2023

AP

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free-Response Question 2

☑ Scoring Guidelines

☑ Student Samples

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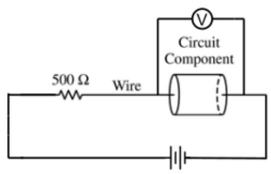
Question 2: Experimental Design — 12 points

(a)(i) For a diagram including a source of potential difference (e.g., battery, power supply) that is in a complete circuit that results in a current in the unknown circuit component — **1 point**

For a diagram including a measurement device that is appropriately connected in the circuit (e.g., voltmeter, ammeter) — **1 point**

Scoring Note: A lightbulb that is connected in series with the circuit component is an acceptable alternative for an ammeter.

Example Responses



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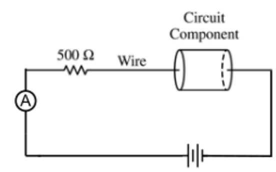

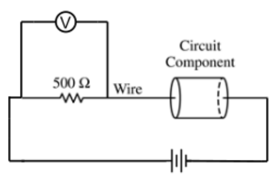

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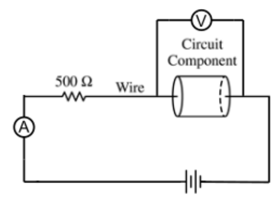

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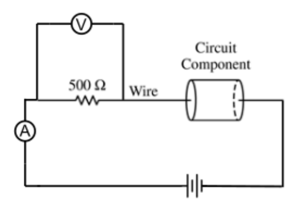


(a)(ii) For describing a procedure that includes a measurement of **one** of the following: — **1 point**

- The potential difference across the circuit component
- The current in the circuit
- The potential difference across the known resistor

For taking measurements at two different times after the circuit is closed or taking one measurement a long time after the circuit is closed, consistent with the procedure described — **1 point**

Example Responses

Measure the current in the ammeter immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component immediately after the circuit is closed and a long time after the circuit is closed.

OR

Measure the potential difference across the circuit component a long time after the circuit is closed.

OR

Measure the potential difference across the $500\,\Omega$ *resistor immediately after the circuit is closed and a long time after the circuit is closed.*

(a)(iii)	For describing a correct result of the experiment that indicates the current in the circuit decreases to zero over time or that the charge of the plates of the capacitor increases over time	**1 point**
	For describing a correct result of the experiment that indicates that the electric potential difference across the capacitor increases from zero over time	**1 point**

Example Response

Immediately after the circuit has been closed, a current should be measured. A long time after the circuit has been closed, a current of zero should be measured. This is because the initially uncharged capacitor becomes fully charged. This results in a potential difference across the capacitor that is equal to the potential difference across the battery a long time after the circuit has been closed. Therefore, according to Kirchhoff's loop rule, a potential difference will not be measured across any other circuit components.

Total for part (a) 6 points

(b)(i)	For an equation that correctly applies the loop rule	**1 point**

Example Response

$0 = +\varepsilon - Ir - IR_{\text{var}}$

(b)(ii)	For indicating appropriate quantities that, when graphed, result in a linear graph that allow students to determine emf ε	**1 point**

