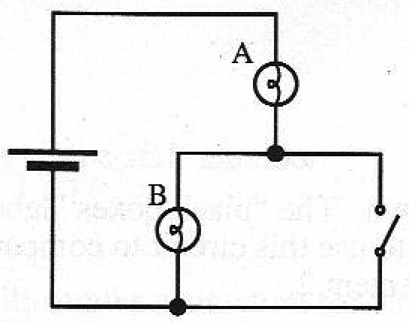
Physics 9 — Monday, December 3, 2018

- Pick up "practice exam" (due on the last day of class, 12/10) which is effectively a take-home portion of your final exam, intended to help you to prepare for the in-class exam (12/17).
- HW11 due this Friday. (Last one!)
- Nothing to read for today. But if you want to borrow an Arduino board (+ some related components) and try on your own to program it to blink LEDs, play sounds, etc., that is yet another extra-credit option.
- For Wednesday, read Eric Mazur's ch 27 (magnetic interactions), which will help us to see how to make electricity do useful work (turn a motor, ring a doorbell, etc.)
- FYI: positron.hep.upenn.edu/wja/p009/2016/files/exam.pdf
  positron.hep.upenn.edu/wja/p009/2016/files/exam_solns.pdf
- Full-featured python interpreter in a web browser:
  https://www.pythonanywhere.com/try-ipython/
- If you want to "build" some circuits on your (or your neighbor's) computer in class today:

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

If you were to build this circuit, when would bulb A be brighter?

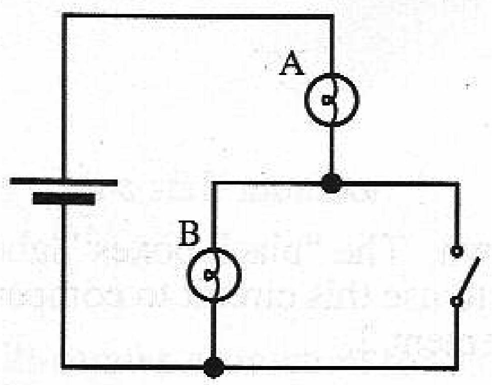


(A) A is brighter when the switch is open

(B) A is brighter when the switch is closed

(C) A is the same brightness in both cases

How does the resistance of bulb B compare with the resistance of a **closed** switch? (A circuit diagram usually shows a switch in its open position, as this one does.)

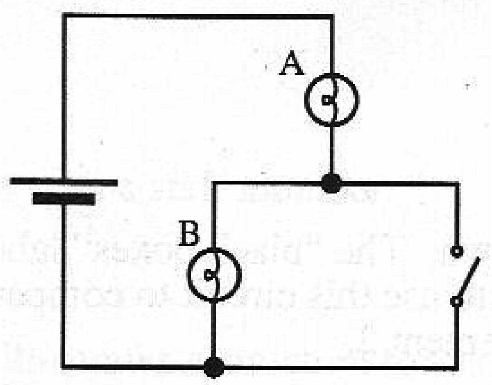


(A) a closed switch has much smaller resistance than bulb B

(B) a closed switch has much larger resistance than bulb B

(C) the resistance of a closed switch is similar to the resistance of bulb B

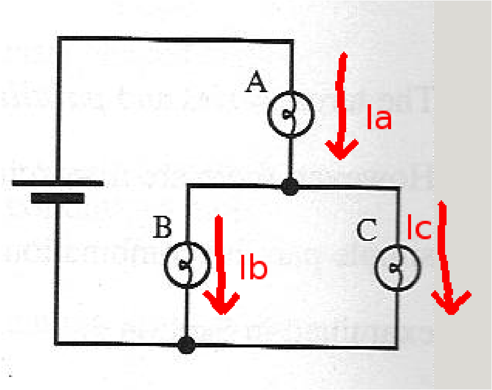
By the way, what is the resistance of an **open** switch? (Is it very easy or is it very difficult for current to flow through an open switch?)



(A) an open switch has a very small resistance, effectively "zero"

(B) an open switch has a very large resistance, effectively "infinite"

What relationship between I_a, I_b, and I_c does the **junction rule** (a.k.a. "Kirchoff's current rule") allow us to write down?



