2018

AP® CollegeBoard

AP Physics C: Electricity and Magnetism

Sample Student Responses and Scoring Commentary

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AP® PHYSICS
2018 SCORING GUIDELINES

General Notes About 2018 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

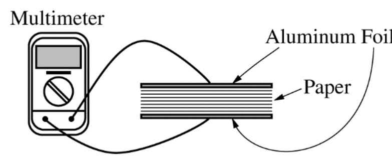
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked to derive an expression, it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 2

15 points total | **Distribution of points**



An experiment is designed to measure the dielectric constant of paper that has an area $A = 0.060\ \text{m}^2$. Using aluminum foil, two parallel plates are created with the same area as the paper. Five hundred sheets of paper are placed between the aluminum foil plates to create a parallel plate capacitor, as shown in the figure above. Using a multimeter, the capacitance C of the capacitor is measured. The number of sheets and the total thickness d of the stack of paper are recorded. The experiment is repeated, reducing the number of sheets of paper each time. The data are recorded in the table below.

Sheets of Paper	d (m)	C (F)		
500	0.045	6.5×10^{-11}		
400	0.036	7.4×10^{-11}		
300	0.027	8.9×10^{-11}		
200	0.018	11.9×10^{-11}		
100	0.010	21.0×10^{-11}		

(a) 1 point

Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the dielectric constant of the paper.

Vertical axis: ____________

Horizontal axis: ____________

Use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given. Label each column you use and include units.

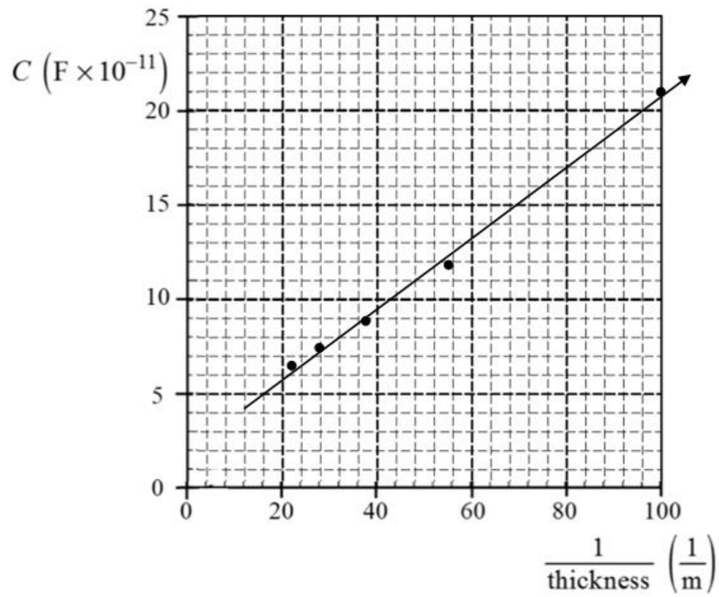
For indicating variables that will create a straight line whose slope can be used to determine the dielectric constant of the paper		1 point
Example: Vertical axis: C *Horizontal axis: $\frac{1}{d}$*		
Note: Student earns full credit if the axes are reversed or if they use another acceptable combination.		

Question 2 (continued)

Distribution of points

(b) 4 points

Plot the data points for the quantities indicated in part (a) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



For a correct scale that uses more than half the grid		1 point
For correctly labeling the axes including units		1 point
For correctly plotting the data		1 point
For drawing a straight line consistent with the plotted data		1 point

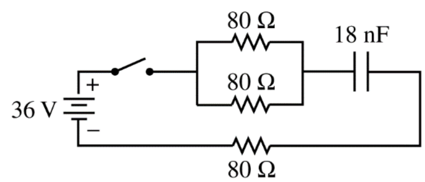
(c) 3 points

Using the straight line, calculate a dielectric constant for the paper.

