AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2007 SCORING GUIDELINES

General Notes About 2007 AP Physics Scoring Guidelines

1. The solutions contain the most common method of solving the free-response questions and the allocation of points for this solution. Some also contain a common alternate solution. Other methods of solution also receive appropriate credit for correct work.

2. Generally, double penalty for errors is avoided. For example, if an incorrect answer to part (a) is correctly substituted into an otherwise correct solution to part (b), full credit will usually be awarded. One exception to this may be cases when the numerical answer to a later part should be easily recognized as wrong, e.g., a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth one point, and a student's solution contains the application of that equation to the problem but the student does not write the basic equation, the point is still awarded. However, when students are asked to derive and expression it is normally expected that they will begin by writing one or more fundamental equations, such as those given on the AP Physics exam equation sheet. For a description of the use of such terms as "derive" and "calculate" on the exams, and what is expected for each, see "The Free-Response Sections—Student Presentation" in the *AP Physics Course Description* .

4. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but use of 10 m/s^2 is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

5. Strict rules regarding significant digits are usually not applied to numerical answers. However, in some cases answers containing too many digits may be penalized. In general, two to four significant digits are acceptable. Numerical answers that differ from the published answer due to differences in rounding throughout the question typically receive full credit. Exceptions to these guidelines usually occur when rounding makes a difference in obtaining a reasonable answer. For example, suppose a solution requires subtracting two numbers that should have five significant figures and that differ starting with the fourth digit (e.g., 20.295 and 20.278). Rounding to three digits will lose the accuracy required to determine the difference in the numbers, and some credit may be lost.

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Question 3

15 points total **Distribution of points**

(a) 3 points

For marking the "Counterclockwise" choice — 1 point
For explaining that there must be opposition to a change in magnetic flux — 1 point
For explaining that, in order to oppose the increase in magnetic flux, the induced magnetic field must be out of the paper. Therefore, the induced current must be counterclockwise to produce the induced field. — 1 point

Alternate solution — *Alternate points*
For marking the "Counterclockwise" choice — *1 point*
For correctly explaining that positive charge carriers in the rod experience a force toward the top of the page. (for example, by using the "right-hand rule," or by using $\mathbf{F} = q\mathbf{v} \times \mathbf{B}$*, since* $\mathbf{v}$ *is to the right and* $\mathbf{B}$ *is into the paper)* — *2 points*

(b) 4 points

For correctly identifying V in Ohm's law as the induced emf (ignoring the sign from Faraday's law) — 1 point
$IR = V = \mathcal{E} = \frac{d\phi_m}{dt}$ or $B\frac{dA}{dt}$ or $B\ell\frac{dx}{dt}$ or $B\ell v$

For a correct expression for the resistance of the loop — 1 point
$R = \lambda(L + 2vt)$ or $\lambda(L + 2x)$

For a correct expression for $\mathcal{E}$ — 1 point
$\mathcal{E} = B\ell v$ or BLv

For correctly substituting the expressions for R and V from above into Ohm's law, with no explicit negative sign — 1 point
$I = \frac{BLv}{\lambda(L + 2vt)}$

<u>Note</u>*: The substitutions had to be in terms of the given quantities only in order to earn the substitution points.*

(c) 2 points

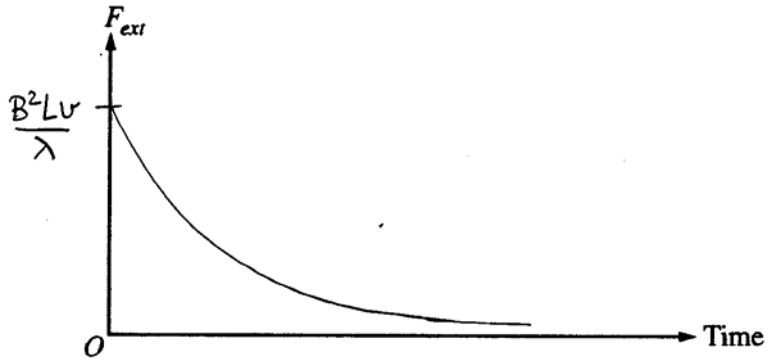
For a correct expression for the magnetic force, using L and not including $\sin\theta$ — 1 point
$F_B = ILB$

For a correct substitution of the expression for I from part (b) — 1 point
$F_B = \frac{B^2L^2v}{\lambda(L + 2vt)}$

Question 3 (continued)

