CIRCUIT ANALYSIS

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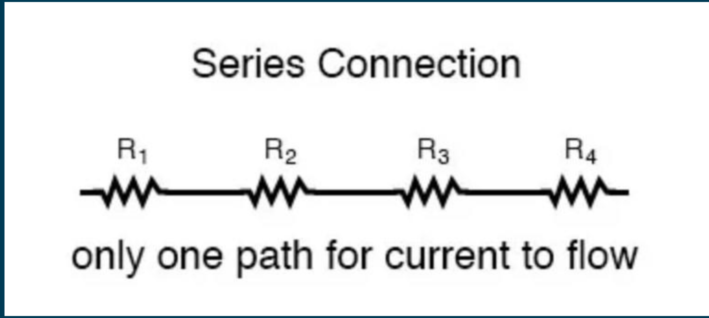
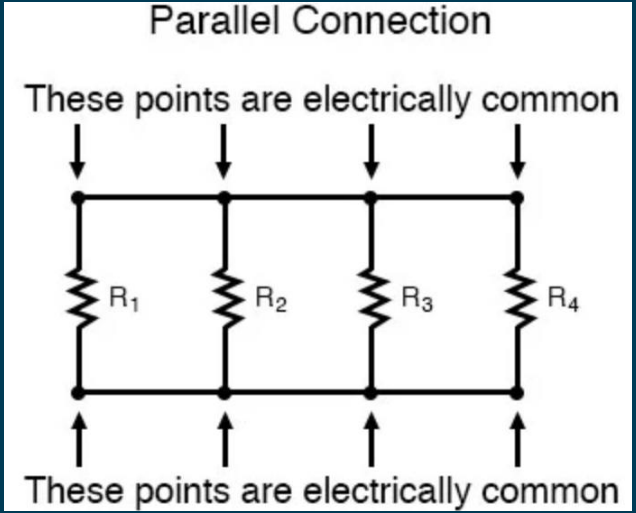
Electrical Engineering – SS 2019 – Duke TIP

SERIES VS. PARALLEL RESISTORS

Series vs. Parallel

- Series – same current flows through all components
- Parallel – same voltage across all components



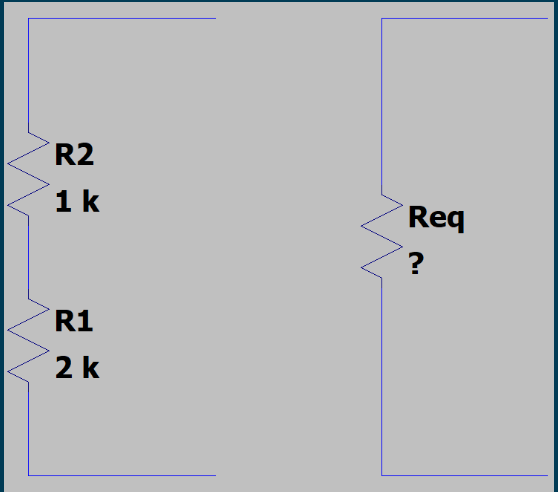


Series

- Components connected in series are connected along a single conductive path.
- The same current flows through all of the components.
- The voltage is gained or dropped in different amounts across each component.

Resistors in Series

- When resistors are in series, the same current must flow through both of them.
- Essentially this makes one new resistor with a new value that is the same as adding all series resistors together.
- $R_{eq} = R_1 + R_2 = 3\ k\Omega$

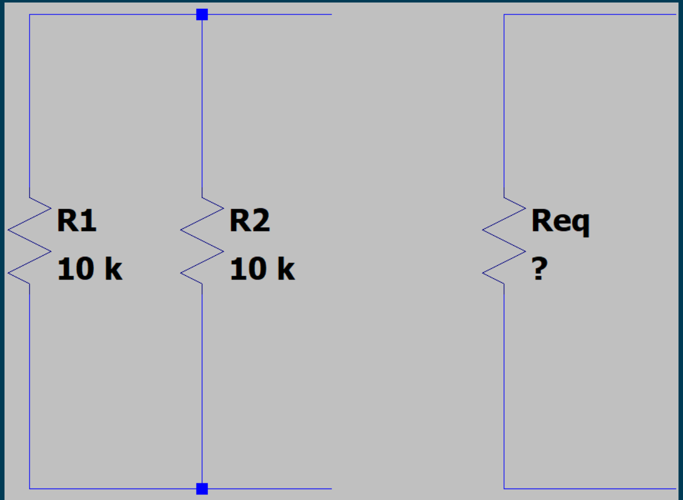


Parallel

- Components connected in parallel are connected along multiple paths.
- The current splits up and travels along different paths.
  - Current levels on each of the paths can be different and are dictated by the components on that path.
- The same voltage is applied across each path.

Resistors in Parallel

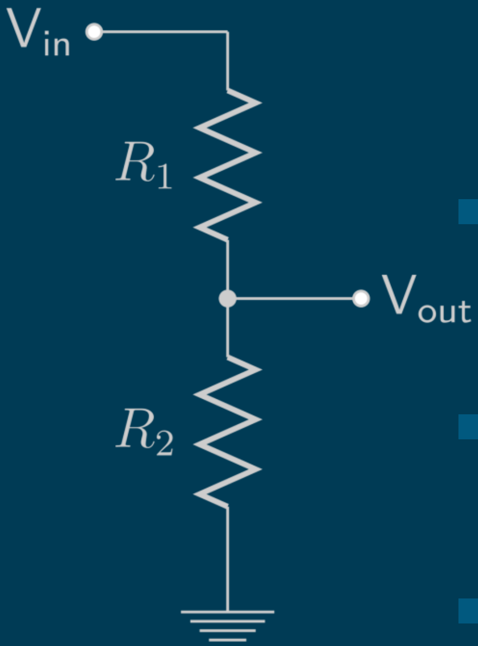
- When resistors are in series, the same current must flow through both of them.
- Essentially this makes one new resistor with a new value that is the same as adding all series resistors together.
- $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{10k\Omega} + \frac{1}{10k\Omega}$
- $R_{eq} = \frac{1}{\frac{1}{10\ k\Omega} + \frac{1}{10\ k\Omega}} = 5\ k\Omega$



VOLTAGE DIVIDERS

Voltage Dividers

- Voltage divider circuits can be useful to reduce voltage.
- If you have a high voltage you want to measure, you can use a voltage divider and measure reduced voltage.
- If you know the reduced voltage and the resistor values, you can calculate the original voltage.
- $V_{in} = \frac{R_1+R_2}{R_2} \times V_{out}$; $V_{out} = \frac{R_2}{R_1+R_2} \times V_{in}$



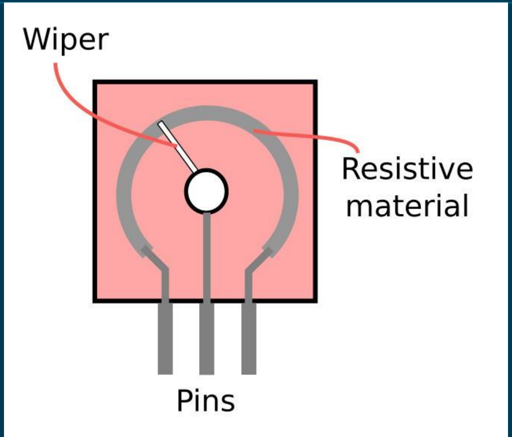
Activity: Voltage Dividers

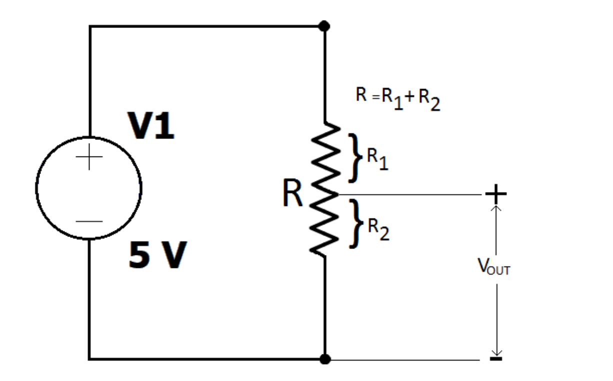
- Use voltage dividers to take a 9V input and divide it down to 5 V and 3.3 V.

