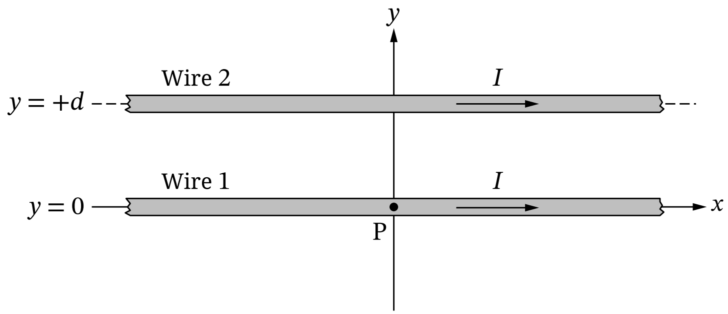
Question 1: Version J

1. Very long Wire 1 carries current I in the $+x$-direction along the line $y = 0$. Very long Wire 2 carries current I in the $+x$-direction along the line $y = +d$. Point P is located along Wire 1 at the origin, as shown in Figure 1. The diameters of the wires are small compared to the distance between the wires. Both wires are in the xy-plane.

Figure 1



Note: Figure not drawn to scale.

A.

i. Complete the following tasks in figures 2 and 3. Use either arrows or the symbols shown in the box above the figures for your response.

- **Indicate** the direction of the magnetic field from Wire 2 at Point P in Figure 2.
- **Indicate** the direction of the magnetic force that is exerted on Wire 1 by Wire 2 in Figure 3.

Symbols

× Into the page   ● Out of the page

Magnetic Field from Wire 2 at Point P

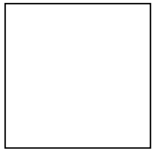


Figure 2

Magnetic Force on Wire 1 by Wire 2

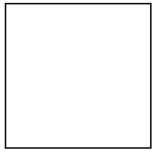


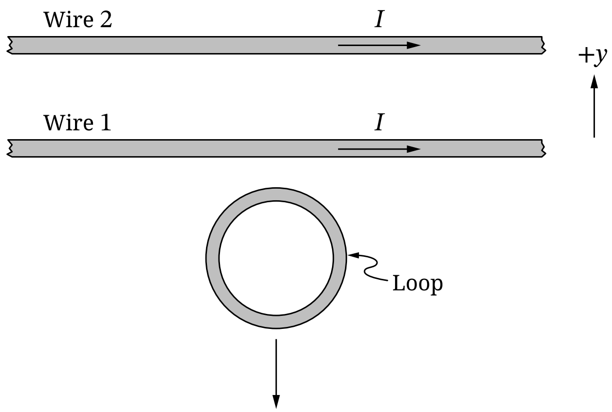
Figure 3

ii. Very long Wire 3 carrying current $2I$ in the $+x$-direction is placed in the xy-plane along the line $y = y_3$. The net magnetic force exerted on Wire 1 by the currents in wires 2 and 3 is zero.

Derive an expression for y_3 in terms of d. Begin your derivation by writing a fundamental physics principle or an equation from the reference information.

B. Wire 3 is moved very far away from wires 1 and 2. A circular conducting loop in the *xy*-plane is initially held at rest below Wire 1. The loop is then moved at a constant speed in the $-y$-direction, as shown in Figure 4.

Figure 4



Note: Figure not drawn to scale.

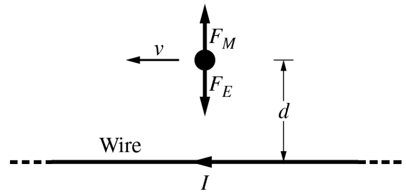
Indicate whether there is a clockwise induced current in the loop, a counterclockwise induced current in the loop, or no induced current in the loop.

______ Clockwise

______ Counterclockwise

______ There is no induced current in the loop.

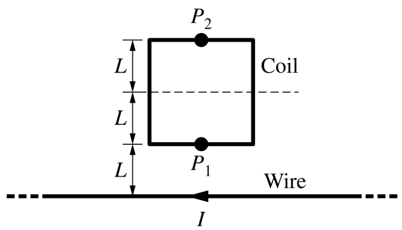
Justify your answer.



(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.



(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.

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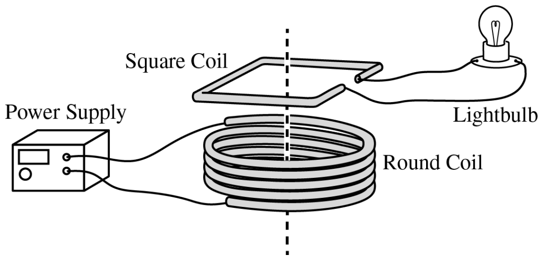
Continue your response to **QUESTION 4** on this page.