Distribution of points

(d) 3 points



For recognizing that $F_{ext} = F_B$ 1 point

For labeling the *y*-intercept, consistent with the result from part (c) 1 point

$F_{ext}(t = 0) = \frac{B^2Lv}{\lambda}$

For a graph shape that is consistent with the expression found in part (c) 1 point

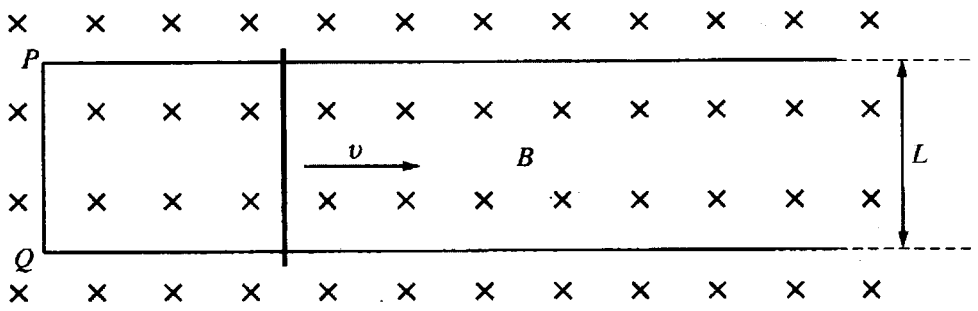
(e) 3 points

For marking the "Decreases" choice 1 point

For a correct, clear, and complete justification 2 points

Example: If $F_{ext} = 0$, then the only force on the rod is F_B. Since F_B is in the opposite direction of the velocity, the acceleration of the rod is opposite the velocity and therefore the velocity decreases.

Note: Partial credit of 1 point was awarded for the justification if the justification was only partially correct, clear, or complete.



Top View

E&M 3.

In the diagram above, a nichrome wire of resistance per unit length λ is bent at points P and Q to form horizontal conducting rails that are a distance L apart. The wire is placed within a uniform magnetic field of magnitude B pointing into the page. A conducting rod of negligible resistance, which was aligned with end PQ at time $t = 0$, slides to the right with constant speed v and negligible friction. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate the direction of the current induced in the circuit.

_____Clockwise ✓ Counterclockwise

Justify your answer.

As time goes by, the flux through the loop going into the page increases. To counteract this change, the induced magnetic field must come out of the page (Lenz's law); by the right hand rule, the current must go counterclockwise

(b) Derive an expression for the magnitude of the induced current as a function of time t.

$\mathcal{E} = -\frac{d\Phi}{dt}$ (1 loop) $\quad \Phi = BA \Rightarrow \frac{d\Phi}{dt} = B\frac{dA}{dt} = BLv$

$\Rightarrow \mathcal{E} = BLv$

$R(t) = \lambda(L + 2vt)$

$\Rightarrow I = \frac{\mathcal{E}}{R} = \frac{BLv}{\lambda(L+2vt)}$

GO ON TO THE NEXT PAGE.

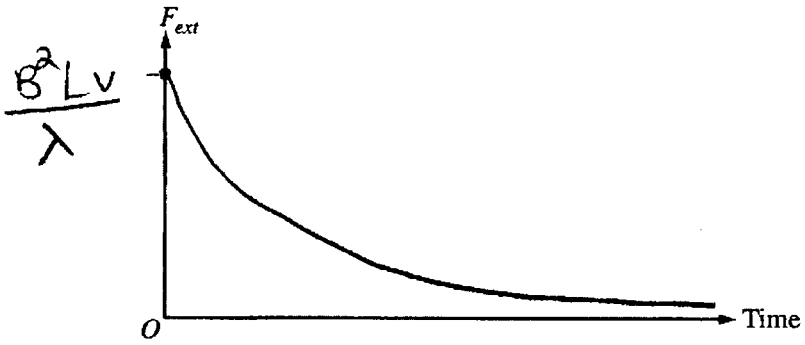
(c) Derive an expression for the magnitude of the magnetic force on the rod as a function of time.

$F_B = BiL = \frac{B^2L^2v}{\lambda(L+2vt)}$

(Force from induced current in wire PQ is negligible:

$\frac{\mu_0 i}{2\pi r} \Rightarrow \frac{i}{r} \times 2 \times (10^{-7})$

(d) On the axes below, sketch a graph of the external force F_{ext} as a function of time that must be applied to the rod to keep it moving at constant speed while in the field. Label the values of any intercepts.