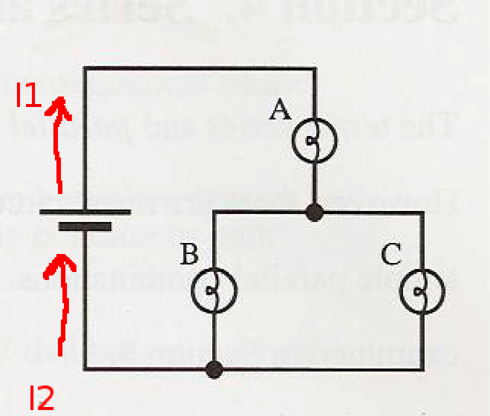
(A) $I_a + I_b = I_c$

(B) $I_a = I_b + I_c$

(C) $I_a = I_b - I_c$

(D) $I_a + I_b + I_c = 0$

In the steady state, how does the current I_1 flowing out of the battery compare with the current I_2 flowing back into the battery?



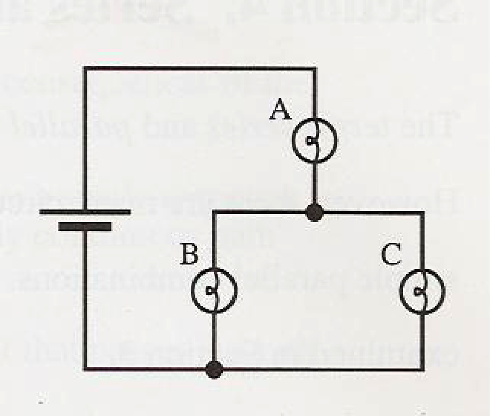
(A) They are equal.

(B) I_1 is bigger, because the current is "used up" by the light bulbs.

(C) They should have the same magnitude, but I_2 should be flowing downward instead.

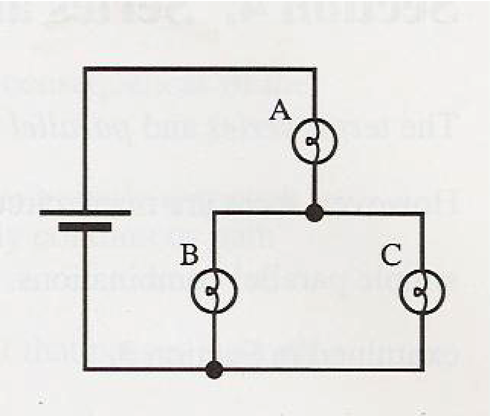
(D) You can't tell, because there is a junction where the 3 bulbs meet.

Predict the relative brightness for the three bulbs (assuming the bulbs are identical). Once you predict, feel free to try it — either by combining parts with two other groups or by using the "circuit construction kit: DC" web app!



(A) $A < B < C$
(B) $A < B = C$
(C) $A = B = C$
(D) $A > B = C$
(E) $A > B > C$

You just predicted $A > B = C$ when all 3 (identical) bulbs are present. Now predict what will happen to the brightness of bulbs A and B if bulb C is unscrewed. Once you predict, feel free to try it.



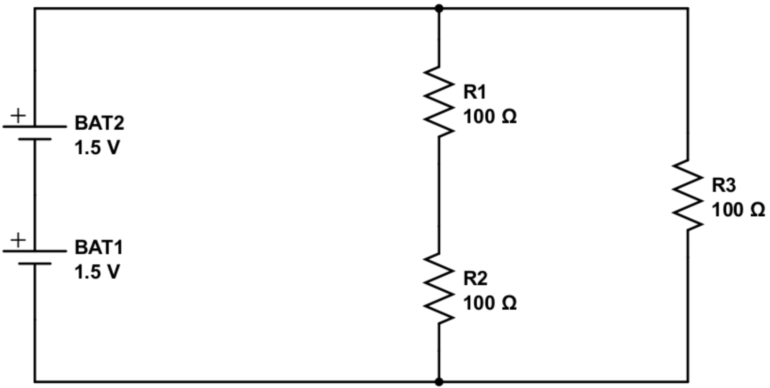
(A) A and B will both become brighter.