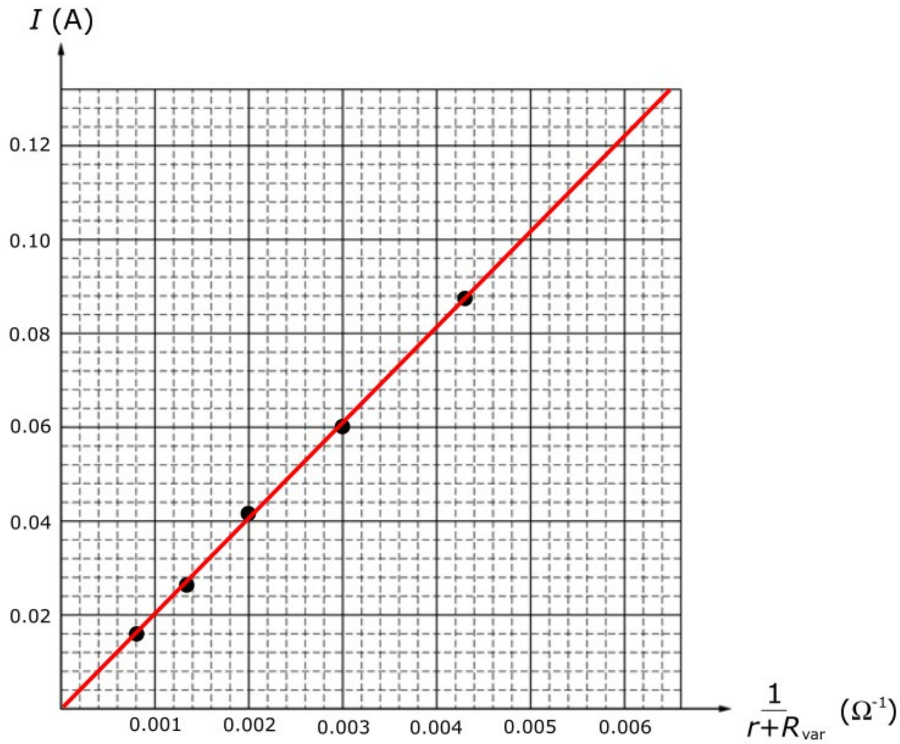
Example Responses

- $\dfrac{1}{r + R_{\text{var}}}$ *vs.* I
- I *vs.* IR_{var}
- R_{var} *vs.* $\dfrac{1}{I}$

(b)(iii)	For including numerical values on both axes with a linear scale and labeling the axes with appropriate labels and units	**1 point**
	For a graph in which data are plotted within at least half of the grid area	**1 point**

For drawing a best-fit line that approximates the trend of the data **1 point**

Example Responses



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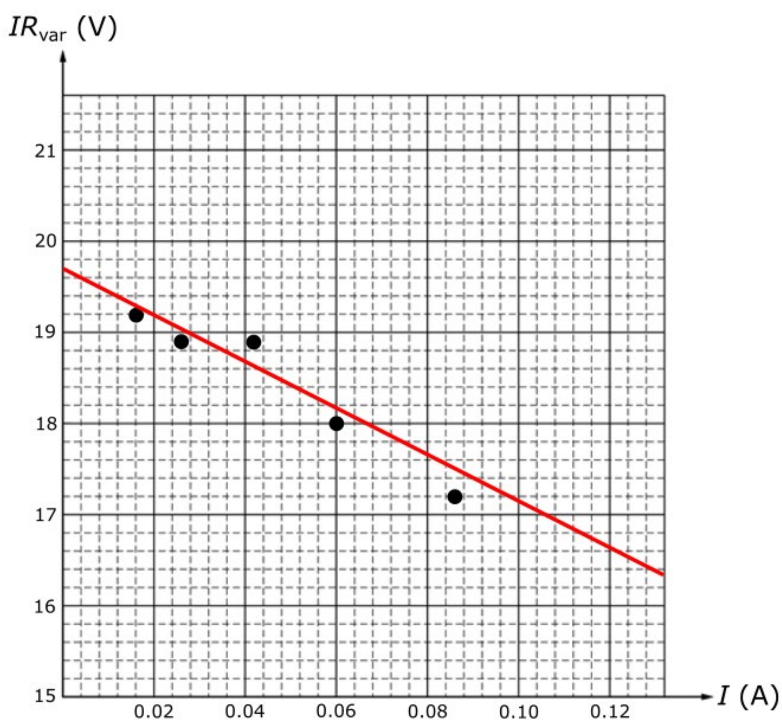


(b)(iv)	For correctly using the graph to determine an experimental value for emf ε, including correct units, between $18.0\ \text{V}$ and $22.0\ \text{V}$	**1 point**

Example Solutions

I as a function of $\dfrac{1}{r + R_{\text{var}}}$

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - I\left(r + R_{\text{var}}\right) = 0$$
$$I\left(r + R_{\text{var}}\right) = \varepsilon$$
$$I = \varepsilon\left(\frac{1}{r + R_{\text{var}}}\right)$$
$$I = \varepsilon\left(\frac{1}{30\ \Omega + R_{\text{var}}}\right)$$
$$\text{Slope} = \varepsilon$$
$$\frac{\Delta y}{\Delta x} = \varepsilon$$
$$\frac{(0.08\ \text{A} - 0.04\ \text{A})}{\left(0.004\ \Omega^{-1} - 0.002\ \Omega^{-1}\right)} \approx \varepsilon$$
$$\varepsilon \approx 20\ \text{V}$$

