2022

AP® | CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 2

- ☑ Scoring Guidelines
- ☑ Student Samples
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Question 2: Experimental Design — 12 points

(a) For a correct ranking — **1 point**

__1__ ΔV_A __1__ ΔV_B __3__ ΔV_C __2__ ΔV_D

For indicating that the resistors in parallel will have the same potential difference — **1 point**

For a justification that indicates $\Delta V_D > \Delta V_C$ because $R_D = 2R_C$ — **1 point**

Total for part (a) — 3 points

(b)(i) For calculating the correct value of the charge on the $200\,\mu F$ capacitor, including units — **1 point**

Example Response

$$\Delta V = \frac{Q}{C}$$

$$Q = C\Delta V = (200\,\mu F)(0.91\text{ V})$$

$$Q = 1.82 \times 10^{-4}\text{ C}$$

(b)(ii) For indicating one of the following as evidence that the capacitors are in series: — **1 point**

- the potential differences across the capacitors are different
- the sum of the potential differences across the capacitors is constant
- the sum of the potential differences across the capacitors is approximately equal to the potential difference across the battery

(b)(iii) For an explanation that correctly addresses one of the following: — **1 point**

- that the potential differences across the known and unknown capacitor will always be the same
- that the charge on the unknown capacitor cannot be determined

Example Response

Both charge and potential difference across the capacitor are needed to determine C. Arranging the capacitors in parallel will mean both capacitors will have the same potential difference. However, capacitors in parallel will have differing amounts of charge, making it impossible to determine the charge, and, therefore, the capacitance of the unknown capacitor.

Total for part (b) — 3 points

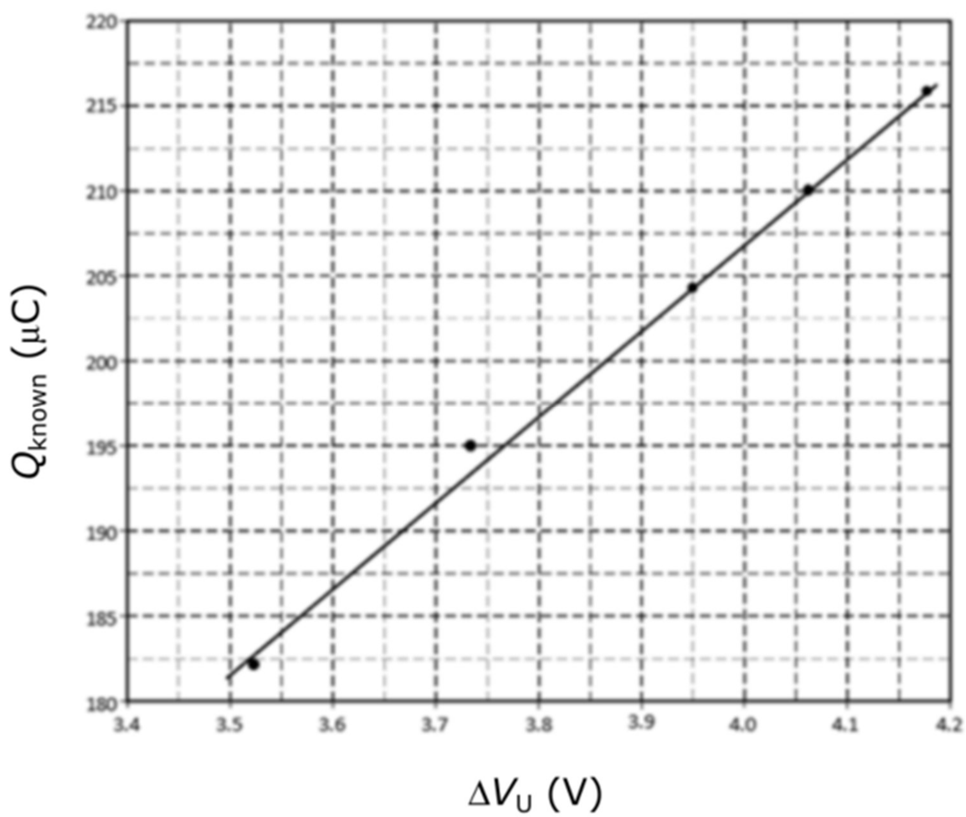
(c)(i)	For choosing two quantities that will produce a linear plot that can be used to find C_U	**1 point**

