2019

AP® CollegeBoard

AP® Physics C: Electricity and Magnetism

Sample Student Responses and Scoring Commentary Set 1

Inside:

Free Response Question 3

- ☑ Scoring Guideline
- ☑ Student Samples
- ☑ Scoring Commentary

General Notes About 2019 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. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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.

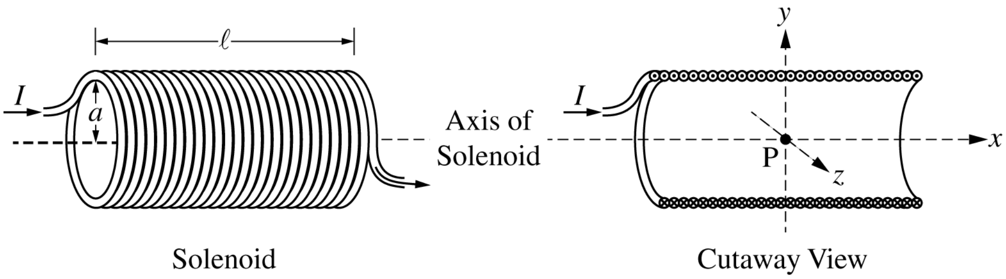
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

6. 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 receive 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



Note: Figures not drawn to scale.

A solenoid is used to generate a magnetic field. The solenoid has an inner radius a, length ℓ, and N total turns of wire. A power supply, not shown, is connected to the solenoid and generates current I, as shown in the figure on the left above. The x-axis runs along the axis of the solenoid. Point P is in the middle of the solenoid at the origin of the xyz-coordinate system, as shown in the cutaway view on the right above. Assume $\ell >> a$.

(a) LO CNV-8.E.a, SP 7.A, 7.C
2 points

Select the correct direction of the magnetic field at point P.

____ $+x$-direction ____ $+y$-direction ____ $+z$-direction
____ $-x$-direction ____ $-y$-direction ____ $-z$-direction

Justify your selection.

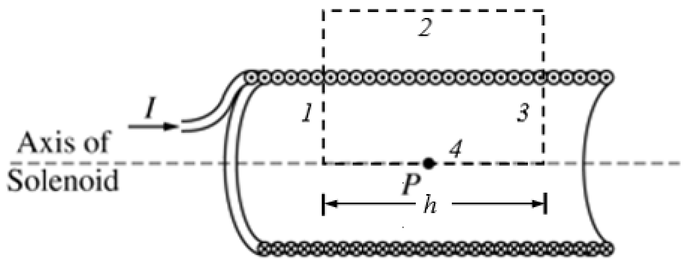
For choosing the "$+x$-direction" and providing a justification		1 point
For a correct justification		1 point
Example: Using the right-hand rule for current on the left side of the solenoid, the fingers curl into the loop, so the magnetic field points to the right, or in the $+x$-direction.		
Example: Using the right-hand rule for solenoids, when the fingers curl around the solenoid in the direction of the current, the thumb points to the right, therefore the magnetic field is to the right, or in the $+x$-direction.		

Question 3 (continued)

(b)

i. LO CNV-8.C.c, SP 3.D
1 point

On the cutaway view below, clearly draw an Amperian loop that can be used to determine the magnetic field at point P at the center of the solenoid.



For drawing a rectangle with one side along the central axis of the solenoid and another side outside the solenoid and whose edges do not extend beyond the solenoid		1 point

ii. LO CNV-8.C.c, SP 5.A, 5.E
2 points

Use Ampere's law to derive an expression for the magnetic field strength at point P. Express your answer in terms of I, ℓ, N, a, and physical constants, as appropriate.

For using Ampere's law to calculate the magnetic field along the axis of the solenoid		1 point
$\int B \bullet d\ell = \mu_0 I_{enc} \therefore \left(\int B \bullet d\ell\right)_1 + \left(\int B \bullet d\ell\right)_2 + \left(\int B \bullet d\ell\right)_3 + \left(\int B \bullet d\ell\right)_4 = \mu_0 I_{enc}$		
$\left(\int B \bullet d\ell\right)_1 + 0 + \left(-\left(\int B \bullet d\ell\right)_1\right) + Bh = \mu_0 \frac{N}{\ell} hI$		
$Bh = \mu_0 \frac{N}{\ell} hI$		
For a correct answer		1 point
$B = \frac{\mu_0 NI}{\ell}$		

