Studio Week 7
Complicated Loops

```
233         for (i = 0; i < ancestors.length; i++) {
234           var plan = ancestors[i];
235           var firstCommon = ReactTreeTraversal.getLowestCommonAncestor(
236             getInst(plan.one),
237             getInst(plan.two),
238           );
239           expect(firstCommon).toBe(getInst(plan.com));
240         }
241       });
242     });
243   });
```

Picture credit: medium.com.

Principles for Success

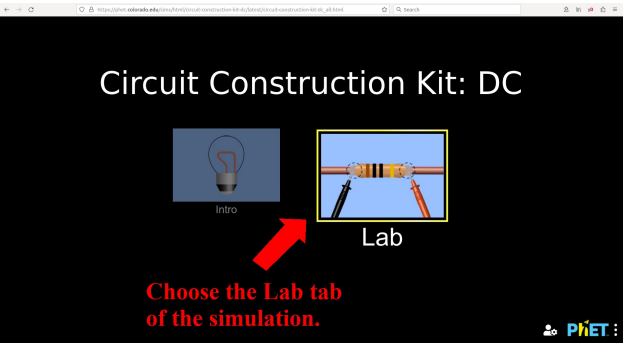
- **Treat everyone with respect.**
- **Learn by doing and questioning.**
- **Everything should make sense.**

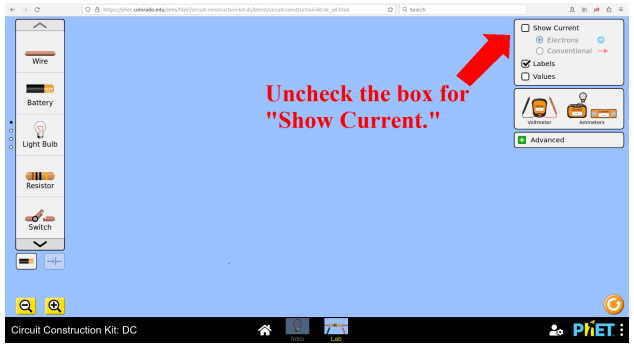
PhET Simulation

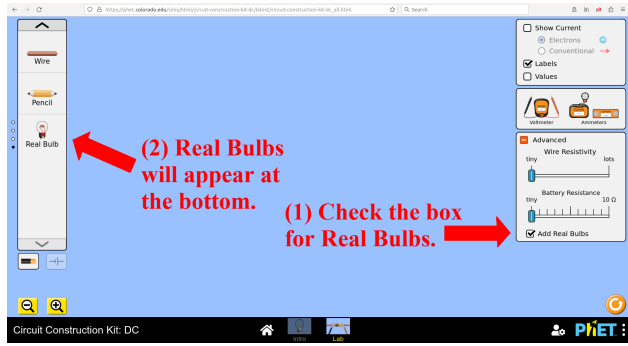
- Everyone open the simulation below:

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)

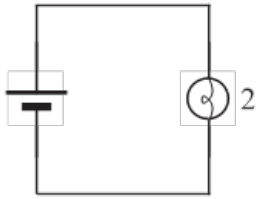




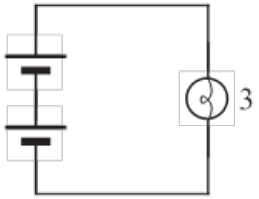


Activity 7-1

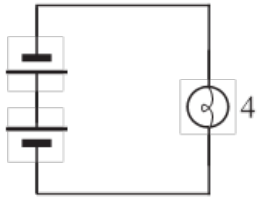
A. Consider the circuits at right. *Predict* the ranking of the bulbs according to brightness, from brightest to dimmest. If any bulbs have the same brightness or do not light, state so explicitly. Explain.
   - After you have made a prediction, construct the circuit in the simulation and check your prediction.



Circuit II

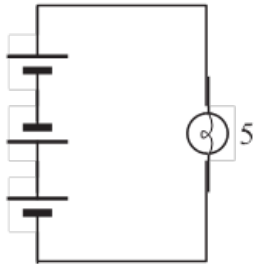


Circuit III



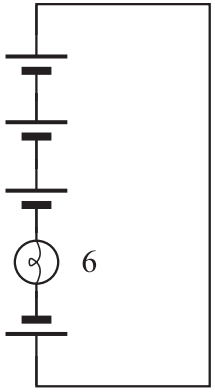
Circuit IV

B. Predict whether the brightness of bulb 5 in the circuit at right will be the same as that of any of the bulbs in the circuits in part A. If so, which bulb(s)? Explain. If not, explain why not.
   - After you have made a prediction, construct the circuit in the simulation and check your prediction.



