

Physics 212

Lecture 12

Today's Concept:

Magnetic Force on Moving Charges

Your Comments

I understand right-hand rule and in/out of the page, but where does up/down force come from? I was totally lost on that one. <https://www.youtube.com/watch?v=1TKSfAkWWN0>

Please explain the two wire slide in the prelecture. I'm not sure how the direction of the current affects the magnetic field.

Is it true that a magnetic field will never change the speed of a particle? If that's true, then a magnetic field will never change the momentum of a particle right?

Please go over the checkpoint with the two chambers carefully! I really don't see anything magical happening there. Just looks like a speck of dust in a box to my untrained eyes. Also, what do you get when you cross an elephant with a banana?
|elephant||banana|sin(theta)!!!! :D

Does that mean a charged moving particle always move in a circle under any magnetic field? Since the Earth has a magnetic field itself does that mean all particles move in a circular motion on Earth?

In all honesty, do physicists look down upon on engineers?

WHAT? WHY? WHAT?!?! If I throw a ball, and gravity points down, the ball falls diagonally. If I throw a charged ball, and the magnetic field points down, the ball flies off to the left? WHAT? Why not right? What does the ball care if I'm right or left handed?

Key Concepts:

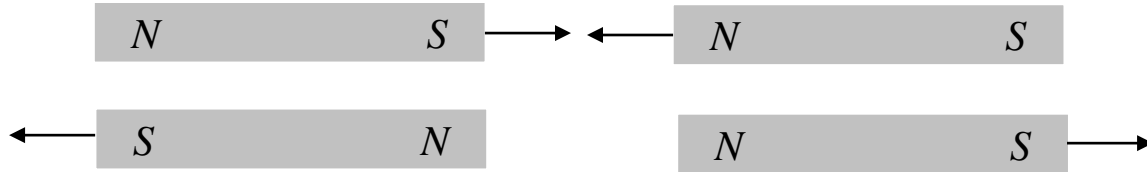
- 1) The force on moving charges due to a magnetic field.
- 2) The cross product.

Today's Plan:

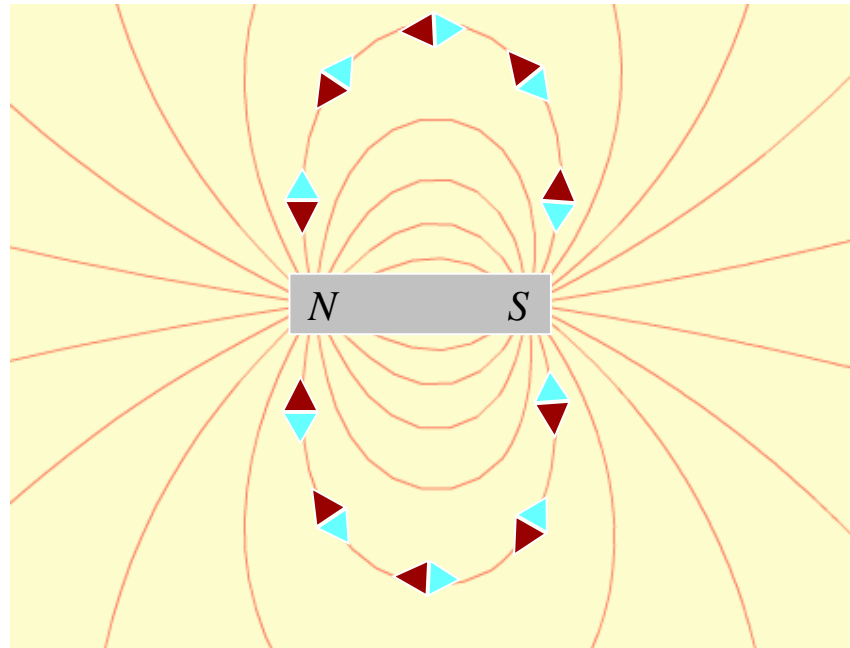
- 1) Review of magnetism
- 2) Review of cross product
- 3) Example problem

Magnetic Observations

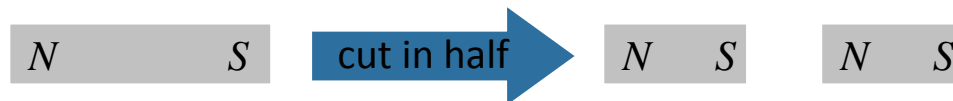
Bar Magnets



Compass Needles

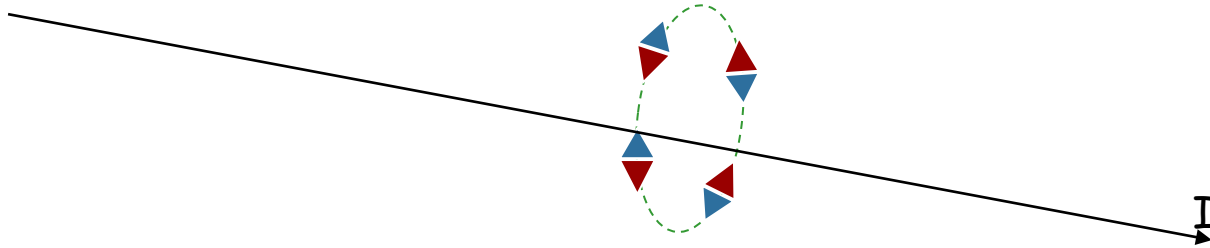


Magnetic Charge?



