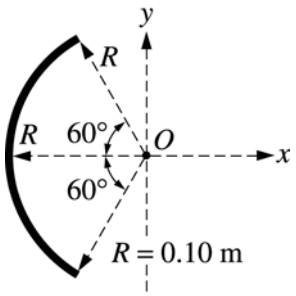
PHYSICS C

Section II, ELECTRICITY AND MAGNETISM

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 the pink booklet in the spaces provided after each part, NOT in this green insert.



E&M 1.

A rod of uniform linear charge density $\lambda = +1.5 \times 10^{-5}$ C/m is bent into an arc of radius $R = 0.10$ m. The arc is placed with its center at the origin of the axes shown above.

(a) Determine the total charge on the rod.

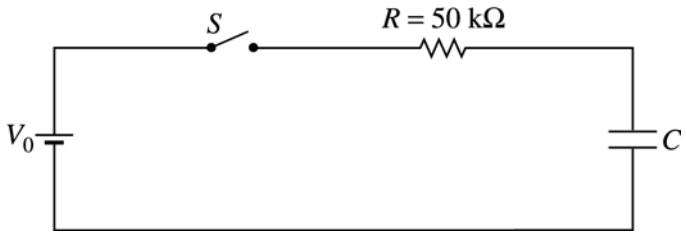
(b) Determine the magnitude and direction of the electric field at the center O of the arc.

(c) Determine the electric potential at point O.

A proton is now placed at point O and held in place. Ignore the effects of gravity in the rest of this problem.

(d) Determine the magnitude and direction of the force that must be applied in order to keep the proton at rest.

(e) The proton is now released. Describe in words its motion for a long time after its release.



E&M 2.

Your engineering firm has built the RC circuit shown above. The current is measured for the time t after the switch is closed at $t = 0$ and the best-fit curve is represented by the equation $I(t) = 5.20\, e^{-t/10}$, where I is in milliamperes and t is in seconds.

(a) Determine the value of the charging voltage V_0 predicted by the equation.

(b) Determine the value of the capacitance C predicted by the equation.

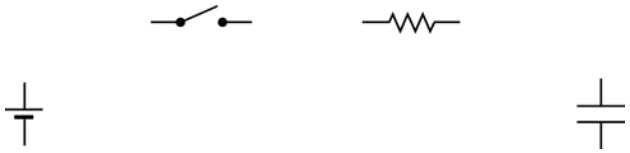
(c) The charging voltage is measured in the laboratory and found to be greater than predicted in part (a).

i. Give one possible explanation for this finding.

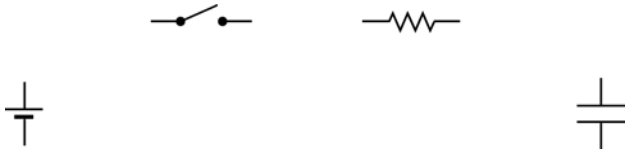
ii. Explain the implications that your answer to part i has for the predicted value of the capacitance.

(d) Your laboratory supervisor tells you that the charging time must be decreased. You may add resistors or capacitors to the original components and reconnect the RC circuit. In parts i and ii below, show how to reconnect the circuit, using either an additional resistor or a capacitor to decrease the charging time.

i. Indicate how a resistor may be added to decrease the charging time. Add the necessary resistor and connections to the following diagram.



ii. Instead of a resistor, use a capacitor. Indicate how the capacitor may be added to decrease the charging time. Add the necessary capacitor and connections to the following diagram.



Question 1 (cont'd.)

Distribution of points

(c) 3 points

For a correct formula, either 1, 2, or 3 below — 1 point

1. $V = \dfrac{kq}{r}$ (recognizing that all the charge is the same distance from point O)

$$V = \frac{\left(9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(3.1\times10^{-6}\ \text{C}\right)}{0.10\ \text{m}} = 2.8\times10^{5}\ \text{V}$$

2. $dV = \dfrac{k\ dq}{r}$

3. $V = k\int \dfrac{\lambda\ d\ell}{r}$

$$V = k\int \frac{\lambda\ d\ell}{r} = k\lambda \int_{2\pi/3}^{4\pi/3} \frac{r\ d\theta}{r}$$

$$= \left(9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(1.5\times10^{5}\ \text{C/m}\right)\left(\frac{4\pi}{3} - \frac{2\pi}{3}\right) = 2.8\times10^{5}\ \text{V}$$

OR

$$V = k\int \frac{\lambda\ d\ell}{r} = \frac{k\lambda(2\pi r/3)}{r}$$

$$= \frac{\left(9\times10^{9}\ \text{N}\cdot\text{m}^2/\text{C}^2\right)\left(1.5\times10^{-5}\ \text{C/m}\right)2\pi}{3} = 2.8\times10^{5}\ \text{V}$$

For correct numeric answer for V of 2.8×10^{5} — 1 point

For correct unit of volts (or any equivalent) — 1 point

(d) 2 points

$$F = qE$$

$$F = \left(1.6\times10^{-19}\ \text{C}\right)\left(2.3\times10^{6}\ \text{N/C}\right)$$

For the correct numerical answer — 1 point

$$F = 3.7\times10^{-13}\ \text{N}$$

For the correct direction, such as in the $-x$ direction, or to the left, or to the West — 1 point

(e) 2 points

For the correct direction, such as the $+x$ direction, or to the right, or to the East — 1 point

For an additional correct description of the motion, such as the proton moves with decreasing acceleration, OR with its velocity approaching a constant value, OR with its velocity asymptotic to some value. — 1 point

Note: Velocity approaching zero is incorrect and "negative" acceleration is incorrect.