AP® Physics C: Electricity & Magnetism
2002 Sample Student Responses

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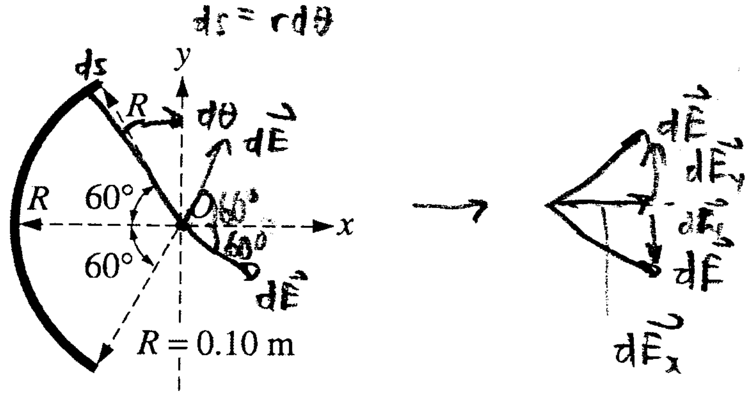
PHYSICS C

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

$$s = (2\pi R)\left(\frac{2\pi}{3} \cdot \frac{1}{2\pi}\right) = \frac{2}{3}\pi R$$

$$q = \lambda s$$

$$q = (1.5 \cdot 10^{-5} C/m)\frac{2}{3}\pi(0.10 m)$$

$$= \pi \cdot 10^{-6} C \approx 3.1 \cdot 10^{-6} C$$

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

$$dq = \lambda ds$$

$$dE = \frac{1}{4\pi\varepsilon_0} \cdot \frac{dq}{r^2}$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{\lambda ds}{r^2}$$

$$dE_x = dE \cos\theta$$

$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{\lambda \cos\theta ds}{r^2} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{\lambda \cos\theta d\theta}{r}$$

$$E = \int dE_x = \frac{\lambda}{4\pi\varepsilon_0 r}\int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} \cos\theta d\theta$$

$$= \frac{\lambda}{4\pi\varepsilon_0 r}[\sin\theta]_{-\frac{\pi}{3}}^{\frac{\pi}{3}} = \frac{1.5 \cdot 10^{-5} C/m}{4\pi(8.85 \cdot 10^{-12} C^2/N m^2)(0.10 m)}\left[\frac{\sqrt{3}}{2} + \frac{\sqrt{3}}{2}\right]$$

$$= 2.3361 \cdot 10^{6} N/C \rightarrow x$$

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$\approx 2.3 \cdot 10^{6}$ N/C in +x direction

(c) Determine the electric potential at point O.

$$dV = \frac{1}{4\pi\varepsilon_0} \cdot \frac{dq}{r}$$
$$= \frac{1}{4\pi\varepsilon_0} \cdot \frac{\lambda ds}{r}$$
$$= \frac{1}{4\pi\varepsilon_0} \cdot \lambda d\theta$$
$$V = \int dV = \frac{\lambda}{4\pi\varepsilon_0} \int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} d\theta$$
$$= \frac{\lambda}{4\pi\varepsilon_0} \theta \Big]_{-\frac{\pi}{3}}^{\frac{\pi}{3}}$$
$$= \frac{1.5 \cdot 10^{-5} C/m}{4\pi (8.85 \cdot 10^{-12} C^2/Nm^2)} \left[\frac{\pi}{3} + \frac{\pi}{3}\right]$$
$$= 282485.8757 \text{ J/C}$$
$$\approx 2.8 \cdot 10^{5} \text{ J/C}$$

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.

$$F = q_0 E$$
$$F = (1.6 \cdot 10^{-19} C)(x)$$
$$= 3.7378 \ldots \cdot 10^{-13} N$$
$$\approx 3.7 \cdot 10^{-13} N$$
$$\therefore F_A = 3.7 \cdot 10^{-13} N \text{ in } -x \text{ direction}$$

$\xleftarrow{F_A} \quad \xrightarrow{F}$

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

After its release, the proton moves to the right in +x-direction with its acceleration decreasing as it moves further away from the rod.

