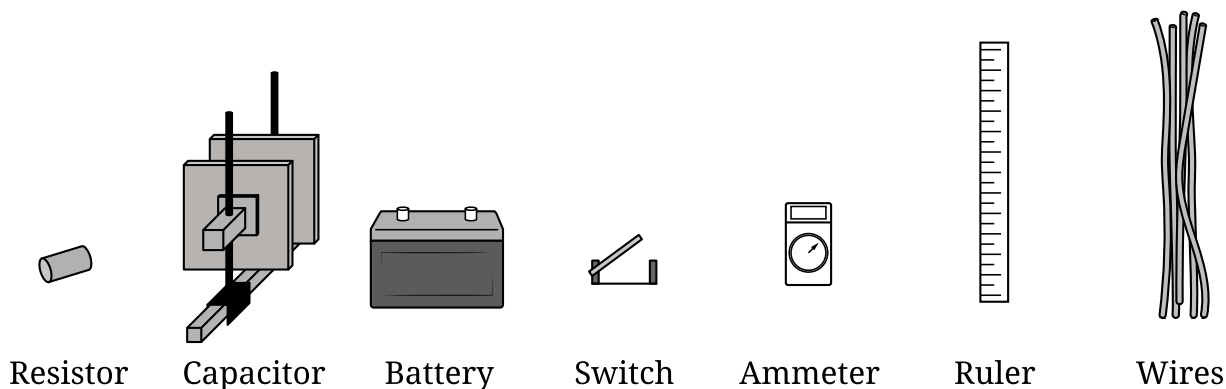


Question 3

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.

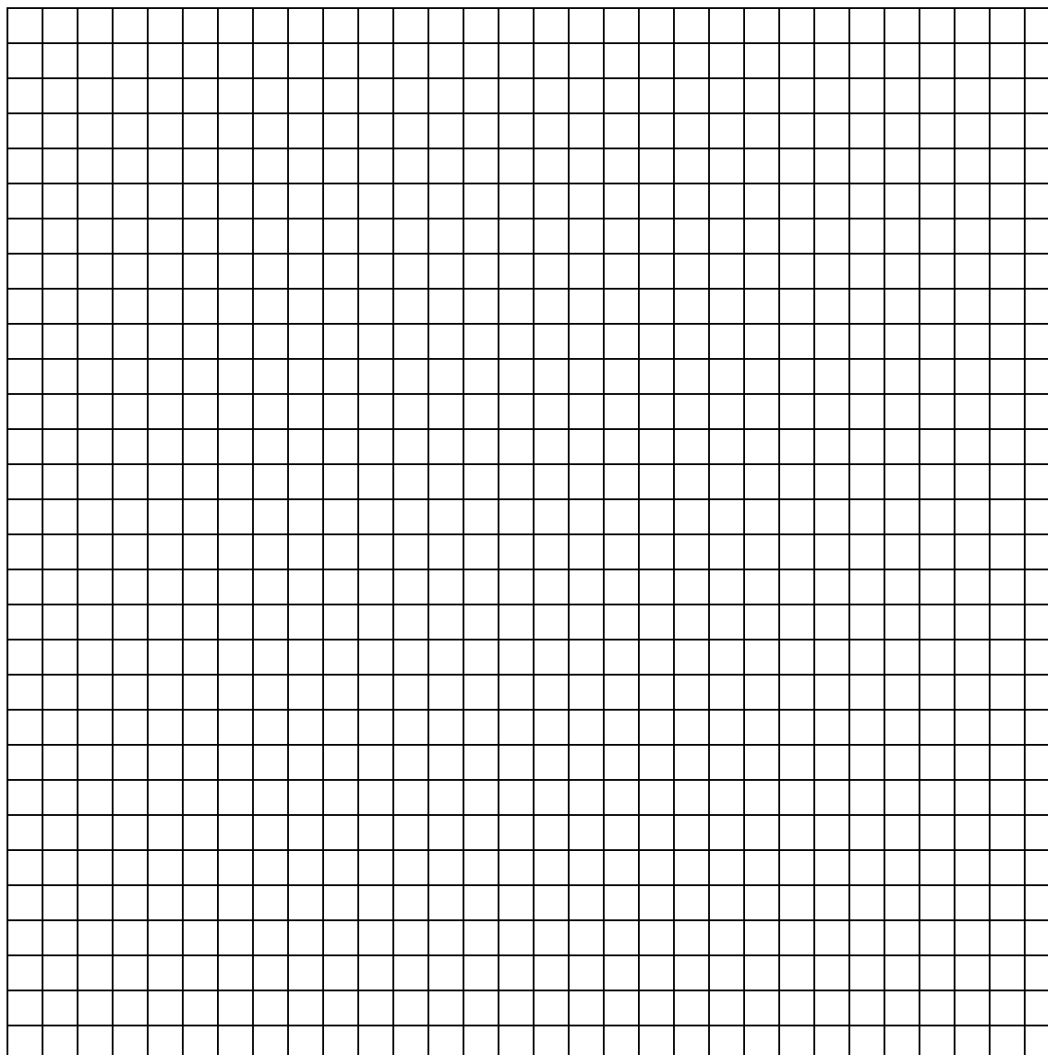
Table 1

$ \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.