Circuit V

C. Predict whether the brightness of bulb 6 in the circuit at right will be the same as that of any of the bulbs in the circuits in part A. If so, which bulb(s)? Explain. If not, explain why not.
   - After you have made a prediction, construct the circuit in the simulation and check your prediction.

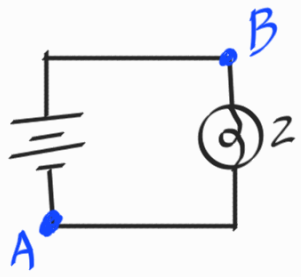


Circuit VI

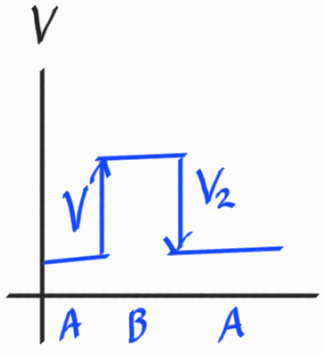
If you have not already done so, draw a voltage diagram for each circuit. Make sure your diagrams agree with your observations!

7-1 Batteries Galore

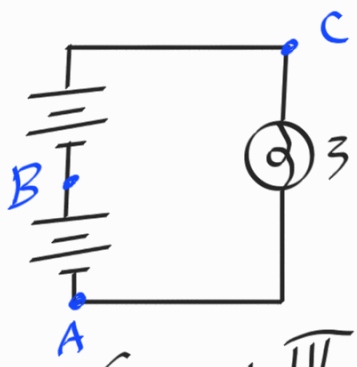
A)



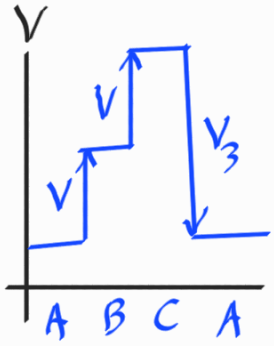
Circuit II



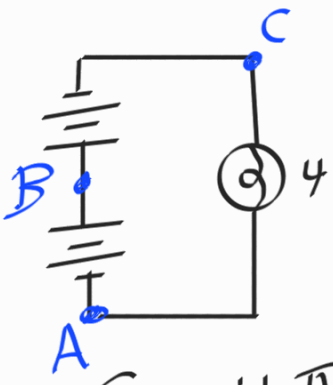
$|V_2| = V$



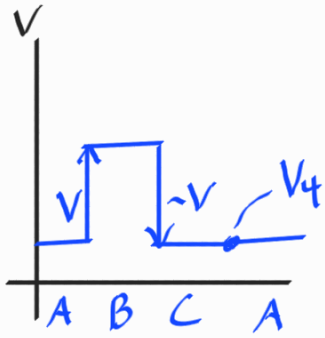
Circuit III



$|V_3| = 2V$



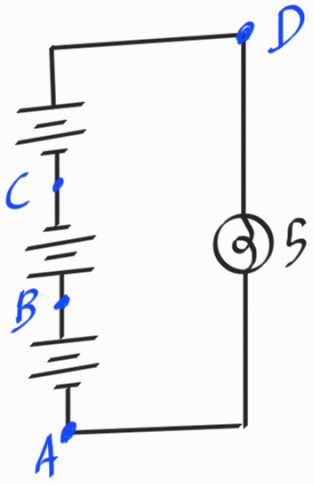
Circuit IV



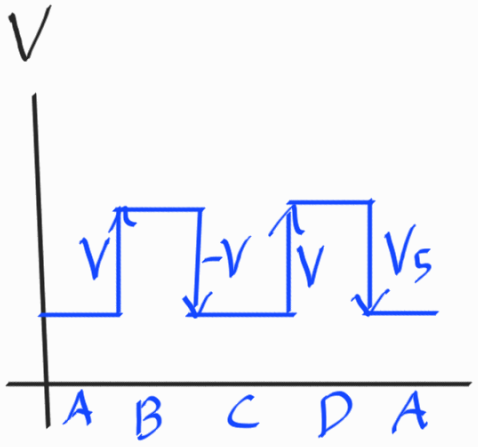
$V_4 = 0$

Bulb 3 will be brightest (as it has the highest magnitude of voltage across it), bulb 2 will be dimmer, and bulb 4 will not light (as the wires on either side of it are at the same potential; no charge is compelled to flow across the bulb).

