*Jump to Kirchoff's Laws

Heating in Circuits

- As the electric field moves charges in a conductor, the charges collide with the atoms of the material
    - Atoms of the conductor vibrate the collisions (KE) → heat/thermal energy.
    - Drift speed decreases (↓) as conductor heats up (↑) as # of collisions increases (↑)

Resistance (Ohms, Ω)

- Resistance determines how much electricity will flow
    - *property* of the conductor
- Conducting wires typically have very low resistance
    - often ignored/***negligible* resistance**
- **Resistor** - a conductor with ***non-negligible* resistance**

Ohm's Law and Resistivity

- When temperature of *most* metallic conductors is constant, **I ∝ V**
- R = Resistance (Ohms / Ω or JsC^{-2})
- V = Voltage (Volts / V or JC^{-1})
- I = Current (Amperes / A or Cs^{-1})

$$R = \frac{V}{I} \text{ or } V = IR$$

Resistivity (ρ) - a property of a material at a *fixed* temperature that combines the factors of resistance, area, and length:

ρ, R

A = cross-sectional area

L = length

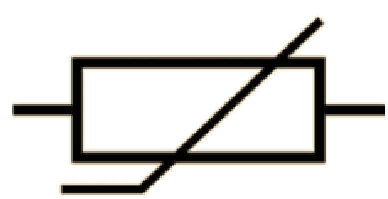
$$\rho = \frac{RA}{L}$$

*"The **resistance** of an object (i.e., a resistor) depends on its shape and the material of which it is composed.**Resistivity** ρ is an intrinsic property of a material and directly proportional to the total **resistance** R, an extrinsic quantity that depends on the length and cross-sectional area of a resistor."*

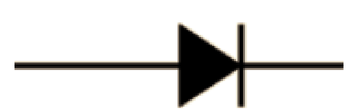
- Think of resistivity as similar to atomic mass or density.

Thermistors and Diodes

- Both are non-Ohmic
    - Sometimes don't follow Ohm's law
- Thermistors (portmanteau of thermal resistor)
    - resistors that significantly change resistance with temperature

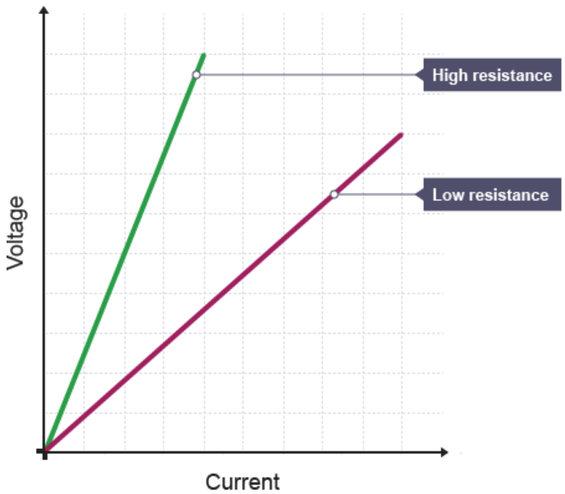


- Diodes

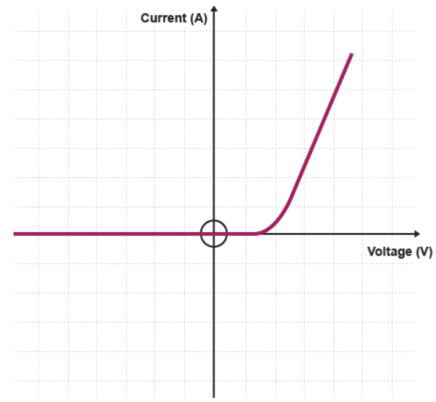


- very low resistance when current flows one direction, and very high resistance the other direction