OR

IR_{var} as a function of I

$$\varepsilon - Ir - IR_{\text{var}} = 0$$
$$\varepsilon - Ir = IR_{\text{var}}$$
$$IR_{\text{var}} = -Ir + \varepsilon$$
$$y\text{-intercept} = \varepsilon$$
$$\varepsilon \approx 20\ \text{V}$$

Total for part (b) 6 points

Total for question 2 12 points

Question 2

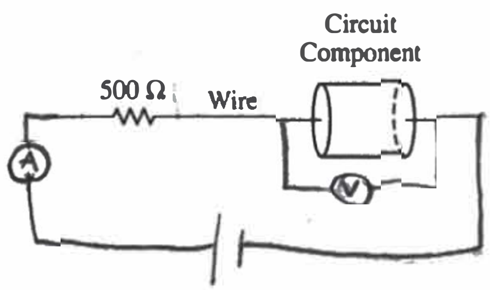
Begin your response to QUESTION 2 on this page.

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 Ω.

(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).

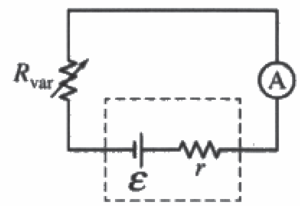
1) Place a battery with a known voltage in series with the 500Ω resistor and the circuit component
2) Place a voltmeter in parallel with the circuit component and ammeter in series with the resistor and circuit component
3) Measure the current and voltage at fixed intervals of 10 seconds.

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

The students would expect to see a decrease in the ammeter reading, (the current) and an increase in the voltmeter reading (the potential difference) if the component is an uncharged capacitor. They would expect to see this because over time, the capacitor will store more charge and across a greater potential difference

Question 2

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)	$\frac{1}{R_{var}+r}$ (Ω^{-1})	
0.087	200	0.0043	
0.060	300	0.0030	
0.042	450	0.0021	
0.027	700	0.0014	
0.016	1200	0.00081	

(b)

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

$\mathcal{E} = I(r + R_{var})$

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?

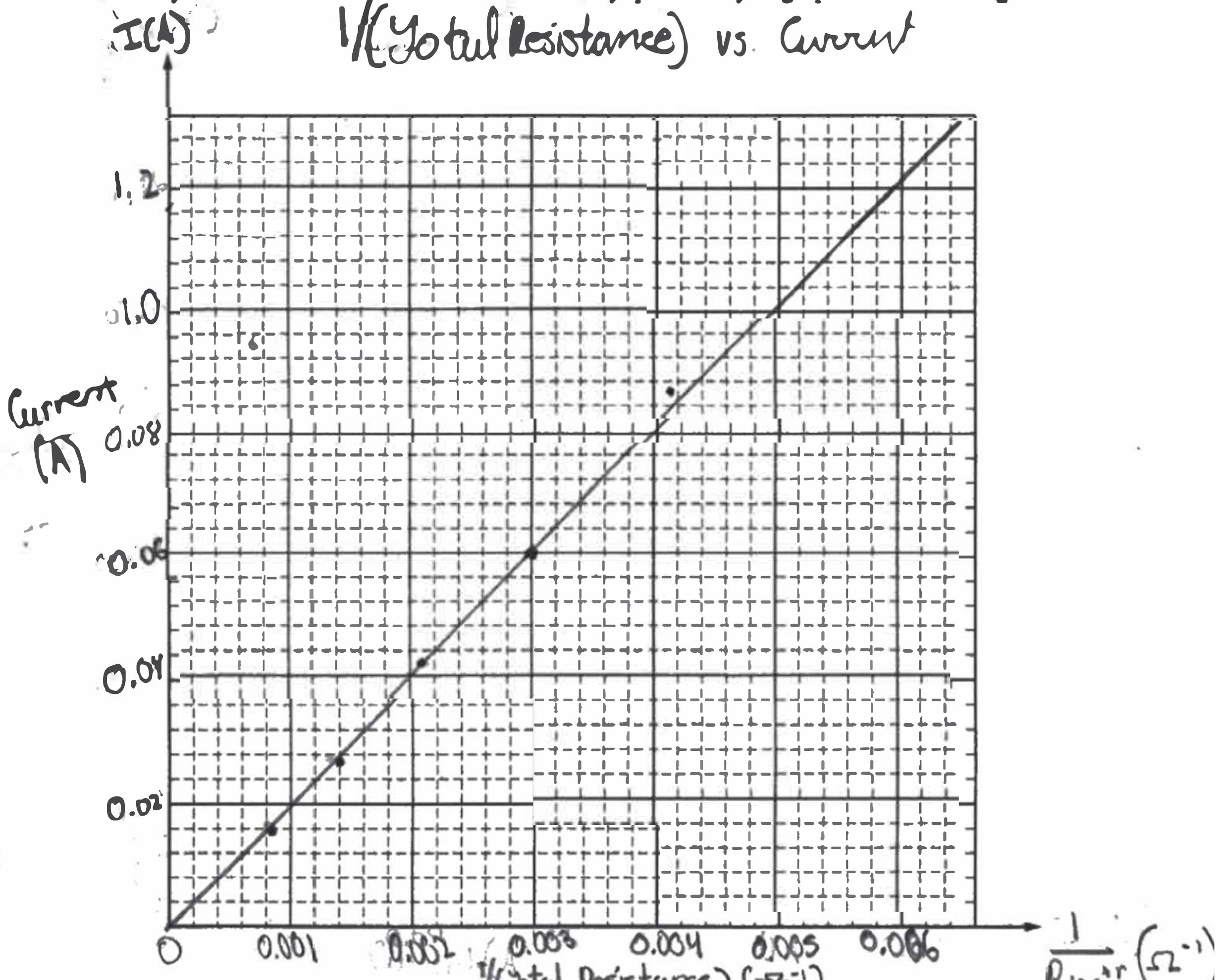
Horizontal Axis: $\frac{1}{\text{Total Resistance}}$ (Ω^{-1}) Vertical Axis: Current (A)