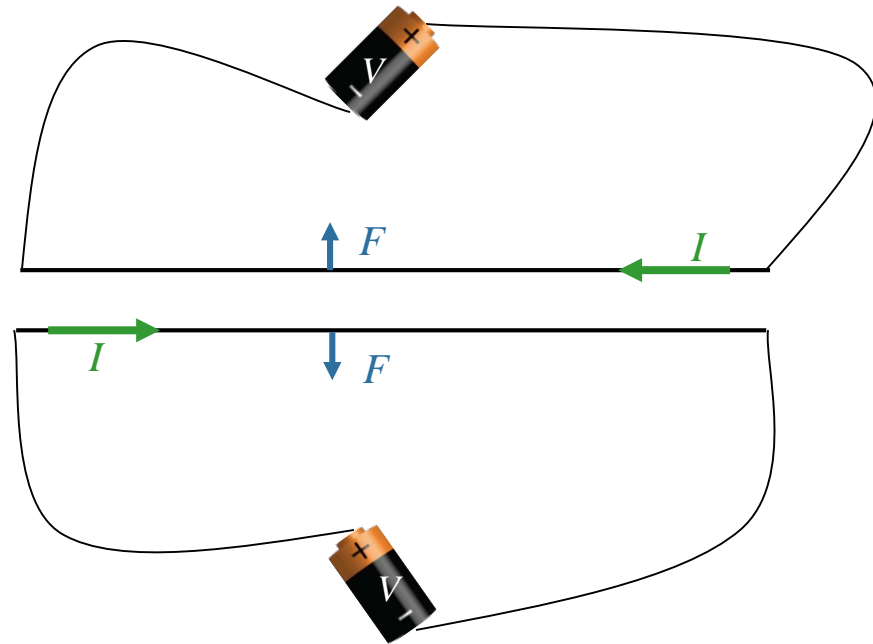
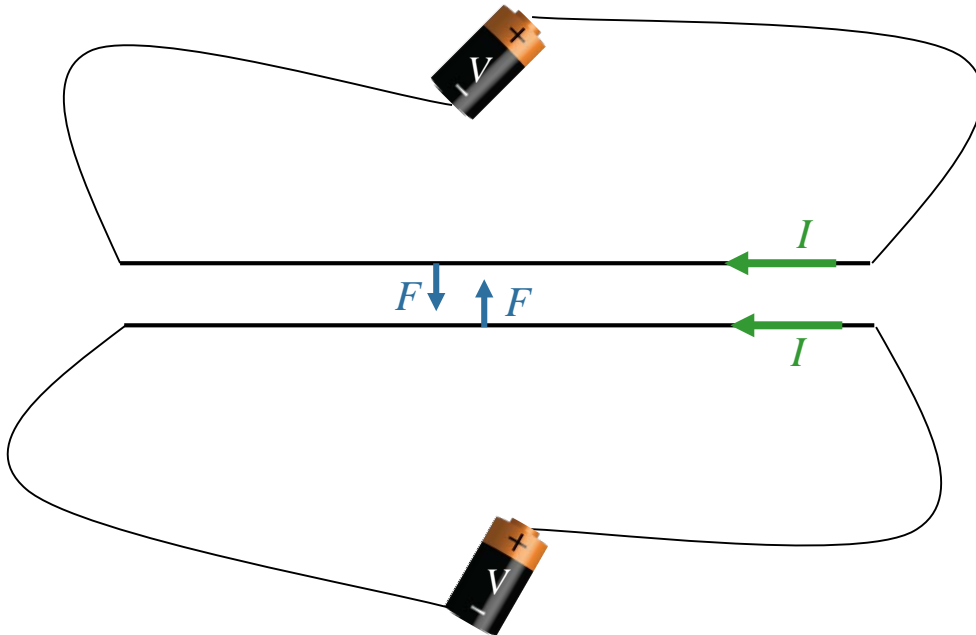
Magnetic Observations

Compass needle deflected by electric current



Magnetic fields created by electric currents

Magnetic fields exert forces on electric currents (charges in motion)



Magnetic Observations



really confusing on how to figure out the force direction and what do the "Xs" really mean??

•
 P



I (out of the screen)

Case I

•
 P



I (into of the screen)

Case II

The magnetic field at P points

- A.** Case I: left, Case II: right **B.** Case I: left, Case II: left
C. Case I: right, Case II: left **D.** Case I: right, Case II: right

WHY? Direction of \vec{B} : right thumb in direction of I ,
fingers curl in the direction of \vec{B}

Magnetism & Moving Charges

All observations are explained by two equations:

$$\vec{F} = q\vec{v} \times \vec{B}$$

Today

$$d\vec{B} = \frac{\mu_0 I}{4\pi} \frac{d\vec{s} \times \hat{r}}{r^2}$$

Next Week

Cross Product Review

Cross Product different from Dot Product

$A \bullet B$ is a scalar; $A \times B$ is a vector

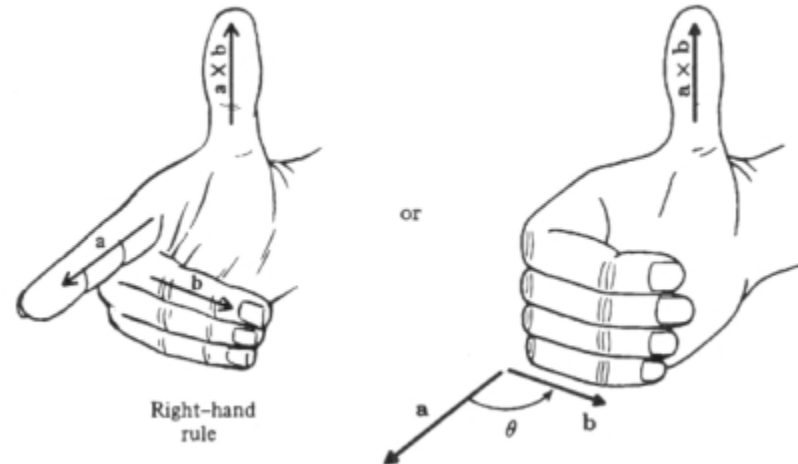
$A \bullet B$ proportional to the component of B parallel to A

