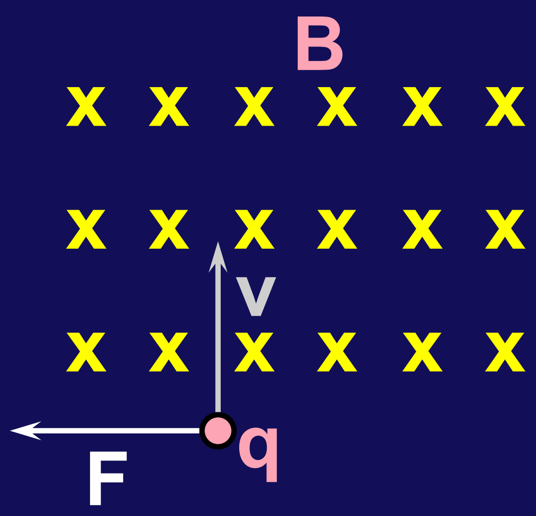
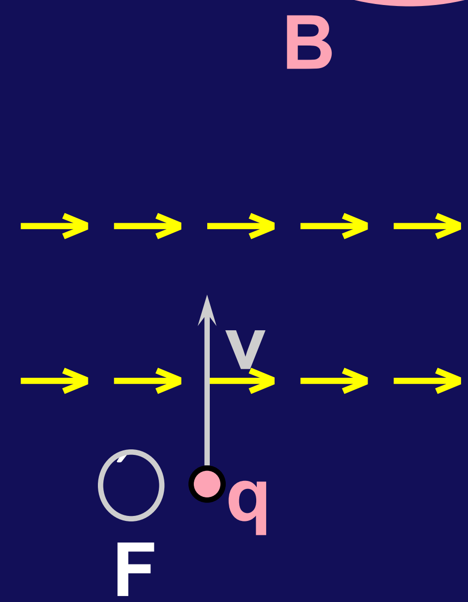
The Magnetic Force

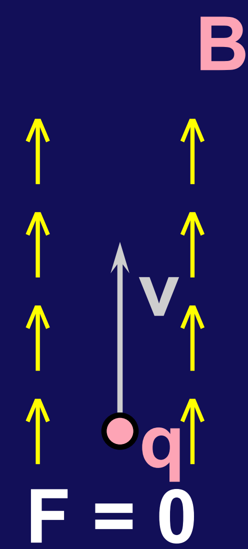
$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$

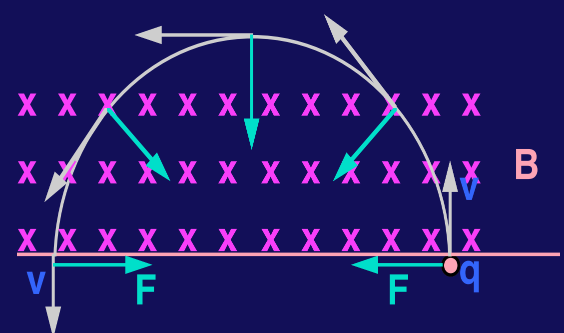
Comment:
I LOVE MAGNETISM

Comment:
What just happened....?









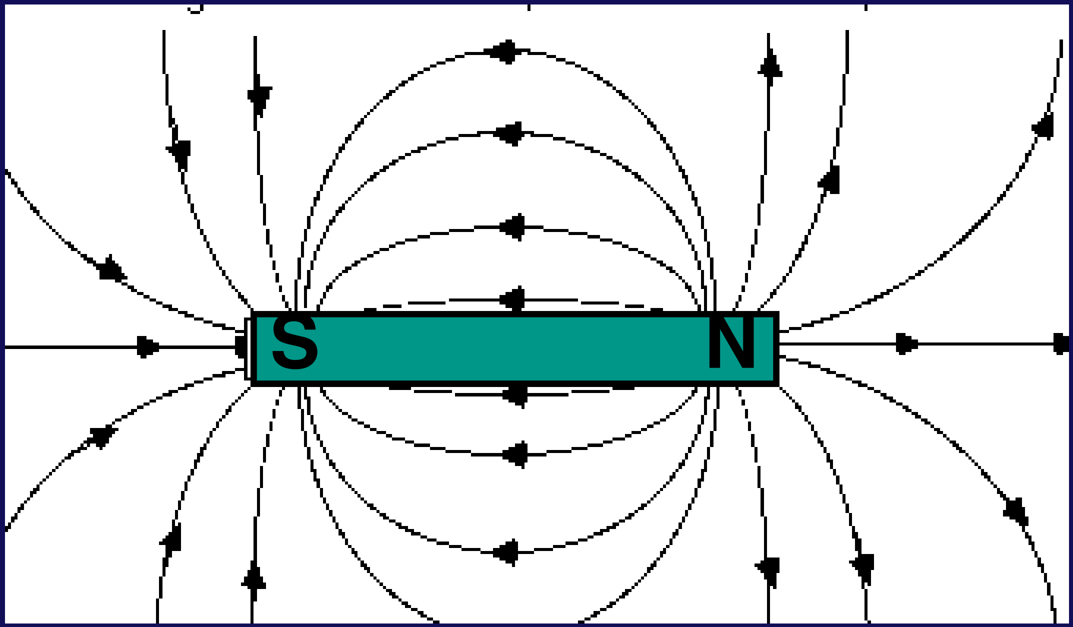
G. Rybka

Magnetic Phenomenon

- **Bar magnet ... two poles: N and S**

  Like poles repel; Unlike poles attract.

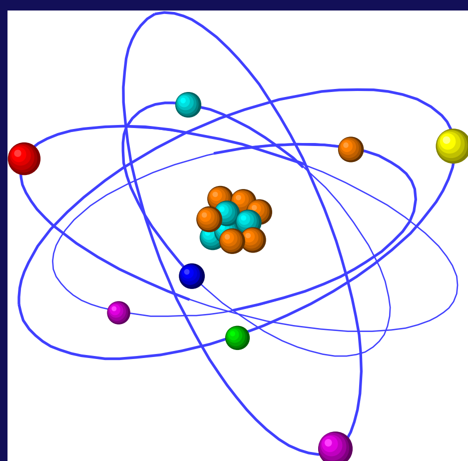
- **Magnetic Field lines: (defined in same way as electric field lines, direction and density)**



Looks just like the electric dipole

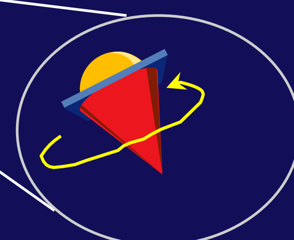
Source of Magnetic Fields?

