2021

AP CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

Inside:

Free Response Question 3

☑ Scoring Guideline

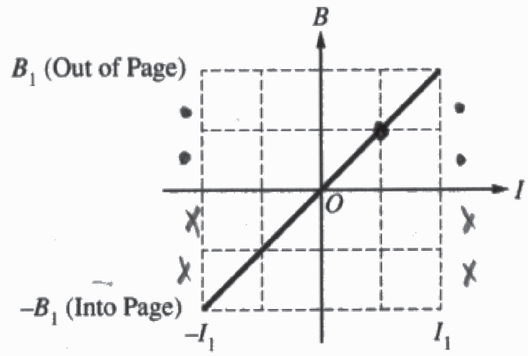
☑ Student Samples

☑ Scoring Commentary

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**

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

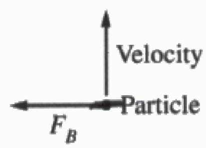


Graph 1

3. (12 points, suggested time 25 minutes)

$F_M = qvB = \frac{qvI}{r}$

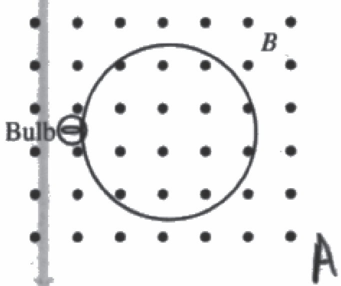
An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page. . 5I

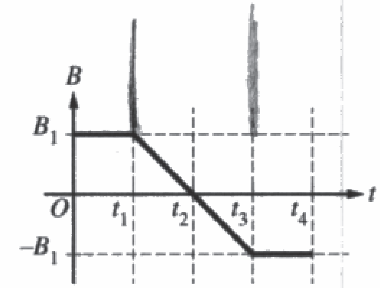


(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted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

• The current could change directions & be doubled so that it was $-I_1$. Changing direction of the current changes the magnetic field direction as seen by the graph. This would change the direction of F_B to the right by rules of RHR. Also, by doubling the current, we double the magnitude of the field & thereby double the force shown by $F_M = qvB$.

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

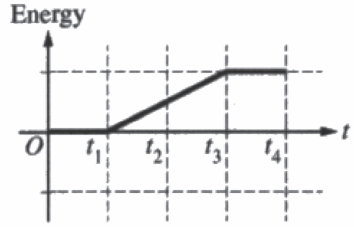




Graph 2

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.

$\varepsilon = IR$ ↓↑ $\quad I = \frac{\varepsilon}{R} \quad \varepsilon = \frac{\Delta\phi}{\Delta t} = \frac{\Delta BA}{t}$



Graph 3

$P = I\Delta V \qquad P = IV = \frac{V^2}{R} = \frac{BA^2}{t}$

(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.

The graph would by the same shape, but the slope from t_1 to t_3 would be less & the final energy dissapated would be less. This is ∵ by changing the light's resistance, we don't change the V induced shown by $\varepsilon = \frac{\Delta\phi}{t}$ & $\varepsilon = \frac{\Delta B\cos\theta A}{t}$. Neither B or A changed. What did change is the current seen by V=IR. R & I are inversely prop so I decreases. Energy dissipated is prop to power shown by $P = I\Delta V$. If ΔV is constant, but I decreased, then overall energy dissipated must decrease.

GO ON TO THE NEXT PAGE.

4X

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.

The slope from t_1 to t_3 would be 4 times greater. ∵ the voltage induced is changed shown by $V = \frac{\Delta\phi}{t}$ & $V = \frac{\Delta B \cos\theta A}{t}$. ΔB doubled over the same time period, so V induced did as well. If V induced doubled, then so did current seen by V=IR ∵ resistance was constant. As stated, the energy dissipated is prop to power seen by $\frac{E}{t} = P = I\Delta V$. If ΔV & I doubled, then P must quadruple.

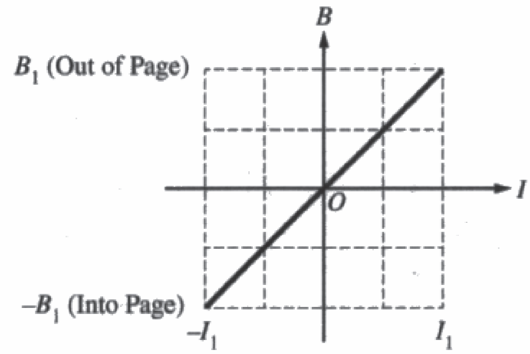
(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

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

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.

