2021

AP® CollegeBoard

AP® Physics C: Electricity and Magnetism

Sample Student Responses and Scoring Commentary

Inside:

Free Response Question 1

☑ Scoring Guideline

☑ Student Samples

☑ Scoring Commentary

Question 1: Free-Response Question — 15 points

(a) For an indication that the capacitors act like a short circuit immediately after the switch is closed — **1 point**

$R_{EQ} = R_1 = 100\ \Omega$

For using Ohm's law to calculate the current through R_1 — **1 point**

$$I = \frac{\Delta V}{R} = \frac{(10\ \text{V})}{(100\ \Omega)}$$

$I = 0.10\ \text{A}$

Total for part (a) — 2 points

(b) For correctly determining the equivalent resistance during steady-state — **1 point**

$$\frac{1}{R_P} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{30\ \Omega} + \frac{1}{60\ \Omega} \therefore R_P = 20\ \Omega$$

$R_{EQ} = R_1 + R_P = 100\ \Omega + 20\ \Omega = 120\ \Omega$

For correctly calculating the current through the battery — **1 point**

$$I = \frac{\Delta V}{R} = \frac{(10\ \text{V})}{(120\ \Omega)}$$

$I = 0.083\ \text{A}$

The potential difference across R_1

$\Delta V = (0.083\ \text{A})(100\ \Omega) = 8.3\ \text{V}$

Total for part (b) — 2 points

(c) i. For using a correct equation to calculate the potential difference across C_3 — **1 point**

$\Delta V_{C_3} = \Delta V_P = IR_P = (0.083\ \text{A})(20\ \Omega) = 1.67\ \text{V}$

For using the correct equivalent capacitance of the series combination to calculate the charge stored in capacitor C_2 — **1 point**

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{10\ \mu\text{F}} + \frac{1}{15\ \mu\text{F}} \therefore C_S = 6.0\ \mu\text{F}$$

$Q_2 = Q_S = C_S \Delta V_{C_{12}} = (1.67\ \text{V})(6.0\ \mu\text{F}) = 10\ \mu C$

ii. For selecting "Greater than" and attempting a relevant justification — **1 point**

For a correct justification — **1 point**

Example response for part (c)(ii)

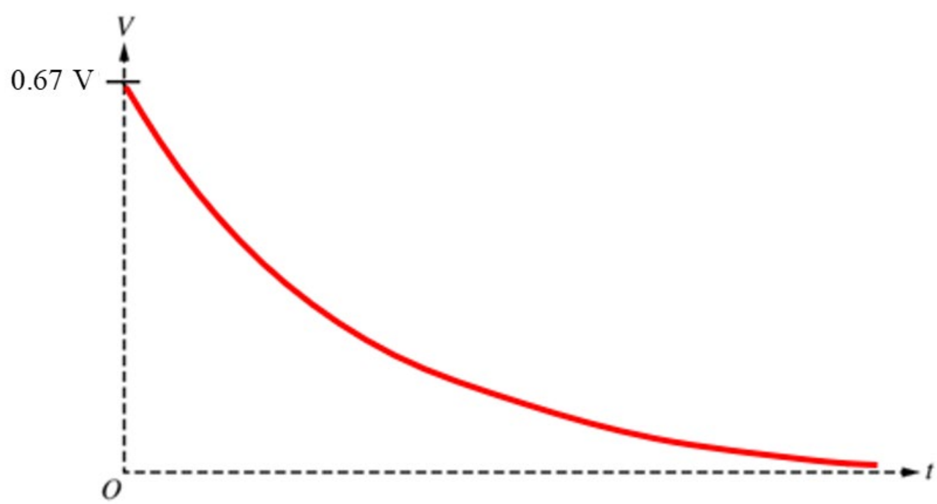
The potential difference across the series combination of C_1 and C_2 is the same as the potential difference across C_3; thus, capacitor C_3 has a greater potential difference across its plates than C_2 and has a greater capacitance. Because $Q = C\Delta V$, C_3 stores a greater charge.

Scoring note: A justification showing a mathematical proof earns full credit.