- **Answer:** electric charge in motion!
- Understanding source of field by bar magnet lies in understanding currents at atomic level within bulk matter.



Orbits of electrons about nuclei

Intrinsic “spin” of electrons (more important effect)



Comment: “What is the difference between magnetic and electric fields? They seem similar, and although I understand that electric fields are created with charge distributions I don't understand how magnetic fields are generated with current”

The Magnetic Field is defined by the magnetic force on a test charge

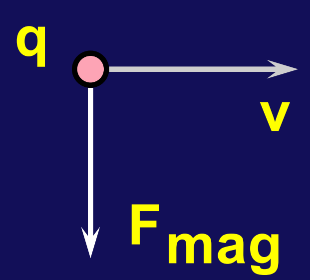
Same approach for electric field: $\vec{E} = \frac{\vec{F}}{q}$

- **What is "magnetic force"?**
- **How is it distinguished from "electric" force?**

Start with some observations: CRT deflection

- **Empirical facts:** **a) magnitude: μ to velocity of q**

  b) direction: ⊥ to direction of q

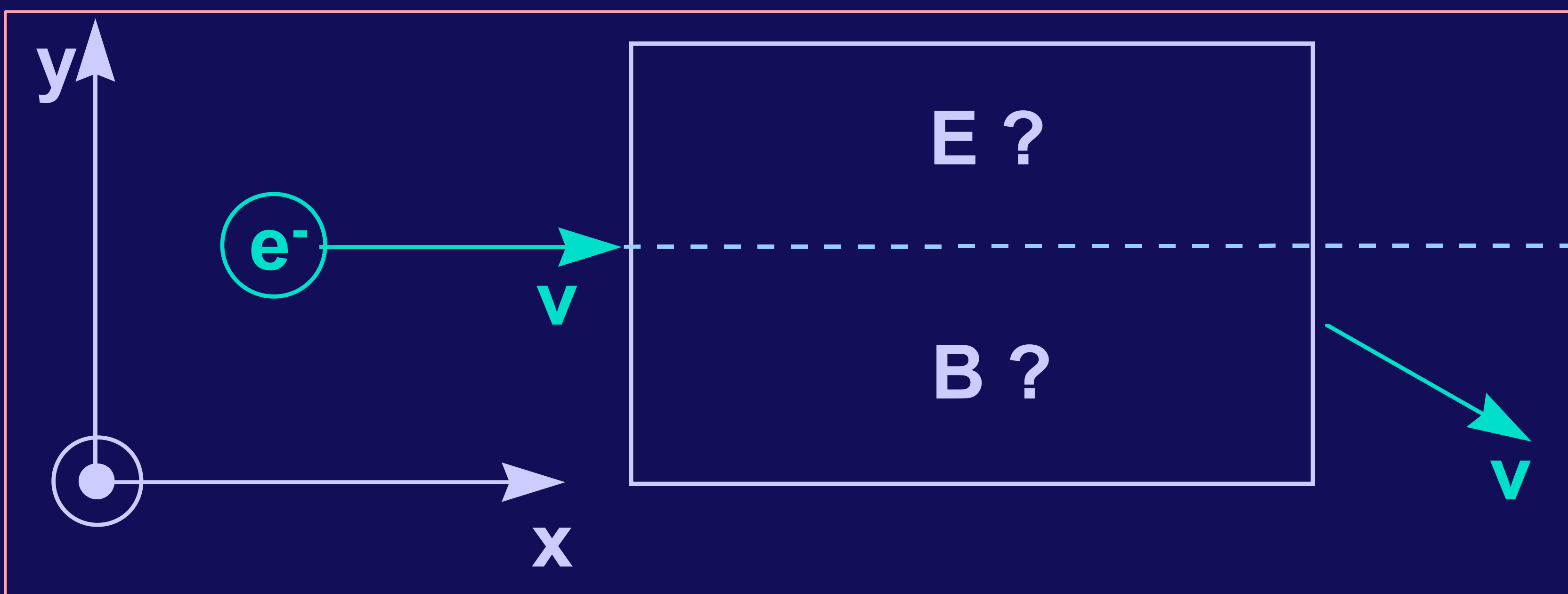


Clicker

An electron enters a region of space with speed v and exits the region as shown with the same speed (magnitude) v.

From this information, what can we infer about the E_y and B_z fields in the region?

A. Only E_y exists
B. Only B_z exists
C. Both E_y & B_z can exist



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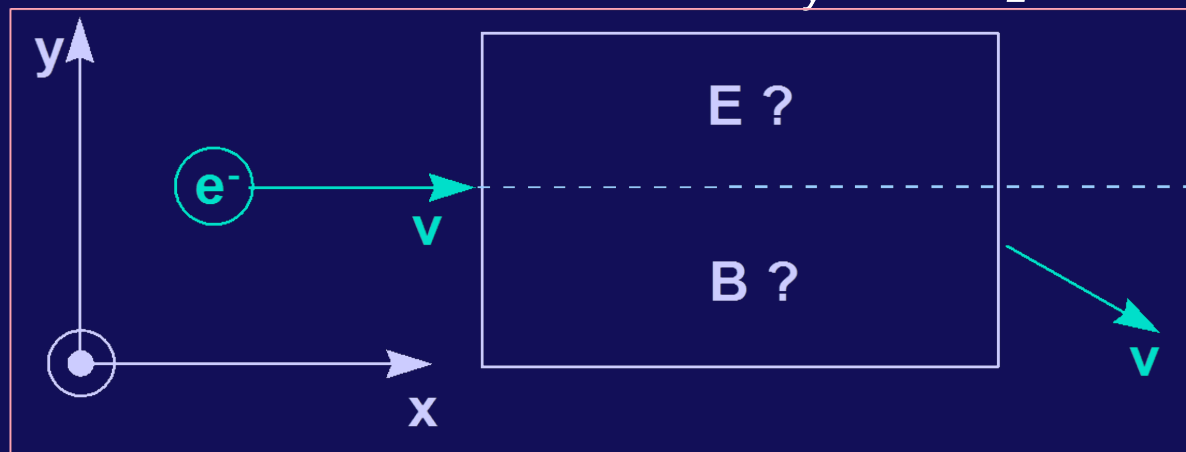