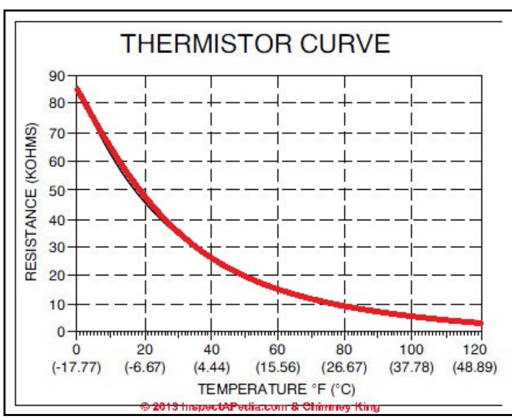
Ohmic Graph

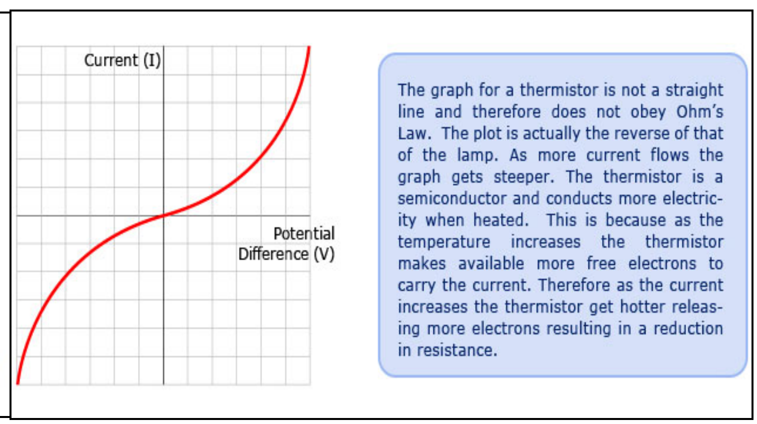


Diode Graph



Thermistor Graphs





Electric Power and EMF

- Power is the rate at which work is done moving charges from point to point.

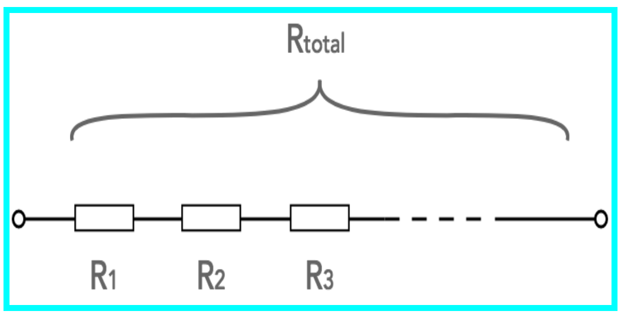
$$P = IV = I^2R = \frac{V^2}{R}$$

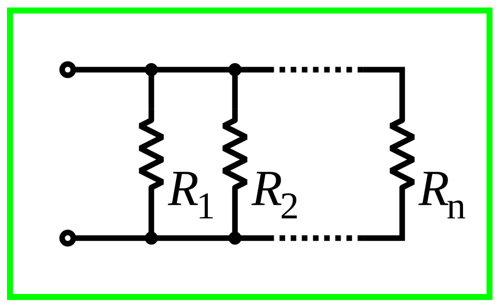
- Electromotive Force, measured in volts, defined as the work done per unit of charge when moving charges across a battery terminal

$$\varepsilon = \frac{W}{q} = \frac{P}{I}$$

Series vs Parallel Connections

- Series (left) components are connected one after the other
- Parallel (right) components are connected so they all have common ends





Resistors in Series

- Current is the same across each resistor
- Potential differences must add up to the total value
- Add resistors to get a total resistance.

$$R_{total} = R_1 + R_2 + ...$$

Resistors in Parallel

- Potential difference is the same across each resistor
- Currents must add up to the total value
- Add the inverses of the resistors to find total resistance

$$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$$

Ammeters and Voltmeters

- Ammeters measure current, and are connected in series. They have sufficiently small resistance so as not to add extra resistance to the circuit.
- Voltmeters measure potential difference, and are connected in parallel. In theory they have infinite resistance so that they draw no current from the circuit.

