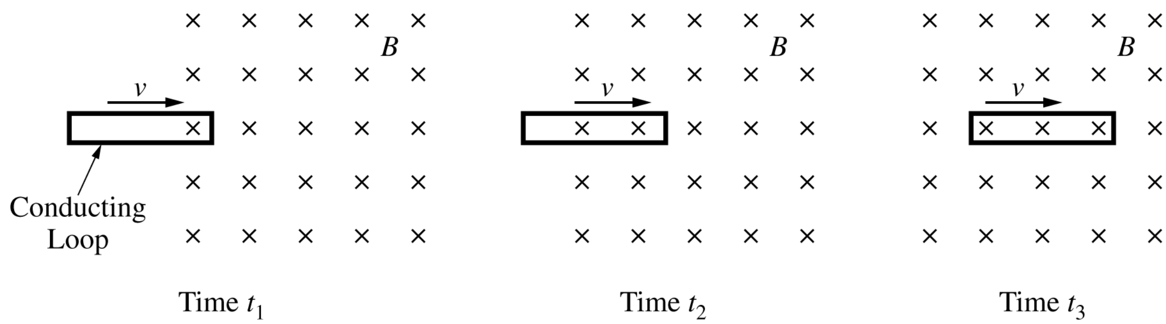
PHYSICS 2

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.

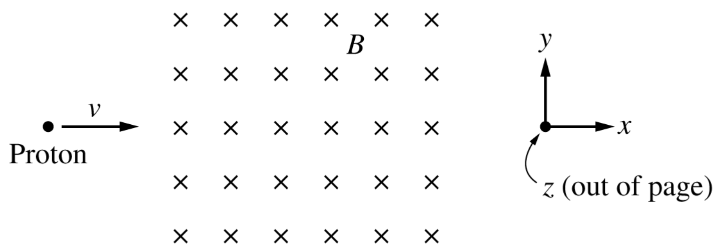


1. (10 points, suggested time 20 minutes)

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.

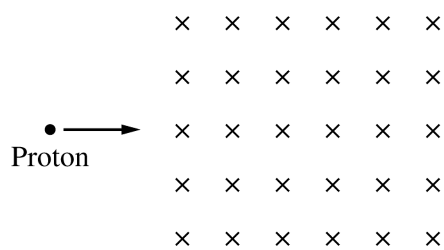
(a) In a coherent paragraph-length response, compare the magnitude and direction of the current at times t_1, t_2, and t_3. Include an explanation of why there is or is not a current and the direction of the current if one is present. Use fundamental physics concepts and principles in your explanation.

(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 $v = 3.0 \times 10^5\ \text{m/s}$. 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.

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

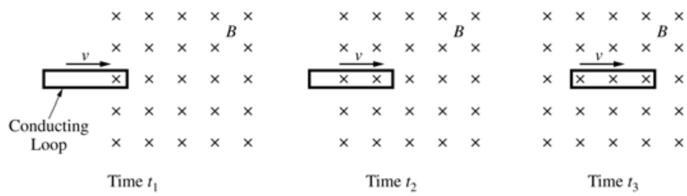


iii. A second proton now enters the magnetic field at the same point and from the same direction but at a greater speed than the first proton. On the figure above, draw the path of the second proton as it travels through the field. Clearly label the path P2.

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).

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)

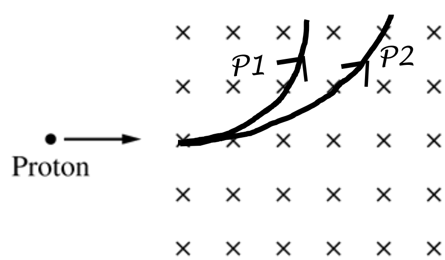
i. LO 2.D.1.1, SP 2.2
1 point

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]