

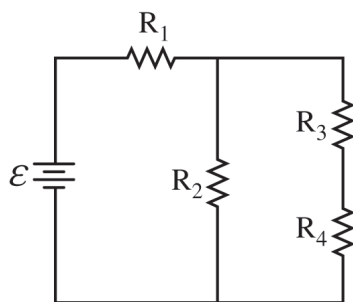
Begin your response to **QUESTION 3** on this page.

Figure 1

3. (12 points, suggested time 25 minutes)

A circuit consists of an ideal battery of emf $\mathcal{E}$ and four identical resistors R_1 , R_2 , R_3 , and R_4 , each of resistance R , as shown in Figure 1.

(a) For parts (a)(i) and (a)(ii), express your answers in terms of numerical values, $\mathcal{E}$, and R only.

i. **Derive** an expression for the current I_1 in Resistor R_1 .

ii. **Derive** an expression for the current I_3 in Resistor R_3 .

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(b) The partially completed bar chart in Figure 2 shows a bar that represents the absolute value $|\Delta V|$ of the potential difference across the ideal battery.

- In Figure 2, **draw** a bar to represent $|\Delta V|$ across each resistor, relative to the emf $\mathcal{E}$ of the ideal battery.
- The height of each bar should be proportional to the value of $|\Delta V|$ represented by that bar. If $|\Delta V|$ is zero, write a “0” in that column.

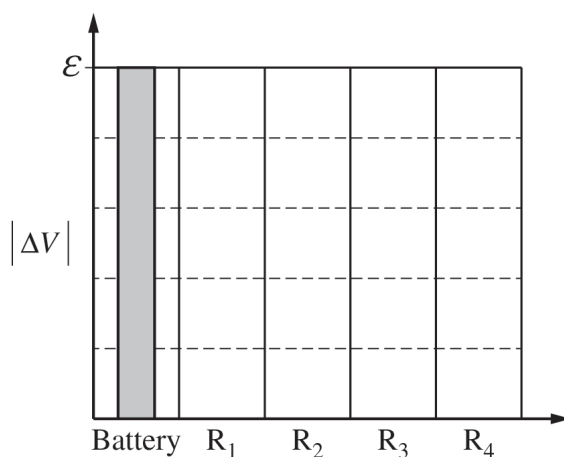


Figure 2

A student claims that the rate at which energy is dissipated (power) by the circuit can be expressed

as $P = \frac{3\mathcal{E}^2}{5R}$.

(c) **State** whether the expression for P is correct or incorrect. **Justify** your answer by referring to the derivations from part (a) or the bar chart from part (b).

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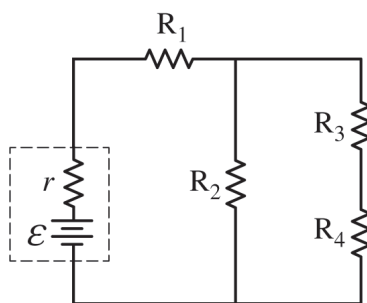
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Figure 3

When the ideal battery is connected in the original circuit, the rate at which energy is dissipated by Resistor R_1 is P_{original} . The ideal battery is now replaced with a nonideal battery of emf $\mathcal{E}$ and internal resistance r to form the new circuit shown in Figure 3. The rate at which energy is dissipated by Resistor R_1 in the new circuit is P_{new} .

(d) **Indicate** whether P_{new} is greater than, less than, or equal to P_{original} .

_____ $P_{\text{new}} > P_{\text{original}}$ _____ $P_{\text{new}} < P_{\text{original}}$ _____ $P_{\text{new}} = P_{\text{original}}$

Briefly **justify** your answer.

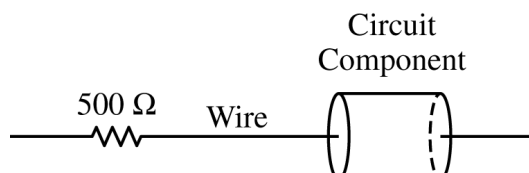
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2. (12 points, suggested time 25 minutes)

Students are given an unknown circuit component that is connected in series to a resistor with known resistance $500\ \Omega$.

(a) The students are asked to experimentally determine whether the component is a resistor or an uncharged capacitor.

i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.

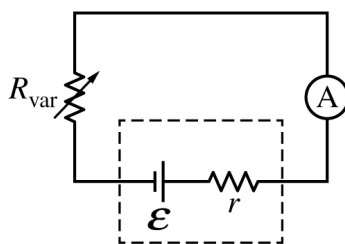


ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

iii. What results would the students expect if the component is an uncharged capacitor? Support your answer in terms of potential difference and charge.