Example Responses

- Q_{known} $(C_{known}\Delta V_{known})$ and ΔV_U
- Q_U and ΔV_U
- C_{known} and $\dfrac{\Delta V_U}{\Delta V_{known}}$

(c)(ii)	For labeling the axes and including appropriate units consistent with Part (c)(i)	**1 point**
	For correctly plotting points (with valid scaling consistent with units) so that the plotted points cover at least half of the grid's width and height	**1 point**
	For drawing an appropriate linear best-fit line	**1 point**

Example Response



(c)(iii)	For using points on the best-fit line to calculate the slope of the line	**1 point**
	For correctly determining the capacitance from the slope of the line	**1 point**

Example Response

Capacitance is equal to slope

$$C_U = \frac{212\ \mu C - 190\ \mu C}{4.10\ V - 3.67\ V}$$

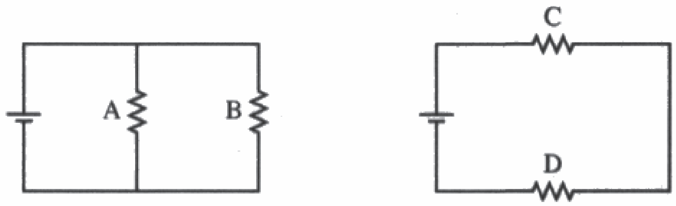
$$C_U = 51.2\ \mu F$$

Total for part (c) 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 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.

1 ΔV_A 1 ΔV_B 3 ΔV_C 2 ΔV_D

Justify your answer.

Let $\mathcal{E}$ be the potential difference across the battery.

$\Delta V_A = \Delta V_B = \mathcal{E}$ since the resistors A and B are connected in parallel, which means the ~~tot~~ potential difference across them is the same.

In the second circuit, $R_{eq} = R_C + R_D = R + 2R = 3R$. So, the current I through both resistors is $I = \frac{V}{R_{eq}} = \frac{\mathcal{E}}{3R}$. The potential differences across them is $\Delta V_C = IR = \frac{\mathcal{E}}{3R} \cdot R = \frac{\mathcal{E}}{3}$ and $\Delta V_D = IR = \frac{\mathcal{E}}{3R} \cdot 2R = \frac{2}{3}\mathcal{E}$. So $\Delta V_A = \Delta V_B > \Delta V_D > \Delta V_C$.

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.

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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.

Question 2

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

Known Capacitance of Capacitors (μF)	ΔV_{known} (V)	ΔV_U (V)	$\Delta V_{known} \times C_{known} = Q_{known}$ (μC)	
200	0.91	3.53	182	
300	0.65	3.74	195	
400	0.51	3.95	204	
500	0.42	4.06	210	
600	0.36	4.17	216	

(b)

i. Calculate the amount of charge on the capacitor of known capacitance of 200 μF in the students' experiment.

$\Delta V = \frac{Q}{C}$ so $Q = C\Delta V = (200\,\mu F)(0.91\,V)$

$Q = 182\,\mu C$

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

The sum of potential differences $\Delta V_{known} + \Delta V_u$ is around 4.5V ~~3.40~~ for all of the trials, which means the capacitors are connected in series where the sum of the voltage drops across components equals the potential difference of the battery.

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.

With a voltmeter and the capacitors connected in parallel, we would only be able to determine the voltage across the capacitor which would be around 4.5V, the voltage of the battery. Since $C = \frac{Q}{\Delta V}$, we would have no way of finding the charge of the capacitor so we wouldn't be able to find the unknown capacitance.