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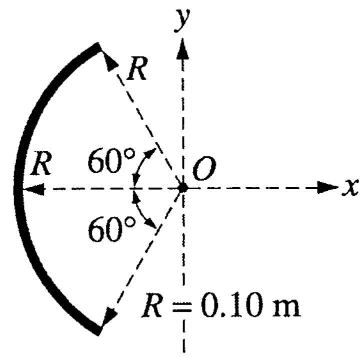


E&M 1.

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.

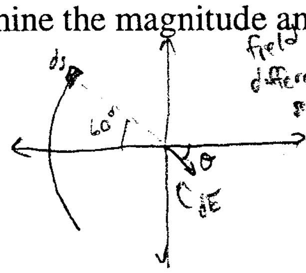
Total charge = charge density · length of rod
q λ L

$L = \frac{2\pi \cdot 0.1}{\left(\frac{2\pi}{3}\right)}$ $\lambda = 1.5 \times 10^{-5}$ C/m $\boxed{q = 4.5 \times 10^{-6}\ C}$

$L = 0.3$ m $q = \lambda L$

$q = 0.3 \cdot 1.5 \times 10^{-5}$

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



field from differential segment $\rightarrow$ $dE = \frac{\lambda ds}{4\pi\epsilon_0 R^2}$ $\leftarrow$ charge in differential segment

$dE = \frac{\lambda R d\theta}{4\pi\epsilon_0 R^2}$

All components on the y-axis cancel due to symmetry, and we only need to add up the x-axis ones

$\int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} dE \cos(\theta) = \int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} \frac{\lambda}{4\pi\epsilon_0 R} \cos(\theta) d\theta$ But $\lambda = 1.5 \times 10^{-5}$

$\downarrow$ $R = 0.1$

$E = \frac{\lambda}{4\pi\epsilon_0 R} \sin(\theta) \Big]_{-\frac{\pi}{3}}^{\frac{\pi}{3}}$ $\frac{1}{4\pi\epsilon_0} \simeq 9.0 \times 10^9$

$\uparrow$
$\sqrt{3}$

$\boxed{\text{So } E = 2338 \times 10^5 \text{ toward the positive x-axis}}$

$E = \frac{\lambda\sqrt{3}}{4\pi\epsilon_0 R}$

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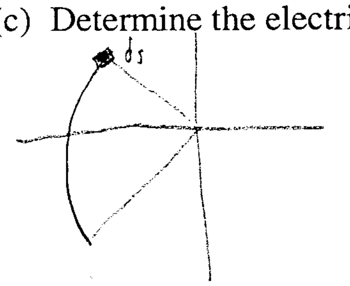
(c) Determine the electric potential at point O.



$ds = R\,d\theta$

$$dV = \frac{\lambda\,ds}{4\pi\epsilon_0 R}$$

$$dV = \frac{\lambda R\,d\theta}{4\pi\epsilon_0 R}$$

$$dV = \frac{\lambda\,d\theta}{4\pi\epsilon_0}$$

Potential is not a vector, but a scalar, so we simply integrate

$$V = \int_{-\frac{\pi}{3}}^{\frac{\pi}{3}} \frac{\lambda\,d\theta}{4\pi\epsilon_0}$$

$$= \frac{\lambda}{4\pi\epsilon_0}\,\theta\Big]_{-\frac{\pi}{3}}^{\frac{\pi}{3}}$$

$\lambda = 1.5\times10^{-5}$

$\frac{1}{4\pi\epsilon_0} \approx 9.0\times10^{9}$

$$\boxed{\approx 2.827\times10^{5}\ \text{V}}$$

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.

$\vec{F} = q\vec{E}$ $\qquad$ $\vec{E} = 2.338\times10^{5}$ (as calculated before)

$q_{proton} = 1.6\times10^{-19}$ $\qquad$ $F = 1.6\times10^{-19}\cdot 2.338\times10^{5}$

$\boxed{= 3.741\times10^{-14}\ \text{N}}$
toward the arc of charge

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

The proton will first begin to accelerate faster and faster. As the field weakens, though, its acceleration will stop increasing and begin to decrease (not decelerate). The accelereration will approach 0 as the proton travels off to infinity and reach a terminal velocity.

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