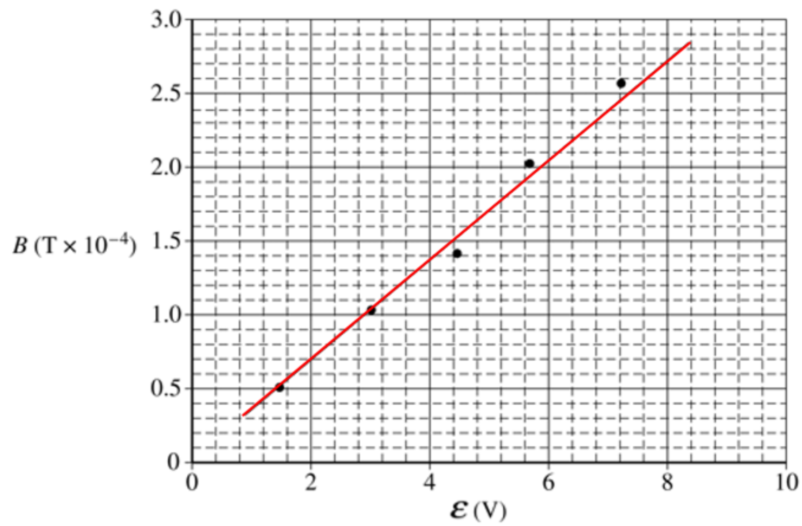
Some physics students conduct an experiment to determine the resistance R_S of a solenoid with radius $a = 0.015$ m, total turns $N = 100$, and total length $\ell = 0.40$ m. The students connect the solenoid to a variable power supply. A magnetic field sensor is used to measure the magnetic field strength along the central axis at the center of the solenoid. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.

Question 3 (continued)

(c) LO CNV-8.C.c, SP 4.C

i. 1 point

On the graph above, draw a best-fit line for the data.



For drawing a best-fit line with at least one point above and one point below the line		1 point

ii. LO CNV-8.C.c, SP 6.B, 6.C

2 points

Use the straight line to determine the resistance R_S of the solenoid used in the experiment.

For calculating the slope using the best-fit line and not the data points unless they fall on the best-fit line		1 point
$slope = \dfrac{\Delta y}{\Delta x} = \dfrac{(2.5-0.9)(\times 10^{-4}\ \text{T})}{(6.4-2.0)\ \text{V}} = 0.36\times 10^{-4} = 3.6\times 10^{-5}\ \text{T/V}$		
For correctly giving the expression that relates the slope to the resistance of the solenoid		1 point
$B = \dfrac{\mu_0 NI}{\ell} = \dfrac{\mu_0 N\mathcal{E}}{\ell R}\ \therefore\ slope = \dfrac{\mu_0 N}{\ell R_S}\ \therefore\ R_S = \dfrac{\mu_0 N}{\ell \times slope}$ $R_S = \dfrac{(4\pi\times 10^{-7}\ (\text{T}\cdot\text{m})/\text{A})(100\ \text{turns})}{(0.40\ \text{m})(3.6\times 10^{-5}\ \text{T/V})} = 8.7\ \Omega$		

One of the students notes that the horizontal component of the magnetic field of Earth is 2.5×10^{-5} T.

Question 3 (continued)

(d)

i. LO CNV-8.E.a, SP 2.D
1 point

Is there evidence from the graph that the horizontal orientation of the solenoid affects the measured values for B?

____ Yes ____ No

Justify your answer.

If the line on the graph does not go through the origin, select "Yes"		
For a correct justification		1 point
Example: The horizontal component of Earth's magnetic field will add or subtract from the magnetic field of the solenoid depending on the orientation of the solenoid.		
Alternate Solution		*Alternate Points*
If the line on the graph does pass through the origin, select "No"		
For a correct justification		*1 point*
Example: Based on the graph, the line passes through the origin, so the magnetic field is zero when the emf of the power supply is zero, therefore Earth's magnetic field is not affecting the values of B.		

ii. LO CNV-8.E.a, SP 2.E
1 point

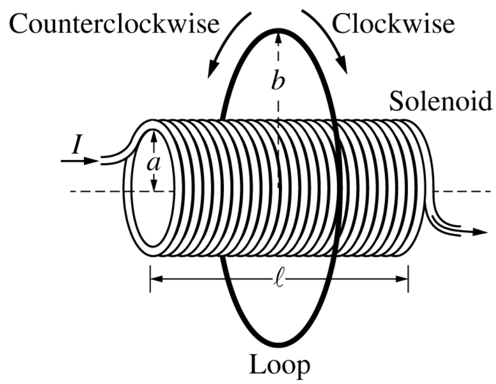
Would the horizontal orientation of the solenoid affect the calculated value for R_S ?