Kirchoff's Current/First Law

- States that for a junction in a parallel circuit, whatever amount of current entering the junction must equal the sum of the currents leaving the junction

$$\Sigma I_{in} = \Sigma I_{out} \text{ and } \Sigma I = 0\ (junction)$$

Multiloop Circuits

- Uses Kirchoff's Loop (Second) Law, which states that the sum of the potential differences in a loop must equal zero.
- Can be used to find current

$$\Sigma V = 0\ (loop)$$

Rules for Multi-loop Circuits

Positive (+)	Negative (-)
Loop goes from - to + across a battery (V)	Loop goes from + → - across a battery (V)
Loop goes **against** the current in a resistor (Ω)	Loop goes **with** the current in a resistor (Ω)

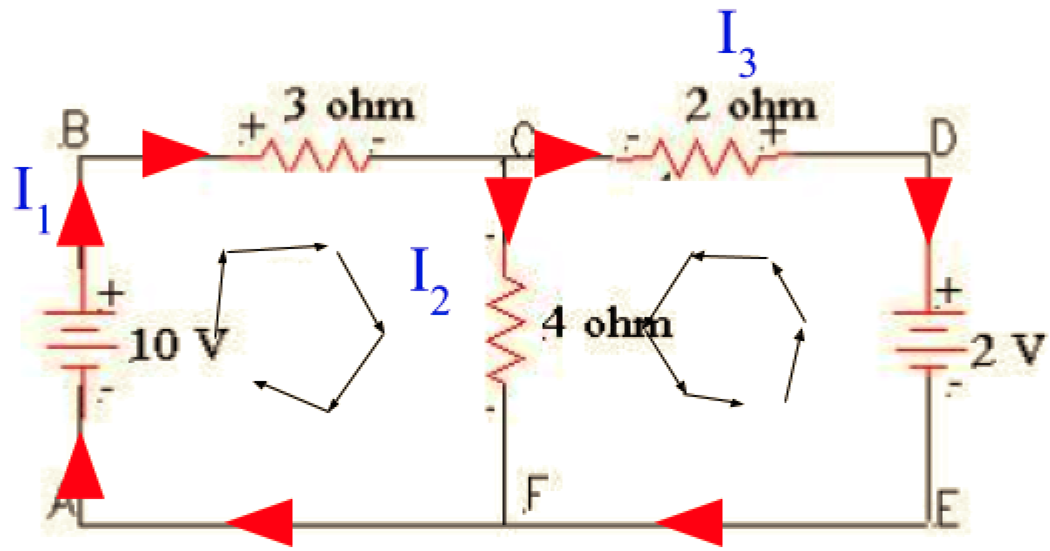
General Guidelines

- Look for the I that shows up twice
- Solve each equation for the other I's
- Substitute both of those expressions into

$$I_1 = I_2 + I_3$$

- Solve for the I that showed up twice
- Substitute that value into your other expressions to solve for the remaining I's
- If a current comes out negative it just means you picked the wrong direction. Just make it positive.

Practice Problem



1. We start with 2 batteries (10 V & 2 V) and 3 resistors (3 ohm, 4 ohm, & 2 ohm).
2. Choose a direction and a battery and start drawing arrows to mark the flow of the current.
3. Because the loop goes from negative (-) → positive (+) for both batteries, V is positive.
4. Look at the direction of the current vs the direction of the loop to find the sign for each current.
5. **Left loop**
   a. $\Sigma V = 0\ (loop)$
   b. $V_1 - R_1 I_1 - R_2 I_2 = 0$
      i. The loop goes with both I_1 and I_2, thus both are negative.
   c. $10 - 3I_1 - 4I_2 = 0$
   d. Solve for I_1 in the left loop equation
6. **Right loop**
   a. $\Sigma V = 0\ (loop)$
   b. $V_2 + R_3 I_3 - R_2 I_2 = 0$
      i. The loop goes against I_3, thus it's positive.
      ii. The loop goes with I_2, thus it's negative.
   c. $2 + 2I_3 - 4I_2 = 0$
   d. Solve for I_3 in the right loop equation
7. Substitute I_1 from the left loop equation and I_3 from the right loop equation into the equation $I_1 = I_2 + I_3$

8. The answers should be $I_1 = 2$, $I_2 = 1$, and $I_3 = 1$