2018

AP® CollegeBoard

# AP Physics 2: Algebra-Based

## Sample Student Responses and Scoring Commentary

**Inside:**

Free Response Question 1

- ☑ Scoring Guideline
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## General Notes About 2018 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. The requirements that have been established for the paragraph-length response in Physics 1 and Physics 2 can be found on AP Central at https://secure-media.collegeboard.org/digitalServices/pdf/ap/paragraph-length-response.pdf.

3. 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.

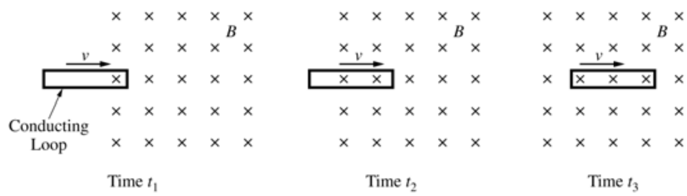
4. Implicit statements of concepts normally receive credit. For example, if use of the equation expressing a particular concept is worth 1 point, and a student's solution embeds the application of that equation to the problem in other work, the point is still awarded. However, when students are asked 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 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; Physics C: Mechanics, Physics C: Electricity and Magnetism Course Description* or "Terms Defined" in the *AP Physics 1: Algebra-Based Course and Exam Description* and the *AP Physics 2: Algebra-Based Course and Exam Description*.

5. The scoring guidelines typically show numerical results using the value $g = 9.8 \text{ m/s}^2$, but the 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.

6. 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.

## Question 1

**10 points total** **Distribution of points**




The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed $v$ into and through a region of constant, uniform magnetic field $B$ directed into the page. The magnetic field is zero outside the region.

(a) LO 2.D.1.1, SP 2.2; LO 4.E.2.1, SP 6.4
5 points

In a coherent paragraph-length response, compare the magnitude and direction of the current at times $t_1$, $t_2$, and $t_3$. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

| | | |
|---|---|---|
| For indicating that the currents at $t_1$ and $t_2$ have equal nonzero magnitudes and are in the same direction | | 1 point |
| For indicating that there is no current at $t_3$ | | 1 point |
| For correctly indicating that the currents depend on the change in flux through the loop or the forces on the charges moving in the field | | 1 point |
| For correctly identifying the direction of the current as counter-clockwise and either explaining that the direction of the current generates a magnetic field that opposes the change in flux <u>or</u> analyzing the force on the charge carriers in each segment of the loop | | 1 point |
| For an on-topic response that has sufficient paragraph structure, as described in the published requirements for the paragraph length response | | 1 point |

(b)

The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.

## Question 1 (continued)

**Distribution of points**

(b) (continued)

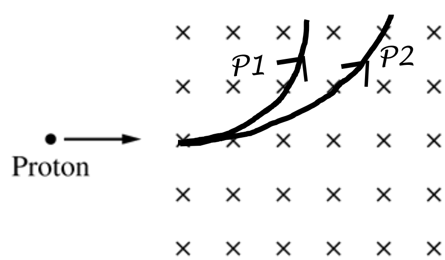
i. LO 2.D.1.1, SP 2.2
1 point

Calculate the magnitude of the force on the proton as it enters the field.

| | | |
|---|---|---|
| For correct substitutions into a correct expression and correct units on the final answer | | 1 point |
| $F = qvB$ | | |
| $F = \left(1.6 \times 10^{-19}\ \text{C}\right)\left(3.0 \times 10^{5}\ \text{m/s}\right)(0.03\ \text{T})$ | | |
| $F = 1.4 \times 10^{-15}\ \text{N}$ | | |

ii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4; LO 3.C.3.1, SP 1.4
1 point

On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.




| | | |
|---|---|---|
| For drawing a curved arc through the field, curved upward where the proton enters | | 1 point |
| Anything greater than a semi-circle or a path that does not reach the edge of the field does not earn credit. Any path after exiting the field is ignored. | | |

iii. LO 2.D.1.1, SP 2.2; LO 3.B.1.4, SP 6.4
1 point

A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

| | | |
|---|---|---|
| For drawing a path with a larger radius that is consistent with answer to (b)(ii) | | 1 point |