Question 2

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.

1/(Total Resistance) vs. Current



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

$$\mathcal{E} = \frac{I_2 - I_1}{\left(\frac{1}{R_{var_2}+r}\right) - \left(\frac{1}{R_{var_1}+r}\right)} = \frac{0.06 - 0.016}{0.003 - 0.0008} = 20\text{ V}$$

$\mathcal{E} = 20\text{V}$

GO ON TO THE NEXT PAGE.

Question 2

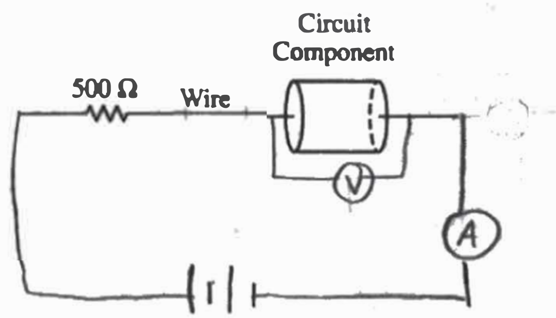
Begin your response to QUESTION 2 on this page.

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 Ω.

(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).

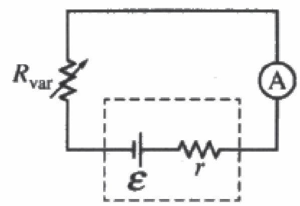
1. Connect the voltmeter in parallel to the circuit component and the ammeter to the circuit in series
2. Measure the voltage and current immediately after turning on the power supply or connecting the battery.
3. Wait 10 seconds before measuring the voltage and current again
4. Repeat Step 3 5 times

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

If the component is an uncharged capacitor, then the potential difference and current should decrease nonlinearly and begin to approach 0. According to Ohm's Law ($\frac{V}{I}=R$), the current should decrease as the resistance increases, and after a long time in steady-state, there should be approximately ∞ resistance, which means that the current should be about 0 and therefore ΔV should be 0.