For correctly calculating the slope from the best-fit line and not the data points unless the points fall on the best-fit line		1 point
$\text{slope} = \dfrac{\Delta y}{\Delta x} = \dfrac{(17-8)\left(\mathrm{F}\times 10^{-11}\right)}{(80-32)(1/\mathrm{m})} = 0.19\ \mathrm{F{\bullet}m}$ (Linear regression $= 0.187\ \mathrm{F{\bullet}m}$)		
For correctly relating the slope to the dielectric constant		1 point
$\text{slope} = \kappa\varepsilon_0 A$		
$\kappa = \dfrac{\text{slope}}{\varepsilon_0 A} = \dfrac{(0.19\ \mathrm{F{\bullet}m})}{\left(8.85\times 10^{-12}\ \mathrm{C^2/N{\bullet}m^2}\right)\left(0.060\ \mathrm{m^2}\right)}$		
For a correct answer		1 point
$\kappa = 3.58$ (Linear regression $= 3.52$)		

Question 2 (continued)

Distribution of points



The student now makes a capacitor using the same aluminum foil plates and just one sheet of paper. Using the experimentally determined dielectric constant, the student calculates the capacitance to be 18 nF. The student uses this uncharged capacitor to build a circuit using wire, a 36 V battery, 3 identical $80\ \Omega$ resistors, and an open switch, as shown in the figure above.

(d) 3 points

Calculate the current in the battery immediately after the switch is closed.

For calculating the equivalent resistance for the parallel resistors		1 point
$\dfrac{1}{R_P} = \dfrac{1}{R_1} + \dfrac{1}{R_2} = \dfrac{1}{80\ \Omega} + \dfrac{1}{80\ \Omega} = \dfrac{2}{80\ \Omega} = \dfrac{1}{40\ \Omega}$		
$R_P = 40\ \Omega$		
For using Ohm's law with the potential difference across the capacitor equal to zero		1 point
$I = \dfrac{V}{R} = \dfrac{V}{R_P + R_3} = \dfrac{(36\ \text{V})}{R_P + R_3}$		
For substitution of values for resistance including the value for combined resistance above		1 point
$I = \dfrac{V}{R_P + R_3} = \dfrac{(36\ \text{V})}{(40\ \Omega + 80\ \Omega)} = 0.30\ \text{A}$		

(e) 2 points

Determine the time constant for this circuit.

For using the equation for the time constant with the equivalent resistance from above		1 point
$\tau = R_{eq}C = (120\ \Omega)(18\ \text{nF})$		
For an answer with units consistent with part (d)		1 point
$t = 2.16\ \mu\text{s}$		

Question 2 (continued)

Distribution of points

(f) Students A and B measure the time it takes after the switch is closed for the voltage across the capacitor to reach half its maximum value and find that it is longer than expected.

i. 1 point

Student A assumes that the capacitance value is correct. Would Student A conclude that the resistance value is larger or smaller than measured?

____ Larger than measured ____ Smaller than measured

Explain experimentally what could account for this.

Select "Larger than measured"		
For an appropriate explanation		1 point
Example: The battery is not ideal and has internal resistance, so the actual resistance for the circuit is larger than the measured resistance.		

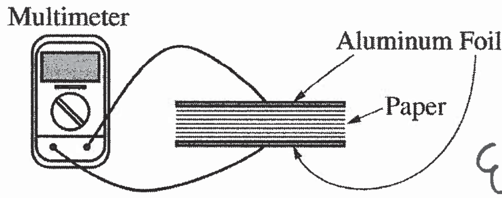
ii. 1 points

Student B assumes that the resistance value is correct. Would Student B conclude that the capacitance value is larger or smaller than measured?

____ Larger than measured ____ Smaller than measured

Explain experimentally what could account for this.

Select "Larger than measured"		
For an appropriate explanation		1 point
Example: Some of the sheets of paper may be thinner than expected, so the actual capacitance for the circuit is larger than the measured capacitance.		