The dependence does make sense ∵ it shows that as the time interval increases, the energy dissipated will decrease. This makes sense ∵ the magnetic field would be changing at a rate of almost 0, so the change in flux would be almost 0, the induced emf would be almost 0, & thereby the energy dissipated would be almost 0.

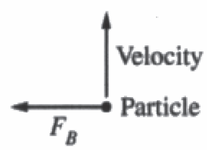
Begin your response to QUESTION 3 on this page.



Graph 1

3. (12 points, suggested time 25 minutes)

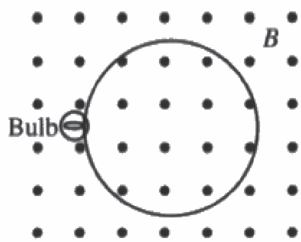
An electromagnet produces a magnetic field that is uniform in a certain region and zero outside that region. The graph above represents the field as a function of the current in the electromagnet, with positive field directed out of the page and negative field directed into the page.

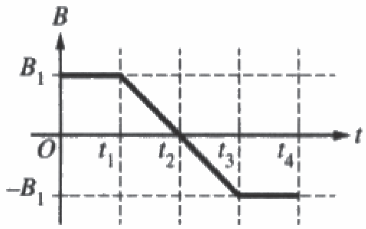


(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted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

Setting the current at $-\sqrt{2}\,I_1$ would make the Force exerted equal to $2F_B$ due to the Formula $F = ILB$. Making the current negative switches the direction of the field, and due to the RHR, would switch the force to the right. Since L is constant, if $F = 0.5I_1 \cdot 0.5B_1$, then $2F = -\sqrt{2}\,I_1 \cdot -\sqrt{2}\,B_1$, where the coefficient of I_1 and B_1 must be the same due to function of the current and field.

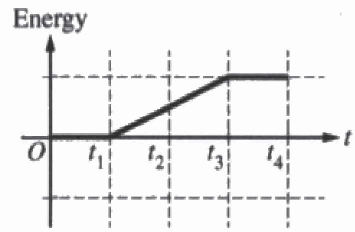
Continue your response to **QUESTION 3** on this page.





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.

Since the ε would remain the same and the resistance is larger, the current would be smaller; therefore the graph would be smaller sloped during $t_1 < t < t_3$.

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.

Since the Flux would increase due to the greater change in the magnetic field, the ε would be larger. With the same resistor the current would be larger therefore the graph at 3 would have a higher slope during $t_1 < t < t_3$.

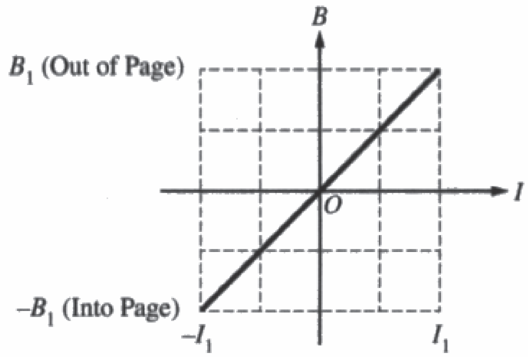
(d) A student derives the following expression for the cumulative energy dissipated by the original bulb during the interval $t_1 < t < t_3$ and with the original change in magnetic field shown in Graph 2.

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

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.

Yes, because the ε depends on the ~~[illegible]~~ change of time; therefore the overall ~~[illegible]~~ energy depends on how long the light bulb dissipated energy. $\varepsilon = \frac{\Delta \Phi}{\Delta t}$

Begin your response to QUESTION 3 on this page.