B)



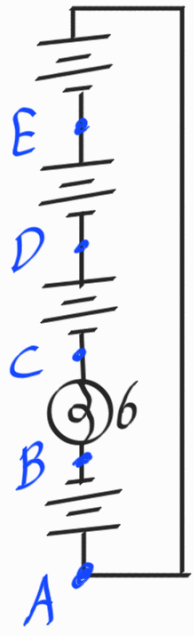
Circuit V



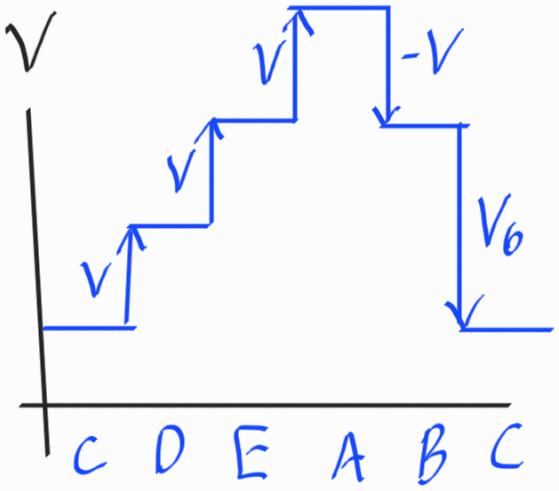
$|V_5| = V$

Bulb 5 is as bright as bulb 2, as it has the same magnitude of voltage across it.

c)



Circuit VI



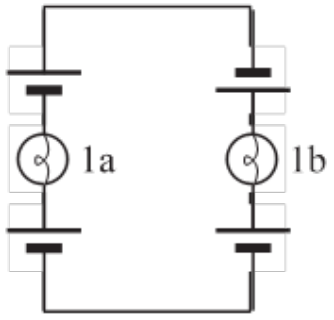
$|V_6| = 2V$

Bulb 6 will be as bright as bulb 3, as it has the same magnitude of voltage across it.

Activity 7-2

1. Consider the following incorrect predictions about the behavior of the circuit at right.
   - Student 1: *"Bulbs 1a and 1b are in parallel branches. Since bulb 1a is connected to both a positive and a negative battery terminal, the left branch is a complete circuit and bulb 1a will light. The right branch isn't, so bulb 1b won't light."*
   - Student 2: *"I agree. Bulb 1b won't light because it is connected to two positive terminals. Since both positive terminals must be at the same potential, there's no potential difference across bulb 1b and it won't light."*

   Identify the flaw(s) in each student's reasoning. Explain.



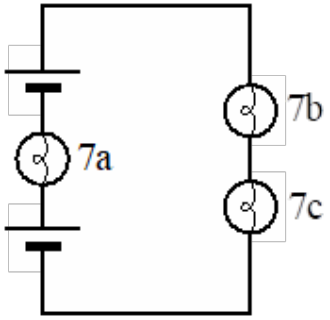
Circuit I

2. Before setting up the circuit shown at right, a student makes the following prediction:

   "Bulb 7a gets all of the potential difference of one battery, while bulbs 7b and 7c have to share the potential difference from the other battery. So, bulb 7a will be the brightest."

   Do you agree or disagree with this prediction? Explain.

3. Construct the circuit in the simulation to check whether or not the student's prediction is correct!
4. If you have not already done so, draw a voltage diagram for this circuit. Make sure your diagram agrees with your observations!



Circuit VII

7-2 Logic Evaluation

1) Student 1 says the bulbs are in parallel branches, but these bulbs exist in series along a single loop. There are no junctions to make parallel branches. Also, the student equates completeness of a circuit to a bulb being linked to a positive and negative battery terminal on either side, but that is not a correct characterization. A closed circuit is one with an uninterrupted loop in which charge carriers can flow.

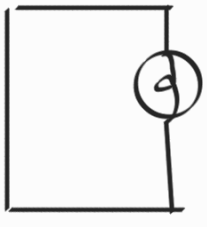
Examples

Open

Current cannot flow

Closed

Current could flow, but there is no battery to drive it.