$\varepsilon_0 = 8.85 \times 10^{-12} \frac{C^2}{Nm^2} \cdot m^2 / m$

2. An experiment is designed to measure the dielectric constant of paper that has an area $A = 0.060\ m^2$. Using aluminum foil, two parallel plates are created with the same area as the paper. Five hundred sheets of paper are placed between the aluminum foil plates to create a parallel plate capacitor, as shown in the figure above. Using a multimeter, the capacitance C of the capacitor is measured. The number of sheets and the total thickness d of the stack of paper are recorded. The experiment is repeated, reducing the number of sheets of paper each time. The data are recorded in the table below.

$C = \frac{K\varepsilon_0 A}{d}$

Sheets of Paper	d (m)	C (F)	$\frac{\varepsilon_0 A}{d} \cdot \left(\frac{C^2}{Nm}\right)$	
500	0.045	6.5×10^{-11}	1.18×10^{-11}	
400	0.036	7.4×10^{-11}	1.475×10^{-11}	
300	0.027	8.9×10^{-11}	1.97×10^{-11}	
200	0.018	11.9×10^{-11}	2.95×10^{-11}	
100	0.010	21.0×10^{-11}	5.31×10^{-11}	

(a) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the dielectric constant of the paper.

Vertical axis: C

Horizontal axis: $\frac{\varepsilon_0 A}{d}$

C

$\frac{\varepsilon_0 A}{d}$

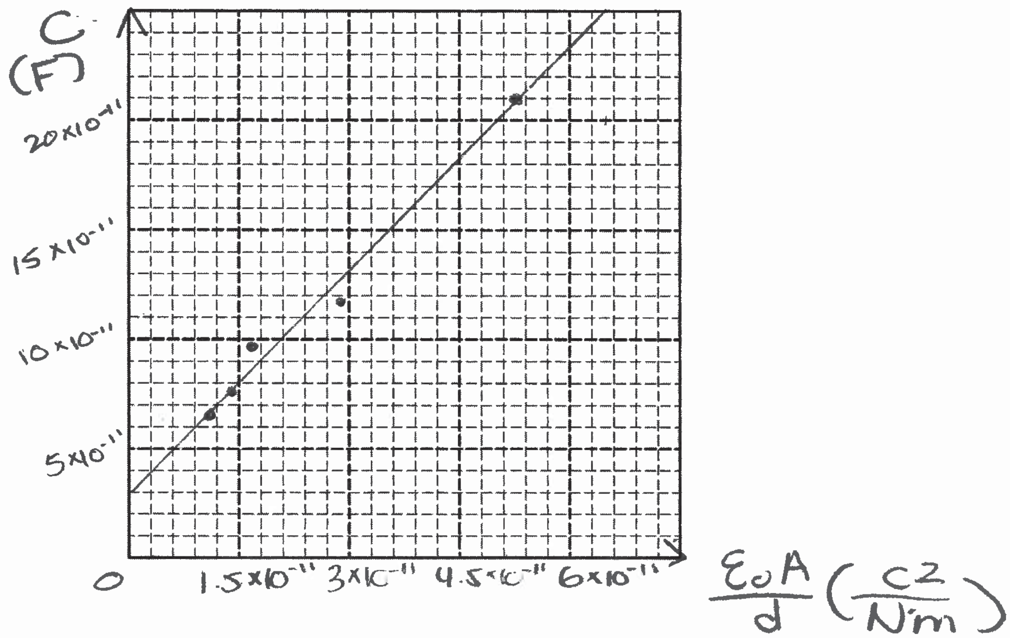
Use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given. Label each column you use and include units.

$F = K \frac{\frac{C^2}{N\cancel{m^2}}(\cancel{m^2})}{m}$

$\frac{C^2}{Nm}$

GO ON TO THE NEXT PAGE.

(b) Plot the data points for the quantities indicated in part (a) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(c) Using the straight line, calculate a dielectric constant for the paper.

