2022

AP® CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free-Response Question 4

☑ Scoring Guidelines

☑ Student Samples

☑ Scoring Commentary

Question 4: Short Answer — 10 points

(a)	For an appropriate use of Newton's laws to set the magnetic force equal to the electric force	**1 point**
	For using correct expressions for the magnetic and electric forces	**1 point**
	For substituting an expression for the magnetic field to yield a correct expression that includes v and the given quantities	**1 point**

Example Response

$$\Sigma\vec{F} = m\vec{a}$$

$$F_M - F_E = 0$$

$$F_M = F_E$$

$$qvB = qE$$

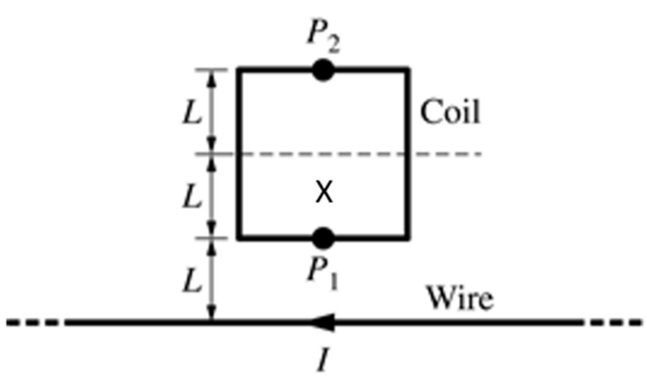
$$v\left(\frac{\mu_0 I}{2\pi d}\right) = E$$

$$v = \frac{2\pi d E}{\mu_0 I}$$

Total for part (a) — 3 points

(b)(i)	For an "X" between point P_1 and the dashed line	**1 point**

Example Response



For indicating that the magnetic field strength is inversely proportional to the distance from the wire — **1 point**

Example Response

Magnetic field is inversely proportional to the distance from a long, straight current carrying wire: $B = \frac{\mu_0 I}{2\pi r}$ *. Doubling the distance from the wire from* L *to* $2L$ *would reduce the magnetic field from* $3B_0$ *to* $1.5B_0$*. Therefore, the magnetic field would be equal to* $2B_0$ *somewhere between* L *and* $2L$ *.*

(b)(ii)	For using the change in flux, with correct substitutions, to determine the emf	**1 point**
	For correctly applying Ohm's law with correct substitutions	**1 point**
	Scoring Note: It is not necessary to independently calculate a numerical value for the emf.	

Example Response

$$|\mathcal{E}| = \left|-\frac{\Delta\Phi_B}{\Delta t}\right| = \frac{\left(5.0\times10^{-5} - 1.0\times10^{-5}\right)\ \text{T}\bullet\text{m}^2}{2.0\ \text{s}} = 2.0\times10^{-5}\ \text{V}$$

$$I = \frac{|\mathcal{E}|}{R} = \frac{2.0\times10^{-5}\ \text{V}}{10\ \Omega} = 2.0\times10^{-6}\ \text{A}$$

Total for part (b) 4 points

(c)	For indicating that the current in the round coil produces a magnetic field	**1 point**
	For indicating that the magnetic field from the round coil produces a flux through the square coil	**1 point**
	For indicating that the changing flux produces an emf or current in the square coil circuit **Scoring Note:** A response that indicates that the magnetic flux only changes during a portion of the entire time interval does not earn this point.	**1 point**

Example Response

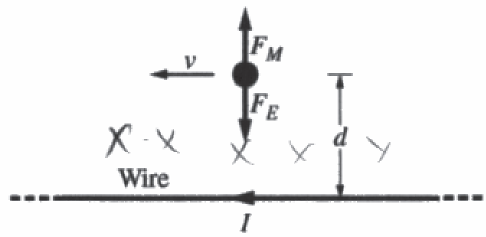
The current in the round coil produces a magnetic field. The magnetic field from the round coil passes through the square coil, producing a flux. As the current in the power supply increases, so does the current in the round coil, and, therefore, the magnetic field created by the current increases. Since the magnetic field changes, the flux through the square coil changes. The constantly changing magnetic flux through the square coil produces an emf and, therefore, current in the square coil to light the lightbulb.

