2019

AP® CollegeBoard

AP® Physics 2: Algebra-Based

Sample Student Responses and Scoring Commentary

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Free Response Question 1

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AP® PHYSICS
2019 SCORING GUIDELINES

General Notes About 2019 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*.

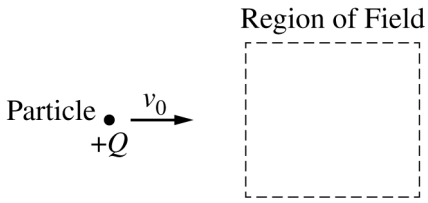
5. The scoring guidelines typically show numerical results using the value $g = 9.8\ \text{m/s}^2$, but the use of $10\ \text{m/s}^2$ is of course also acceptable. Solutions usually show numerical answers using both values when they are significantly different.

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.

AP® PHYSICS 2
2019 SCORING GUIDELINES

Question 1

10 points

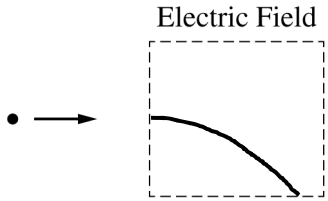


The figure above shows a particle with positive charge $+Q$ traveling with a constant speed v_0 to the right and in the plane of the page. The particle is approaching a region, shown by the dashed box, that contains a constant uniform field. The effects of gravity are negligible.

(a)

i. LO 2.C.1.1, SP 6.4
2 points

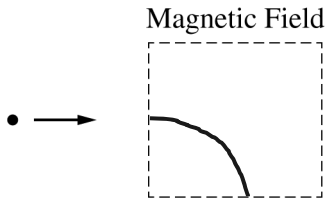
On the figure below, draw a possible path of the particle in the region if the region contains only an electric field directed toward the bottom of the page.



For a curved path that is initially horizontal and does not have a component of velocity toward the left		1 point
For a path that deflects toward the bottom of the page and reaches an edge of the region		1 point

ii. LO 3.C.3.1, SP 1.4
2 points

On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



For a curved path that is initially horizontal, is not more than a semicircle, and reaches an edge of the region		1 point
For a path that deflects toward the bottom of the page		1 point

Question 1 (continued)

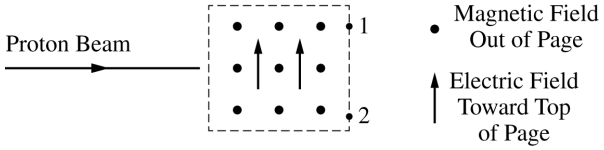
(a) (continued)

iii. LO 2.C.5.3, SP 1.1, 7.1
1 point

For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?

For indicating that the motion in the electric field is more similar to a projectile because the force or acceleration is always down or constant, or the shape is parabolic		1 point

(b) LO 2.D.1.1, SP 2.2; LO 3.A.3.4, SP 6.1, 6.4; LO 3.B.1.4, SP 6.4, 7.2; LO 3.B.2.1, SP 1.1, 1.4, 2.2
5 points



Another region of space contains an electric field directed toward the top of the page and a magnetic field directed out of the page. Both fields are constant and uniform. A horizontal beam of protons with a variety of speeds enters the region, as shown above. Protons exit the region at a variety of locations, including points 1 and 2 shown on the figure. In a coherent, paragraph-length response, explain why some protons exit the region at point 1 and others exit at point 2. Use physics principles to explain your reasoning.

For indicating that initially the electric and magnetic forces act in opposite directions		1 point
For indicating or implying that the magnetic force is affected by speed, but the electric force is not		1 point
For indicating that different paths occur as a result of the addition of forces		1 point
For indicating that slower protons exit higher than faster protons (i.e., slower protons exit at point 1 and faster protons exit at point 2)		1 point
For a logical, relevant, and internally consistent argument that addresses the question asked and follows the guidelines described in the published requirements for the paragraph-length response		1 point
Example: For a charged particle to travel through the region undeflected, the net force on it must be zero. This means that the upward electric force and the downward magnetic force must be equal and opposite to each other. This occurs for a particular speed. The electric force is independent of the particle's velocity, but the magnetic force will be larger for greater velocities and less for smaller velocities. If a particle is moving faster than the particular speed, it will experience a greater magnetic force and be deflected downward. If it is moving more slowly than the particular speed, it will be deflected upward.		

Question 1 (continued)

(b) (continued)

Claim: Slower protons exit higher than faster protons (i.e., slower protons exit at point 1 and faster protons exit at point 2). Evidence: The electric and magnetic forces act in opposite directions. The magnetic force is affected by speed, but the electric force is not. Reasoning: Different paths occur as a result of the addition of forces.		