$A \times B$ proportional to the component of B perpendicular to A

Definition of $A \times B$

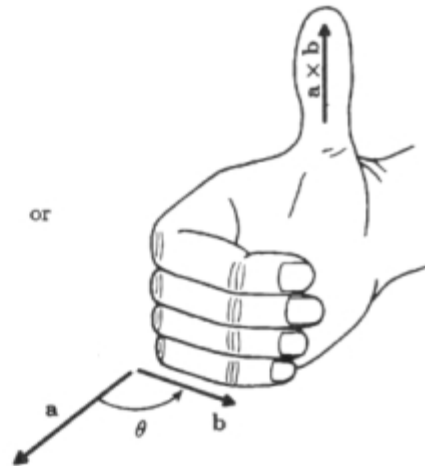
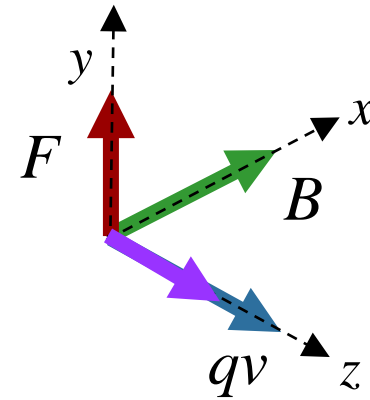
Magnitude: $AB \sin \theta$

Direction: perpendicular to plane defined by A and B with sense given by right-hand-rule



Remembering Directions: The Right Hand Rule

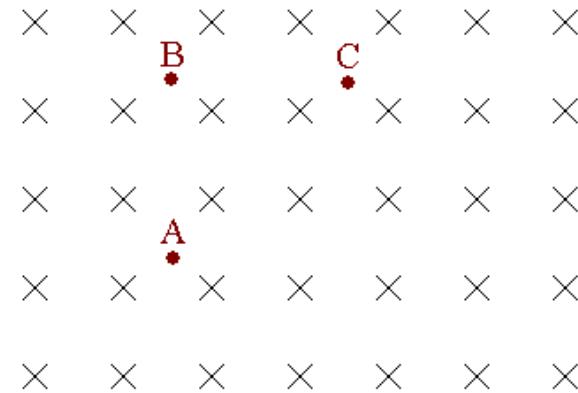
$$\vec{F} = q\vec{v} \times \vec{B}$$



CheckPoint 1a



Three points are arranged in a uniform magnetic field. The **B** field points into the screen.



A positively charged particle is located at point A and is stationary. The direction of the magnetic force on the particle is

A. right

B. left

C. into the screen

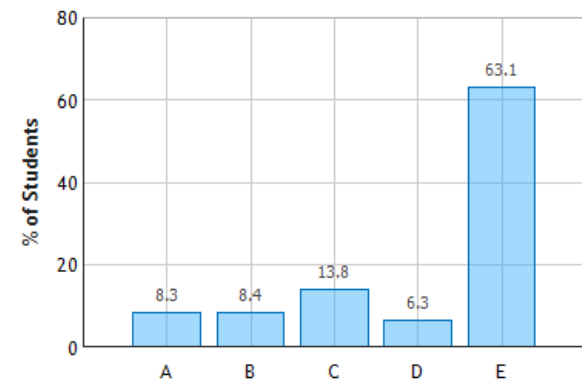
D. out of the screen

E. zero

$$\vec{F} = q\vec{v} \times \vec{B}$$

The particle is stationary so there is no magnetic force..

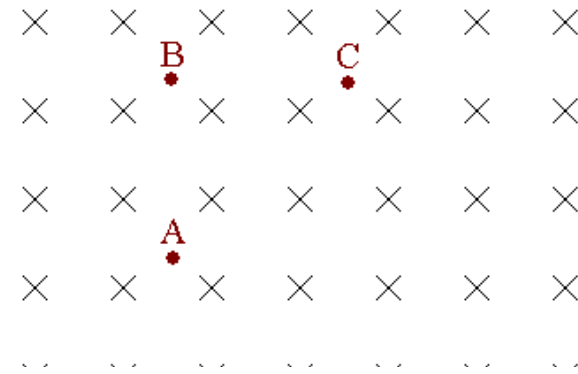
Magnetic Forces: Question 1 (N = 759)



CheckPoint 1b



Three points are arranged in a uniform magnetic field. The **B** field points into the screen.



The positive charge moves from A toward B. The direction of the magnetic force on the particle is

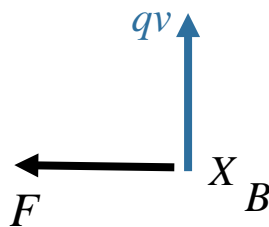
A. right
E. zero

B. left

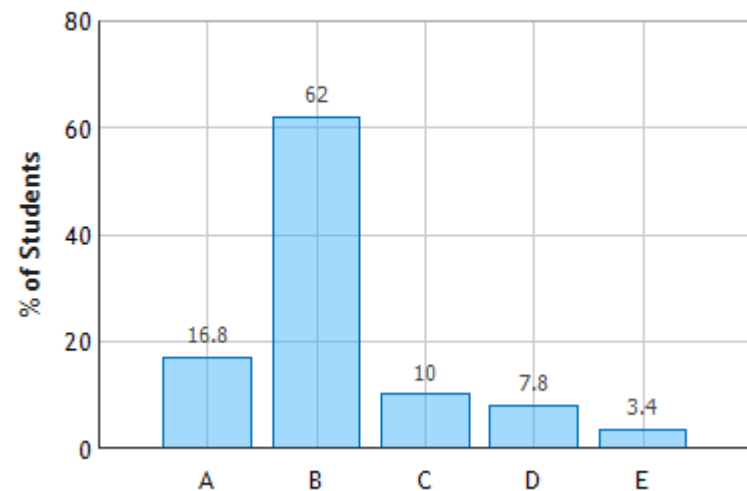
C. into the screen

D. out of the screen

$$\vec{F} = q\vec{v} \times \vec{B}$$



Magnetic Forces: Question 3 (N = 758)



