knowledge(s):

- Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.
  - An electrical current is a movement of charge through a conductor.
  - A circuit is a closed loop of electrical current.

# Essential Knowledge(s):

- The resistance of a resistor, and the capacitance of a capacitor, can be understood from the basic properties of electric fields and forces, as well as the properties of materials and their geometry.
  - The current through a resistor is equal to the potential difference across the resistor divided by its resistance.

# Essential Knowledge(s):

- Matter has a property called resistivity.
  - The resistivity of a material depends on its molecular and atomic structure.
  - The resistivity depends on the temperature of the material.

# Learning Objective(s):

- The student is able to make claims about natural phenomena based on conservation of electric charge.
- The student is able to choose and justify the selection of data needed to determine resistivity for a given material.

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- The student is able to make predictions, using the conservation of electric charge, about the sign and relative quantity of net charge of objects or systems after various charging processes, including conservation of charge in simple circuits.

# Data Guide Equations

- In Data Guide
  - $\left|\overrightarrow{F_E}\right| = k\frac{|q_1 q_2|}{r^2}$
  - $I = \frac{\Delta q}{\Delta t}$
  - $R = \frac{\rho l}{A}$
  - $I = \frac{\Delta V}{R}$
  - $P = I\Delta V$
  - $R_s = \sum_i R_i$
  - $\frac{1}{R_p} = \sum_i \frac{1}{R_i}$
- NOT in Data Guide
  - $V = IR$