## Question 1 (continued)

**Distribution of points**

(b) (continued)

iv. LO 2.C.1.1, SP 6.4; LO 2.C.1.2, SP 2.2; LO 3.B.2.1, SP 1.4, 2.2
2 points

Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

| | | |
|---|---|---|
| For indicating a direction of the electric field that is consistent with the response to (b)(ii) | | 1 point |
| Given the correct response to (b)(ii) illustrated above, the electric field must be directed in the -*y* direction (or toward the bottom of the page) | | |
| For equating the electric and magnetic forces and substituting into the correct expression using values consistent with the response to (b)(i) | | 1 point |
| $qE = qvB$ (Implicitly equating the calculated magnetic force to the electric force is acceptable.) | | |
| $E = vB$ | | |
| $E = \left(3.0 \times 10^5 \text{ m/s}\right)(0.03 \text{ T})$ | | |
| $E = 9000 \text{ N/C}$ | | |

Learning Objectives (LO)

**LO 2.C.1.1**: The student is able to predict the direction and the magnitude of the force exerted on an object with an electric charge $q$ placed in an electric field $E$ using the mathematical model of the relation between an electric force and an electric field: $\vec{F} = q\vec{E}$; a vector relation. [See Science Practices 6.4, 7.2]

**LO 2.C.1.2**: The student is able to calculate any one of the variables — electric force, electric charge, and electric field — at a point given the values and sign or direction of the other two quantities. [See Science Practice 2.2]

**LO 2.D.1.1**: The student is able to apply mathematical routines to express the force exerted on a moving charged object by a magnetic field. [See Science Practice 2.2]

**LO 3.B.1.4**: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]

**LO 3.B.2.1**: The student is able to create and use free-body diagrams to analyze physical situations to solve problems with motion qualitatively and quantitatively. [See Science Practices 1.1, 1.4, 2.2]

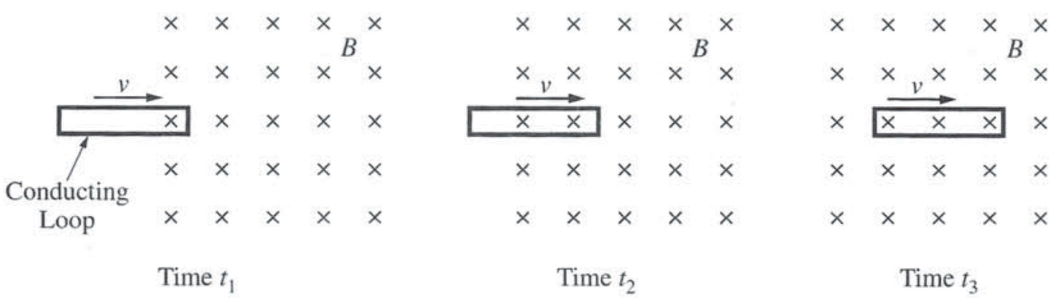
**LO 3.C.3.1**: The student is able to use right-hand rules to analyze a situation involving a current-carrying conductor and a moving electrically charged object to determine the direction of the magnetic force exerted on the charged object due to the magnetic field created by the current-carrying conductor. [See Science Practice 1.4]

**LO 4.E.2.1**: The student is able to construct an explanation of the function of a simple electromagnetic device in which an induced emf is produced by a changing magnetic flux through an area defined by a current loop (i.e., a simple microphone or generator) or of the effect on behavior of a device in which an induced emf is produced by a constant magnetic field through a changing area. [See Science Practice 6.4]

P2 Q1 A p1

# PHYSICS 2
## Section II
**Time—1 hour and 30 minutes**
**4 Questions**

**Directions:** Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.




1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed $v$ into and through a region of constant, uniform magnetic field $B$ directed into the page. The magnetic field is zero outside the region.