$(1.5\times10^{-11}, 8\times10^{-11})$

$(3\times10^{-11}, 13\times10^{-11})$

$$K = \frac{13\times10^{-11}\,F - 8\times10^{-11}\,F}{3\times10^{-11}\,\frac{C^2}{Nm} - 1.5\times10^{-11}\,\frac{C^2}{Nm}}$$

$$= 3.33\,\frac{FNm}{C^2}$$

Question 2 continues on the next page.

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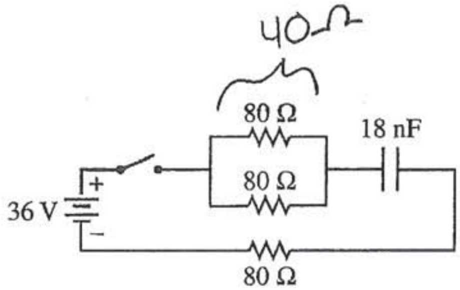

The student now makes a capacitor using the same aluminum foil plates and just one sheet of paper. Using the experimentally determined dielectric constant, the student calculates the capacitance to be 18 nF. The student uses this uncharged capacitor to build a circuit using wire, a 36 V battery, 3 identical 80 Ω resistors, and an open switch, as shown in the figure above.

(d) Calculate the current in the battery immediately after the switch is closed.

$R_{eq} = 40\Omega + 80\Omega = 120\Omega$

$I = \frac{V}{R} = \frac{36V}{120\Omega} = .3A$

(e) Determine the time constant for this circuit.

$\tau = RC$

$= 120\Omega(18\times10^{-9}F)$

$= 2.16\times10^{-6}\Omega\cdot F$

(f) Students A and B measure the time it takes after the switch is closed for the voltage across the capacitor to reach half its maximum value and find that it is longer than expected.

i. Student A assumes that the capacitance value is correct. Would Student A conclude that the resistance value is larger or smaller than measured?

____ Larger than measured ✓ Smaller than measured

Explain experimentally what could account for this.

Resistance in the wires could account for this

ii. Student B assumes that the resistance value is correct. Would Student B conclude that the capacitance value is larger or smaller than measured?

✓ Larger than measured ____ Smaller than measured

$C = \frac{\varepsilon_0 A}{d}$

Explain experimentally what could account for this.

The student could have measured the distance wrong when calculating capacitance

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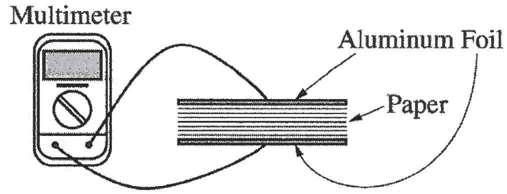

2. An experiment is designed to measure the dielectric constant of paper that has an area $A = 0.060\ \text{m}^2$. Using aluminum foil, two parallel plates are created with the same area as the paper. Five hundred sheets of paper are placed between the aluminum foil plates to create a parallel plate capacitor, as shown in the figure above. Using a multimeter, the capacitance C of the capacitor is measured. The number of sheets and the total thickness d of the stack of paper are recorded. The experiment is repeated, reducing the number of sheets of paper each time. The data are recorded in the table below.

Sheets of Paper	d (m)	C (F)		
500	0.045	6.5×10^{-11}		
400	0.036	7.4×10^{-11}		
300	0.027	8.9×10^{-11}		
200	0.018	11.9×10^{-11}		
100	0.010	21.0×10^{-11}		

(a) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the dielectric constant of the paper.