Question 2

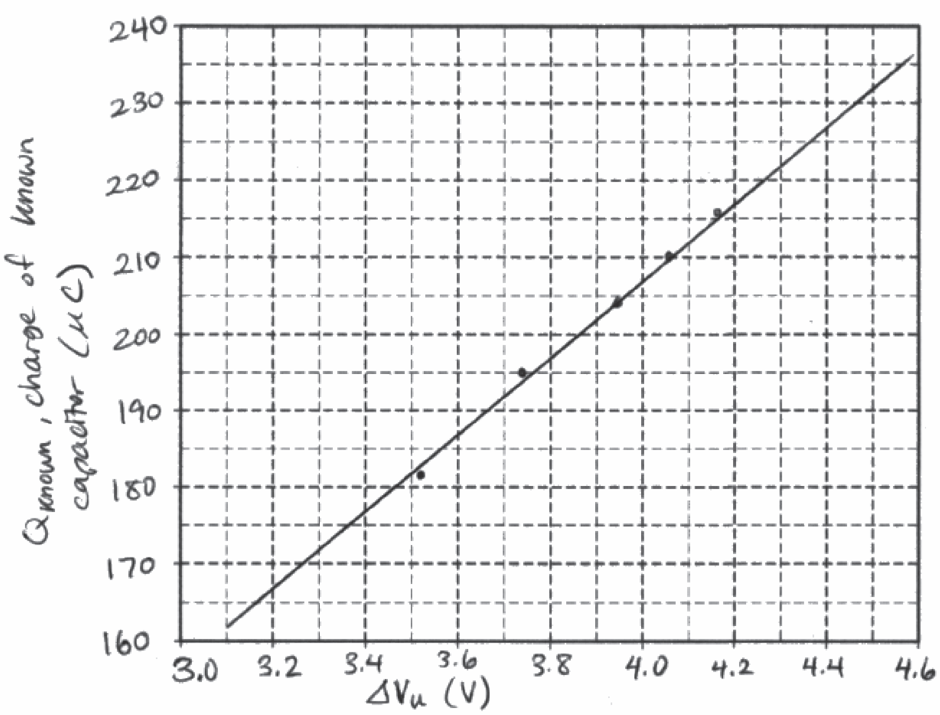
Continue your response to **QUESTION 2** on this page.

(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 Q_{known} - charge of known capacitor Horizontal axis ΔV_u

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.

$Q_{known} = Q_u = C_u \Delta V_u$ so slope $= C_u$

$$\text{slope} = \frac{(207 - 187)\,\mu C}{(4.0 - 3.6)\,V} = \frac{20\,\mu C}{0.4\,V} = 50\,\mu F = C_u$$

Question 2

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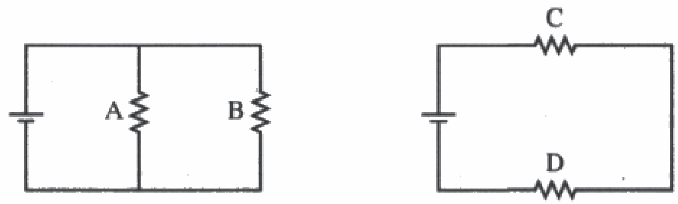

2. (12 points, suggested time 25 minutes)

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.

1 ΔV_A 1 ΔV_B 2 ΔV_C 3 ΔV_D

Justify your answer.

R_A is in || to R_B, so $\Delta V_A = \Delta V_B = \Delta V_{Batt}$.
ΔV_{Batt} is the same for both circuits because they use the same battery, so $\Delta V_C + \Delta V_D = \Delta V_{Batt}$.
Because $R_C < R_D$ and they are in series so I is same for both, by $\Delta V = IR$, $\Delta V_C < \Delta V_D$ and both are $< \Delta V_{Batt}$.

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.

Question 2

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 μF in the students' experiment.

$Q = C \cdot \Delta V$

$Q = (200\ \mu F)(0.91\ V)$

$= 181\ C$

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

When capacitors are is series, $\frac{1}{C_{total}} = \frac{1}{C_{known}} + \frac{1}{C_u}$. As Cknown is increasd, the Ctotal decreases which increases ΔV ($\Delta V = Q/C$) of the circuit which is reflected in the graph's data.

