# AP® PHYSICS
# 2012 SCORING GUIDELINES

## General Notes About 2012 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 in part (b). One exception to this practice may occur in cases where the numerical answer to a later part should easily be recognized as wrong, for example, a speed faster than the speed of light in vacuum.

3. Implicit statements of concepts normally receive credit. For example, if the use of an equation expressing a particular concept is worth 1 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 an 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 sheets. 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 $10 \text{ m/s}^2$ 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 owing 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 eliminate the level of accuracy required to determine the difference in the numbers, and some credit may be lost.

# AP® PHYSICS C: ELECTRICITY AND MAGNETISM
# 2012 SCORING GUIDELINES

## Question 3

**15 points total** — **Distribution of points**

(a) 1 point

$$\phi_m = \int \mathbf{B} \bullet d\mathbf{A}$$

For a correct answer — 1 point

$\phi_m = B_0 L h_0$

(b) 2 points

For a correct direction arrow — 1 point

For a valid justification using Lenz's Law or the right-hand rule, if the direction is also correct — 1 point

<u>Examples</u>

The flux is decreasing as the area is decreasing, and a current to the right would cause an inward magnetic field that would increase flux.

The force on the falling positive charge carriers is to the right, which causes a conventional current to the right.

(c) 3 points

For a correct relationship between current, voltage, and resistance — 1 point

$$I = \frac{\mathcal{E}}{R}$$

For a correct relationship between the induced emf and the magnetic field — 1 point

$$|\mathcal{E}| = \frac{d\phi_m}{dt}$$

$$|\mathcal{E}| = B_0 L \frac{dh}{dt}$$

$$|\mathcal{E}| = B_0 L \upsilon$$

For a correct answer — 1 point

$I = B_0 L \upsilon / R$

<u>Note</u>: If only the correct answer is given, with no accompanying work, only 1 point can be awarded.

**Question 3 (continued)**

**Distribution of points**

(d) 4 points

For a correct net force equation showing opposite directions for the gravitational and magnetic forces, $F_g$ and $F_M$ — 1 point

$$\sum F = ma = F_g - F_M = mg - F_M$$

$$a = g - \frac{F_M}{m}$$

For using an appropriate equation to find $F_M$ — 1 point

$$F_M = \int I \left| d\ell \times \mathbf{B} \right| = ILB_0$$

For substituting the current from part (c) — 1 point

$$F_M = \left(\frac{B_0 L \upsilon}{R}\right) LB_0 = \frac{B_0^2 L^2 \upsilon}{R}$$

For expressing acceleration $a$ as $d\upsilon/dt$ — 1 point

$$\frac{d\upsilon}{dt} = g - \frac{B_0^2 L^2 \upsilon}{mR}$$

(e) 2 points

For setting the gravitational force equal to the magnetic force — 1 point

$a = 0$; therefore $F_M = F_g$

For correct substitution of expressions for the forces — 1 point

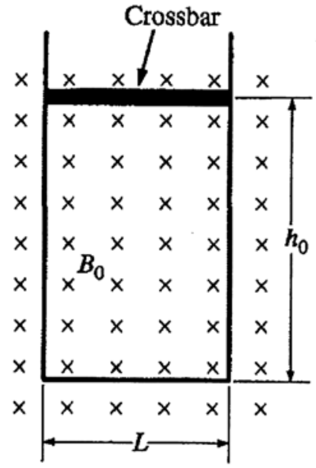
$$mg = ILB_0 = B_0^2 L^2 \upsilon_T / R$$

$$\upsilon_T = \frac{mgR}{B_0^2 L^2}$$

<u>Note</u>: If the correct expression for $\upsilon_T$ is stated without support, 2 points are awarded.

**Question 3 (continued)**

| | Distribution of points |
|---|---|
| (f) 3 points | |
| For correctly checking "Increases" | 1 point |
| Note: If an incorrect choice is made for the change in terminal speed, the justification points cannot be earned. | |
| For indicating the inverse relationship between resistance and current | 1 point |
| For indicating that a smaller current produces a smaller magnetic force on the bar, leading to the conclusion that to achieve a magnetic force equal to the bar's weight, the bar must be moving faster to produce the necessary current in the bar. | 1 point |
| Note: If the only justification is stating that $\upsilon_T \propto R$ from the equation for $\upsilon_T$ in part (e), only 1 justification point is awarded, because the question specifically asks for the answer in terms of forces on the crossbar. | |




E&M. 3.