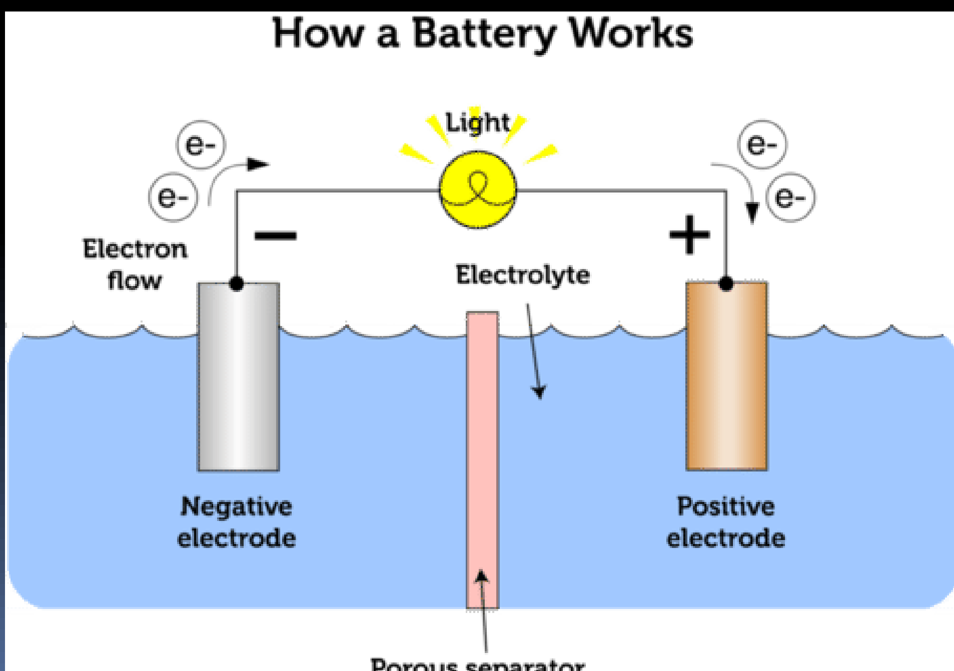
# Batteries

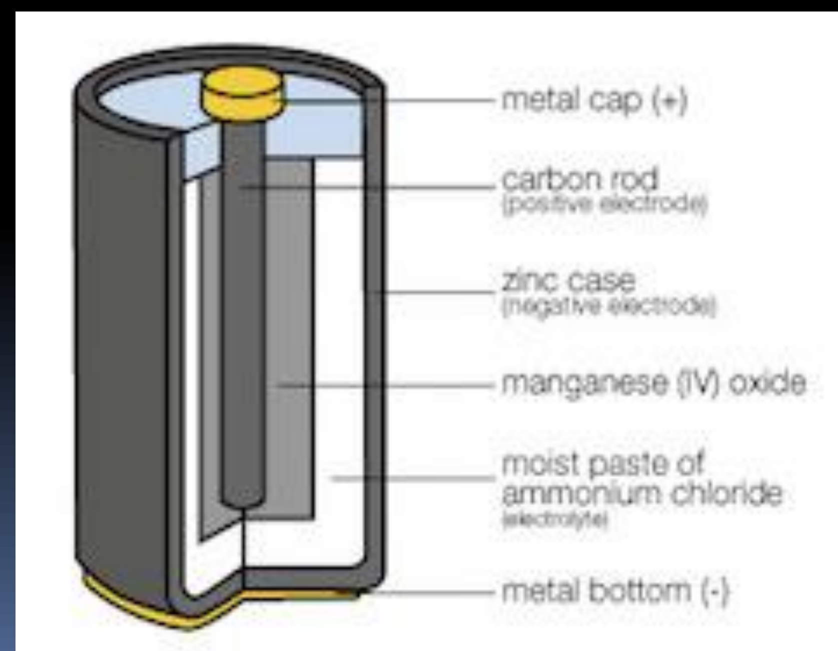
- Sources of Electricity
  - battery - converts stored chemical energy into electrical energy
  - generator – converts mechanical energy into electrical energy
  - thermocouple – converts thermal energy into electrical energy
  - photoelectric material – converts solar energy into electrical energy

# Batteries: Practical Source of Electric Current

# Batteries

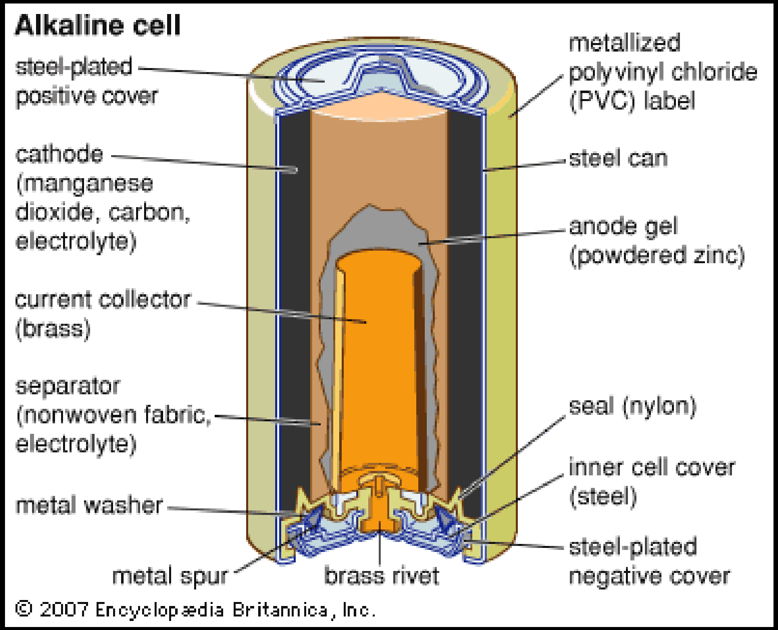
- Battery Parts
  - Electrodes: one positive (anode), one negative (cathode)
  - Electrolyte: breaks down the negative electrode
  - Terminals: outlets for electricity