____ Yes ____ No

Justify your answer.

Select "No"		
For a correct justification		1 point
Example: The horizontal component of Earth's magnetic field will not affect the change in magnetic field as the emf is changed. Therefore, the value for the resistance of the solenoid will not change.		

Question 3 (continued)



A thin conducting loop of radius b and resistance R_L is placed concentric with the solenoid, as shown above. The current in the solenoid is decreased from I to zero over time Δt.

(e)

i. LO FIE-6.A.b, SP 7.A, 7.C
2 points

Is the direction of the induced current in the loop clockwise or counterclockwise during the time period that the current in the solenoid is decreasing?

____ Clockwise ____ Counterclockwise

Justify your answer.

Select "Clockwise"		
For a justification indicating that the magnetic field inside the solenoid, and therefore the loop, will decrease		1 point
For a justification using Lenz's law to relate the change in magnetic field to the direction of the current		1 point
Example: As the current in the solenoid decreases, the magnetic field inside the solenoid decreases. As the solenoid's magnetic field decreases, the induced current in the loop will create a magnetic field to oppose this change. Because the solenoid's magnetic field is toward the right and decreasing, the magnetic field due to the current in the loop must be toward the right. Therefore, the current in the loop must be clockwise.		

Question 3 (continued)

(e) continued
ii. LO FIE-6.A.d, SP 5.A, 5.E
3 points

Derive an equation for the average induced current i_{IND} in the loop during the time period that the current in the solenoid is decreasing. Express your answer in terms of I, ℓ, N, a, b, R_L, R_S, Δt, and physical constants, as appropriate.

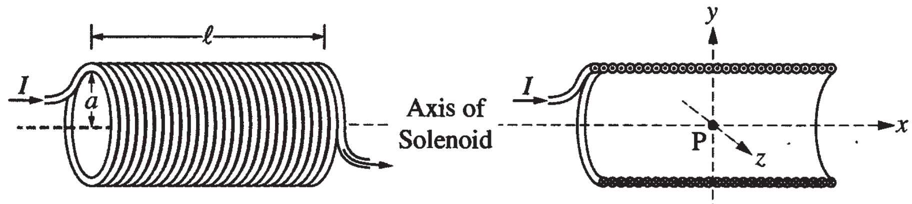
For using Faraday's law to calculate the emf in the loop		1 point
$\mathcal{E} = \left\lvert \dfrac{d\Phi}{dt} \right\rvert = \dfrac{d(BA)}{dt} = A\dfrac{\Delta B}{\Delta t}$		
For using Ohm's law to calculate the current in the loop		1 point
$I_{\text{IND}} = \dfrac{V}{R} = \dfrac{A\Delta B/\Delta t}{R_L} = \dfrac{A\Delta B}{R_L \Delta t}$		
For using the correct radius for the area in the equation above		1 point
$I_{\text{IND}} = \dfrac{\pi a^2 \mu_0 N \Delta I/\ell}{R_L \Delta t} = \dfrac{\pi a^2 \mu_0 N I}{R_L \ell \Delta t}$		

Learning Objectives

CNV-8.C.c: Derive the expression for the magnetic field of an ideal solenoid (length dimension is much larger than the radius of the solenoid) using Ampère's law.
CNV-8.E.a: Describe the direction of a magnetic field at a point in space due to various combinations of conductors, wires, cylindrical conductors, or loops.
FIE-6.A.b: Describe the direction of an induced current in a conductive loop that is placed in a changing magnetic field.
FIE-6.A.d: Calculate the magnitude and direction of induced EMF and induced current in a conductive loop (or conductive bar) when the magnitude of either the field or area of loop is changing at a constant rate.

Science Practices

2.D: Make observations or collect data from representations of laboratory setups or results.
2.E: Identify or describe potential sources of experimental error.
3.D: Create appropriate diagrams to represent physical situations.
4.C: Linearize data and/or determine a best-fit line or curve.
5.A: Select an appropriate law, definition, or mathematical relationship or model to describe a physical situation.
5.E: Derive a symbolic expression from known quantities by selecting and following a logical algebraic pathway.
6.B: Apply an appropriate law, definition, or mathematical relationship to solve a problem.
6.C: Calculate an unknown quantity with units from known quantities, by selecting and following a logical computational pathway.
7.A: Make a scientific claim.
7.C: Support a claim with evidence from physical representations.



Solenoid   Cutaway View

Note: Figures not drawn to scale.

