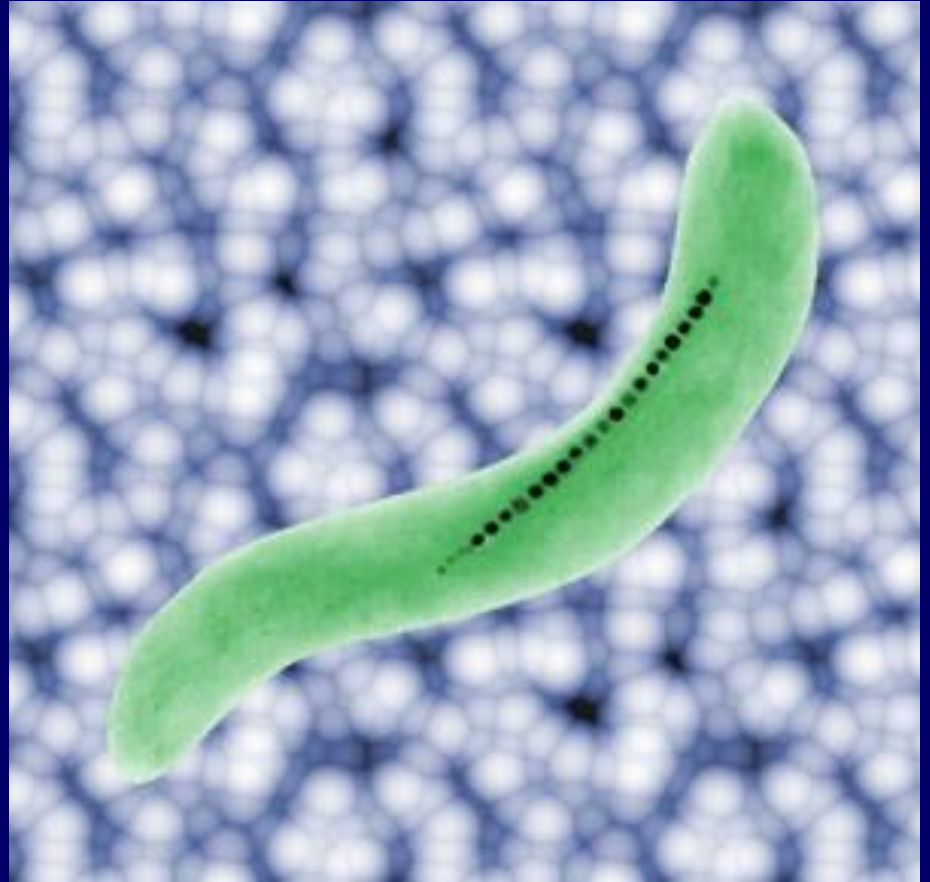


# Physics 102: Lecture 08

## Magnetism

This  
material is  
**NOT** on  
exam 1!



**Magnetotactic bacterium**

# Exam I, Monday, Feb 24, 7pm

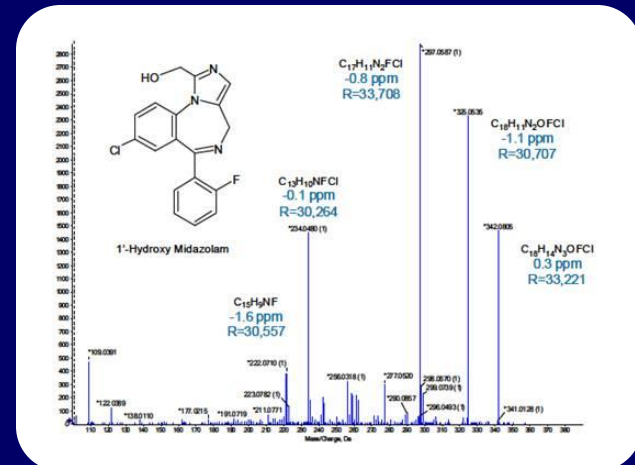
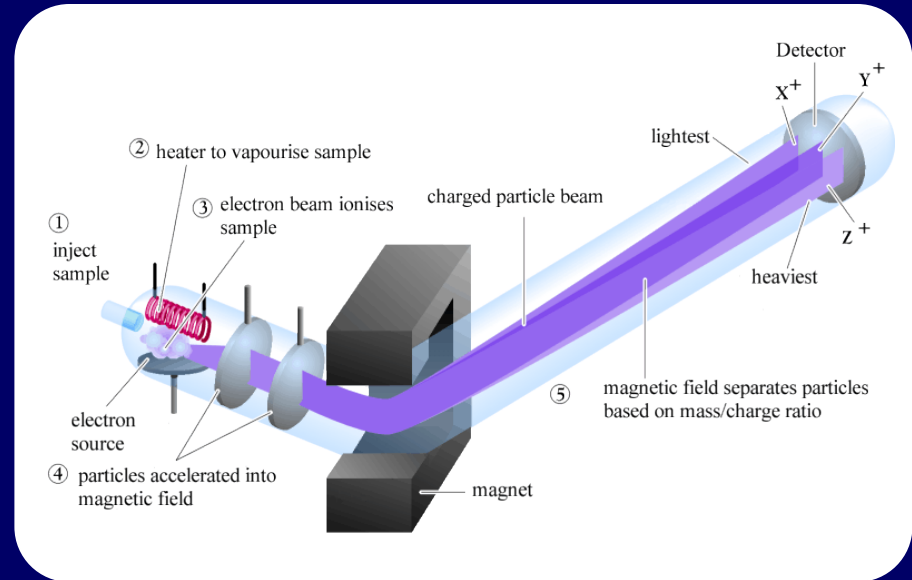
- What will exam cover?
  - Lectures 1 – 7 (Electric charge – RC circuits)
  - NOT TODAY'S LECTURE
- What do you need to bring?
  - Be sure to bring your ID and go to correct room
  - All you need is a #2 pencil, calculator, and your ID (NO cell phones, iPods, iPads, laptops, etc.)
- Conflict exams
  - You **MUST** register in **ADVANCE** in the gradebook!
- ByteShelf/SmartIllinois Unit 8
  - Fall 2013 Hour Exam 1 Solutions