- Draw the circuit.
- How many resistors did you have to use?
- What resistor values did you use?

Introducing... Potentiometers!

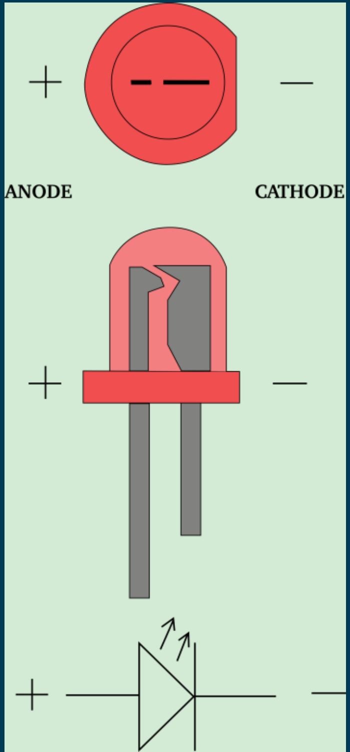
- 3-terminal adjustable resistor.
- Between two end terminals, there is a constant resistance.
- Middle terminal is called a wiper. Changes resistance value across resistance range as wiper moves.

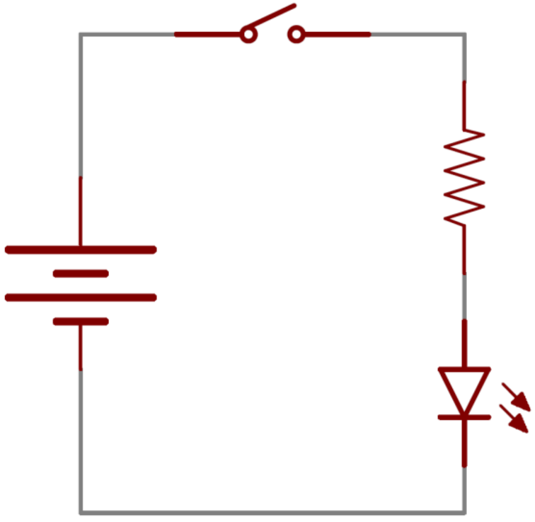




Activity: Potentiometer

- Use potentiometer as a dimmer switch for an LED.
  - Use 5V power supply
  - Change the R values and document the I/V changes.





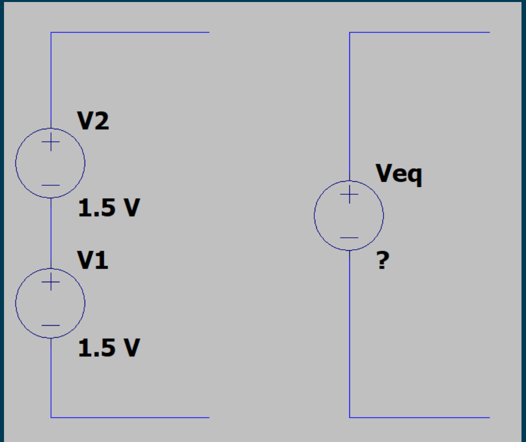
MORE ABOUT SERIES AND PARALLEL

How is your home wired up?

- We want the same voltage at every outlet.
- We don’t want the same current flowing through every outlet.

Voltage Sources in Series

- When voltage sources are in series, you add their voltage values together to find the equivalent voltage.
- Example: AA batteries are 1.5V. You can connect 2 AA batteries positive end to negative end to create 3V.
  - What happens if you connect 3?
  - What happens if you connect positive end to positive
- Polarity matters!



Can you have voltage sources in parallel?

- Draw the circuit.

Voltage Sources in Parallel

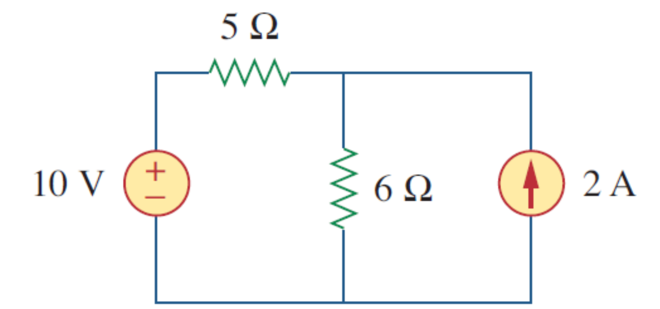
- You can't have voltage sources in parallel if they have different voltages!
- Different voltage levels would damage the sources.
- Why would you want voltage sources in parallel?
  - Longer battery life
  - More *available* current
- How could you put 2 voltage sources with different voltage levels in parallel?

SERIES/PARALLEL PRACTICE PROBLEMS

KIRCHHOFF'S LAWS

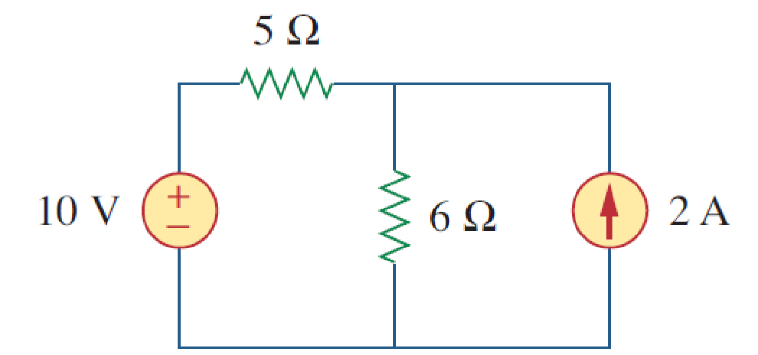
Quick Note: Current Sources

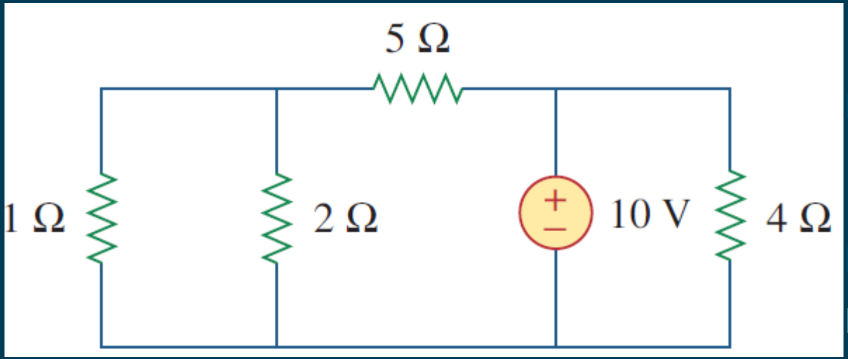
- In addition to voltage sources, there are also current sources.
- These sources provide pure current.
  - But kind of “provide” voltage require by the circuit.
- We won’t cover these as much because they won’t appear in our labs and projects, but they help us understand circuit diagrams.