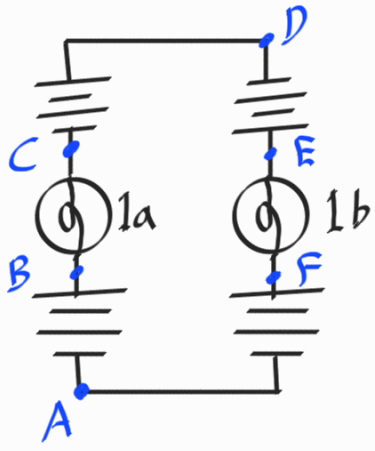
Student 2 says that the two positive battery terminals to either side of bulb 1b are at the same potential, but that isn't necessarily true. Both batteries have the

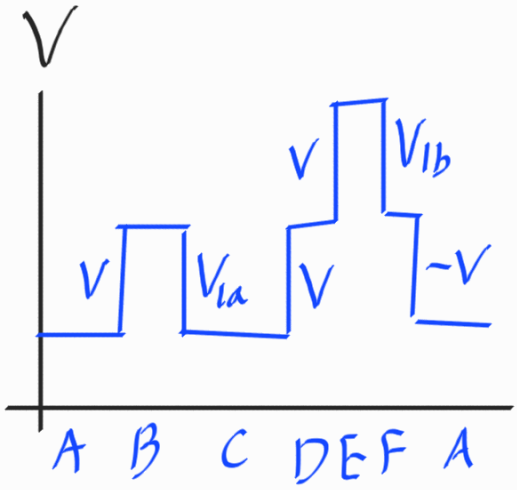
same voltage difference from the negative terminal to the positive terminal, but that doesn't mean the positive terminals have to be at the same potential.

Analogy

If I am 6 feet and 2 inches tall, and another 6'2" person stands on a chair next to me, our heads are not at the same height.

Both bulbs are in series in a single loop, so if one lights, they both must light (and at the same brightness, since they have the same current).

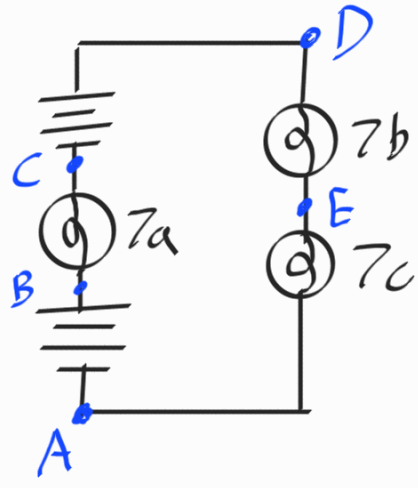


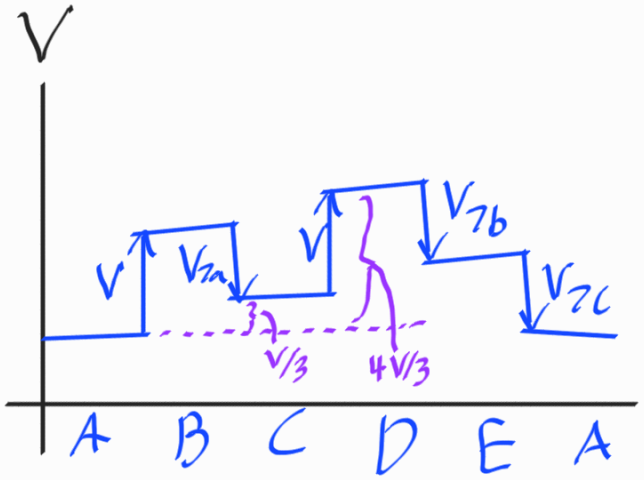


2) Bulbs 7a, 7b, and 7c are all in series, so they must have the same current (and thus the same voltage and brightness), so the prediction is incorrect.

Once again this relies on a faulty premise that the positive terminals of the two batteries lie at the same voltage.

4)





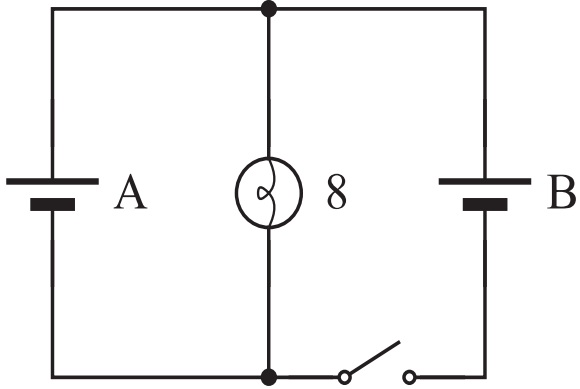
$$V + V_{7a} + V + V_{7b} + V_{7c} = 0$$

