2021

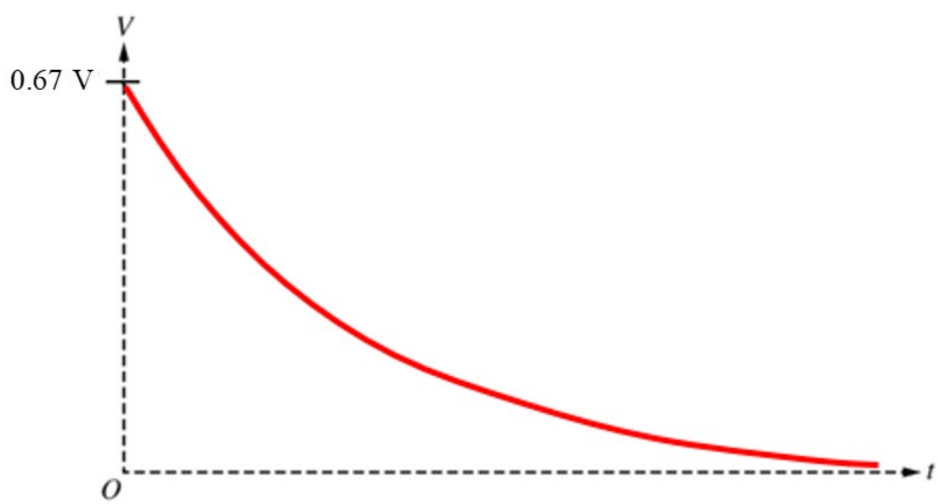
AP® CollegeBoard

AP® Physics C: Electricity and Magnetism

Scoring Guidelines

Question 1: Free-Response Question — 15 points

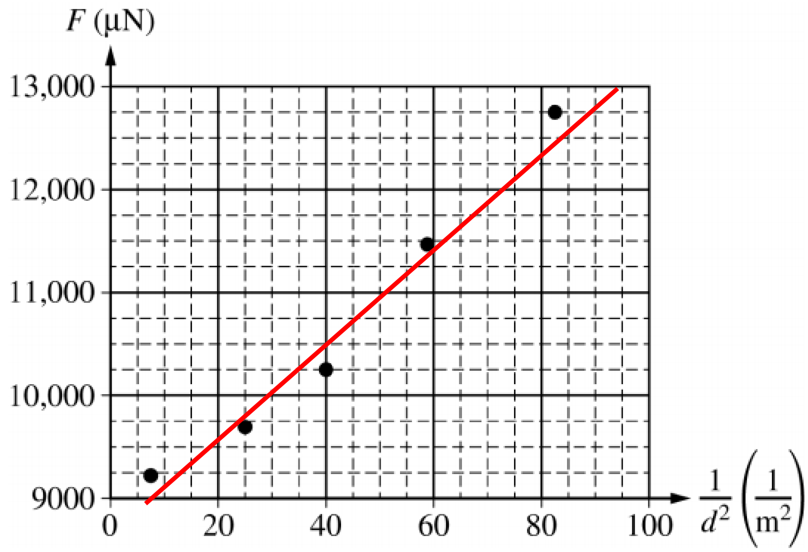
(a)	For an indication that the capacitors act like a short circuit immediately after the switch is closed $R_{EQ} = R_1 = 100\ \Omega$	**1 point**
	For using Ohm's law to calculate the current through R_1 $I = \dfrac{\Delta V}{R} = \dfrac{(10\text{ V})}{(100\ \Omega)}$ $I = 0.10\text{ A}$	**1 point**
	Total for part (a)	**2 points**
(b)	For correctly determining the equivalent resistance during steady-state $\dfrac{1}{R_P} = \dfrac{1}{R_2} + \dfrac{1}{R_3} = \dfrac{1}{30\ \Omega} + \dfrac{1}{60\ \Omega} \therefore R_P = 20\ \Omega$ $R_{EQ} = R_1 + R_P = 100\ \Omega + 20\ \Omega = 120\ \Omega$	**1 point**
	For correctly calculating the current through the battery $I = \dfrac{\Delta V}{R} = \dfrac{(10\text{ V})}{(120\ \Omega)}$ $I = 0.083\text{ A}$ 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 $\dfrac{1}{C_S} = \dfrac{1}{C_1} + \dfrac{1}{C_2} = \dfrac{1}{10\ \mu\text{F}} + \dfrac{1}{15\ \mu\text{F}} \therefore C_S = 6.0\ \mu\text{F}$ $Q_2 = Q_S = C_S \Delta V_{C_{12}} = (1.67\text{ V})(6.0\ \mu\text{F}) = 10\ \mu C$	**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**