Cross Product Practice



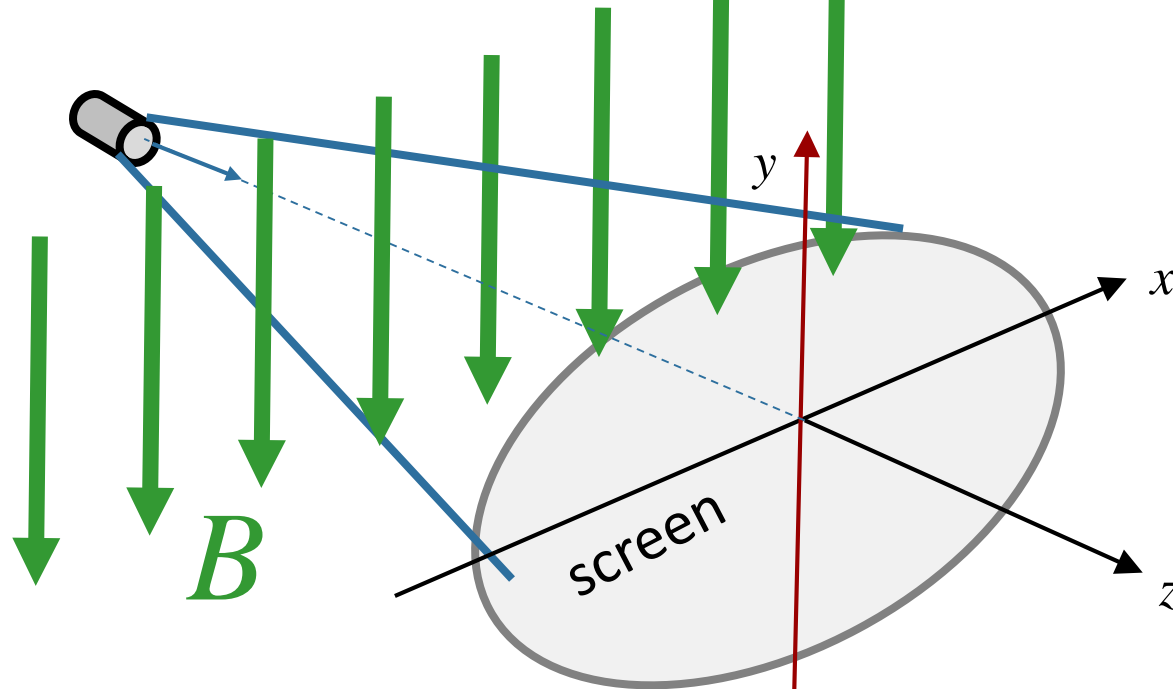
Protons (**positive charge**) coming out of screen

Magnetic field pointing down

What is direction of force on **POSITIVE** charge?

$$\vec{F} = q\vec{v} \times \vec{B}$$

- ← A) Left $-x$
- B) Right $+x$
- ↑ C) UP $+y$
- ↓ D) Down $-y$
- E) Zero



Motion of Charge q in Uniform B Field

Force is perpendicular to v

Speed does not change

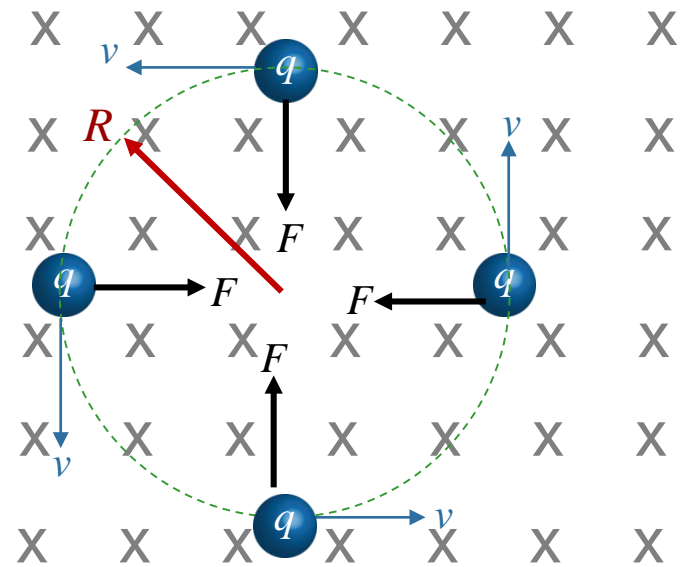
Uniform Circular Motion

Solve for R :

