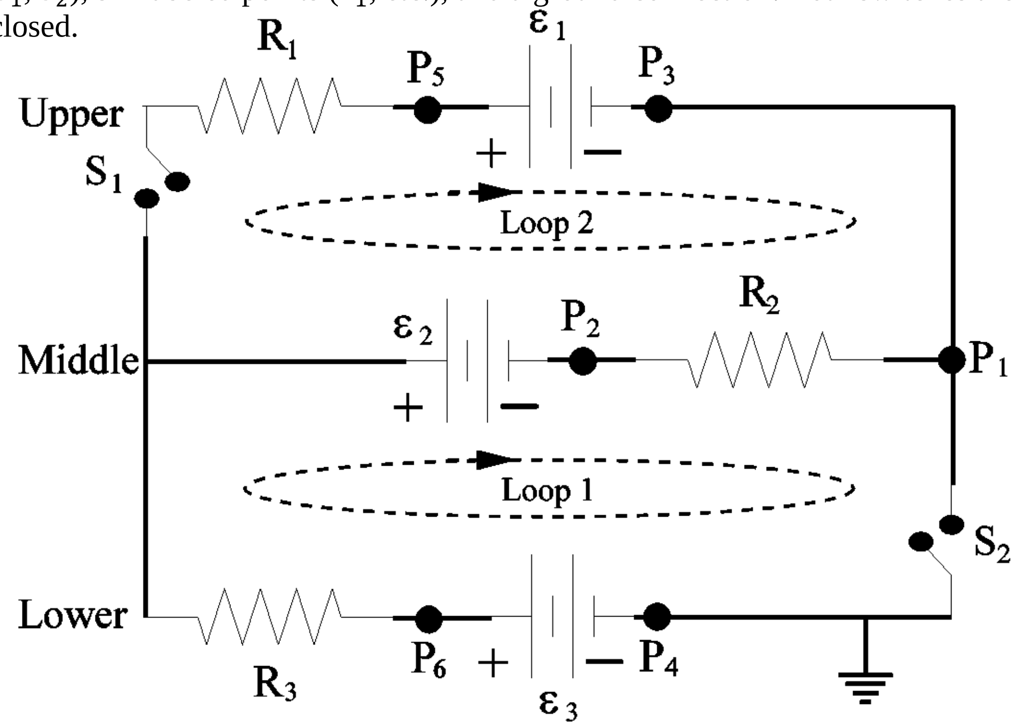
First Name: ____________________ Last Name:________________________________

Let's analyze the following circuit. There are three DC batteries, three resistors, two switches (S_1, S_2), six labeled points (P_1, etc.), and a ground connection. Both switches are suddenly closed.



1. The current directions are often difficult to determine in a complicated circuit. Imagine that ϵ_1 completely controls what happens in this circuit. What would be the current direction in the lower, middle and upper branches? Your answers should be left to right or right to left. Explain your reasoning.

2. Repeat Question #1 if ϵ_2 completely controls what happens in this circuit.

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3. Repeat Question #1 if ϵ_3 completely controls what happens in this circuit.

It should now be obvious that we need more information to be able to accurately predict the current directions. Let's use the following parameters: $\epsilon_1 = \epsilon_3 = 14\ V$, $\epsilon_2 = 4\ V$, $R_1 = R_2 = 10\ \Omega$ and $R_3 = 5\ \Omega$. In this specific situation, the current directions can be determined. Let's slowly work through the logic.

4. Is the electric potential at P_3 larger, smaller, or the same size as the electric potential at P_4? Explain your reasoning.

5. Is the electric potential at P_5 larger, smaller, or the same size as the electric potential at P_6? Explain your reasoning.

6. Is it possible for the current to flow from right to left through R_3 **and** to flow from left to right through R_1? Explain why or why not.

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7. Now predict the correct current directions and explain any remaining logical steps. Mark those current directions on the original diagram. Use I_1 for the current in the upper branch, etc.

8. Write Kirchhoff's junction rule at P_1.

9. Which current flows through S_1? Explain your reasoning.

10. If you measure $V_{P_2} - V_{P_1}$, will it be positive, negative or zero? Explain your reasoning.

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11. Write out Kirchhoff's loop rule for Loop #1 using the indicated loop direction starting from P_1.

12. Write out Kirchhoff's loop rule for Loop #2 using the indicated loop direction starting from P_1.

13. Algebraically combine your answers to Questions #8, 11 and #12 to determine all three currents. Hint: The algebra will be easiest if you substitute your answers from Questions #11-12 into your answer to Question #8.

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14. You should have found that $I_3 = 2I_1$. Does this make sense based upon the parameters describing the circuit? Explain your answer.

15. You should have found that I_2 is flowing to the right. However, ϵ_2 (acting alone) would have created a current flowing to the left. How do you interpret this situation? Explain.

We should now verify that energy is conserved in this circuit. If we wrote Kirchhoff's rules correctly it has to be but it will be useful to make certain that we understand the sources and sinks for the energy.

16. Determine the power supplied by ϵ_1 and ϵ_3.

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17. Determine the power delivered to R_1, R_2 and R_3.

18. Determine the power delivered to ϵ_2.

19. Do your answers to Questions #16, #17 and #18 verify that energy is conserved? Explain.

20. Determine the energy delivered to R_3 in 20 s.

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Comments about this Tutorial:

This can be used in either algebra-based or calculus-based courses.

During spring 2016 in a calculus-based class, this tutorial was used during the third of four days covering basic DC circuits. They had seen a discussion of Kirchhoff's rules in class but they had not been applied to anything. Approximately half of the groups were working on Question #13 at the end of 50 minutes. More generally, most groups were between Questions #10 and #16.

During the spring of 2018, it was used in an algebra-based physics course. All the groups at least got to Question #10 but very few got past Question #13.

Changes Made 2016:

Initial paragraph: I added the labels for the switches and the points since there was some confusion.

Questions #1-3: I previously had the phrase "dominates this circuit" which has been replaced by "controls what happens in this circuit". Several groups were confused by what dominates meant. Hopefully this is better.

Question #13: I added the hint on how to make the algebra easier since way too much time was spent trying to solve this.

Comments about individual questions:

Questions #6 and #10: These obviously both require understanding how you know whether the voltage increases or decreases as you move across a resistor. In general, Question #6 usually is quite hard for them. Some of them realize that one couldn't increase while the other one decreased (even if they don't actually know which is which). You might view Question #10 as a bit redundant but I don't think it hurts to leave it in here.

Questions #11-12: As suggested above, my class found these difficult since it really was their first experience doing this. How quickly they get through these questions will strongly depend upon how much of this they have seen in class.

Question #15: Many students don't really know what this is asking. There may be a better thing to ask than "How do you interpret this situation?" but for now I have left the question as is.

Comments Specifically for the algebra-based course:

Question #5: Even if they have gotten Question #4 correct, they still found this difficult.

Question #6: Many students wanted to say that this was not possible because the batteries both created currents to the left. In other words, they were forgetting the point of the first three questions on this tutorial.

Question #8: Admittedly, this is a bit amusing. Many students literally went back to the first page of the tutorial and actually wrote the junction rule right next to point P_1 in the circuit diagram. It's not clear if there is an easy way to prevent that.

Tutorial Source(s):

All questions were written by Drew Milsom.

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