Branches

- A branch represents a single element such as a voltage source or a resistor.
- In other words, a branch represents any two-terminal element.
- How many branches do you see in the 2 circuits below?





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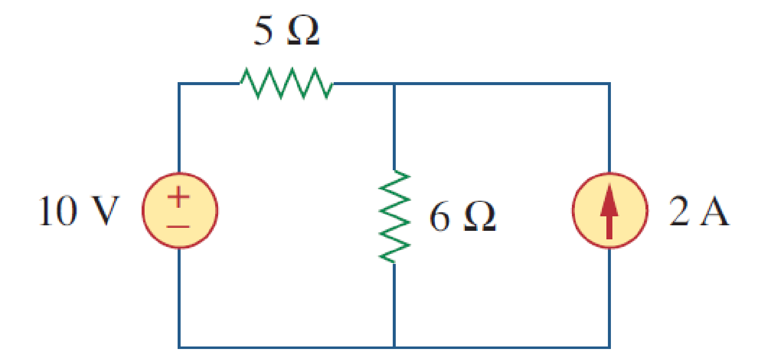
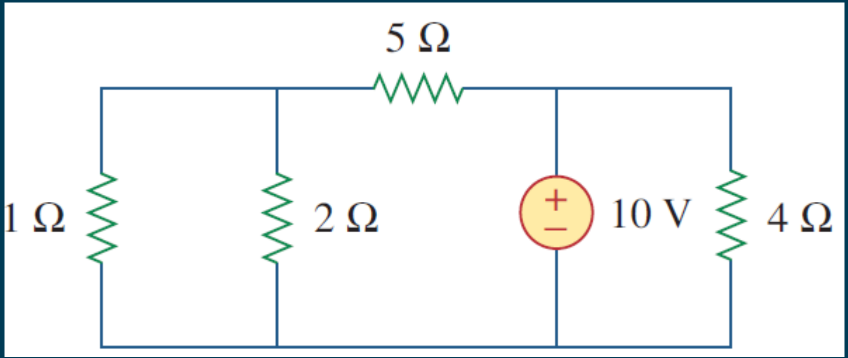


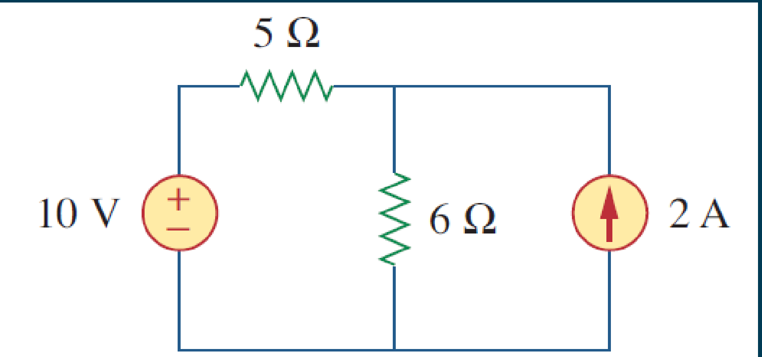
4 branches

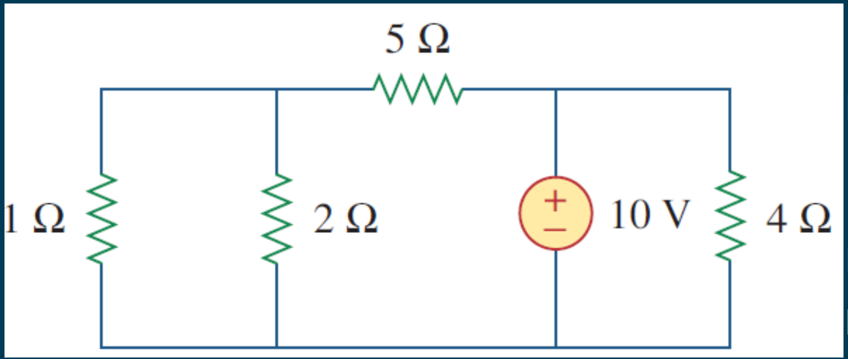


5 branches

Nodes

- A branch is the point of connection between two or more branches.
- How many nodes do you see in the 2 circuits below?





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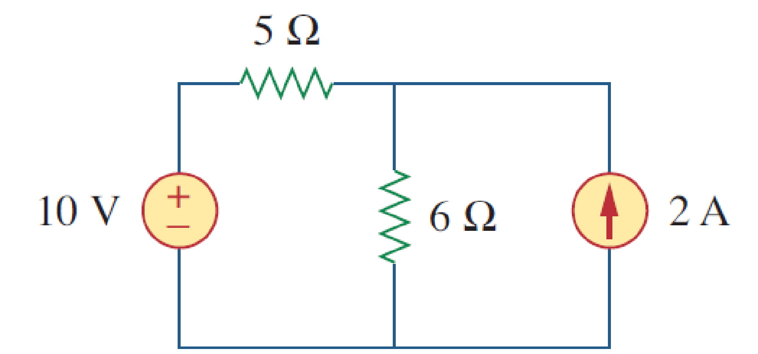
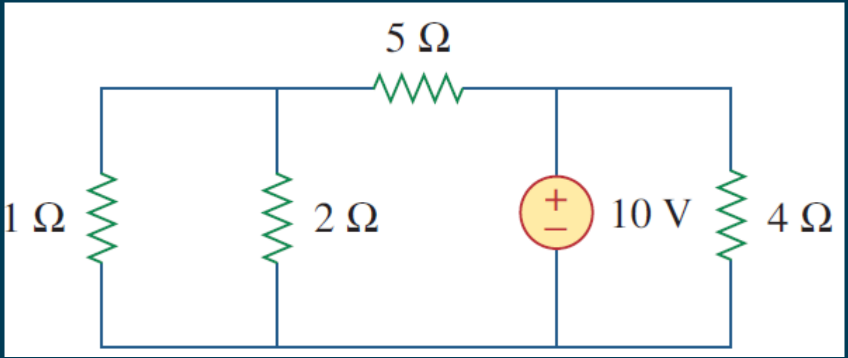