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The students conduct a different experiment to determine the emf $\mathcal{E}$ of a battery that is not ideal and has internal resistance $r = 30\ \Omega$. The battery is connected to a variable resistor in a circuit, as shown. The students measure the current I through the circuit for different values of resistance R_{var} of the variable resistor that is connected to the battery. The following table contains the data collected.

I (A)	R_{var} (Ω)		
0.087	200		
0.060	300		
0.042	450		
0.027	700		
0.016	1200		

(b)

i. Write an equation describing the circuit in terms of $\mathcal{E}$, I , r , and R_{var} .

ii. Which quantities could be graphed to yield a straight line that could be used to calculate a numerical value for the emf $\mathcal{E}$ of the battery?

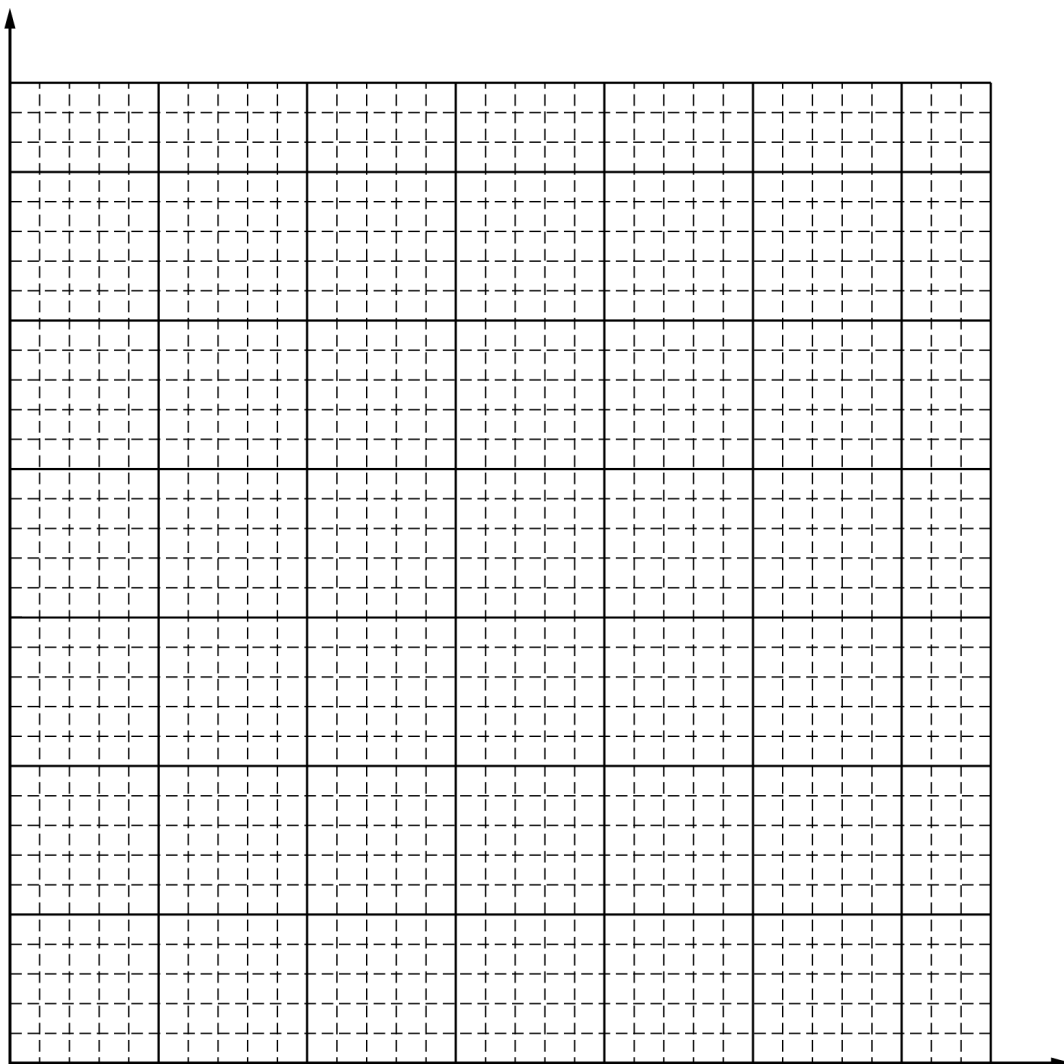
Horizontal Axis: _____

Vertical Axis: _____

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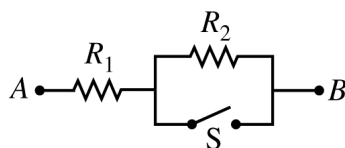
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- iii. Plot the data points for the quantities indicated in part (b)(ii) on the following graph. Clearly scale and label all axes, including units. Draw a straight line that best represents the data. You may use the blank columns in the table for any quantities you graph other than the given data.



