Studio Week 6
Simple Loops

Picture credit: jenwlee.com.

Principles for Success

- **Treat everyone with respect.**
- **Learn by doing and questioning.**
- **Everything should make sense.**

Circuits Rules

The Loop Rule

- The voltages around a complete loop add to zero.

$$\sum V = 0$$

The Junction Rule

- At a junction, the sum of the incoming currents must equal the sum of the outgoing currents.

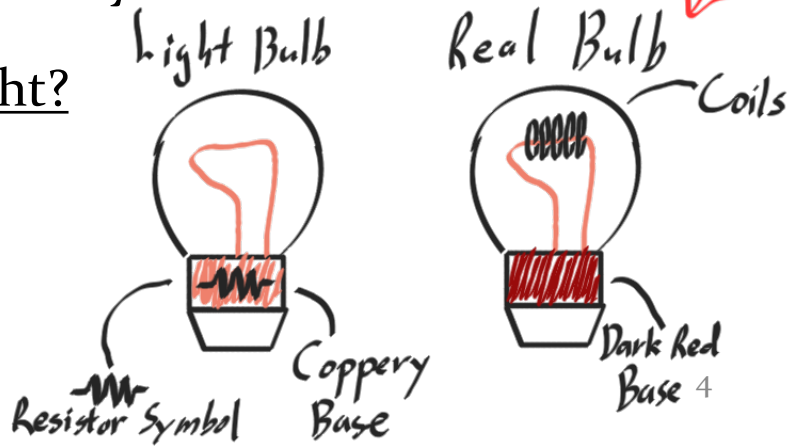
$$\sum I_{in} = \sum I_{out}$$

PhET Simulation

- Everyone open the simulation below:

https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

- In the Lab tab, start by **unchecking** the box that says Show Current
- Then click on the Advanced button on the right and check the box that says **Add Real Bulbs** (use real bulbs throughout today's activities)
- Now make a circuit with a single battery and a single light bulb. This will be a reference that we use for all of today's activities.
- Why do you think the light bulb is bright?



PhET Simulation

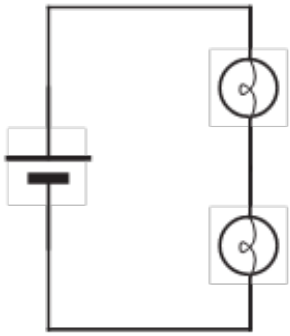
- Everyone open the simulation below:

https://phet.colorado.edu/en/simulation/circuit-construction-kit-dc

- In the Intro tab, start by **unchecking** the box that says Show Current
- Now make a circuit with a single battery and a single light bulb. This will be a reference that we use for all of today's activities.
- Why do you think the light bulb is bright?

1. **A flow of *electric current* exists in a complete circuit.**
2. **For identical bulbs, bulb brightness can be used as an indicator of the amount of current through that bulb: the brighter the bulb, and the greater the current.**