Vertical axis: C (F)

Horizontal axis: d (m)

Use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given. Label each column you use and include units.

$$C = \frac{K \varepsilon_0 A}{d}$$

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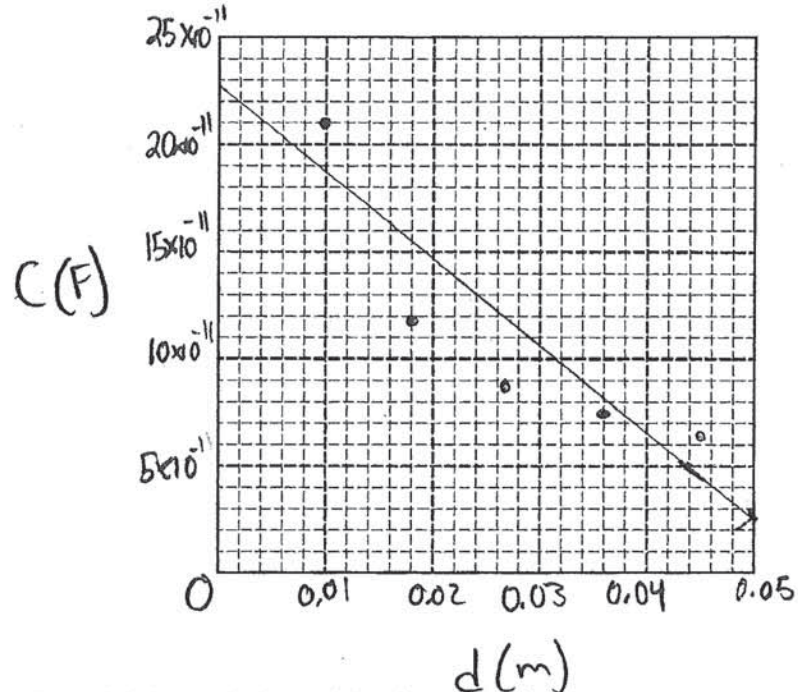
(b) Plot the data points for the quantities indicated in part (a) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(c) Using the straight line, calculate a dielectric constant for the paper.

$$K = \frac{(5\times10^{-11}) - (18\times10^{-11})}{0.044 - 0.012} = \boxed{-4.06\times10^{-9}}$$

Question 2 continues on the next page.

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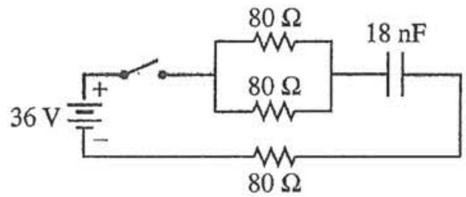
E Q2 B p3



The student now makes a capacitor using the same aluminum foil plates and just one sheet of paper. Using the experimentally determined dielectric constant, the student calculates the capacitance to be 18 nF. The student uses this uncharged capacitor to build a circuit using wire, a 36 V battery, 3 identical 80 Ω resistors, and an open switch, as shown in the figure above.

(d) Calculate the current in the battery immediately after the switch is closed.

$$\frac{1}{\frac{1}{80}+\frac{1}{80}} = 40+80 = 120\,\Omega$$

$$V_T = I_T R_T \qquad \frac{36}{120} = \boxed{I = 0.3\,A}$$

(e) Determine the time constant for this circuit.

$$\tau = RC$$

$$\tau = (120)(18\times10^{-9}) = \boxed{2.16\times10^{-6}}$$

(f) Students A and B measure the time it takes after the switch is closed for the voltage across the capacitor to reach half its maximum value and find that it is longer than expected.

i. Student A assumes that the capacitance value is correct. Would Student A conclude that the resistance value is larger or smaller than measured?

X Larger than measured ____ Smaller than measured

Explain experimentally what could account for this.

The cross-sectional Area of the wire could've been greater than expected causing the actual resistance to increase

ii. Student B assumes that the resistance value is correct. Would Student B conclude that the capacitance value is larger or smaller than measured?