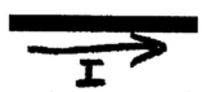
A closed loop is made of a U-shaped metal wire of negligible resistance and a movable metal crossbar of resistance $R$. The crossbar has mass $m$ and length $L$. It is initially located a distance $h_0$ from the other end of the loop. The loop is placed vertically in a uniform horizontal magnetic field of magnitude $B_0$ in the direction shown in the figure above. Express all algebraic answers to the questions below in terms of $B_0$, $L$, $m$, $h_0$, $R$, and fundamental constants, as appropriate.

(a) Determine the magnitude of the magnetic ~~flux through the loop when~~ the crossbar is in the position shown.

$\Phi = B_0 (h_0)(L)$

The crossbar is released from rest and slides with negligible friction down the U-shaped wire without losing electrical contact.

(b) On the figure below, indicate the direction of the current in the crossbar as it falls.




Justify your answer.

As the crossbar falls, the magnetic flux into the page is decreasing because the area is decreasing. So, from Lenz's law, the induced current tries to compensate for less magnetic flux in by creating more magnetic flux in, and so the current goes to the right.



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(c) Calculate the magnitude of the current in the crossbar as it falls as a function of the crossbar's speed $v$. 2 of 2

$$\frac{v\ell B}{R} = I$$

(d) Derive, but do NOT solve, the differential equation that could be used to determine the speed $v$ of the crossbar as a function of time $t$.

$\Sigma F = ma$

$mg - I\ell B = ma$

$mg - \left(\frac{B\ell v}{R}\right)(\ell)(B) = m\left(\frac{dv}{dt}\right)$

$$mg - \frac{B^2\ell^2 v}{R} = m\frac{dv}{dt}$$

(e) Determine the terminal speed $v_T$ of the crossbar.

$\Sigma F = ma$

$a = 0$

$mg - \left(\frac{B\ell v_T}{R}\right)(\ell)(B) = 0$

$mg = \frac{B^2\ell^2 v_T}{R}$

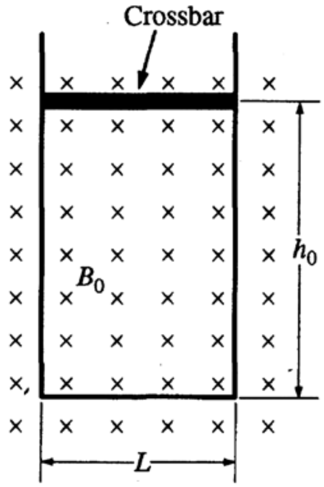
$$\frac{mgR}{B^2\ell^2} = v_T$$

(f) If the resistance $R$ of the crossbar is increased, does the terminal speed increase, decrease, or remain the same?

✓ Increases ____ Decreases ____ Remains the same

Give a physical justification for your answer in terms of the forces on the crossbar.

There are two forces, the gravitational force and the magnetic force. The gravitational force does not change, but the magnetic force does change in response to the resistance With more resistance and still the same amount of emf induced, current decreases and with that a weaker force, which leads to an increased terminal speed

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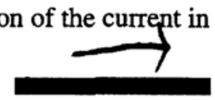
(a) Determine the magnitude of the magnetic flux through the loop when the crossbar is in the position shown.

$\phi_r = \int B \cdot dA = B_0 \cdot 0 = 0$

The crossbar is released from rest and slides with negligible friction down the U-shaped wire without losing electrical contact.

(b) On the figure below, indicate the direction of the current in the crossbar as it falls.



Justify your answer.

$\phi = \int B \cdot dA \qquad dA < 0$

$\mathcal{E} = -\frac{d\phi}{dt} \qquad V = IR$

it opposes the change in magnetic field

(c) Calculate the magnitude of the current in the crossbar as it falls as a function of the crossbar's speed $v$.

$V = IR$ $\quad \mathcal{E} = -\frac{d\phi}{dt}$ $\quad \phi = \int B \cdot dA$ $\quad dA = B \cdot L \cdot v$

$B \cdot L \cdot V = \mathcal{E}$ $\quad \frac{d}{dt}\int dA = dA$

$\frac{BLV}{R} = I$

(d) Derive, but do NOT solve, the differential equation that could be used to determine the speed $v$ of the crossbar as a function of time $t$.