3. A solenoid is used to generate a magnetic field. The solenoid has an inner radius a, length ℓ, and N total turns of wire. A power supply, not shown, is connected to the solenoid and generates current I, as shown in the figure on the left above. The x-axis runs along the axis of the solenoid. Point P is in the middle of the solenoid at the origin of the xyz-coordinate system, as shown in the cutaway view on the right above. Assume $\ell \gg a$.

(a) Select the correct direction of the magnetic field at point P.

_X_ $+x$-direction   ____ $+y$-direction   ____ $+z$-direction

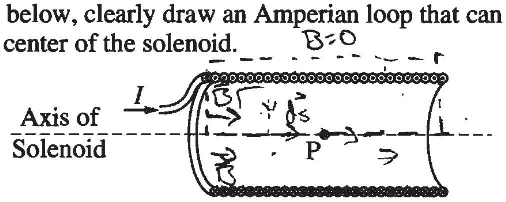
____ $-x$-direction   ____ $-y$-direction   ____ $-z$-direction

Justify your selection.

Using the right hand rule, curl your fingers in the direction of the current, thumb points in the direction of $\vec{B}$ field

(b)

i. On the cutaway view below, clearly draw an Amperian loop that can be used to determine the magnetic field at point P at the center of the solenoid.



Cutaway View

ii. Use Ampere's law to derive an expression for the magnetic field strength at point P. Express your answer in terms of I, ℓ, N, a, and physical constants, as appropriate.

$\oint \vec{B} \cdot d\vec{s} = \mu_0 I$ N = number of turns

$\oint \vec{B} \cdot d\vec{s} = \mu_0 N I$ ← only place $\theta = 0$ is along axis of solenoid

$\int B \cos\theta \, ds = \mu_0 N I$

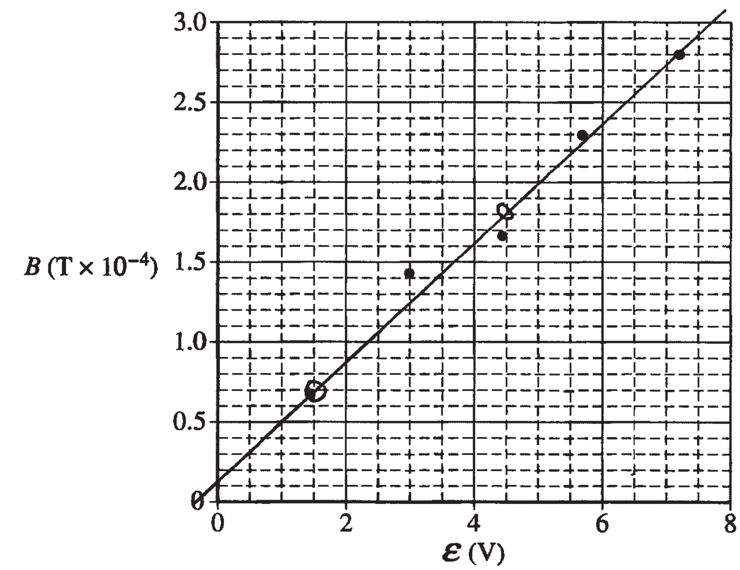
$\int B \, ds = \mu_0 N I$

$B \ell = \mu_0 N I$

$\boxed{B_s = \frac{\mu_0 N I}{\ell}}$

GO ON TO THE NEXT PAGE.

Some physics students conduct an experiment to determine the resistance R_S of a solenoid with radius $a = 0.015$ m, total turns $N = 100$, and total length $\ell = 0.40$ m. The students connect the solenoid to a variable power supply. A magnetic field sensor is used to measure the magnetic field strength along the central axis at the center of the solenoid. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.



$\frac{(1.8 - 0.7) \times 10^{-4}}{4.5 - 1.5}$

slope = 3.7 e-5

(c)

i. On the graph above, draw a best-fit line for the data.

ii. Use the straight line to determine the resistance R_S of the solenoid used in the experiment.

$B_S = \frac{\mu_0 N I}{\ell} = \frac{\mu_0 N V}{\ell R}$ B vs. V slope $= \frac{\mu_0 N}{\ell R}$

$R = \frac{\mu_0 N}{\ell (\text{slope})}$

$R = \frac{(4\pi \times 10^{-7})(100)}{(.40)(3.7e^{-5})} = \boxed{8.5 \Omega}$

(d) One of the students notes that the horizontal component of the magnetic field of Earth is 2.5×10^{-5} T.

i. Is there evidence from the graph that the horizontal orientation of the solenoid affects the measured values for B?

