



## AP<sup>®</sup> Physics C: Electricity and Magnetism 2003 Scoring Guidelines

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**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  $1/4\pi\epsilon_0$  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

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

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**Question 1 (cont'd.)**

(c) (continued)

**Distribution  
of points**

*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*

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

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

For a correct answer

*1 point*

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

(d) 3 points

$\rho_0$  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*

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

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

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

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**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

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{1}{\epsilon_0} \int dq \quad \text{OR} \quad dE = \frac{k}{r^2} dq$$

$$E4\pi r^2 = \frac{1}{\epsilon_0} \int \rho(r) dV \quad \text{OR} \quad E = \frac{k}{r^2} \int \rho(r) dq$$

For correct substitution of  $\rho_0$ ,  $dV$ , and correct limits 1 point

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

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

$$E = \frac{1}{4\pi\epsilon_0 r^2} \frac{Q}{R^3} \left(4r^3 - \frac{3r^4}{R}\right) \quad \text{OR} \quad E = \frac{k}{r^2} \frac{Q}{R^3} \left(4r^3 - \frac{3r^4}{R}\right)$$

For a correct answer 1 point

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

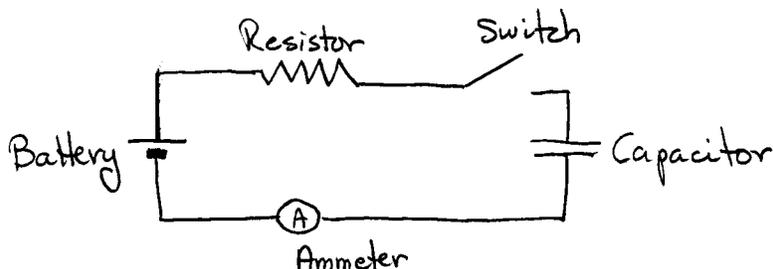
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**Question 2**

**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
- $R = (12 \text{ V}) / (0.010 \text{ A})$
- $R = 1200 \Omega$

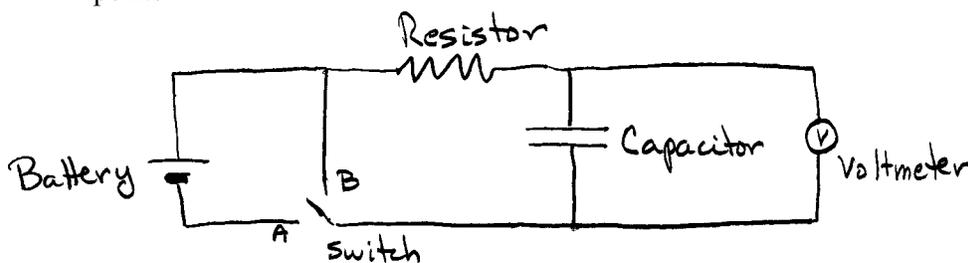
- Alternate solution* *Alternate points*
- For using the given equation for the current *1 point*
- $i(t) = \frac{\mathcal{E}}{R} e^{-t/\tau}$
- For substituting consistent current and time values from the graph into the above equation *1 point*
- For a value of resistance consistent with the substituted values *1 point*

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**Question 2 (cont'd.)**

	<b>Distribution of points</b>
(c) 4 points	
For the equation for the time constant $\tau = RC$	1 point
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) $C = (4 \text{ s}) / (1200 \Omega)$	1 point
For a value of capacitance consistent with the substituted values, including units $C = 3.3 \times 10^{-3} \text{ F}$	1 point
<i>Alternate solution</i>	<i>Alternate points</i>
For any statement of the equation relating capacitance, charge, and voltage $C = Q/V$	1 point
For an equation relating current and charge $i = dQ/dt$ OR $Q = \int i dt$	1 point
For evaluating the integral $Q = \int i dt$ , including clearly identifying the limits of integration	1 point
For example, $Q = \frac{\mathcal{E}}{R} \int_0^6 e^{-t/4} dt = -4(0.010) e^{-t/4} \Big _0^6 = -(0.040)(e^{-6/4} - e^0) = 0.031 \text{ C}$	
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 $3.4 \times 10^{-3} \text{ F}$ .	
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

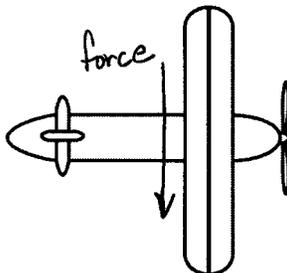
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**Question 3**

**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,  $-(\text{north} \times \text{down}) = \text{east}$ , 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  $\sin 55^\circ$

1 point

For substitution of other given values

1 point

$$E = vB \sin \theta = (75 \text{ m/s})(6 \times 10^{-5} \text{ T}) \sin 55^\circ$$

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

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

$$V = 0.0553 \text{ V}$$

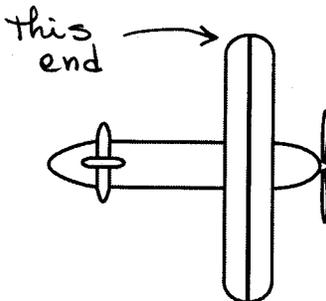
An alternate method is to do part (c) first, using principles noted in part (b), then substituting  $V$  into the relationship  $V = Ed$  to obtain  $E$ . Points equivalent to those above were awarded for this method.

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**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

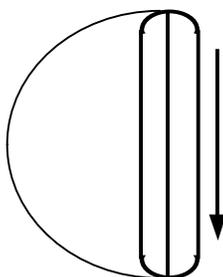
For showing the correct direction of the resulting induced current on the diagram, based upon the conditions indicated in part (e) i.

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.

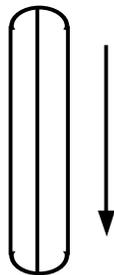
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Question 3 (cont'd.)

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.