CollegeBoard
Advanced Placement Program

AP® Physics C: Electricity and Magnetism 2004 Scoring Guidelines

General Notes about 2004 AP Physics Scoring Guidelines

1. The solutions contain the most common method(s) of solving the free-response questions, and the allocation of points for these solutions. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g. a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded.

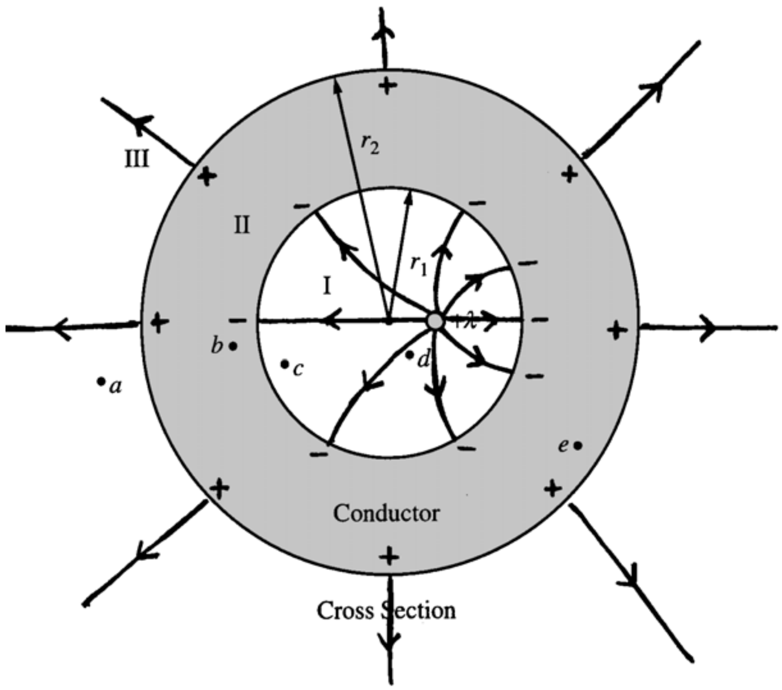
4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable.

5. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. The exception is usually when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g. 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

Question 1

15 points total **Distribution of points**

(a)



i. 3 points

For field lines inside the shell that point outward and are reasonably close to being $90°$ to both the line charge and the shell surface, with obviously more lines on the right side than the left	1 point
For field lines outside the shell that are radial and noncontinuous with those inside the shell, reasonably close to $90°$ to the shell surface, and approximately evenly spaced	1 point
For no field lines inside the shell, given that there are field lines drawn elsewhere	1 point

ii. 2 points

For only negative charges on the inside surface of the shell, with obviously more charges on the right side	1 point
For only positive charges on the outside of the shell, approximately evenly spaced	1 point

Question 1 (continued)

Distribution of points

(b) 4 points

$\underline{\ 4\ } V_a$ $\underline{\ 3\ } V_b$ $\underline{\ 2\ } V_c$ $\underline{\ 1\ } V_d$ $\underline{\ 3\ } V_e$

For giving the lowest number to V_d (i.e. placing it at the highest potential) — 1 point

For giving V_c a higher number than V_d (i.e. placing it at a lower potential) — 1 point

For giving V_b and V_e the same number — 1 point

For giving the highest number to V_a (i.e. placing it at the lowest potential) — 1 point

(c)

i. 2 points

Using Gauss's law:

$$\oint \mathbf{E} \bullet d\mathbf{A} = \frac{Q}{\epsilon_0}$$

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

For the correct expression for the value of the integral of the area — 1 point

$A = 2\pi r \ell$ (where ℓ is the length of the Gaussian surface)

For the correct expression for the total charge enclosed, which comes only from the line charge — 1 point

$Q = \lambda \ell$

Substituting and solving for the field:

$$E(2\pi r \ell) = \frac{\lambda \ell}{\epsilon_0}$$

$$E = \frac{\lambda}{2\pi \epsilon_0 r}$$

Question 1 (continued)