X Yes ____ No

Justify your answer.

The best Fit line will not have a y-intercept of zero. The y-intercept will be 2.5×10^{-5} T.

Question 3 continues on the next page.

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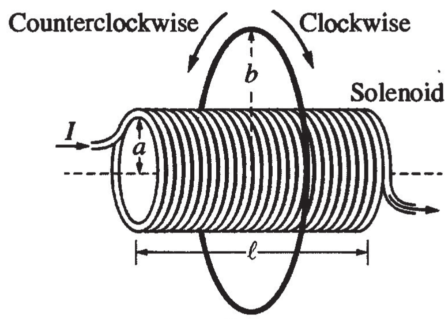
ii. Would the horizontal orientation of the solenoid affect the calculated value for R_S ?

____ Yes _X_ No

Justify your answer.

the y-intercept of the graph has no affect on the slope



A thin conducting loop of radius b and resistance R_L is placed concentric with the solenoid, as shown above. The current in the solenoid is decreased from I to zero over time Δt.

(e)

i. Is the direction of the induced current in the loop clockwise or counterclockwise during the time period that the current in the solenoid is decreasing?

_X_ Clockwise ____ Counterclockwise

Justify your answer.

According to Lenz's Law, a decreasing field to the right will induce a field in the same direction in order to maintain $\frac{d\Phi_{net}}{dt} = 0$

ii. Derive an equation for the average induced current i_{IND} in the loop during the time period that the current in the solenoid is decreasing. Express your answer in terms of I, ℓ, N, a, b, R_L, R_S, Δt, and physical constants, as appropriate.

$$\varepsilon = \frac{\Delta \Phi}{\Delta t} = \frac{\Delta(BA)}{\Delta t} = A\frac{\Delta(\mu_0 \frac{N}{\ell} I)}{\Delta t} = \frac{A\mu_0 N}{\ell}\frac{\Delta I}{\Delta t}$$

$$I = \frac{\varepsilon}{R} = \frac{A\mu_0 N}{R_L \ell}\frac{\Delta I}{\Delta t} = \boxed{\frac{(\pi a^2)\mu_0 N}{R_L \ell}\left(\frac{\Delta I}{\Delta t}\right)}$$

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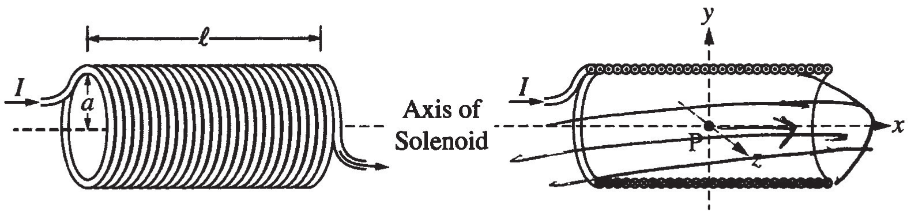


Solenoid Cutaway View

Note: Figures not drawn to scale.

3. A solenoid is used to generate a magnetic field. The solenoid has an inner radius a, length ℓ, and N total turns of wire. A power supply, not shown, is connected to the solenoid and generates current I, as shown in the figure on the left above. The x-axis runs along the axis of the solenoid. Point P is in the middle of the solenoid at the origin of the xyz-coordinate system, as shown in the cutaway view on the right above. Assume $\ell >> a$.

(a) Select the correct direction of the magnetic field at point P.

✓ $+x$-direction ____ $+y$-direction ____ $+z$-direction

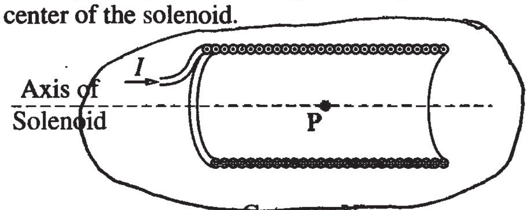
____ $-x$-direction ____ $-y$-direction ____ $-z$-direction

Justify your selection.

According The the right hand rule, the fingers wrap the way current is flowing and the thumb points to the magnetic field.

(b)

i. On the cutaway view below, clearly draw an Amperian loop that can be used to determine the magnetic field at point P at the center of the solenoid.



Cutaway View

ii. Use Ampere's law to derive an expression for the magnetic field strength at point P. Express your answer in terms of I, ℓ, N, a, and physical constants, as appropriate.

?

