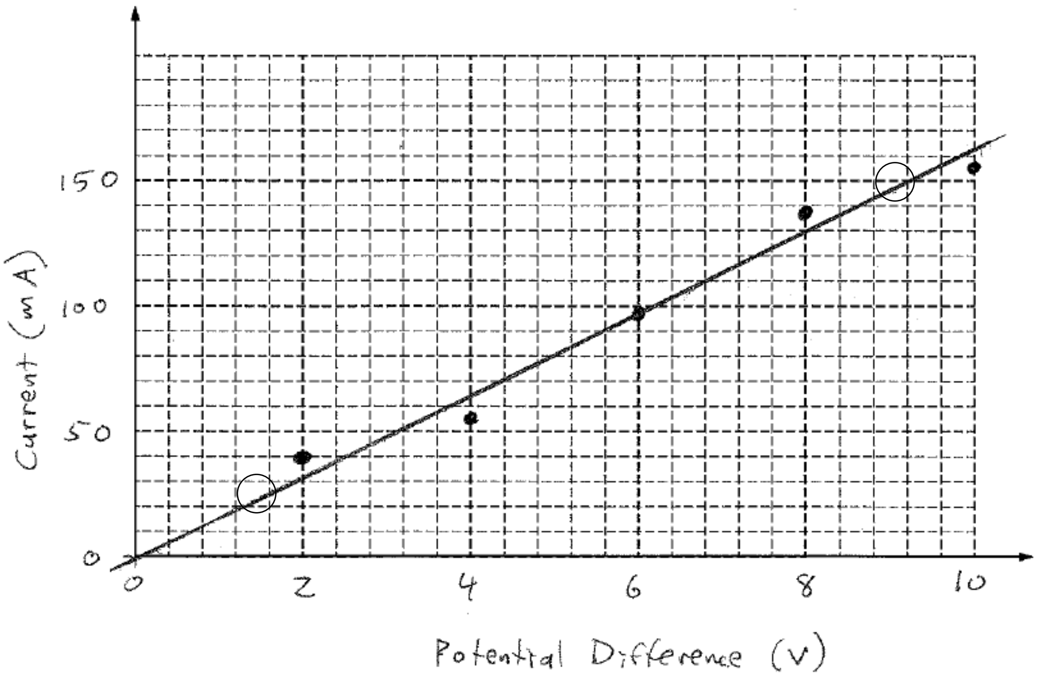
Question 1

15 points total **Distribution of points**

(a) 3 points



For labeling both axes with proper variables and units, and using appropriate linear scales for both axes — 1 point

For properly plotting the data points — 1 point

For drawing a reasonable best-fit straight line — 1 point

(b) 3 points

For calculating a slope using points on the line drawn in part (a), not data points unless they are on that line — 1 point

$$m = \frac{\Delta I}{\Delta V} = \frac{(150 - 25\ ) \times 10^{-3}\ \text{A}}{(9.2 - 1.6)\ \text{V}} = 0.0164\ \text{A/V}$$

For correctly relating the slope to the resistance — 1 point

$V = IR$

$I = \frac{V}{R} = \frac{1}{R}V$

$\text{slope} = \frac{1}{R}$

$R = \frac{1}{\text{slope}} = \frac{1}{(0.0164\ \text{A/V})}$

For an answer with correct units consistent with the calculated slope — 1 point

$R = 61\ \Omega$

Note: linear regression yields a slope of $0.01565\ \text{A/V}$ and an answer of

$R = 63.9\ \Omega$

Question 1 (continued)

Distribution of points

(c) 2 points

For substituting the answer from part (b) into a correct equation to solve for R_1 — 1 point