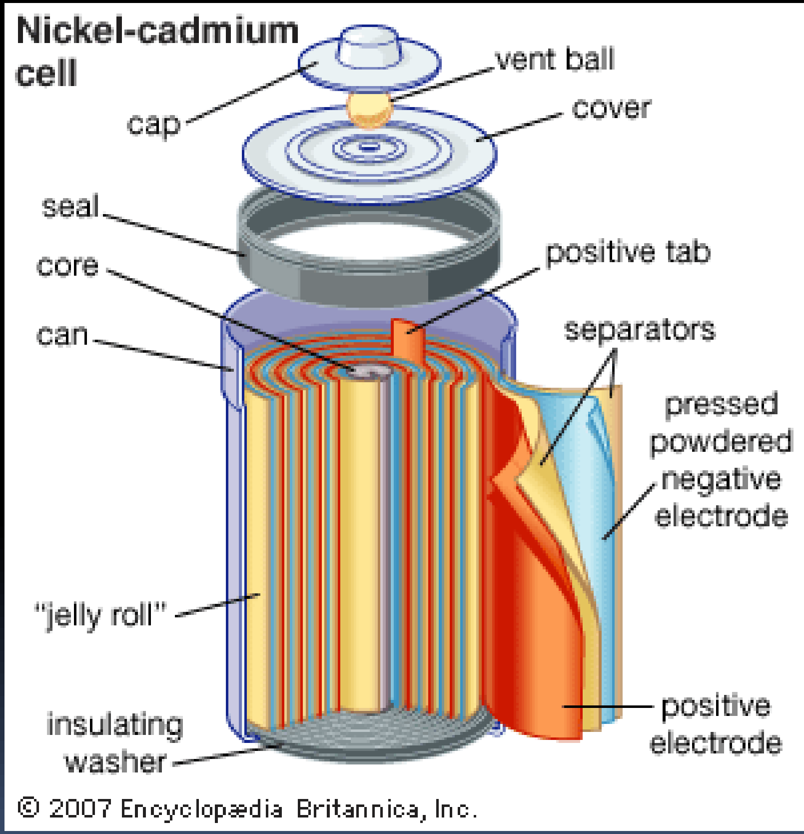


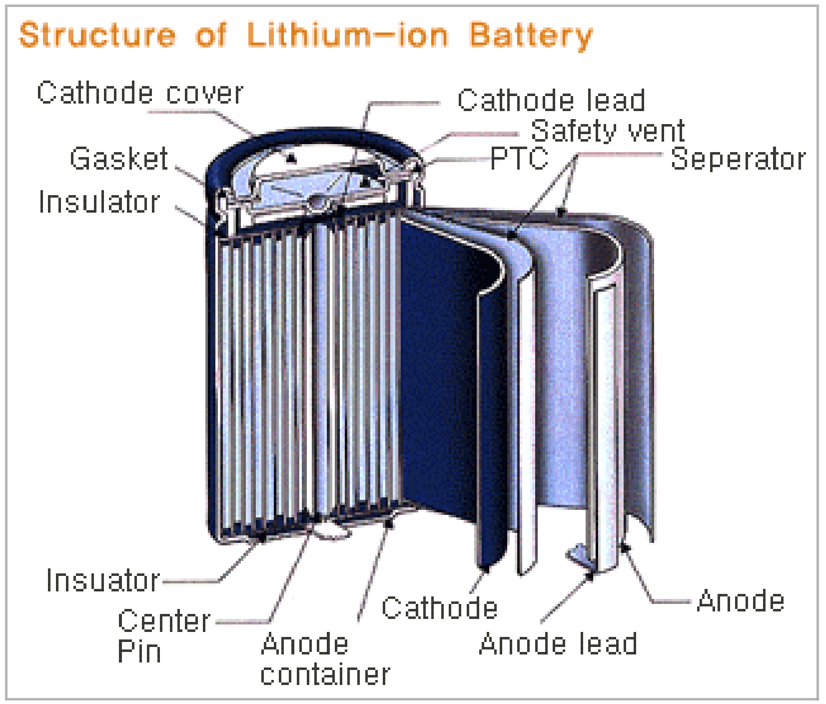



# Batteries

- Battery Types



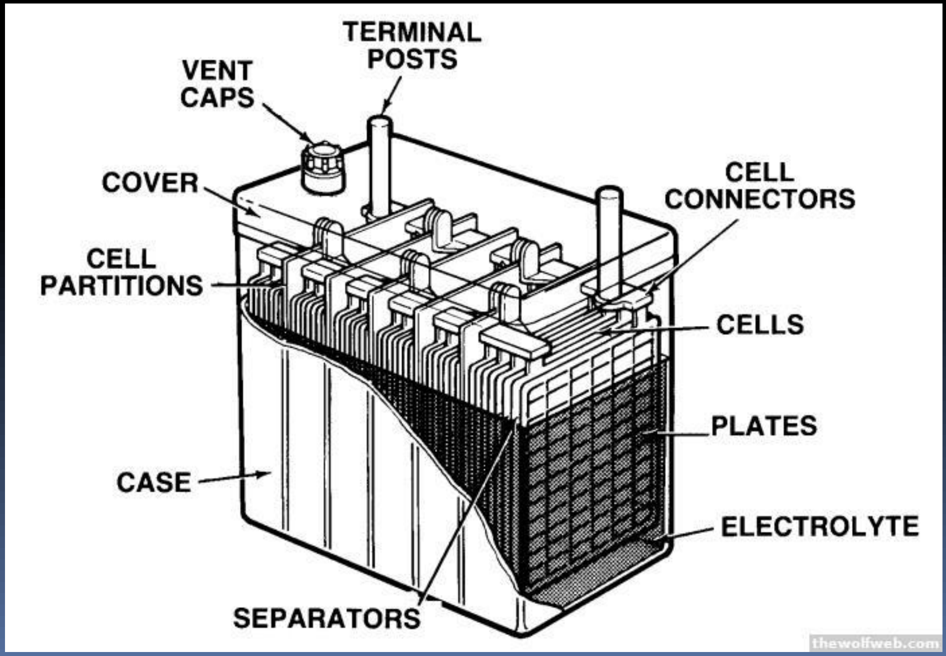
# Secondary Cells

- Primary cells are those that can only be used once
- Secondary cells can be recharged

# Secondary Cells

# Batteries

- These devices are electric cells, even though we call them batteries
- A "battery" is a group of cells like in a car battery
  - Any military buffs know why it is called a "battery"?



# Video: Electric Current

# Electric Current

- Electric current is the amount of charge that moves through the cross-sectional area of a wire per unit time

$$I = \frac{\Delta Q}{\Delta t}$$

- The unit for current is the ampere (A) and is equal to 1C/s

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- **EXAMPLE: Light falling on a metallic surface causes the surface to emit $2.2 \times 10^{15}$ electrons per second. What is the current leaving the surface?**

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- **EXAMPLE: Light falling on a metallic surface causes the surface to emit 2.2x10^15 electrons per second. What is the current leaving the surface?**
- **ANSWER:**

$$2.2x10^{15}\,\frac{electrons}{second}\,x1.6x10^{-19}\,\frac{Coulombs}{electron}$$