$$\vec{F} = q\vec{v} \times \vec{B} \Rightarrow F = qvB$$

$$a = \frac{v^2}{R}$$

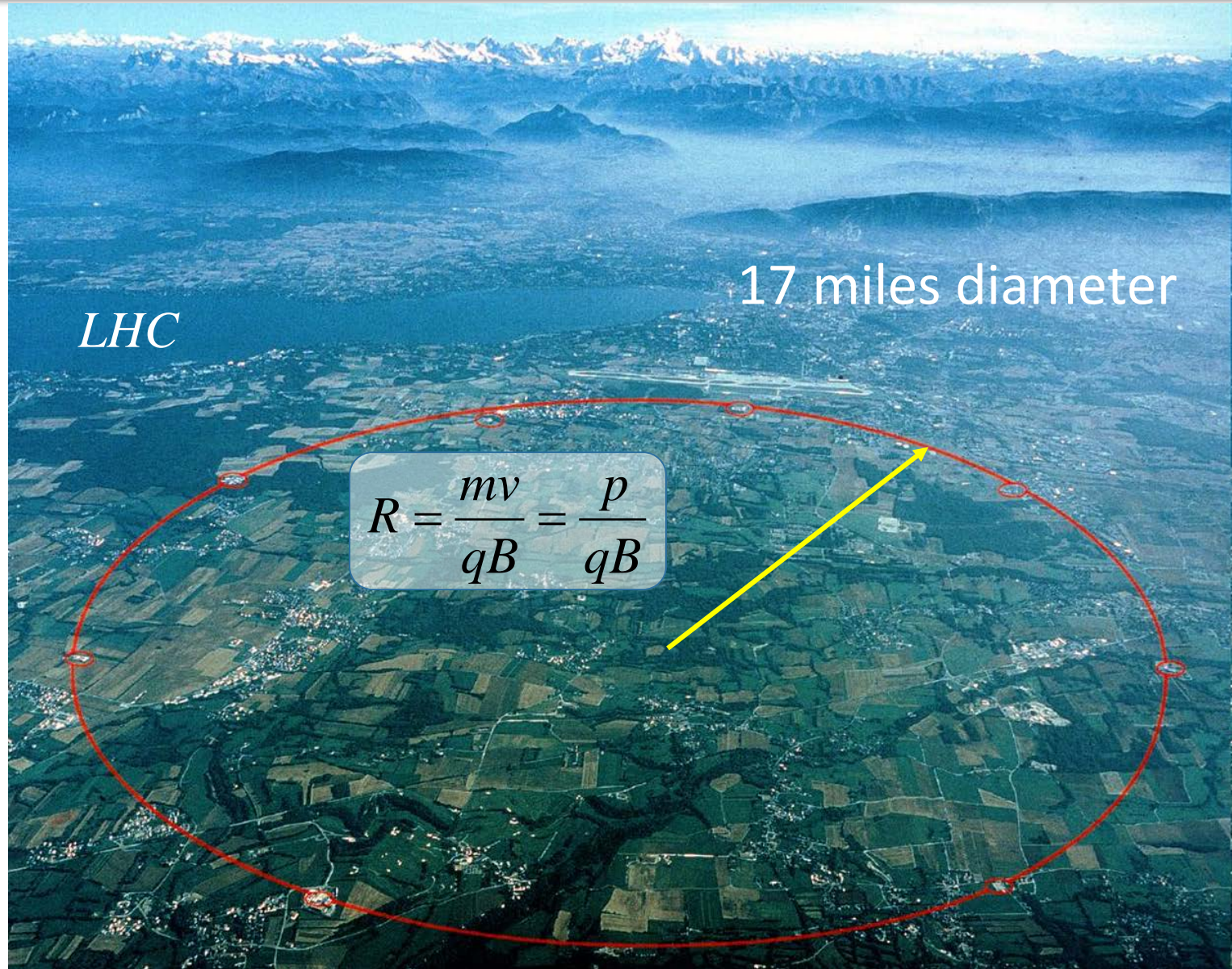
$$qvB = m \frac{v^2}{R} \quad \longrightarrow \quad R = \frac{mv}{qB}$$



Uniform B into page

Demo

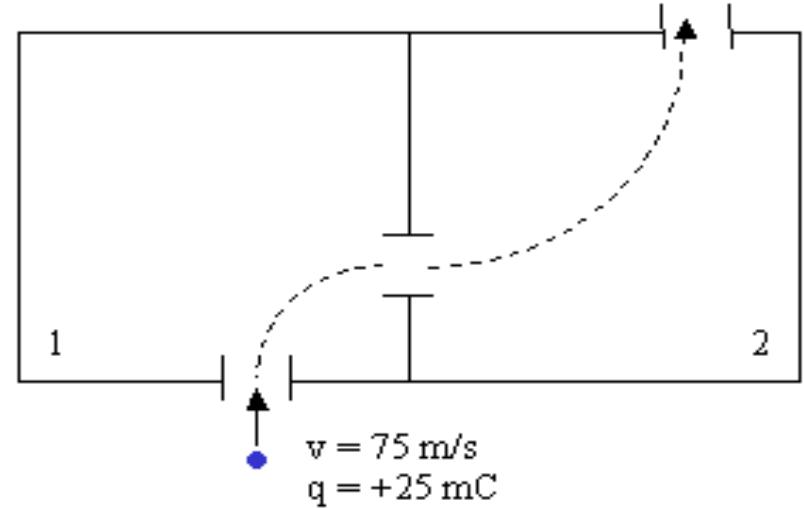
Can you take us to the LHC to see some of the big magnets in the ring and the detectors there?



CheckPoint 2a



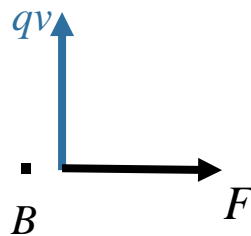
The drawing below shows the top view of two interconnected chambers. Each chamber has a unique magnetic field. A positively charged particle is fired into chamber 1, and observed to follow the dashed path shown in the figure.



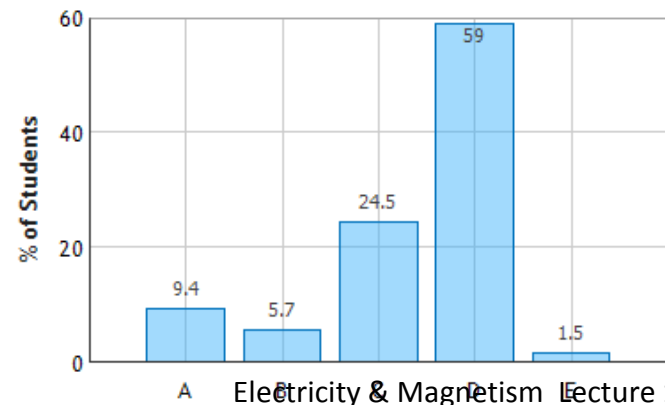
What is the direction of the magnetic field in chamber 1?