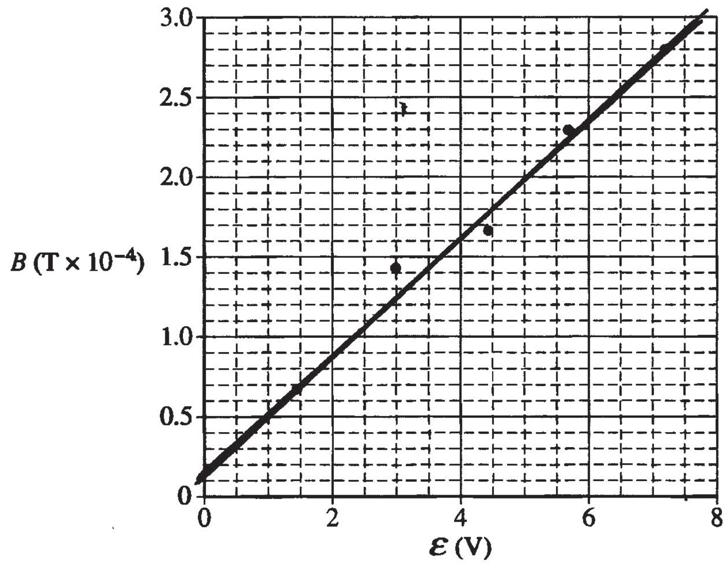
$B = \mu_0 n I$

$B = \mu_0 N I$

GO ON TO THE NEXT PAGE.

E Q3 B p2

Some physics students conduct an experiment to determine the resistance R_S of a solenoid with radius $a = 0.015$ m, total turns $N = 100$, and total length $\ell = 0.40$ m. The students connect the solenoid to a variable power supply. A magnetic field sensor is used to measure the magnetic field strength along the central axis at the center of the solenoid. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.



(c)

i. On the graph above, draw a best-fit line for the data.

ii. Use the straight line to determine the resistance R_S of the solenoid used in the experiment.

$(0.5,\ 0.3)\times10^{-4}$
$(7.5,\ 2.9)\times10^{-4}$ slope $= \dfrac{2.9\times10^{-4} - 0.3\times10^{-4}}{7.5-0.5} = \dfrac{2.6\times10^{-4}}{7} = 3.7\times10^{-5}\ \frac{T}{V}$

(d) One of the students notes that the horizontal component of the magnetic field of Earth is 2.5×10^{-5} T.

i. Is there evidence from the graph that the horizontal orientation of the solenoid affects the measured values for B ?

✓ Yes ____ No

Justify your answer.

The y intercept is not zero it is ~ 2.0×10^{-5} T

Question 3 continues on the next page.

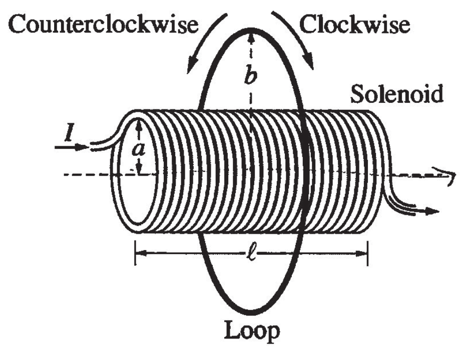
GO ON TO THE NEXT PAGE.

ii. Would the horizontal orientation of the solenoid affect the calculated value for R_S ?

____ Yes ✓ No

Justify your answer.

The orientation would only effect the direction of the magnetic field, while the magnitude would stay the same.



A thin conducting loop of radius b and resistance R_L is placed concentric with the solenoid, as shown above. The current in the solenoid is decreased from I to zero over time Δt.

(e)

i. Is the direction of the induced current in the loop clockwise or counterclockwise during the time period that the current in the solenoid is decreasing?

✓ Clockwise ____ Counterclockwise

Justify your answer.

Current is decreased, so the magnetic field decreases, decreasing the flux, so the induced current has to make up for the decrease by having an increased induced magnetic field.

ii. Derive an equation for the average induced current i_{IND} in the loop during the time period that the current in the solenoid is decreasing. Express your answer in terms of I, ℓ, N, a, b, R_L, R_S, Δt, and physical constants, as appropriate.

