



# Phys 102 – Lecture 10

**Magnetic fields & forces**

Office Hours: Prof. Yoshi Oono  
3 - 4PM 222 Loomis

# *Today we will...*

- Learn about the magnetism

Magnetic field  $B$

Magnetic force  $F$  on moving charge

- Apply these concepts!

Charged particle motion in a magnetic field

Mass spectrometry

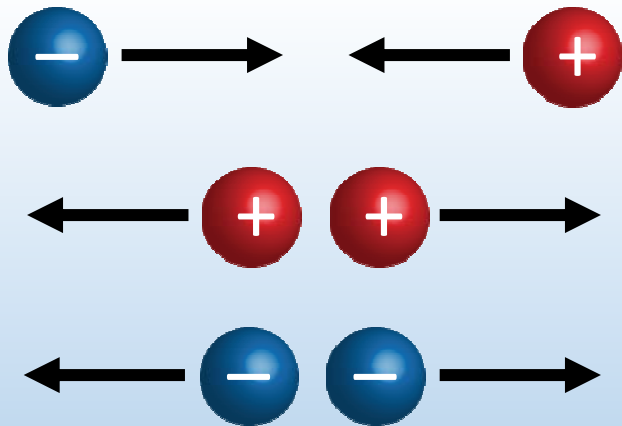
Earth's magnetic field & northern/southern lights

# *Electricity vs. magnetism*

- Electricity

Positive & negative charge

Opposite charges attract, like charges repel

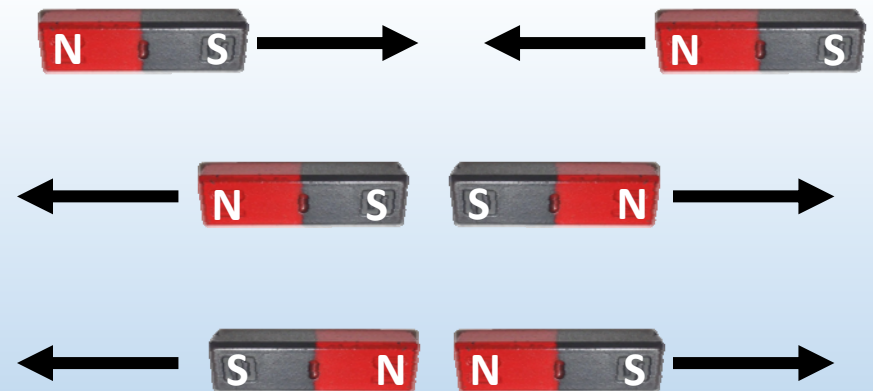


- Magnetism

N & S poles

N & S *always* together as dipole (NO “magnetic charge”)

Opposite poles attract, like poles repel



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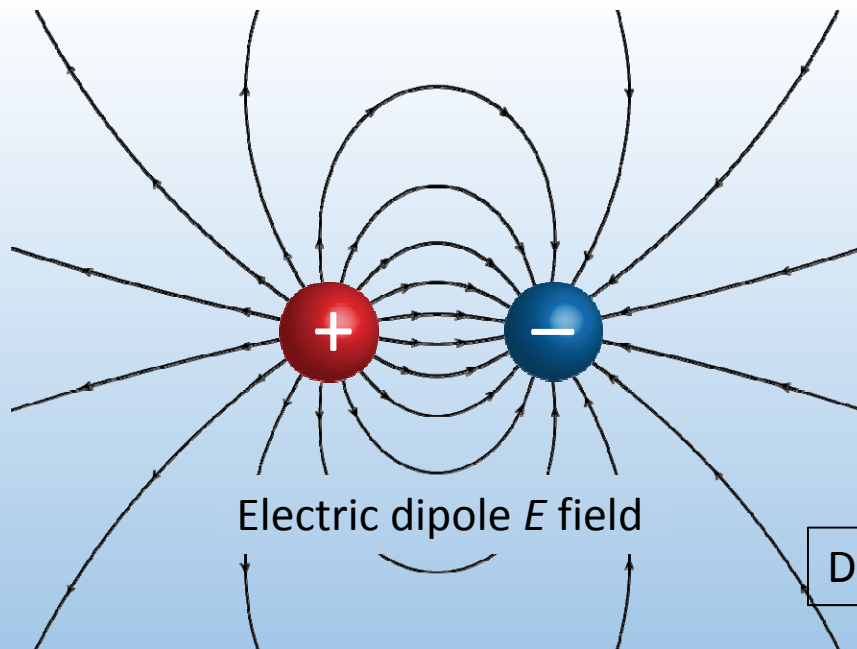
# ***Electricity vs. magnetism***