Question 2: Free-Response Question — 15 points

(a) **i.** For drawing an appropriate best-fit line **1 point**

Example response for part (a)(i)



ii. For calculating the slope using two points from the best-fit line **1 point**

$$slope = m = \frac{\Delta y}{\Delta x} = \frac{(12{,}000 - 10{,}500)\ \mu\text{N}}{(72 - 40)\ \text{m}^{-2}} = 4.7 \times 10^{-5}\ \text{N}\bullet\text{m}^2$$

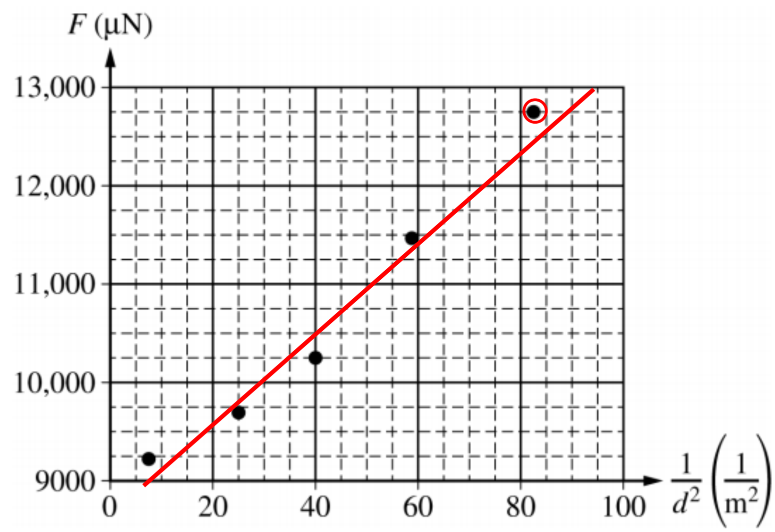
For correctly relating the slope to the charge **1 point**

$$F = \frac{kQ^2}{r^2} \therefore \text{slope} = kQ^2$$

For correctly calculating the charge consistent with the slope from the best-fit line **1 point**

$$Q = \sqrt{\frac{\text{slope}}{k}} = \sqrt{\frac{\left(4.7 \times 10^{-5}\ \text{N}\bullet\text{m}^2\right)}{\left(9 \times 10^9\ \text{N}\bullet\text{m}^2/\text{C}^2\right)}} = 7.2 \times 10^{-8}\ \text{C}$$

(a) **iii.** For drawing a circle around the appropriate data point — **1 point**



iv. For a correct answer — **1 point**

From the graph, $\dfrac{1}{d^2} = 82.5\ \text{m}^{-2}$

$d = 0.11\ \text{m}$

v. For indicating that the y-intercept should be the weight of the conducting sphere and insulating rod — **1 point**

For a correct justification — **1 point**

Example responses for part (a)(v).

When the spheres are infinitely far apart, there is no electric force between them. The only force recorded by the balance must be the weight of the lower sphere and insulating rod.

OR

The scale is zeroed before the insulating rod, and lower sphere are placed on it, so the nonzero y-intercept is their weight.

Total for part (a) — **8 points**

(b) For selecting "Yes" and providing a correct justification — **1 point**

Example response for part (b)

Because the later force measurements are lower than the expected values on the best-fit line, then a decrease in charge could explain the discrepancy seen in the data.

(c) **i.** For correctly indicating the position of the excess positive charges **1 point**

For correctly indicating that the net charge is positive **1 point**

Example response for part (c)(i)

ii. For a correct justification **1 point**

Example response for part (c)(ii)

On a conductor, excess charges are free to move and will repel each other. The excess charges in the sphere will rearrange themselves until they are as far apart from each other as possible; thus, the repelling force decreases.

Total for part (c) **3 points**

(d) **i.** For appropriately indicating the position of the excess charges on both spheres **1 point**

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

For a correct justification **1 point**

Example response for part (d)

Because the opposite charged spheres will attract each other, this will decrease the upward normal force exerted by the scale on the lower sphere; thus, the reading on the scale will be less than when the spheres had the same charge.