Question 2

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)	$\left(\frac{1}{k\Omega}\right)$ $\frac{1}{R_{eq}}$	
0.087	200	2	
0.060	300	1.667	
0.042	450	1.333	
0.027	700	1	
0.016	1200	0.667	

(b)

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

$V = IR_{eq}$ $\qquad$ $R_{eq} = R_{var} + r$

$\therefore \mathcal{E} = I(R_{var} + r)$ $\qquad$ $V = \mathcal{E}$

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: $\frac{1}{R_{eq}}$ $\left(\frac{1}{k\Omega}\right)$ $\qquad$ Vertical Axis: I (A)

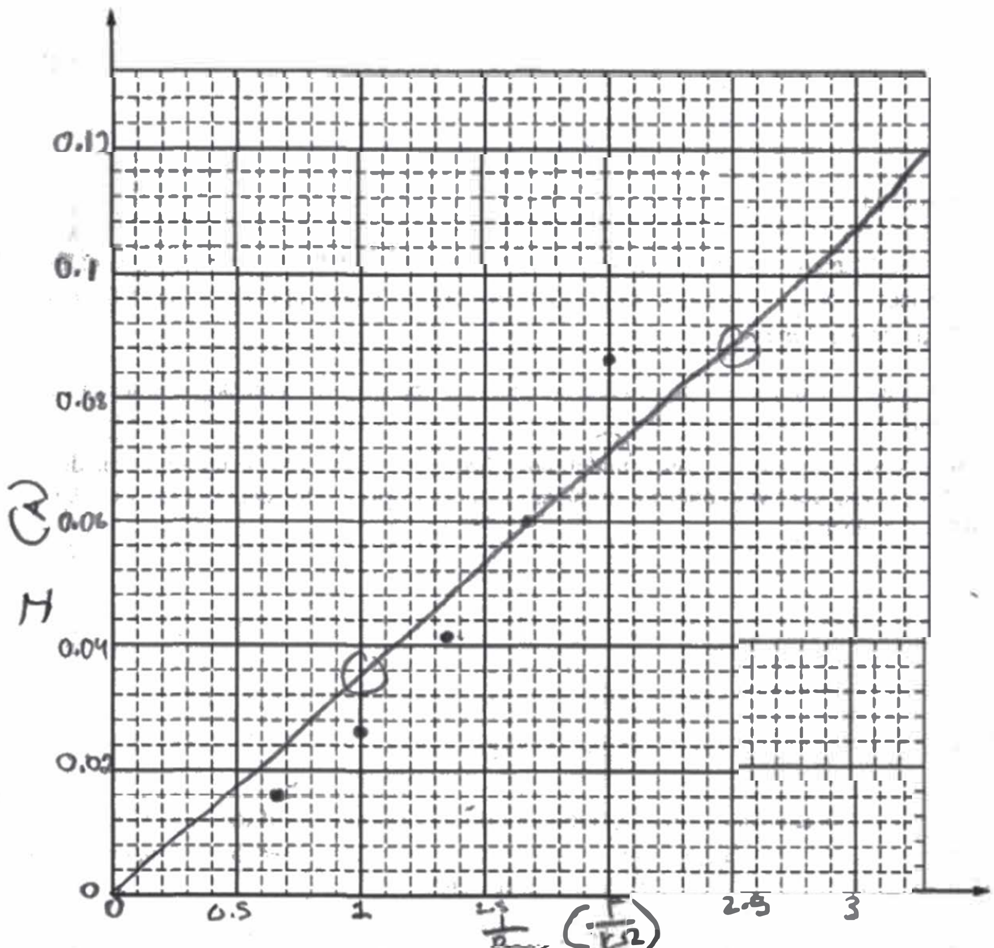
$$I = \frac{\mathcal{E}}{(R_{var} + r)}$$

GO ON TO THE NEXT PAGE.

Question 2

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.

Slope: $\frac{y_2 - y_1}{x_2 - x_1} = \frac{\cancel{0.088 - 0.036}}{(2.5 - 1} = 0.0346$

$I R_{eq} = \mathcal{E}$

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Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Q5186/9

Question 2

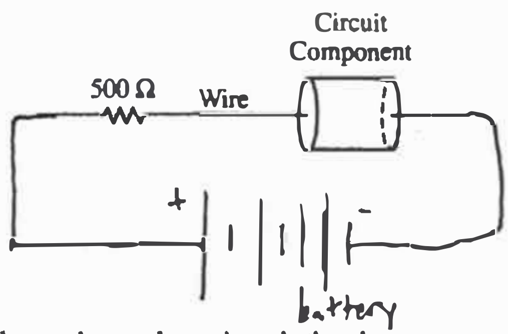
Begin your response to QUESTION 2 on this page.