A. Only E_y exists

B. Only B_z exists

C. Both E_y & B_z can exist

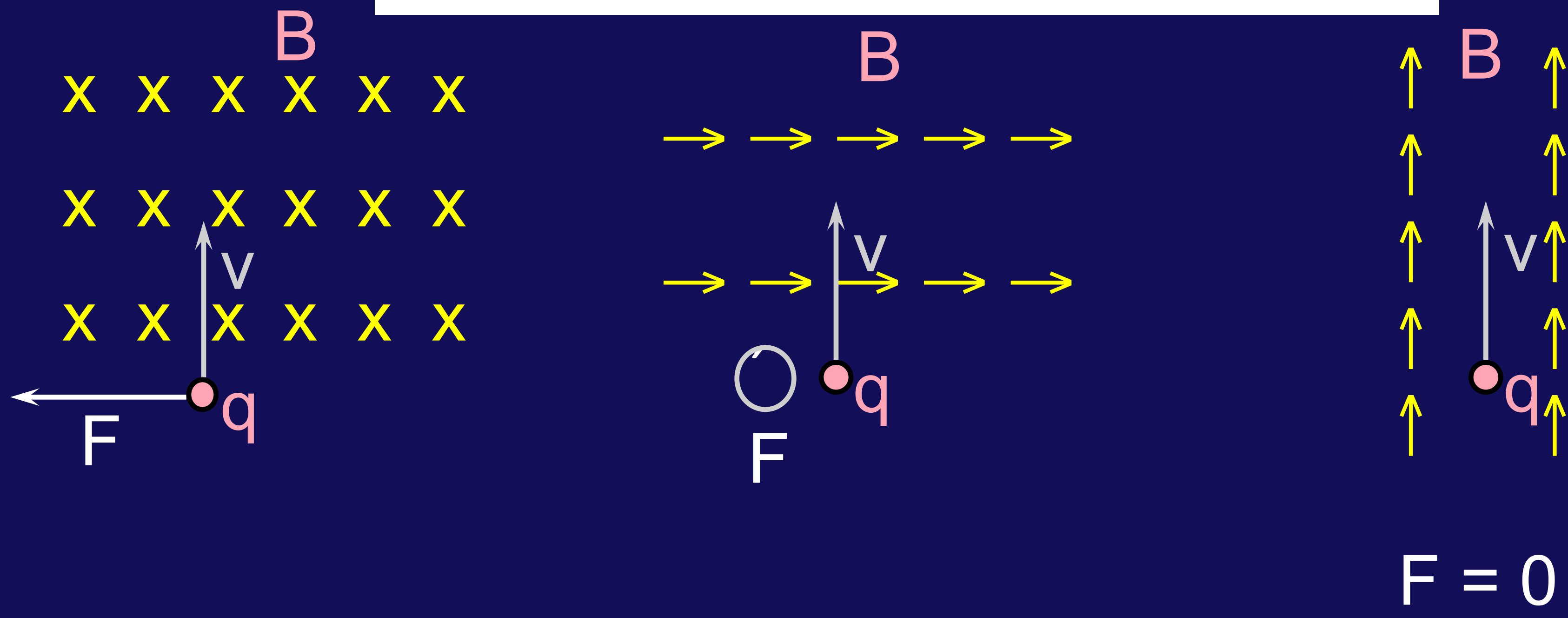
- If E_y exists: Force $F_y = q\,E_y = ma_y$ will *accelerate* charge in y direction
- The x velocity is unchanged. The y velocity is new
- Superposition: overall speed is increasing.
- Therefore: NO E_y possible

- How about B_z ?
- Produces force on electron in x-y plane, perpendicular to v.
- Therefore, B_z will NOT change the speed.
- But it will change the direction of q.
- B_z exists in this example.

Lorentz Force

- The force F on a charge q moving with velocity v through a region of space with electric field E and magnetic field B is given by:

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



Cross Product Review

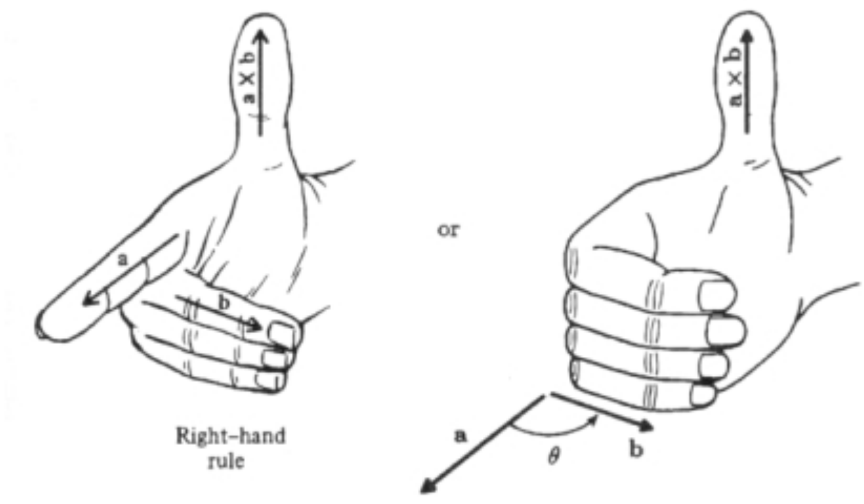
Cross Product different from Dot Product

- **A** · **B** is a scalar; **A x B** is a vector
- **A** · **B** proportional to the component of **B** parallel to **A**
- **A x B** proportional to the component of **B** perpendicular to **A**

Definition of **A x B**

Magnitude: **ABsinθ**

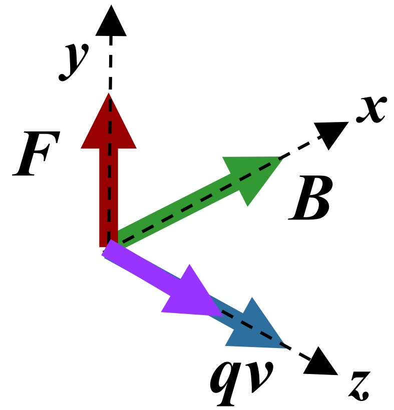
- Direction: perpendicular to plane defined by **A** and **B** with sense given by **right-hand-rule**