- Electric field  $\vec{E}$

Vector at location in space

Points from positive & negative  $Q$

Units:  $\text{N/C} = \text{V/m}$



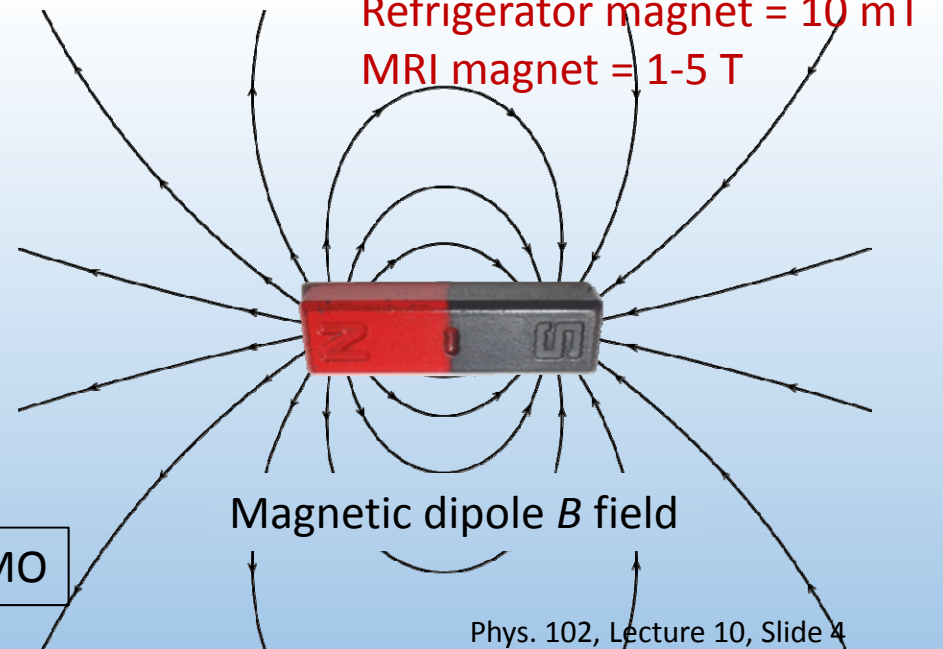
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- Magnetic field  $\vec{B}$

Vector at location in space

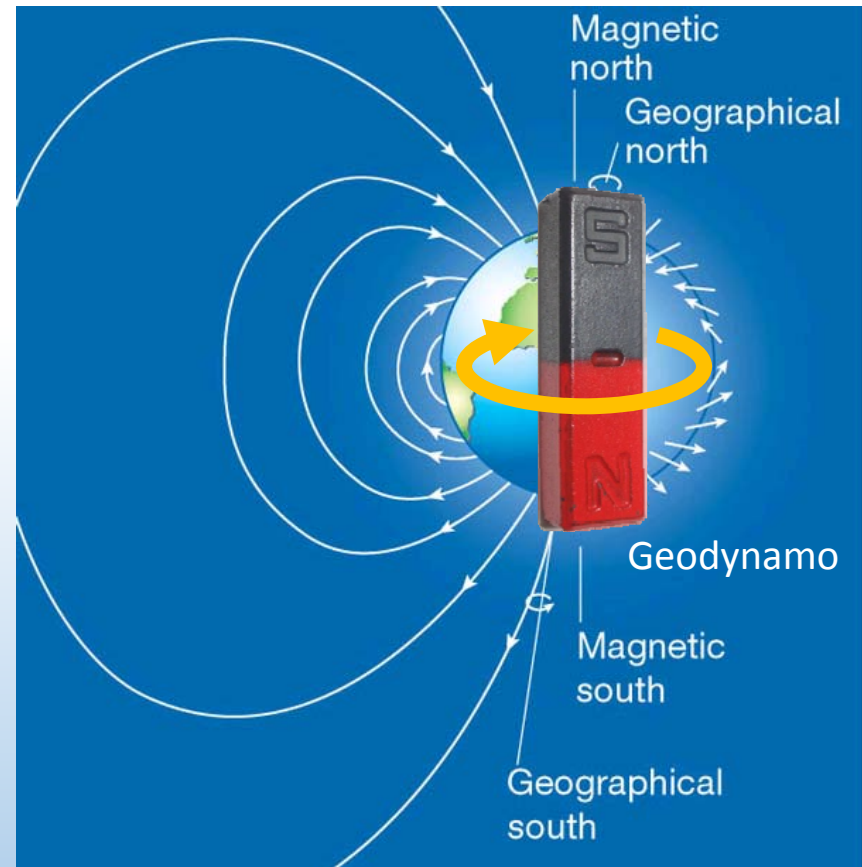
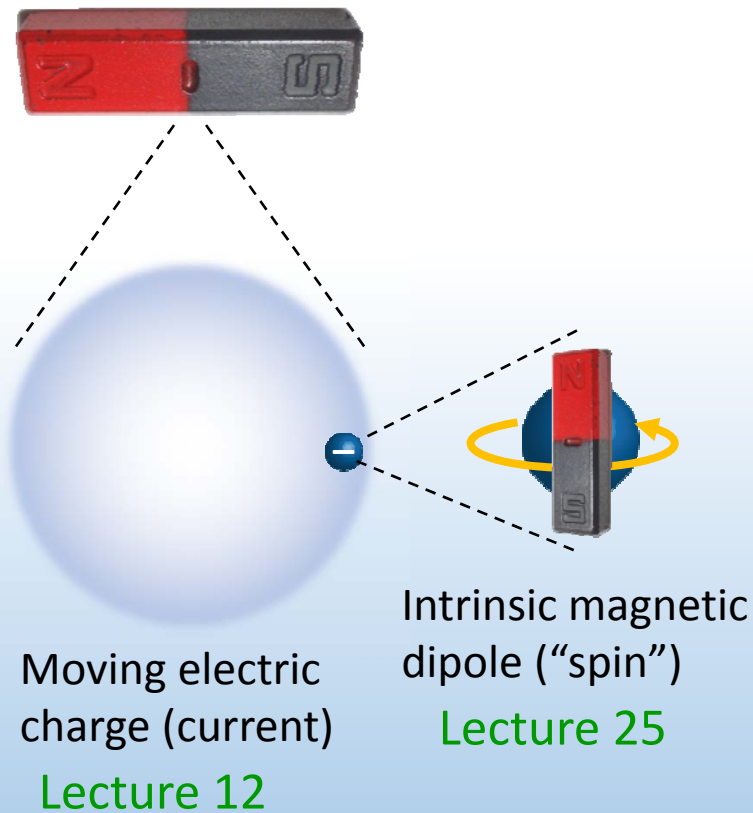
Points from N to S pole

Units: T ("Tesla")



# *Sources of magnetic fields*

There is no magnetic charge, so where do magnetic fields come from?



