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

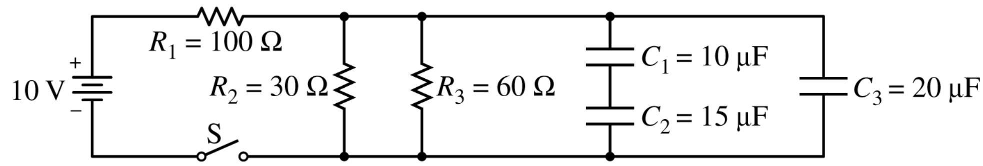
PHYSICS C: ELECTRICITY AND MAGNETISM

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.



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.

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.

(c)
i. Calculate the charge stored on the positive plate of capacitor C_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.

GO ON TO THE NEXT PAGE.

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

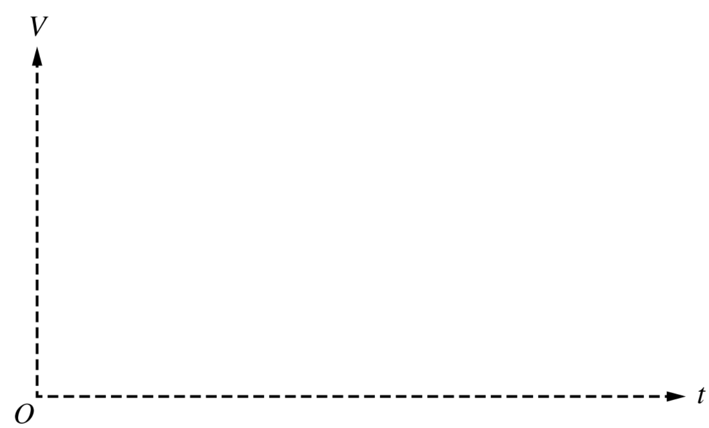
Switch S is then opened.

(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 $10\,\mu F$ 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.

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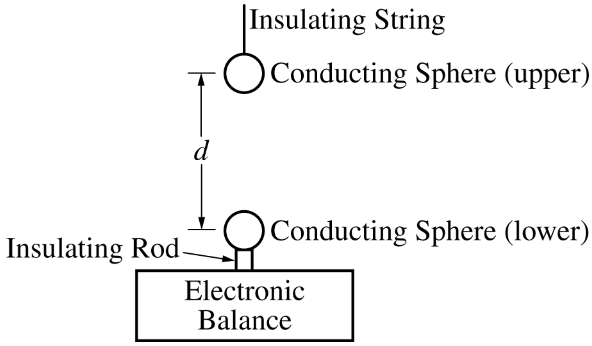
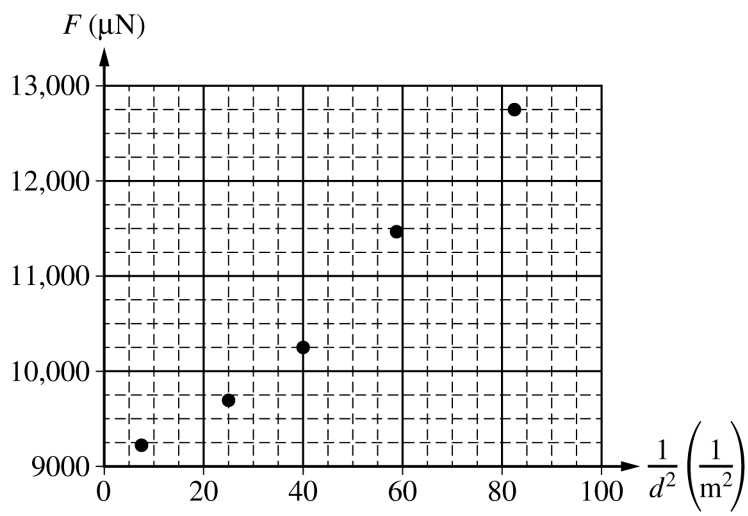
Begin your response to **QUESTION 2** on this page.