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.

Capacitors in parrallel increase Ctotal. Increasing the capacitance in the circuit will end up making ΔV very small and difficult to measure with a voltmeter.

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Question 2

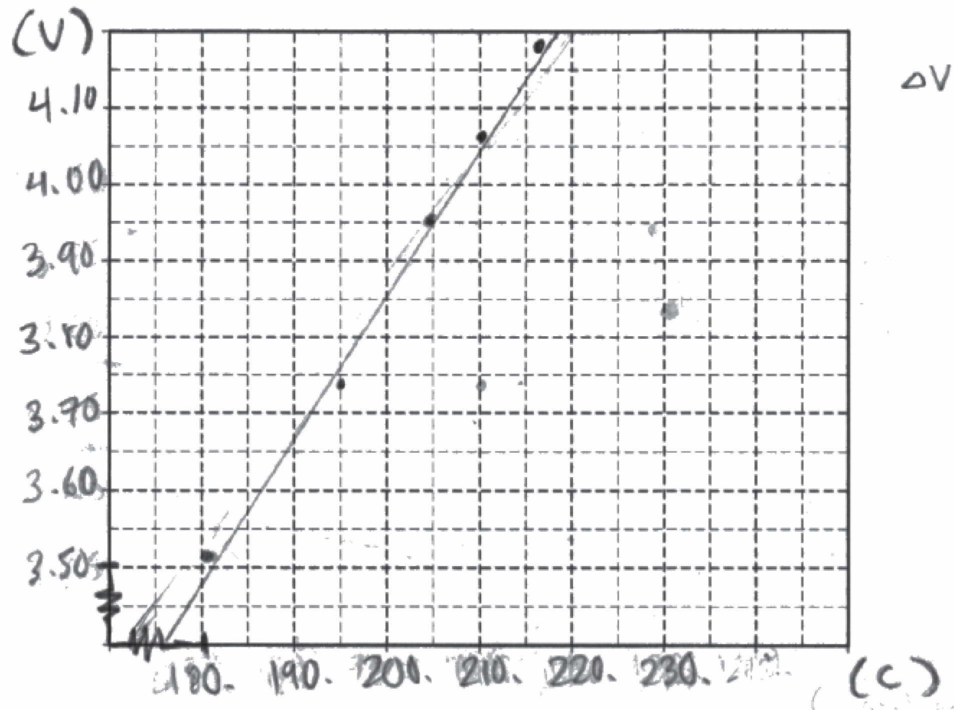
Continue your response to **QUESTION 2** on this page.

(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 ΔV_u Horizontal axis ΔV_{unown} · (Known Capacitance)

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.



$\Delta V = \frac{1}{C} Q$

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

$$\left(\frac{4.14 - 3.85}{215. - 200}\right)^{-1} = 51.7\ \mu F = C_u$$

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Q5331/7

Question 2

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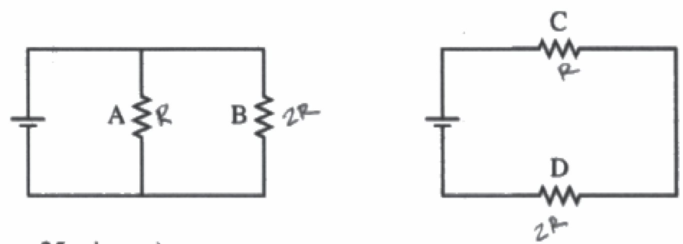


2. (12 points, suggested time 25 minutes)

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.

V=IR
↓↑

2 ΔV_A 1 ΔV_B 4 ΔV_C 3 ΔV_D

Justify your answer.

B has the greater magnitude of potential diffrence because it has the greater current flow and resistance. A has slightly less because it has less resistance, and D has even less because there is less current flow but it still has a greater resistance than that of C

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.

