AP® PHYSICS
2011 SCORING GUIDELINES

General Notes About 2011 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. 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 earned. 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 earn 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 earned. However, when students are asked to derive an expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections — Student Presentation" in the *AP Physics Course Description*.

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 also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically earn full credit. Exceptions to these guidelines usually occur 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 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

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

$I_{enc} = 0$

For the correct answer — 1 point

$B = 0$

ii. 3 points

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

For a correct simplification of the line integral — 1 point

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

Calculating the current density:

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

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

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

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

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

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

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

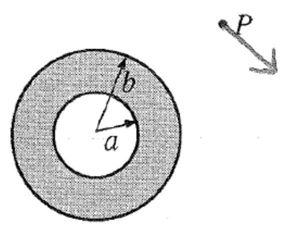
For the correct expression for B — 1 point

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

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.

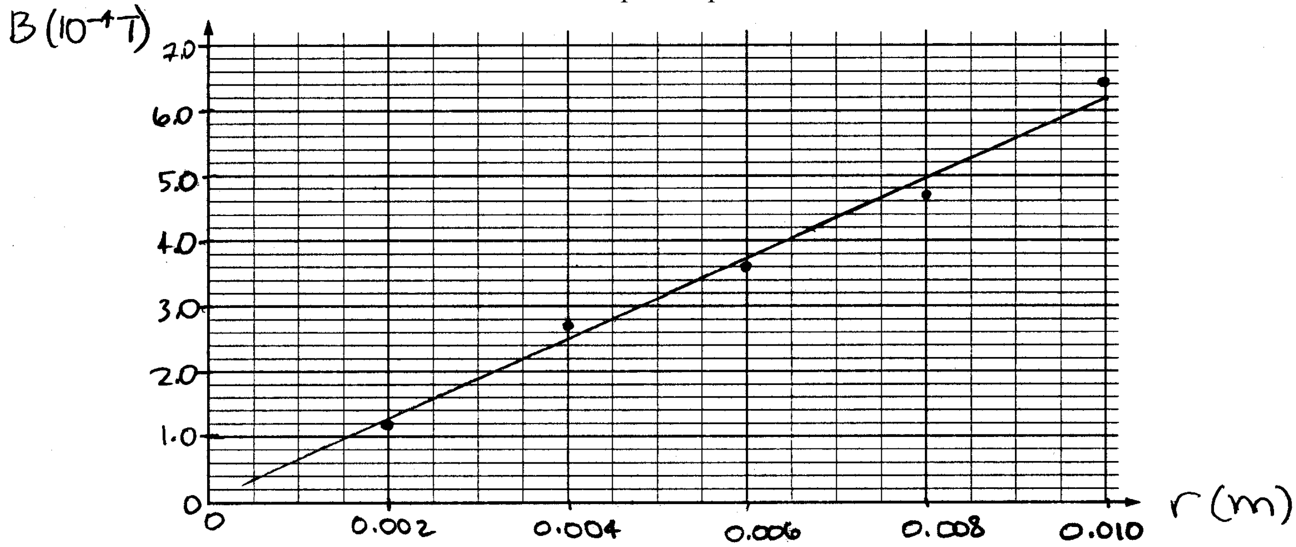
Question 3 (continued)

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

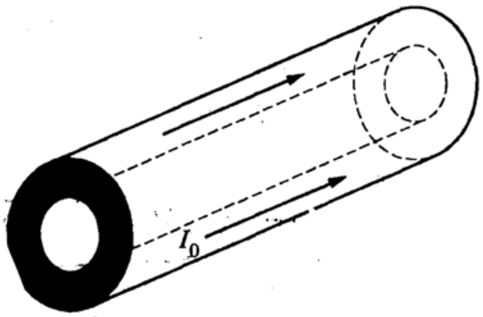
From the given equation $B = \mu_0 I_0 r / 2\pi b^2$, the slope can be written as $\mu_0 I_0 / 2\pi b^2$.

