



AP[®] Physics C: Electricity and Magnetism 2003 Sample Student Responses

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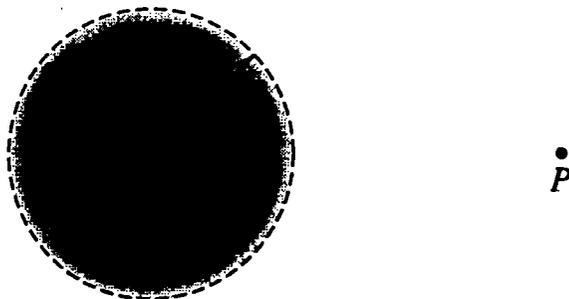
PHYSICS C

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 spherical cloud of charge of radius R contains a total charge $+Q$ with a nonuniform volume charge density that varies according to the equation

$$\rho(r) = \rho_0 \left(1 - \frac{r}{R}\right) \text{ for } r \leq R \text{ and}$$

$$\rho = 0 \text{ for } r > R,$$

where r is the distance from the center of the cloud. Express all algebraic answers in terms of Q , R , and fundamental constants.

(a) Determine the following as a function of r for $r > R$.

i. The magnitude E of the electric field

$$\oint E \cdot dA = \frac{Q}{\epsilon_0}$$

$$E(4\pi r^2) = \frac{Q}{\epsilon_0} \quad E = \frac{Q}{4\pi\epsilon_0 r^2}$$

ii. The electric potential V

A spherical distribution acts as a point charge so

$$V = \frac{Q}{4\pi\epsilon_0 r}$$

(b) A proton is placed at point P shown above and released. Describe its motion for a long time after its release.

The proton experiences a force to the right from the electric field. The field strength decreases with distance, so the acceleration of the proton decreases with time until it reaches a final constant speed.

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(c) An electron of charge magnitude e is now placed at point P , which is a distance r from the center of the sphere, and released. Determine the kinetic energy of the electron as a function of r as it strikes the cloud.

Energy conserved

$$k_i + U_i = k_f + U_f$$

$$0 + qV_i = k_f + U_f$$

$$eV_i - eV_f = k_f$$

$$-\frac{eQ}{4\pi\epsilon_0 r} + \frac{eQ}{4\pi\epsilon_0 R} = k_f = \frac{eQ}{4\pi\epsilon_0} \left(\frac{1}{R} - \frac{1}{r} \right)$$

(d) Derive an expression for ρ_0 .

$$dq = \rho(r) dv \quad dv = 4\pi r^2 dr$$

$$\int dq = \int_0^R \rho_0 \left(1 - \frac{r}{R}\right) 4\pi r^2 dr$$

$$Q = 4\pi\rho_0 \int_0^R r^2 \left(1 - \frac{r}{R}\right) dr$$

$$Q = 4\pi\rho_0 R^3 \left(\frac{1}{3} - \frac{1}{4R} \right)$$

$$\rho_0 = \frac{Q}{4\pi R^3 \left(\frac{1}{3} - \frac{1}{4R} \right)} = \frac{3Q}{\pi R^3}$$

(e) Determine the magnitude E of the electric field as a function of r for $r \leq R$.

$$\oint E \cdot dA = \frac{q_{enc}}{\epsilon_0} \rightarrow dq = \rho(r) dv$$

$$dq_{enc} = \rho(r) (4\pi r^2 dr)$$

$$(4\pi r^2) E = \frac{4\pi\rho_0 r^3 \left(\frac{1}{3} - \frac{r}{4R} \right)}{\epsilon_0}$$

$$q_{enc} = \int_0^r \rho_0 \left(1 - \frac{r}{R}\right) (4\pi r^2) dr$$

$$q_{enc} = 4\pi\rho_0 \int_0^r \left(1 - \frac{r}{R}\right) r^2 dr = 4\pi\rho_0 \int_0^r \left(r^2 - \frac{r^3}{R}\right) dr$$

$$q_{enc} = 4\pi\rho_0 \left[\frac{r^3}{3} - \frac{r^4}{4R} \right]_0^r$$

$$q_{enc} = 4\pi\rho_0 r^3 \left(\frac{1}{3} - \frac{r}{4R} \right)$$

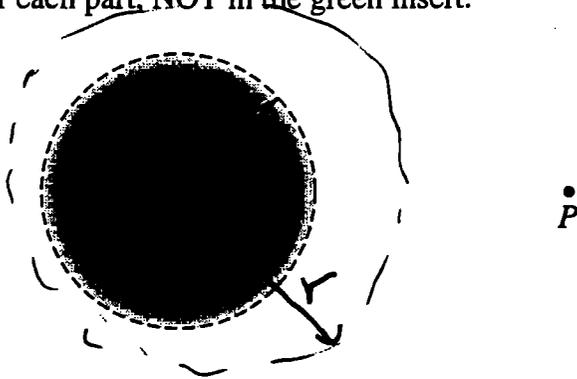
$$E = \frac{\rho_0 r \left(\frac{1}{3} - \frac{r}{4R} \right)}{\epsilon_0}$$

$$= \frac{3Qr}{\pi\epsilon_0 R^3} \left(\frac{1}{3} - \frac{r}{4R} \right)$$

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(a) Determine the following as a function of r for $r > R$.

i. The magnitude E of the electric field

$$\int E \cdot dA = \frac{Q_{\text{enc}}}{\epsilon_0} \quad E \int dA = \frac{Q_{\text{enc}}}{\epsilon_0} \quad EA = \frac{Q}{\epsilon_0}$$

$$E(4\pi r^2) = \frac{Q}{\epsilon_0}$$

$$E = \frac{Q}{4\pi r^2 \epsilon_0}$$

ii. The electric potential V

$$E = -\frac{dV}{dr} \quad -\frac{Q}{4\pi r^2 \epsilon_0} dr = dV \quad -\frac{Q}{4\pi \epsilon_0} \int \frac{dr}{r^2} = V$$

$$V = \frac{-Q}{4\pi \epsilon_0} (-r^{-1}) \quad V = \frac{Q}{4\pi \epsilon_0 r}$$

(b) A proton is placed at point P shown above and released. Describe its motion for a long time after its release.

the proton will accelerate away from the cloud along a straight line from the center of the cloud through point P . The acceleration decreases as the proton gets farther away, but the velocity increases.

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