For recognizing that R_2 and R_3 are in series — 1 point

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2 + R_3}$$

$$\frac{1}{R_1} = \frac{1}{(R_T)} - \frac{1}{(R_2 + R_3)} = \frac{1}{(61\ \Omega)} - \frac{1}{(50\ \Omega + 50\ \Omega)} = 0.0064/\Omega$$

$$R_1 = 156\ \Omega$$

(d) 2 points

For using a correct equation to solve for I_2 — 1 point

$$I_2 = \frac{V}{R_2 + R_3}$$

Substitute values

$$I_2 = \frac{(12\ \text{V})}{(50\ \Omega + 50\ \Omega)}$$

For a correct answer with units — 1 point

$$I_2 = 0.12\ \text{A}$$

(e) i. 1 point

For substituting proper values into a correct equation to solve for I_2 — 1 point

$$I_2 = \frac{V}{R_2} = \frac{(12\ \text{V})}{(50\ \Omega)}$$

$$I_2 = 0.24\ \text{A}$$

ii. 2 points

For selecting “Less than” — 1 point

For a correct justification — 1 point

Example: After a long time, the capacitor is completely charged and there is no current in the capacitor branch because the voltage across the capacitor is equal to the battery voltage, so there is no current through or voltage drop across R_2 .

Note: If the wrong choice is selected, then no credit is given .

Question 1 (continued)

Distribution of points

(f) 2 points

For selecting "Equal to"	1 point
For a correct justification	1 point

Examples:

Immediately after the switch is closed, the uncharged capacitor has no resistance to current or it acts like a wire. Therefore it does not affect the current through R_2.

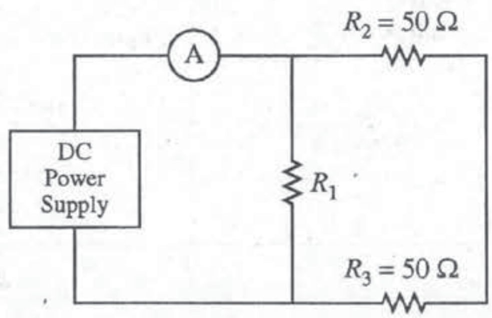
The mathematical calculation in part (e)i does not depend on the value of C so changing the capacitance has no effect.

Note: If the wrong choice is selected, then no credit can be earned.

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II
Time—45 minutes
3 Questions

Directions: Answer all three questions. The suggested time is about 15 minutes for answering each of the questions, which are worth 15 points each. The parts within a question may not have equal weight. Show all your work in this booklet in the spaces provided after each part.