$$2V + \underbrace{V_{7a} + V_{7b} + V_{7c}}_{3\,V_{7a}\ (\text{or } 7b \text{ or } 7c)} = 0$$

$$V_{7a} = -\frac{2}{3}V$$

Interlude

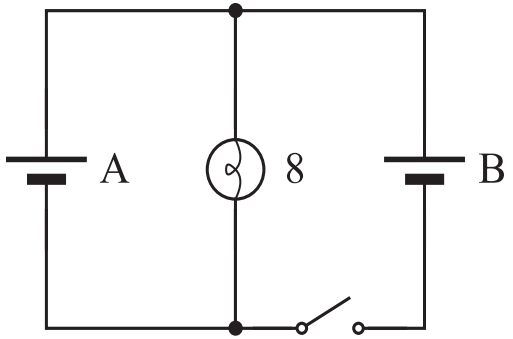
- Predict whether the brightness of light bulb 8 will *increase*, *decrease*, or *remain the same* when we close the switch.



Circuit VIII

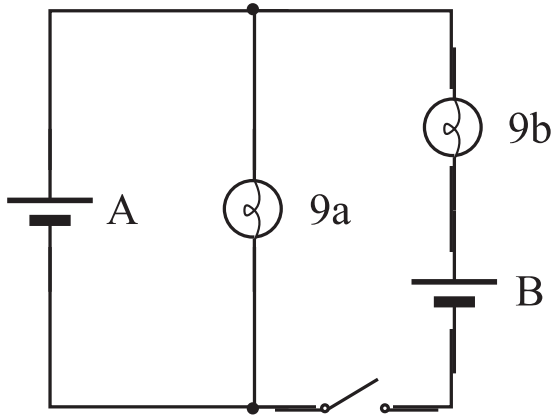
Activity 7-3

1. What did you observe when the switch was closed in circuit VIII?
   a. Why do you think this happens?
   b. When the switch is closed, does the current through <u>battery A</u> *increase, decrease,* or *remain the same?*



Circuit VIII

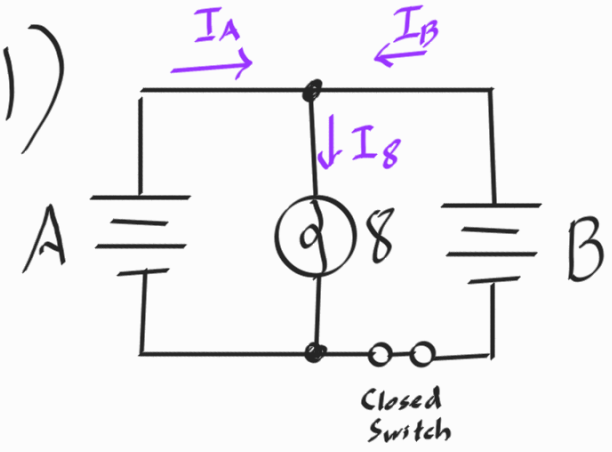
2. Suppose that a bulb, bulb 9b, were added to circuit VIII, creating circuit IX.
   a. *Predict* whether the brightness of bulb 9a in circuit IX will *increase, decrease,* or *remain the same* when the switch is closed. Explain.
   b. *Predict* whether light bulb 9b will be *brighter, less bright,* or *the same brightness* as light bulb 9a when the switch is closed. Explain.
   c. Construct this circuit in the simulation and check your predictions.
   d. If you have not already done so, draw voltage diagrams for this circuit. Make sure your diagrams agree with your observations!



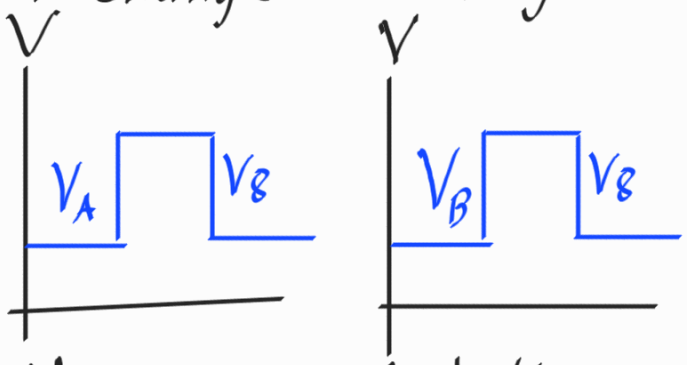
Circuit IX

7-3 Batteries in Parallel

1)



Closing the switch does not change the brightness!