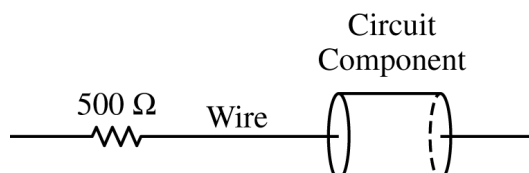
- iii. **Draw** a best-fit line for the data graphed in part C (ii).
- D. Using the best-fit line that you drew in part C (iii), **calculate** an experimental value for capacitance C .

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.

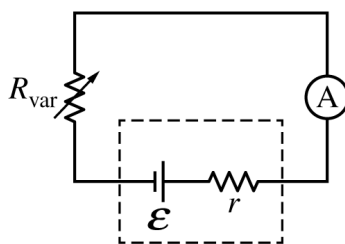


ii. Describe an experimental procedure to determine whether the component is a resistor or an uncharged capacitor. Refer to the circuit equipment in the diagram drawn in part (a)(i).

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?

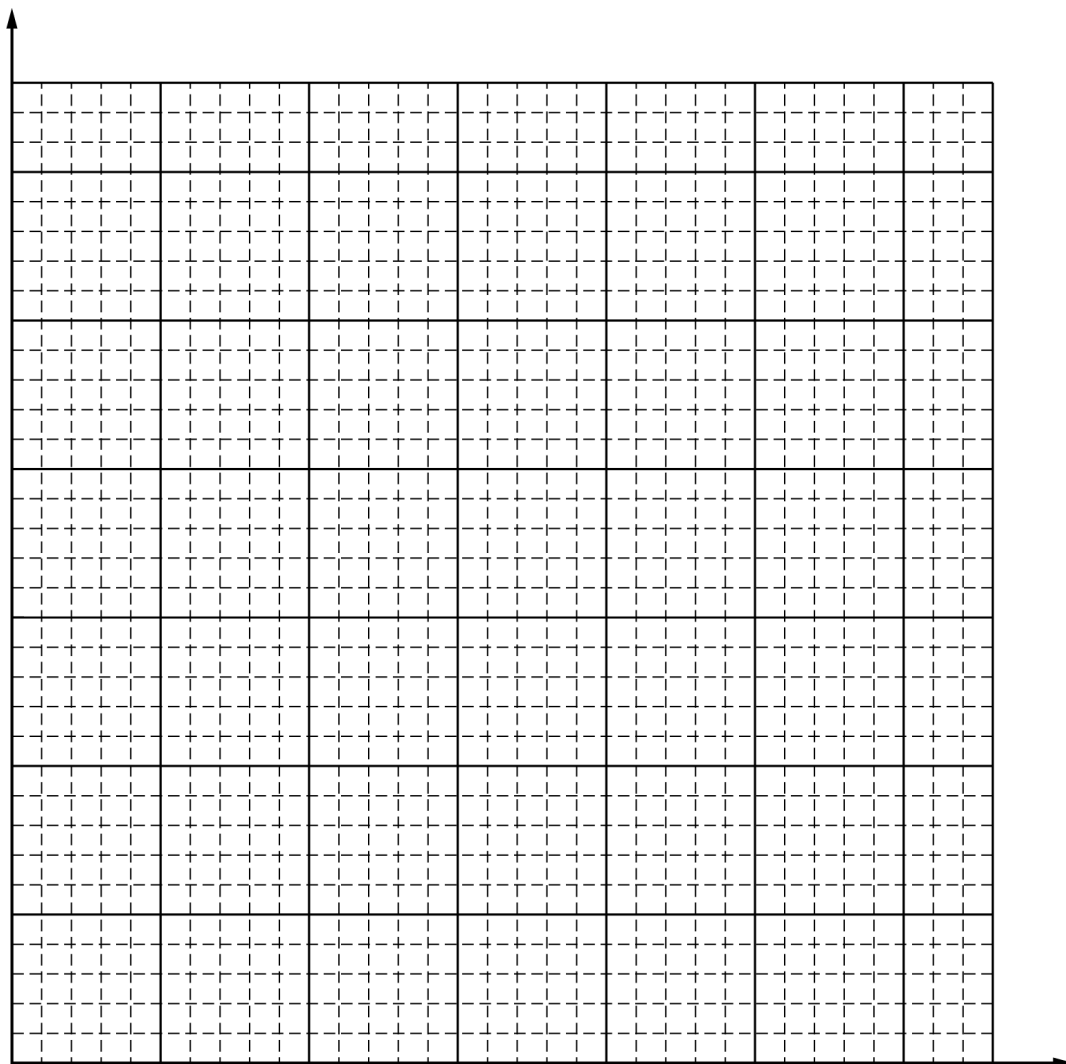
Horizontal Axis: _____

Vertical Axis: _____

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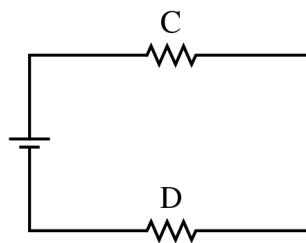
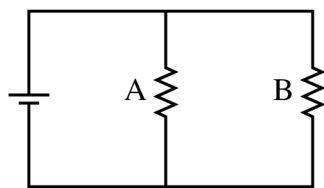
Continue your response to **QUESTION 2** on this page.

- 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.

GO ON TO THE NEXT PAGE.

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

2. (12 points, suggested time 25 minutes)

Students perform an experiment with a battery and four resistors, A, B, C, and D. The resistance of resistors A and C is $R_A = R_C = R$. The resistance of resistors B and D is $R_B = R_D = 2R$. The students create the two circuits shown above and measure the potential differences ΔV_A , ΔV_B , ΔV_C , and ΔV_D across resistors A, B, C, and D, respectively.

- (a) From greatest to least, rank the magnitudes of the potential differences across the resistors. Use “1” for the greatest magnitude, “2” for the next greatest magnitude, and so on. If any potential differences have the same magnitude, use the same number for their ranking.