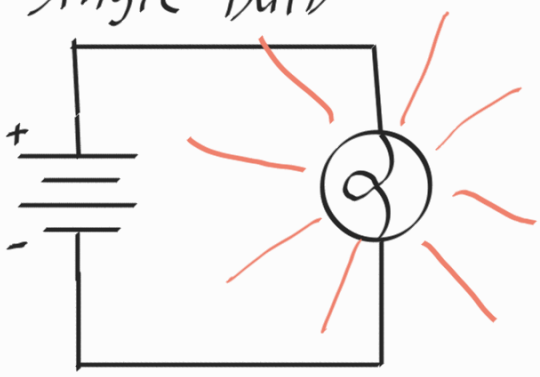
Activity 6-1



1. Set up a two-bulb circuit in the program with identical bulbs connected one after the other as shown (leave your one-bulb circuit set up). Bulbs connected in this way are said to be connected in *series*.
2. Compare the brightness of the two bulbs with each other.
   A. Is current "used up" in the first bulb, or is the current the same through both bulbs?
   B. On the basis of your observations alone, can you tell the direction of the flow through the circuit?
3. Compare to the single-bulb circuit.
   A. How does the current compare to the single-bulb circuit? Explain.
   B. What does your answer imply about how the current through the battery in the two circuits compares? Explain.
4. We may think of a bulb as presenting an obstacle, or resistance, to the current in the circuit.
   A. Thinking of the bulb in this way, would adding more bulbs in series cause the total obstacle to the flow, or total resistance, to increase, decrease, or stay the same as before?
   B. Formulate a rule for predicting how the current through the battery would change if the number of bulbs connected in series increases or decreases.
   C. Check your prediction using the program.
5. Sketch a voltage diagram for this circuit.
   A. How do you think the voltages across the bulbs compare to each other?
   B. How do you think the voltages compare to the single-bulb voltage?

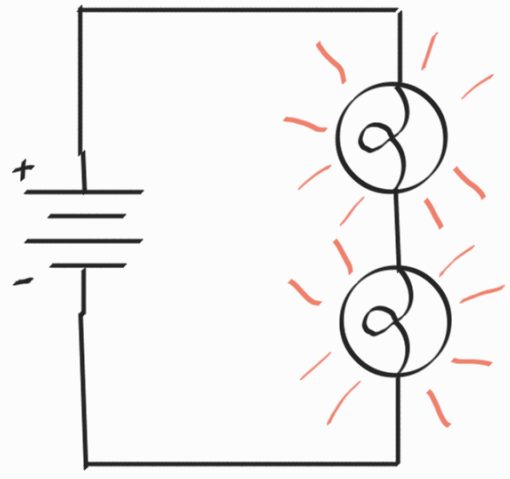
6-1 Bulbs in Series

Single Bulb



2A) The bulbs have the same brightness, so they should have the same current. Current is not "used up." If less current left the bulb than entered it, then conservation of charge would imply that charge is building up in the bulb which would quickly make a massive (detectable) electric field.

Two Bulbs



2B) We cannot tell just from our observations which way the current is going. That would require very sophisticated experiments.

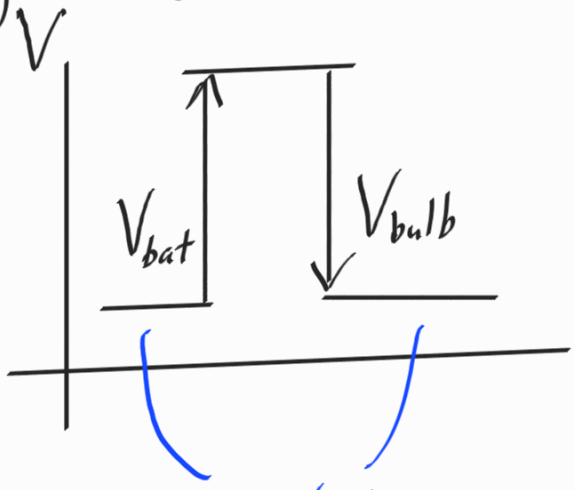
3A) The bulb is brighter in the single-bulb circuit, so that bulb has more current.

3B) The current passing through the bulbs must pass through the battery, so the current through the battery is higher in the single-bulb circuit. Batteries (ideally) have a fixed voltage, but can provide any current the circuit allows (so long as it is not so high that the battery bursts into flame — try to make the simulation do that!).

4) More bulbs means more obstacles (like beavers placing more and more dams along a river), so the resistance will increase and the current will decrease.

5)