# Exam I, Monday, Sept. 30, 7pm

- What can you expect on a Phys 102 exam?
  - 24–28 multiple choice questions (5-, 3-, 2-answer)
  - Mix of conceptual & computation
- How do you study for a Phys 102 exam?
  - Emphasize understanding concepts & problem solving, NOT memorization
  - Review lecture notes, problem solver summary
  - Understand formula sheet (i.e. when to use and when NOT to use an equation) & know what each symbol means
  - Do practice exam problems (time yourself!)
  - Go to office hours (there are extra office hours)

# Lecture Overview

- Magnetic fields
- Magnetic forces on moving charges
  - Direction: “Right hand rule”
  - Magnitude
  - Circular motion



Mass spectrometer

# Magnets & magnetic fields

- North Pole and South Pole

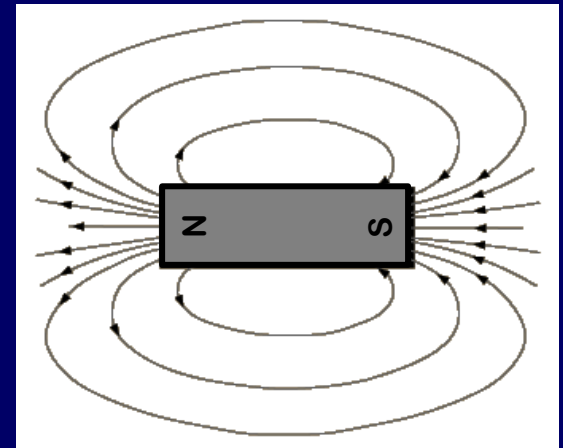
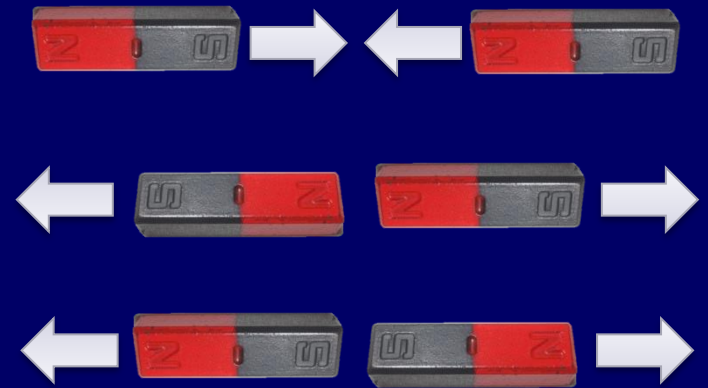
- Opposites Attract
- Likes Repel