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.



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.

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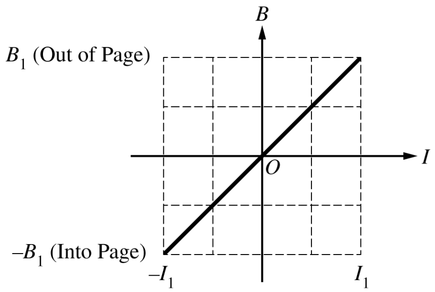
STOP

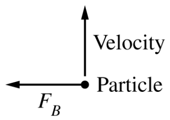
END OF EXAM



Graph 1

3. (12 points, suggested time 25 minutes)

An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.



(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted on the particle equal to $2F_B$ and the direction of the force to the right? Support your answer using physics principles.

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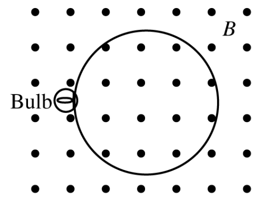
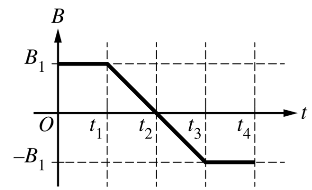
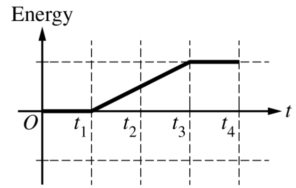




Graph 2

A circuit is made by connecting an ohmic lightbulb of resistance R and a circular loop of area A made of a wire with negligible resistance. The circuit is placed with the plane of the loop perpendicular to the field of the electromagnet, as shown above on the left. The magnetic field changes as a function of time, as shown in Graph 2. The bulb dissipates energy during the interval $t_1 < t < t_3$. Graph 3 below shows the cumulative energy dissipated by the bulb (the total energy dissipated since $t = 0$) as a function of time.



Graph 3

(b) The original bulb is replaced by a new ohmic lightbulb with a greater resistance, but everything else stays the same. How would the cumulative energy graph for the new bulb be different, if at all, from Graph 3 above? Support your answer using physics principles.

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(c) The new lightbulb is removed and replaced by the original lightbulb. The magnetic field now changes from $2B_1$ to $-2B_1$ during the same interval $t_1 < t < t_3$. A new cumulative energy graph is created for this situation. How would the new graph be different, if at all, from Graph 3 ? Support your answer using physics principles.

(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

$$\text{Energy} = \frac{A^2 B_1 R}{4(t_3 - t_1)}$$

Whether or not the equation is correct, does the functional dependence of cumulative energy on the elapsed time $(t_3 - t_1)$ make physical sense? Support your answer using physics principles.

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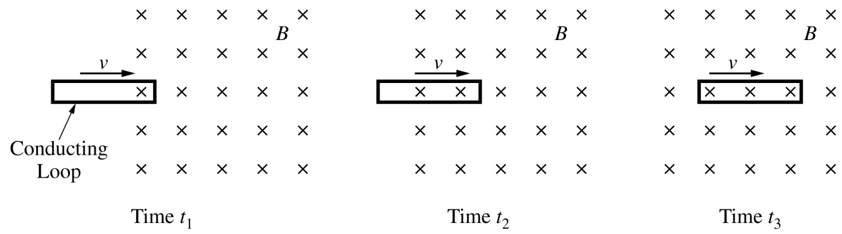
PHYSICS 2

Section II

Time—1 hour and 30 minutes

4 Questions

Directions: Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.

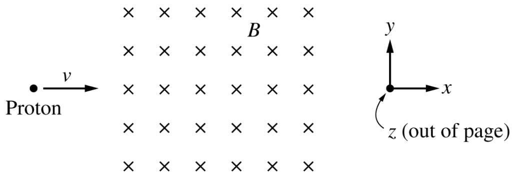


1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed v into and through a region of constant, uniform magnetic field B directed into the page. The magnetic field is zero outside the region.

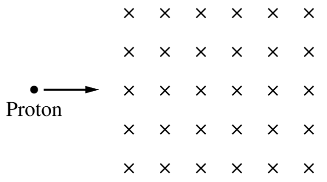
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



i. Calculate the magnitude of the force on the proton as it enters the field.

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.



iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).