Question 2

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

C

Known Capacitance of Capacitors (μF)	ΔV_{known} (V)	ΔV_U (V)	$\frac{1}{\Delta V_{Known}}$	$Q = C\Delta V$
200	0.91	3.53	1.0989	219.78
300	0.65	3.74	1.53846	461.538
400	0.51	3.95	1.96078	784.314
500	0.42	4.06	2.38095	1170.46
600	0.36	4.17	2.77778	1666.67

(b)

i. Calculate the amount of charge on the capacitor of known capacitance of 200 μF in the students' experiment.

$\Delta V = \frac{Q}{C}$

$Q = \Delta V C$

$Q = (0.91\ v)(200\ \mu F)$

$= \boxed{182\ C}$

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

When capacitors are connected in series, their resistance is measured as if they were in parallel in normal circuits. Because the know ΔV is less than 1, they were measured as parallels, using $\frac{1}{C}$.

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.

To determine the capacitance of the unknown capacitor, they must be in series to be able to measure using the voltmeter.

Question 2

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

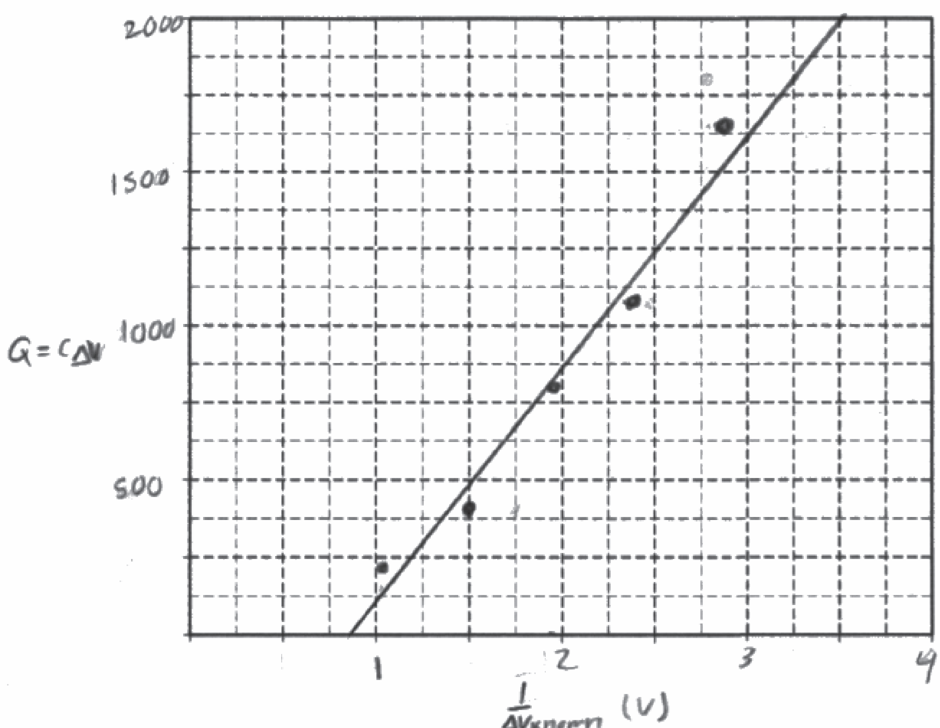
(c) The students want to produce a linear graph of the data so that the capacitance C_U of the unknown capacitor can be determined from the slope of the best-fit line for the data.

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.

$C = \frac{Q}{\Delta V}$

Vertical axis: Q   Horizontal axis: $\frac{1}{\Delta V_{known}}$

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.

$C_U = \frac{2000 - 0}{3.5 - .85} = 754.717$

$\approx$ **755 uF**

V = 4.5 V

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Q5331/7

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:

- Differentiate between the potential difference across resistors that are connected in series and parallel.
- Calculate the amount of charge on a fully charged capacitor using data from an experiment.
- Use data to describe the arrangement of capacitors in a circuit, i.e., whether the capacitors are connected in series or parallel.
- Utilize the fact that the amount of charge stored on two capacitors in series is equal in order to analyze experimental data.
- Plot data with appropriate scaling, labeling the 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.
- Calculate the slope of a best-fit line using two points on the line.