- A.** up **B.** down **C.** into the page **D.** out of the page

$$\vec{F} = q\vec{v} \times \vec{B}$$

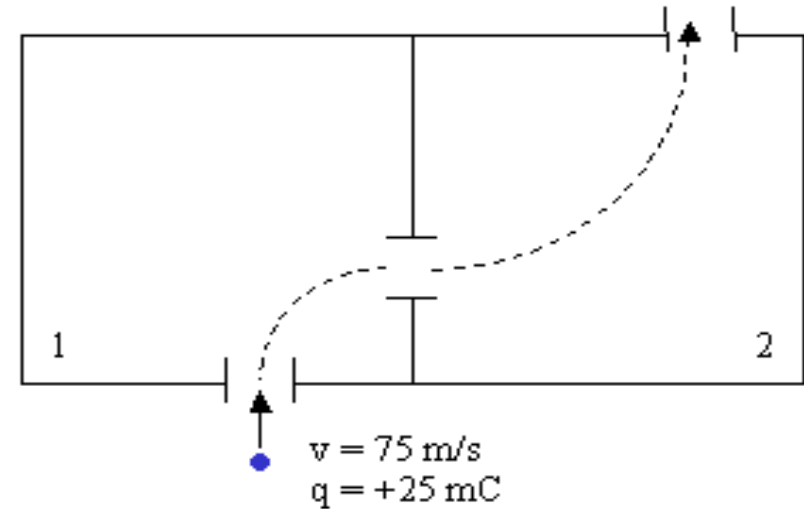


Motion in a Magnetic Field: Question 1 (N = 758)



CheckPoint 2c

The drawing below shows the top view of two interconnected chambers. Each chamber has a unique magnetic field. A positively charged particle is fired into chamber 1, and observed to follow the dashed path shown in the figure.



Compare the magnitude of the magnetic field in chamber 1 to the magnitude of the magnetic field in chamber 2

A. $|B_1| > |B_2|$

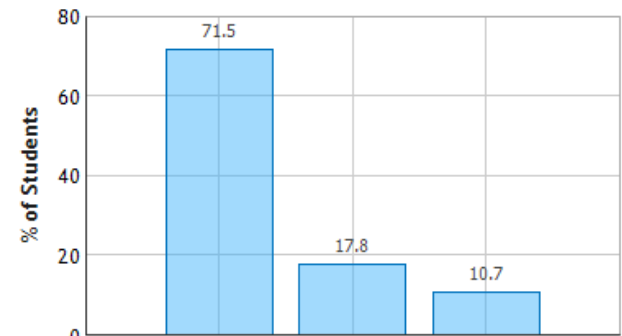
B. $|B_1| = |B_2|$

C. $|B_1| < |B_2|$

Observation: $R_2 > R_1$

$$R = \frac{mv}{qB} \longrightarrow |B_1| > |B_2|$$

Motion in a Magnetic Field: Question 3 (N = 758)

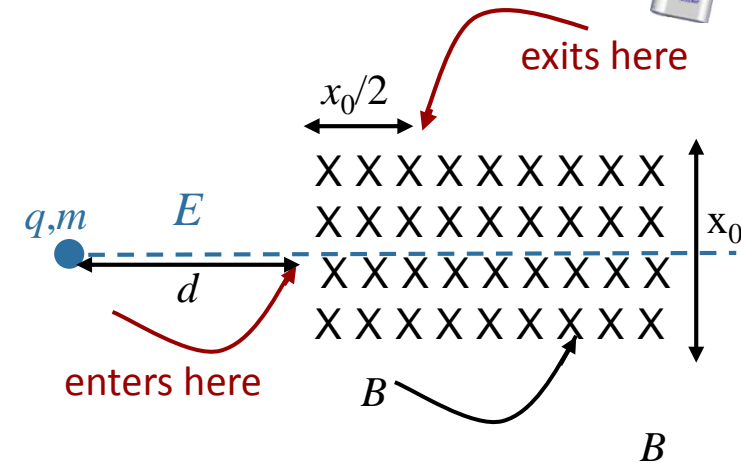


Calculation



A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.

What is B ?



Conceptual Analysis

What do we need to know to solve this problem?

A) Lorentz Force Law

$$(\vec{F} = q\vec{v} \times \vec{B} + q\vec{E})$$

B) E field definition

C) V definition

D) Conservation of Energy/Newton's Laws

E) All of the above

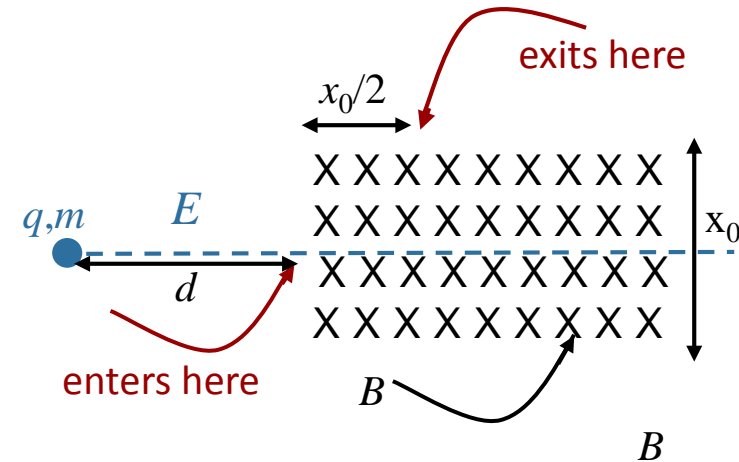
Absolutely ! We need to use the definitions of V and E and either conservation of energy or Newton's Laws to understand the motion of the particle before it enters the B field.