# Magnetic force

Magnetic field  $B$  exerts a force on a moving charge  $q$ :

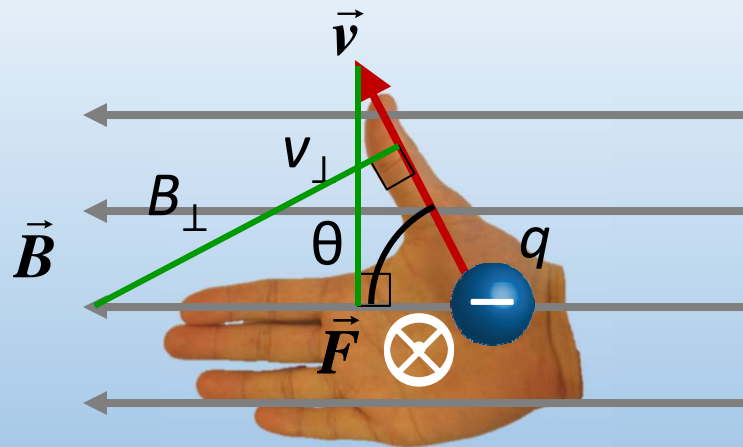
Magnitude

$$F = |q| v B \sin \theta = |q| v_{\perp} B = |q| v B_{\perp}$$

Speed of charge  $v$  (or  $v_{\perp}$ ) matters  
Only component of  $v$   $\perp$  to  $B$  (or  $B_{\perp}$  to  $v$ ) matters

Direction

“Right-hand rule” (RHR)



Thumb along  $\vec{v}$   
Fingers along  $\vec{B}$   
 $\vec{F}$  on  $+q$  is out of palm  
 $\vec{F}$  on  $-q$  is into palm

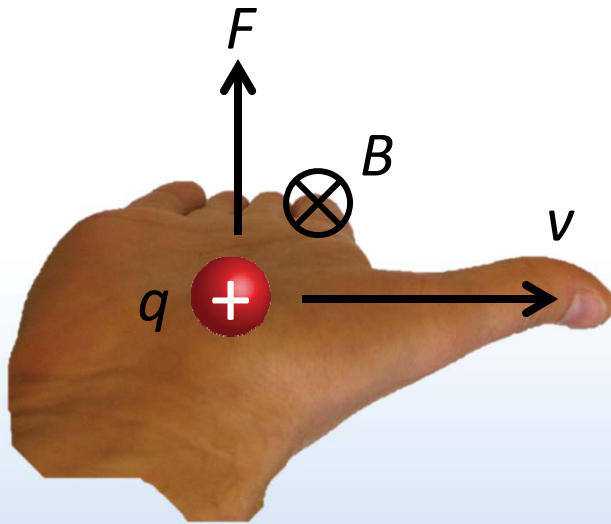
$F$  is  $\perp$  to both  $v$  and  $B$

DEMO



# ***ACT: right hand rule practice***

A + charge moving to the right in a uniform  $B$  field experiences a force  $F$  up. Which way does the  $B$  field point?



A. Up

B. Down

C. Into the page

D. Out of the page

Thumb along  $\vec{v}$

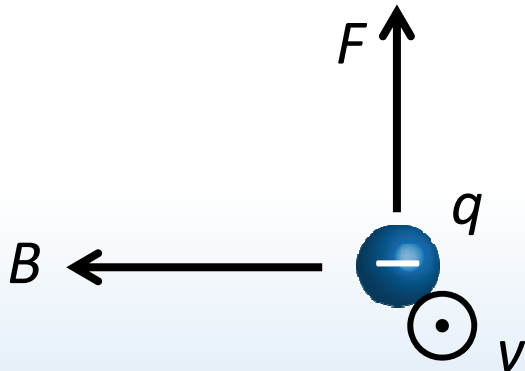
Fingers along  $\vec{B}$

$\vec{F}$  on +  $q$  is out of palm



## ***ACT: right hand rule practice***

A – charge moving out of the page in a uniform  $B$  field to the left experiences a force  $F$  in which direction?



A. Up

B. Down

C. Into the page

D. Out of the page

Thumb along  $\vec{v}$   
Fingers along  $\vec{B}$   
 $\vec{F}$  on  $-q$  is *into palm*