$$3.5x10^{-4}\,C/s\left(A\right)$$

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- In an uncharged conductor, the electrons move *randomly* at speeds on the order of $10^5$ m/s
- The presence of an electric field in a conductor causes the electrons to accelerate in a direction opposite to the electric field.
- This ordering of the electron motion is what causes current.

# Electric Current

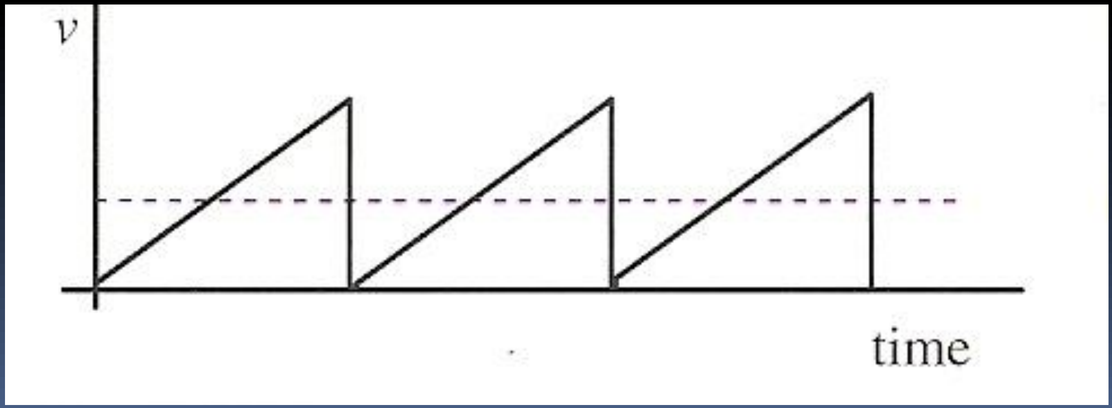
$$I = \frac{\Delta Q}{\Delta t}$$

- As the electrons move, they collide with atoms of the material and impart some of their energy to those atoms
  - This causes the atoms to increase the amplitude of their vibrations about their equilibrium position
  - These increased vibrations show up as heat
  - This is how we get toast

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- After the collision, the electrons are again accelerated by the electric field
- The graph below represents this pattern. The dotted line represents the average, or *drift velocity* of the electron



# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- For a typical metal, the drift velocity is on the order of $6 \times 10^{-4}$ m/s
- With this velocity, how long should it take for the lights to come on when you flip the switch?

