# Intro to Circuits

PHY 114-01

Fall 2026

# Announcements

- New office hours times!
  - ~~Friday 12-1:30pm~~
  - Friday 11-12pm, 2-3pm SENG 208b
  - Not official office hours, but I'm usually available W/F 9-10am

# Agenda

- Last time:
  - Capacitor Energy
  - Dielectrics

- This time:
  - Electric Current
  - Batteries
  - Resistors
  - Ohm’s Law
  - Electric power

# Electric Current

- So far: charges at rest or moving in free space
  - Motion governed by force on a single charge in space F = qE

- Circuits behave differently
  - Motion of charge is complicated, depends on materials properties
  - We summarize the laws of with some simple models and quantities

  - Current the rate of flow of charges moving in the circuit
  - Potential (Voltage) drives current – similar to free space
  - Resistance controls the flow rate (current)

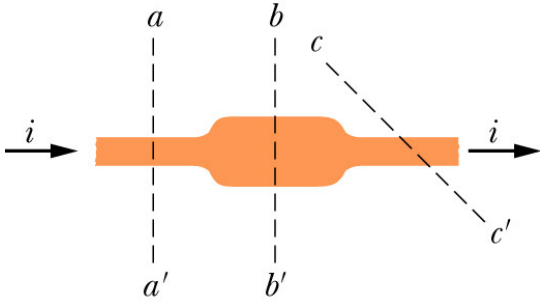
# Electric Current

- Current is, qualitatively, the flow of charge through a material
- We can define a rate of flow for charges passing through some surface:

$$I = \frac{dQ}{dt}$$

Units:

$$\frac{[charge]}{[time]} = \frac{[C]}{[s]} = [A]$$ Amperes

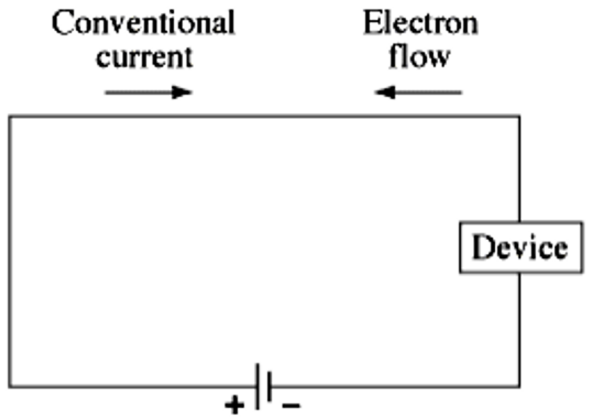



- Charge continuity:
  - Charges cannot be created or destroyed
  - What goes in, must also go out
  - Current must be the same everywhere in a continuous path

# Electric Current

- **Current direction**
  - **in conductors, it is electrons that are free to move and carry the charge**
  - **however, for historical reasons, the direction of the current is defined as flowing from the *positive* to the *negative* terminal.**

- **Here, the direction of current is *opposite* the direction of flow of electrons**

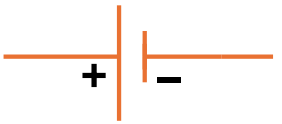


# Batteries, Potential, and EMF

- In most circuits, we assume that we have some perfect, constant source of potential
- Battery: constant voltage output
  - Real batteries have internal resistance – disrupts ideal output

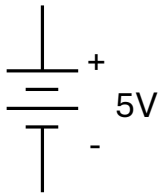
- EMF: electromotive force $\mathcal{E}$
  - A theoretical, ideal voltage source
  - Just treat it as a battery