$$\varepsilon = \oint E\,d\ell = -\frac{d\Phi}{dt}$$

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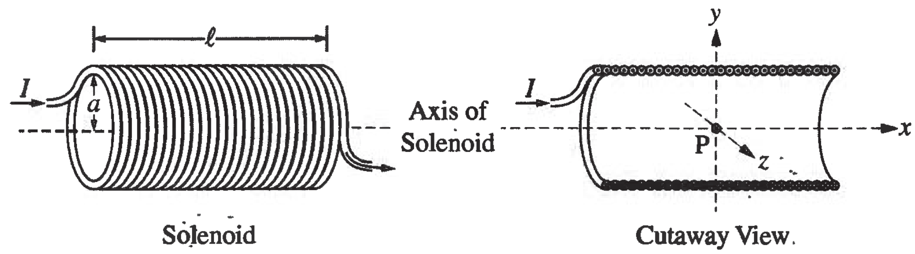

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3. A solenoid is used to generate a magnetic field. The solenoid has an inner radius a, length ℓ, and N total turns of wire. A power supply, not shown, is connected to the solenoid and generates current I, as shown in the figure on the left above. The x-axis runs along the axis of the solenoid. Point P is in the middle of the solenoid at the origin of the xyz-coordinate system, as shown in the cutaway view on the right above. Assume $\ell >> a$.

(a) Select the correct direction of the magnetic field at point P.

✓ $+x$-direction ____ $+y$-direction ____ $+z$-direction

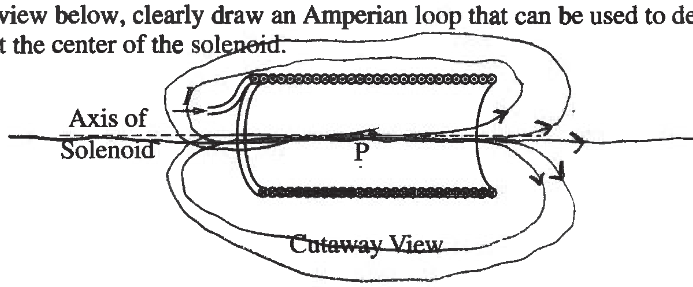
____ $-x$-direction ____ $-y$-direction ____ $-z$-direction

Justify your selection.

Right hand rule shows direction of B-field

(b)

i. On the cutaway view below, clearly draw an Amperian loop that can be used to determine the magnetic field at point P at the center of the solenoid.



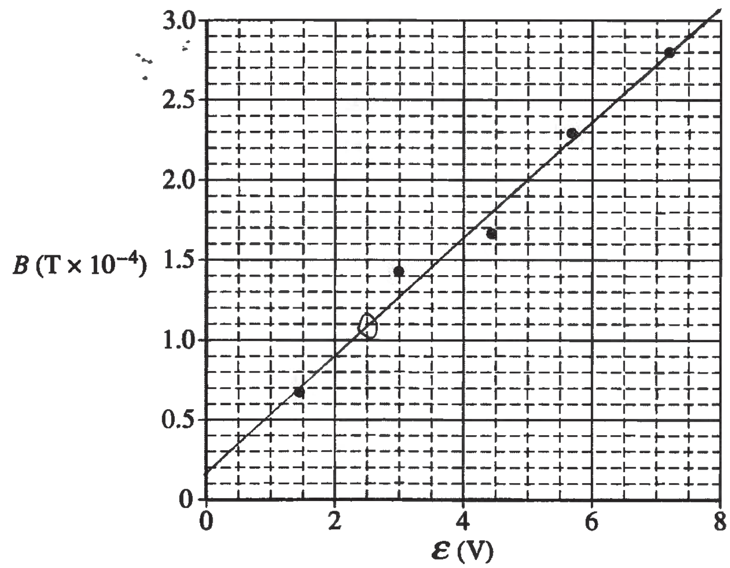
ii. Use Ampere's law to derive an expression for the magnetic field strength at point P. Express your answer in terms of I, ℓ, N, a, and physical constants, as appropriate.

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

$B \cdot \pi r^2 = \mu_0 I$

GO ON TO THE NEXT PAGE.

Some physics students conduct an experiment to determine the resistance R_S of a solenoid with radius $a = 0.015$ m, total turns $N = 100$, and total length $\ell = 0.40$ m. The students connect the solenoid to a variable power supply. A magnetic field sensor is used to measure the magnetic field strength along the central axis at the center of the solenoid. The plot of the magnetic field strength B as a function of the emf $\mathcal{E}$ of the power supply is shown below.



(c)

i. On the graph above, draw a best-fit line for the data.

ii. Use the straight line to determine the resistance R_S of the solenoid used in the experiment.