Total for part (c) 3 points

Total for question 4 10 points

Question 4

Begin your response to **QUESTION 4** on this page.



4. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.

$\Sigma F_y: F_M - F_E = ma_y \; ; \; a_y = 0 \text{ m/s}^2$

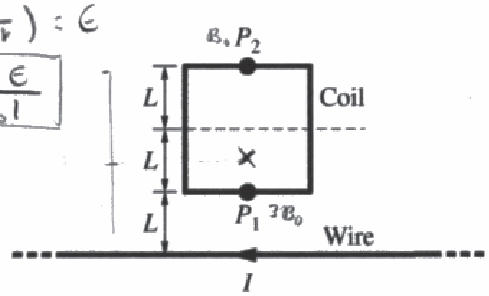
$F_M = F_E$

$qvB = qE$

$vB = E$

$v\left(\frac{\mu_0}{2\pi} \cdot \frac{1}{r}\right) = E$

$v = \frac{2\pi d E}{\mu_0 I}$



(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

$B = \frac{\mu_0}{2\pi} \cdot \frac{I}{r}$

$3B_0 = \frac{\mu_0 I}{2\pi} \cdot \frac{1}{L}$

$B_0 = \frac{\mu_0 I}{2\pi} \cdot \frac{1}{3L}$

$3B_0\left(\frac{2}{3}\right) = 2B_0$

$\frac{\mu_0 I}{2\pi L}\left(\frac{2}{3}\right) = \frac{\mu_0 I}{2\pi} \cdot \frac{2}{3L} = 2B_0$

$\frac{1}{r} = \frac{2}{3L}$

$r = \frac{3L}{2}$

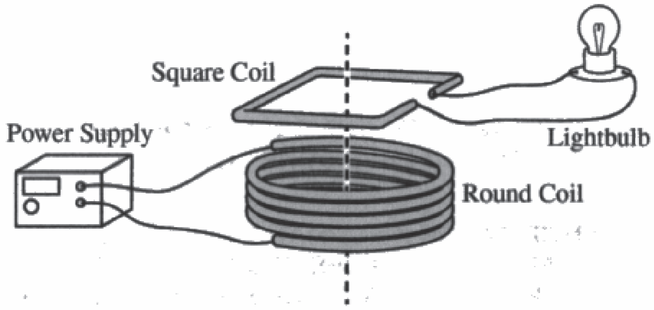
Question 4

Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$ and the final magnetic flux through the coil is $1.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$. The coil has a total resistance of 10 Ω. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.

$$\mathcal{E} = -\frac{\Delta \Phi_B}{\Delta t} = \frac{-(1\times10^{-5}\ \text{T}\cdot\text{m}^2 - 5\times10^{-5}\ \text{T}\cdot\text{m}^2)}{2\ \text{s}} = 2\times10^{-5}\ \text{V}$$

$$I = \frac{\Delta V}{R} = \frac{2\times10^{-5}\ \text{V}}{10\ \Omega} = \boxed{2\times10^{-6}\ \text{A}}$$



The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

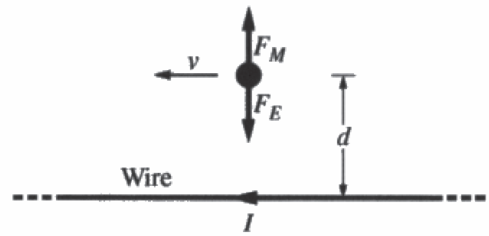
(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

Since magnetic field is based on current, ($B = \frac{\mu_0}{2\pi}\frac{I}{r} \therefore B \propto I$) and flux is based on area and magnetic field ($\Phi_B = B \cdot A \therefore \Delta\Phi_B = \Delta B A$), if current is increasing over time, then the magnetic field increases, resulting in change in flux - and since $\mathcal{E} = \frac{\Delta \Phi_B}{\Delta t}$, this change in flux over time induces a voltage in the square coil. With this voltage, since $I = \frac{V}{R}$, we can then see a current induced in the coil, and since the brightness of a bulb is based on power ($P = IV = I^2R$) which is based on current, we can see the bulb light up.