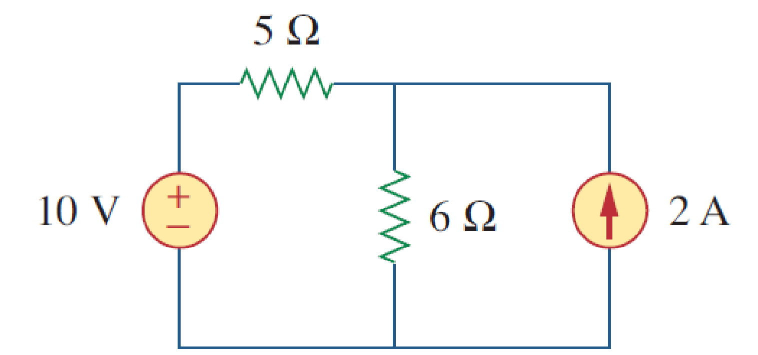
3 nodes

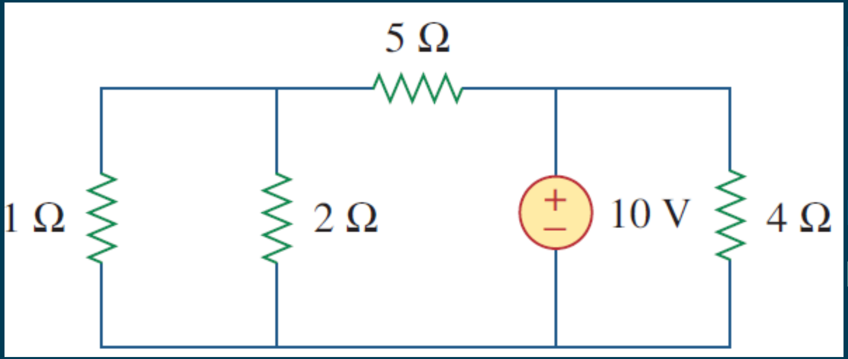


3 nodes

Loops

- A loop is any closed path in a circuit.
- Formed by starting at a node, passing through a set of nodes, and returning to the starting node without passing through any node more than once.
- How many loops do you see in the 2 circuits below?





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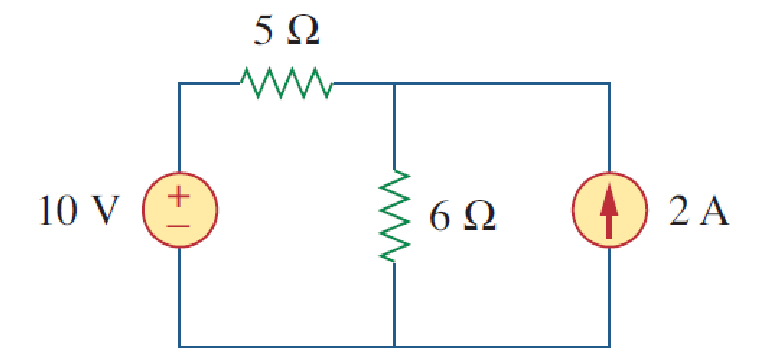
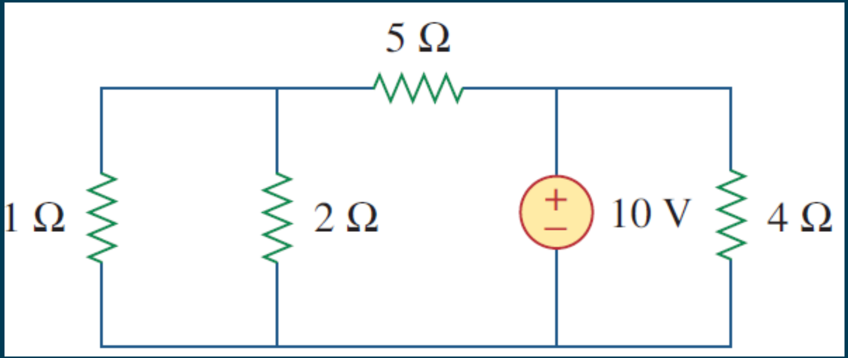


3 loops



6 loops

Kirchhoff's Laws

- Named for Gustav Kirchhoff who created two fundamental equality laws for circuit analysis based on Ohm's Law.
- Kirchhoff's Current Law (KCL) – "The algebraic sum of all currents entering and exiting a node must equal zero."
- Kirchhoff's Voltage Law (KVL) – "The algebraic sum of all voltages in a loop must equal zero"

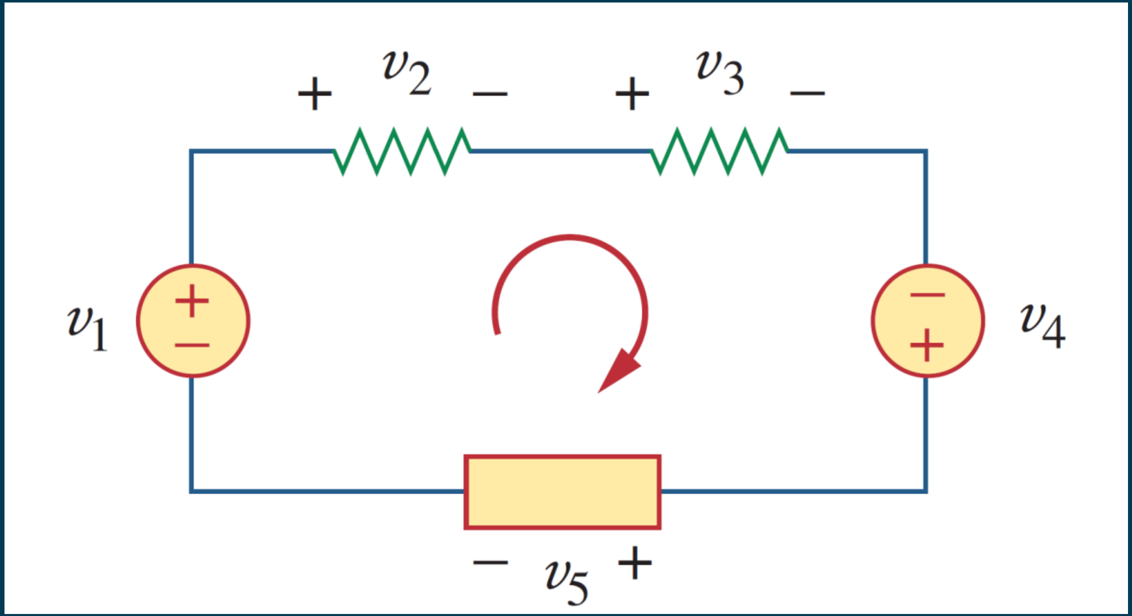
KVL

Kirchhoff's Voltage Law (KVL)

- "The algebraic sum of all voltages in a loop must equal zero."
- Perform mesh analysis based on KVL to find unknown currents.
- Do this by identifying loops and forming meshes.

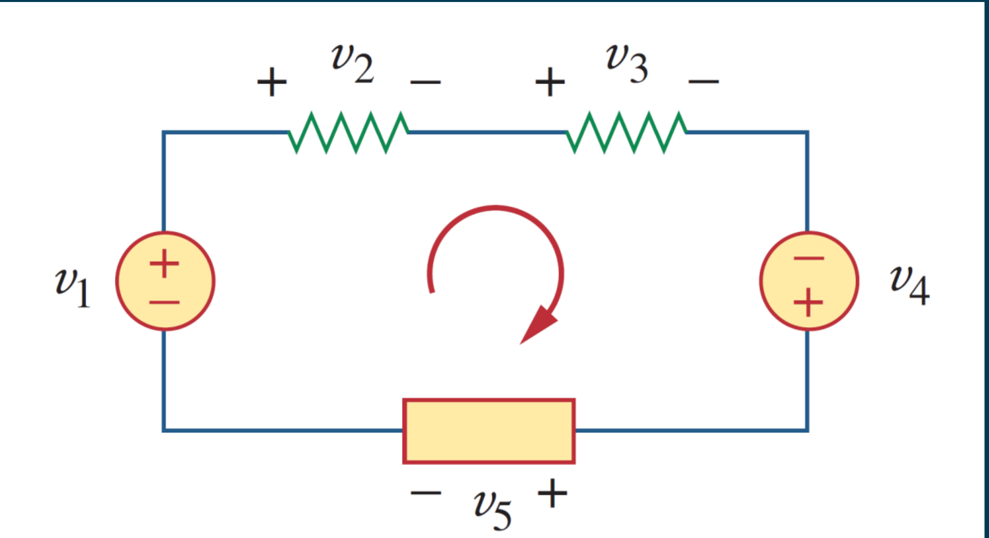
KVL Example

- Write a single equation with all of the voltages shown below using KVL.