	Distribution of points
(c) (continued)	
ii. 2 points	
For any indication that the total field or the total charge enclosed is the sum of contributions from the line charge and the shell	1 point

$Q_{tot} = Q_{line} + Q_{shell}$ or $E_{tot} = E_{line} + E_{shell}$

The field from the line charge is the same as calculated in part i.

$$E_{line} = \frac{\lambda}{2\pi\epsilon_0 r}$$

For the shell, the charge enclosed is that between r and r_1

$$Q_{shell} = \rho\left(\pi r^2\ell - \pi r_1^2\ell\right)$$

For substitution of the correct enclosed charge for the shell into Gauss's law — 1 point

$$E_{shell}(2\pi r\ell) = \frac{\rho}{\epsilon_0}\left(\pi r^2\ell - \pi r_1^2\ell\right)$$

$$E_{shell} = \frac{\rho}{2\epsilon_0 r}\left(r^2 - r_1^2\right)$$

$$E_{tot} = \frac{\lambda}{2\pi\epsilon_0 r} + \frac{\rho}{2\epsilon_0 r}\left(r^2 - r_1^2\right)$$

iii. 2 points

For any indication that the total field or the total charge enclosed is the sum of contributions from the line charge and the shell — 1 point

$Q_{tot} = Q_{line} + Q_{shell}$ or $E_{tot} = E_{line} + E_{shell}$

The field from the line charge is the same as calculated in part i.

$$E_{line} = \frac{\lambda}{2\pi\epsilon_0 r}$$

For the shell, the charge enclosed is that between r_2 and r_1

$$Q_{shell} = \rho\left(\pi r_2^2\ell - \pi r_1^2\ell\right)$$

For substitution of the correct enclosed charged for the shell into Gauss's law — 1 point

$$E_{shell}(2\pi r\ell) = \frac{\rho}{\epsilon_0}\left(\pi r_2^2\ell - \pi r_1^2\ell\right)$$

$$E_{shell} = \frac{\rho}{2\epsilon_0 r}\left(r_2^2 - r_1^2\right)$$

$$E_{tot} = \frac{\lambda}{2\pi\epsilon_0 r} + \frac{\rho}{2\epsilon_0 r}\left(r_2^2 - r_1^2\right)$$

Question 2

15 points total | **Distribution of points**

(a) 1 point

Once the switch is closed, $V_{R_1} = V_C$.

From the graph, one can see that at $t = 0$, $V_C = 0$. Therefore, all the voltage drop occurs across resistor R_2.

For the correct answer, with units — 1 point

$V_{R_2} = 20\ \text{V}$

(b) 1 point

From the graph, the maximum voltage across the capacitor (and thus also R_1), is 12 V.

The remaining voltage drop occurs across R_2.

$V_{R_2} = 20\ \text{V} - 12\ \text{V}$

For the correct answer, with units — 1 point

$V_{R_2} = 8\ \text{V}$

(c) 3 points

A long time after the switch is closed, $I_C = 0$.

For any indication that $I_{R_1} = I_{R_2}$ — 1 point

Using Ohm's law to calculate the current in R_1:

$I_{R_1} = V_{R_1} / R_1 = (12\ \text{V})/(15\ \text{k}\Omega) = 0.8 \times 10^3\ \text{A}$

Using Ohm's law to calculate R_2:

$R_2 = V_{R_2} / I_{R_2} = (8\ \text{V}) / \left(0.8 \times 10^{-3}\ \text{A}\right)$

For the correct numerical answer — 1 point

For the correct units — 1 point

$R_2 = 10\ \text{k}\Omega$

<u>NOTE:</u> There was a discrepancy in this question between information in the graph and the circuit diagram. The value of the time constant as shown in the graph was about a factor of ten too large when compared to the value determined from the information in the diagram. Determination of R_2 by equating the expression for the time constant in terms of resistance and capacitance to the time constant from the graph yields a negative resistance. Since it was not the fault of the students that the correct analysis yielded a negative value of resistance, full credit could be earned for this method.