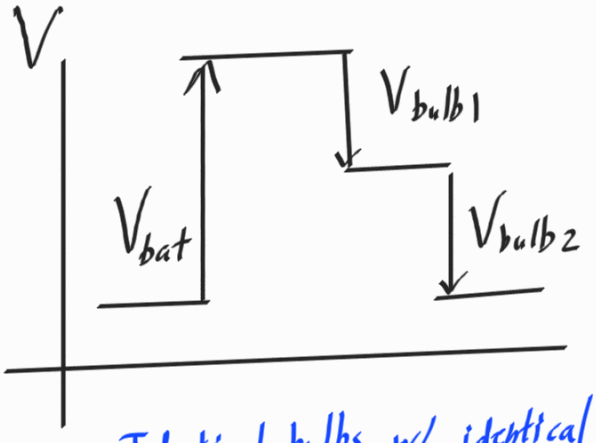
Single Bulb



Begin/end at same V

$\Rightarrow V_{bulb} = -V_{bat}$

Two Bulbs



Identical bulbs w/ identical brightness

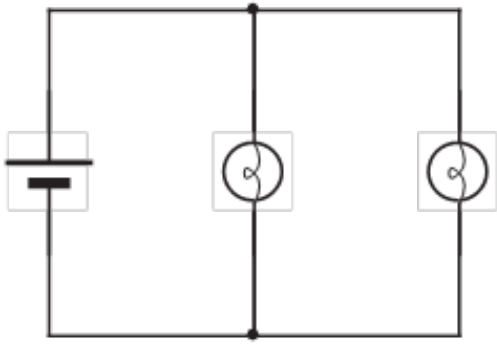
$\Rightarrow V_{bulb1} = V_{bulb2}$

$V_{bat} = -V_{bulb1} - V_{bulb2}$

$= -2V_{bulb\,(1\text{ or }2)}$

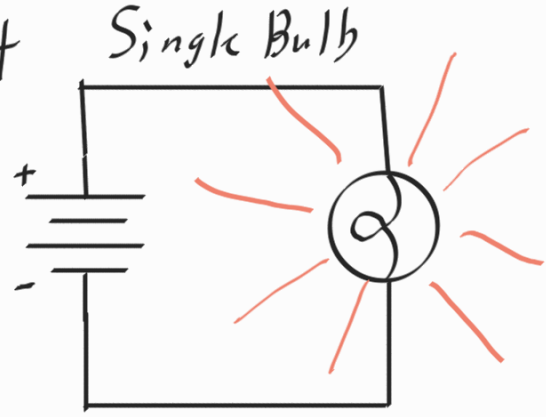
The bulbs in the two-bulb circuit have half of the voltage of the bulb in the one-bulb circuit.

Activity 6-2

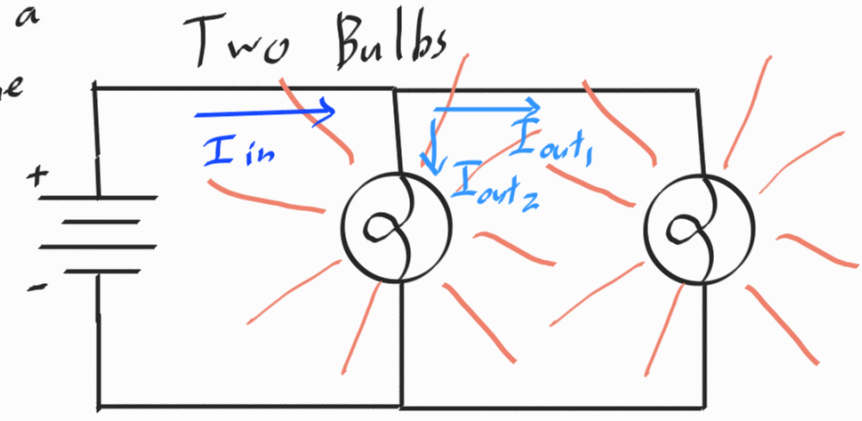


1. Set up a two-bulb circuit with identical bulbs so that their terminals are connected together as shown. Bulbs connected together in this way are said to be connected in *parallel*.
2. Compare the brightness of the bulbs in this circuit.
   - A. What can you conclude from your observation about the amount of current through each bulb?
   - B. Describe the current in the entire circuit. In particular, how does the current through the battery divide and recombine at the junctions?
   - C. Is the brightness of each bulb in the two-bulb parallel circuit *greater than, less than,* or *equal to* that of a bulb in a single-bulb circuit?
   - D. How does the amount of current through a battery connected to a single bulb compare to the current through a battery connected to a two-bulb parallel circuit?
3. Formulate a rule for predicting how the current through the battery would change if the number of bulbs connected in parallel were increased or decreased. Base your answer on your observation of the behavior of the two-bulb parallel circuit and the model for current.
   - A. What can you infer about the *total resistance of a circuit* as the number of parallel branches is increased or decreased?
4. Sketch voltage diagrams for each branch of this circuit. What can you learn from these diagrams?