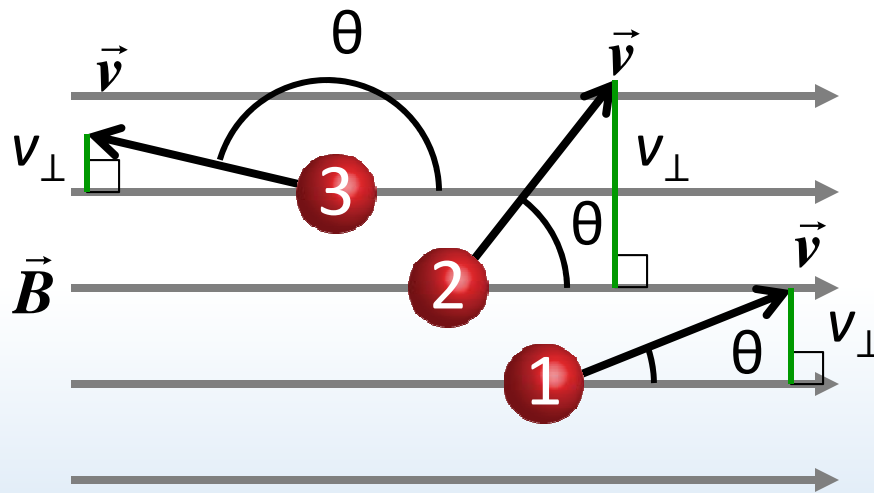
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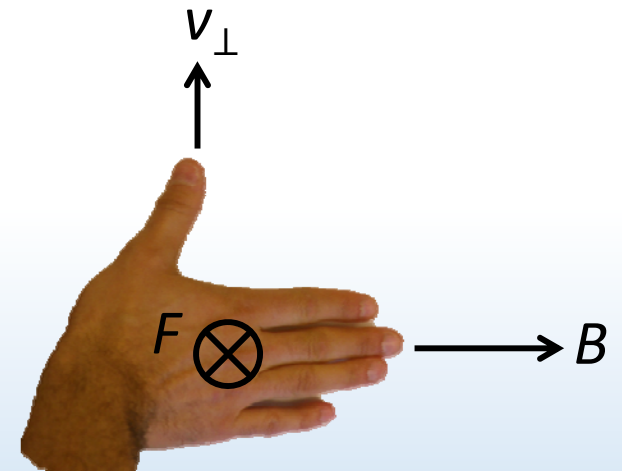


# ACT: Moving charges

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



$$F = |q|vB \sin \theta = |q|v_{\perp}B$$



Which particle experiences the greatest magnetic force?

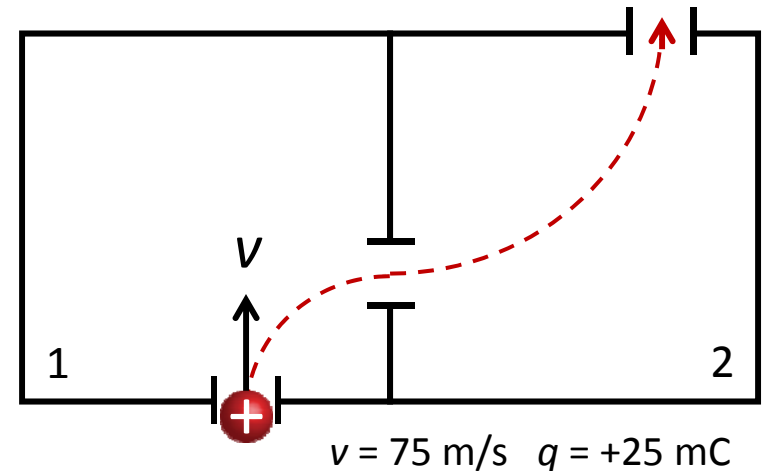
- A. 1 B. 2 C. 3 D. All same

The force on charge 3 is in the same direction as the force on 1

- A. True B. False

# Checkpoint 1.1

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?

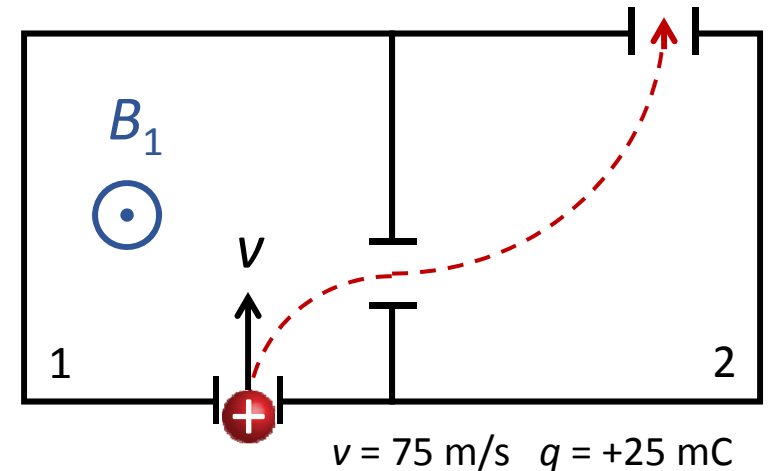
- A. up
- B. down
- C. left
- D. right

Particle is moving straight upwards then veers to the right



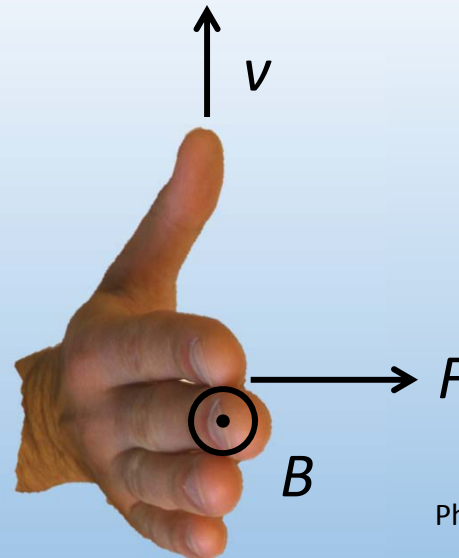
## ACT: Checkpoint 1.2

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.