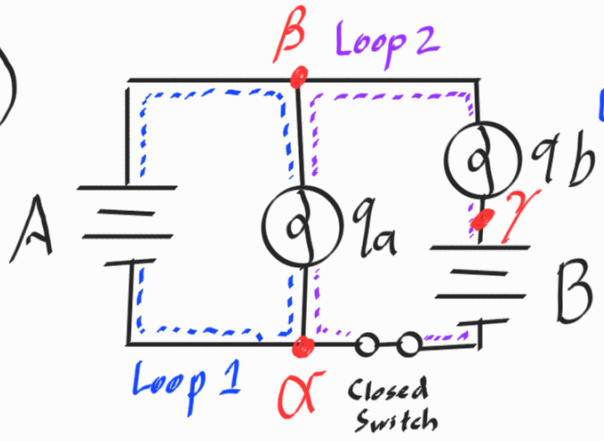


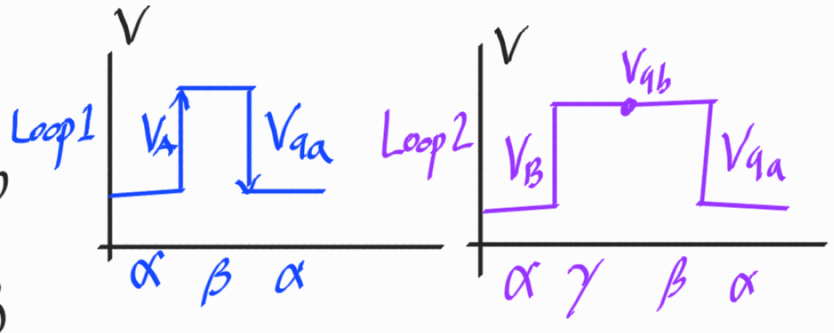
Since the bulb's brightness didn't change, its current didn't change either. The current through battery A decreases, as both batteries are now equally sharing the load.

Adding a second battery in parallel to the first does not add to the voltage across the bulb.

Junction rule: $I_A + I_B = I_g$

2)





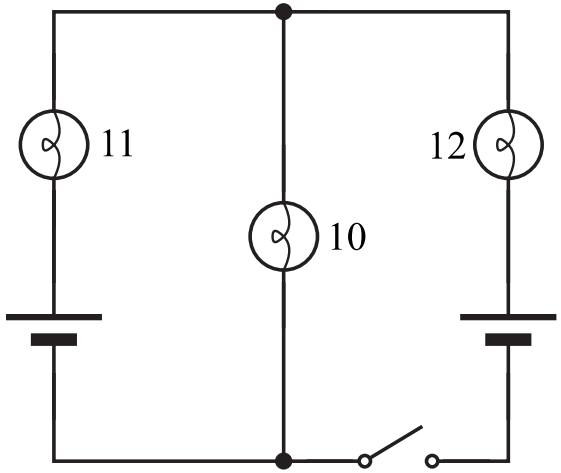
$|V_{qa}| = V_A$, no matter what, so closing the switch will not change the brightness of q_a.

V_A, V_B, and $|V_{qa}|$ are all the same, so $|V_{qb}| = 0$. With no voltage difference, q_b will not light.

Note that, unlike previously, I_A stays the same and $I_B = 0$.

Activity 7-4

- Suppose that another bulb is added, creating circuit X.

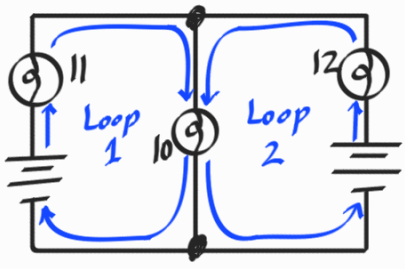


Circuit X

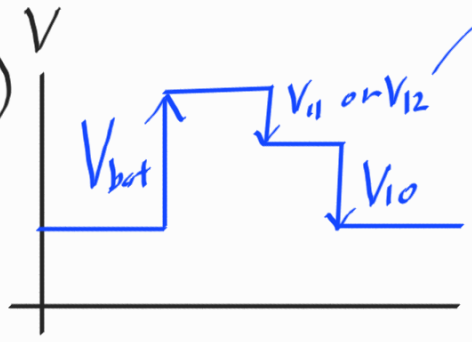
1. When the switch is <u>closed</u>:
   - *A.* *Predict* the relative brightness of the three light bulbs. Explain.
   - B. Construct this circuit in the simulation and check your predictions.
   - C. If you have not already done so, draw voltage diagrams for this circuit. Make sure your diagrams agree with your observations!
2. When you <u>open</u> the switch:
   - *A.* *Predict* how (if at all) the brightness of each light bulb will change. Explain.
   - B. Construct this circuit in the simulation and check your predictions.
   - C. If you have not already done so, draw voltage diagrams for this circuit. Make sure your diagrams agree with your observations!