6-2 Parallel-Bulb Circuit



2A) The bulbs have the same brightness, and therefore the same current.



2B) The current entering a junction is equal to the current leaving, so some I_{in} leaves the battery, splits in half at the first junction ($I_{out_1} = I_{out_2}$) to pass equally through the two bulbs, then recombines at the second junction to return to the battery.

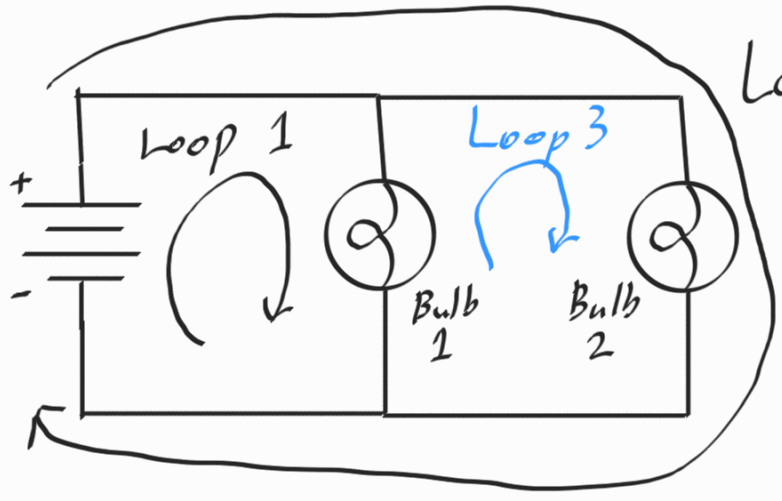
2C) The brightness (and therefore the current) is the same through the bulbs in the different circuits.

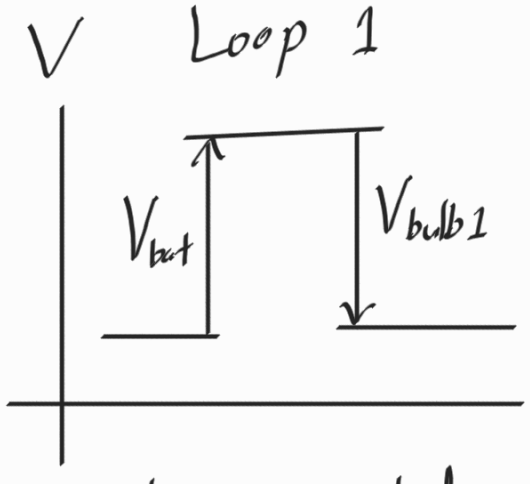
2D) Since the currents through the parallel bulbs are individually the same as the current through the single bulb, there must be twice as much current through the battery in the parallel-bulb circuit.

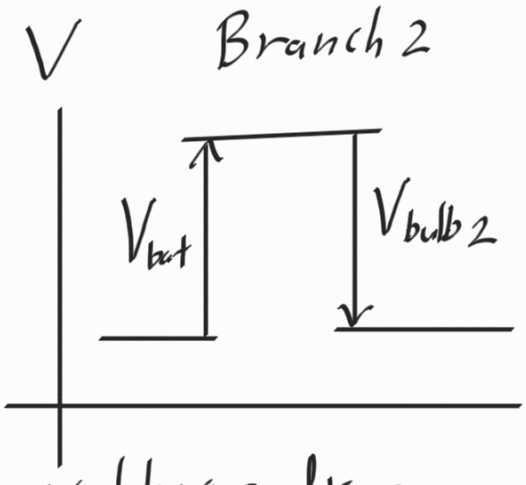
3) Adding more bulbs in parallel increases the current through the battery, so the equivalent resistance of the circuit decreases.