Use a pencil or a pen with black or dark blue ink. Do NOT write your name. Do NOT write outside the box.

Question 4

Begin your response to QUESTION 4 on this page.

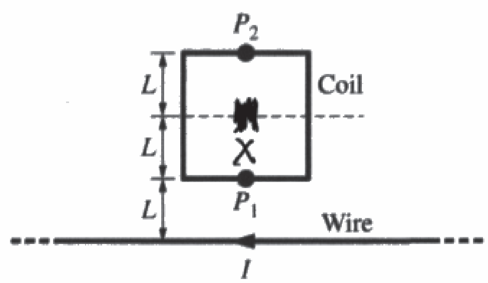


4. (10 points, suggested time 20 minutes)

At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.

V is constant, it is not dependent on those variables.



(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

magnetic field varies with distance so if at L the field is $3B_0$, at $\frac{3}{2}L$ the field is $\frac{3B_0}{\frac{3}{2}} = 2B_0$

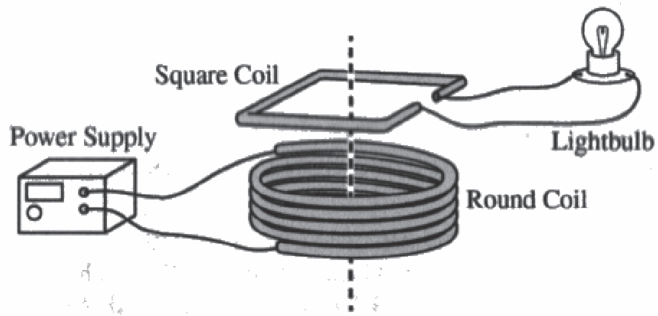
Question 4

Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is 5.0×10^{-5} T·m^2 and the final magnetic flux through the coil is 1.0×10^{-5} T·m^2. The coil has a total resistance of 10 Ω. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.

$$V = \frac{\Delta\phi}{t} = \frac{5\times10^{-5} - 1\times10^{-5}}{2} = 2\times10^{-5}$$

$$V = IR \quad 2\times10^{-5} = I \cdot 10 \quad \boxed{I = 2\times10^{-6} A}$$



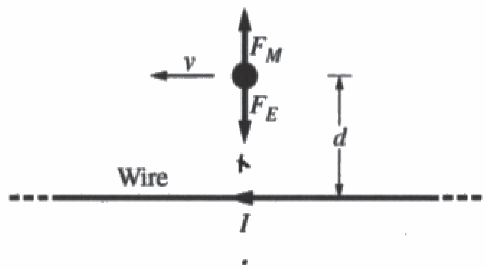
The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

as the power sply current is increasing, the resulting B field around the coil is increasing as well. This means the flux through the square coil is constantly increasing as well, which creates emf or voltage in the coil/light, that voltage powers the light. Since voltage is induced anytime flux is changing, and the flux never stops changing because the power supply current is constantly increasing, the light is always lit.

Question 4

Begin your response to **QUESTION 4** on this page.



4. (10 points, suggested time 20 minutes)

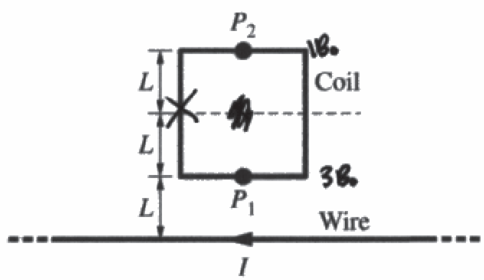
At the instant shown above, a negatively charged object is moving to the left with constant velocity v near a long, straight wire that has a current I directed to the left. The region contains a uniform electric field of magnitude E, and the charged object is at a distance d from the wire. The figure shows the electric and magnetic forces, F_E and F_M, respectively, exerted on the charged object.

