AP® Physics C: Electricity and Magnetism
2011 Scoring Guidelines

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Question 1

15 points total | **Distribution of points**

(a) 3 points

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

For a proper application of Gauss's Law using spherical symmetry — 1 point

$$E\left(4\pi r^2\right) = \frac{Q_{enc}}{\epsilon_0}$$

For a proper description of the correct Gaussian surface — 1 point

A proper description of the Gaussian surface should indicate that it is a sphere, concentric with the charged shell, and with a radius less than the radius of the shell. Drawing a proper Gaussian surface is acceptable.

For completing the response with an indication that $E = 0$, consistent with previous work — 1 point

The enclosed charge Q is zero for all radii of the Gaussian surface; therefore, the electric field E is also zero everywhere inside the sphere.

(b) 2 points

For selecting the correct answer of "No" — 1 point

For a correct justification — 1 point

Example: With a nonsymmetric distribution, the fields from individual charges no longer have the net effect of completely canceling inside the shell.

(c) 5 points

For correctly selecting face *ABCD* — 1 point

For correctly selecting face *ABGH* — 1 point

For correctly selecting face *ADEH* — 1 point

One earned point is deducted for each incorrect face selected.

For a correct and complete justification of the correctly checked choices — 2 points

Examples:

The electric field from the sphere is radial, so it is parallel to the three correct faces.

The electric field vector does not penetrate the area of any of the three correct faces.

Note: One point can be earned for a partial explanation or an explanation with a minor factual error.

Question 1 (continued)

	Distribution of points
(d) 1 point	
For correctly identifying corner A as having the smallest magnitude of electric field. Corner A is inside the small conducting sphere, so the electric field there is zero. All other corners have a nonzero electric field.	1 point
(e) 1 point	
For correctly determining the electric field strength at the position indicated in part (d). As explained above, the electric field at point A is zero. A correct calculation for whatever point is indicated in part (d) also receives full credit.	1 point
(f) 3 points	
For proper use of Gauss's Law that recognizes that the flux is a constant	1 point
Total electric flux $= \phi_{\text{total}} = \dfrac{Q_{\text{enc}}}{\epsilon_0}$. The cube encloses $\dfrac{1}{8}$ of the charge, i.e. $Q_{\text{enc}} = \dfrac{Q}{8}$.	
For recognizing that the flux is the same through each of the three nonzero flux sides of the cube and is equal to $1/3$ of the total flux through the cube.	1 point
For proper reasoning leading to the final correct answer	1 point
$\phi_{\text{total}} = 3\phi_{CDEF} = \dfrac{Q/8}{\epsilon_0}$	
$\phi_{CDEF} = \dfrac{Q}{24\epsilon_0}$	

Question 2

15 points total | **Distribution of points**

(a)

i. 2 points

For correctly calculating the magnitude of the charge on the bottom plate of the capacitor and including correct units — 1 point

$V = Q/C$

$Q = CV$

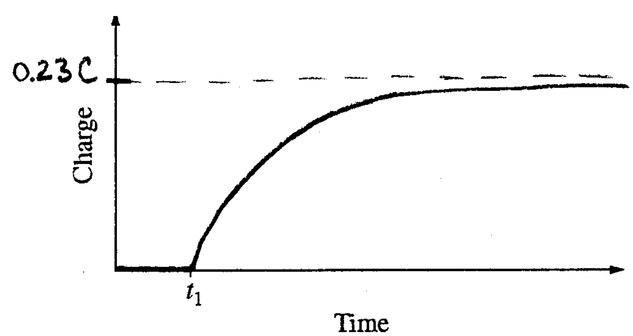
$Q = \left(25 \times 10^{-3}\ \text{F}\right)(9.0\ \text{V})$

$Q = 0.23\ \text{C}$

For correctly identifying the charge on the bottom plate as negative. — 1 point

With the polarity of the battery terminal attached to the bottom plate shown in the figure, the charge is negative.

ii. 3 points



For correctly indicating and labeling the asymptote, with either the value determined in part (a) or an equivalent algebraic expression — 1 point

For explicitly showing $Q = 0$ for $t < t_1$ — 1 point

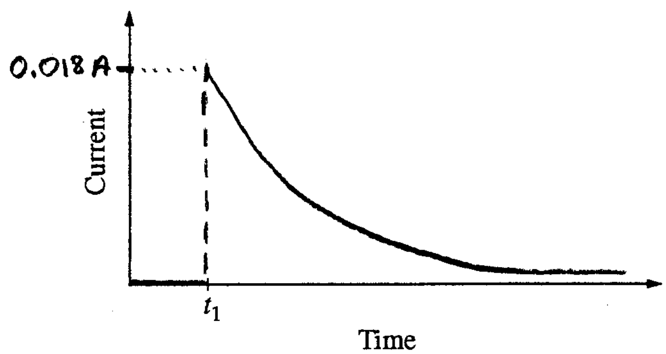
For correctly sketching the curve, starting at $t = t_1$ and asymptotically approaching the maximum charge — 1 point

Question 2 (continued)

Distribution of points

(a) (continued)

iii. 3 points



The maximum current occurs just after the switch is closed, when there is no charge on the capacitor.