We have more branches for current to go down, like opening more lanes on the freeway or more checkout counters at the grocery store; current can flow more easily with more ways to go through the circuit.

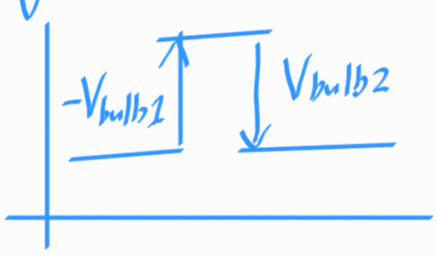
4)







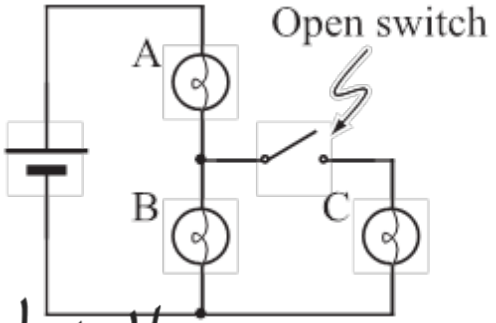
The magnitude of the voltage drop of each bulb must equal the voltage of the battery, so the two bulbs have the same voltage drop.

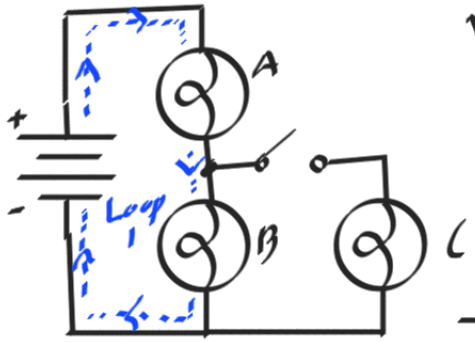


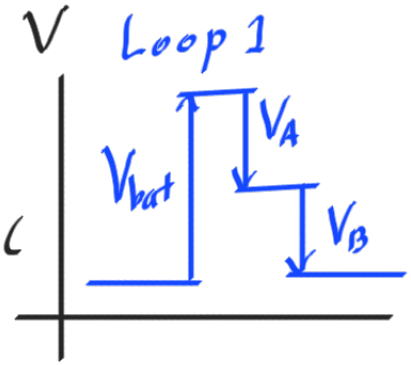
You can do this with the loop through the two bulbs, finding the same thing. Just remember that going against current through a bulb reverses the sign of its voltage change.

Interlude

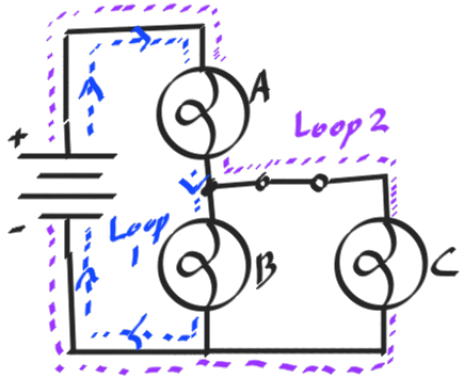
- Predict how bulbs A and B will change in brightness when we close the switch!

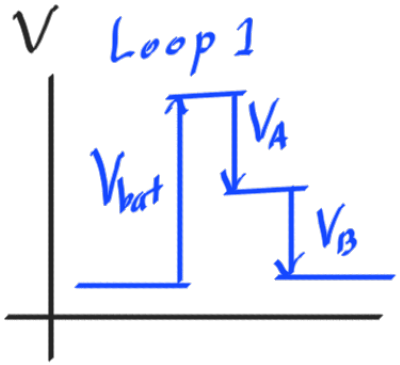


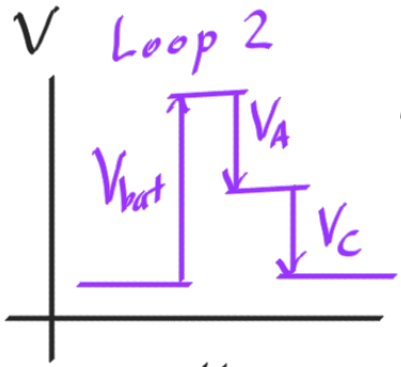




A certainly gets brighter, as B & C in parallel lower the resistance and allow more current to flow from the battery (and thus through A).