KVL Example Solution

- $V_1 - V_2 - V_3 + V_4 - V_5 = 0$
- $V_1 + V_4 = V_2 + V_3 + V_5$



KVL PROBLEMS

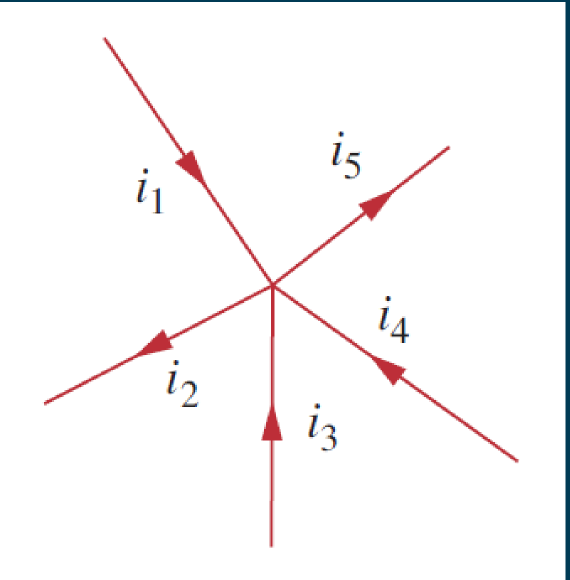
KCL

Kirchhoff's Current Law (KCL)

- "The algebraic sum of all currents entering and exiting a node must equal zero."
- Perform nodal analysis based on KCL to find unknown voltages.
- Do this by identifying nodes.

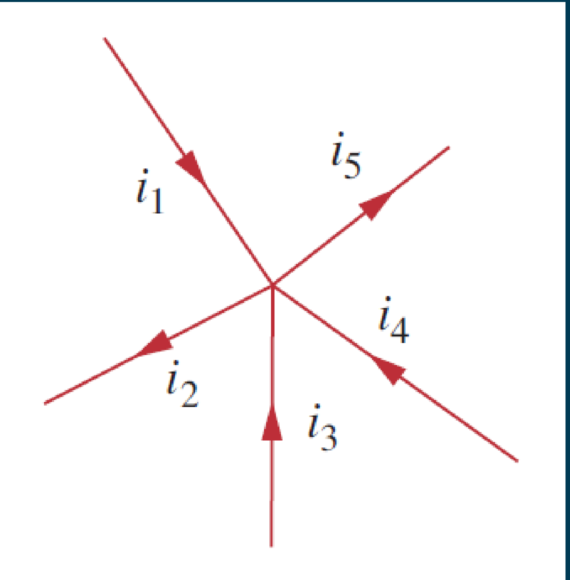
KCL Example

- Write a single equation using all of the currents shown below by applying KCL to the center node.



KCL Example Solution

- $I_1 - I_2 + I_3 + I_4 - I_5 = 0$
- $I_1 + I_3 + I_4 = I_2 + I_5$

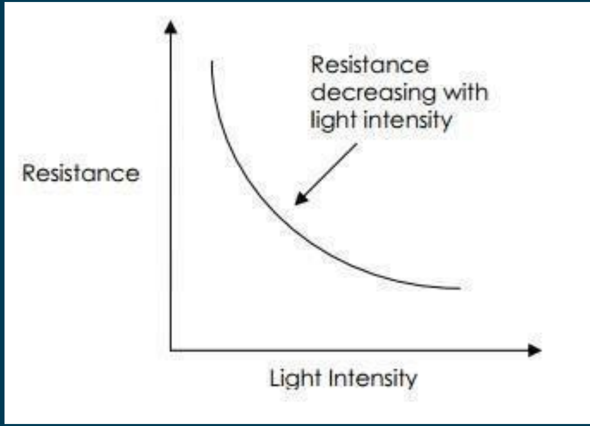


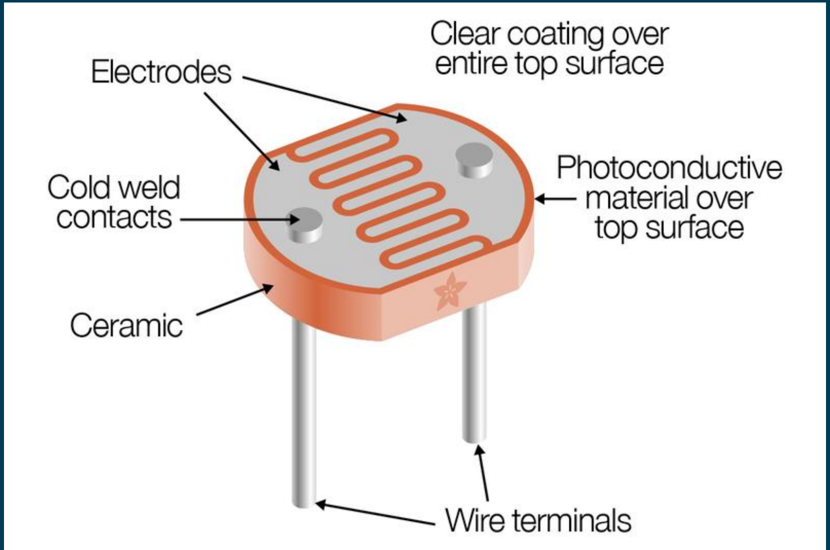
KCL PROBLEMS

LAB ACTIVITIES

Activity: Photoresistor Ambient Light

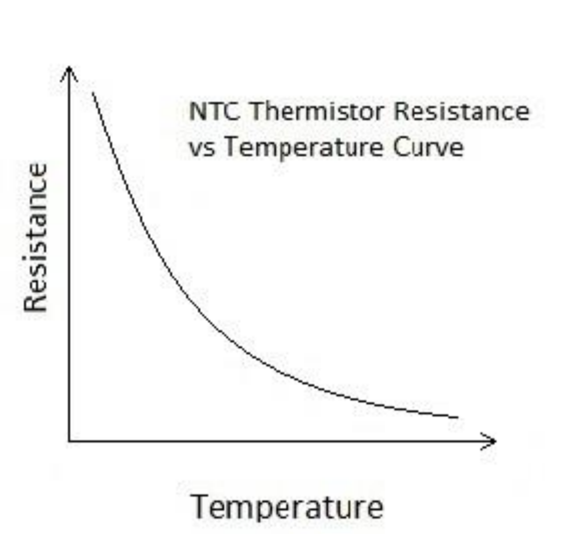
- Can you use a photoresistor to control the brightness of an LED based on ambient light? (brighter LED when it's brighter out, like your phone)
- What is the resistance range you observed?





Activity: NTC Thermistor Heat Indicator

- Can you use an NTC thermistor to control the brightness of an LED based on temperature?
- Use it as a heat indicator.
- What is the resistance range you observed?