- Magnetic Field  $B$

- Units = Tesla (T)
- Like  $E$ , vector at a location
- Points N to S

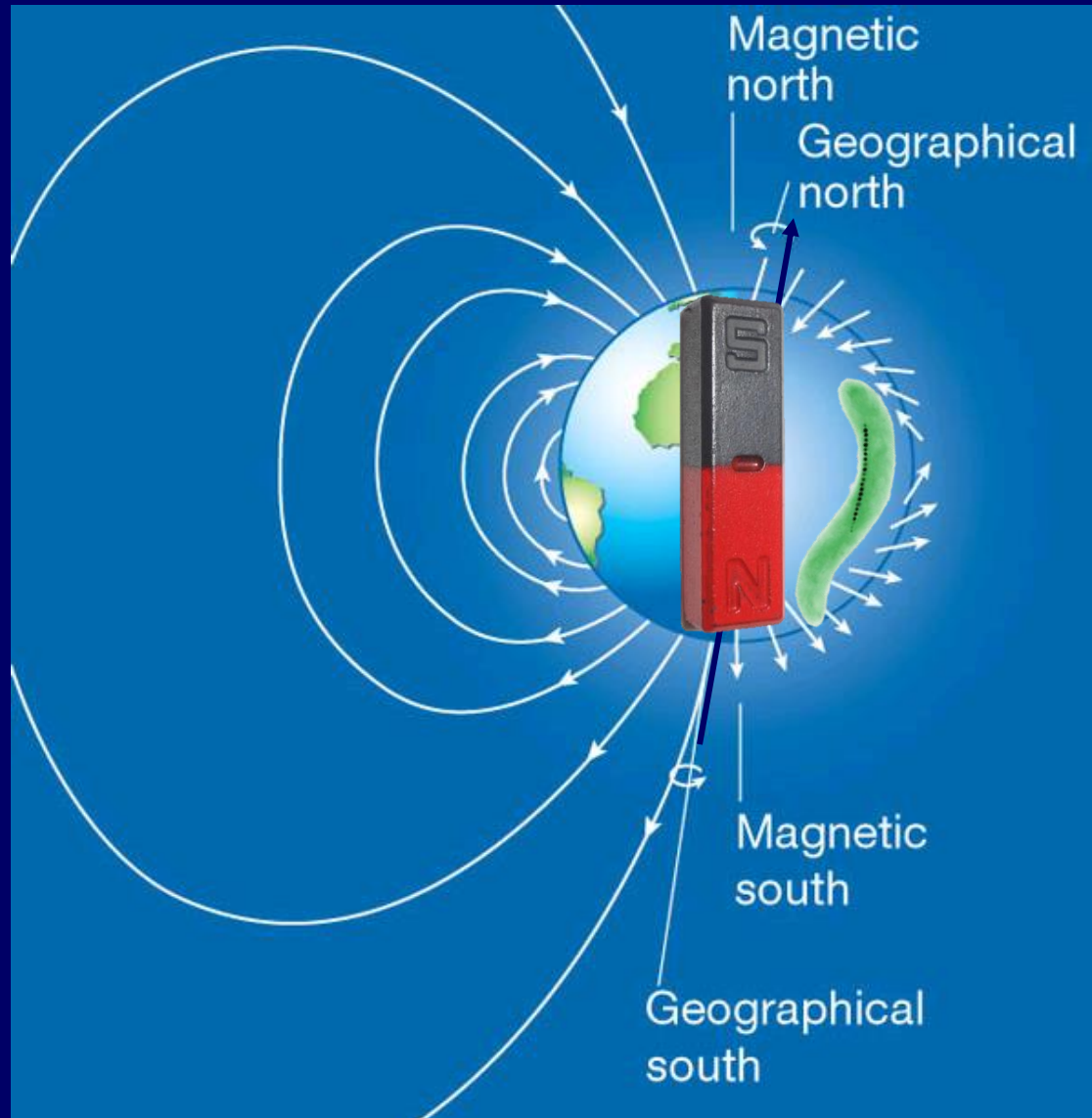
- Magnetic Field Lines

- Arrows give direction
- Density gives strength
- Looks like dipole!



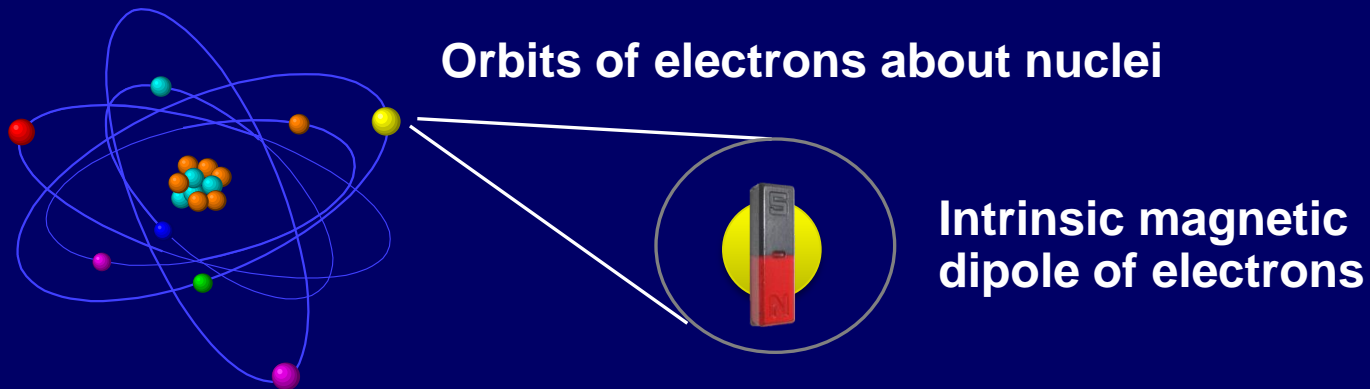
(Checkpoint 1.1)

# The Earth is a Magnet



# No Magnetic Charges

- N and S poles always go together
- Magnetic Fields are created by moving electric charge and intrinsic dipoles



# Magnetic Fields and Forces

- Magnetic field  $B$  exerts force on moving charge

Magnitude

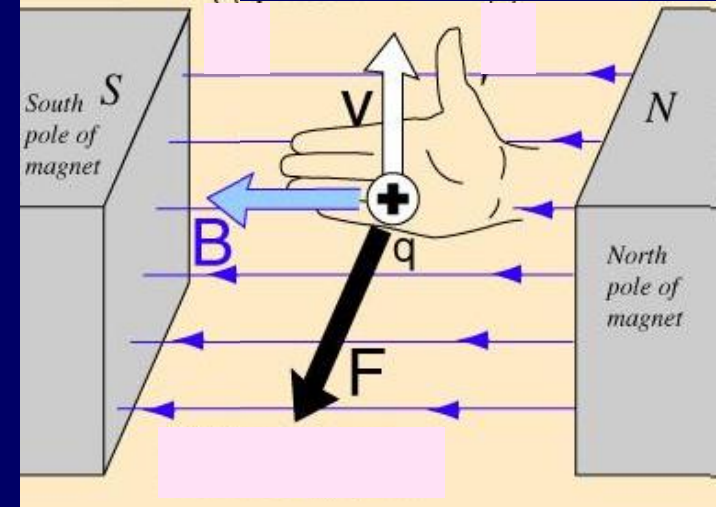
$$F = qvB \sin \theta$$

- Magnetic force is perpendicular to both  $B$  and  $v$

- “Right-hand rule” (RHR):