We need to use the Lorentz Force Law (and Newton's Laws) to determine what happens in the magnetic field.

Calculation

A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.

What is B ?



Strategic Analysis

Calculate v , the velocity of the particle as it enters the magnetic field

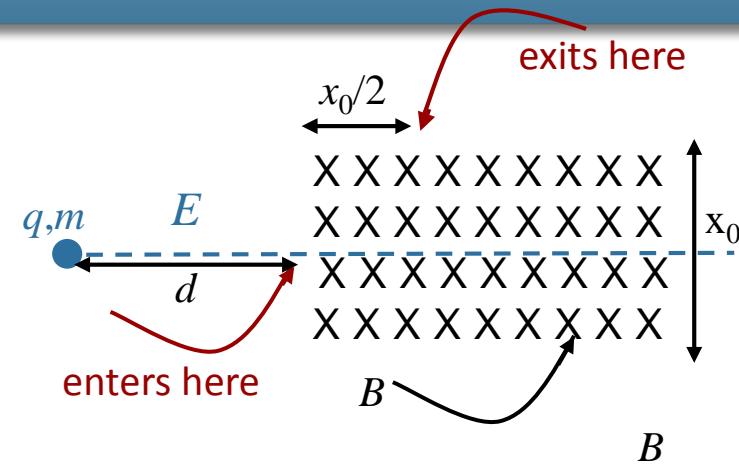
Use Lorentz Force equation to determine the path in the field as a function of B

Apply the entrance-exit information to determine B

Let's Do It !

Calculation

A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.



What is B ?

- What is the change in the particle's potential energy after travelling distance d ?

$$\Delta U = -qEd$$

(A)

$$\Delta U = -Ed$$

(B)

$$\Delta U = 0$$

(C)

- Why??

- How do you calculate change in the electric potential given an electric field?



$$\Delta V = -\int \vec{E} \cdot d\vec{\ell} = -Ed$$

- What is the relation between the electric potential and the potential energy?

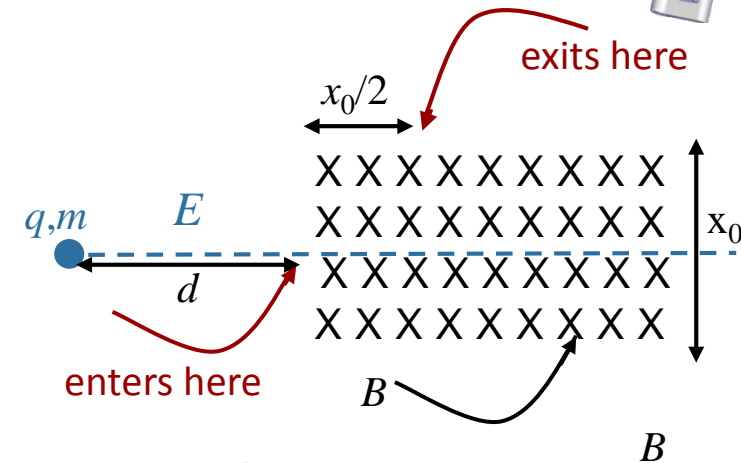


$$\Delta U = q\Delta V$$

Calculation



A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.



What is B ?

What is v_0 , the speed of the particle as it enters the magnetic field ?

$$v_o = \sqrt{\frac{2E}{m}}$$

A

$$v_o = \sqrt{\frac{2qEd}{m}}$$

B

$$v_o = \sqrt{2gd}$$

C

$$v_o = \sqrt{\frac{2qE}{md}}$$

D

$$v_o = \sqrt{\frac{qEd}{m}}$$

E

Why?

Conservation of Energy

Initial: Energy = $U = qV = qEd$

Final: Energy = $KE = \frac{1}{2} mv_0^2$

Newton's Laws

$a = F/m = qE/m$

$v_0^2 = 2ad$

$$\longrightarrow \frac{1}{2} mv_0^2 = qEd \longrightarrow v_o = \sqrt{\frac{2qEd}{m}}$$

$$\longrightarrow v_o^2 = 2 \frac{qE}{m} d \longrightarrow v_o = \sqrt{\frac{2qEd}{m}}$$

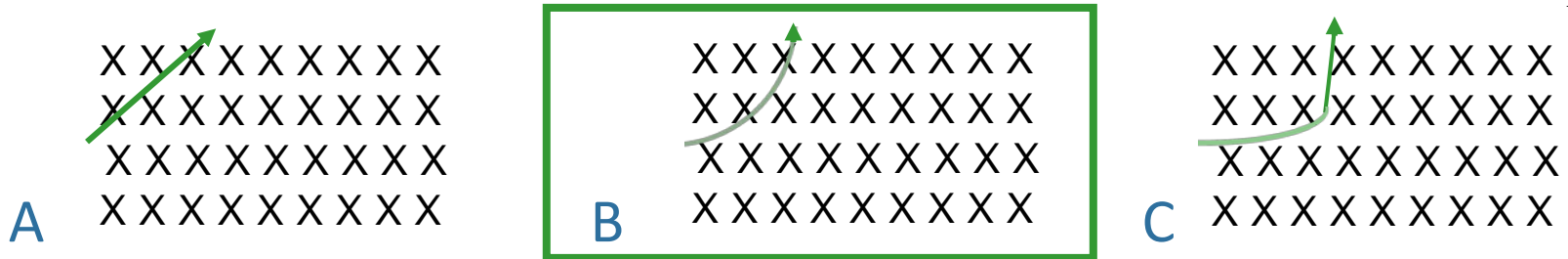
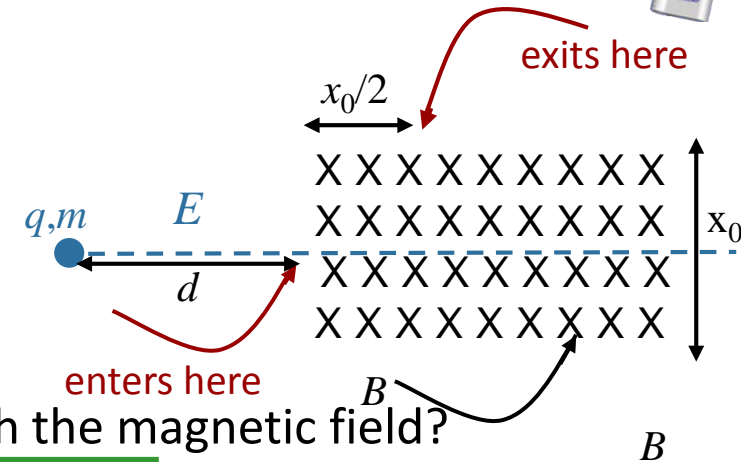
Calculation