Question 2 (continued)

		Distribution of points

(d) 3 points

Using the relationship for the energy stored in a capacitor:

$U = \frac{1}{2}CV^2$

For substituting the correct value of voltage — 1 point

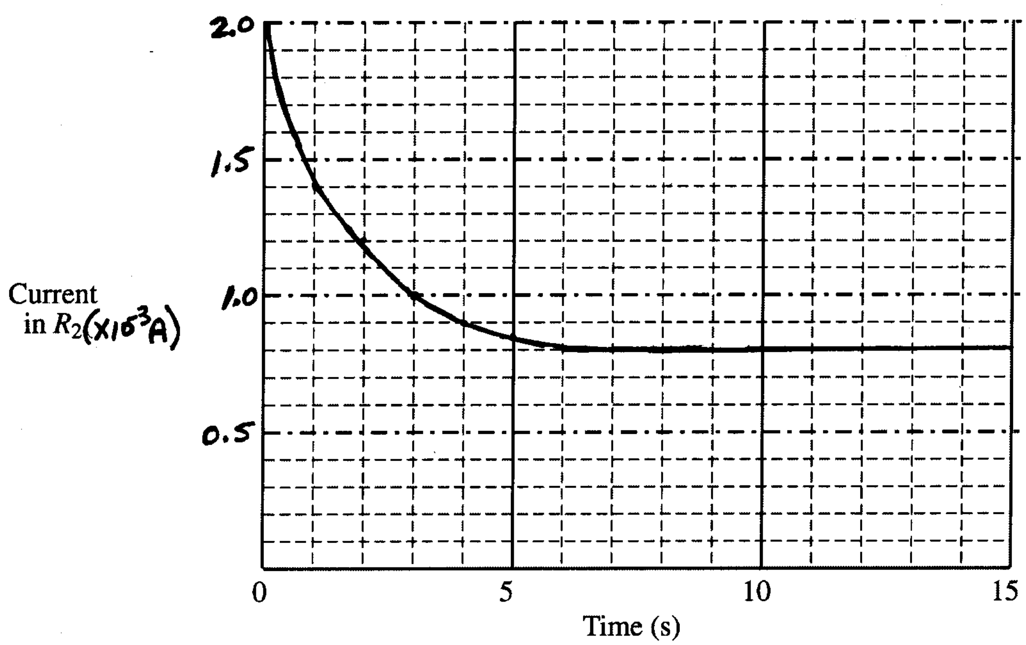
For substituting the correct value of capacitance — 1 point

$U = \frac{1}{2}(20\ \mu\text{F})(12\ \text{V})^2$

For the correct answer, with correct units — 1 point

$U = 1.44 \times 10^{-3}\ \text{J}$

(e) 4 points



For a correct value for the initial current — 1 point

From part (a), $V_{R_2} = 20\ \text{V}$ immediately after the switch is closed

$I_{\max R_2} = (20\ \text{V})/(10\ \text{k}\Omega) = 2 \times 10^{-3}\ \text{A}$

For a correct value for the final current — 1 point

From part (c), $I_{R_2} = 0.8 \times 10^{-3}\,\text{A}$ a long time after the switch is closed

For a correctly curving graph — 1 point

For labeling the vertical axis (including units) — 1 point

Only the general shape of the graph and the endpoints were graded. The time constant of the graph was not evaluated.

Question 2 (continued)

	Distribution of points
(f) 3 points	
For indicating that the energy would be greater	1 point
For a correct and complete explanation	2 points

For example: Consider the circuit a long time after the switch is closed, when there is no current in the capacitor. If R_2 is replaced with a smaller resistance, then the total resistance decreases. This results in a larger current through the resistors. Therefore, the voltage across R_1, and thus across the capacitor, increases. Since $U = \frac{1}{2}CV^2$, energy increases.

One of the two explanation points could be earned for an incomplete but correct explanation.