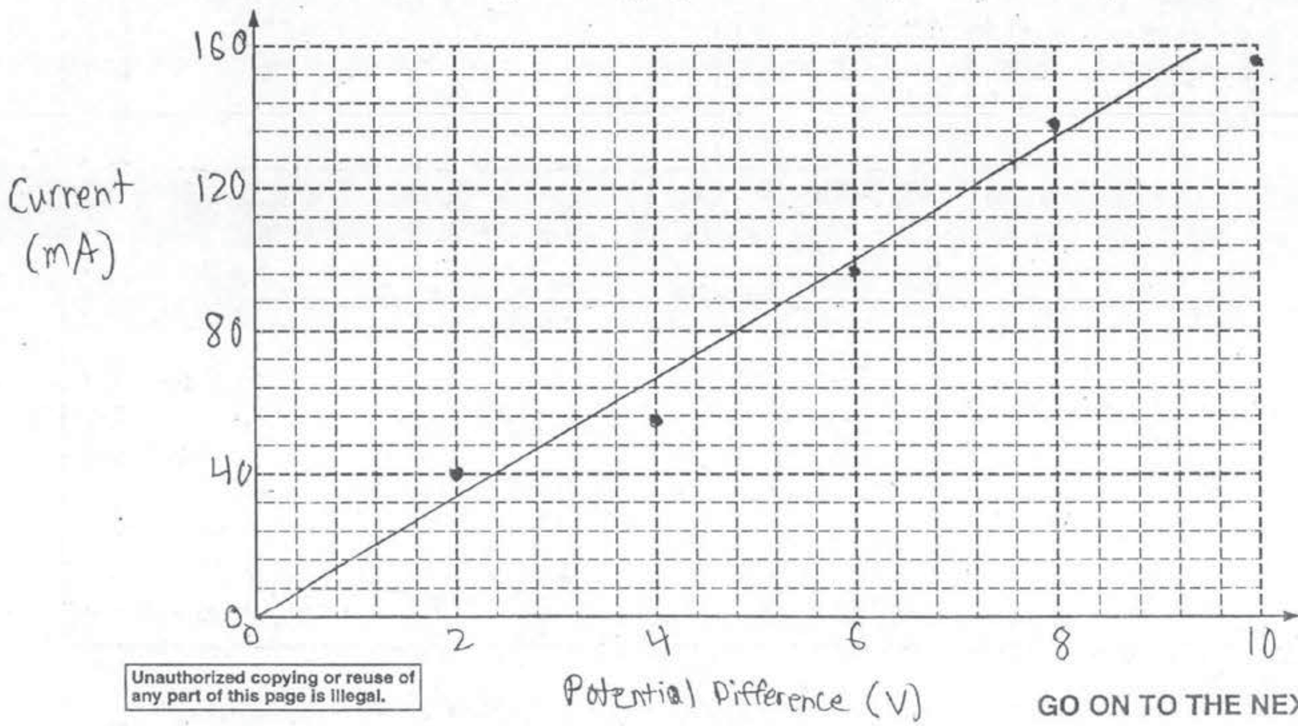


E&M. 1.

Physics students are analyzing the circuit above. A variable DC power supply is connected to an ammeter and three resistors. The resistances of two of the resistors are known to be $R_2 = R_3 = 50\ \Omega$, but the resistance of the third resistor is unknown. The students collect data on the potential difference across the power supply and the current measured by the ammeter, as follows.

Potential Difference (V)	2	4	6	8	10
Current (mA)	40	55	97	138	155

(a) On the grid below, plot the data points for the current as a function of the potential difference. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



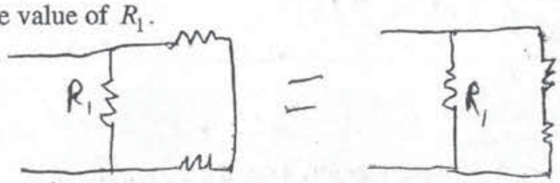
GO ON TO THE NEXT PAGE.

(b) Using the straight line from part (a), calculate the total resistance of the three-resistor combination.

$$R = \frac{V}{I} = \frac{6V}{100\,mA} = \frac{6V - 0V}{0.1A \;\; 0.0A}$$

$$R_{Tot} = 60\,\Omega$$

(c) Calculate the value of R_1.



$$R' = R_2 + R_3 = 50\,\Omega + 50\,\Omega = 100\,\Omega$$

$$R_1 = 150\,\Omega$$

$$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R'}$$

$$\frac{1}{60} = \frac{1}{R_1} + \frac{1}{100} \qquad \frac{1}{R_1} = \frac{1}{60} - \frac{1}{100} = \frac{5}{300} - \frac{3}{300} = \frac{1}{150}$$

The power supply is now fixed at 12 V.

(d) Calculate the current through R_2.

$$R_{TOT} = 60\,\Omega;\; V = 12V$$

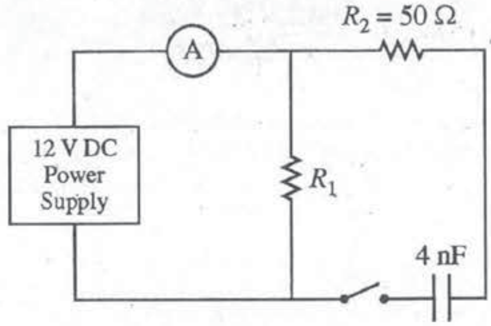
$$I_{net} = \frac{V}{R_{TOT}} = \frac{1}{5}A$$

$$I_{R_2+R_3} = \frac{V}{R_2+R_3} = \frac{12V}{100\,\Omega} = 0.12\,A$$

$$I_{R_2} = 0.12A$$

GO ON TO THE NEXT PAGE.