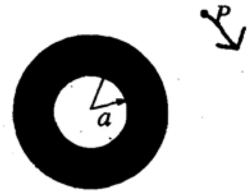
$$\text{slope} = \mu_0 I_0 / 2\pi b^2$$

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

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

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





Cross-sectional View
(current into page)

E&M. 3.

A section of a long conducting cylinder with inner radius a and outer radius b carries a current I_0 that has a uniform current density, as shown in the figure above.

(a) Using Ampère's law, derive an expression for the magnitude of the magnetic field in the following regions as a function of the distance r from the central axis.

i. $r < a$

$\oint B \cdot ds = \mu_0 I_{enc}$

$B\, 2\pi r = \mu_0 I_{enc}$

$B = \frac{\mu_0 I_{enc}}{2\pi r}$, $I_{enc} \to 0$

$I_{enc} = 0$

$B = 0$

ii. $a < r < b$

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

$\oint B \cdot ds = \mu_0 \int_a J \cdot dA$

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

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

iii. $r = 2b$

$\oint B \cdot ds = \mu_0 I_{enc}$

$B\, 2\pi (2b) = \mu_0 I_0$

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

(b) On the cross-sectional view in the diagram above, indicate the direction of the field at point P, which is at a distance $r = 2b$ from the axis of the cylinder.

(c) An electron is at rest at point P. Describe any electromagnetic forces acting on the electron. Justify your answer.

No magnetic force, since $F_B = qv \times B$ and $v = 0$

No electric force, since there is no electric field or change in electric potential near point P.

No eleetro magnetic forces

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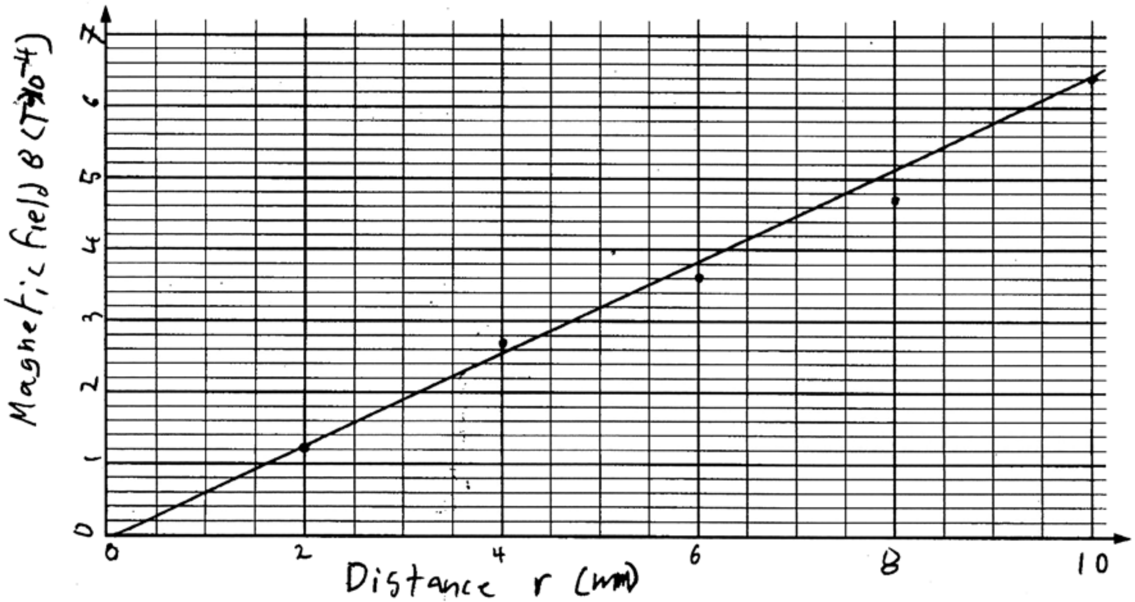
Now consider a long, <u>solid</u> conducting cylinder of radius b carrying a current I_0. The magnitude of the magnetic field inside this cylinder as a function of r is given by $B = \mu_0 I_0 r / 2\pi b^2$. An experiment is conducted using a particular solid cylinder of radius 0.010 m carrying a current of 25 A. The magnetic field inside the cylinder is measured as a function of r, and the data is tabulated below.