- iv. Using the graph from part (b)(iii), determine the emf $\mathcal{E}$ of the battery.

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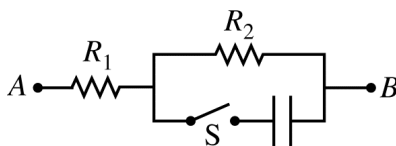
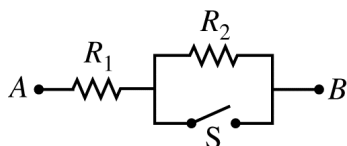
2. (12 points, suggested time 25 minutes)

Students are given resistor 1 with resistance R_1 connected in series with the parallel combination of a switch S and resistor 2 with resistance R_2 , as shown above. The circuit elements cannot be disconnected from each other, and other circuit components can only be connected at points A and B . The students also are given an ammeter and one 9 V battery. The teacher instructs the students to take measurements that can be used to determine R_1 and R_2 .

- (a) Complete the diagram below to show how the ammeter and the battery should be connected to experimentally determine the resistance of each resistor. Describe the experiment by listing the measurements to be taken and explaining how the measurements would be used to calculate resistances R_1 and R_2 .

Complete the Diagram

Describe the Experiment

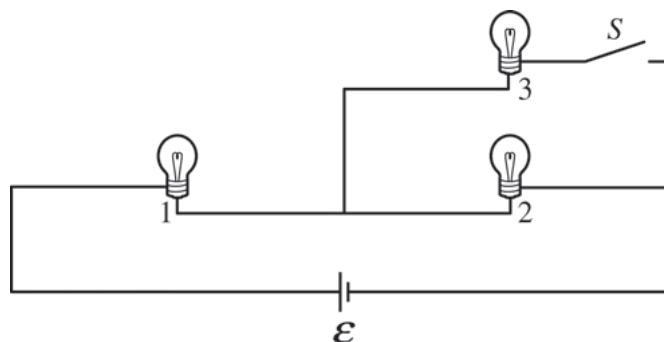


A second group of students is given a combination of circuit elements that is similar to the previous one but has an initially uncharged capacitor in series with the open switch, as shown above. The combination is placed in a circuit with a power supply so that the potential difference between A and B is maintained at 9 V. The students close the switch and immediately begin to record the current through point B . The initial current is 0.9 A, and after a long time the current is 0.3 A.

- (b)
- Compare the currents through resistor 1, resistor 2, and the switch immediately after the switch is closed to the currents a long time after the switch is closed. Specifically state if any current is zero.
 - Calculate the values of R_1 and R_2 .
 - Determine the potential difference across the capacitor a long time after the switch is closed.

A third group of students now uses the combination of circuit elements with the capacitor. They connect it to a 9 V battery that they treat as ideal but which is actually not ideal and has internal resistance.

- (c) How does the third group's value of R_1 calculated from the data they collected compare to the second group's value? Explain your reasoning with reference to physics principles and/or mathematical models.



2. (12 points, suggested time 25 minutes)

A battery of emf $\mathcal{E}$ and negligible internal resistance, three identical incandescent lightbulbs, and a switch S that is initially open are connected in the circuit shown above. The bulbs each have resistance R . Students make predictions about what happens to the brightness of the bulbs after the switch is closed.

(a) A student makes the following prediction about bulb 1: “Bulb 1 will decrease in brightness when the switch is closed.”

- i. Do you agree or disagree with the student’s prediction about bulb 1 ? Qualitatively explain your reasoning.
- ii. Before the switch is closed, the power expended by bulb 1 is P_1 . Derive an expression for the power P_{new} expended by bulb 1 after the switch is closed in terms of P_1 .
- iii. How does the result of your derivation in part (a)ii relate to your explanation in part (a)i?

(b) A student makes the following prediction about bulb 2: “Bulb 2 will decrease in brightness after the switch is closed.”

- i. Do you agree or disagree with the student’s prediction about bulb 2 ? Explain your reasoning in words.
- ii. Justify your explanation with a calculation.

(c) While the switch is open, bulb 3 is replaced with an uncharged capacitor. The switch is then closed.

- i. How does the brightness of bulb 1 compare to the brightness of bulb 2 immediately after the switch is closed? Justify your answer.
- ii. How does the brightness of bulb 1 compare to the brightness of bulb 2 a long time after the switch is closed? Justify your answer.