Direction

- Thumb of right hand along  $v$
- Fingers of right hand along  $B$
- Out-of-palm points
  - in the direction of  $F$  for + charge
  - opposite to  $F$  for – charge



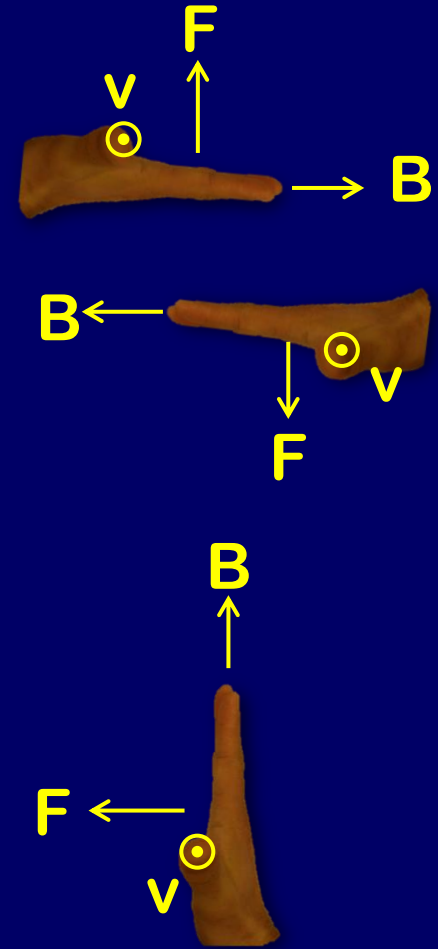
Note: there are different versions of RHR



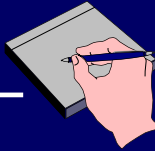


# ACT: Direction of Magnetic Force on + Moving Charge

Velocity	B	Force
out of page	right	up
out of page	left	down
out of page	up	

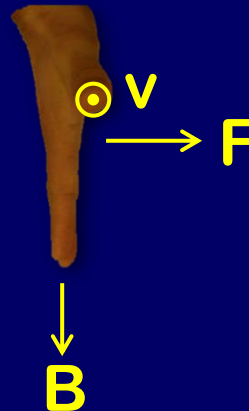


1) Up    2) Down    3) Right    4) Left    5) Zero



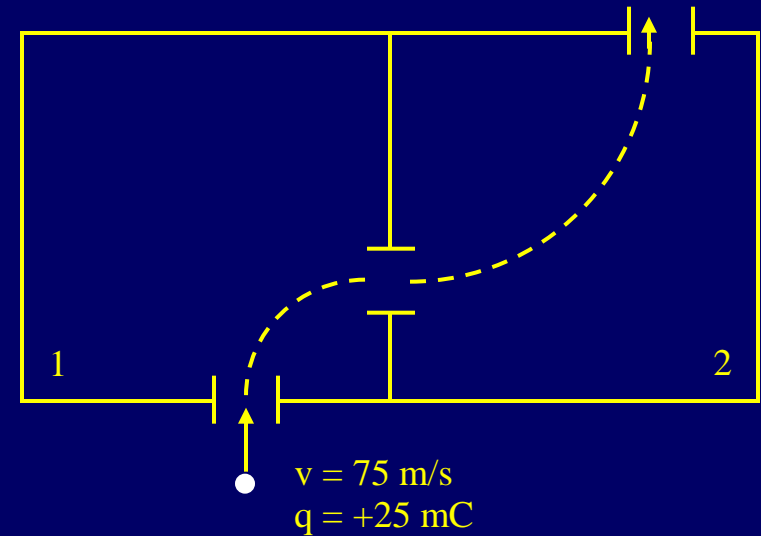
# Direction of Magnetic Force on + Moving Charges

Velocity	B	Force
out of page	right	up
out of page	left	down
out of page	up	left
out of page	down	right



# CheckPoint 2.1

Each chamber has a unique magnetic field. A **positively** charged particle enters chamber 1 with velocity 75 m/s up, and follows the dashed trajectory.



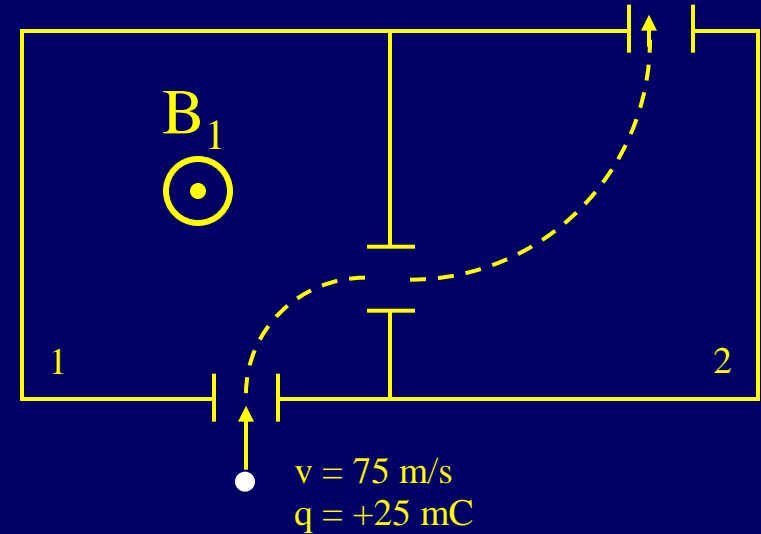
What is the direction of the **force** on the particle just as it enters region 1?