____ Larger than measured X Smaller than measured

Explain experimentally what could account for this.

their measurements for capacitance could've been measured inaccurately

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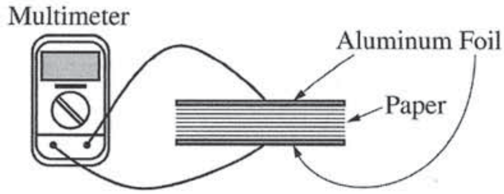

2. An experiment is designed to measure the dielectric constant of paper that has an area $A = 0.060\ \text{m}^2$. Using aluminum foil, two parallel plates are created with the same area as the paper. Five hundred sheets of paper are placed between the aluminum foil plates to create a parallel plate capacitor, as shown in the figure above. Using a multimeter, the capacitance C of the capacitor is measured. The number of sheets and the total thickness d of the stack of paper are recorded. The experiment is repeated, reducing the number of sheets of paper each time. The data are recorded in the table below.

Sheets of Paper	d (m)	C (F)	A	Cd
500	0.045	6.5×10^{-11}	30	0.2925×10^{-11}
400	0.036	7.4×10^{-11}	24	0.2664×10^{-11}
300	0.027	8.9×10^{-11}	18	0.2403
200	0.018	11.9×10^{-11}	12	0.2142
100	0.010	21.0×10^{-11}	6	0.21

(a) Indicate below which quantities should be graphed to yield a straight line whose slope could be used to calculate a numerical value for the dielectric constant of the paper.

Vertical axis: Cd

Horizontal axis: A

Use the remaining columns in the table above, as needed, to record any quantities that you indicated that are not given. Label each column you use and include units.

$$C = \frac{K\varepsilon_0 A}{d}$$

$$K = \frac{Cd}{A}$$

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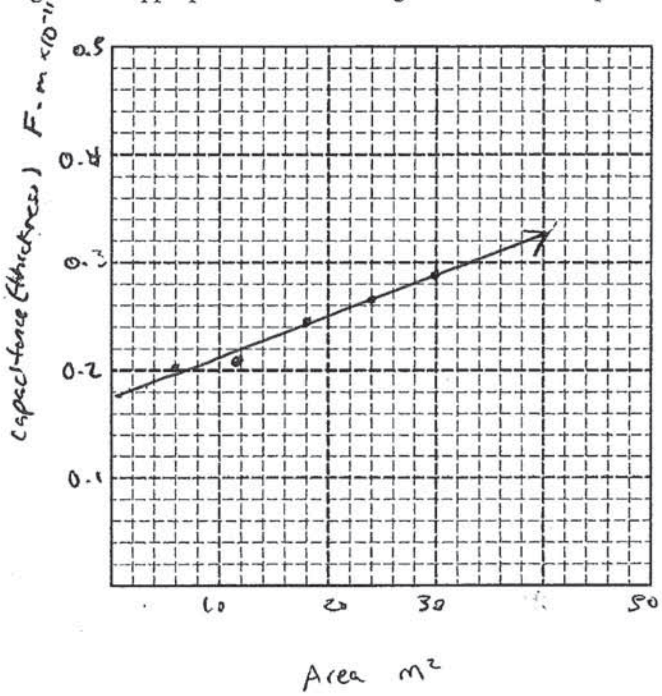
(b) Plot the data points for the quantities indicated in part (a) on the graph below. Clearly scale and label all axes, including units if appropriate. Draw a straight line that best represents the data.



(c) Using the straight line, calculate a dielectric constant for the paper.

points : $(30, 0.2925 \times 10^{-11})$

$(18, 0.2403 \times 10^{-11})$

$$\frac{30 - 18}{0.2525 - 0.2403}$$

2.298×10^{12}

Question 2 continues on the next page.

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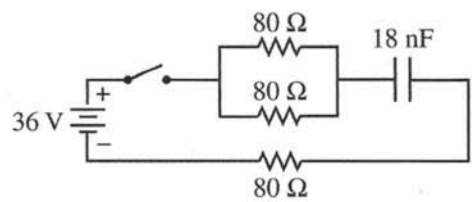
E Q2 C p3



The student now makes a capacitor using the same aluminum foil plates and just one sheet of paper. Using the experimentally determined dielectric constant, the student calculates the capacitance to be 18 nF. The student uses this uncharged capacitor to build a circuit using wire, a 36 V battery, 3 identical 80 Ω resistors, and an open switch, as shown in the figure above.