A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.

What is B ? $v_o = \sqrt{\frac{2qEd}{m}}$

What is the path of the particle as it moves through the magnetic field?



Why?

Path is circle!

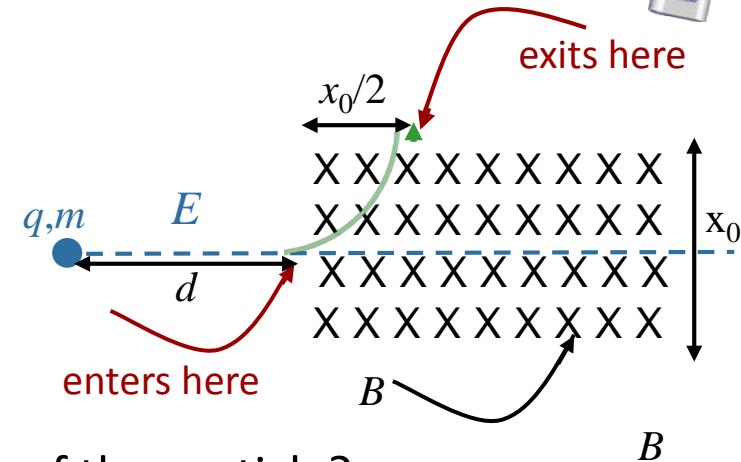
- Force is perpendicular to the velocity
- Force produces centripetal acceleration
- Particle moves with uniform circular motion

Calculation



A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.

What is B ? $v_o = \sqrt{\frac{2qEd}{m}}$



What can we use to calculate the radius of the path of the particle?

$$R = x_o$$

A

$$R = 2x_o$$

B

$$R = \frac{1}{2} x_o$$

C

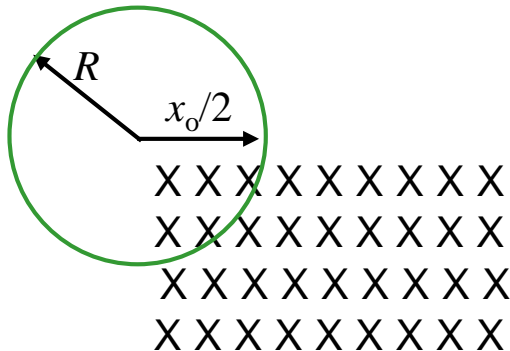
$$R = d + x_o / 2$$

D

$$R = d$$

E

Why?



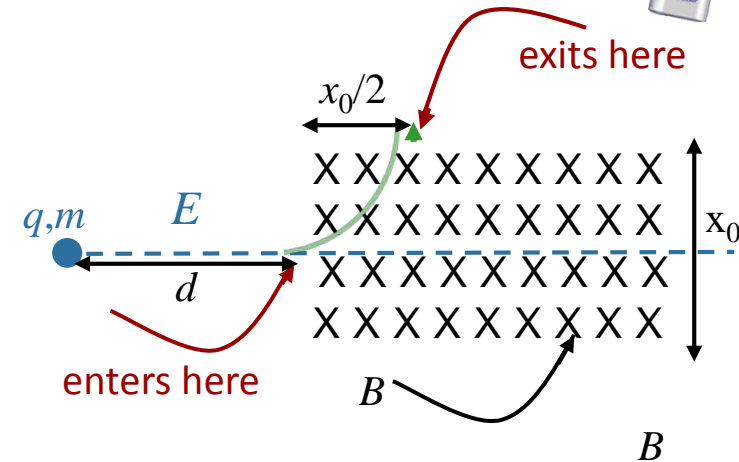
Calculation



A particle of charge q and mass m is accelerated from rest by an electric field E through a distance d and enters and exits a region containing a constant magnetic field B at the points shown. Assume q, m, E, d , and x_0 are known.

What is B ?

$$v_o = \sqrt{\frac{2qEd}{m}} \quad R = \frac{1}{2} x_0$$



$$B = \frac{2}{x_o} \sqrt{\frac{2mEd}{q}}$$

A

$$B = \frac{E}{v}$$

B

$$B = E \sqrt{\frac{m}{2qEd}}$$

C

$$B = \frac{1}{x_o} \sqrt{\frac{2mEd}{q}}$$

D

$$B = \frac{mv_o}{qx_o}$$

E

Why?

$$\begin{aligned} \vec{F} = m\vec{a} &\longrightarrow qv_o B = m \frac{v_o^2}{R} \longrightarrow B = \frac{m}{q} \frac{v_o}{R} \longrightarrow B = \frac{m}{q} \frac{2}{x_o} \sqrt{\frac{2qEd}{m}} \\ &\qquad\qquad\qquad \downarrow \\ &B = \frac{2}{x_o} \sqrt{\frac{2mEd}{q}} \end{aligned}$$