AP® Physics C: Electricity and Magnetism
2003 Scoring Guidelines

Question 1

15 points total	**Distribution of points**

Answers shown here are expressed in terms of Coulomb's law constant k, but equivalent answers in terms of $1/4\pi\varepsilon_0$ were acceptable.

(a) 3 points

The sphere of charge can be treated as a point charge located at the sphere's center.

i. (2 points)

$$E = \frac{kq}{r^2}$$

For indicating that the total charge is Q	1 point
For a correct answer	1 point

$$E = \frac{kQ}{r^2}$$

ii. (1 point)

For a correct answer	1 point

$$V = \frac{kQ}{r}$$

Credit was also awarded for integrating E to obtain V

(b) 3 points

For indicating that the proton will move away from the charged sphere	1 point
For indicating that the velocity of the proton will increase or reach a finite value	1 point
For indicating that the acceleration of the proton will decrease	1 point

(c) 3 points

For a correct statement of conservation of energy	1 point

$$K = U_r - U_R$$

For the substitution of an electrical potential energy with the correct form	1 point

$$K = \frac{-keQ}{r} - \frac{-keQ}{R}$$

For a correct answer	1 point

$$K = keQ\left(\frac{1}{R} - \frac{1}{r}\right)$$

Question 1 (cont'd.)

Distribution of points

(c) (continued)

Alternate solution — *Alternate points*

For showing correct use of the work-energy theorem — *1 point*

$$K = W = \int \mathbf{F} \cdot d\mathbf{r}$$

For setting up the correct integration — *1 point*

$$K = \int_r^R \frac{-kQe}{r^2}\, dr$$

$$K = -kQe\left(-\frac{1}{r}\right)\Bigg|_r^R = -kQe\left(-\frac{1}{R} - \left(-\frac{1}{r}\right)\right) = -kQe\left(\frac{1}{r} - \frac{1}{R}\right)$$

For a correct answer — *1 point*

$$K = keQ\left(\frac{1}{R} - \frac{1}{r}\right)$$

(d) 3 points

ρ_0 can be determined by integrating the volume distribution and setting it equal to the total charge Q

For indicating that an integration is necessary — 1 point

$$Q = \int_0^R \rho(r)\, dV$$

For showing a correct volume element — 1 point

$$dV = 4\pi r^2\, dr$$

For substitution of $\rho(r)$ and dV — 1 point

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

$$Q = 4\pi\rho_0 \int_0^R \left(r^2 - \frac{r^3}{R}\right) dr = 4\pi\rho_0 \left(\frac{r^3}{3} - \frac{r^4}{4R}\right)\Bigg|_0^R = 4\pi\rho_0 \left(\frac{R^3}{3} - \frac{R^3}{4}\right) = 4\pi\rho_0 \frac{R^3}{12}$$

$$\rho_0 = \frac{3Q}{\pi R^3}$$

Question 1 (cont'd.)

Distribution of points

(e) 3 points

For writing Gauss's law with a charge element dq OR showing the relationship between E and $\int dq$ — 1 point

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{1}{\varepsilon_0}\int dq \quad \text{OR} \quad dE = \frac{k}{r^2}\,dq$$

$$E4\pi r^2 = \frac{1}{\varepsilon_0}\int \rho(r)\,dV \quad \text{OR} \quad E = \frac{k}{r^2}\int \rho(r)\,dq$$

For correct substitution of ρ_0, dV, and correct limits — 1 point

$$\int_0^r \rho(r)\,dV = \int_0^r \frac{3Q}{\pi R^3}\left(1-\frac{r}{R}\right)4\pi r^2 dr$$

$$\int_0^r \rho(r)\,dV = \frac{12Q}{R^3}\int_0^r\left(r^2-\frac{r^3}{R}\right)dr = \frac{12Q}{R^3}\left(\frac{r^3}{3}-\frac{r^4}{4R}\right)\Bigg|_0^r = \frac{Q}{R^3}\left(4r^3-\frac{3r^4}{R}\right)$$

$$E = \frac{1}{4\pi\varepsilon_0 r^2}\frac{Q}{R^3}\left(4r^3-\frac{3r^4}{R}\right) \quad \text{OR} \quad E = \frac{k}{r^2}\frac{Q}{R^3}\left(4r^3-\frac{3r^4}{R}\right)$$