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- For a typical metal, the drift velocity is on the order of 6x10$^{-4}$ m/s
- With this velocity, how long should it take for the lights to come on when you flip the switch?

$$(7m)\left(\frac{1}{6x10^{-4}}\right) = 11{,}667s = 3hrs, 15\min$$

- So why do the lights come on instantaneously?

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- **When an electric field is applied, every free electron in the conductor is energized – like the difference between opening a valve at the end of a pipe that is full of water versus opening a valve at the beginning of a pipe that is empty.**

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- Special Cases:
  - When a conductor is heated, it emits electrons through a process called *thermionic emission* which creates a current, or increases conductivity
  - When light hits a metallic surface, electrons are emitted which creates a current – photoelectric effect

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- By convention, *the direction of current is the opposite direction of the flow of electrons*

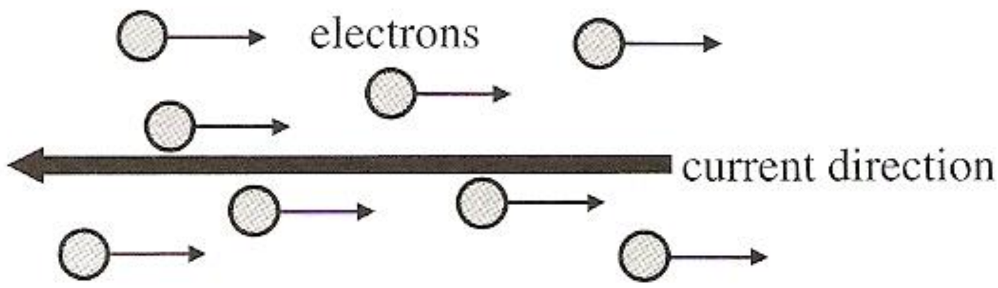


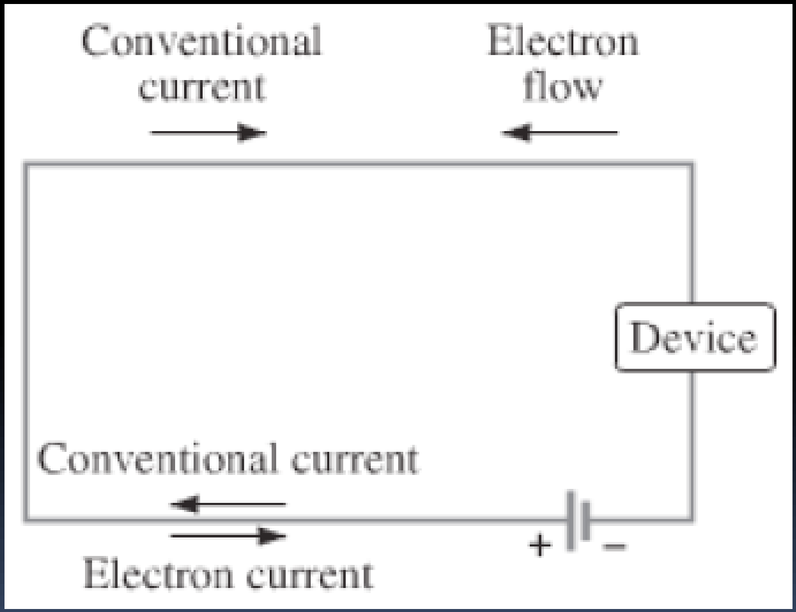

**Figure 4.3** The direction of the current is taken to be opposite to the actual electron motion.

  - Current flows from positive to negative
  - Electrons move from negative to positive

# Electric Current

$$I = \frac{\Delta Q}{\Delta t}$$

- For current to flow, there must be a path from the positive electrode of a source to the negative electrode
- This is called a *complete or closed circuit*
- If there is a break in this path, current will not flow and this is called an *open circuit*