Distance r (m)	0.002	0.004	0.006	0.008	0.010
Magnetic Field B (T)	1.2×10^{-4}	2.7×10^{-4}	3.6×10^{-4}	4.7×10^{-4}	6.4×10^{-4}

(d)

i. On the graph below, plot the data points for the magnetic field B as a function of the distance r, and label the scale on both axes. Draw a straight line that best represents the data.



ii. Use the slope of your line to estimate a value of the permeability μ_0.

$$m = \frac{\Delta B}{\Delta r} = \frac{(6.4 \cdot 10^{-4}\,T - 1.2 \cdot 10^{-4}\,T)}{(0.010m - 0.002m)} = 0.065 \frac{T}{m}$$

$$B = \frac{\mu_0 I_0}{2\pi b^2} r$$

$$m = \frac{\mu_0 I_0}{2\pi b^2} \Rightarrow \mu_0 = \frac{2\pi b^2 m}{I_0} = 1.634 \cdot 10^{-6}$$

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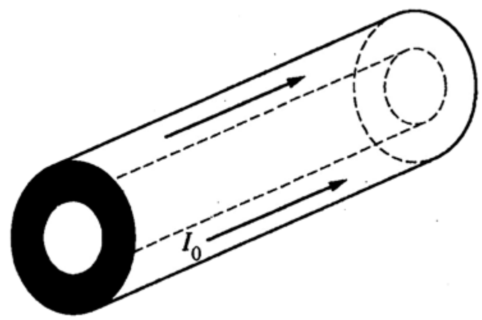
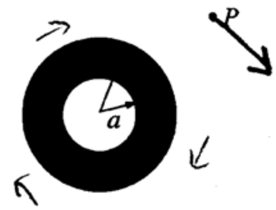




Cross-sectional View
(current into page)

E&M. 3.

A section of a long ~~conducting cylinder~~ with inner radius a and outer radius b carries a current I_0 that has a uniform current density, as shown in the figure above.

(a) Using Ampère's law, derive an expression for the magnitude of the magnetic field in the following regions as a function of the distance r from the central axis.

i. $r < a$

$$\oint B \cdot dl = \mu_0 I$$
$$B(2\pi r) = \mu_0 I$$
$$B = \frac{\mu_0 I}{2\pi r}$$

ii. $a < r < b$

$$B = 0$$

iii. $r = 2b$

$$\oint B\,dl = \mu_0 I$$
$$B(2\pi 2b) = \mu_0 I$$
$$B = \frac{\mu_0 I}{4\pi b}$$

(b) On the cross-sectional view in the diagram above, indicate the direction of the field at point P, which is at a distance $r = 2b$ from the axis of the cylinder.

(c) An electron is at rest at point P. Describe any electromagnetic forces acting on the electron. Justify your answer.