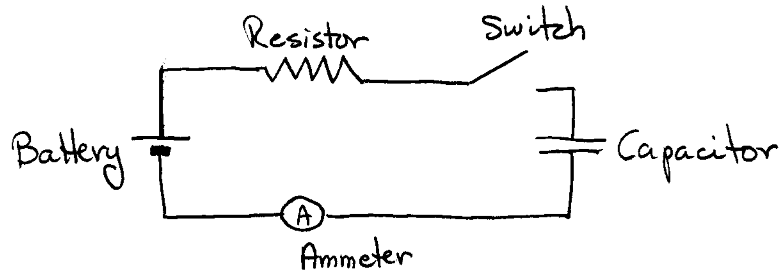
For a correct answer — 1 point

$$E = \frac{kQr}{R^3}\left(4-\frac{3r}{R}\right)$$

Question 2

15 points total | **Distribution of points**

(a) 4 points



For including the resistor, capacitor, battery and switch elements with common symbols and clear labels in the diagram — 2 points

One point was deducted for using one uncommon symbol or mislabeling one element

No credit was given for a circuit missing any elements or with two or more uncommon symbols or mislabeled elements

For correctly showing the resistor, capacitor, and battery connected in series — 1 point

For placing the ammeter in series with the resistor — 1 point

(b) 3 points

For any statement of Ohm's law — 1 point

$R = V/I$

One point each for substituting the values of the initial conditions consistent with the graph into the above equation — 2 points

$R = (12\text{ V})/(0.010\text{ A})$

$R = 1200\ \Omega$

Alternate solution — *Alternate points*

For using the given equation for the current — *1 point*

$i(t) = \dfrac{\mathcal{E}}{R}e^{-t/4}$

For substituting consistent current and time values from the graph into the above equation — *1 point*

For a value of resistance consistent with the substituted values — *1 point*

Question 2 (cont'd.)

Distribution of points

(c) 4 points

For the equation for the time constant — 1 point

$\tau = RC$

For substituting the value of the time constant from the given equation for current, i.e. 4 s — 1 point

For substituting the resistance from part (b) — 1 point

$C = (4\text{ s})/(1200\ \Omega)$

For a value of capacitance consistent with the substituted values, including units — 1 point

$C = 3.3\times10^{-3}$ F

Alternate solution — *Alternate points*

For any statement of the equation relating capacitance, charge, and voltage — *1 point*

$C = Q/V$

For an equation relating current and charge — *1 point*

$i = dQ/dt$ OR $Q = \int i\,dt$

For evaluating the integral $Q = \int i\,dt$, including clearly identifying the limits of integration — *1 point*

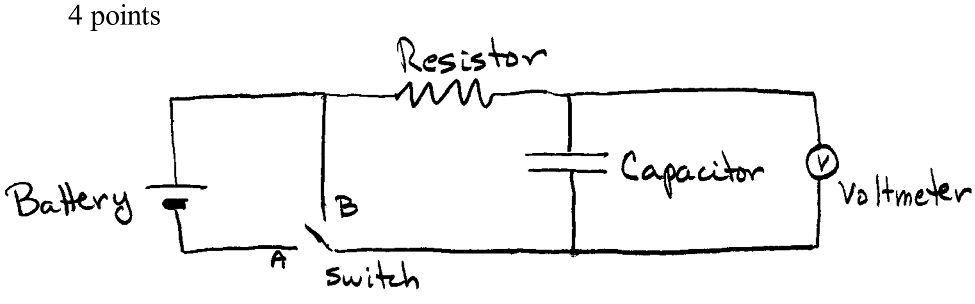
For example, $Q = \frac{\mathcal{E}}{R}\int_0^6 e^{-t/4}dt = -4(0.010)e^{-t/4}\Big|_0^6 = -(0.040)\left(e^{-6/4} - e^0\right) = 0.031\text{ C}$

The value of Q and the potential difference associated with the time interval used in the integral are then substituted into the first equation.

Using the above example, the associated voltage would be $12\text{ V} - (0.0025\text{ A})(1200\ \Omega) = 9\text{ V}$, and the capacitance would be 3.4×10^{-3} F.