(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times $t_1$, $t_2$, and $t_3$. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

$t_1$ the current induced will be counterclockwise as the loop enters the field, because the magnetic field begins to enter the loop creating a change in flux, inducing a current counter clockwise. At $t_2$ the loop is still entering the field and changing the flux continuing the inducing of current counterclockwise. The current will be the same strength as $t_1$. At $t_3$ the loop is allready in the field so there is no more change in flux and therefore no more current.



GO ON TO THE NEXT PAGE.

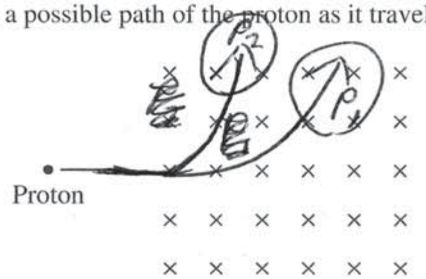
(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.


i. Calculate the magnitude of the force on the proton as it enters the field.

$F = qVB$

$1.6 \times 10^{-19} \cdot 3.0 \times 10^5 \times .03T = 1.44 \times 10^{-15} N$

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.




iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

$F = qVB = Eq$

$VB = E$

$3.0 \times 10^5 \times .03 = E = 9000 \frac{N}{C}$ downward ↓



GO ON TO THE NEXT PAGE.

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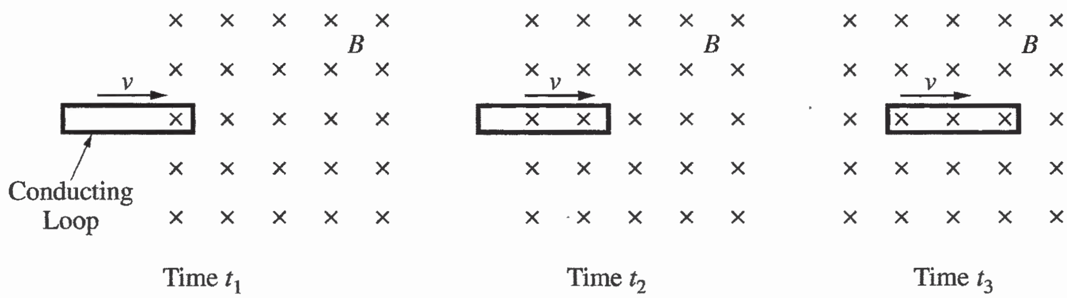



1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed $v$ into and through a region of constant, uniform magnetic field $B$ directed into the page. The magnetic field is zero outside the region.

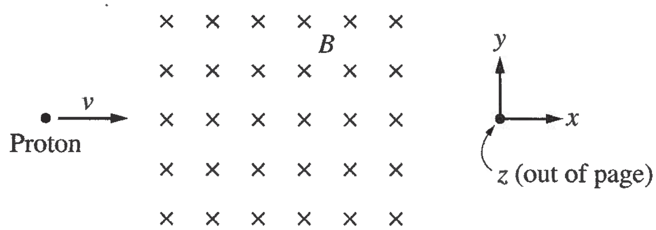
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times $t_1$, $t_2$, and $t_3$. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

~~At time $t_1$~~ The magnitude of the current is greatest at time $t_3$, smallest at time $t_1$, and in-between at time $t_2$. The direction of the current is the same at all times as the velocity of the loop is constant. The magnitude of the current at time $t_3$ is greatest because the greatest area of the wire (its entire area) is under the influence of the field. Likewise, more of the wire is influenced at $t_2$ than at $t_1$.



GO ON TO THE NEXT PAGE.

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



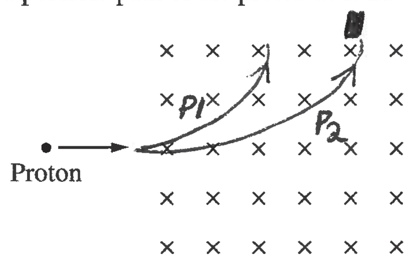

i. Calculate the magnitude of the force on the proton as it enters the field.