(e) Resistor 3 is now removed and replaced by an open switch in series with an uncharged 4 nF capacitor, as shown below. The power supply is still fixed at 12 V.



i. Calculate the current in R_2 immediately after the switch is closed.

$$I_{R_2} = \frac{V}{R_2} = \frac{12V}{50\Omega} = 0.24A$$

ii. A long time after the switch is closed, will the magnitude of the current in R_2 be greater than, less than, or equal to the current through R_2 found in part (d) ?

__ Greater than ✓ Less than __ Equal to

Justify your answer.

Once the voltage difference across the capacitor equals the voltage of the power supply, the capacitor will act as an open switch (not let any current through). Therefore, R_2 will have 0 A of current flowing through it as well since it is in series with the capacitor.

(f) The 4 nF capacitor is replaced with an uncharged 10 nF capacitor. Will the magnitude of the current in R_2 immediately after the switch is closed be greater than, less than, or equal to the current in part (e)i?

__ Greater than __ Less than ✓ Equal to

Justify your answer.

Before the capacitor starts storing charge, it has no voltage drop across it, and therefore acts like a piece of wire. Different capacitances have no effect in the instant after the switch is closed.

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

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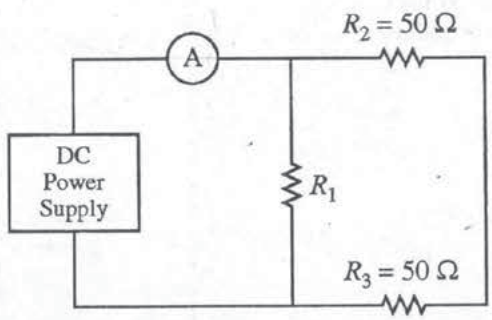

E&M. 1.

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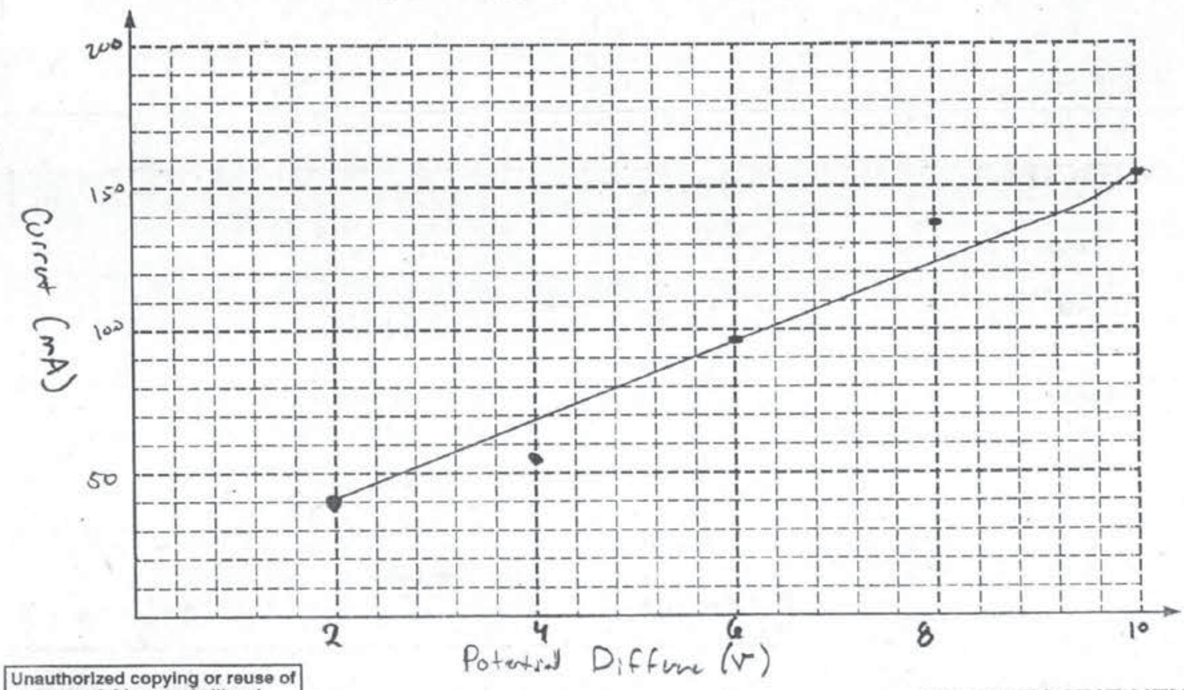