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 Ω.

(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).

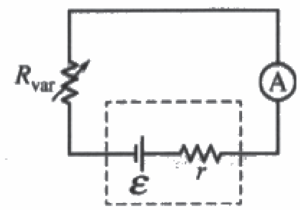
You would use an ameter to find the current and if the system doesn't have the same current after traveling through. Than you can predict that it is a resistor due to resistors limiting current through systems.

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

The potential difference would be around or equal to zero. The charge of the system would be neutral due to the capacitor holding the charge.

Question 2

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}.

$$\mathcal{E} = \frac{Ir}{R}$$

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?

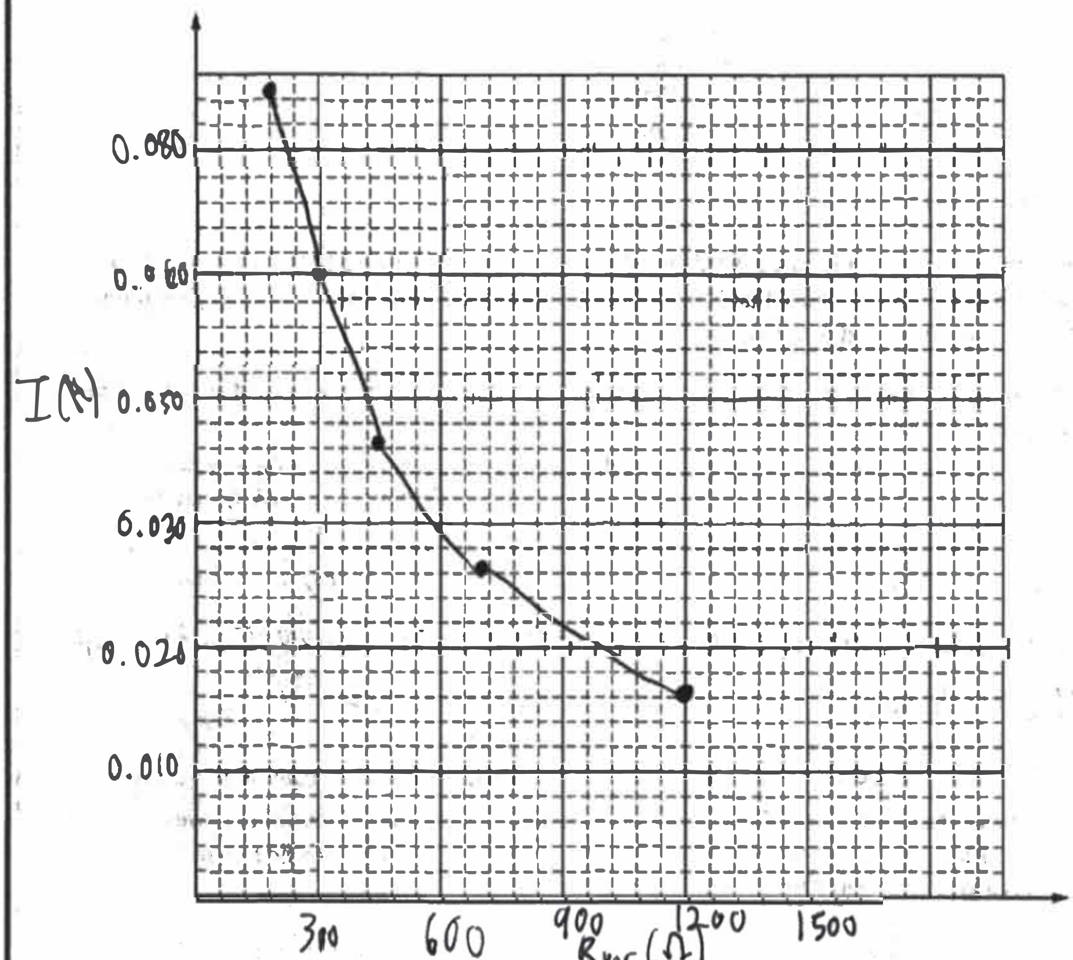
Horizontal Axis: I (A) Vertical Axis: R_{var} (Ω)

GO ON TO THE NEXT PAGE.