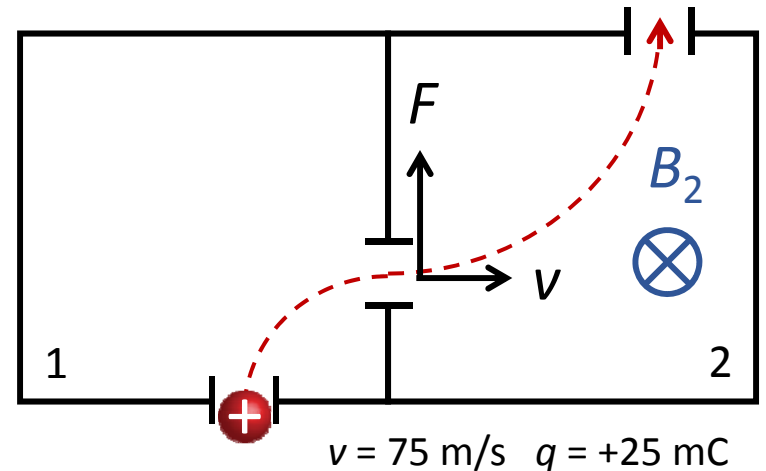
What is the direction of the *magnetic field* in region 1?

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



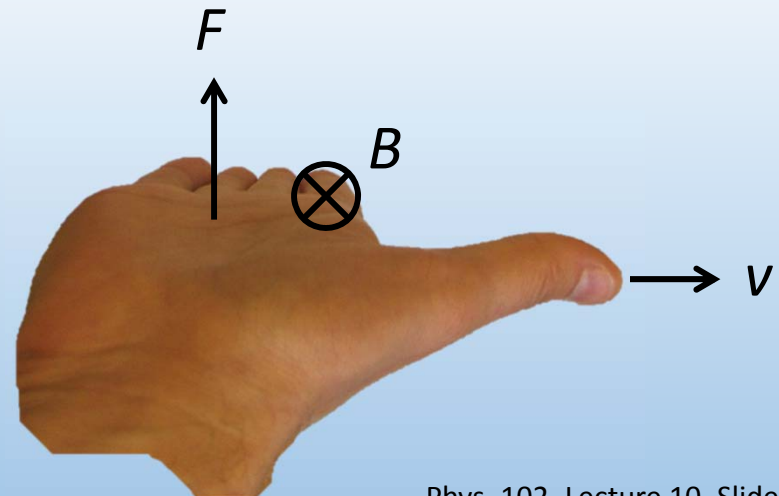
# Checkpoint 1.4

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?

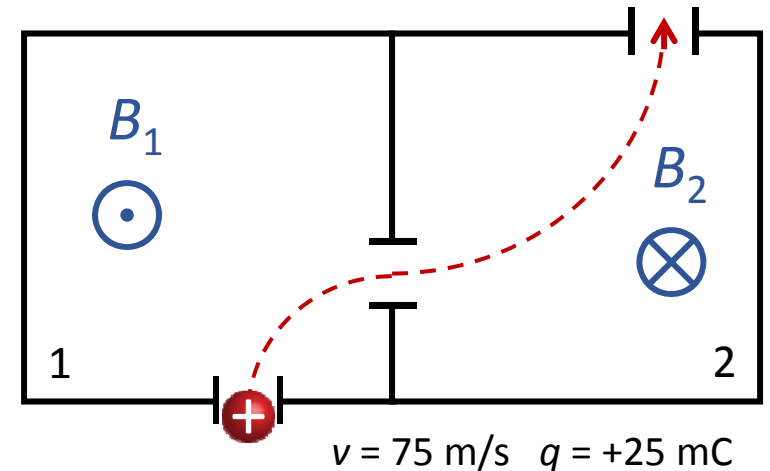
- A. up
- B. down
- C. into page
- D. out of page





## ACT: Checkpoint 1.5

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.



How do the *magnitudes* of the  $B$  fields in region 1 and 2 compare?

- A.  $|B_1| > |B_2|$
- B.  $|B_1| = |B_2|$
- C.  $|B_1| < |B_2|$

$$F = |q| v B \sin \theta$$

If  $B = 0$ ,  $F = 0$  and particle moves in straight line.  
The sharper the bend, the higher  $F$  and  $B$

# Motion in uniform $B$ field

Charged particle moves along  $x \perp$  to  $B$  field

Particle moves in a circle

$$F = qvB = \frac{mv^2}{R}$$

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

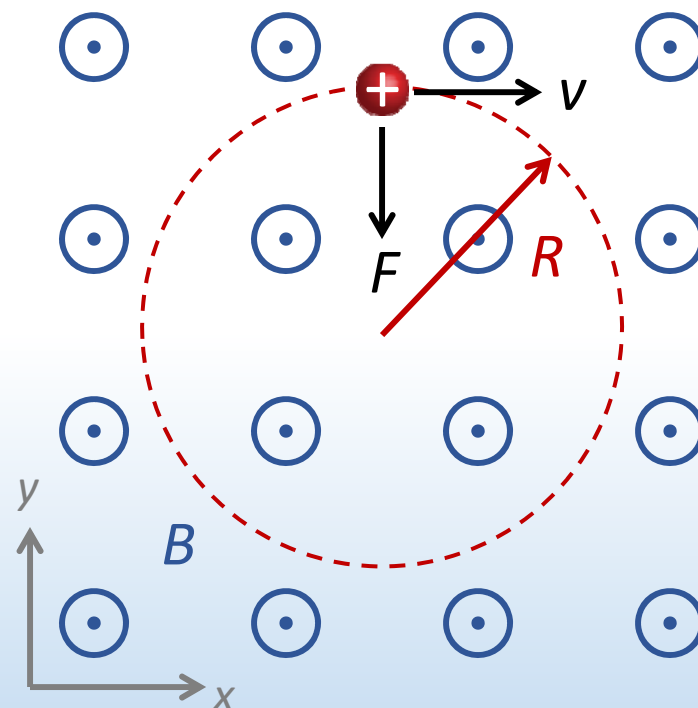
Principle of mass spectrometer

$B$  field does no work (since  $F \perp d$ )