For a value of capacitance consistent with the result of the integration and the correct voltage difference for that time interval, including units — *1 point*

(d) 4 points



For correctly labeling the capacitor, resistor, battery, and the A and B switch elements — 1 point

For a circuit that has the resistor, capacitor, and battery connected in series when the switch is closed at A, and will charge the capacitor to 12 V — 1 point

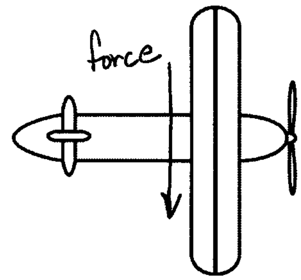
For a circuit that has the resistor and capacitor connected in series when the switch is closed at B, and will discharge the capacitor from 12 V to zero — 1 point

For a voltmeter connected in parallel across the capacitor — 1 point

Question 3

15 points total | **Distribution of points**

(a) 2 points



For an arrow downward on or near antenna	1 point
For one correct justification statement	1 point

Examples: $\mathbf{F} = q\mathbf{v}\times\mathbf{B}$, the right-hand rule, $-$(north $\times$ down) = east, the left-hand rule for electrons

(b) 5 points

An equilibrium is reached when the electric force due to the separation of charge in the antenna balances the magnetic force on an electron

For a correct expression for the magnetic force, showing a cross product or an angular dependence	1 point
For a correct expression for the electric force	1 point

Equating the electric and magnetic forces:

$q\mathbf{E} = q\mathbf{v}\times\mathbf{B}$

$E = vB\sin\theta$

For substitution of sin 55°	1 point
For substitution of other given values	1 point

$E = vB\sin\theta = (75\ \text{m/s})(6\times10^{-5}\ \text{T})\sin 55°$

For the correct answer	1 point

$E = 0.0037\ \text{V/m}$ (or N/C)

(c) 2 points

Using the relationship between electric field and potential difference for the linear situation:

$V = Ed$

For substitution of the value of E from part (b)	1 point
For substitution of the correct length, 15 m	1 point

$V = (0.0037\ \text{V/m})(15\ \text{m})$

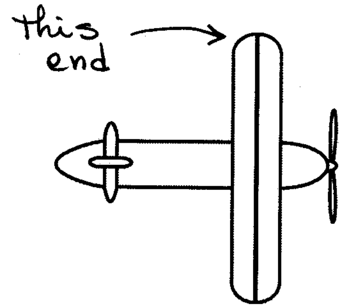
$V = 0.0553\ \text{V}$

An alternate method is to do part (c) first, using principles noted in part (b), then substituting V into the relationship $V = Ed$ to obtain E. Points equivalent to those above were awarded for this method.

Question 3 (cont'd.)

Distribution of points

(d) 1 point



For indicating that the top of the wing is at the higher potential	1 point

Note: To earn credit, this answer must be consistent with the student's answer to part (a).

(e) 5 points

i. (3 points)

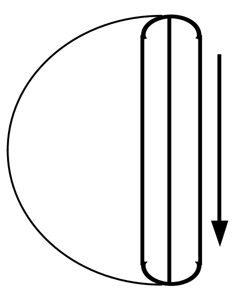
For indicating that there must be a change in the magnetic flux through the closed loop	2 points
For specifying a correct change in the plane's orientation or the connected wire that could result in a change in flux through the closed loop.	1 point

ii. (2 points)

For any indication of the position of the connected wire in the closed loop	1 point
For showing the correct direction of the resulting induced current on the diagram, based upon the conditions indicated in part (e) i.	1 point

Examples

Ex. 1: The connecting wire trails behind the antenna, over the body of the plane.
The plane goes into a forward dive, increasing its angle with respect to horizontal.



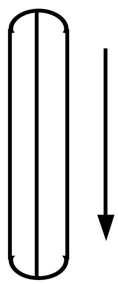
The forward dive would decrease magnetic flux downward through the loop, so a current will be induced to create an increased downward flux.

Question 3 (cont'd.)

Distribution of points

(e) (continued)

Ex. 2: The connecting wire loops under the wing, directly under the antenna.
The plane makes a level right turn.



The turn will decrease the northward component of magnetic flux through the loop, so a current will be induced to create an increased flux to the north.

Other acceptable concepts were arranging the loop so its area can be changed, or shielding a part of the circuit from the magnetic field.