(B) A and B will both become dimmer.

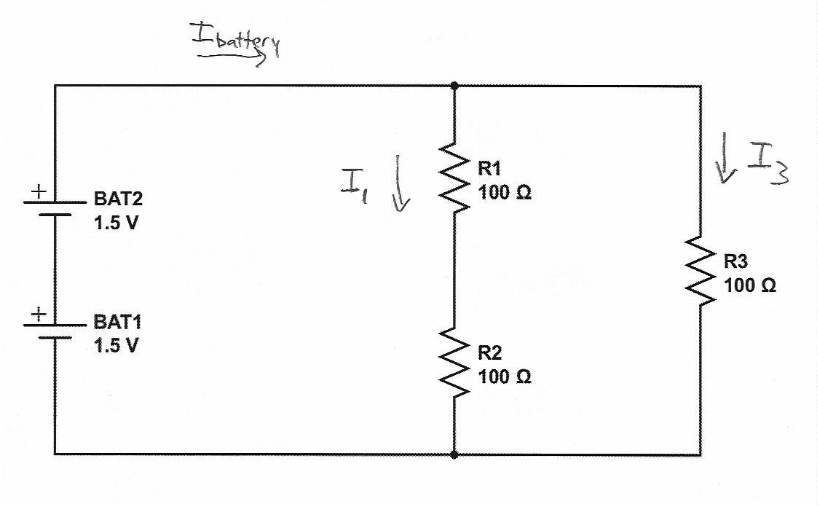
(C) A will become brighter, and B will become dimmer.

(D) A will become dimmer, and B will become brighter.

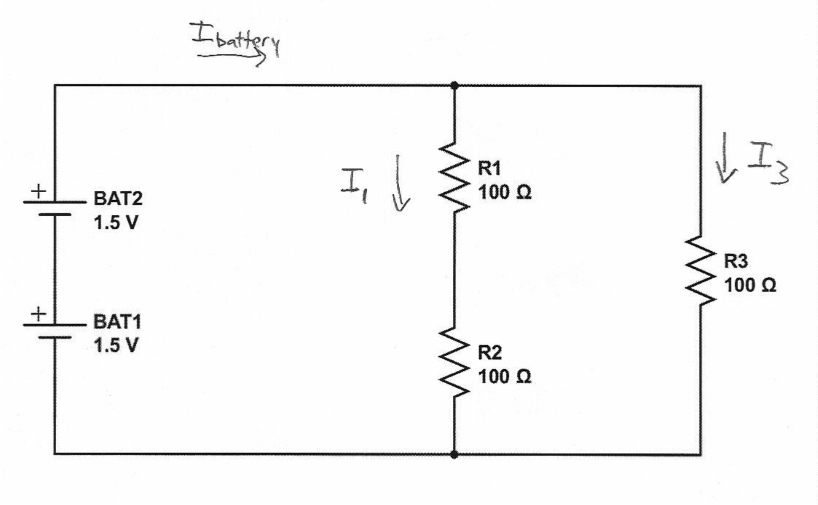
(E) The brightness of A and B will not change.



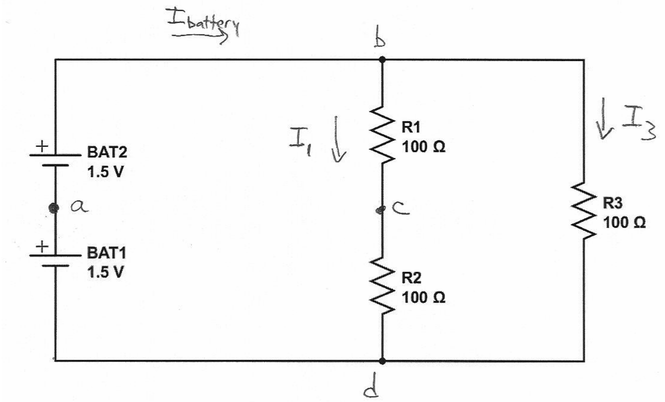
First, identify all of the **branches** in the circuit. For each branch, choose a **reference direction** for the current through that branch. How many branches? How many junctions?