- 33% 1) up
- 4% 2) down
- 7% 3) left
- 45% 4) right
- 5% 5) into page
- 5% 6) out of page

**Particle is moving straight upwards then veers to the right.**

# CheckPoint 2.2

Each chamber has a unique magnetic field. A **positively** charged particle enters chamber 1 with velocity 75 m/s up, and follows the dashed trajectory.



What is the direction of the **magnetic field** in region 1?

16%

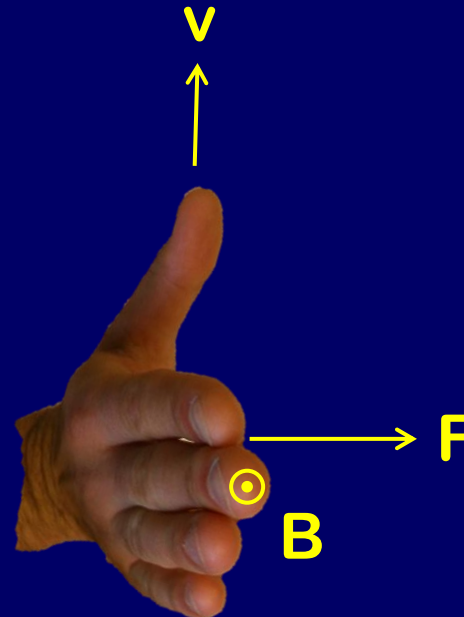
4% a) down

7% b) left

40% c) right

8% d) into page

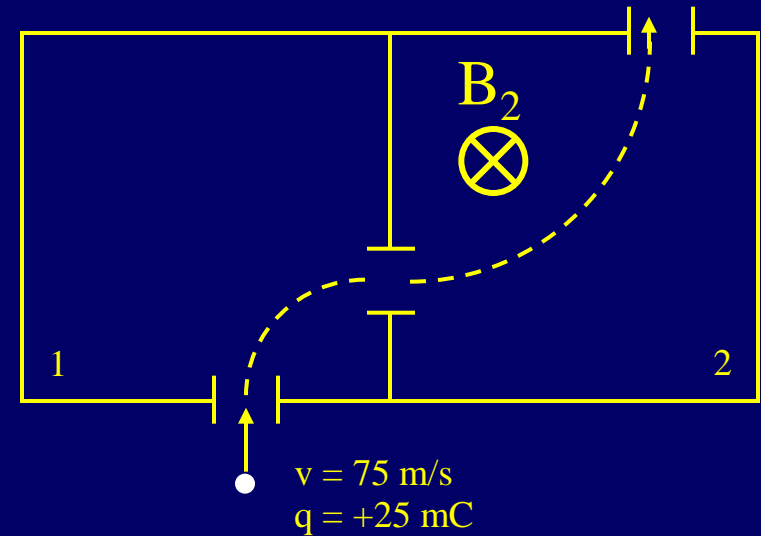
25% e) out of page





# ACT: 2 Chambers

Each chamber has a unique magnetic field. A **positively** charged particle enters chamber 1 with velocity 75 m/s up, and follows the dashed trajectory.



What is the direction of the magnetic field in region 2?

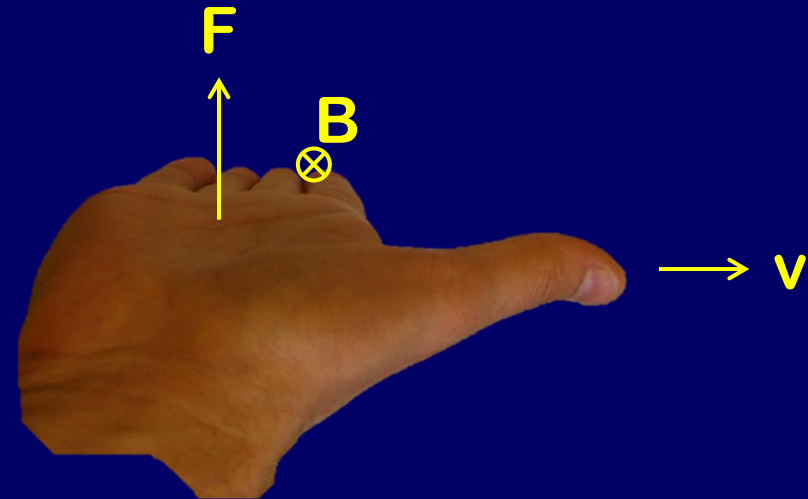
A) down

B) left

C) right

D) into page

E) out of page



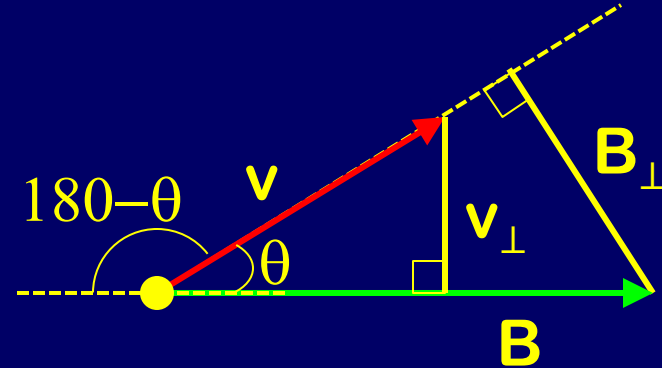
# Magnitude of Magnetic Force on Moving Charges