7-4 Three Bulbs

1A) Bulb 10 will be brightest, as it has the combined currents of bulb 11 and bulb 12 going through it.



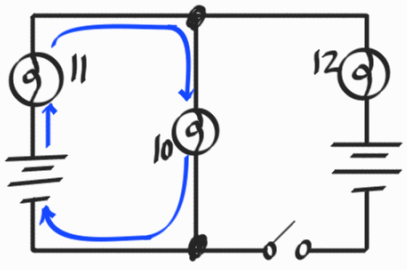
1C)



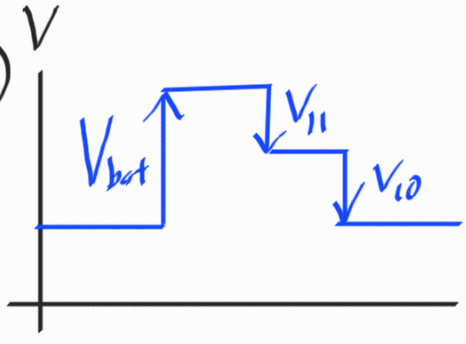
Since V_{bat} and V_{10} are the same in either loop, V_{11} and V_{12} must be the same to fill the same gap in the voltage diagrams.

Bulbs 11 and 12 will be equally bright.

2A) When the switch is opened, the circuit becomes a single loop, and bulbs 10 and 11 must share the same current and be equally bright. Bulb 12 is in an open circuit and will not light.



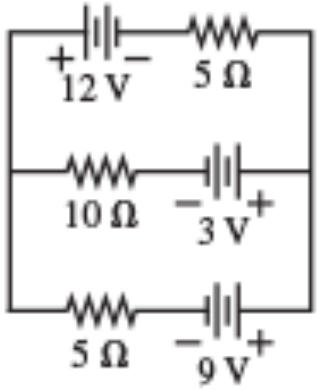
2C)



$V_{11} = V_{10}$

Bulb 10 must be dimmer than it was when the switch was closed (its voltage difference is smaller in magnitude), and bulb 11 gets brighter than before (its voltage difference is larger now).

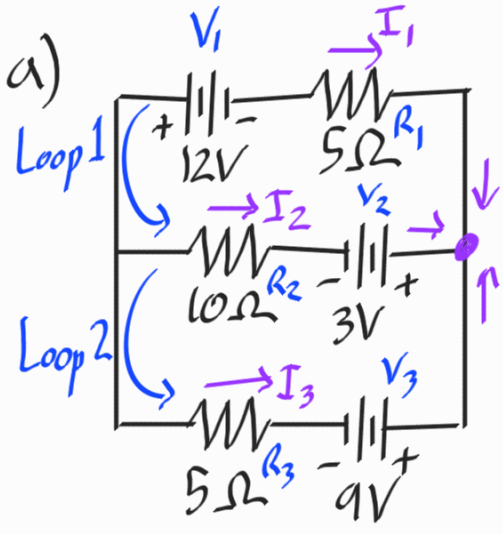
Activity 7-5



1. For the circuit at right, our objective is to find the current through each of the three resistors.
   a. Start by choosing a direction for the current through each resistor and labeling it on the circuit diagram.
   b. What do you think will happen if you accidentally choose the wrong direction?
   c. Write an equation relating the different currents you have drawn.
   d. Next, choose at least one loop and write down an equation expressing the Voltage Loop Law for that loop.
   e. How do you know whether to make the voltage across a resistor *positive* or *negative*?

7-5 Three Batteries and Three Resistors

a)



c) $0 = I_1 + I_2 + I_3$

3 currents entering, 0 currents leaving

b) If we pick the wrong direction for current, then we will find that the current comes out negative in our solution. No harm done.

d/e) Loop 1: $0 = V_1 - I_2R_2 + V_2 + I_1R_1$

$= 12V - I_2(10\Omega) + 3V + I_1(5\Omega)$

Negative because we are moving with the assumed current through the resistors.