Total for part (c) — 4 points

(d) i.	For indicating that the current through R_1 is zero when the switch is opened $I_1 = 0$	**1 point**
ii.	For indicating that the potential difference across R_2 is equal to the potential difference across the capacitors before the switch was opened $\Delta V_{R_2} = \Delta V_{C_{12}} = 1.67\text{ V}$	**1 point**
	For using Ohm's law to calculate the current through R_2 $I = \dfrac{\Delta V_{R_2}}{R_2} = \dfrac{(1.67\text{ V})}{(30\ \Omega)}$ $I = 0.056\text{ A}$	**1 point**
	Total for part (d)	**3 points**
(e)	For a curve starting at a nonzero, labeled maximum value	**1 point**
	For a concave-up curve with the horizontal axis as an asymptote	**1 point**

Example response for part (e)



	Total for part (e)	**2 points**
(f)	For selecting "Below" and attempting a relevant justification	**1 point**
	For a correct justification	**1 point**

Example response for part (f)

Because the equivalent capacitance of the circuit would decrease, the time constant would also decrease. Thus the capacitors would discharge more rapidly, and the new curve would be below the original curve.

Total for part (f)	**2 points**
Total for question 1	**15 points**

Begin your response to **QUESTION 1** on this page.

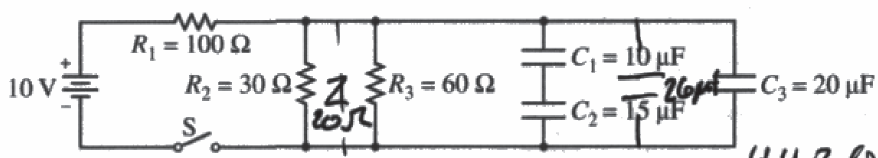
PHYSICS C: ELECTRICITY AND MAGNETISM

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.



44.2 Q

1. The circuit shown above is composed of an ideal 10 V battery, three resistors and three capacitors with the values shown, and an open switch S. The capacitors are initially uncharged. Switch S is now closed.

(a) Calculate the current through R_1 immediately after switch S is closed.

$V = IR$

$10V = I \cdot 100\Omega$

~~$\frac{10}{120} = I = .083A$~~

$I = .1A$

Switch S has been closed for a long time, and the circuit has reached a steady state.

(b) Calculate the potential difference across R_1.

$V = I_T R$ $\quad I_T = .083$ $\quad 100 \cdot .083 = V$

$10V = I\,120\Omega$ $\quad V = 8.3V$

(c)

i. Calculate the charge stored on the positive plate of capacitor C_2.

$\left(\frac{1}{C_1} + \frac{1}{C_2}\right)^{-1} = C_T$ $\quad C_T = 6\mu F$

$10 - 8.3 = \frac{Q}{C}$ $\quad 1.7 = \frac{Q}{6\mu F}$

$10.2\mu C = Q$

ii. Is the charge stored on capacitor C_3 greater than, less than, or equal to the charge stored on capacitor C_2 ?

X Greater than ____ Less than ____ Equal to

Justify your answer.

$20 \cdot 1.7 = \frac{Q}{20\mu} \cdot 20$ $\quad Q = 34\mu C$

because the Voltage Drop is equal between parallel wires and C_3 has a higher Capacitance Q is also larger

Continue your response to **QUESTION 1** on this page.

Switch S is then opened.

(d)

i. Determine the current through R_1 immediately after the switch is opened.

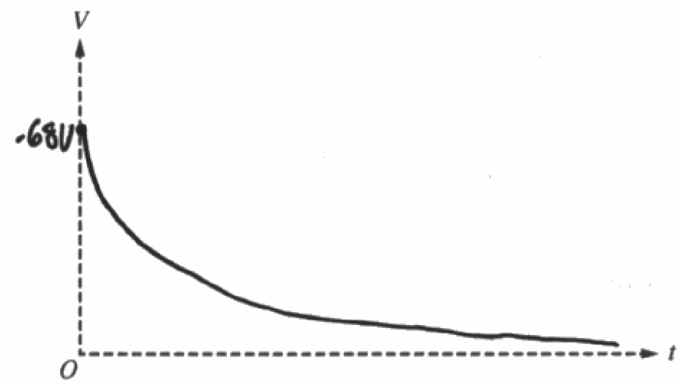
0 A

ii. Calculate the current through R_2 immediately after the switch is opened.

$V = IR$

$1.7V = I \cdot 30$ $I = .05\cancel{6}A$

(e) On the axes below, sketch a graph of the potential difference V across capacitor C_2 as a function of time t if switch S is opened at time $t = 0$. Label the maximum value.