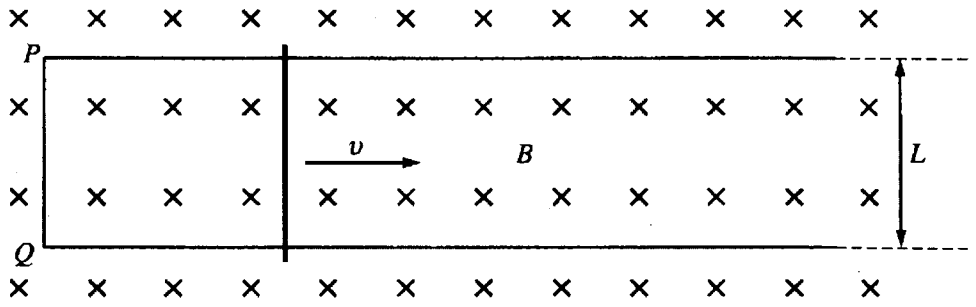


(e) The force pulling the rod is now removed. Indicate whether the speed of the rod increases, decreases, or remains the same.

_____Increases ✓ Decreases _____Remains the same

Justify your answer.

According to the right-hand rule, the force in (c) ~~pulls~~ accelerates the rod to the left. Since ~~it is~~ the rod is traveling right, its speed must decrease



Top View

$\lambda = R/L$

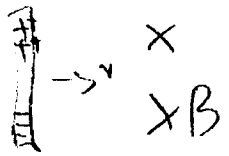
E&M 3.

In the diagram above, a nichrome wire of resistance per unit length λ is bent at points P and Q to form horizontal conducting rails that are a distance L apart. The wire is placed within a uniform magnetic field of magnitude B pointing into the page. A conducting rod of negligible resistance, which was aligned with end PQ at time $t = 0$, slides to the right with constant speed v and negligible friction. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate the direction of the current induced in the circuit.

_____Clockwise _X_Counterclockwise

Justify your answer.



v →

⊗ B ∴ F ↑ by Right hand rule

- also there is a change in magnetic flux (increase into page) so the circuit responds by attempting to create a B out of page which causes a counterclockwise I by right hand rule

(b) Derive an expression for the magnitude of the induced current as a function of time t.

$\Phi_B = \int B \cdot dA = \mu_0 I$

$L \cdot V = dA$

t

$\int_0 B \cdot L V dt = \mu_0 I$

$I = \dfrac{BL\int_0^t V\,dt}{\mu_0}$

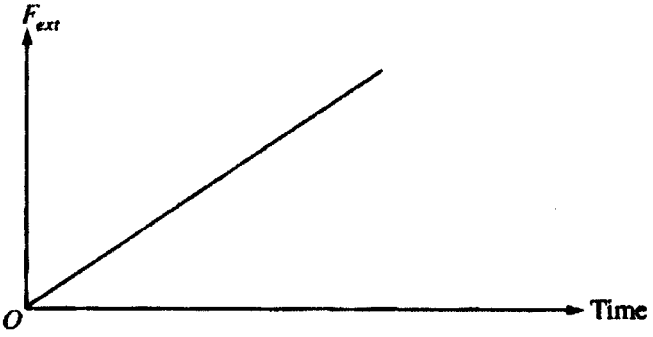
GO ON TO THE NEXT PAGE.

(c) Derive an expression for the magnitude of the magnetic force on the rod as a function of time.

$F = IlB = \frac{BL\int_0^t v\,dt\,(L)(B)}{\mu_0} - \frac{B^2L^2\int_0^t v\,dt}{\mu_0}$

(d) On the axes below, sketch a graph of the external force F_{ext} as a function of time that must be applied to the rod to keep it moving at constant speed while in the field. Label the values of any intercepts.

$F_{ext} = \frac{B^2L^2\int_0^t v\,dt}{\mu_0}$

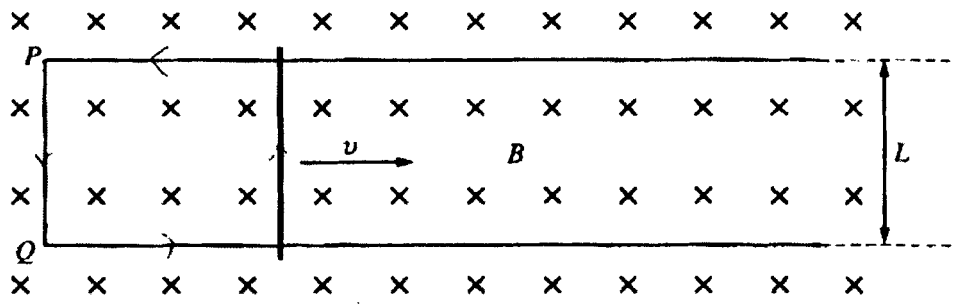


(e) The force pulling the rod is now removed. Indicate whether the speed of the rod increases, decreases, or remains the same.