Positive because we are moving against the assumed current in the resistors.

Loop 2: $0 = -I_3R_3 + V_3 - V_2 + I_2R_2$

$= -I_3(5\Omega) + 9V - 3V + I_2(10\Omega)$

Negative because we are moving from + terminal to −.

Symbolic Solution

$V_1 = 4V_2, \quad V_3 = 3V_2, \quad R_3 = R_1 = \frac{1}{2}R_2$

Loop 1: $0 = 4V_2 - I_2(2R_1) + V_2 + I_1R_1$

$= 5V_2 + (I_1 - 2I_2)R_1$

Loop 2: $0 = -I_3R_1 + 3V_2 - V_2 + I_2(2R_1)$

$= 2V_2 + (-I_3 + 2I_2)R_1$

Junction: $I_1 = -I_2 - I_3$

Loop 1 & Junction $\Rightarrow 0 = 5V_2 + (-I_3 - 3I_2)R_1$

Subtract Loop 2: $-[0 = 2V_2 + (-I_3 + 2I_2)R_1]$

$$0 = 3V_2 - 5I_2R_1$$

$$\Rightarrow I_2 = \frac{3}{5}\frac{V_2}{R_1}$$

Loop 2: $0 = 2V_2 + \left(-I_3 + 2\frac{3}{5}\frac{V_2}{R_1}\right)R_1$

$$= 2V_2 - I_3R_1 + \frac{6}{5}V_2$$

$$= \frac{16}{5}V_2 - I_3R_1$$

$$\Rightarrow I_3 = \frac{16}{5}\frac{V_2}{R_1}$$

$$I_1 = -I_2 - I_3 = -\frac{3}{5}\frac{V_2}{R_1} - \frac{16}{5}\frac{V_2}{R_1} = -\frac{19}{5}\frac{V_2}{R_1}$$

Current is negative! My assumption was backward.

Numerical Solution

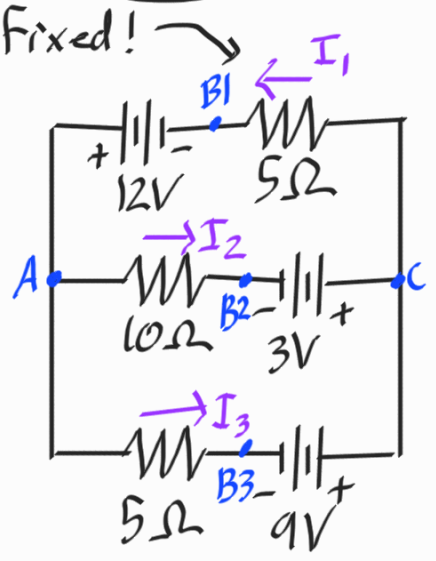
$$\frac{V_2}{R_1} = \frac{3V}{5\Omega} = \frac{3}{5}A$$

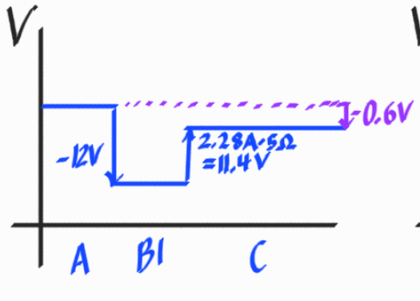
$$I_1 = \frac{57}{25}A = 2.28\,A$$

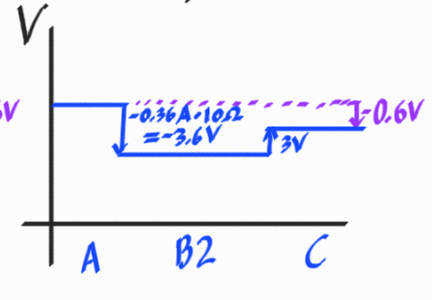
$$I_2 = \frac{9}{25}A = 0.36\,A$$

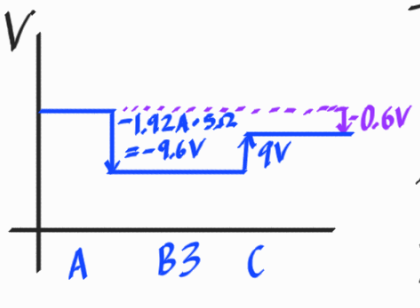
$$I_3 = \frac{48}{25}A = 1.92\,A$$

Fixed!









The right hand side of the circuit is 0.6V lower in potential than the left (no matter what path you take to get there).