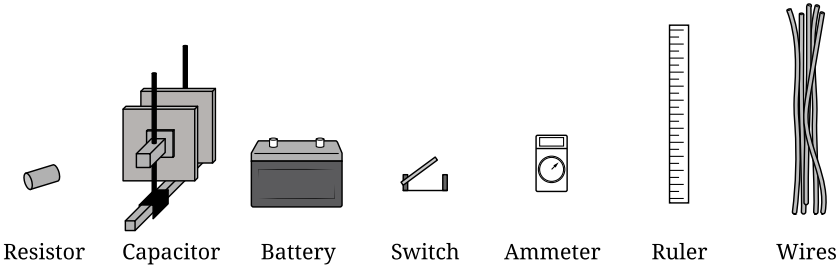


Question 3

3. In Experiment 1, a student is given a resistor of unknown resistance and an air-filled parallel-plate capacitor of unknown capacitance. The student is asked to predict the expected time constant τ of a circuit if these two circuit elements were connected in series with a battery. The student has access to a battery of known emf, a switch, an ammeter, a ruler, and wires, as shown in Figure 1. The plates of the capacitor are square, and the separation between the plates is small compared to the dimensions of the plates. The capacitor is initially uncharged. Assume that the dielectric constant of air is 1.

Figure 1



Note: Figure not drawn to scale.

- A. **Describe** a procedure for collecting data that would allow the student to determine the expected time constant τ . In your description, include the measurements to be made. Include any steps necessary to reduce experimental uncertainty.
- B. **Describe** how the collected data could be analyzed to determine τ . Include references to appropriate equations and to relationships between measured and known quantities.

C. In Experiment 2, the student is asked to determine the capacitance C of a new parallel-plate capacitor. For each trial, the absolute value $|\Delta V|$ of the potential difference across the capacitor is varied and the charge q stored on one plate of the fully charged capacitor is measured. Table 1 contains the data collected.

Table 1

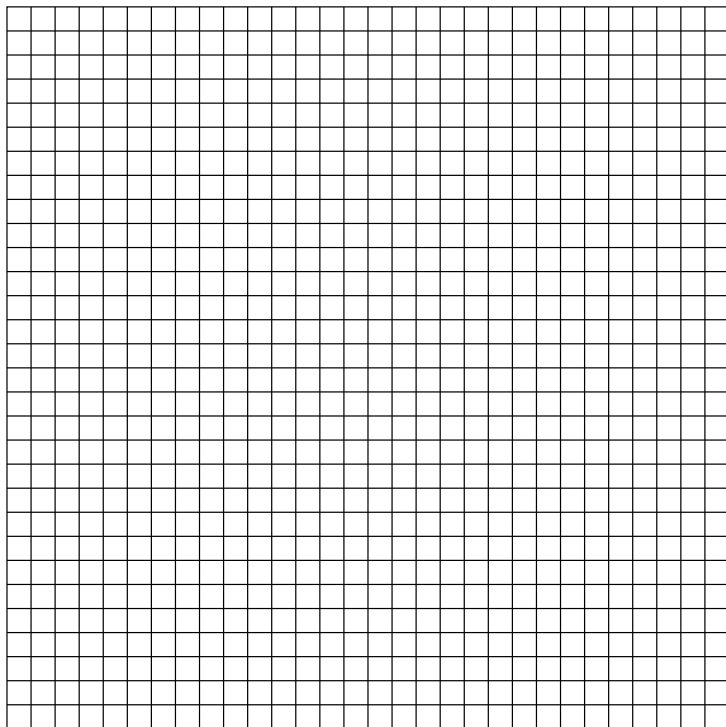
$ \Delta V $ (V)	q ($\times 10^{-10}$ C)
3.0	2.4
5.0	4.2
7.2	5.6
8.0	6.6
10.0	8.0

- i. **Indicate** two quantities, either measured quantities from Table 1 or additional calculated quantities, that could be graphed to produce a straight line that could be used to determine C .

Vertical axis: _____ Horizontal axis: _____

ii. On the grid provided, create a graph of the quantities indicated in part C (i).

- Use Table 2 to record the measured or calculated quantities that you will plot.
- Clearly **label** the axes, including units as appropriate.
- **Plot** the points you recorded in Table 2.



iii. **Draw** a best-fit line for the data graphed in part C (ii).

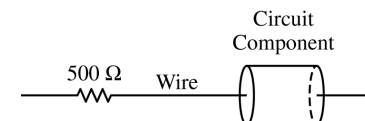
D. Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for capacitance C .

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.

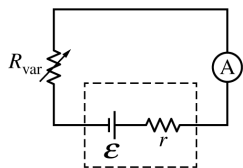
i. Complete the following diagram to show how to use standard circuit equipment to determine whether the component is a resistor or an uncharged capacitor.