$\frac{dV}{dt} = \frac{RI}{BL}$

(e) Determine the terminal speed $v_T$ of the crossbar.

$F = Il \times B$ $\quad F = mg$

$\Sigma F = 0$

$V_T$ occurs when $mg = Il \times B$

$mg = \frac{BLV}{R} LB$

$mg = \frac{B^2 L^2 V}{R}$

$V_T = \frac{Rmg}{B^2 L^2}$

(f) If the resistance $R$ of the crossbar is increased, does the terminal speed increase, decrease, or remain the same?

√ Increases ___ Decreases ___ Remains the same

Give a physical justification for your answer in terms of the forces on the crossbar.

If R increases I decreases $V = IR$
if I decreases then the force from the magnetic field also decreases $F = IL \times B$
therefore a smaller force is opposing gravity



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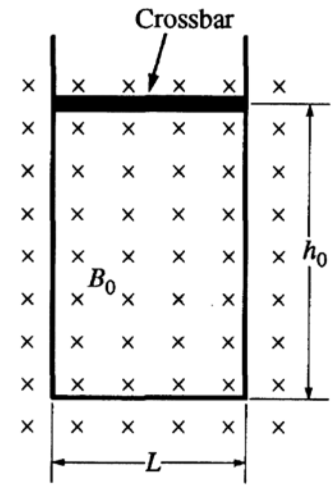


E&M. 3.

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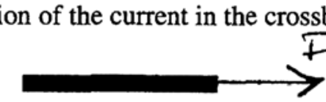
(a) Determine the magnitude of the magnetic flux through the loop when the crossbar is in the position shown.

~~$\Phi = \int B\,dA = B_0 L$~~ $\Phi_m = \int B \cdot dA = B_0 A$

$B_0 A = \boxed{B_0 L h_0}$

The crossbar is released from rest and slides with negligible friction down the U-shaped wire without losing electrical contact.

(b) On the figure below, indicate the direction of the current in the crossbar as it falls.




Justify your answer.

Area is decreasing, so flux is decreasing. The induced current will move opposite to the change in flux. Current is clockwise so when flux decreases ~~the~~ the ~~current~~ induced current moves clockwise.



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(c) Calculate the magnitude of the current in the crossbar as it falls as a function of the crossbar's speed $v$.

$F_m = qvB$ ~~$I = \frac{qv}{L}$~~ $IBL = m\frac{dv}{dt}$ ~~IBL~~

~~$IBL = qvB$~~ $= ma$

$I = \frac{qv}{L}$

(d) Derive, but do NOT solve, the ~~differential~~ equation that could be used to determine the speed $v$ of the crossbar as a function of time $t$.

$IBL = m\frac{dv}{dt}$

$IBL\,dt = m\,dv$

$IBLt = mv$

(e) Determine the terminal speed $v_T$ of the crossbar.

$IBL\,dt = m\,dv$

$IBLt = mv$

$\frac{IBLt}{m} = v_t$

(f) If the resistance $R$ of the crossbar is increased, does the terminal speed increase, decrease, or remain the same?

✓ Increases ~~✓~~ Decreases ____ Remains the same

Give a physical justification for your answer in terms of the forces on the crossbar.

If R ~~de~~ increases, I ~~de~~ increases ~~which~~ thus increasing $v_t$.

## Question 3

### Overview

This question assessed students' understanding of Faraday's and Lenz's Laws in the scenario of dropping a bar in a uniform magnetic field.

**Sample: E3-A**
**Score: 13**

This is an excellent and well-organized response. Points were lost only in part (c). When the question says to "calculate," students must show their work to receive full credit. This response received only 1 point in part (c) for the correct answer. Also note that in part (b) no penalty was imposed for giving a direction to the flux, even though it is a scalar.

**Sample: E3-B**
**Score: 9**

The answer in part (a) is incorrect and earned no credit. In part (b) 1 point was earned for the correct direction, but the justification is insufficient. Full credit was earned in parts (c), (e), and (f). Part (d) shows no useful work, so no credit was awarded.

**Sample: E3-C**
**Score: 6**

Full credit was earned in parts (a) and (b). In parts (c) and (e) no useful work is presented, so no credit was awarded. Two points were earned in part (d) for the correct expression of magnetic force and for substituting $dv/dt$ for $a$. In part (f) 1 point was earned for selecting the correct answer, but the justification is insufficient.