Question 2

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.

$$\varepsilon = \frac{(300)(20\Omega)}{(10\Omega)}$$

$$\varepsilon = 30\ \Omega$$

Question 2

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses were expected to demonstrate the ability to:

- Complete a circuit diagram to use in an experiment to determine the identity of an unknown circuit component.
- Describe an experiment to properly collect data about the electric circuit over a period of time.
- Demonstrate understanding of the decrease in the current in an RC circuit and the increase of the potential difference across a capacitor while a capacitor is being charged.
- Write a Kirchhoff's Loop Rule equation to describe a circuit that includes a nonideal battery that has internal resistance.
- Recognize how Kirchhoff's Loop Rule equation can be used to determine the emf of the battery by selecting the appropriate variables to graph.
- Plot data with appropriate scaling and label axes of a graph with the appropriate quantities and units.
- Draw a best-fit line using a straightedge that follows the trend of the data.
- Use the graph and appropriate equation to determine the emf of a nonideal battery.

Sample: 2A
Score: 12

Part (a) earned 6 points. The first point was earned for correctly including a source of potential difference in the diagram. The second point was earned for correctly including an appropriately connected measuring device in the diagram. The third point was earned for correctly describing a procedure that includes a measurement of current and voltage. The fourth point was earned for correctly describing a procedure that includes a measurement at different times. The fifth point was earned for correctly indicating both that the current in the circuit would decrease over time and that the capacitor would store more charge. The sixth point was earned for correctly indicating that the potential difference across the capacitor would increase over time. Part (b) earned 6 points. The first point was earned for correctly including an equation that applies the loop rule. The second point was earned for correctly indicating quantities that, when graphed, result in a linear graph that allows the determination of the emf of the battery. The third point was earned for correctly labeling both axes with a linear scale and with correct labels and units. The fourth point was earned for correctly plotting the data over more than half of the grid area. The fifth point was earned for correctly drawing a best-fit line that approximates the data. The sixth point was earned for correctly using the graph to determine an experimental value for the emf with correct units of volts.

Question 2 (continued)

Sample: 2B
Score: 10

Part (a) earned 5 points. The first point was earned for correctly including a source of potential difference in the diagram. The second point was earned for correctly including an appropriately connected measuring device in the diagram. The third point was earned for correctly describing a procedure that includes a measurement of current. The fourth point was earned for correctly describing a procedure that includes a measurement at different times. The fifth point was earned for correctly indicating both that the current in the circuit would decrease over time and that the capacitor would store more charge. The sixth point was not earned because the response does not correctly indicate that the potential difference across the capacitor would increase over time. Part (b) earned 5 points. The first point was earned for correctly including an equation that applies the loop rule. The second point was earned for correctly indicating quantities that, when graphed, result in a linear graph that allows the determination of the emf of the battery. The third point was earned for correctly labeling both axes with a linear scale, and with correct labels and units. The fourth point was earned for correctly plotting the data over more than half of the grid area. The fifth point was earned for correctly drawing a best-fit line that approximates the data. The sixth point was not earned because the response does not correctly determine an experimental value for the emf . This is a result of incorrectly calculating the inverse of the total resistance.

Sample: 2C
Score: 3

Part (a) earned 2 points. The first point was earned for correctly including a battery in a complete circuit. The second point was not earned because the response does not correctly include a measurement device that is appropriately connected in the circuit. The third point was earned because the response describes the appropriate use of a measurement device by measuring the current in the circuit. The fourth point was not earned because the response does not describe taking measurements at different times or after a long time. The fifth point was not earned because the response does not describe a correct result of the experiment that indicates the current in the circuit decreases to zero over time. The sixth point was not earned because the response does not describe a correct result of the experiment that indicates that the electric potential difference across the capacitor increases from zero over time. Part (b) earned 1 point. The first point was not earned because the response does not include an equation that correctly applies the loop rule. The second point was not earned because the response does not indicate appropriate quantities that, when graphed, result in a linear graph that would allow for a determination of the emf . The third point was not earned because, although the response does correctly include numerical values on both axes with a linear scale, the scale on the y-axis is not linear. The fourth point was earned for correctly displaying the data plotted within at least half of the grid area. The fifth point was not earned because the response does not correctly display a smoothly drawn best-fit line that approximates the trend of the data. The sixth point was not earned because the response does not correctly determine the emf of the battery.