# Developing Ohm’s Law

# Electric Resistance and Ohm's Law

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

- When the temperature of a conductor is kept constant, current is proportional to the potential difference across it
- Ohm's Law

$$I \propto V$$

  - This implies resistance is constant

# Electric Resistance and Ohm's Law

- Electric resistance of a conductor is defined as the potential difference across its ends, divided by the current flowing through it:

$$\boxed{R = \frac{V}{I}} \qquad \boxed{V = IR}$$

- The unit for resistance is the Ohm (**Ω**) and is equal to 1 V/A

# Electric Resistance and Ohm's Law

$$I \propto V$$

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

- A conductor with zero electric resistance is known as a perfect conductor
  - Current can flow without a potential difference
  - *Superconductors* can achieve zero resistance at very low temperatures (critical temperature) and are thus perfect conductors

# Electric Resistance and Ohm's Law

$$I \propto V$$

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

- For metals, increase in temperature results in increased resistance
- Assuming the conductor is kept at constant temperature, three factors affect resistance:
  - properties of the material
  - length
  - cross-sectional area.

# Electric Resistance and Ohm's Law

$$I \propto V$$

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

- **Electric resistance of a wire (at constant temperature) is proportional to its length (L) and inversely proportional to the cross-sectional area**

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

  - Resistance increases with length
  - Resistance decreases with cross-sectional area

# Electric Resistance and Ohm's Law

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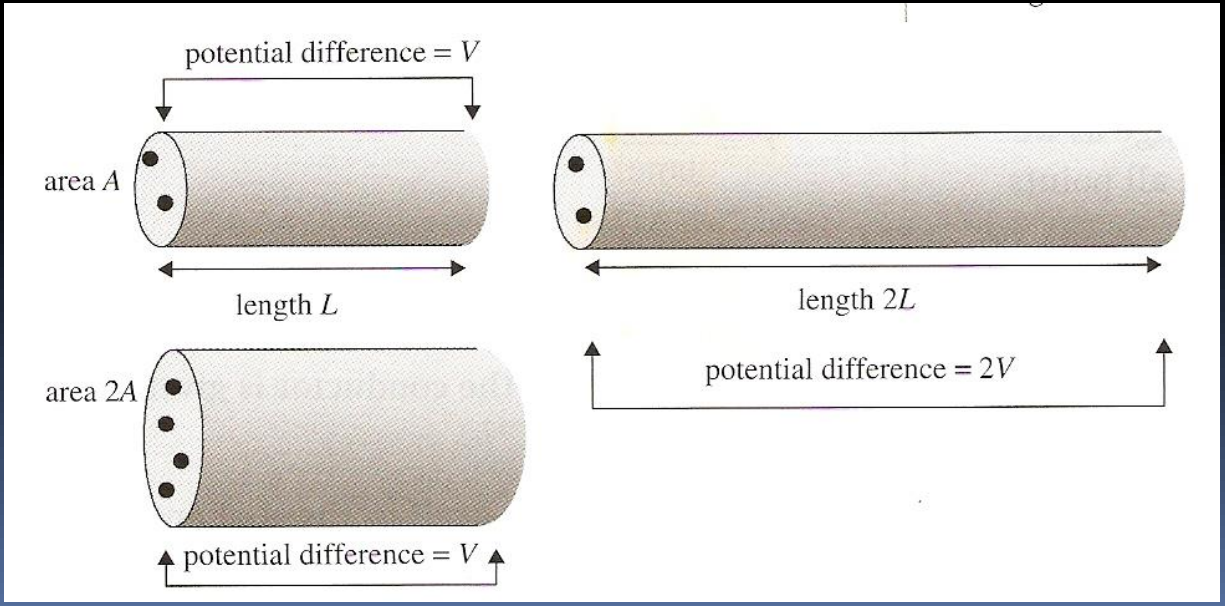