$F_M$ ~~$F_B$~~ $= qV \times B$

$F_M$ ~~$F_B$~~ $= (+1.6 \times 10^{-19}\ C)(3 \times 10^5\ \frac{m}{s})(.030\ T)$

$F_M = 1.44 \times 10^{-15}\ N$

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.




iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

$\vec{E} = \frac{\vec{F}_E}{q}$ ; $|\vec{E}| = \left|\frac{F_E}{q}\right|$ ; $E = \frac{(1.44 \times 10^{-15}\ N)}{(1.6 \times 10^{-19}\ C)} = 9000\ \frac{N}{C}$

The direction of the electric field relative to the coordinate system shown in part (b) is down (towards the bottom of the page.)



GO ON TO THE NEXT PAGE.

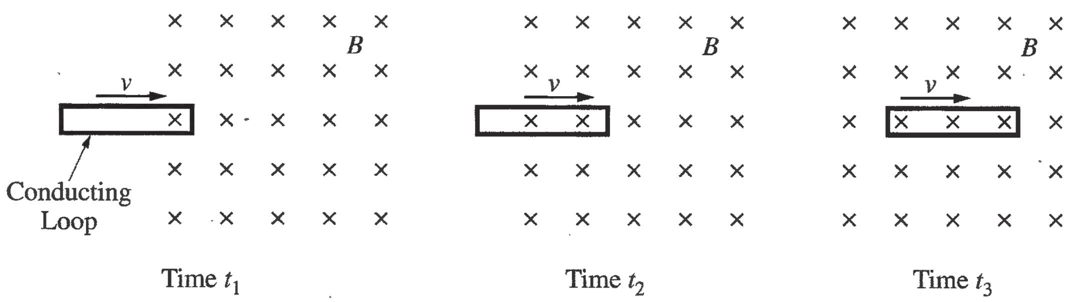
# PHYSICS 2

## Section II

**Time—1 hour and 30 minutes**

**4 Questions**

**Directions:** Questions 1 and 4 are short free-response questions that require about 20 minutes each to answer and are worth 10 points each. Questions 2 and 3 are long free-response questions that require about 25 minutes each to answer and are worth 12 points each. Show your work for each part in the space provided after that part.



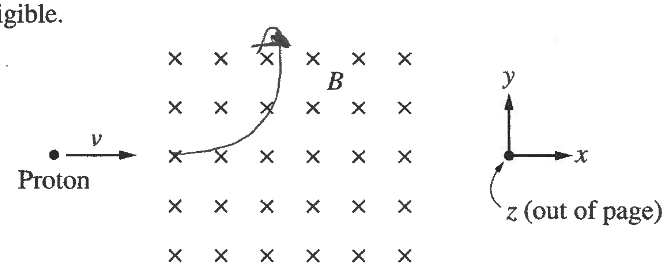

1. (10 points, suggested time 20 minutes)

The figures above show a rectangular conducting loop at three instants in time. The loop moves at a constant speed $v$ into and through a region of constant, uniform magnetic field $B$ directed into the page. The magnetic field is zero outside the region.

(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times $t_1$, $t_2$, and $t_3$. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

In $t_1$ the current direction is clockwise but magnitude would be low because more field lines through a wire means more current being produce ∴ $t_1$ it would be lowest. In $t_2$ the direction is the same clockwise but this time there is more current then before because more field lines. In $t_3$ there's no current because the electrons are countering eachother ∴ no current

(b) The loop is removed. A proton traveling to the right in the plane of the page, as shown below, then enters the region of magnetic field with a speed $v = 3.0 \times 10^5$ m/s. The magnitude of the field is 0.030 T. The effects of gravity are negligible.



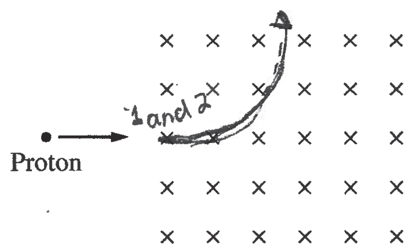

i. Calculate the magnitude of the force on the proton as it enters the field.