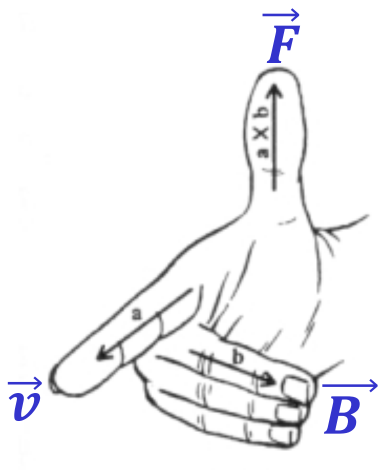


Remembering Directions: The Right Hand Rule

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

1. 1st Finger in direction of $\vec{v}$
2. Curl other fingers in direction of $\vec{B}$
3. Thumb points in direction of $\vec{F}$

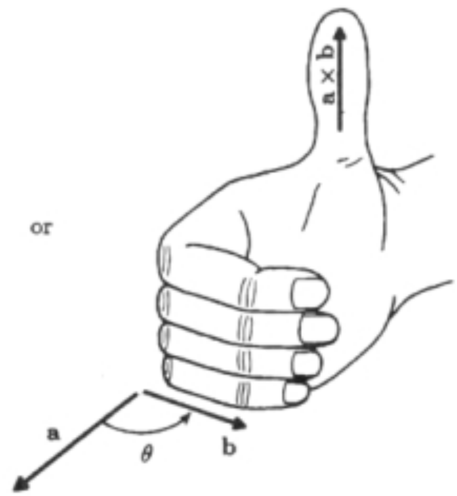




Right-hand rule

1. Point Fingers in direction of $\vec{v}$
2. Curl all fingers in direction of $\vec{B}$
3. Thumb points in direction of $\vec{F}$

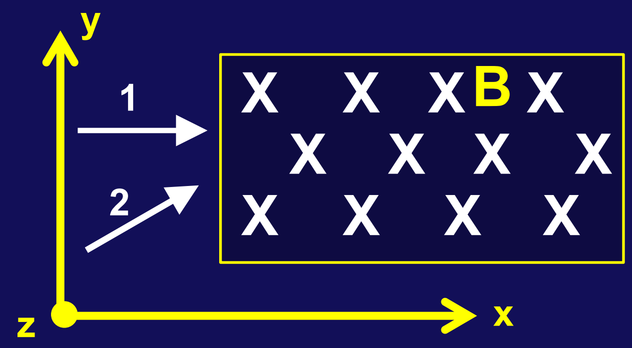
or



Clicker

Two protons each move at speed v toward a region of space which contains a constant B field in the –z direction.

- *What is the relation between the magnitudes of the forces on the two protons in the magnetic field region?*

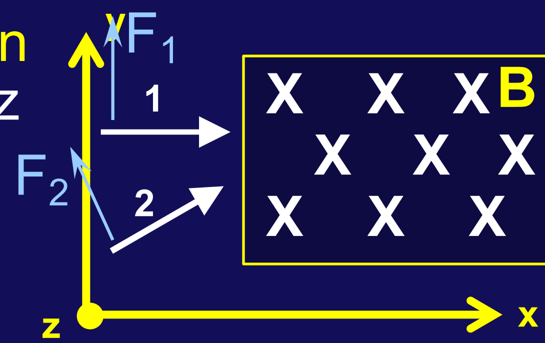


(a) $F_1 < F_2$ (b) $F_1 = F_2$ (c) $F_1 > F_2$

- The magnetic force is given by: $\vec{F} = q\vec{v} \times \vec{B} \Rightarrow |F| = qvB\sin\theta$
- In both cases the angle between v and B is 90° Therefore $F_1 = F_2$.

Clicker

Two protons each move at speed v toward a region of space which contains a constant B field in the –z direction.



What is F_{2x}, the x-component of the force on the second proton?

(a) $F_{2x} < 0$ (b) $F_{2x} = 0$ (c) $F_{2x} > 0$

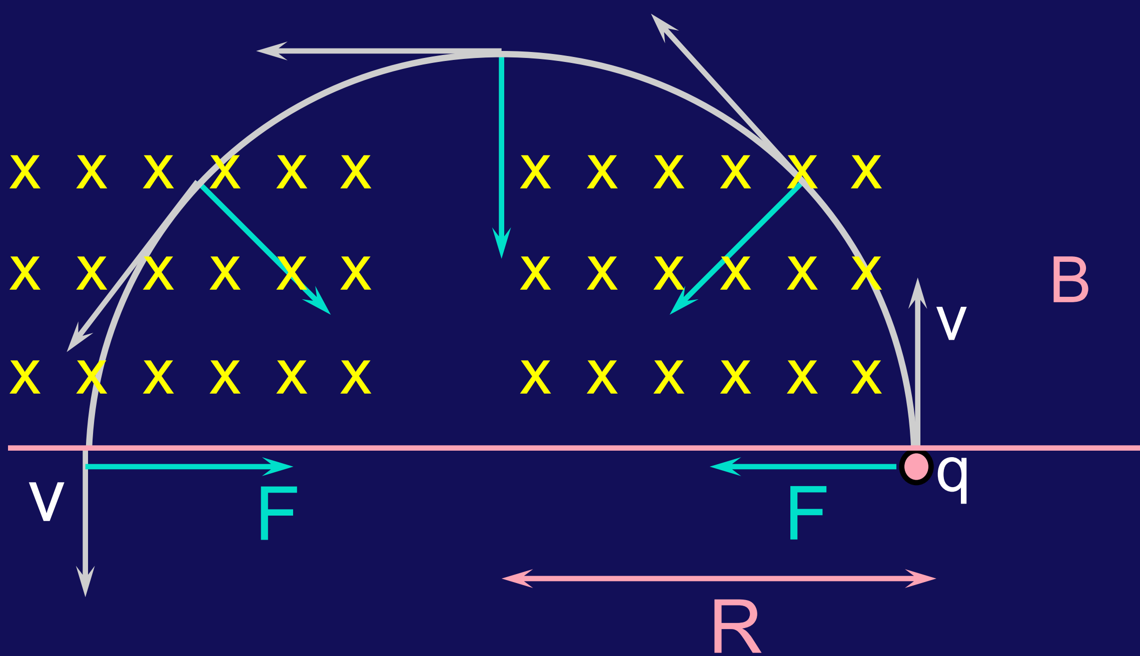
- To determine the direction of the force, we use the right-hand rule.