Sample: 2A
Score: 12

Part (a) earned 3 points. The first point was earned for a correct ranking. The second point was earned for indicating that the resistors in parallel will have the same potential difference. The third point was earned for discussing the proportionality of the potential difference across a resistor in series to the resistor's resistance. Part (b)(i) earned 1 point because the response includes the correct value and units for the charge on the known capacitor. Part (b)(ii) earned 1 point because the response correctly points out the evidence that the capacitors are in series because the total potential difference across the capacitors is approximately 4.5 V. Part (b)(iii) earned 1 point because the response addresses that the issue with connecting the capacitors in parallel is that the capacitors would have the same potential difference, so the charge on the unknown capacitor cannot be determined. Part (c)(i) earned 1 point because the response provides quantities that when plotted, produce a graph that can be used to determine the unknown capacitance. Part (c)(ii) earned 3 points. The first point was earned because the axes are labeled with the quantities provided in part (c)(i) and include units. The second point was earned because the data points are spread over the graph and are accurately plotted. The third point was earned because a reasonable linear best-fit line is also drawn. Part (c)(iii) earned 2 points. The first point was earned because two points on the best-fit line that are not data points are used to calculate the slope. The second point was earned because the correct value of the capacitance is calculated from the slope.

Question 2 (continued)

Sample: 2B
Score: 7

Part (a) earned 2 points. The first point was not earned because the ranking is inaccurate. The second point was earned because the response does include a statement that resistors in parallel have the same potential difference. The third point was earned because the response indicates that the resistor with the large resistance will also have a larger potential difference across it when the resistors are in series. Part (b)(i) earned 0 points because the calculated charge is not the correct value, and the units are not correct. Part (b)(ii) earned 0 points because the response discusses how to calculate the equivalent capacitance but does not reference data from the table. Part (b)(iii) earned 0 points because the response does not address that the potential differences across the known and unknown capacitors will always be the same, or that the charge on the unknown capacitor cannot be determined. Part (c)(i) earned 1 point because the response provides quantities that when plotted, produce a graph that can be used to determine the unknown capacitance; the capacitance will be the reciprocal of the slope. Part (c)(ii) earned 2 points. The first point was not earned because the axes are labeled with the quantities provided in part (c)(i), but the units are not included. The second point was earned because the data points are spread over the graph and are accurately plotted. The third point was earned because a reasonable linear best-fit line is also drawn. Part (c)(iii) earned 2 points. The first point was earned because two points on the best-fit line that are not data points are used to calculate the slope. The second point was earned because the correct value of the capacitance is calculated from the slope.

Sample: 2C
Score: 3

Part (a) earned 0 points. The first point was not earned because the ranking is inaccurate. The second point was not earned because the response does not include a statement that resistors in parallel have the same potential difference. The third point was not earned because the response does not describe the relationship between resistance and potential difference for resistors in series. Part (b)(i) earned 0 points because the calculated charge is correct, but the units are not consistent. Part (b)(ii) earned 0 points because the response discusses how to calculate the equivalent capacitance but does not reference data from the table. Part (b)(iii) earned 0 points because the response does not address that the potential differences across the known and unknown capacitors will always be the same, or that the charge on the unknown capacitor cannot be determined. Part (c)(i) earned 0 points because the response does not provide quantities that when plotted, produce a graph that can be used to determine the unknown capacitance. Part (c)(ii) earned 2 points. The first point was not earned because the axes are labeled with the quantities from part (c)(i) but do not include appropriate units. The second point was earned because the data points are spread over the graph and are accurately plotted. The third point was earned because a reasonable linear best-fit line is also drawn. Part (c)(iii) earned 1 point. The first point was earned because two points on the best-fit line that are not data points are used to calculate the slope. The second point was not earned because the correct value of the capacitance is not calculated from the slope.