$$W_B = 0$$

Kinetic energy is constant

Speed is constant

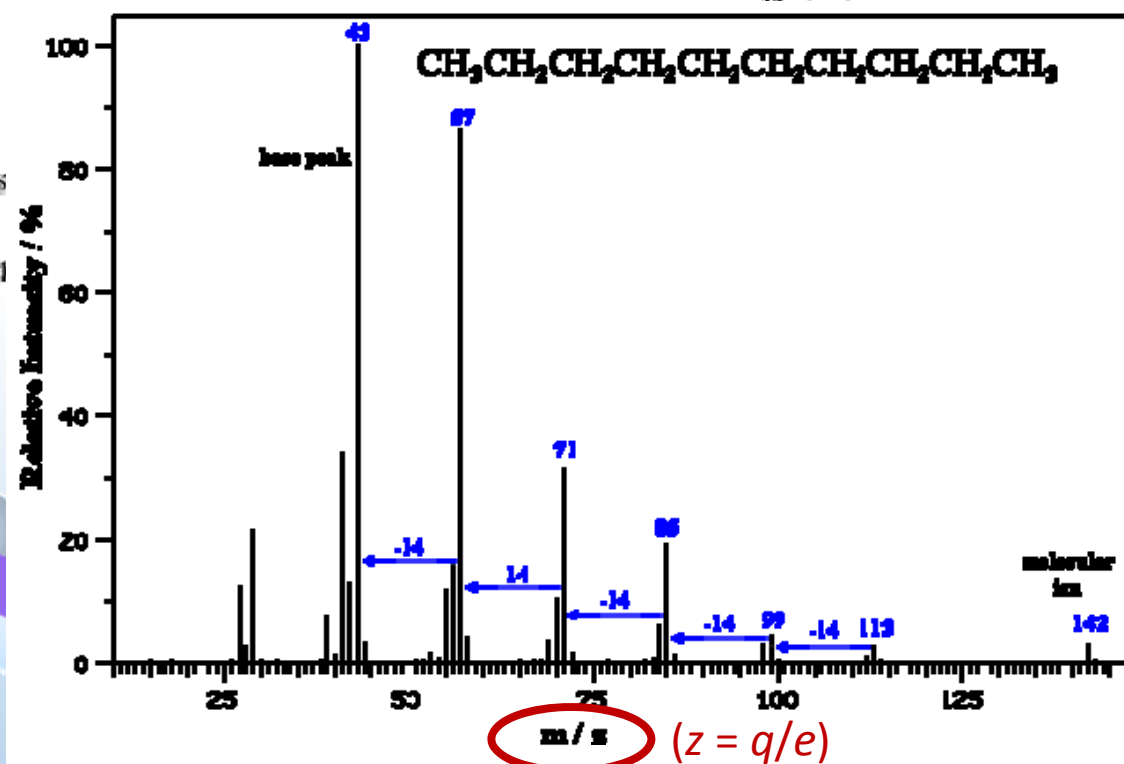
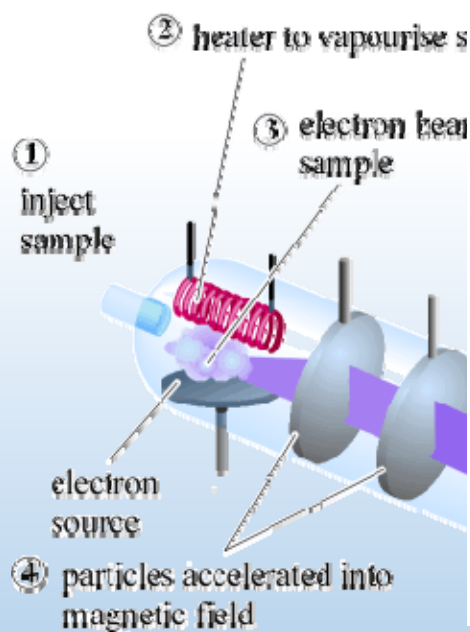


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# Mass spectrometer

Mass spectrometry uses a  $B$  field to analyze chemical compounds

Compound is vaporized into fragments & ionized, accelerated with a  $E$  field into a  $B$  field



Fragments separate according to mass to charge ratio ( $m/q$ )

# Calculation: Mass spectrometer

A mass spectrometer is used to separate different isotopes of carbon. Carbon ions are accelerated to a speed  $v = 10^5$  m/s; assume all have charge  $+1e = 1.6 \times 10^{-19}$  C.

Find which C isotope travels along the green dotted path to the detector.