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

- As shown in the diagram, $F_{2x} < 0$.

Trajectory in Constant B Field

- Suppose charge q enters B field with velocity v as shown below. What will be the path q follows?



- Force is always ⊥ to velocity and B. What is path?
  - Path will be circle. F will be the centripetal force needed to keep the charge in its circular orbit. Calculate R:

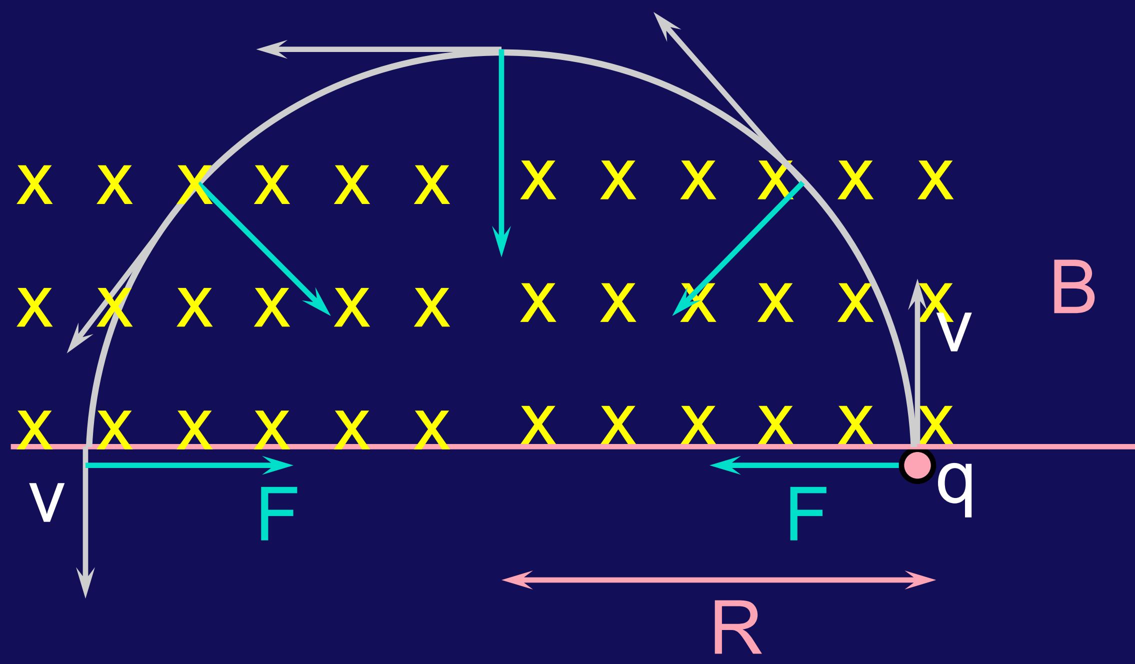
Radius of Circular Orbit

- Lorentz force:

$$F = qvB$$

- centripetal acc:

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



- Newton's 2nd Law:

$F = ma$ Þ $qvB = m\frac{v^2}{R}$

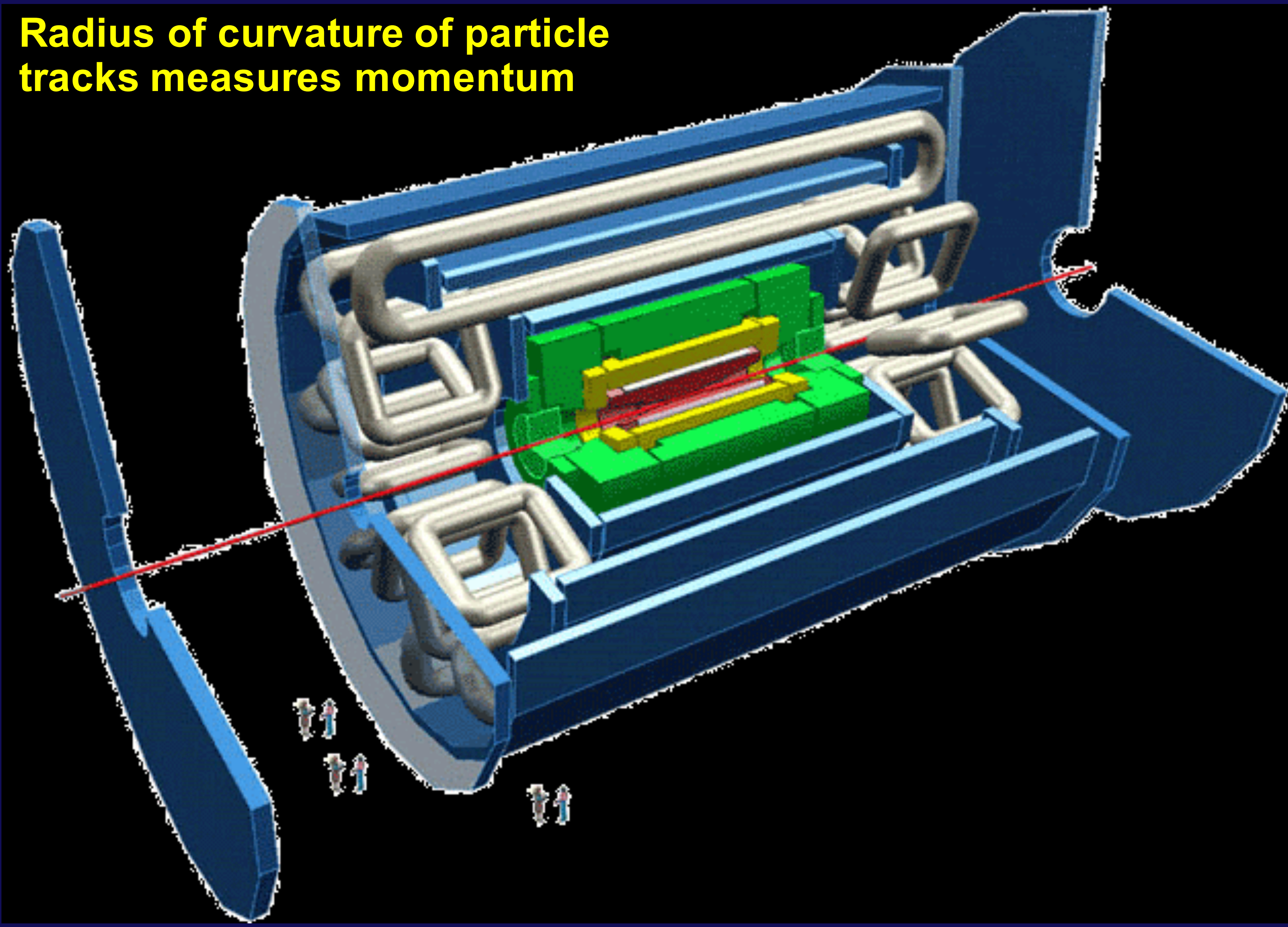
This is momentum

Þ $$R = \frac{mv}{qB}$$

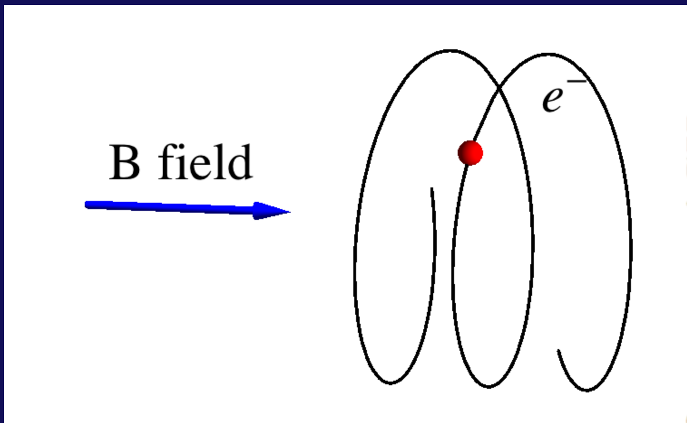
This is an important result, with useful experimental consequences !