We need to add more to our model to predict what B does. The total current increases, but then is divided in half. That could mean more or less brightness, depending on how much the battery current increases.

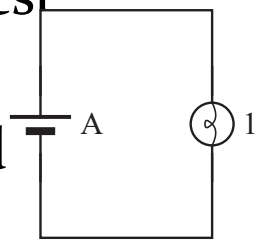
B actually dims — the current from the battery did not double, so the half of the new battery current that goes through B is less than the original current through B.

But why?

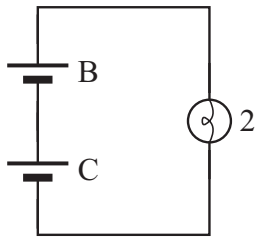
For all of the next activities, predict before checking against the simulation.

Activity 6-3

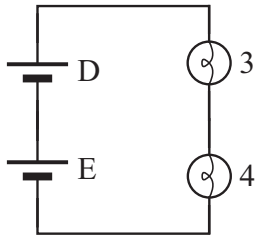
1. **Predict**: rank the brightness of the four bulbs shown at right from greatest to least.
2. Now use the simulation to set up and observe the circuits!
   a. Is the current through battery D *greater than, less than,* or *equal to* the current through battery A? Explain how you can tell.
   b. Is the current through battery B *greater than, less than,* or *equal to* the current through battery A? Explain how you can tell.
   c. Draw voltage diagrams for each circuit.
   d. Rank the bulbs according to *absolute value of the voltage across the bulb,* from largest to smallest.
   e. How does the ranking of the bulbs according to voltage compare to that according to brightness?



Circuit I



Circuit II



Circuit III

6-3 Changing Source Voltage

1) Warning: What follows for part 1 is just my prediction and my reasoning. It is not inherently better than your prediction, and it should not be taken as scientific fact.

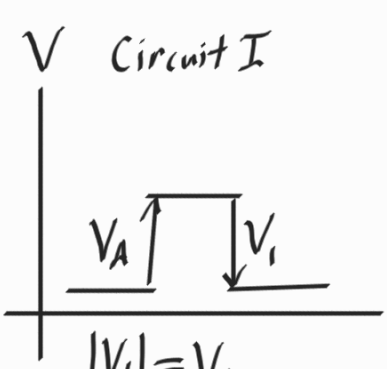
Prediction: One intuitive ranking would be to guess that using two batteries to power a single bulb would make it brighter. Similarly, putting a two-bulb load on the same two batteries might result in less brightness, since the batteries have twice as many bulbs to light. It might be the case that the two bulbs powered by two batteries will be as bright as the single bulb powered by the single battery, since circuit III doubles the source and the load.

Summary: Bulbs 1, 3, 4 same brightness; 2 more brightness.

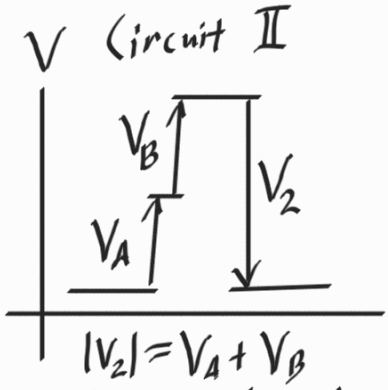
2A) Observing that bulbs 1, 3, and 4 have the same brightness, and knowing that the current through them is the same as the current through the batteries (there are no alternative branches for the current to split across), it must be that the currents through batteries A and D are the same.

2B) Bulb 2 is brighter than bulb 1, so it has more current going through it. Since the single loop of circuit II has more current than the single loop of circuit I, battery B has more current than battery A.