Force depends on magnitude of charge, velocity, and magnetic field

$$F = qvB \sin \theta$$

$$= qv_{\perp}B = qvB_{\perp}$$



Only component of  $v \perp$  to  $B$  (or  $B \perp$  to  $v$ ) matters

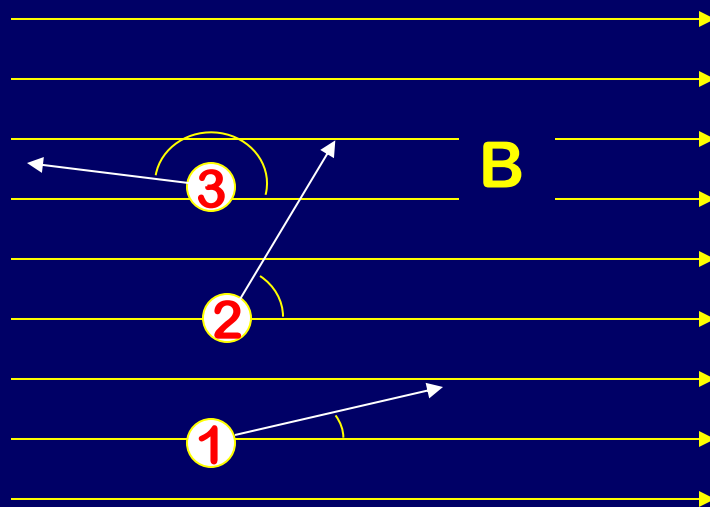
If  $v$  is parallel to  $B$  then  $F = 0$

Does not matter whether you use  $\theta$  or  $180 - \theta$

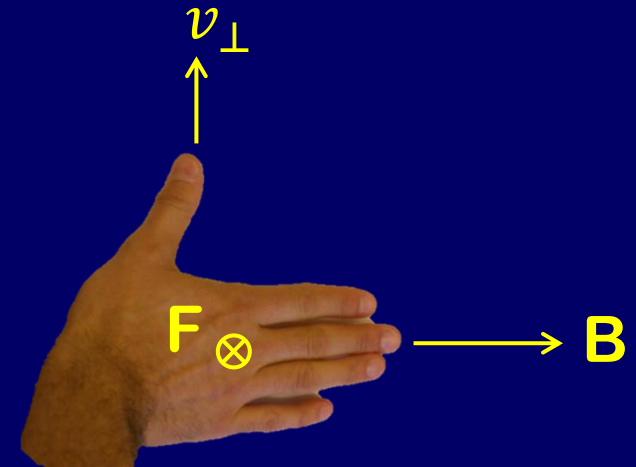


# ACT: Moving Charges

The three charges below have equal charge and speed, but are traveling in different directions in a uniform magnetic field.



$$F = qvB\sin(\theta)$$



1) Which particle experiences the greatest magnetic force?

- A) 1   **B) 2**   C) 3   D) All Same

2) The force on particle 3 is in the same direction as the force on particle 1.

- A) True**   B) False

# Comparison

## *Electric vs. Magnetic*

	Electric	Magnetic
Source:	Charges	Moving Charges
Act on:	Charges	Moving Charges
Magnitude:	$F = q E$	$F = q v B \sin(\theta)$
Direction:	Parallel to E	Perpendicular to v, B

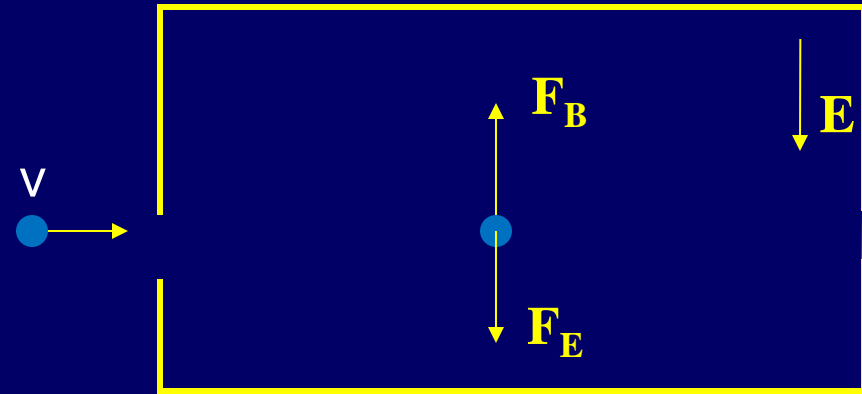


# Example

## Velocity Selector

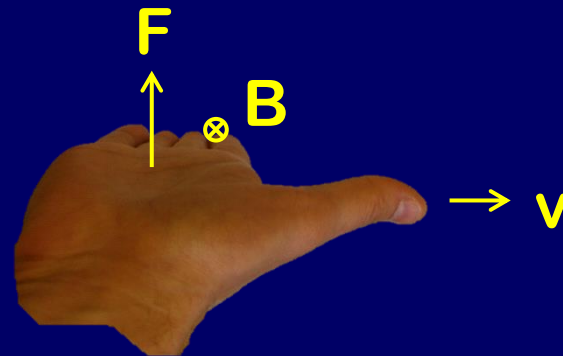


Determine magnitude and direction of magnetic field such that a *positively* charged particle with initial velocity  $v$  travels straight through and exits the other side.



Electric force is down, so need magnetic force up.

