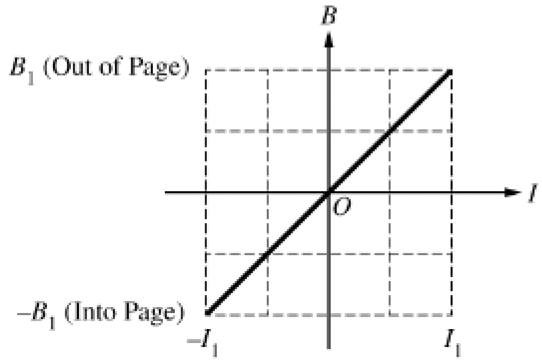
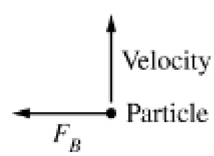
Begin your response to **QUESTION 3** on this page.



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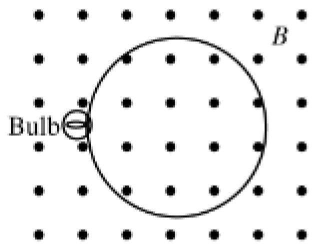
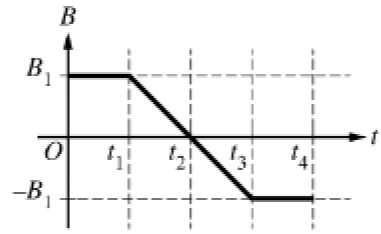
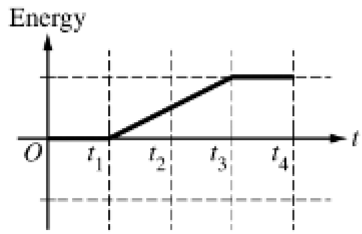
Continue your response to **QUESTION 3** on this page.





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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(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.