2C)



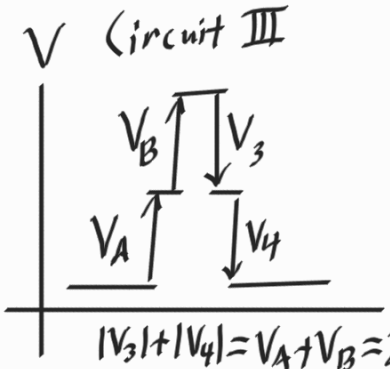
$|V_1| = V_A$



$|V_2| = V_A + V_B$

Batteries identical $\Rightarrow V_A = V_B$

$\Rightarrow |V_2| = 2V_A$



$|V_3| + |V_4| = V_A + V_B = 2V_A$

Bulbs identical & same brightness

$\Rightarrow |V_3| = |V_4| = V_A$

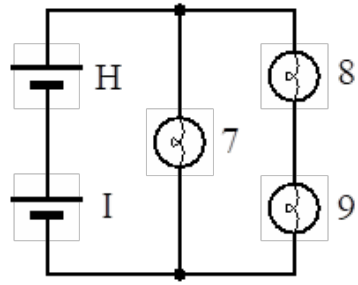
2D) $|V_1| = |V_3| = |V_4| < |V_2|$

2E) The voltage ranking is the same as the brightness ranking.

Model for Circuits

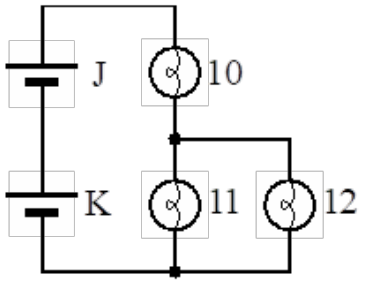
1. **A flow of *electric current* exists in a complete circuit.**
2. **For identical bulbs, bulb brightness can be used as an indicator of the amount of current through that bulb: the brighter the bulb, and the greater the current.**
3. **The brightness of a bulb is not only an indicator of the current through a bulb but also an indicator of the voltage (potential difference) across it.**

Activity 6-4



Circuit V

1. Consider circuit V, shown at right (do not set up the circuit yet).
   a. Sketch a voltage diagram for each branch of the circuit.
   b. Rank the bulbs according to the absolute value of the voltage across each bulb, from largest to smallest. Explain.
   c. Create this circuit and check your predictions!

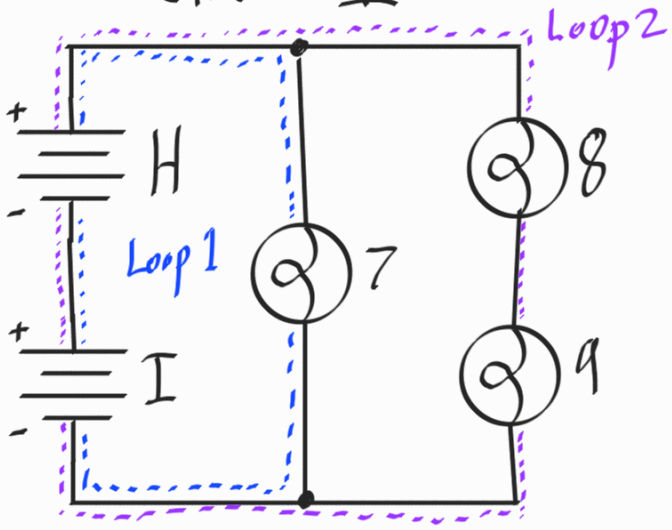


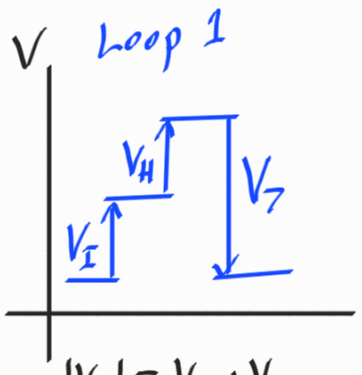
Circuit VI

2. Consider circuit VI, shown at right (do not set up the circuit yet).
   a. Sketch a voltage diagram for the circuit.
   b. Rank the bulbs according to the absolute value of the voltage across each bulb, from largest to smallest. Explain.
   c. Create this circuit and check your predictions!
3. **Challenge—Which bulb is brighter: 11 or 9?**