Capacitor C_3 is replaced by two 10 μF capacitors connected in series, switch S is closed, and the circuit reaches equilibrium. Switch S is then opened at time $t = 0$.

(f) For $t > 0$, would the sketch of a graph of the new voltage across C_2 as a function of time be above, below, or the same as the sketch for part (e)?

____ Above ____ Below X The same

Justify your answer.

because two 10μF Capactors act the same as One 20μF Capacitor

Begin your response to **QUESTION 1** on this page.

PHYSICS C: ELECTRICITY AND MAGNETISM

SECTION II

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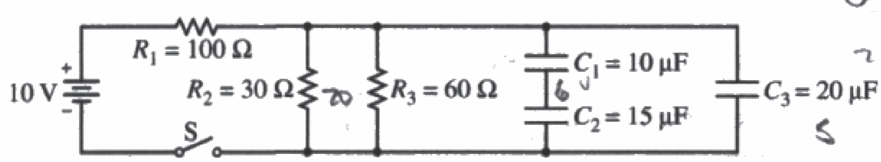
$Q = CV$



1. The circuit shown above is composed of an ideal 10 V battery, three resistors and three capacitors with the values shown, and an open switch S. The capacitors are initially uncharged. Switch S is now closed.

(a) Calculate the current through R_1 immediately after switch S is closed.

$V = IR \Rightarrow I = \frac{V}{R} = \frac{10}{100} = 0.1\ A$

Switch S has been closed for a long time, and the circuit has reached a steady state.

(b) Calculate the potential difference across R_1.

$\frac{1}{30} + \frac{1}{60} = .05 \qquad \frac{1}{.05} = 20$

$10 - I(100) - I(20) = 0$

$120I = 10$

$I = \frac{1}{12} = .083 \qquad V = 100(.083) = 8.3V$

(c)

i. Calculate the charge stored on the positive plate of capacitor C_2.

$Q = CV = (15 \times 10^{-6})(10)$

$= 1.5 \times 10^{-4}\ C$

$20 = \frac{Q_1}{C_1} + \frac{Q_2}{C_2}$

$V = V_1 + V_2$

ii. Is the charge stored on capacitor C_3 greater than, less than, or equal to the charge stored on capacitor C_2 ?

✓ Greater than ____ Less than ✓ Equal to

Justify your answer.

Charge equals voltage times capacitance, and $C_2V_2 < C_3V$

$Q = (20 \times 10^{-6})(10)$

$= 2 \times 10^{-4}$

Switch S is then opened.

(d)

i. Determine the current through R_1 immediately after the switch is opened.

0 A

ii. Calculate the current through R_2 immediately after the switch is opened.

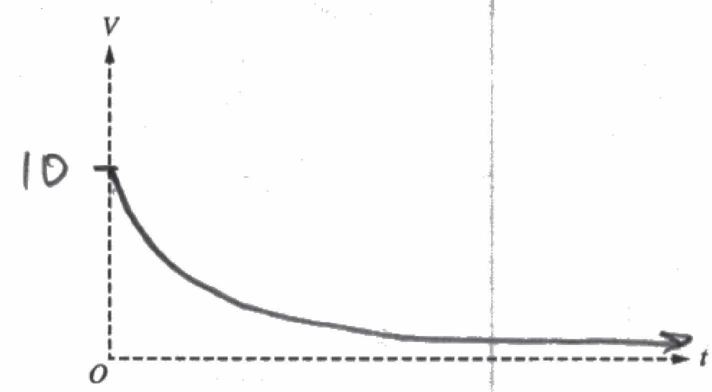
$V = IR$

$10 = I(20)$ $\boxed{I = 0.5\ A}$

$\frac{1}{C_1} + \frac{1}{C_2} = 6$

$6 + 20 = 26 = C$

(e) On the axes below, sketch a graph of the potential difference V across capacitor C_2 as a function of time t if switch S is opened at time $t = 0$. Label the maximum value.



Capacitor C_3 is replaced by two 10 μF capacitors connected in series, switch S is closed, and the circuit reaches equilibrium. Switch S is then opened at time $t = 0$.

(f) For $t > 0$, would the sketch of a graph of the new voltage across C_2 as a function of time be above, below, or the same as the sketch for part (e) ?