_____Increases X Decreases _____Remains the same

Justify your answer.

If F_{ext} is removed, then F_B still exists which is to the left this force will decrease the speed of the rod with no opposing ext force.



Top View

E&M 3.

In the diagram above, a nichrome wire of resistance per unit length λ is bent at points P and Q to form horizontal conducting rails that are a distance L apart. The wire is placed within a uniform magnetic field of magnitude B pointing into the page. A conducting rod of negligible resistance, which was aligned with end PQ at time $t = 0$, slides to the right with constant speed v and negligible friction. Express all algebraic answers in terms of the given quantities and fundamental constants.

(a) Indicate the direction of the current induced in the circuit.

_____Clockwise __X__Counterclockwise

Justify your answer.

As v moves to the right, the change of flux is increasing into the page. Based on Lenses Law, the induced current will counter that and create a larger field pointing out of the page

(b) Derive an expression for the magnitude of the induced current as a function of time t.

$$\mathcal{E} = -\frac{d\Phi}{dt} = \frac{d(B \cdot A)}{dt} = B\frac{dA}{dt} = B\frac{d(Lx)}{dt} = BL\frac{dx}{dt} = BLv$$

$$\frac{dI}{dt} = BLv$$

$$I = \int BLv\,dt = \boxed{BLvt}$$

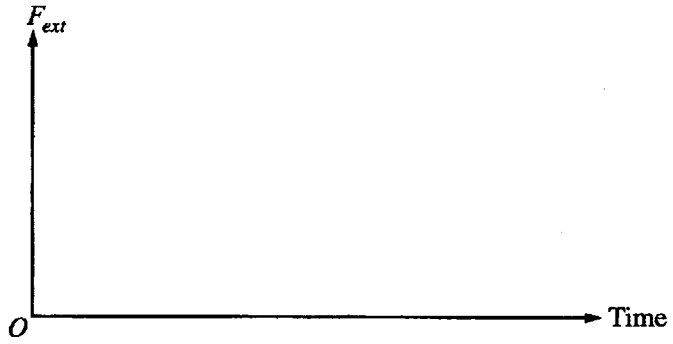
GO ON TO THE NEXT PAGE.

(c) Derive an expression for the magnitude of the magnetic force on the rod as a function of time.

$F = \int I\, dL \times B$

$F = \int BLvt\, dL \times B = \frac{B^2 L^2 v t}{2}$

(d) On the axes below, sketch a graph of the external force F_{ext} as a function of time that must be applied to the rod to keep it moving at constant speed while in the field. Label the values of any intercepts.



(e) The force pulling the rod is now removed. Indicate whether the speed of the rod increases, decreases, or remains the same.

_____Increases _____Decreases _____Remains the same

Justify your answer.

AP® PHYSICS C: ELECTRICITY AND MAGNETISM
2007 SCORING COMMENTARY

Question 3

Overview

The intent of this question was to measure students' understanding of induced emf and induced current, as well as the magnetic force on a current-carrying wire. The question also assessed their ability to determine and qualitatively sketch the time-dependent external force required to keep a wire (carrying a varying induced current) moving at constant speed through a magnetic field. In addition, the question evaluated students' aptitude to analyze what would happen if the external force was removed.

Sample: E2A
Score: 15

This clearly written response received full credit on all parts. In the answer to part (c) the student also recognizes that there could be an additional contribution to the magnetic field due to the current in the segment *PQ* of the wire but says that it would be negligible, an assumption that would be true under most circumstances. Students received no penalty for not incorporating this contribution to the field in their solution, and none attempted to do so.

Sample: E2B
Score: 9

Full credit was awarded for part (a); the justification recognizes both the change in magnetic flux and the need for an induced magnetic field to oppose it. Part (b) received no credit, but part (c) received full credit for the correct substitutions. In part (d) only 1 point was awarded for recognizing that the external force is equal in magnitude to the magnetic force. Part (e) received full credit.

Sample: E1C
Score: 5

Part (a) received full credit. In part (b) only 1 point was awarded for $\mathcal{E} = BL\upsilon$. In part (c) only 1 point was awarded for substituting the current from part (b). No other points were awarded, since parts (d) and (e) were left blank.