Question 3

15 points total — **Distribution of points**

(a) 4 points

The magnetic field from the wire with current I is given by:

$B = \dfrac{\mu_0 I}{2\pi r}$ (this equation can be remembered or derived from Ampere's law)

Using the equation for the flux:

$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$

For correctly including the dimension 4ℓ of the loop when re-expressing the area integral as an integral over r — 1 point

$dA = 4\ell\ dr$

For the correct limits on the integral — 1 point

$$\phi_m = \int_{\ell}^{4\ell} \frac{\mu_0 I}{2\pi r}\ 4\ell\ dr = \frac{2\ell\mu_0 I}{\pi}\int_{\ell}^{4\ell} \frac{dr}{r}$$

For correctly performing the integration — 1 point

$$\phi_m = \frac{2\ell\mu_0 I}{\pi} \ln r\Big|_{\ell}^{4\ell} = \frac{2\ell\mu_0 I}{\pi}(\ln 4\ell - \ln \ell)$$

For the correct answer — 1 point

$$\phi_m = \frac{2\ell\mu_0 I}{\pi}\ \ln 4$$

(b) 3 points

For correctly indicating that the induced current is counterclockwise — 1 point

For a complete correct explanation — 2 points

For example: The decreasing current means that the magnetic field, which points out of the plane of the page, is decreasing in magnitude. Using Lenz's law, the induced current thus needs to create a field to counteract this change. The current must therefore be counterclockwise to create a field directed out of the page

Only one point was awarded for incomplete explanations, such as merely saying that Lenz's law or the right-hand rule justifies the answer.

Question 3 (continued)

Distribution of points

(c) 4 points

For a correct relationship between the current, resistance, and derivative of the flux — 1 point

$I_{loop} = \mathcal{E}/R = (1/R)(-d\phi/dt)$

For using the expression for flux from part (a) — 1 point

$\phi_m = \dfrac{2\ell\mu_0 I}{\pi} \ln 4$

For substituting $I(t)$ in the flux equation — 1 point

$\phi_m = \dfrac{2\ell\mu_0 I_0}{\pi}(\ln 4)\ e^{-kt}$

For correctly differentiating this expression to determine the emf — 1 point

$\mathcal{E} = -\dfrac{d\phi}{dt} = -(-k)\dfrac{2\ell\mu_0 I_0}{\pi}(\ln 4)\ e^{-kt}$

$\mathcal{E} = \dfrac{2\ell k\mu_0 I_0}{\pi}(\ln 4)\ e^{-kt}$

Substituting into the expression for current:

$I_{loop} = \dfrac{2\ell k\mu_0 I_0}{\pi R}(\ln 4)\ e^{-kt}$

(d) 4 points

For using a correct expression for power — 1 point

$P = I^2 R$

For substituting the expression for current from part (c) — 1 point

$P = \left(\dfrac{2\ell k\mu_0 I_0}{\pi R}(\ln 4)e^{-kt}\right)^2 R \ = \left(\dfrac{2\ell k\mu_0 I_0}{\pi}(\ln 4)\right)^2 \dfrac{1}{R}\ e^{-2kt}$

For indicating that the dissipated energy is the integral of the power — 1 point

$U = \displaystyle\int_0^\infty P\ dt$

$U = \left(\dfrac{2\ell k\mu_0 I_0}{\pi}(\ln 4)\right)^2 \dfrac{1}{R}\displaystyle\int_0^\infty e^{-2kt}\ dt$

For correctly integrating the expression — 1 point

$U = \left(\dfrac{2\ell k\mu_0 I_0}{\pi}(\ln 4)\right)^2 \dfrac{1}{R}\left(-\dfrac{1}{2k}\right)e^{-2kt}\Big|_0^\infty$

$U = \left(\dfrac{2\ell k\mu_0 I_0}{\pi}(\ln 4)\right)^2 \dfrac{1}{R}\left(-\dfrac{1}{2k}\right)(0-1)$

$U = \left(\dfrac{2\ell\mu_0 I_0}{\pi}(\ln 4)\right)^2 \dfrac{k}{2R}$