# AP® Physics C: Electricity and Magnetism
# 2003 Scoring Guidelines



These materials were produced by Educational Testing Service® (ETS®), which develops and administers the examinations of the Advanced Placement Program for the College Board. The College Board and Educational Testing Service (ETS) are dedicated to the principle of equal opportunity, and their programs, services, and employment policies are guided by that principle.

The College Board is a national nonprofit membership association whose mission is to prepare, inspire, and connect students to college and opportunity. Founded in 1900, the association is composed of more than 4,300 schools, colleges, universities, and other educational organizations. Each year, the College Board serves over three million students and their parents, 22,000 high schools, and 3,500 colleges through major programs and services in college admissions, guidance, assessment, financial aid, enrollment, and teaching and learning. Among its best-known programs are the SAT®, the PSAT/NMSQT®, and the Advanced Placement Program® (AP®). The College Board is committed to the principles of equity and excellence, and that commitment is embodied in all of its programs, services, activities, and concerns.

For further information, visit www.collegeboard.com

# 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*

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

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

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

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

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

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

**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

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

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

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

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

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

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

For a correct answer — 1 point

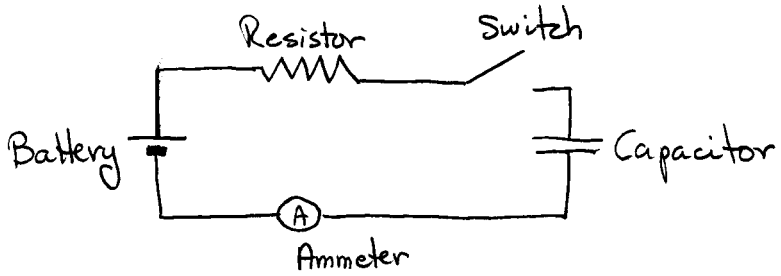
$E = \frac{kQr}{R^3}\left(4 - \frac{3r}{R}\right)$

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2003 SCORING GUIDELINES

## 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 $Q = \int i\,dt$

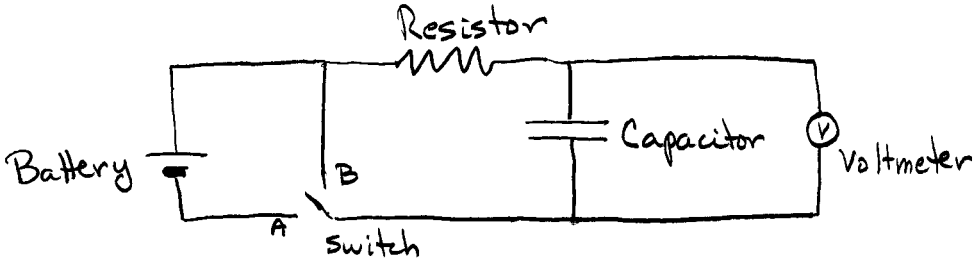
For evaluating the integral $Q = \int i\,dt$, including clearly identifying the limits of integration *1 point*

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

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 $3.4\times10^{-3}$ 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

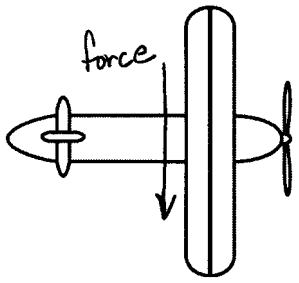
For a voltmeter connected in parallel across the capacitor 1 point

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2003 SCORING GUIDELINES

## 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:
$q\mathbf{E} = q\mathbf{v} \times \mathbf{B}$
$E = \upsilon B \sin\theta$
For substitution of sin 55° 1 point
For substitution of other given values 1 point
$E = \upsilon B \sin\theta = (75 \text{ m/s})(6 \times 10^{-5} \text{ T}) \sin 55°$
For the correct answer 1 point
$E = 0.0037 \text{ V/m}$ (or N/C)

(c) 2 points

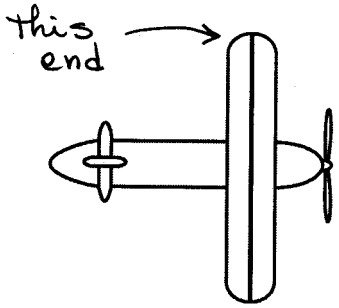
Using the relationship between electric field and potential difference for the linear situation:
$V = Ed$
For substitution of the value of $E$ from part (b) 1 point
For substitution of the correct length, 15 m 1 point
$V = (0.0037 \text{ V/m})(15 \text{ m})$
$V = 0.0553 \text{ V}$

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)

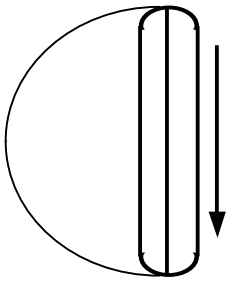
For indicating that there must be a change in the magnetic flux through the closed loop — 2 points
For specifying a correct change in the plane's orientation or the connected wire that could result in a change in flux through the closed loop. — 1 point

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.