(d) Calculate the current in the battery immediately after the switch is closed.

$V = IR$ $\quad \frac{V}{R} = I = 0.3\ A$

$\frac{1}{80} + \frac{1}{80} = 40 + 80 = 120$

(e) Determine the time constant for this circuit.

0.786 s

(f) Students A and B measure the time it takes after the switch is closed for the voltage across the capacitor to reach half its maximum value and find that it is longer than expected.

i. Student A assumes that the capacitance value is correct. Would Student A conclude that the resistance value is larger or smaller than measured?

_X_ Larger than measured ____ Smaller than measured

Explain experimentally what could account for this.

the larger resistance means the current moves slower, taking more time to reach half of max

ii. Student B assumes that the resistance value is correct. Would Student B conclude that the capacitance value is larger or smaller than measured?

_X_ Larger than measured ____ Smaller than measured

Explain experimentally what could account for this.

half would be more if the capacitance was larger so it would take more time

Question 2

Overview

The responses to this question were expected to demonstrate the following:

- The ability to use the given capacitance equation to create a linear graph from which the dielectric constant could be determined.
- The ability to identify the appropriate horizontal and vertical axis terms, record the necessary numerical calculations in a provided table, scale the axes appropriately, and plot the numbers accurately on the graph.
- The ability to label the axes, including units, and draw a best-fit line to describe their data.
- The ability to use the slope of the line to calculate an experimental value for the dielectric constant.
- The ability to apply Ohm's law and to combine resistors in series and in parallel to determine the current flowing from a battery when the capacitor is initially connected to a network of three resistors.
- Calculate the time constant of the *RC* circuit by using an expression that is not included on the provided equation sheet.
- Students were asked two questions about the experimental issues that might have led to the measurement of an unexpectedly long time constant.
    - The ability to identify intrinsic resistance of the wires or battery.
    - The ability to identify measurement error regarding the capacitor plate area, plate separation, or dielectric constant, as possible explanations for the unexpectedly long time constant.

Sample: E Q2 A
Score: 15

All parts earned full credit. In part (a) the indicated variables will yield a straight line graph, which earned 1 point. In part (b) the scale is appropriate, the axes are labeled with units, the data are correctly plotted, and an appropriate best-fit line is drawn, so 4 points were earned. In part (c) the slope is calculated from the best-fit line and not the data points, the slope is related to κ, and the answer is correct, so 3 points were earned. In part (d) the correct calculation for the parallel resistance is indicated, and Ohm's law is used with correct substitutions to calculate the current, so 3 points were earned. In part (e) the correct equation is used, and a correct answer with units is shown, which earned 2 points. In part (f) both justifications are correct and refer to the experiment, so 2 points were earned.

Sample: E Q2 B
Score: 9

In part (a) the indicated quantities will not yield a straight line graph, so no points were earned. In part (b) the scale is appropriate, the axes is consistent with part (a), the data are correctly plotted, and an appropriate best-fit line is drawn, so all 4 points were earned. In part (c) the slope is calculated, and the answer is correct, but the slope is not related to κ, so 1 point was earned. Part (d) earned full credit of 3 points. Part (e) has a correct equation, but the answer does not have units, so 1 point was earned. In part (f)(i) the justification is incorrect, and in part (f)(ii) the justification has no connection to the experiment, so no points were earned.

Question 2 (continued)

Sample: E Q2 C
Score: 5

In part (a) the area is not variable (it is constant), so no points were earned. In part (b) the data are correctly plotted, and an appropriate best-fit line is drawn, but the scale does not use half the grid, and the vertical axis label is ambiguous, so 2 points were earned. In part (c) the slope is calculated from data points and one of the points is not on the best-fit line, the slope is not related to κ, and the answer is incorrect, so no points were earned. Part (d) earned full credit of 3 points. In part (e) no equation is shown, so no points were earned. In part (f) the justifications are insufficient, so no points were earned.