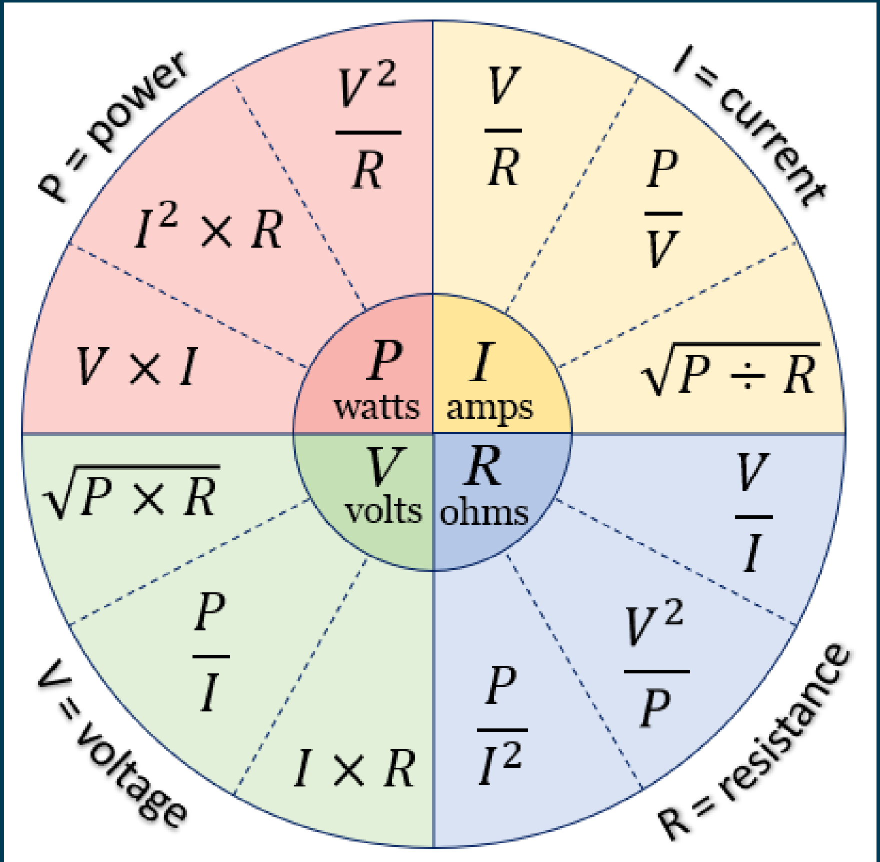


POWER & ENERGY

Power

- Electrical power is the rate of doing work.
- $Power = \frac{work}{time}$
- Power is measured in watts (W) and is abbreviated with an uppercase "P".
- $P = \frac{VQ}{t} = VI = I^2R = \frac{V^2}{R}$

Ohm's Law Wheel



Energy

- Energy is how much work has been done.
- Energy is power (how much work can be done) multiplied by time (how long that rate of work has been done).
- Energy is measured in joules (J) and is abbreviated with an uppercase “E”.
- $E = Pt = VQ$

Joules or Watt-hours

- Both a unit of energy. Joules (J), Watt-hours (Wh)
- $1\,W = \frac{1\,J}{1\,s}; \quad 1\,J = 1\,W \times 1\,s$
- $1\,Wh \;=\; 1\,W \times 1\,hour \;\times \frac{3600\,s}{1\,hour} = 3600\,J$
- 1 Wh = 3600 J

Law of Conservation of Energy

- Energy can neither be created not destroyed.

- This means that when a component or a circuit "consumes" energy, it is not gone.
- It merely changes forms.
- In electronics, the most of this energy is turned into heat.

Derating Components

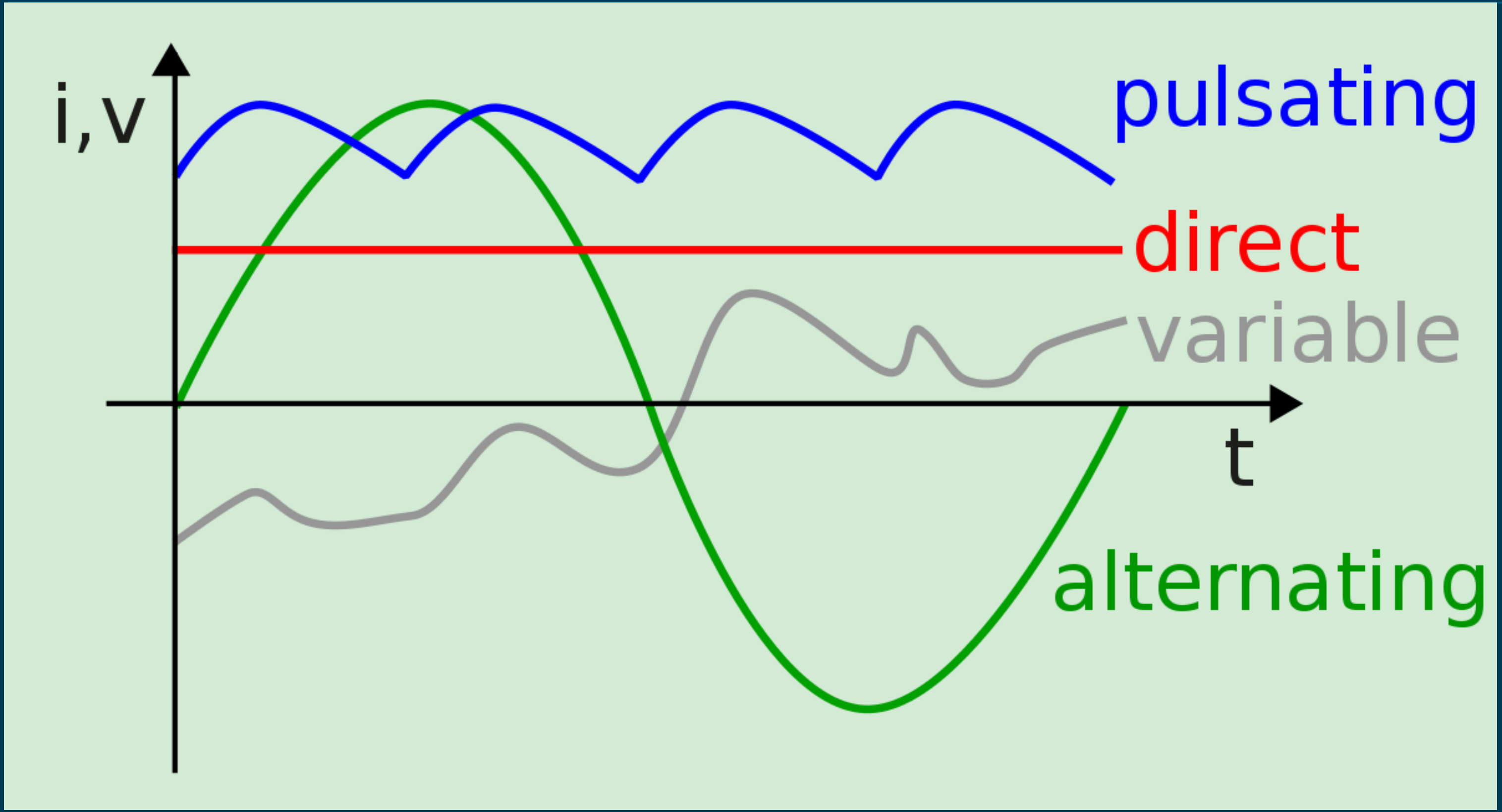
- All components have a power rating.
- It is important to calculate the maximum current through a device to make sure that you won't exceed the power rating.
- If you do exceed the rating, the component will not be able to dissipate all of the heat. It will breakdown and explode.
- It is important to oversize your components so that they do not fail.