Total for part (d) **3 points**

Total for question 2 **15 points**

Question 3: Free-Response Question — 15 points

(a) For using Faraday's law to relate emf to change in flux — **1 point**

$$\mathcal{E} = \left|\frac{d\Phi}{dt}\right| = \left|\frac{d(B \cdot A)}{dt}\right|$$

For a correct expression for the emf — **1 point**

$$\mathcal{E} = \left|A\frac{dB}{dt}\right| = \left|A\frac{d}{dt}\left(\frac{\beta}{t}\right)\right| = \left|-\frac{A\beta}{t^2}\right| = \frac{A\beta}{t^2}$$

For correctly substituting into Ohm's law — **1 point**

$$I = \frac{\Delta V}{R} = \frac{\mathcal{E}}{R} = \frac{A\beta}{Rt^2}$$

Scoring note: Full credit is earned if the negative sign is included.

Total for part (a) — 3 points

(b) For using a correct equation to calculate the energy dissipated in the ring — **1 point**

$$E = \int P dt = \int I^2 R dt$$

For correctly substituting into the equation above — **1 point**

$$E = \int\left(\frac{A\beta}{Rt^2}\right)^2 R dt = \int \frac{A^2\beta^2}{R^2t^4} R dt$$

For indicating the correct limits or constant of integration — **1 point**

$$E = \frac{A^2\beta^2}{R}\int_1^2 \frac{1}{t^4} dt$$

For a correct answer with units — **1 point**

$$E = \frac{A^2\beta^2}{R}\left[-\frac{1}{3t^3}\right]_1^2 = \frac{\left(0.50\ \text{m}^2\right)^2 (0.50\ \text{T}\cdot\text{s})^2}{(3)(2.00\ \Omega)}\left(-\frac{1}{2^3} - \left(-\frac{1}{1^3}\right)\right) = 0.0091\ \text{J}$$

Total for part (b) — 4 points

(c) For selecting "Less than" and attempting a relevant justification — **1 point**

For a correct justification — **1 point**

Example response for part (c)

After the ring rotates, fewer magnetic field lines pass through the ring, and the flux is less than before. Thus, the emf, current, and rate at which energy is dissipated is less.

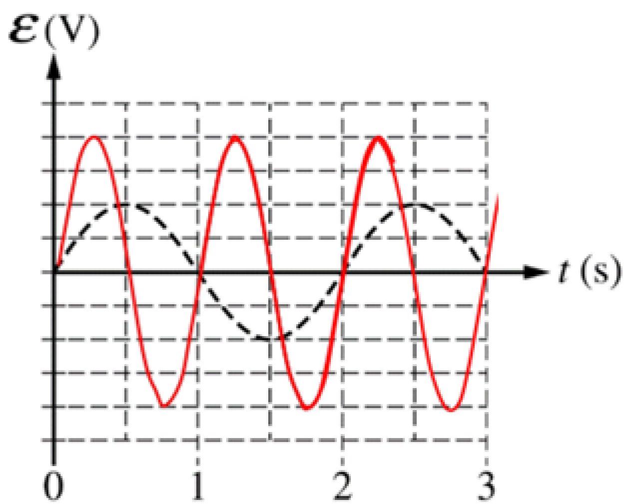
Total for part (c) — 2 points

(d) For using a correct equation to calculate angular speed — **1 point**

$$\omega = \frac{2\pi}{T}$$

	For substituting appropriate values from the graph in the correct equation $\omega = \dfrac{(2\pi)}{(2\text{ s})} = 3.14\ \dfrac{\text{rad}}{\text{s}}$	**1 point**
	Total for part (d)	**2 points**
(e)	For using a correct equation for solving for the emf in terms of the angular speed $\mathcal{E} = \dfrac{d\Phi}{dt} = \dfrac{d(B \cdot A)}{dt} = BA\dfrac{d}{dt}(\cos(\omega t)) = -BA\omega\sin(\omega t)$	**1 point**
	For correctly substituting into the correct equation $\mathcal{E}_{\text{MAX}} = BA\omega = (0.50\text{ T})\left(0.50\text{ m}^2\right)\left(3.14\ \dfrac{\text{rad}}{\text{s}}\right) = 0.79\text{ V}$	**1 point**
	Total for part (e)	**2 points**
(f)	For a sine curve with half the period of the dashed curve and a correct justification	**1 point**
	For a sine curve with twice the amplitude of the dashed curve and a correct justification **OR** a sine curve with an amplitude consistent with work shown in part (e)	**1 point**

Example response for part (f)



Because the rotational speed is twice the original speed, then, according to the equation $|\mathcal{E}| = B_0 A\omega\sin(\omega t)$ *this will double the amplitude of the curve and cut the period in half.*

Total for part (f)	**2 points**
Total for question 3	**15 points**