✓ Above ____ Below ____ The same

Justify your answer.

Q = CV, if capacitance decreases, then voltage increases because charge is conserved when the switch is opened.

Begin your response to **QUESTION 1** on this page.

PHYSICS C: ELECTRICITY AND MAGNETISM

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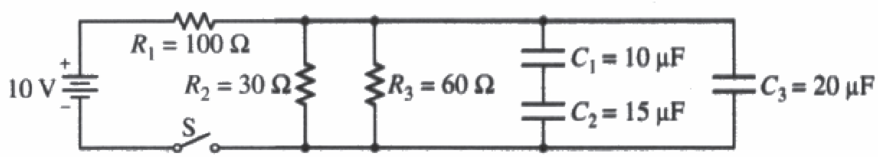
3 Questions

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.



1. The circuit shown above is composed of an ideal 10 V battery, three resistors and three capacitors with the values shown, and an open switch S. The capacitors are initially uncharged. Switch S is now closed.

(a) Calculate the current through R_1 immediately after switch S is closed.

$I = \frac{\Delta V}{R}$ $I = \frac{10}{100}$ $I = 0.1\ A$

Switch S has been closed for a long time, and the circuit has reached a steady state.

(b) Calculate the potential difference across R_1.

$\Delta V = \frac{Q}{C}$ $I = \frac{\Delta V}{R}$ $\Delta V = 10\ V$

(c)

i. Calculate the charge stored on the positive plate of capacitor C_2.

$\Delta V = \frac{Q}{C}$ $U_C = \frac{1}{2}(600)(15)$ $U_C = 750$ $750 = \frac{1}{2} Q (\Delta V)$ $Q = 150\ C$

ii. Is the charge stored on capacitor C_3 greater than, less than, or equal to the charge stored on capacitor C_2 ?

_____ Greater than   __✓__ Less than   _____ Equal to

Justify your answer.

C_2 has a lower capacitance than C_3 so C_3 can hold more charge

Continue your response to **QUESTION 1** on this page.

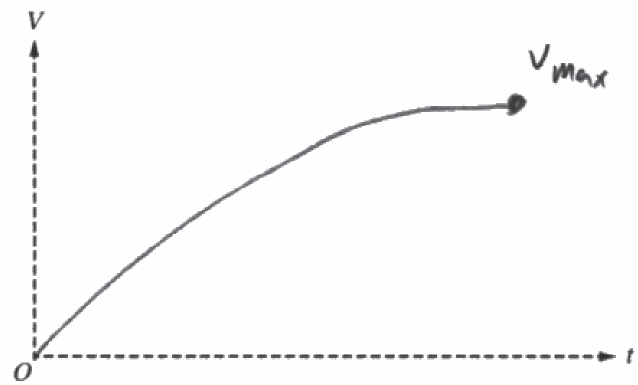
Switch S is then opened.

(d)

i. Determine the current through R_1 immediately after the switch is opened.

ii. Calculate the current through R_2 immediately after the switch is opened.

(e) On the axes below, sketch a graph of the potential difference V across capacitor C_2 as a function of time t if switch S is opened at time $t = 0$. Label the maximum value.



Capacitor C_3 is replaced by two 10 μF capacitors connected in series, switch S is closed, and the circuit reaches equilibrium. Switch S is then opened at time $t = 0$.

(f) For $t > 0$, would the sketch of a graph of the new voltage across C_2 as a function of time be above, below, or the same as the sketch for part (e) ?

_____ Above _____ Below __✓__ The same

Justify your answer.

These new conditions would still equal a total capacitance of 20μF on the other side of the parallel circuit so it wouldn't change what happened to C2

GO ON TO THE NEXT PAGE.

Question 1

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

Overview

The responses were expected to demonstrate the ability to:

- Identify a short in a circuit.
- Recognize that the steady-state current is zero in branches with fully-charged capacitors.
- Determine the potential difference across charged capacitors, wired in series and/or in parallel.
- Determine the potential difference across a resistor with charge flowing through it and across resistors wired in series and/or in parallel.
- Identify equipotentials in a circuit.
- Analyze how changes in the overall capacitance affect the time it takes for capacitors to discharge and to model these changes graphically.
- Relate the charge stored on a capacitor to its capacitance and the potential difference across it.
- Relate the current in a resistor to its resistance and the potential difference across it.