$V = IR$

$I_{max} = V/R = 9.0\text{ V}/500\ \Omega = 0.018\text{ A}$

For correctly indicating and labeling the maximum current, with either the correct value or an equivalent algebraic expression — 1 point

For explicitly showing $I = 0$ for $t < t_1$ — 1 point

For correctly sketching the curve, starting at the maximum current at $t = t_1$ and asymptotically approaching zero — 1 point

(b)

i. 2 points

$$U_C = \frac{1}{2}QV = \frac{1}{2}Q\frac{Q}{C} = \frac{1}{2}\frac{Q^2}{C}$$

For substituting correct values into a correct expression — 1 point

For example, $U_C = \dfrac{1}{2}\dfrac{\left(105 \times 10^{-3}\text{ C}\right)^2}{\left(25 \times 10^{-3}\text{ F}\right)}$

For a consistent answer with correct units — 1 point

$U_C = 0.22\text{ J}$

Question 2 (continued)

Distribution of points

(b) (continued)

ii. 2 points

The maximum current occurs when there is no charge on the capacitor and all the energy is stored in the inductor.

$U_L = \frac{1}{2}LI^2$

The total energy is the energy that was stored in the capacitor at time t_2.

For a correct expression of energy conservation — 1 point

$\frac{1}{2}LI^2 = U_C$

$I = \sqrt{2U_C/L}$

Substituting the given value for L and the value of U_C determined in part (b) i

$I = \sqrt{2(0.22\text{ J})/5.0\text{ H}}$

For an answer with units consistent with previous work — 1 point

$I = 0.30\text{ A}$

iii. 3 points

For a correct application of the loop rule — 1 point

$L\frac{dI}{dt} + \frac{Q}{C} = 0$

$\frac{dI}{dt} = -\frac{Q}{CL}$

$\frac{dI}{dt} = -\frac{(50 \times 10^{-3}\text{ C})}{(25 \times 10^{-3}\text{ F})(5.0\text{ H})}$

For a correct numerical answer obtained from a correct procedure, with or without the negative sign — 1 point

For the correct units on a calculated answer — 1 point

$\frac{dI}{dt} = -0.40\text{ A/s}$

Question 3

15 points total | **Distribution of points**

(a)

For all three cases, the path of integration when applying Ampere's law is a circle concentric with the cylinder and perpendicular to its axis, with a radius r in the range specified.

i. 2 points

For explicitly stating Ampere's law in at least one of parts (a)i, (a)ii or (a)iii — 1 point

$\oint \mathbf{B} \bullet d\ell = \mu_0 I_{enc}$

$I_{enc} = 0$

For the correct answer — 1 point

$B = 0$

ii. 3 points

$\oint \mathbf{B} \bullet d\ell = \mu_0 I_{enc}$

For a correct simplification of the line integral — 1 point

$\oint \mathbf{B} \bullet d\ell = B(2\pi r)$

Calculating the current density:

$$J = \frac{I_0}{\pi b^2 - \pi a^2}$$

For an expression giving I_{enc} as a fraction of I_0 — 1 point

$$I_{enc} = J \bullet (\text{area enclosed}) = J\left(\pi r^2 - \pi a^2\right) = \frac{I_0\left(\pi r^2 - \pi a^2\right)}{\left(\pi b^2 - \pi a^2\right)} = \frac{I_0\left(r^2 - a^2\right)}{\left(b^2 - a^2\right)}$$

$$B(2\pi r) = \mu_0 \frac{I_0\left(r^2 - a^2\right)}{\left(b^2 - a^2\right)}$$

For the correct expression for B — 1 point

$$B = \frac{\mu_0 I_0\left(r^2 - a^2\right)}{2\pi r\left(b^2 - a^2\right)}$$

iii. 1 point

$\oint \mathbf{B} \bullet d\ell = \mu_0 I_{enc}$

$B(2\pi b) = \mu_0 I_{enc}$

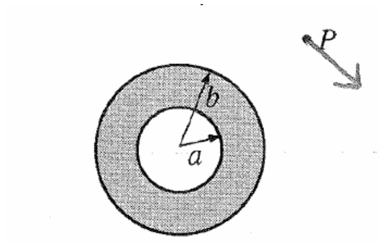
For the correct expression for B — 1 point

$$B = \frac{\mu_0 I_0}{4\pi b}$$

Question 3 (continued)