GO ON TO THE NEXT PAGE.

(b) Using the straight line from part (a), calculate the total resistance of the three-resistor combination.

$$\Sigma R = \frac{\Sigma V}{\Sigma I}$$

$$\frac{1}{\Sigma R} = \frac{\Sigma I}{\Sigma V} = \frac{.155 - 0.04}{10 - 2} = .014735 = \frac{1}{\Sigma R}$$

$$\Sigma = 65.565\,\Omega$$

(c) Calculate the value of R_1.

$$R_2 + R_3 = R_{2+3}$$

$$50 + 50 = R_{2+3}$$

$$100 = R_{2+3}$$

$$\frac{1}{R_{2+3}} + \frac{1}{R_1} = \frac{1}{\Sigma R}$$

$$\frac{1}{100} + \frac{1}{R_1} = \frac{1}{65.565}$$

$$R_1 = 228.57\,\Omega$$

The power supply is now fixed at 12 V.

(d) Calculate the current through R_2.

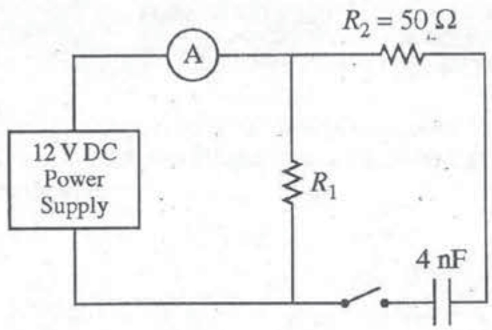
$$\mathcal{E} = 12\,V \qquad V = IR$$

$$R_2 = 50\,\Omega \qquad 12 = I \cdot 50$$

$$0.24\,A = I$$

GO ON TO THE NEXT PAGE.

(e) Resistor 3 is now removed and replaced by an open switch in series with an uncharged 4 nF capacitor, as shown below. The power supply is still fixed at 12 V.



i. Calculate the current in R_2 immediately after the switch is closed.

~~V=IR~~ V=IR $I_0 = \frac{V}{R}$

~~12=I·50~~ 12 = I·50

~~0.24A=I~~ 0.24A = I

ii. A long time after the switch is closed, will the magnitude of the current in R_2 be greater than, less than, or equal to the current through R_2 found in part (d) ?

X Greater than ___ Less than ___ Equal to

Justify your answer.

After a long period of time the capacitor is treated as if it were a simple wire due to the charge and capacitor reaching a level of equilibrium

(f) The 4 nF capacitor is replaced with an uncharged 10 nF capacitor. Will the magnitude of the current in R_2 immediately after the switch is closed be greater than, less than, or equal to the current in part (e)i?

__ Greater than X Less than __ Equal to

Justify your answer.

The increase in capacitan will affect the amount of both chan and current to reach th Resistor, lowering th both as the capacitor begins to charge.

GO ON TO THE NEXT PAGE.