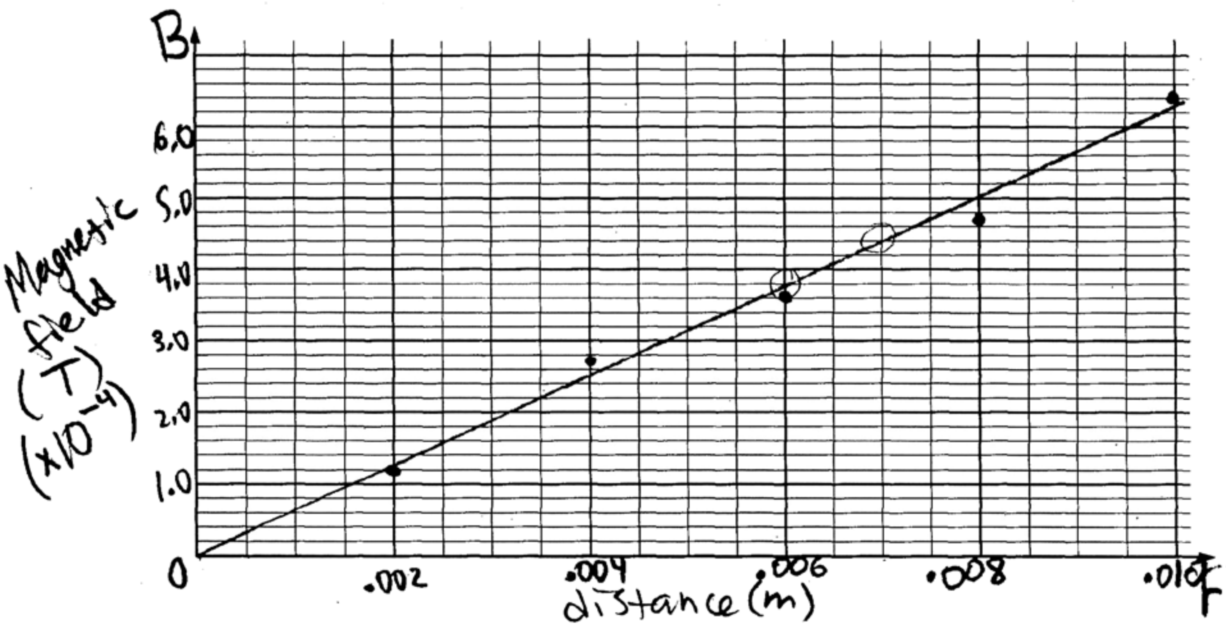
Force from the wire

Now consider a long, <u>solid</u> conducting cylinder of radius b carrying a current I_0. The magnitude of the magnetic field inside this cylinder as a function of r is given by $B = \mu_0 I_0 r / 2\pi b^2$. An experiment is conducted using a particular solid cylinder of radius 0.010 m carrying a current of 25 A. The magnetic field inside the cylinder is measured as a function of r, and the data is tabulated below.

Distance r (m)	0.002	0.004	0.006	0.008	0.010
Magnetic Field B (T)	1.2×10^{-4}	2.7×10^{-4}	3.6×10^{-4}	4.7×10^{-4}	6.4×10^{-4}

(d)

i. On the graph below, plot the data points for the magnetic field B as a function of the distance r, and label the scale on both axes. Draw a straight line that best represents the data.



ii. Use the slope of your line to estimate a value of the permeability μ_0.

$$\text{slope} = \frac{4.4\times10^{-4} - 3.8\times10^{-4}}{.007 - .006} = .06$$

$$.06 = \frac{\mu_0 I_0}{2\pi b^2}$$

$$.06 = \mu_0 \left(\frac{25}{2\pi(.010^2)}\right)$$

$$\mu_0 = 1.51\times10^{-6}$$

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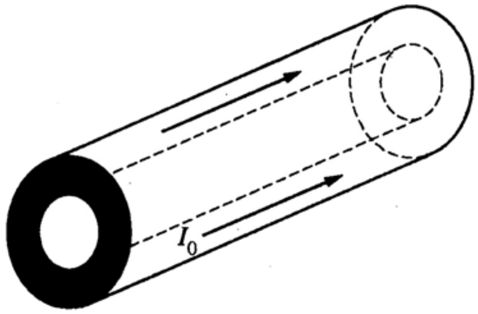

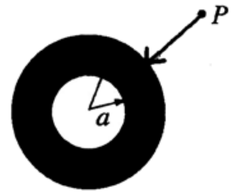

Cross-sectional View
(current into page)

E&M. 3.

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i. $r < a$

$|B| = 0$

ii. $a < r < b$

$|B| = \frac{\pi Q}{a^2}$

iii. $r = 2b$

$|B| = \frac{\pi Q(2b)}{R^3}$

(b) On the cross-sectional view in the diagram above, indicate the direction of the field at point P, which is at a distance $r = 2b$ from the axis of the cylinder.

(c) An electron is at rest at point P. Describe any electromagnetic forces acting on the electron. Justify your answer.

There is an electromagnetic force coming from the conducting cylinder.