Learning Objectives

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.5.3: The student is able to represent the motion of an electrically-charged particle in the uniform field between two oppositely charged plates and express the connection of this motion to projectile motion of an object with mass in Earth's gravitational field. [See Science Practices 1.1, 2.2, 7.1]

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 Practices 2.2]

LO 3.A.3.4: The student is able to make claims about the force on an object due to the presence of other objects with the same property: mass, electric charge. [See Science Practices 6.1, 6.4]

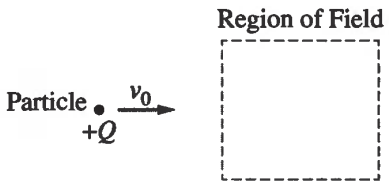
LO 3.B.1.4: The student is able to predict the motion of an object subject to forces exerted by several objects using an application of Newton's second law in a variety of physical situations. [See Science Practices 6.4, 7.2]

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 Practices 1.4]

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.

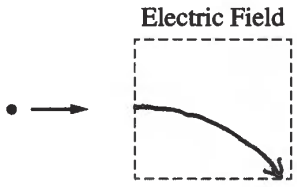


1. (10 points, suggested time 20 minutes)

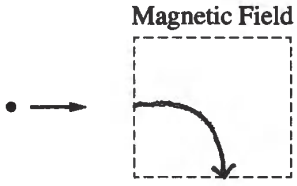
The figure above shows a particle with positive charge $+Q$ traveling with a constant speed v_0 to the right and in the plane of the page. The particle is approaching a region, shown by the dashed box, that contains a constant uniform field. The effects of gravity are negligible.

(a)

i. On the figure below, draw a possible path of the particle in the region if the region contains only an electric field directed toward the bottom of the page.

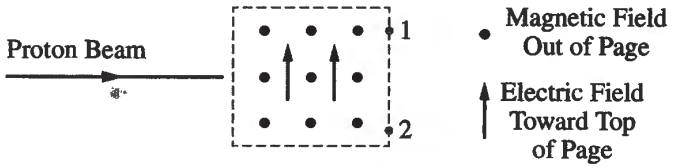


ii. On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



iii. For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?

The particle in the electric field travels in a projectile-like path because the electric force is always acting in the same direction, similar to gravitation. On the other hand, the particle in the magnetic field travels in a circle because the force always acts perpendicular to the motion.



(b) Another region of space contains an electric field directed toward the top of the page and a magnetic field directed out of the page. Both fields are constant and uniform. A horizontal beam of protons with a variety of speeds enters the region, as shown above. Protons exit the region at a variety of locations, including points 1 and 2 shown on the figure. In a coherent, paragraph-length response, explain why some protons exit the region at point 1 and others exit at point 2. Use physics principles to explain your reasoning.

The electric field will accelerate the protons upward, and the magnetic field will accelerate the protons downwards by right-hand rule. For the beam of protons to exit at point 1, the electric force must be greater than the magnetic force. Exiting at point 2 would be caused by the magnetic force being greater. Because the magnetic force is proportional to the velocity of particles, it can be concluded that the protons exiting at point 2 had velocity great enough to create a magnetic force greater than the electric force, and those exiting at point 1 did not.

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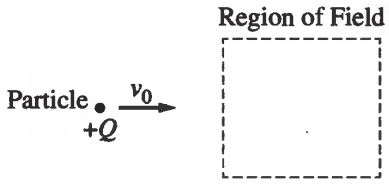

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(a)

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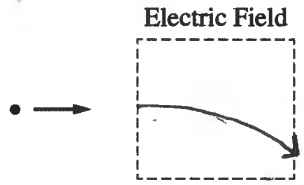
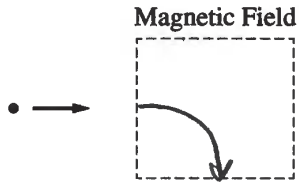
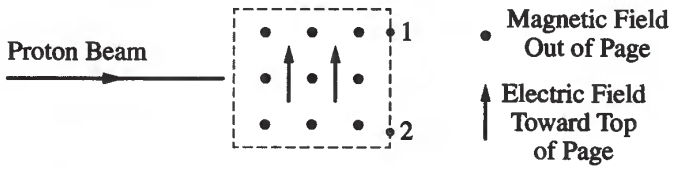


ii. On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



iii. For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?

An electric field is more similar to that of a projectile in a gravitational field near Earth's surface because the proton is forced along a non-circular path while in a magnetic field, it is forced in a circular path because it is gaining centripetal acceleration.