By RHR,  $B$  must be into page



For straight line, need  $|F_E| = |F_B|$

$$q E = q v B \sin(90)$$

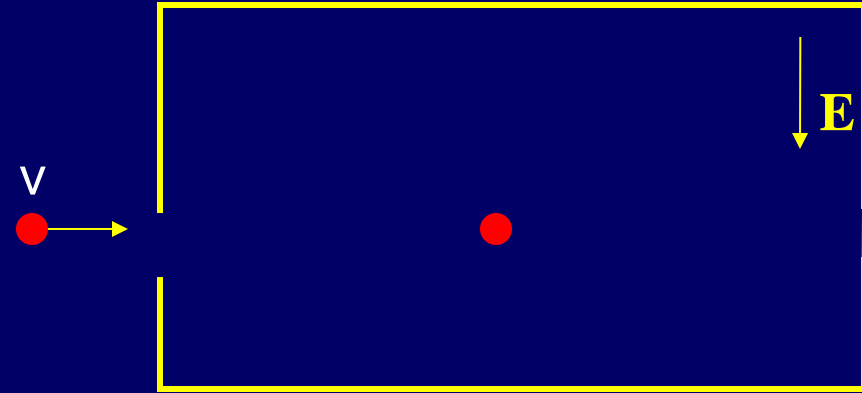
$$B = E/v$$

# Example

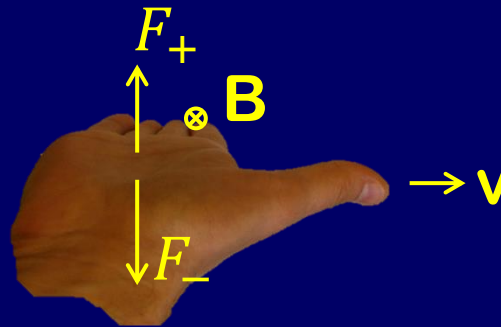
## Velocity Selector



Determine magnitude and direction of magnetic field such that a **negatively** charged particle with initial velocity  $v$  travels straight through and exits the other side.



## ACT: Velocity Selector



Use the RHR and invert the force for  $-$  charges

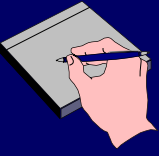
What direction should  $B$  point if you want to select **negative** charges?

A) Into Page

B) Out of page

C) Left

D) Right

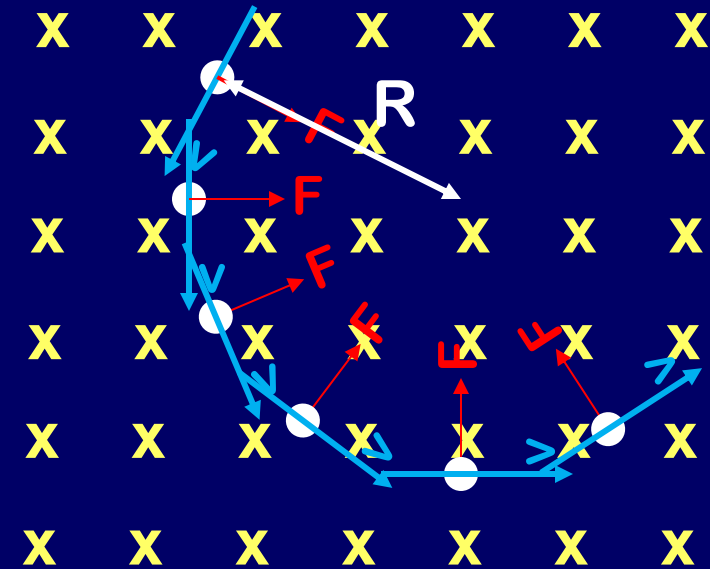


# Motion of $q$ in uniform B field

- Force is perpendicular to  $B, v$ 
  - Motion is circular
  - B does no work! ( $W = F d \cos \theta$ )
  - Speed is constant ( $W = \Delta K.E.$ )
- Solve for R:

Recall circular motion from Phys 101

$$F = m \frac{v^2}{R} = qvB \sin \theta \longrightarrow R = \boxed{\frac{m}{q}} \frac{v}{B}$$

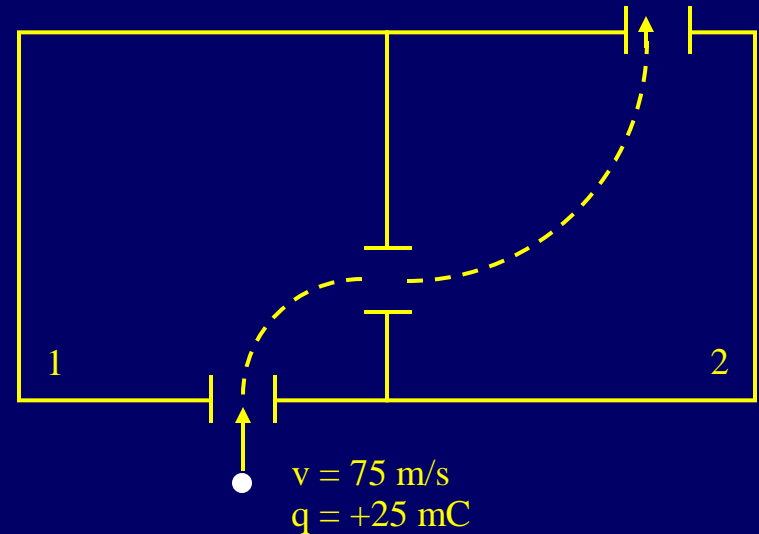


Uniform B into page

**Principle of a  
mass  
spectrometer!**

# Checkpoint 2.4

Each chamber has a unique magnetic field. A **positively** charged particle enters chamber 1 with velocity  $v_1 = 75 \text{ m/s}$  up, and follows the dashed trajectory.