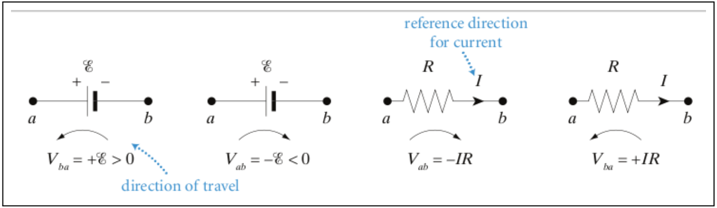
What does the **junction rule** let us write for the junction above R_1? In this case, do we get any additional information by applying the junction rule at the junction below R_2?

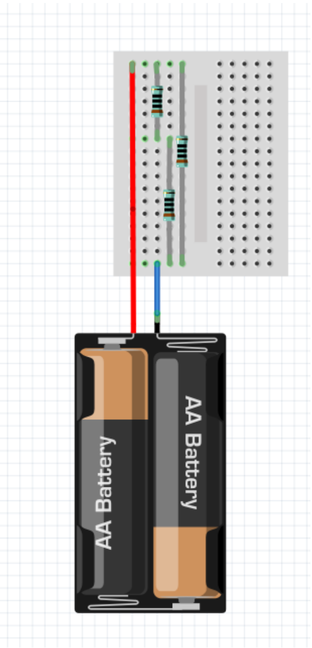


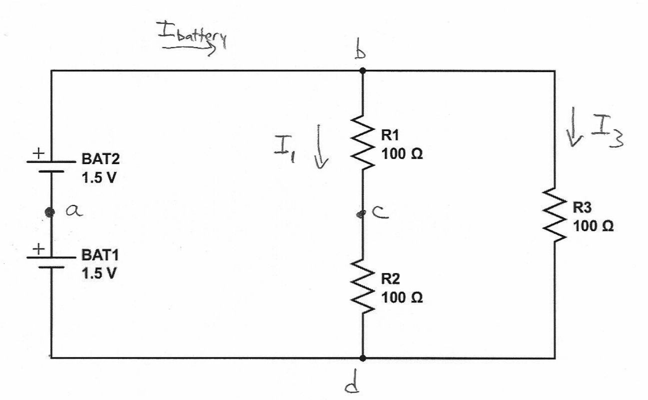
There are 3 loops in this circuit. Where are they? Use the loop rule for each one. (Let's go clockwise around each loop — arbitrary choice.) How many of these 3 equations give us new information?



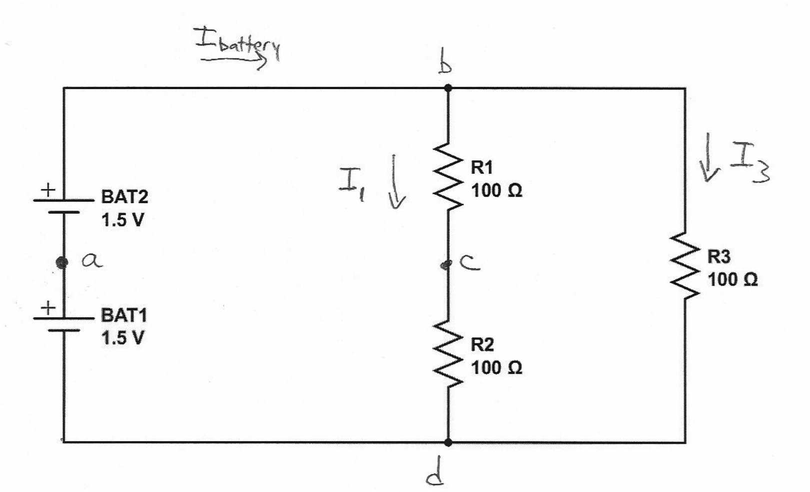
Now predict V_{ab}, V_{bc}, V_{cd}, V_{bd}, and V_{da}.





