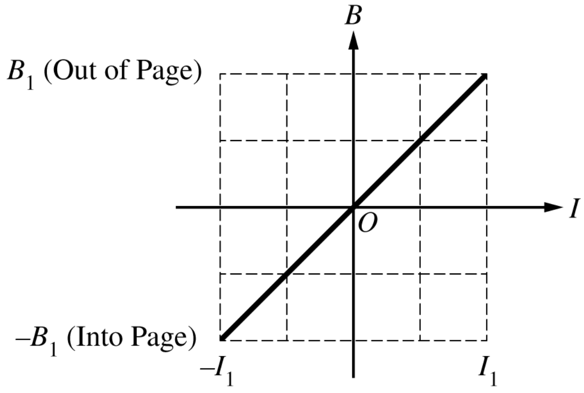
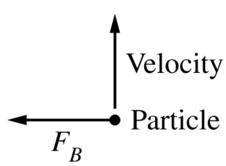
Begin your response to **QUESTION 3** on this page.



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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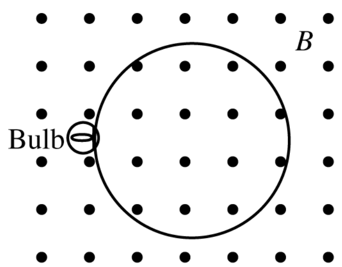
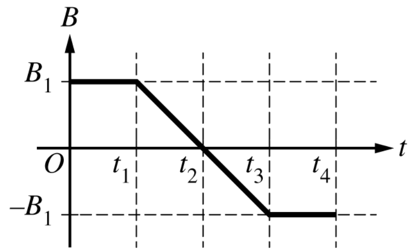
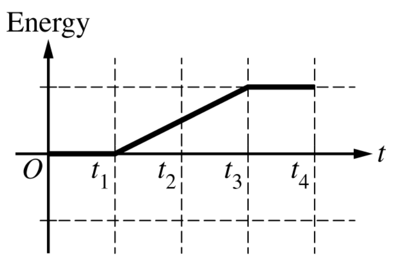
Continue your response to **QUESTION 3** on this page.





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

Continue your response to **QUESTION 3** on this page.

(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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Question 3: Quantitative/Qualitative Translation — 12 points

(a)	For indicating that the magnetic field needs to double in order to double the force (since the force equals qvB)	**1 point**
	For correctly explaining why the magnitude of the current must double, without any incorrect statements	**1 point**
	For indicating that the current must go in the opposite direction, i.e. be negative	**1 point**
	Example response for part (a) *The current must change direction and double in magnitude. The graph shows that when the current doubles the magnetic field doubles. When the magnetic field doubles, the magnetic force doubles. Reversing the direction of the current will reverse the direction of the magnetic field, and therefore the direction of the force.*	
	Total for part (a)	**3 points**
(b)	For indicating that the emf is the same	**1 point**
	For indicating that larger resistance and/or less current means less power, without making any incorrect statements	**1 point**
	For indicating that the slope between t_1 and t_3 is less, or the horizontal line segment at right would be below the one shown	**1 point**
	Example response for part (b) *The slope of the energy vs. time graph represents power. Because the induced emf is the same, but resistance is higher, power is lower. Therefore, the slope would be smaller.*	
	Total for part (b)	**3 points**
(c)	For indicating that the greater change in magnetic field means a greater change in magnetic flux or a larger emf	**1 point**
	For indicating that power increases with increasing emf so the power and thus the energy dissipated is greater, or for an answer that is consistent with the response to the previous point in (c).	**1 point**
	For indicating that the slope between t_1 and t_3 is greater, or the horizontal line segment at right would be above the one shown, or for an answer that is consistent with the response to the first point in (c)	**1 point**
	Example response for part (c) *The induced emf is larger than it was before because the magnetic field changed by a larger amount in the same time period. Power is proportional to the square of the emf, so the power is larger. Power is the slope of energy vs time, so the slope is greater for the new graph.*	
	Total for part (c)	**3 points**
(d)	For any indication the cumulative energy dissipated depends on the time elapsed	**1 point**
	For indicating that the emf depends on the rate of change of the magnetic flux, i.e., it is inversely proportional to the time elapsed	**1 point**
	For indicating that the power is proportional to the square of the emf and the energy dissipated is power times time, so energy is inversely proportional to the time	**1 point**
	Total for part (d)	**3 points**
	Total for question 3	**12 points**