____ ΔV_A ____ ΔV_B ____ ΔV_C ____ ΔV_D

Justify your answer.

In another experiment, the students have a capacitor with unknown capacitance C_U . They want to determine C_U by using a battery of potential difference 4.5 V and several other capacitors of known capacitance. They create circuits with the battery, the unknown capacitor, and one of the capacitors of known capacitance. The students wait until the capacitors are fully charged and then record the potential difference ΔV_{known} across the known capacitor and the potential difference ΔV_U across the unknown capacitor. Their data are shown in the table on the following page.

GO ON TO THE NEXT PAGE.

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

Known Capacitance of Capacitors (μF)	ΔV_{known} (V)	ΔV_{U} (V)		
200	0.91	3.53		
300	0.65	3.74		
400	0.51	3.95		
500	0.42	4.06		
600	0.36	4.17		

(b)

- i. Calculate the amount of charge on the capacitor of known capacitance of $200\ \mu\text{F}$ in the students' experiment.

- ii. Briefly explain why the data in the table provide evidence that the capacitors are connected in series.

- iii. Briefly explain why connecting the capacitors in parallel would not provide enough information to determine the capacitance of the unknown capacitor if the only measuring device available is a voltmeter.

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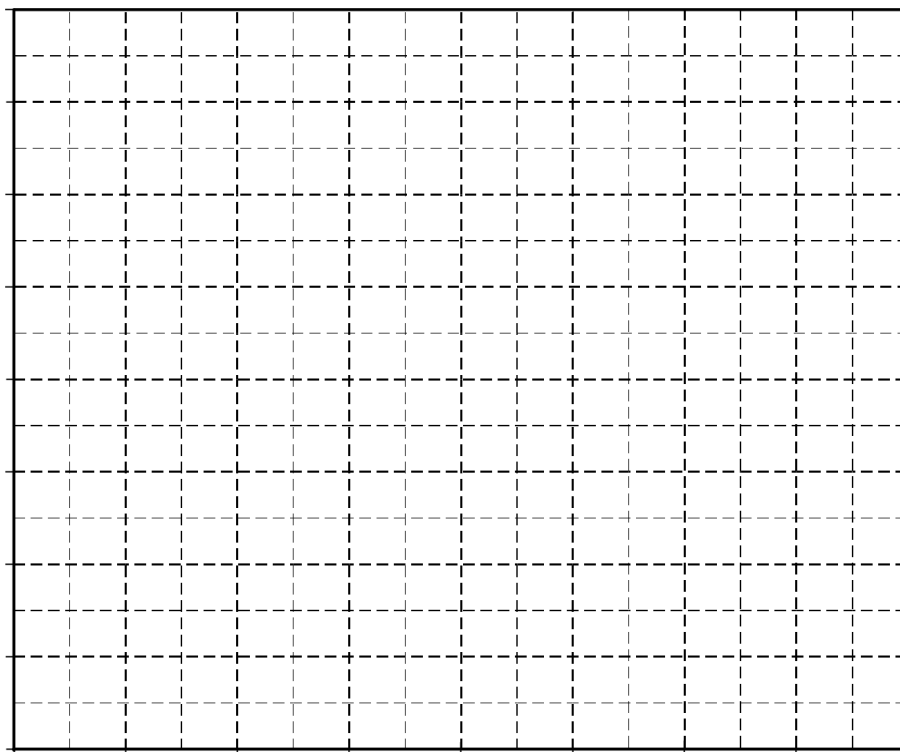
Continue your response to **QUESTION 2** on this page.