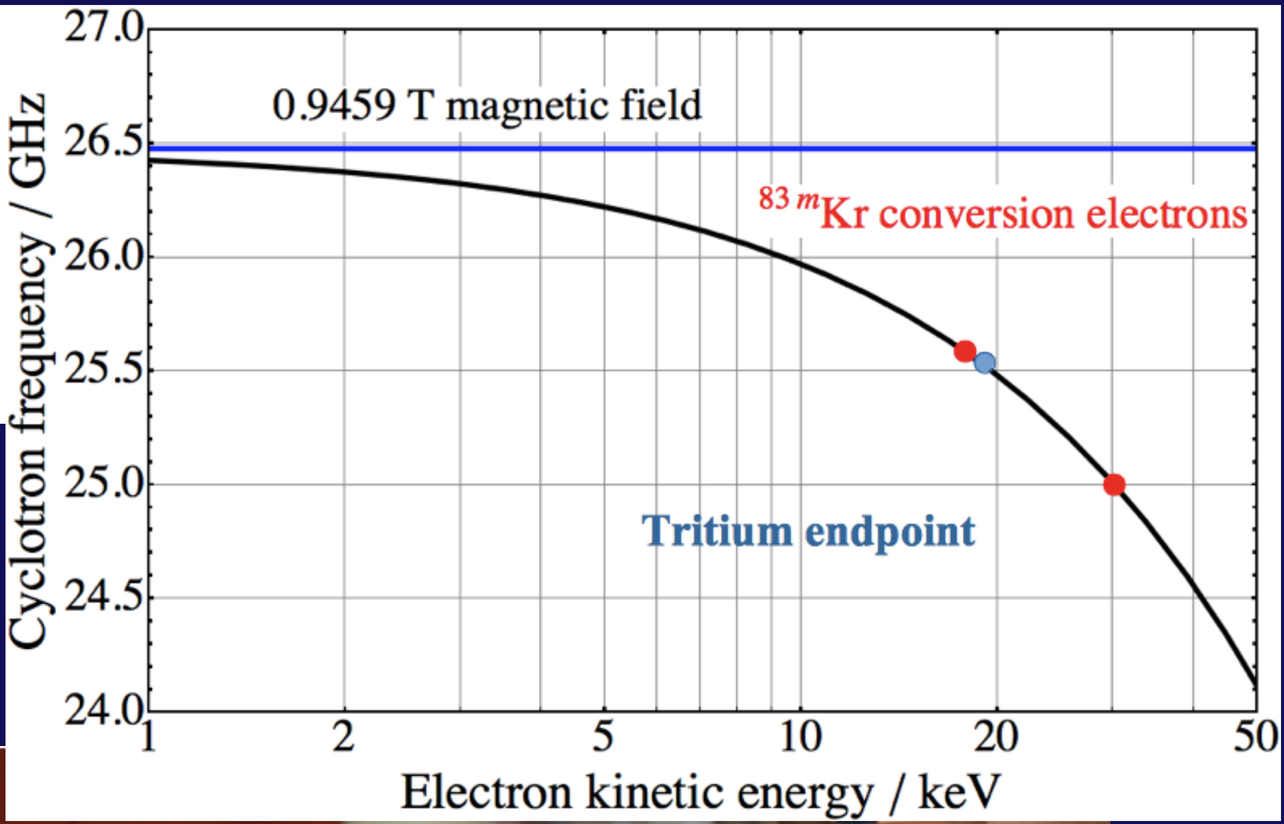
ATLAS detector at CERN

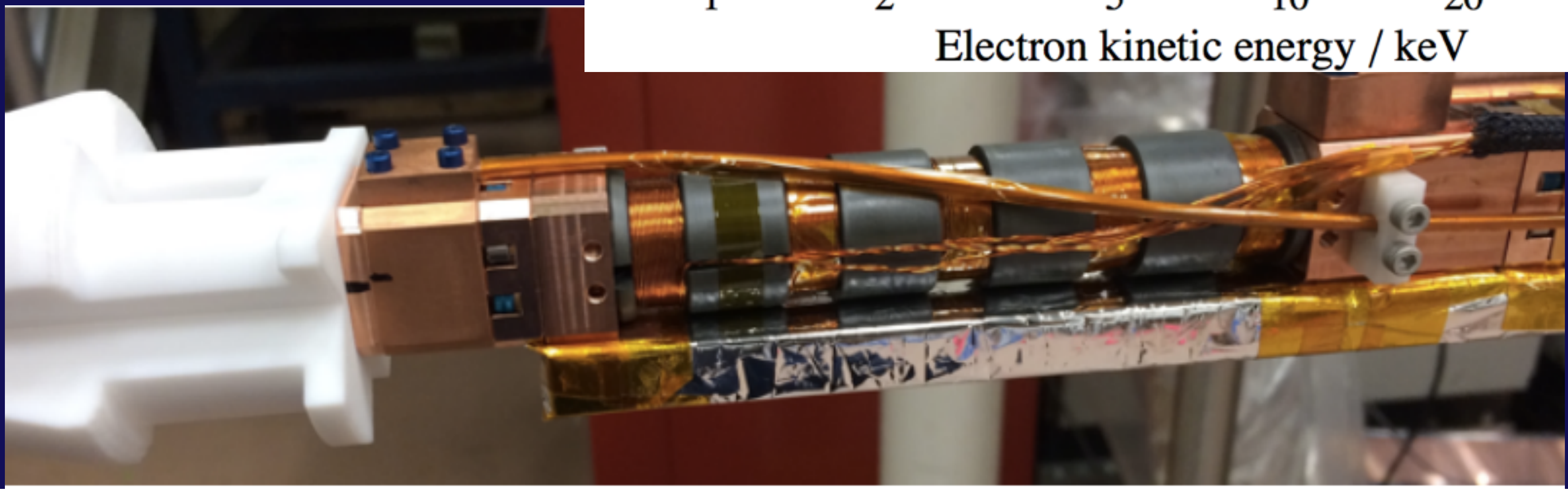
Radius of curvature of particle tracks measures momentum



Project 8 Experiment at UW

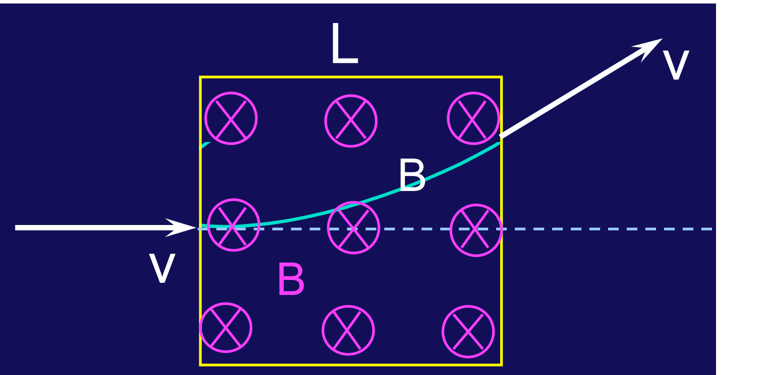




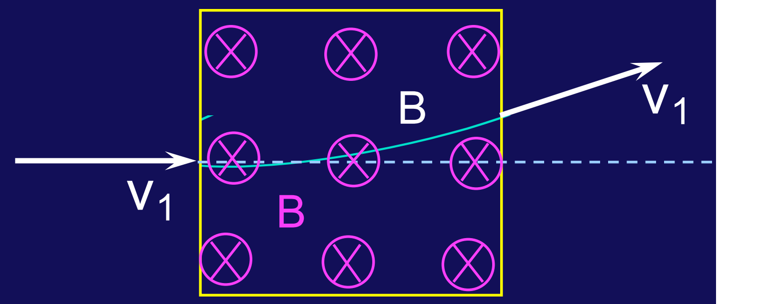


Clicker

A proton, moving at speed v, enters a region of space which contains a constant B field in the –z direction and is deflected as shown.



Another proton, moving at $v_1 = 2v$, enters the same region of space and is deflected as shown.



Compare the work done by the magnetic field
W for v,
W_1 for v_1 to deflect the protons?

(a) $W_1 < W$ (b) $W_1 = W$ (c) $W_1 > W$

- Remember: work done W is defined as: $W \equiv \int \vec{F} \bullet d\vec{x}$
- Remember: magnetic force is always perpendicular to the velocity:

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

- Therefore: the work done is ZERO in each case: $\int \vec{F} \bullet d\vec{x} = \int \vec{F} \bullet \vec{v} dt = 0$

Prelecture Review Question

Particle A has twice the charge and 4 times the mass of particle B. Suppose A and B have the same kinetic energy K and move perpendicular to a constant magnetic field. Which particle moves in the smallest circle? Recall KE = $p^2/2m$.

A. Particle A moves in a smaller circle
B. Particle B moves in a smaller circle
C. Particles A and B move in circles of the same radius.

$$R = \frac{p}{qB}$$

KE $= p_A^2 / 8m = p_B^2 / 2m$

$\rightarrow p_A = 2p_B$

$R_A = p_A / q_A B = 2\, p_B / 2 q_B B = p_B / q_B B$

$R_B = p_B / q_B B$

} The same

Cross Product Practice

Protons (positive charge) coming out of screen

Magnetic field pointing down

What is direction of force on POSITIVE charge?