E1 C1

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

Time—45 minutes

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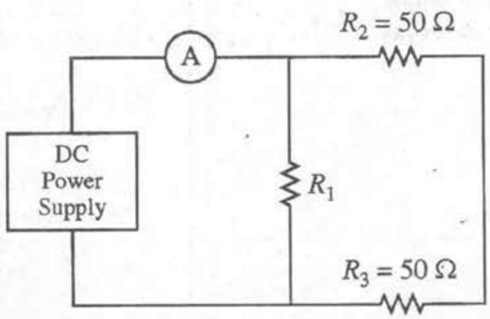

E&M. 1.

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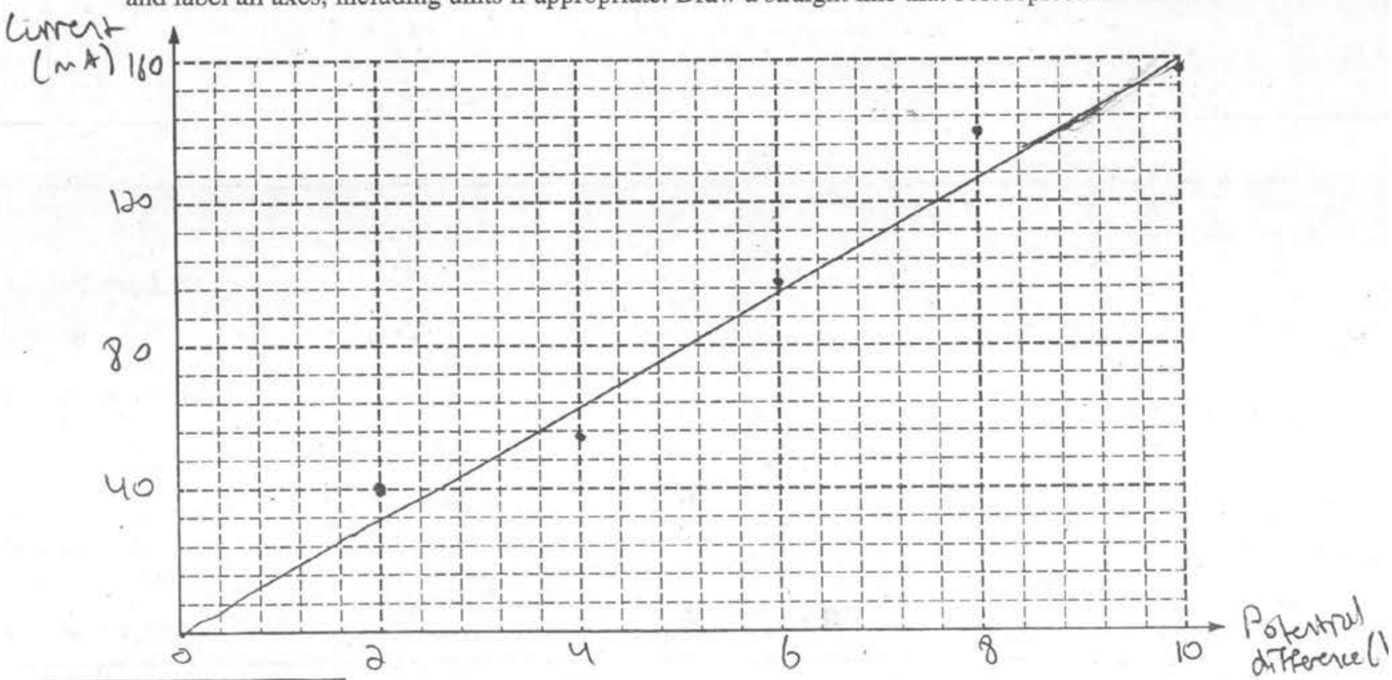


GO ON TO THE NEXT PAGE.

(b) Using the straight line from part (a), calculate the total resistance of the three-resistor combination.