2. Students perform an experiment to study the force between two charged objects using the apparatus shown above, which contains two identical conducting spheres. The upper sphere is attached to an insulating string, which can be used to move the sphere downward. The lower sphere sits on an insulating rod, which is on an electronic balance. The electronic balance is zeroed before the lower sphere and insulating rod are in place.

For the first trial, a charge of Q is placed on each sphere and then the upper sphere is slowly moved downward. The students measure the distance d between the centers of the spheres and the magnitude F of the force that appears on the electronic balance. The recorded data are shown on the graph of F as a function of $\frac{1}{d^2}$ shown below.



(a)

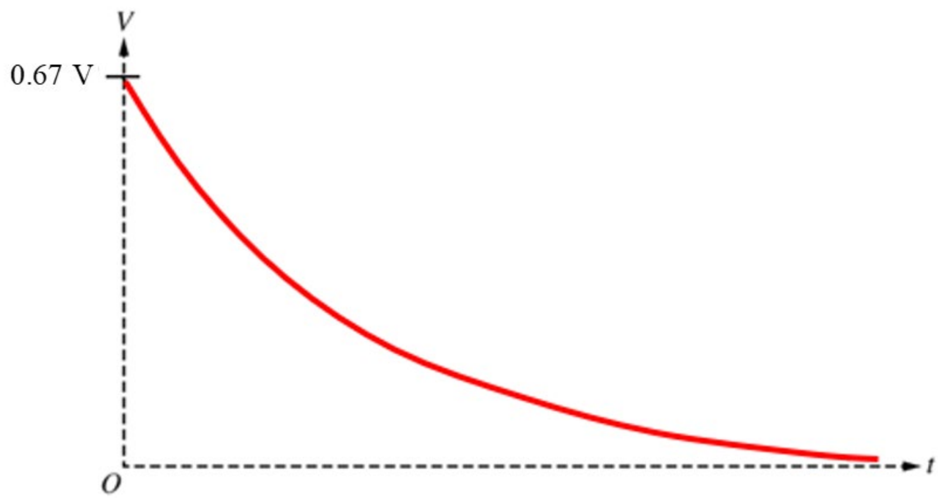
i. Draw a line that represents the best fit to the points shown.

ii. Use the graph to calculate the charge Q.

GO ON TO THE NEXT PAGE.

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 $R_{EQ} = R_1 = 100\ \Omega$	**1 point**
	For using Ohm's law to calculate the current through R_1 $I = \frac{\Delta V}{R} = \frac{(10\text{ V})}{(100\ \Omega)}$ $I = 0.10\text{ A}$	**1 point**
	Total for part (a)	**2 points**
(b)	For correctly determining the equivalent resistance during steady-state $\frac{1}{R_P} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{30\ \Omega} + \frac{1}{60\ \Omega} \therefore R_P = 20\ \Omega$ $R_{EQ} = R_1 + R_P = 100\ \Omega + 20\ \Omega = 120\ \Omega$	**1 point**
	For correctly calculating the current through the battery $I = \frac{\Delta V}{R} = \frac{(10\text{ V})}{(120\ \Omega)}$ $I = 0.083\text{ A}$ The potential difference across R_1 $\Delta V = (0.083\text{ A})(100\ \Omega) = 8.3\text{ V}$	**1 point**
	Total for part (b)	**2 points**
(c) i.	For using a correct equation to calculate the potential difference across C_3 $\Delta V_{C_3} = \Delta V_P = IR_P = (0.083\text{ A})(20\ \Omega) = 1.67\text{ V}$	**1 point**
	For using the correct equivalent capacitance of the series combination to calculate the charge stored in capacitor C_2 $\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{10\ \mu\text{F}} + \frac{1}{15\ \mu\text{F}} \therefore C_S = 6.0\ \mu\text{F}$ $Q_2 = Q_S = C_S \Delta V_{C_{12}} = (1.67\text{ V})(6.0\ \mu\text{F}) = 10\ \mu C$	**1 point**
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**