$R = \frac{1.1 - .9}{2.5 - 2}$

$R = .4\,\Omega$

(d) One of the students notes that the horizontal component of the magnetic field of Earth is 2.5×10^{-5} T.

i. Is there evidence from the graph that the horizontal orientation of the solenoid affects the measured values for B ?

_✓_ Yes ____ No

Justify your answer.

the y-intercept is not =0, therefore there is interference with the B-field generated

Question 3 continues on the next page.

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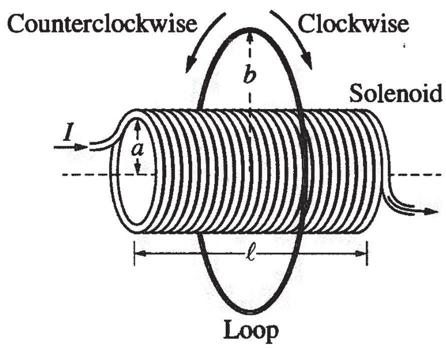
ii. Would the horizontal orientation of the solenoid affect the calculated value for R_S ?

____ Yes ✓ No

Justify your answer.

Resistance is not effected by positioning



A thin conducting loop of radius b and resistance R_L is placed concentric with the solenoid, as shown above. The current in the solenoid is decreased from I to zero over time Δt.

(e)

i. Is the direction of the induced current in the loop clockwise or counterclockwise during the time period that the current in the solenoid is decreasing?

✓ Clockwise ____ Counterclockwise

Justify your answer.

nature makes an induced B-field due to the reducing current in the solenoid

ii. Derive an equation for the average induced current i_{IND} in the loop during the time period that the current in the solenoid is decreasing. Express your answer in terms of I, ℓ, N, a, b, R_L, R_S, Δt, and physical constants, as appropriate.

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

$$\oint B \cdot \pi r^2 = \mu_0 I_{IND}$$

$$B \cdot \pi a^2 = \mu_0 I_{IND}$$

GO ON TO THE NEXT PAGE.

Question 3

Note: Student samples are quoted verbatim and may contain spelling and grammatical errors.

Overview

The responses to this question were expected to demonstrate the following:

- An understanding of the relationship between current and the magnetic field in a solenoid
- The ability to identify an appropriate Amperian loop
- The ability to use Ampere's law
- An understanding of the meaning of the slope of a best-fit line.
- An understanding of the meaning of the *y*-intercept of a best-fit line
- The ability to use Faraday's law to determine induced current
- An understanding of Lenz's law

Sample: E Q3 A
Score: 15

All parts of this response earned full credit. Part (a) has a correct selection and justification, so 2 points were earned. Part (b)(i) has a correct Amperian loop, so 1 point was earned. Part (b)(ii) has a correct use of Ampere's law and a correct answer, so 2 points were earned. Part (c) has an appropriate best-fit line, an acceptable calculation of slope, and correctly relates the slope to the resistance of the solenoid, so 3 points were earned. Part (d)(i) has an appropriate selection and justification based on the best-fit line, so 1 point was earned. Part (d)(ii) has a correct selection and justification, so 1 point was earned. Part (e)(i) has a correct selection and justification, so 2 points were earned. Part (e)(ii) has correct uses of Faraday's law and Ohm's law and substitutes the correct radius, so 3 points were earned.

Sample: E Q3 B
Score: 7

Parts (d)(i) and (e)(i) earned full credit, 1 point and 2 points, respectively. Part (a) has a correct selection but an insufficient justification, so 1 point was earned. Part (b)(i) has an incorrect Amperian loop, so no points were earned. Part (b)(ii) has no statement of Ampere's law, so no points were earned. Part (c) has an appropriate best-fit line and correctly calculates the slope but does not relate the slope to the resistance of the solenoid, so 2 points were earned. Part (d)(ii) has an incorrect justification, so no points were earned. Part (e)(ii) has a correct use of Faraday's law, but it does not use Ohm's law and does not substitute the area, so 1 point was earned.

Sample: E Q3 C
Score: 4

Part (a) has a correct selection but an insufficient justification, so 1 point was earned. Part (b)(i) has an incorrect Amperian loop, so no points were earned. Part (b)(ii) has a statement of Ampere's law but no correct answer, so 1 point was earned. Part (c) has an appropriate best-fit line, but it does not use the vertical axis scale to calculate the slope and does not relate the slope to the resistance of the solenoid, so 1 point was earned. Part (d)(i) has a correct selection and justification, so 1 point was earned. Part (d)(ii) has an incorrect justification, so no points were earned. Part (e)(ii) does not use Faraday's law or Ohm's law and does not substitute the area, so no points were earned.