$F_M = qvB =$

$= (1.60 \cdot 10^{-19} C)(3 \cdot 10^5 m/s)(0.030 T)$

$F = 1.4 \cdot 10^{-15} N$

ii. On the figure below, sketch a possible path of the proton as it travels through the magnetic field. Clearly label the path P1.




iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

iv. Next an electric field is applied in the same region as the magnetic field, such that there is no net force on the first proton as it enters the region. Calculate the magnitude and indicate the direction of the electric field relative to the coordinate system shown in part (b).

$Eq = qvB$

$E = vB$

$= (3.6 \cdot 10^5 m/s)(0.030 T)$

$E = 9000$ N/C [Out of page]



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## Question 1

**Overview**

This question assessed learning objectives 2.C.1.1, 2.C.1.2, 2.D.1.1, 3.B.1.4, 3.B.2.1, 3.C.3.1, and 4.E.2.1.

The responses to this question were expected to demonstrate the following:

- How to determine the direction of an induced current when the magnetic flux is changing through a wire loop.
- The understanding that there is no current when the magnetic flux is not changing and if the magnetic flux were changing, that the amount of current depends on the rate of change of magnetic flux.
- How to determine the magnitude and direction of the force on a moving charge due to a magnetic field.
- The understanding that a charge initially moving perpendicular to a magnetic field will undergo circular motion as it enters a uniform magnetic field, and the radius of the circle increases with the speed of the charged particle.
- The understanding that an electric field will exert a force on a positively-charged particle in the same direction as the electric field, and the magnitude of this force is the charge times the magnitude of the electric field.

**Sample: P2 Q1 A**
**Score: 8**

Part (a) earned 4 out of the 5 points. The response correctly indicates that the current at times $t_1$ and $t_2$ have the same magnitude and same direction within the loop, there is no current at time $t_3$, and the current in the loop depends on the change in magnetic flux through the loop. The response is a coherent and consistent paragraph. Full credit was not earned in part (a) because the response does not fully explain why the current is counterclockwise, for example by including a statement about how the induced current in the loop is generated to oppose the increasing magnetic field that is directed into the page. Part (b)(i) earned 1 point for a correct calculation and the inclusion of newtons (N) as the unit. Part (b)(ii) earned 1 point for a curved upward path for P1. Part (b)(iii) earned no points because path P2 has a smaller radius than P1. Part (b)(iv) earned 2 points for the correct magnitude of the electric field and the correct downward direction.

**Sample: P2 Q1 B**
**Score: 6**

Part (a) earned 1 point for a coherent and consistent yet incorrect paragraph. The response incorrectly links the magnitude of the current to the amount of loop in the field and the direction of the current to the velocity. It does not specifically discuss magnetic flux or how the induced current creates a field to oppose the change in flux. However, it is written in a logical manner, in complete sentences, and is internally consistent. Part (b)(i) earned 1 point for the correct magnetic force and the inclusion of newtons (N) as the unit. Part (b)(ii) earned 1 point for a curved upward path for P1. Part (b)(iii) earned 1 point for drawing P2 with a larger radius and curved in the same direction as P1. Part (b)(iv) earned 2 points for the correct magnitude of the electric field and the correct downward direction.

## Question 1 (continued)

**Sample: P2 Q1 C**
**Score: 4**

Part (a) earned 1 point for indicating that there is no current at time $t_3$. The response indicates that the current in the loop at times $t_1$ and $t_2$ are in the same direction but incorrectly states that the currents are not equal. The response does not relate the magnitude of the current to the change in magnetic flux through the loop and does not explain the direction of the induced current. The response does not have a consistent paragraph because it contains contradictory statements. It indicates that more magnetic field lines through the loop mean more current is induced, then claims that there is no current induced in the loop at $t_3$ when the most field lines pass through the loop. Part (b)(i) earned 1 point for a correct calculation and the inclusion of newtons (N) as the unit. Part (b)(ii) earned 1 point for a curved upward path for P1. Part (b)(iii) earned no points because path P2 is indicated as being the same as path P1. Part (b)(iv) earned 1 point because it has the correct electric field magnitude but an incorrect direction.