(c) The students want to produce a linear graph of the data so that the capacitance C_U of the unknown capacitor can be determined from the slope of the best-fit line for the data.

i. Indicate two quantities that could be plotted to produce the desired graph. Use the empty columns of the data table in part (b) to record any values that you need to calculate.

Vertical axis _____ Horizontal axis _____

ii. Label the axes below and provide an appropriate scale with units. Plot the data points for the quantities indicated in part (c)(i) on the axes and draw a best-fit line.



iii. Using your best-fit line, determine the capacitance of capacitor C_U .

GO ON TO THE NEXT PAGE.

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.

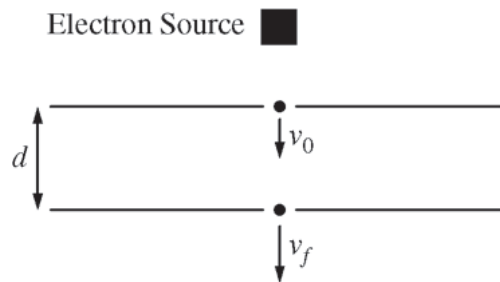
- (a)
- i. Determine the current in the resistor and the potential difference across the capacitor immediately after the switch is closed.
 - ii. Determine the current in the resistor and the potential difference across the capacitor a long time after the switch is closed.
- (b) The switch is opened, 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.
- i. 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 .
 - ii. 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



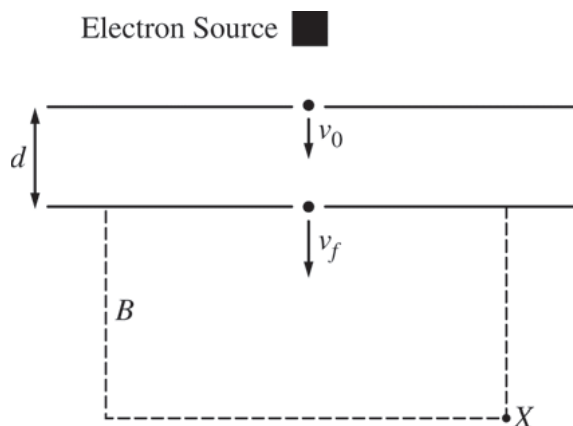
Note: Figure not drawn to scale.

4. (10 points - suggested time 20 minutes)

The apparatus shown in the figure above consists of two oppositely charged parallel conducting plates, each with area $A = 0.25 \text{ m}^2$, separated by a distance $d = 0.010 \text{ m}$. Each plate has a hole at its center through which electrons can pass. High velocity electrons produced by an electron source enter the top plate with speed $v_0 = 5.40 \times 10^6 \text{ m/s}$, take 1.49 ns to travel between the plates, and leave the bottom plate with speed $v_f = 8.02 \times 10^6 \text{ m/s}$.

- (a) Which of the plates, top or bottom, is negatively charged? Support your answer with a reference to the direction of the electric field between the plates.
- (b) Calculate the magnitude of the electric field between the plates.
- (c) Calculate the magnitude of the charge on each plate.

- (d) The electrons leave the bottom plate and enter the region inside the dashed box shown below, which contains a uniform magnetic field of magnitude B that is perpendicular to the page. The electrons then leave the magnetic field at point X .



Note: Figure not drawn to scale.

- On the figure above, sketch the path of the electrons from the bottom plate to point X . Explain why the path has the shape that you sketched.
- Indicate whether the magnetic field is directed into the page or out of the page. Briefly explain your choice.

STOP

END OF EXAM