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.

GO ON TO THE NEXT PAGE.

Continue your response to **QUESTION 2** on this page.

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)

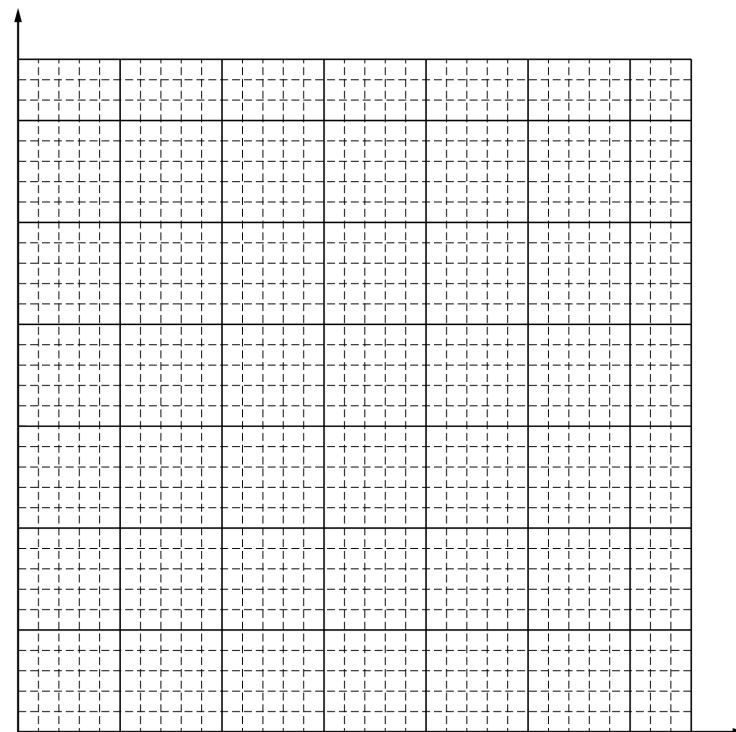
i. Write an equation describing the circuit in terms of $\mathcal{E}$, I , r , and R_{var} .

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: _____

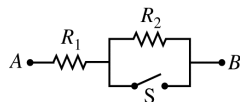
GO ON TO THE NEXT PAGE.Continue your response to **QUESTION 2** on this page.

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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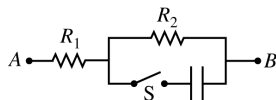
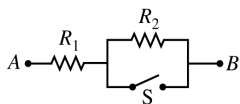
2. (12 points, suggested time 25 minutes)

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.

4. (10 points, suggested time 20 minutes)

Some students are investigating the behavior of a circuit with four components in series: a resistor of resistance R , a capacitor of capacitance C , a battery with potential difference $\mathcal{E}$, and a switch. Initially, the capacitor is uncharged and the switch is open.

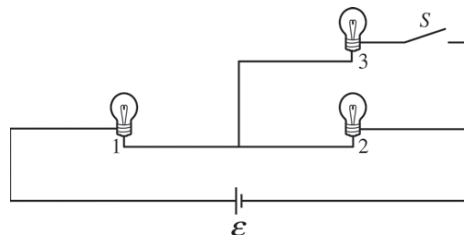
- (a)
- Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.
 - Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.
- (b) The switch is opened, the capacitor is discharged, and a second, identical capacitor is added to the circuit in series with the other components. The switch is then closed again.
- A long time after the switch is closed, the energy stored in the single capacitor in the original circuit is U_1 , and the total energy stored in the two capacitors in the new circuit is U_2 . Calculate the ratio U_1/U_2 .
 - The two capacitors in series are to be replaced with a single capacitor that will have the same energy U_2 . Indicate a plate area and a distance between the plates for the new capacitor, compared with one of the original capacitors, that will accomplish this. Support your reasoning using appropriate physics principles and/or mathematical models.

The students are then asked to design two circuits each containing a switch, a battery with a small internal resistance, a lightbulb, and a capacitor. In arrangement 1, the bulb should gradually light up after the switch is closed, becoming brightest after the switch has been closed a long time. In arrangement 2, the bulb should be brightest when the switch is first closed, getting dimmer with time, and going out completely when the switch has been closed for a long time.

- (c) Using standard symbols, draw two circuit diagrams, one showing a possible circuit for arrangement 1 and the other showing a possible circuit for arrangement 2. Justify your circuit diagrams with a paragraph-length explanation referring to the properties of lightbulbs and capacitors in circuits and the conservation of energy and/or the conservation of charge.

STOP

END OF EXAM



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.”

- Do you agree or disagree with the student’s prediction about bulb 1? Qualitatively explain your reasoning.
- 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 .
- 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.”

- Do you agree or disagree with the student’s prediction about bulb 2? Explain your reasoning in words.
- 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.

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