- Many also have a voltage rating that you cannot exceed!

PROBLEMS

AC & DC

Current/Voltage Waveforms



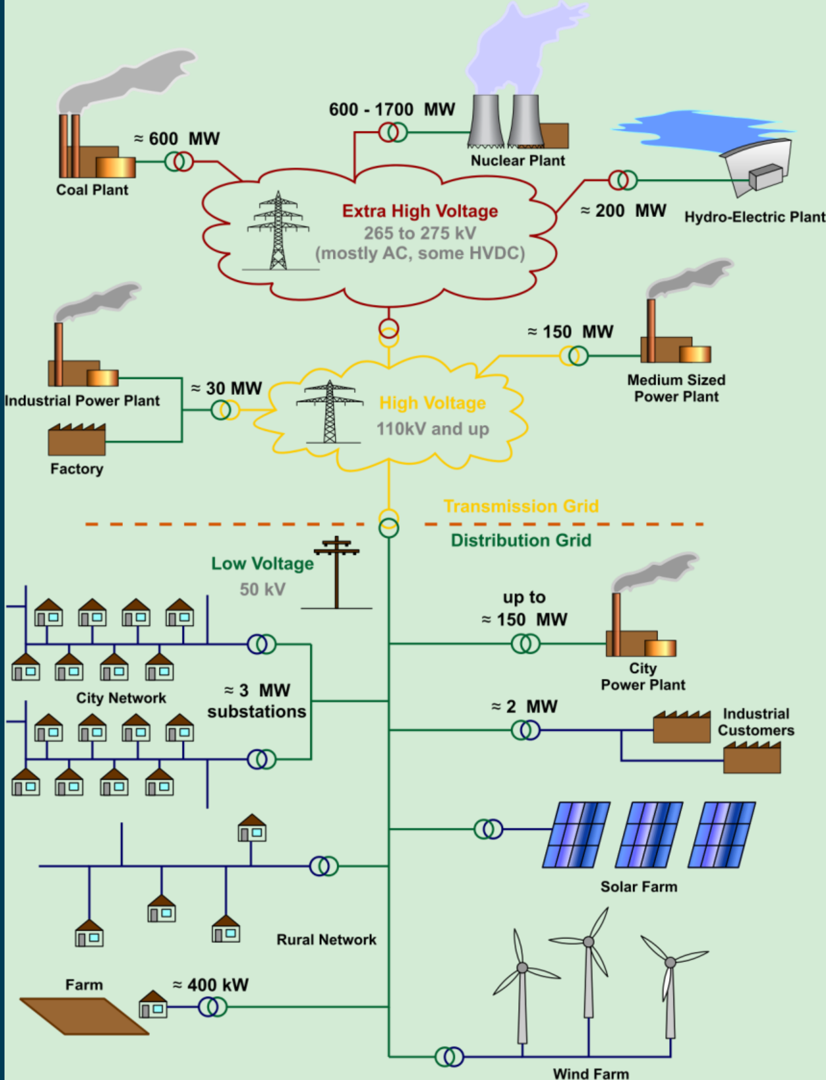
Direct Current (DC)

- Current with a unidirectional flow of an electric charge.
  - Does not change polarity or direction.
  - Always positive or always negative.
- Uses
  - Charging batteries
  - Powering electronics
  - Vehicles
  - Digital logic and communication

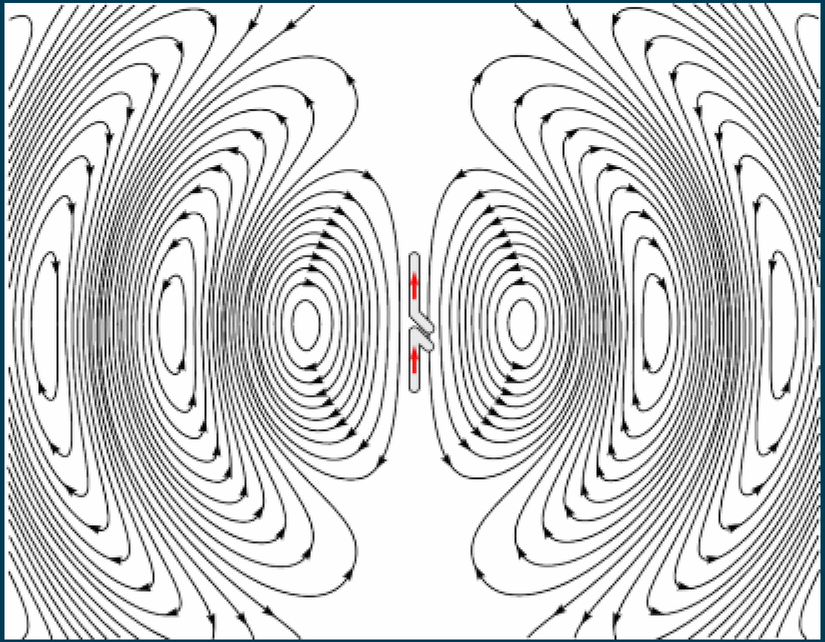
Alternating Current (AC)

- Current with a bidirectional flow of an electric charge.
  - Changes direction.
- Uses:
  - Power generation
  - Power transmission
  - Transforming power
  - Radio waves

- AC/DC Boundary is the home.

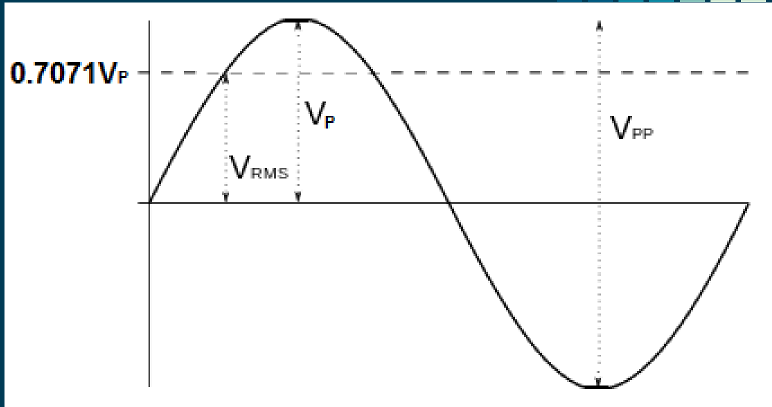


AC – Radio Waves



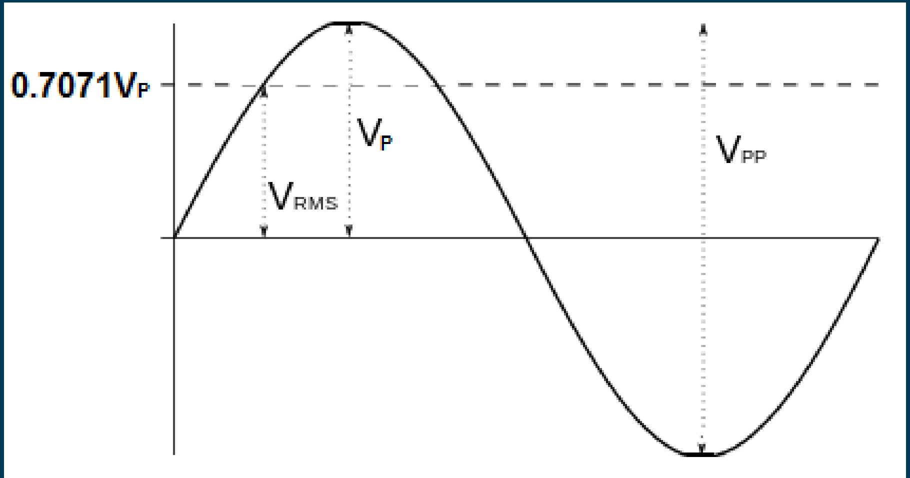
Measuring AC

- How do we measure AC voltage/current?
- The current/voltage levels are constantly changing.
- V_p Peak – max peak from from reference
- V_{pp} Peak-to-Peak – value from max to min
- V_{rms} RMS – root mean square
- The RMS voltage is the square root of the mean over one cycle of the square of the instantaneous voltage.