FA13 EX2

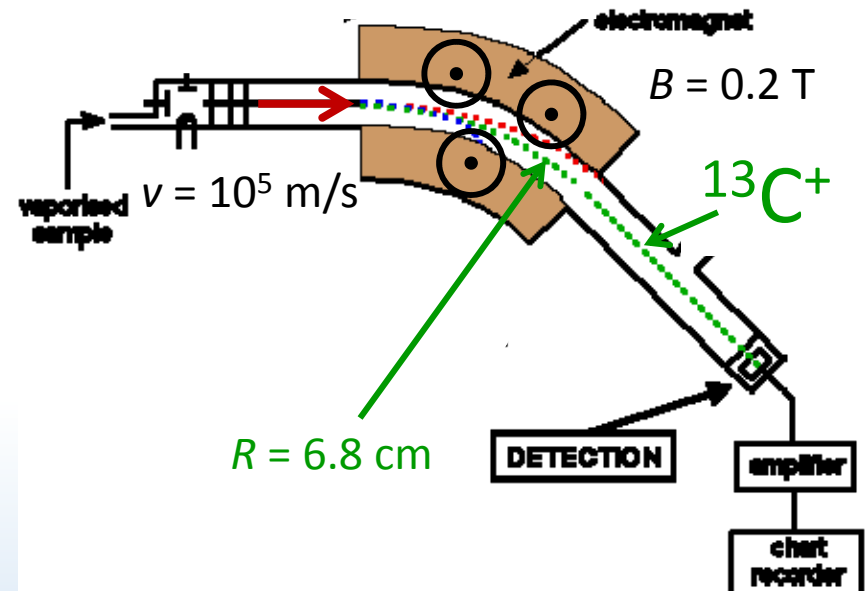
$$R = \frac{mv}{qB}$$

$$m = \frac{qBR}{v} = \frac{1.6 \times 10^{-19} \cdot 0.2 \cdot 0.068}{10^5} = 2.18 \times 10^{-26} \text{ kg} = 13 \text{ amu} \quad {}^{13}\text{C}^+$$

$$1 \text{ amu} = 1.67 \times 10^{-27} \text{ kg}$$

Which way does the B field point?

Out of the page

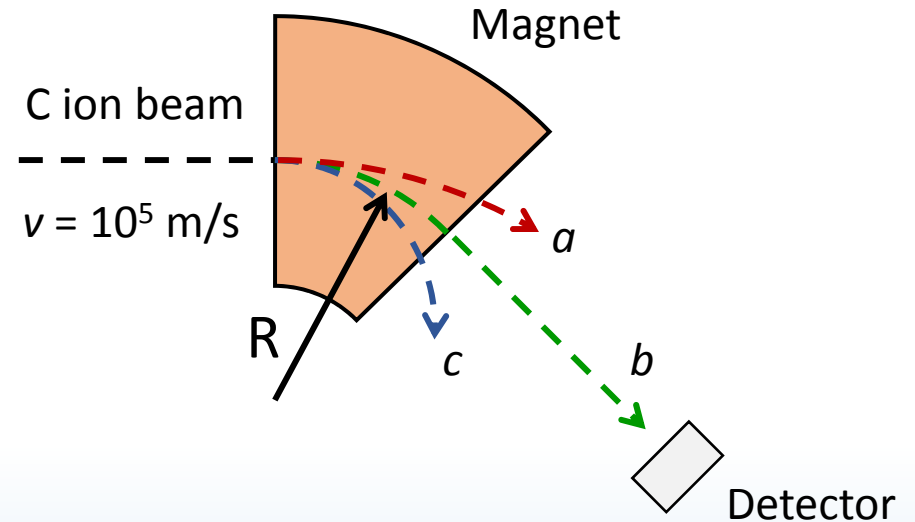






# ACT: Mass spectrometer I

The mass spectrometer isolates three C isotopes  $a$ ,  $b$ ,  $c$ . They move at a speed  $v = 10^5$  m/s entering the  $B$  field and follow the dashed paths.



How do the speeds of the different isotopes  $a$ ,  $b$ ,  $c$  leaving the  $B$  field compare?

A.  $v_a > v_b > v_c$

B.  $v_a = v_b = v_c$

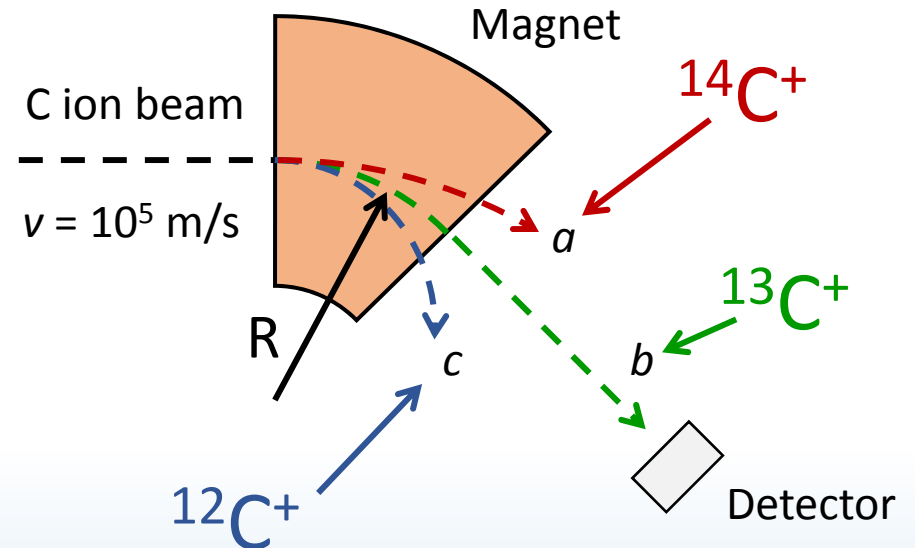
C.  $v_a < v_b < v_c$

$B$  fields do NO work, so kinetic energy cannot change! Speed is the same,  $v = 10^5$  m/s, throughout



# ACT: Mass spectrometer II

The mass spectrometer isolates three C isotopes  $a$ ,  $b$ ,  $c$ . They move at a speed  $v = 10^5$  m/s entering the  $B$  field and follow the dashed paths.



How do the masses of the different isotopes  $a$ ,  $b$ ,  $c$  compare?