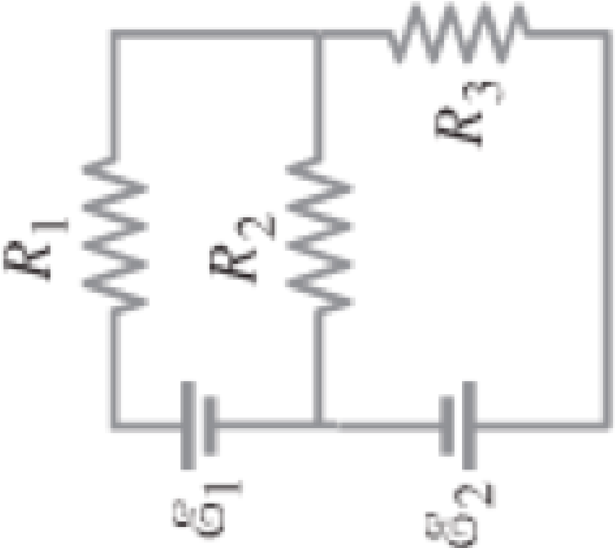


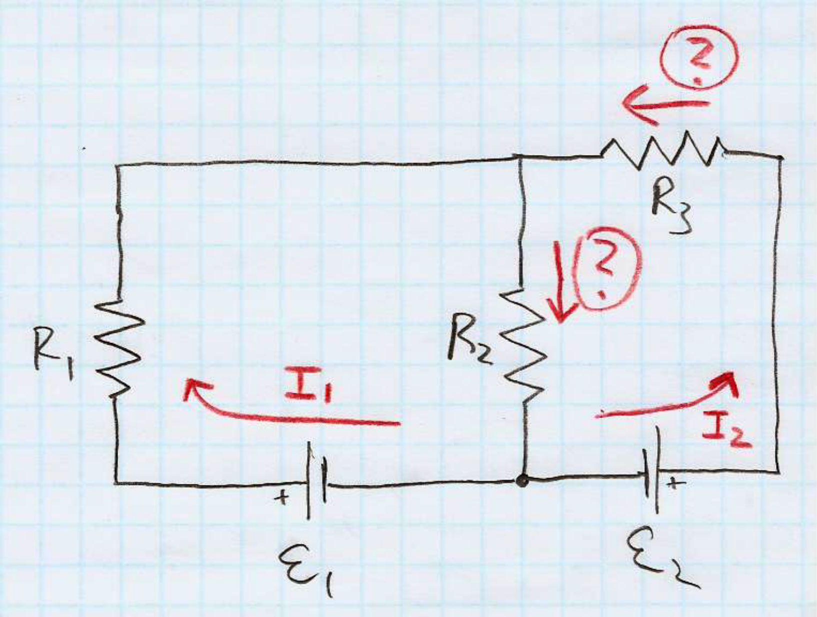
see fritzing.org to draw left, circuitlab.com for right



One more question: What is the power dissipated in each resistor? (Are they all the same, or not?) What is the power supplied by each battery?

Circuits with multiple batteries can be tricky: particularly for getting the signs right. When feasible, I usually try to draw a current going "the conventional way" through each battery, e.g. I_1 going to the left through $\mathcal{E}_1$ and I_2 going to the right through $\mathcal{E}_2$.





What values can we write for the two **?** currents?

What does the loop rule tell us? (3 equations, but 1 is redundant.)

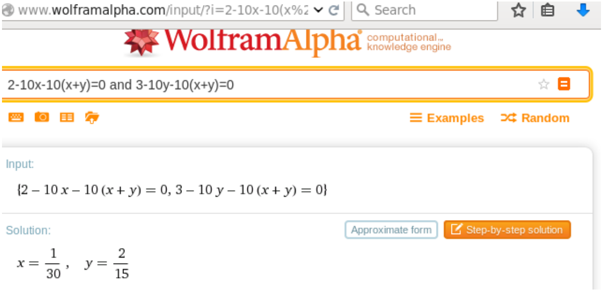
For example, let's plug in
$R_1 = R_2 = R_3 = 10\ \Omega, \quad \mathcal{E}_1 = 2\ \mathrm{V}, \mathcal{E}_2 = 3\ \mathrm{V}$. Then we get