(7.6, 120)
(3.6, 56)

$\frac{120-56}{7.6-3.6} = \frac{64}{4} = 16 = .016$ amps/volt

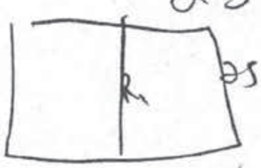
62.5 volts/amp

$\frac{V}{I} = R$ $R = 62.5$

(c) Calculate the value of R_1.

$\left(\frac{1}{50} + \frac{1}{80}\right)^{-1} = 25$

25



$62.5 = 25 + R_1$

$R_1 = 37.5\ \Omega$

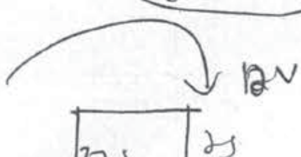
The power supply is now fixed at 12 V.

(d) Calculate the current through R_2.

$V = IR$

$12 = I\,80$

$I = .24$

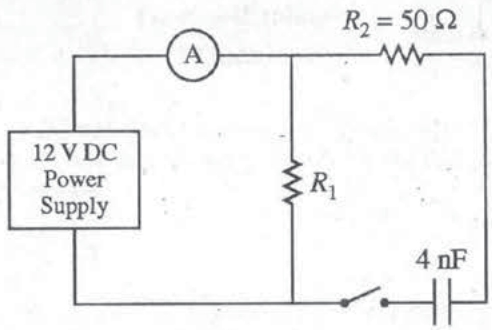


$12 = I\,25$

$I = \frac{1}{2}$

GO ON TO THE NEXT PAGE.

(e) Resistor 3 is now removed and replaced by an open switch in series with an uncharged 4 nF capacitor, as shown below. The power supply is still fixed at 12 V.



i. Calculate the current in R_2 immediately after the switch is closed.

0 V $C = \frac{Q}{V}$ $\frac{}{12} =$ 2.4×10^{-8}

ii. A long time after the switch is closed, will the magnitude of the current in R_2 be greater than, less than, or equal to the current through R_2 found in part (d) ?

__ Greater than __ Less than X Equal to

Justify your answer.

The capacitor will be fully charged after a while so the voltage will be going through as if it was not there as in part (d).

(f) The 4 nF capacitor is replaced with an uncharged 10 nF capacitor. Will the magnitude of the current in R_2 immediately after the switch is closed be greater than, less than, or equal to the current in part (e)i?

__ Greater than X Less than __ Equal to

Justify your answer.

The capacitor is greater and uncharged, so the current will be hindered because the capacitor has to charge and even after it charges it will still allow less current to go through at a time

Question 1

Overview

This question involved an experiment where voltage was varied and current was measured. In addition to assessing data analysis, the question was intended to assess student understanding of *RC* circuits, especially the loop rule. It required students to use data to make a graph of current versus voltage to determine resistance, to solve a few simple loop rule questions, and then to answer and justify questions about capacitor charging behavior.

Sample: E1 A
Score: 15

This response earned full credit in all parts. It also has clear justifications in parts (e)(ii) and (f) that identify the physical reasons why a capacitor acts like an open or a short circuit.

Sample: E1 B
Score: 9

This response earned full credit in parts (a) and (b). Since the best fit line was drawn through two original data points, those points are acceptable to use to calculate the slope. Part (c) also earned full credit, even though the final answer was incorrect, since the points were awarded for understanding the correct procedure and not the final answer. Part (d) earned no credit. Part (e)(i) earned full credit, but parts (e)(ii) and (f) earned zero points because the selections were incorrect.

Sample: E1 C
Score: 5

This response earned full credit in part (a). Part (b) lost 1 point because the final answer has no units. In part (c) the calculation treats R_2 and R_3 as if they were in parallel and then treats their sum as if it was in series with R_1, so no points were earned. In part (d) the response does not include both R_2 and R_3, and no points were earned. No credit was earned for parts (e) or (f).