Graph 1

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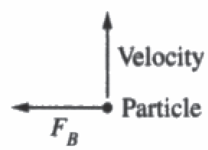
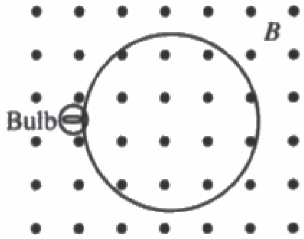
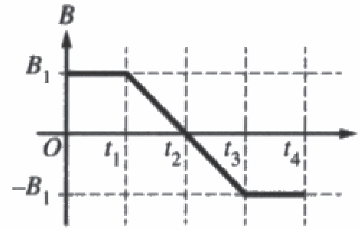


(a) The current in the electromagnet is set at $0.5I_1$. When a charged particle in the region moves toward the top of the page, the force exerted on it by the field is F_B toward the left, as shown above. What changes to the current in the electromagnet could make the magnitude of the force exerted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

To move the Force F_B to the right, the direction of the magnetic field would have to change. At first, the B B directed into the page, which is negative. If B were directed out of the page, the Force F_B would go right. To go from $F_B \rightarrow 2F_B$, the strength of the magnetic field B would need to double $\rightarrow$ $F_B = qvB\sin\theta$.

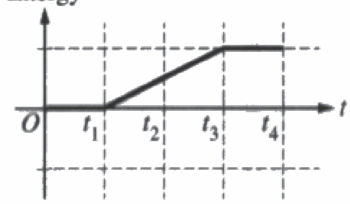
Continue your response to **QUESTION 3** on this page.





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.

A bulb w/ greater Resistance will dissipate less energy, so the slope of the line from $t_1 \rightarrow t_3$ would be less.

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.

The new graph would dissipate more energy (double the energy) from $t_1 \to t_3$. Since we see an inverse relationship between the two graphs, we see that as B ↓, Energy dissipated ↑.

(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.

No. If the equation had to do with Power, which does depend on time, it would make sense. But Energy alone does not depend on time.

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:

- The relationship between current, magnetic field, and force on a moving charged particle
- Electromagnetic induction due to a changing magnetic field
- Electric power/energy dissipated by a resistor
- Interpretation of linear graphs
- Functional dependence in mathematical relationships

Sample: P2 Q3 A
Score: 11

Part (a) earned 3 points. One point was earned for stating that the magnitude of the B field will double, 1 point was earned for indicating the current will double without making any incorrect statements, and 1 point was earned for indicating the current should change directions. Part (b) earned 3 points. One point was earned for stating that the induced EMF is the same, 1 point was earned for linking the increased resistance to decreased power, and 1 point was earned for describing the shallower slope on the new graph between t_1 and t_3. Part (c) earned 3 points. One point was earned for correctly stating that the induced voltage is now greater, 1 point was earned for linking increased EMF and current to increased power, and 1 point was earned for describing a greater slope between t_1 and t_3. Part (d) earned 2 points. One point was earned by articulating a relationship between the value of the time interval and the amount of energy dissipated, and 1 point was earned for discussing the functional dependence of the induced EMF on the time interval. The response does not include how the time interval impacts the power calculation and also does not take into account that the contribution of the EMF is squared.

Sample: P2 Q3 B
Score: 7

Part (a) earned 1 point for indicating that the current's direction should be reversed, for which it earned the third point. The magnitude of the B field is not discussed in the response and incorrectly relies upon F = ILB so the second point cannot be earned. Part (b) earned 2 points. One point was earned by stating that the EMF will remain the same, and 1 point was earned for describing a lesser slope between t_1 and t_3. The response does not link the change in resistance to power. Part (c) earned 2 points for stating that the EMF will be greater and for the description of a greater slope between t_1 and t_3. The response does not link the change in the induced current to power. Part (d) earned 2 points. One point was earned for linking the total energy dissipated to the amount of time, and 1 point was earned for giving the relationship between induced EMF and the change in time. The response does not include how time factors into power and does not discuss how the time contribution due to the EMF is squared.

Question 3 (continued)

Sample: P2 Q3 C
Score: 3

Part (a) earned 1 point for stating that the magnetic field must double, which earned the first point. The response does not discuss the direction or magnitude of the current. Part (b) earned 1 point for describing a lesser slope between t_1 and t_3. The response does not discuss flux or induced EMF, and it does not connect the change in resistance to the change in power. Part (c) earned 1 point for stating that energy values on the graph between t_1 and t_3 will be greater, so the third point was earned. The response does not include flux or EMF, and it does not include resistance or current. Part (d) earned no points. The response makes no reference to the functional dependence of cumulative energy to elapsed time, and it makes no reference to the functional dependence of the induced emf to elapsed time, so the second point was not earned. The response also makes no reference to the functional dependence of power to elapsed time, so the third point was not earned.