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

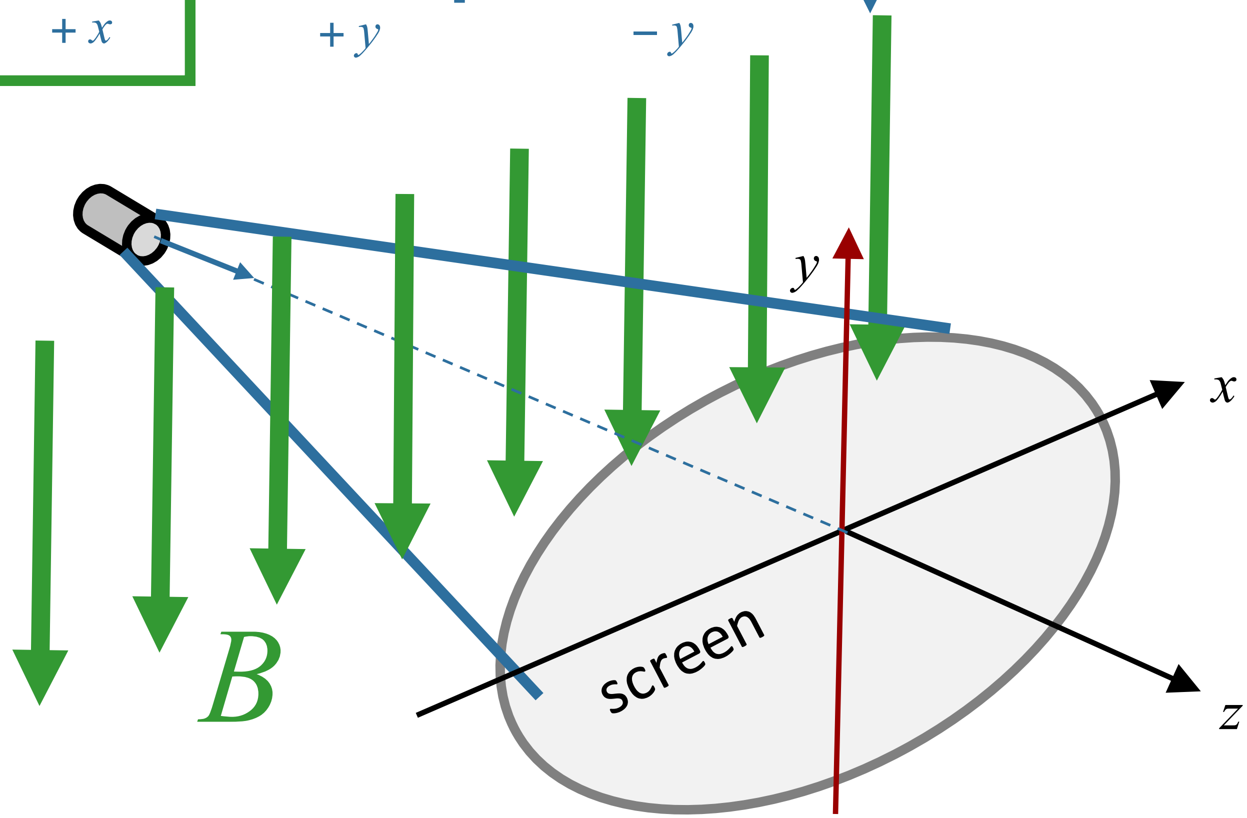
A) Left $-x$

B) Right $+x$

C) UP $+y$

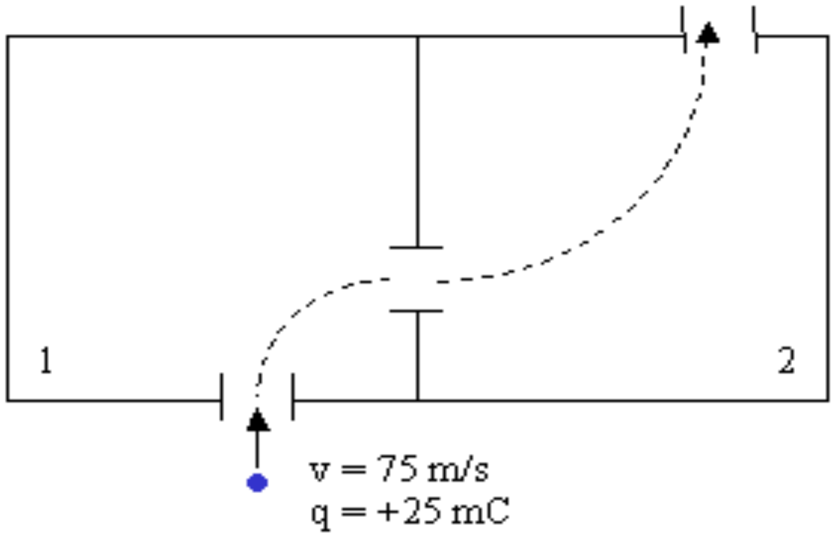
D) Down $-y$

E) Zero



CheckPoint 6

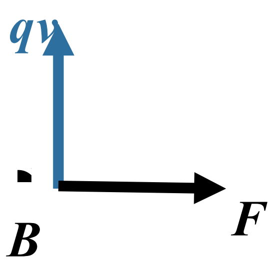
The drawing below shows the top view of two interconnected chambers. Each chamber has a unique magnetic field. A positively charged particle is fired into chamber 1, and observed to follow the dashed path shown in the figure.



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

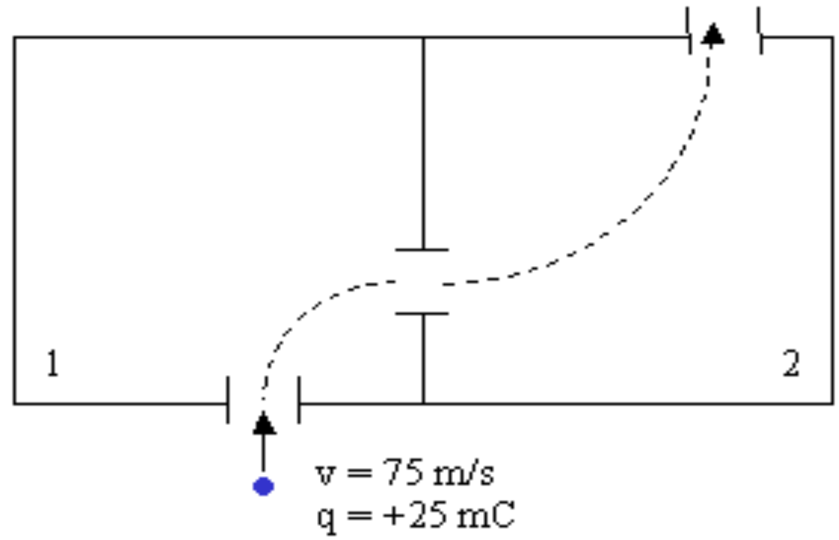
○ up ○ down ○ into the page ○ out of the page

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



CheckPoint 8

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

- ○ $|B_1| > |B_2|$
- ○ $|B_1| = |B_2|$
- ○ $|B_1| < |B_2|$

Observation: $R_2 > R_1$

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