(a) Derive an expression for v in terms of E, d, I, and physical constants, as appropriate.

$F_M = F_E$ $\quad F_M = qvB = I\ell B$

$qvB = k\frac{q_1 q_2}{d^2}$ $\quad Q = I\Delta t$

$v = k\frac{q_1 q_2}{d^2 qB} = k\frac{q}{d^2 B} = k\frac{I\Delta t}{d^2 B} = k\frac{IE}{d^2 BP}$



(b) The charged object is removed, and a square coil with side length $2L$ is placed near the long, straight wire, as shown above. The bottom of the coil is a distance L from the wire. The magnitude of the magnetic field due to the current in the wire is $3B_0$ at point P_1 and B_0 at point P_2.

i. Write an "X" at a location on the figure where the magnitude of the magnetic field is $2B_0$. Briefly justify your reasoning.

$\mathcal{E} = B\ell v$, as $\ell\uparrow$, $B\downarrow$ proportionately

B decreases at a constant rate as ~~&~~ the distance from the current increases

GO ON TO THE NEXT PAGE.

2002039

Q5331/12

Question 4

Continue your response to **QUESTION 4** on this page.

ii. Over a time interval of 2.0 s, the current in the wire is decreased. The initial magnetic flux through the coil is $5.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$ and the final magnetic flux through the coil is $1.0 \times 10^{-5}\ \text{T}\cdot\text{m}^2$. The coil has a total resistance of $10\ \Omega$. Calculate the magnitude of the average current in the coil during the 2.0 s time interval.

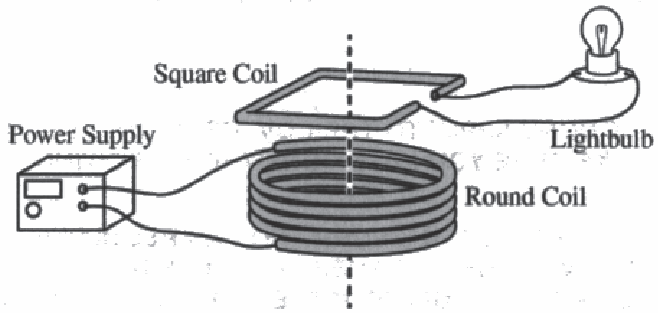
~~$\Phi_B = BA$~~ $\varepsilon = -\frac{\Delta \Phi_B}{\Delta t} = \frac{(1\times10^{-5} - 5\times10^{-5})}{2} = \frac{-4\times10^{-5}}{2} = -2\times10^{-5} = Blv$

$F_M = IlB$ $\quad -2\times10^{-5} = \frac{F_M}{I} v \quad I = \frac{F_M v}{-2\times10^{-5}}$

$l = \frac{F_M}{IB} \quad B\left(\frac{F_M}{IB}\right)v$

4 $\quad 5\times10^{-5}$

5×10^{5} A



The wire is removed and the square coil is positioned so that the coil is directly above and concentric with a round coil of wire connected to a power supply. A part of the square coil is removed and a lightbulb is connected to the coil, as shown above.

(c) During a short time interval, the current in the power supply is constantly increasing. Use physics principles to explain why the lightbulb is lit during the entire time interval.

The current through the round coil creates an induced current in the square coil, allowing the lightbulb to stay lit from the constant current provided by the round coil. the electric field created by the round coil creates a charge that lights the light bulb and does not dissipate since the current is constantly increasing.

Question 4

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

Overview

The responses were expected to demonstrate the ability to:

- Indicate that the magnitude of the electric force on a charged particle in an electric field is given by $|F_E| = |qE|$.
- Use the fact that the magnitude of the magnetic force on a charged particle moving perpendicular to a magnetic field is given by $|F_M| = |qvB|$.
- Apply the relationship $B = \dfrac{\mu_0 I}{2\pi r}$ for the magnetic field created by a long, straight current-carrying wire.
- Apply Faraday's law to changing magnetic flux through a conductive loop of wire to analyze induced emf (potential difference) and current in the loop.
- Calculate the induced current using Ohm's law and induced emf (potential difference), which depends on the rate of change of flux in a loop.