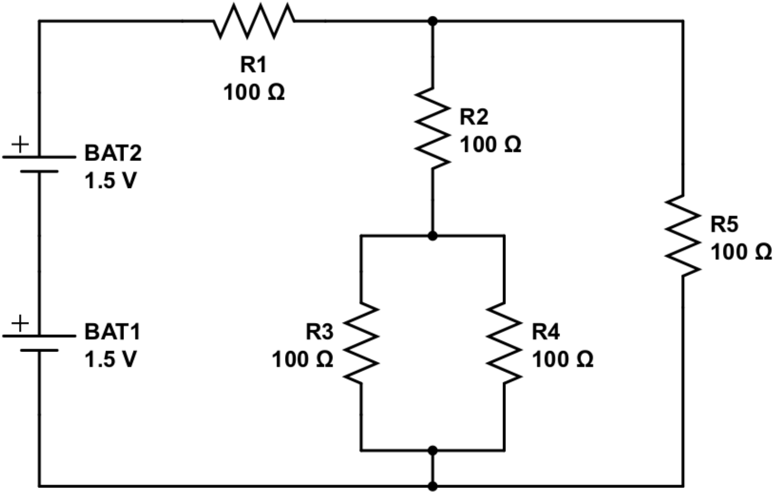
$$2\ \mathrm{V} - (10\ \Omega)I_1 - (10\ \Omega)(I_1 + I_2) = 0$$

$$3\ \mathrm{V} - (10\ \Omega)I_2 - (10\ \Omega)(I_1 + I_2) = 0$$

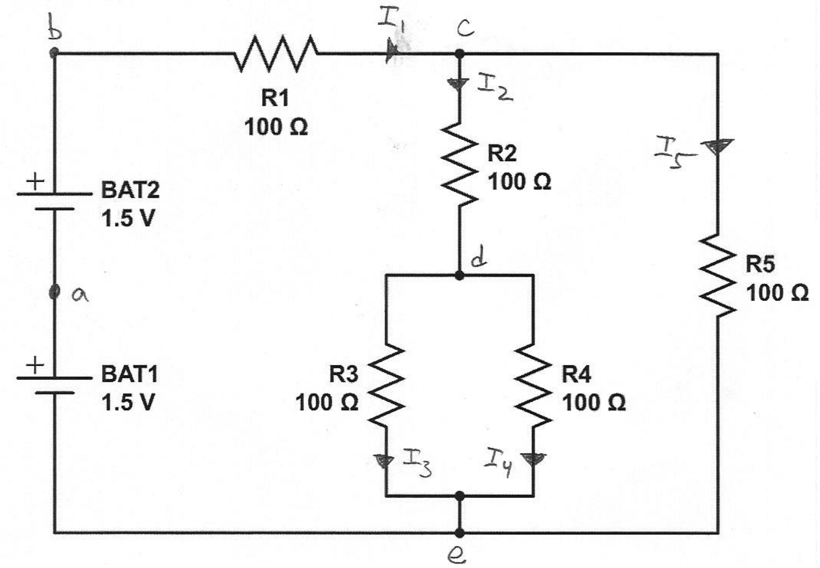
If you have two equations in two unknowns (e.g. x and y), you can go to Wolfram Alpha and type (for example)