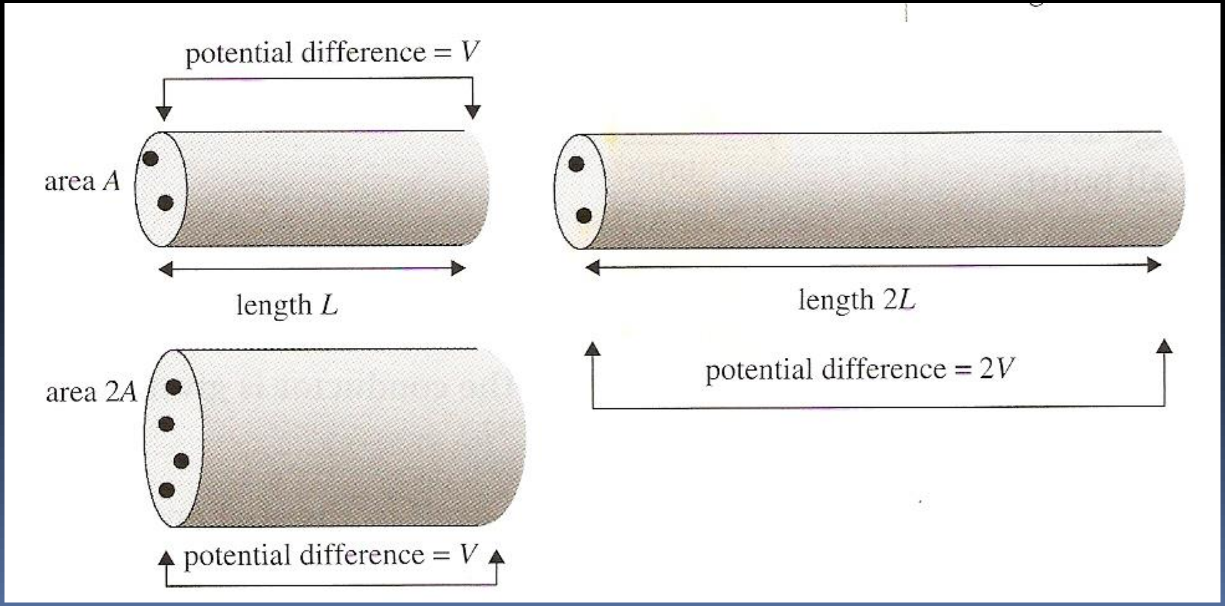
# Electric Resistance and Ohm's Law

$$I \propto V$$

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

- *Powerlines are long and thin which means more resistance and more power lost. How else might they lower resistance?*

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



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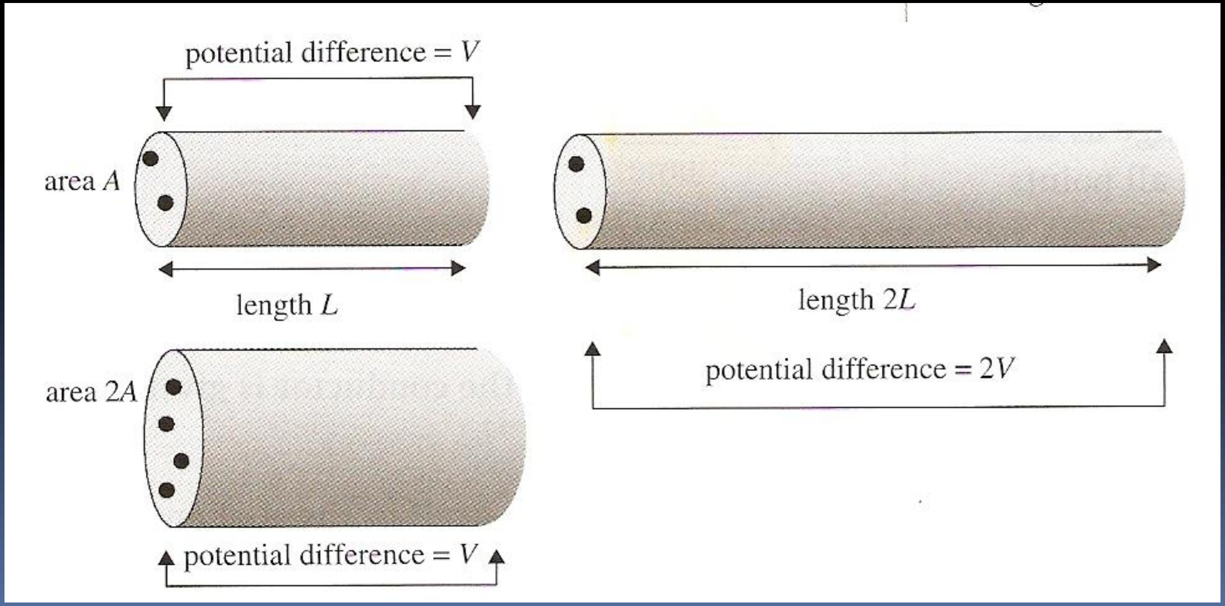
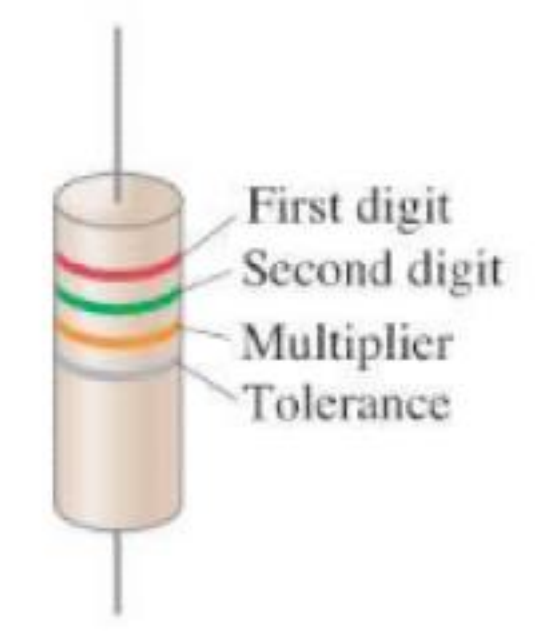