Sample: 4A
Score: 9

Part (a) earned 3 points. The first point was earned because the response correctly uses Newton's second law to set the magnetic force equal to the electric force. The second point was earned because the response uses correct expressions for the magnetic and electric forces. The third point was earned because the response substitutes an expression for the magnetic field that yields a correct expression for v in terms of the given quantities and physical constants. Part (b)(i) earned 2 points. The first point was earned because the response shows the magnetic field would be $2B_0$ at a point between P_1 and the dashed line. The second point was earned because the response uses the inverse relationship between magnetic field strength and distance from the wire to determine the location where the magnetic field would be $2B_0$. Note that an exact value for distance did not need to be calculated, $r = \dfrac{3L}{2}$, but this serves as a representation of the correct relationship. Part (b)(ii) earned 2 points. The first point was earned because the response uses the change in flux to correctly determine the emf. The second point was earned because the response applies Ohm's law with correct substitutions. Part (c) earned 2 points. The first point was earned because the response indicates that the increasing current, the current in the round coil, produces a magnetic field. Note that the mathematical relationship given is for a long, straight wire, not a coil, but the response still addresses the fact that electric currents create magnetic fields. The second point was not earned because while the response mentions flux, the response does not make it clear that there is magnetic flux through the square coil. The third point was earned because the response indicates a changing flux produces an emf in the square coil.

Question 4 (continued)

Sample: 4B
Score: 6

Part (a) earned 0 points. The first point was not earned because the response does not use Newton's second law to equate magnetic force and electric force. The second point was not earned because the response uses incorrect expressions for the magnetic and electric forces. The third point was not earned because the response does not substitute a correct expression for magnetic field that can be used to determine velocity. Part (b)(i) earned 1 point. The first point was earned because the response shows the magnetic field would be $2B_0$ at a point between P_1 and the dashed line. The second point was not earned because while the response indicates the field varies with distance, the response does not describe how the field varies. The math shown is a restatement of the conclusion reached to earn the first point without adding information about the inverse relationship that exists between magnetic field strength and distance from the wire. Part (b)(ii) earned 2 points. The first point was earned because the response uses the change in flux to correctly determine the emf. The second point was earned because the response applies Ohm's law with correct substitutions. Part (c) earned 3 points. The first point was earned because the response indicates that the current in the round coil produces a magnetic field: "the resulting B field around the coil." The second point was earned because the response indicates that the magnetic field from the round coil produces a flux through the square coil. The third point was earned because the response indicates the changing flux, "flux through the square coil is constantly increasing," is the cause of the emf in the coil with the bulb. Additionally, the response indicates that over the entire time interval, the flux never stops changing.

Sample: 4C
Score: 2

Part (a) earned 1 point. The first point was earned because the response begins with a use of Newton's second law to equate magnetic force and electric force: $F_e = F_M$. The second point was not earned because while the response uses a correct expression for the magnetic force, the expression for the electric force is incorrect. The third point was not earned because the response does not substitute a correct expression for magnetic field that can be used to determine velocity. Part (b)(i) earned 0 points. The first point was not earned because the response does not show that the magnetic field would be $2B_0$ at a point between P_1 and the dashed line. The second point was not earned because the response uses an expression for motional emf, rather than magnetic field created by a current-carrying wire. Part (b)(ii) earned 1 point. The first point was earned because the response uses the change in flux to correctly determine the emf. The second point was not earned because the response does not apply Ohm's law but instead, uses an equation for magnetic force on a current-carrying wire. Part (c) earned 0 points. The first point was not earned because the response indicates that the current in the round coil produces an electric field, rather than a magnetic field. The second point was not earned because the response does not indicate that the magnetic field from the round coil produces a flux through the square coil. The third point was not earned because while the response indicates there is an induced current, the response does not describe a changing magnetic flux as the cause of the induced current.