**What is the speed of the particle when it leaves chamber 2?**

16% 1)  $v_2 < v_1$

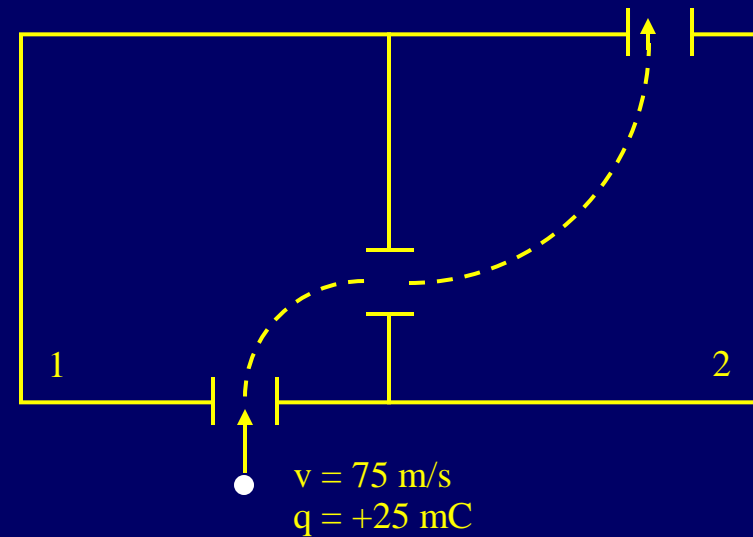
67% 2)  $v_2 = v_1$

17% 3)  $v_2 > v_1$

Magnetic force is always perpendicular to velocity, so it changes **direction**, not **speed** of particle.

# CheckPoint 2.6

Each chamber has a unique magnetic field. A **positively** charged particle enters chamber 1 with velocity  $v_1 = 75 \text{ m/s}$  up, and follows the dashed trajectory.



**Compare the magnitude of the magnetic field in chambers 1 and 2**

47% 1)  $B_1 > B_2$

36% 2)  $B_1 = B_2$

17% 3)  $B_1 < B_2$

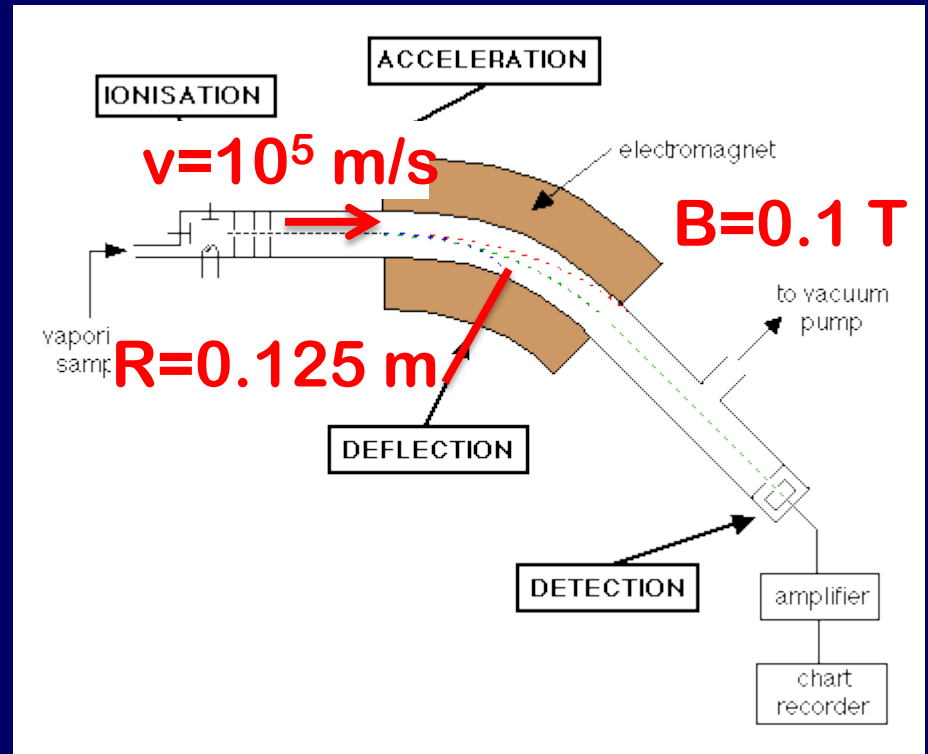
$$R = \frac{mv}{qB}$$

**Larger  $B$ , greater force, smaller  $R$**

# Example

## Mass Spectrometer

In this mass spectrometer, particles with charge  $1.6 \times 10^{-19} \text{ C}$  must go through the magnet around a  $0.125 \text{ m}$  radius of curvature after being accelerated to  $10^5 \text{ m/s}$  in order to be detected. The magnetic field is  $0.1 \text{ T}$ . What is the mass of detected particles?



$$R = \frac{mv}{qB} \rightarrow m = \frac{qBR}{v} = 2 \times 10^{-26} \text{ kg} = 12 \text{ amu}$$

$$\text{amu} = 1.67 \times 10^{-27} \text{ kg} \quad \mathbf{^{12}C^+}$$

# Summary

- We learned about magnetic fields  $B$
- We learned about magnetic forces on moving charged particles

$$F = qvB \sin \theta$$

$$R = \frac{m v}{q B}$$