Sample: E Q1 A
Score: 13

Part (a) earned 2 points. The first point was earned for indicating that the resistance of the circuit at $t = 0$ is 100 Ω. The second point was earned for using Ohm's law to calculate current. Part (b) earned 2 points. The first point was earned for determining the equivalent resistance of 120 Ω. The second point was earned for calculating the current through the battery to determine the potential difference across R_1. Part (c)(i) earned 2 points. The first point was earned for using a correct equation to determine the potential difference across C_3 or $C_{1,2}$. The second point was earned for using the equivalent capacitance of $C_{1,2}$ to determine the charge on C_2. Part (c)(ii) earned 2 points. The first point was earned for checking "Greater than" and attempting a relevant justification. The second point was earned for identifying that $\Delta V_3 > \Delta V_2$, that $C_3 > C_2$, and that $Q = C\Delta V$. Part (d)(i) earned 1 point. The point was earned for indicating that the loop containing R_1 is now open, resulting in 0 A in R_1. Part (d)(ii) earned 2 points. The first point was earned for identifying the correct potential difference across R_2. The second point was earned for using 30 Ω to calculate the current through R_2. Part (e) earned 2 points. The first point was earned for starting the graph on the vertical axis with a labeled maximum value. The second point was earned for a concave up curve with the horizontal axis as the asymptote. Part (f) earned no points. The first point was not earned because "The same" is checked. The second point was not earned because any reference to a decreased equivalent capacitance causing the capacitor to discharge more rapidly is omitted.

Question 1 (continued)

Sample: E Q1 B
Score: 8

Part (a) earned 2 points. The first point was earned for indicating that the resistance of the circuit at t = 0 is 100 Ω. The second point was earned for using Ohm's law to calculate current. Part (b) earned 2 points. The first point was earned for determining the equivalent resistance is 120 Ω as implied by the loop rule. The second point was earned for calculating the current through the battery to determine the potential difference across R_1. Part (c)(i) earned no points. The first point was not earned because a reference to the correct potential difference across C_3 or $C_{1,2}$ is omitted. The second point was not earned because the capacitance of C_2 is used to determine the charge on C_2 instead of the equivalent capacitance of $C_{1,2}$. Part (c)(ii) earned 1 point. The first point was earned for checking "Greater than" and attempting a relevant justification. The second point was not earned because the response uses 10 V across C_3. Part (d)(i) earned 1 point. The point was earned for indicating that the loop containing R_1 is now open, resulting in 0 A in R_1. Part (d)(ii) earned no points. The first point was not earned because the correct potential difference across the capacitors, just before and just after the switch was opened, is not used. The second point was not earned because the resistance of R_2, 30 Ω, is not used to calculate the current. Part (e) earned 2 points. The first point was earned for starting the graph on the vertical axis with a labeled maximum value. The second point was earned for a concave up sketch with the horizontal axis as the asymptote. Part (f) earned no points. The first point was not earned because the "Above" box is checked. The second point was not earned because any reference to the decreased overall capacitance and its effect on the rate of discharge is omitted.

Sample: E Q1 C
Score: 2

Part (a) earned 2 points. The first point was earned for indicating that the resistance of the circuit at t = 0 is 100 Ω. The second point was earned for using Ohm's law to calculate current. Part (b) earned no points. The first point was not earned because an incorrect equivalent resistance when the capacitors are fully charged is used. The second point was not earned because the response does not include a current calculation to determine the potential difference across R_2. Part (c)(i) earned no points. The first point was not earned because an incorrect value for the potential difference across the branch with C_1 and C_2 is used. The second point was not earned because an incorrect value for the equivalent capacitance is used. Part (c)(ii) earned no points. The first point was not earned because "Less than" is checked. The second point was not earned because the justification omits $\Delta V_3 > \Delta V_2$. Part (d)(i) earned no points. The first point was not earned because the response is left blank. Part (d)(ii) earned no points. The first point was not earned because the response is left blank. The second point was not earned because the response is left blank. Part (e) earned no points. The first point was not earned because the sketch starts at a minimum value. The second point was not earned because the curve presented is concave down. Part (f) earned no points. The first point was not earned because "The same" is checked. The second point was not earned because any reference to the decreased overall capacitance and its effect on the rate of discharge is omitted.