`2-10x-10(x+y)=0 and 3-10y-10(x+y)=0`

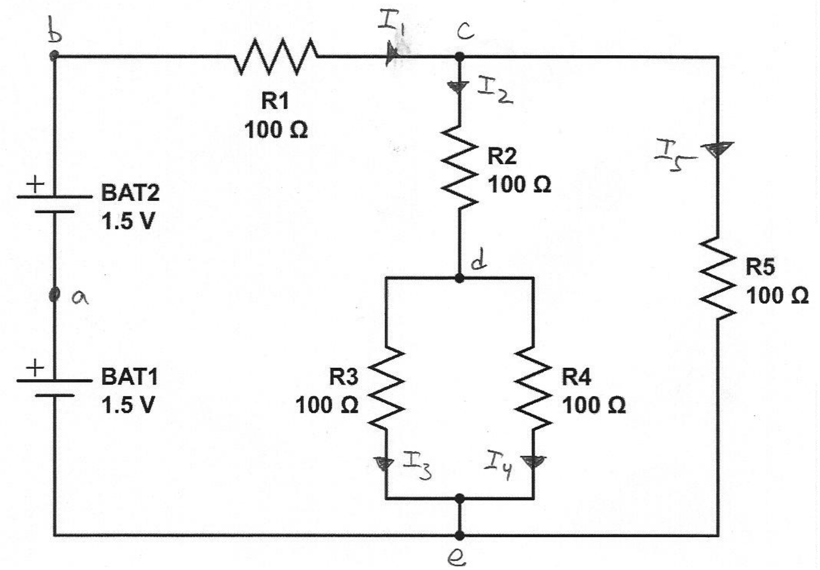




This circuit is more complicated. How many branches? Let's choose a reference direction for each branch, choose a name for the current in each branch, and choose a name for all points between which we might want to measure voltage. (Next page.)



What does junction rule let us write at point *c*? Point *d*? Does the junction rule at point *e* tell us anything new?



I count 4 loops. Let's see what the loop rule tells us. Again, one equation will be redundant. We'll just write down the equations, without wasting time to solve them for $I_1 \ldots I_5$.

loop rule:

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_5 R_5 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_3 R_3 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_4 R_4 = 0$$

junction rule:

$$I_1 = I_2 + I_5 \Rightarrow \boxed{I_5} = I_1 - I_2$$

$$I_2 = I_3 + I_4 \Rightarrow \boxed{I_4} = I_2 - I_3$$

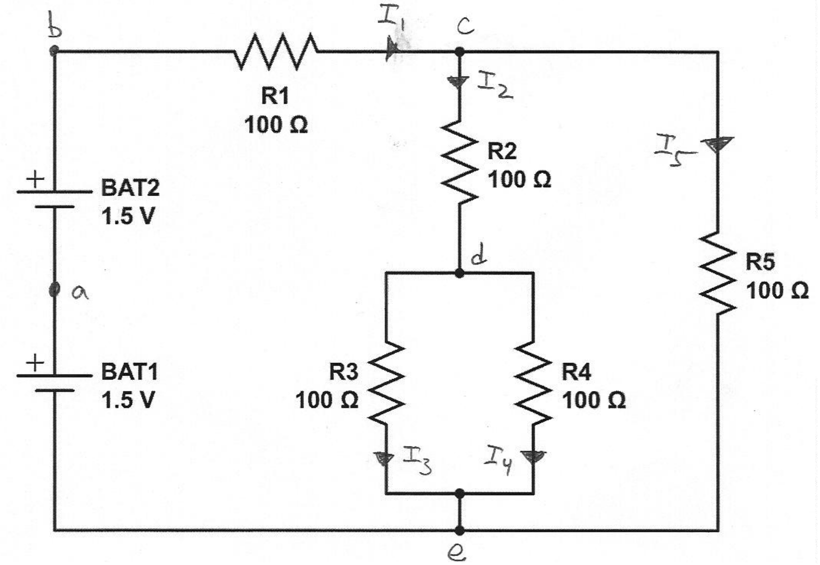
Plug these in to eliminate I_4, I_5:

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - (I_1 - I_2) R_5 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - I_3 R_3 = 0$$

$$\mathcal{E}_1 + \mathcal{E}_2 - I_1 R_1 - I_2 R_2 - (I_2 - I_3) R_4 = 0$$

(Notice that $I_3 R_3 - I_4 R_4 = 0$ is same as we would get by subtracting the last 2 eqns.)



$$I_1 = 0.01875\,\mathrm{A},\ I_2 = 0.0075\,\mathrm{A},\ I_3 = I_4 = 0.00375\,\mathrm{A},\ I_5 = 0.01125\,\mathrm{A}$$
$$I_1 R_1 = 1.875\,\mathrm{V},\ I_2 R_2 = 0.75\,\mathrm{V},\ I_3 R_3 = I_4 R_4 = 0.375\,\mathrm{V},\ I_5 R_5 = 1.125\,\mathrm{V}$$

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