**Symbols for a battery in a circuit**



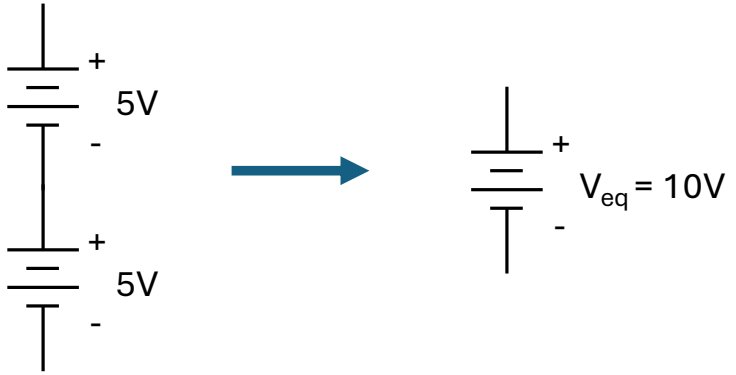

OR



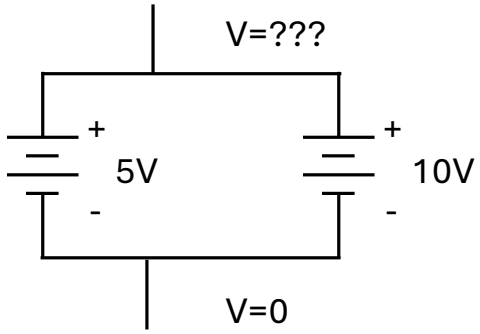



# Combining batteries

- Batteries add voltage in series




- You cannot usually combine batteries in parallel
- (without other devices altering the voltage of the system)



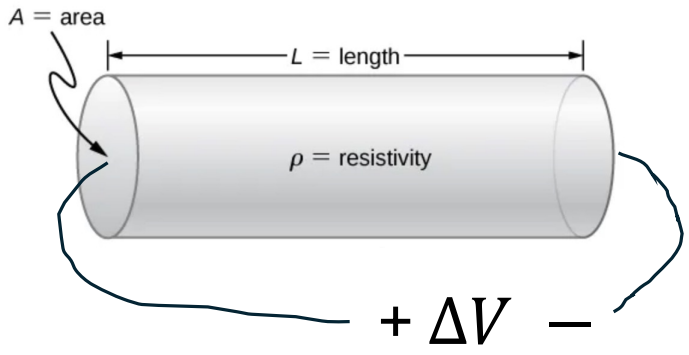

Mismatch in voltage
Not allowed

Okay if they have same voltage.

# Resistance

- In an ideal conductor, charge moves freely
- In a real conductor, there is some resistance to the flow of charge

- Resistance is defined limiting the relationship between current and voltage:




$$\Delta V = i\,R(i)$$

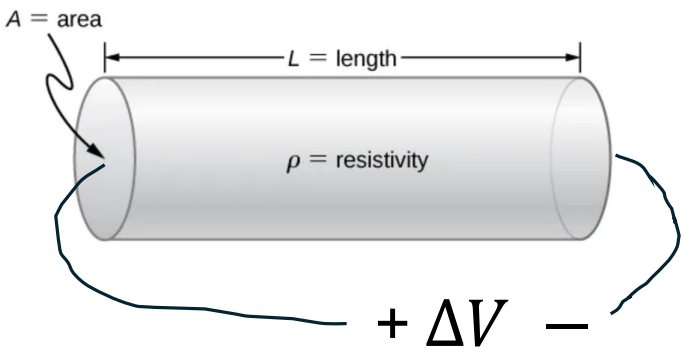
- A voltage difference ($\Delta V$) drives current ($i$) through a conductor
- The amount of current is limited by $R(i)$
- That is resistance as a function of current

- NOTE: NOT OHM's LAW YET! We're getting there.

# Resistance

- Units: $R(i) = \frac{\Delta V}{i} = \frac{[V]}{[A]} = [\Omega]$ Ohms

- Material property: resistivity, $\rho$
- Geometric property: size of resistor material




$$R(i) = \frac{\rho L}{A}$$

Harder to push through longer resistive material

Greater flow through greater cross-sectional area

## *ConceptCheck* Resistance

A wire with resistance *R* is stretched uniformly (keeping its volume constant) until it is twice its original length.

The resistance will:

**A. increase by a factor of 4**

**B. increase by a factor of 2**

**C. stay the same**

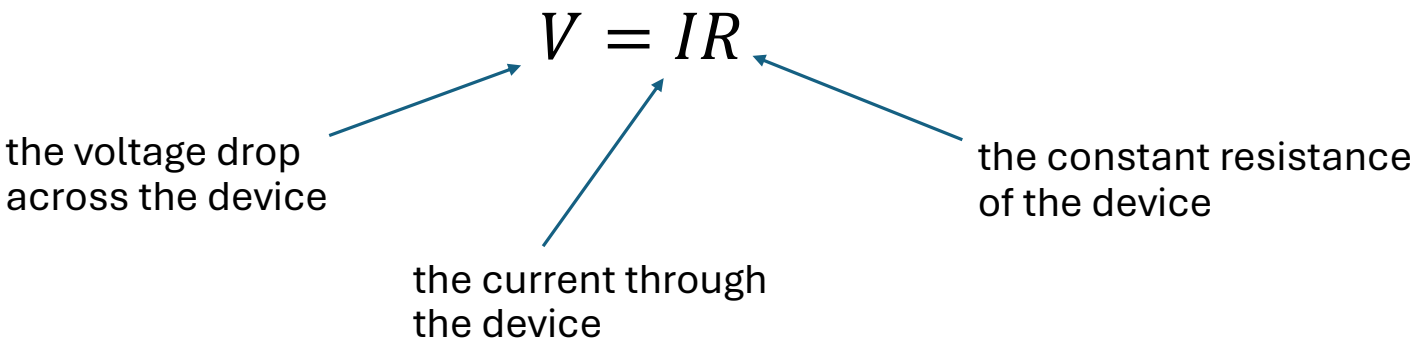
**D. decrease by a factor of 2**

**E. decrease by a factor of 4**

- V = AL
- To keep V the same and get 2L, need A/2
- $R = \frac{\rho L}{A} = \frac{\rho 2L}{A/2} = \frac{4\rho L}{A}$

# Ohm's Law

- IF resistance is the same for every value of current
- THEN we get Ohm's law:

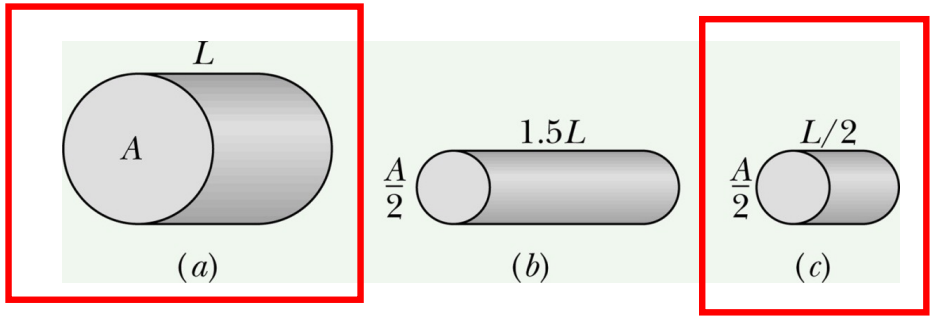


## *ConceptCheck* Ohm's Law

The figure here shows three cylindrical copper conductors along with their face areas and lengths.

Which cylinder has the most current if they all get the same voltage?

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




a and c have the same resistance!
So they will draw the same amount of current.

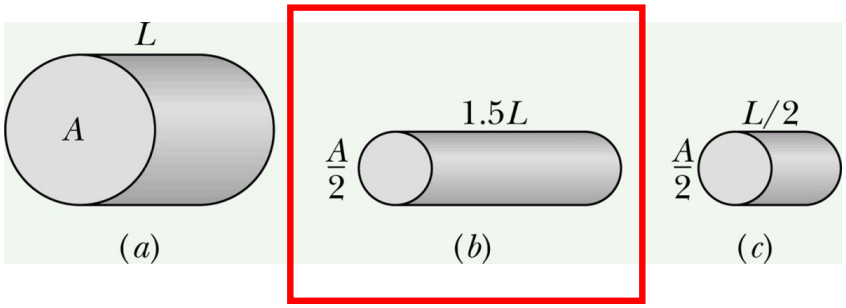
b has higher resistance than a and c.

## *ConceptCheck* Ohm's Law

The figure here shows three cylindrical copper conductors along with their face areas and lengths.

Which cylinder has the least current if they all get the same voltage?