RMS Voltage

- $V_p = \sqrt{2}\, V_{rms}$; $V_{rms} = \frac{V_p}{\sqrt{2}}$;
- $V_{pp} = 2\, V_p$; $\sqrt{2} = 1.4142$; $\frac{1}{\sqrt{2}} = .7071$
- House voltage is 120 Vrms. So Vp is 169.7
- That's why AC hurts more! Higher voltage and current reversing



ADDITIONAL ACTIVITIES

Activity: LED Tester

- Goal: Build a portable LED Tester.
- Requirements:
  - Should be powered by a 9V battery.
  - Should allow for easy plug in of LEDs to make sure they work.
- Stretch Goals:
  - Try adding an active buzzer to emit a tone if the LED works.

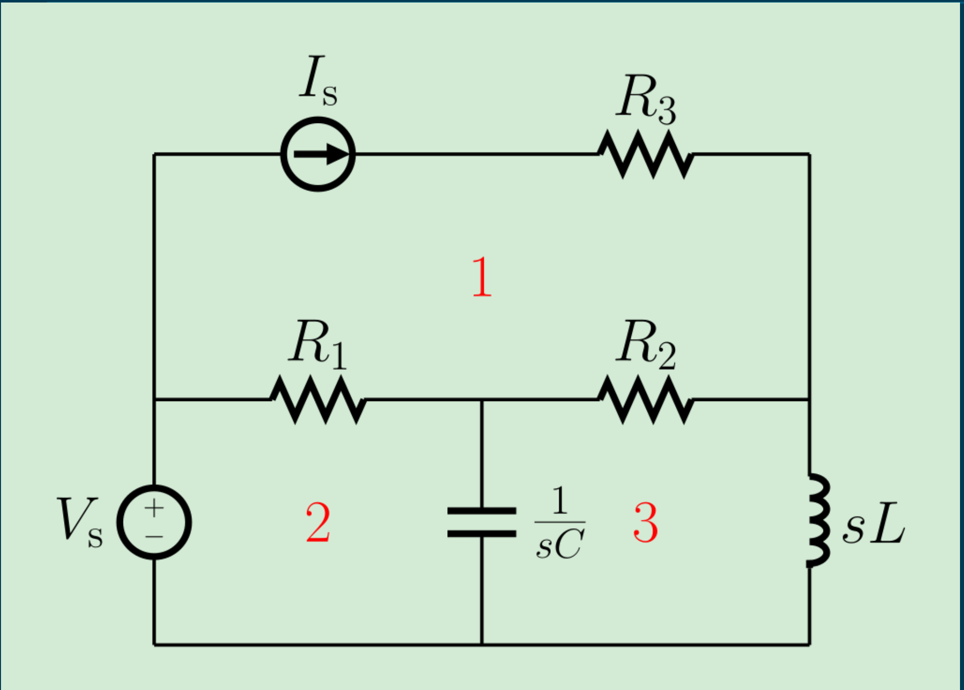
Activity: Continuity Tester

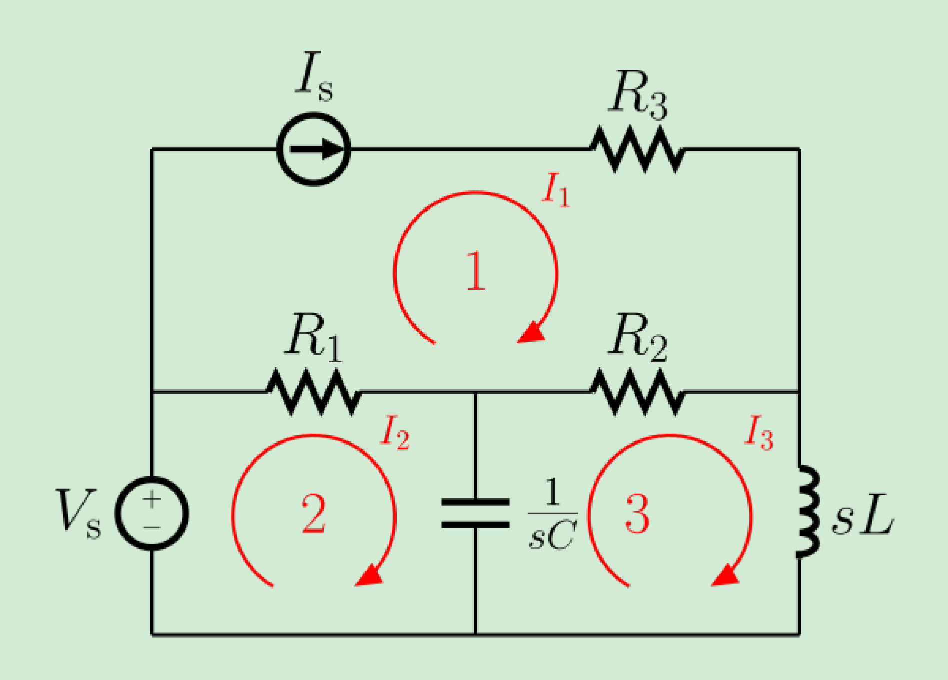
- Goal: Build a portable continuity tester.
- Requirements:
  - Should be powered by a 9V battery.
  - Should allow for easy connection to circuit.
  - Should turn on LED if there is continuity between 2 points.
- Stretch Goals:
  - Try adding an active buzzer to emit a tone if the LED works.

ADDITIONAL NOTES

MESH ANALYSIS

Identifying Loops and Mesh





Mesh Analysis

1. Label all of the loops in the circuit.
2. Label the voltage source and voltage drop polarities.
3. Label the mesh currents in a clockwise direction.
4. Write equations for each loop by summing voltages.
   - Use known voltages.
   - If not known, use mesh current to calculate.
5. Solve equations for unknown currents.
   - If you have the same number of unknowns as you do equations, it is solvable.
   - If you have more unknowns then equations, it is unsolvable.

NODAL ANALYSIS

Nodal Analysis

1. Label all of the nodes in the circuit.
2. Label the voltage source and voltage drop polarities.
3. Write equations for each loop by summing voltages.
4. Solve equations for unknowns.
   - If you have the same number of unknowns as you do equations, it is solvable.
   - If you have more unknowns then equations, it is unsolvable.

OTHER THEOREMS

Additional Theorems

- There are many additional theorems used to simplify complex circuits into easier equivalent circuits.
  - Typically they are used to simplify circuits that have multiple current or voltage sources.
- Superposition, Thevenin, Norton.