Distribution of points

(b) 2 points



Cross-sectional View
(current into page)

For drawing a vector that is perpendicular to a line connecting the center of the cylinder and point *P*	1 point
For indicating the correct direction	1 point

(c) 2 points

For stating that there are no (electromagnetic) forces on the electron. The word "electromagnetic" does not need to be explicitly stated.	1 point
For a correct justification regarding the absence of a magnetic force, related to $\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$	1 point

No explicit mention of the electric force was required. The focus of the question is on magnetic effects. No electric force acts on the electron because there is no electric field present. One earned point was deducted if an incorrect statement about electric forces was made.

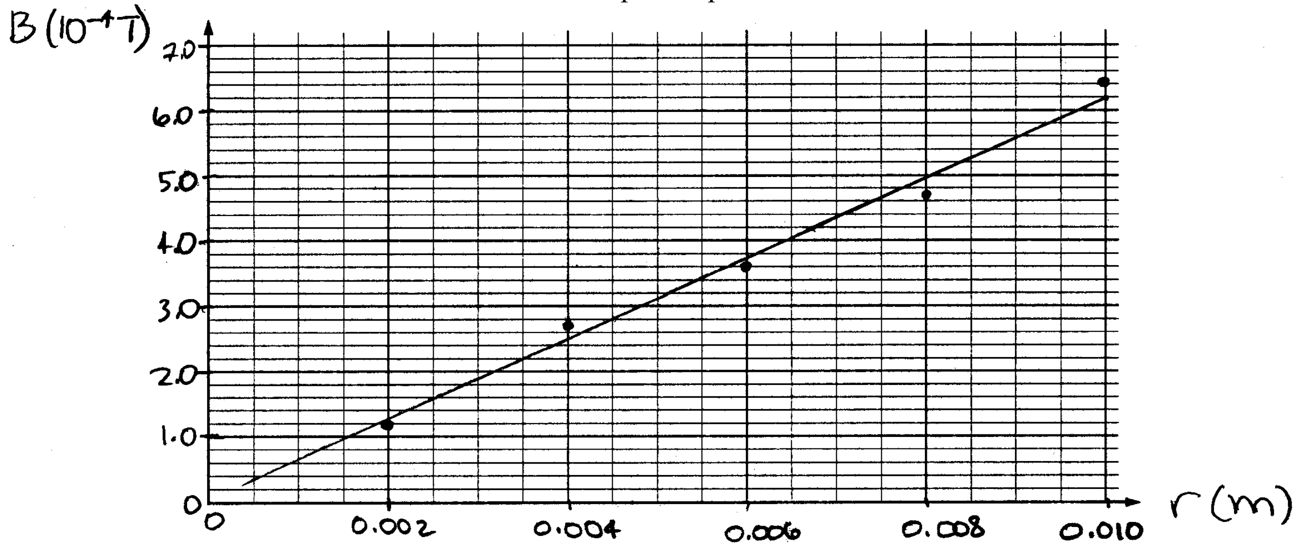
Question 3 (continued)

Distribution of points

(d)

i. 3 points

Sample Graph



For correctly labeling the y-axis with magnetic field units and correctly labeling the x-axis with length units — 1 point

For correctly scaling both axes, with at least one scale using essentially the whole length of the axis — 1 point

For drawing a best-fit straight line — 1 point

ii. 2 points

For calculating the slope of the best-fit straight line from actual points on the line — 1 point

$$\text{slope} = \frac{\Delta B}{\Delta r}$$

Using two points on the sample graph above

$$\text{slope} = \frac{6.2\times10^{-4}\ \text{T} - 2.8\times10^{-4}\ \text{T}}{0.010\ \text{m} - 0.0045\ \text{m}} = \frac{3.4\times10^{-4}\ \text{T}}{0.0055\ \text{m}} = 0.062\ \text{T/m}$$

For the correct relationship between μ_0 and the slope — 1 point

From the given equation $B = \mu_0 I_0 r / 2\pi b^2$, the slope can be written as $\mu_0 I_0 / 2\pi b^2$.

$$\text{slope} = \mu_0 I_0 / 2\pi b^2$$

$$\mu_0 = \frac{2\pi b^2}{I_0}(\text{slope})$$

$$\mu_0 = \frac{2\pi (0.010\ \text{m})^2}{25\ \text{A}}(0.062\ \text{T/m})$$

$$\mu_0 = 1.56\times10^{-6}\ (\text{T•m})/\text{A}$$