*Transformers!!!*

# Resistivity

**Resistor Color Code**

| Color | Number | Multiplier | Tolerance |
|---|---|---|---|
| Black | 0 | 1 | |
| Brown | 1 | $10^1$ | |
| Red | 2 | $10^2$ | |
| Orange | 3 | $10^3$ | |
| Yellow | 4 | $10^4$ | |
| Green | 5 | $10^5$ | |
| Blue | 6 | $10^6$ | |
| Violet | 7 | $10^7$ | |
| Gray | 8 | $10^8$ | |
| White | 9 | $10^9$ | |
| Gold | | $10^{-1}$ | 5% |
| Silver | | $10^{-2}$ | 10% |
| No color | | | 20% |



# Resistivity (ρ)

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

- A physical property of a material
- Units are Ω•m
- Conductors should have low resistivity
  - Silver is the best, but expensive
  - Copper is most frequently used
  - Aluminum has higher resistivity, but is lighter (resistance per pound is less than copper) and cheaper

# Resistivity (ρ)

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

- Resistivity is dependent on temperature
- In general, resistance increases with temperature because of the greater disorder of the atoms
- $\alpha$ is the *temperature coefficient of resistivity*

$$\rho_T = \rho_0[1 + \alpha(T - T_0)]$$

# Resistivity

**TABLE 18–1 Resistivity and Temperature Coefficients** (at 20°C)

| Material | Resistivity, $\rho$ ($\Omega \cdot m$) | Temperature Coefficient, $\alpha$ $(C°)^{-1}$ |
|---|---|---|
| *Conductors* | | |
| Silver | $1.59 \times 10^{-8}$ | 0.0061 |
| Copper | $1.68 \times 10^{-8}$ | 0.0068 |
| Gold | $2.44 \times 10^{-8}$ | 0.0034 |
| Aluminum | $2.65 \times 10^{-8}$ | 0.00429 |
| Tungsten | $5.6 \times 10^{-8}$ | 0.0045 |
| Iron | $9.71 \times 10^{-8}$ | 0.00651 |
| Platinum | $10.6 \times 10^{-8}$ | 0.003927 |
| Mercury | $98 \times 10^{-8}$ | 0.0009 |
| Nichrome (Ni, Fe, Cr alloy) | $100 \times 10^{-8}$ | 0.0004 |
| *Semiconductors*† | | |
| Carbon (graphite) | $(3–60) \times 10^{-5}$ | −0.0005 |
| Germanium | $(1–500) \times 10^{-3}$ | −0.05 |
| Silicon | 0.1–60 | −0.07 |
| *Insulators* | | |
| Glass | $10^{9} – 10^{12}$ | |
| Hard rubber | $10^{13} – 10^{15}$ | |

† Values depend strongly on the presence of even slight amounts of impurities.

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    not in curriculum

# Essential Knowledge(s):

- Electric charge is conserved. The net charge of a system is equal to the sum of the charges of all the objects in the system.
  - An electrical current is a movement of charge through a conductor.
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# QUESTIONS?

# Homework

***#1-16, 20-22***

# STOPPED HERE 9/8/14