6-4 Three-Bulb Circuits

Circuit V

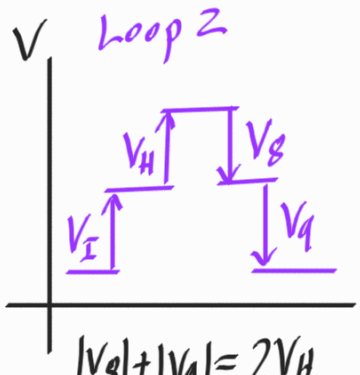




$|V_7| = V_H + V_I$

Identical Batteries $\Rightarrow V_H = V_I$

$\Rightarrow |V_7| = 2V_H$

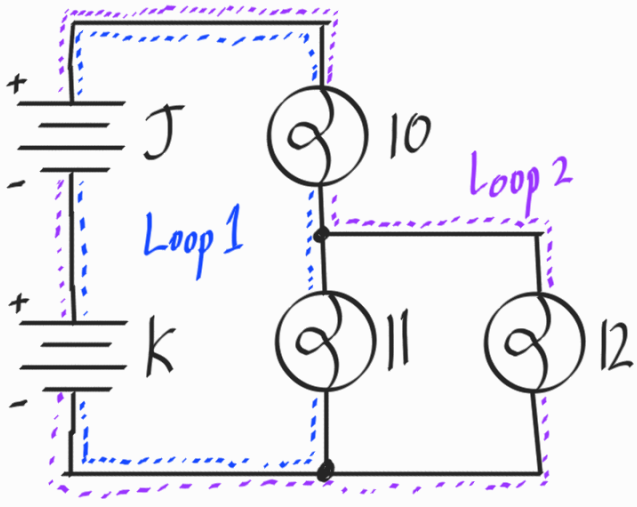


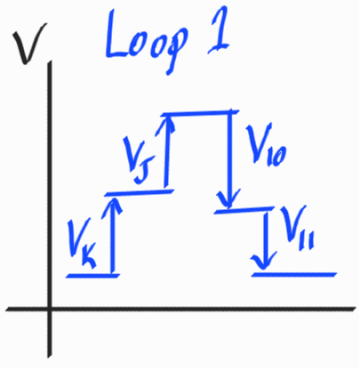
$|V_8| + |V_9| = 2V_H$

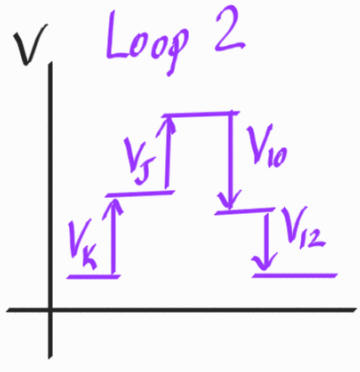
Bulbs in series
$\Rightarrow$ same current
$\Rightarrow$ same brightness
$\Rightarrow |V_8| = |V_9| = V_H$

$|V_7| > |V_8| = |V_9|$

Circuit VI







Bulbs 11 & 12 in parallel
$\Rightarrow |V_{11}| = |V_{12}|$
$\Rightarrow$ same brightness
$\Rightarrow$ same current

Current through 10 is twice the current through 11 or 12
$\Rightarrow$ 10 is brighter
$\Rightarrow$ 10 has a larger voltage

$|V_{10}| > |V_{11}| = |V_{12}|$

Challenge: All batteries are identical, so $V_H = V_I = V_J = V_K$.

$\Rightarrow 2|V_9| = 2V_H = 2V_J = |V_{10}| + |V_{11}|$

$|V_{10}| > |V_{11}|$, therefore $|V_{11}| < V_H$.

$\Rightarrow |V_{11}| < |V_9|$

$\Rightarrow$ Bulb 9 is brighter than bulb 11.