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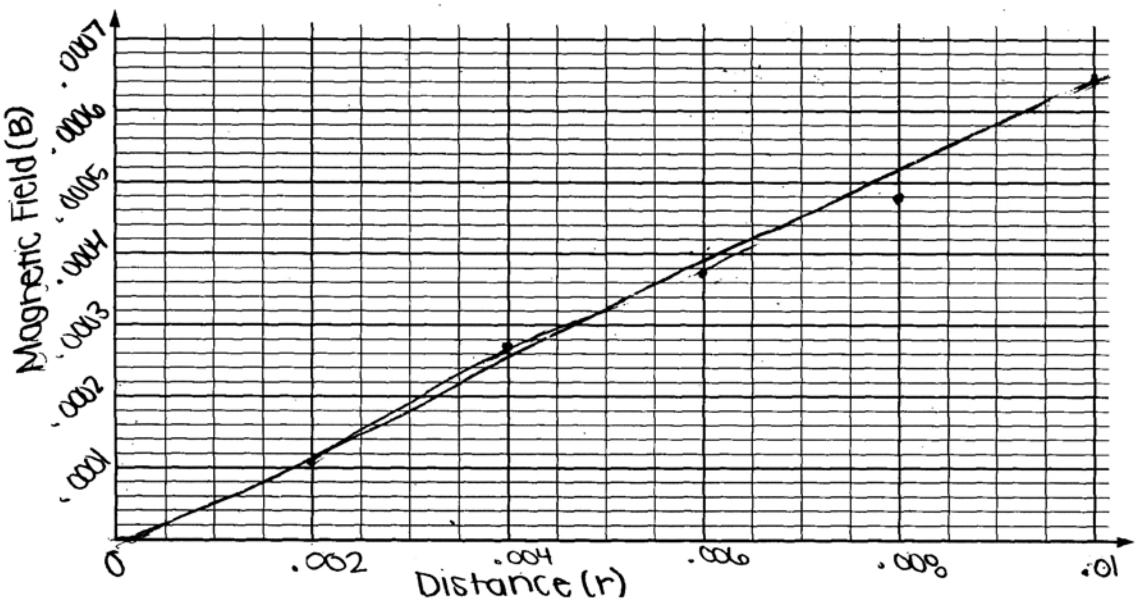
(d)

i. On the graph below, plot the data points for the magnetic field B as a function of the distance r, and label the scale on both axes. Draw a straight line that best represents the data.



ii. Use the slope of your line to estimate a value of the permeability μ_0.

$y = 15.951x + 6.038$

$m = 15.951$

$B = \frac{\mu_0 I_0 r}{2\pi b^2}$

$\frac{2\pi b^2 B}{I_0 r} = \mu_0$

$\frac{2\pi (15.951)^2 (6.4\times10^{-4})}{25A(.01)} = \mu_0$

$\mu_0 = \frac{1.023}{.25}$

6.4

$\mu_0 = 4.092$ permeability

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AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2011 SCORING COMMENTARY

Question 3

Overview

This lab question assessed student understanding of Ampere's law with a long-conducting, hollow, current-carrying cylinder. It also assessed students' ability to graph a set of experimental data and then extrapolate information from the graph to obtain values of physical quantities.

Sample: E3A
Score: 15

The response earned full credit for all parts. The explanation for part (c) includes a correct statement about electric as well as magnetic forces. Note also the somewhat rarely seen units of 10^{-4} T and mm in part (d).

Sample: E3B
Score: 9

In part (a) the response earned 1 point for using Ampere's law and 1 point for the answer in part (a) iii, but the rest of the work is incorrect. Part (b) earned full credit, but part (c) is not specific enough and earned no credit. Part (d) earned full credit.

Sample: E3C
Score: 3

Part (a) i earned 1 point. Part (b) is incorrect and part (c) is not specific enough, so no points were earned. In part (d) i there are no unit labels on the axes, but the other 2 points were earned. In part (d) ii the indicated slope is the reciprocal of the true slope, which is not correctly used in determining μ_0, so no credit was earned.