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The protons exit the region at various points including points 1 and 2 because they are being affected by both a magnetic and electric field. The electric field is forcing the protons to the top of the page while the magnetic field is forcing the protons to the bottom of the page. You can find this out by using the right hand rule. Since the protons are entering the region with a variety of speeds, they are each affected differently by the fields, and some end up above their beginning height while others end up below their beginning height.

PHYSICS 2
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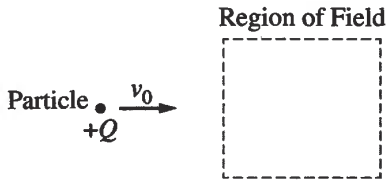

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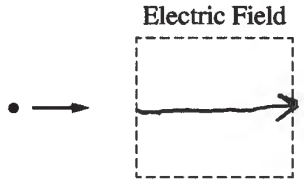
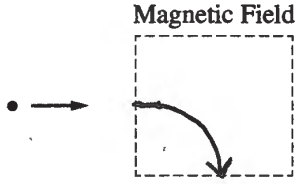


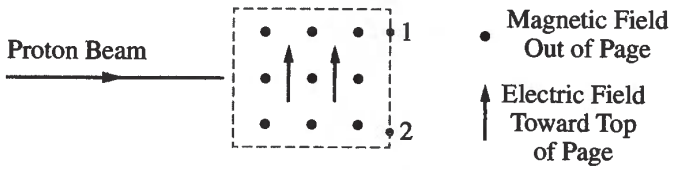
ii. On the figure below, draw a possible path of the particle in the region if the region contains only a magnetic field directed out of the page.



M = •

iii. For which of the previous situations is the motion more similar to that of a projectile in only a gravitational field near Earth's surface, and why?

situation ii, because the motion of a projectile in only a gravitational field is a negative quadratic shape. In situation ii the force is pointing towards the bottom of the page which causes the particle to curve towards the bottom of the page. Both situation ii and the projectile look like such: ⌐



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Some protons exit the region at point 1 while some protons exit the region at point 2 because of different forces acting on the protons at different speeds. Protons will exit at point 1 if they have a greater speed than a proton exiting at point 2.

AP® PHYSICS 2
2019 SCORING COMMENTARY

Question 1

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:

- An understanding of the path a proton takes in a uniform electric field such that students can represent it by drawing a path that is curved and in the direction of the field.
- An understanding of the path a proton takes in a uniform magnetic field by drawing a path that requires the use of the right-hand rule to determine what direction the proton curves.
- How the path of a charge particle in an electric field is parabolic like that of an object in a gravitational field near the Earth's surface because both fields apply a constant downward force.
- The various paths that protons of varying velocity can take in a region of crossed fields such as that used in a velocity selector. This requires an understanding of net force and the dependence of the magnetic force on velocity while the electric force is independent of velocity.
- The ability to put together a clear and coherent paragraph-length response that answers the question with clear reasoning.

Sample: P2 Q1 A
Score: 10

Part (a)(i) earned 2 points for the curved path. It starts out horizontal and has no leftward component, and it curves downward and reaches the edge of the region. Part (a)(ii) also earned 2 points for the curved path. It is initially horizontal, not more than a semicircle, reaches the edge of the region, and curves downward. Part (a)(iii) earned 1 point for indicating the electric force is always acting in the same direction, similar to the gravitational force near Earth's surface. Part (b) earned all 5 points for a coherent paragraph-length response that includes the necessary elements. The response indicates that the fields exert forces on the protons in the correct, opposite directions. The magnetic force is identified as being proportional to the velocity of the proton. The net force is indicated by stating when one force is greater than the other, and the correct points of exit are indicated.

Sample: P2 Q1 B
Score: 6

Part (a)(i) earned 2 points for a curved downward path that reaches the edge of the region. Part (a)(ii) also earned 2 points for a curved downward path. Part (a)(iii) did not earn the point because the response indicates only that it is not circular, not that it is parabolic or that both the electric and gravitational force are always downward. Part (b) earned 1 point for indicating the forces are in the correct, opposite directions and 1 point for a coherent paragraph.

Sample: P2 Q1 C
Score: 2

Part (a)(i) earned no points for a straight-line path that does not curve downward. Part (a)(i) earned 2 points for a curved downward path that reaches the edge of the region. Part (a)(iii) did not earn the point because the response suggests that the magnetic field is more similar to the gravitational field near Earth's surface. Part (b) earned no points for an incorrect description of the exit points at faster and slower speeds as well as an unclear description of different forces.