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

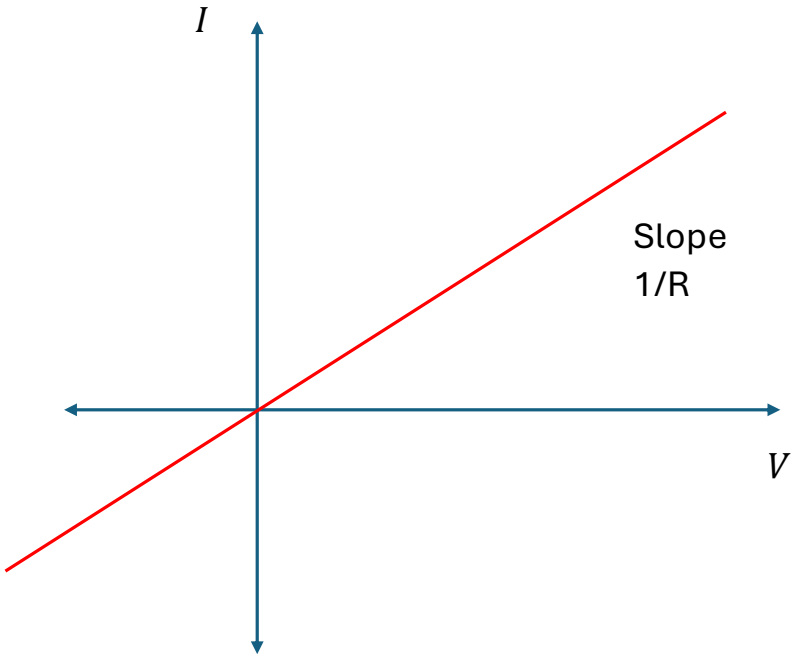



*** Daily quiz!**

# Ohm's Law

$$V = IR$$

$$I = V/R$$



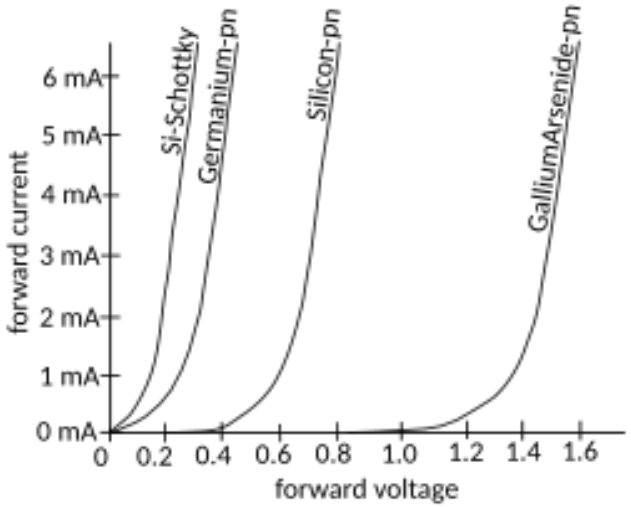

- All "ohmic" devices behave this way
- Resistors are ohmic



# Non-Ohmic devices

- Most devices
- Example: diodes



## *ConceptCheck* Ohm's Law

You double the *voltage* across a certain conductor and you observe the *current* increases three times. What can you conclude?

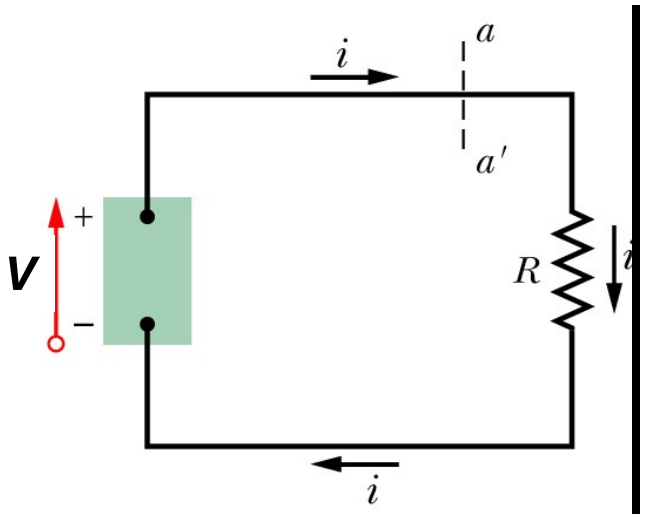
**A. Ohm's Law is obeyed since the current increases when voltage increases**

**B. Ohm's Law is not obeyed**

**C. This has nothing to do with Ohm's Law**

Ohm's law stipulates a proportional dependence of voltage and current. This relationship is violated here.

# Work, Power and Electric Current




- **Imagine some charge *dq* moving through a resistor**
  - **change of potential across the resistor = –V**
  - **the change in potential energy of *dq* is**

$$dU = -Vdq$$

- **since the potential energy has changed (it has decreased), work must have been done by the battery**

$$dW = -dU = Vdq$$

# Electric Power

- **The rate at which electric energy is transformed is given by the electric power:**

$$P = \frac{dW}{dt} \qquad dW = Vdq$$

$$\Rightarrow P = V\frac{dq}{dt} = VI \qquad \text{since} \qquad \frac{dq}{dt} = I$$

$$P = IV = I^2R = \frac{V^2}{R}$$

**Unit of power is the Watt (W):**

**1 Watt = 1 J/s**

# Electric Power

$$P = IV = I^2R = \frac{V^2}{R}$$

- **Electric energy can be converted into many forms of energy**
  - ***thermal energy*** **(heaters, ACs)**
  - ***mechanical energy*** **(motors, speakers)**
  - ***light*** **(light bulbs, lasers)**