A.  $m_a > m_b > m_c$

B.  $m_a = m_b = m_c$

C.  $m_a < m_b < m_c$

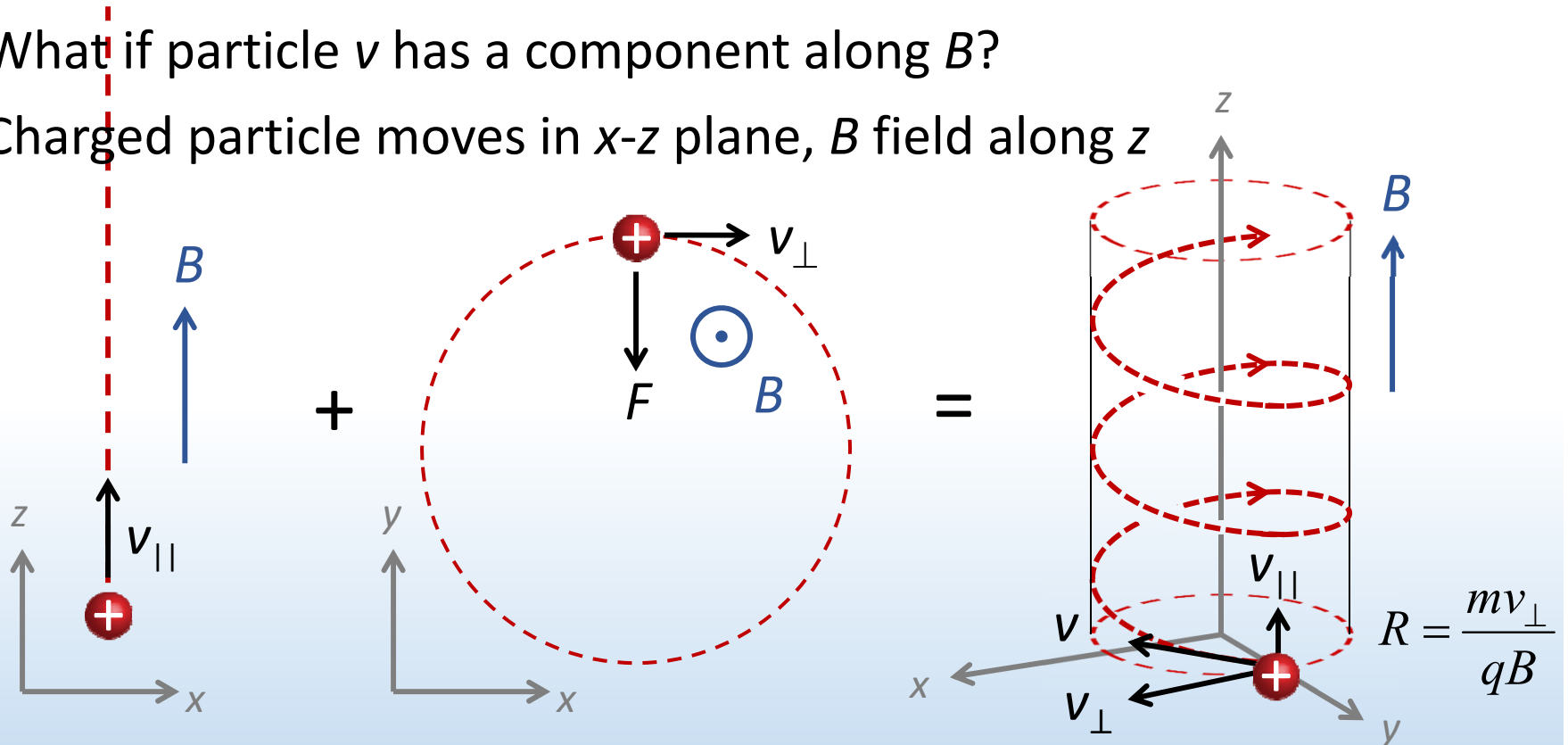
$$R = \frac{mv}{qB}$$

The higher the momentum of the particle, the less it is deflected by the  $B$  field

# 3-D motion in uniform $B$ field

What if particle  $v$  has a component along  $B$ ?

Charged particle moves in  $x$ - $z$  plane,  $B$  field along  $z$



$$F = 0$$

Component  $\parallel$  to  $B$   
remains constant

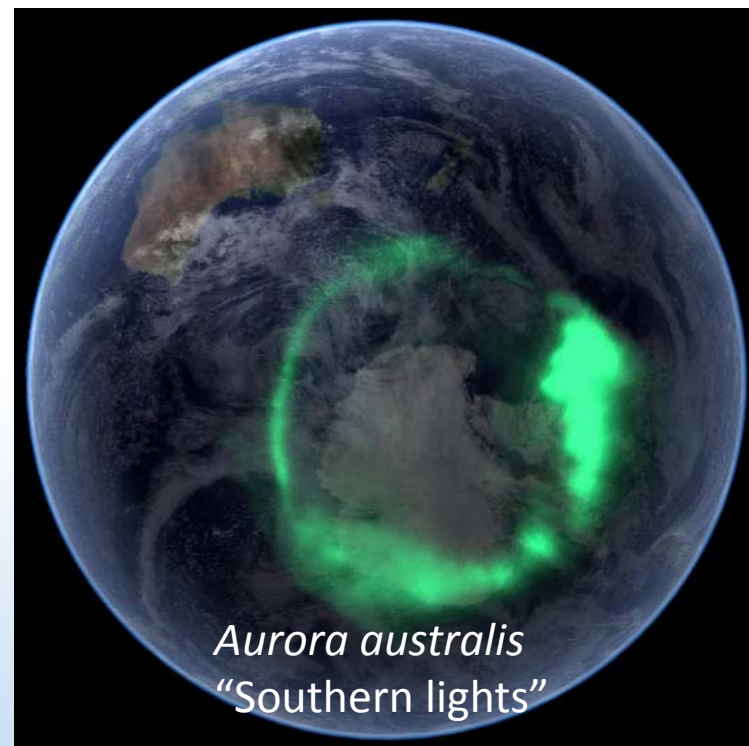
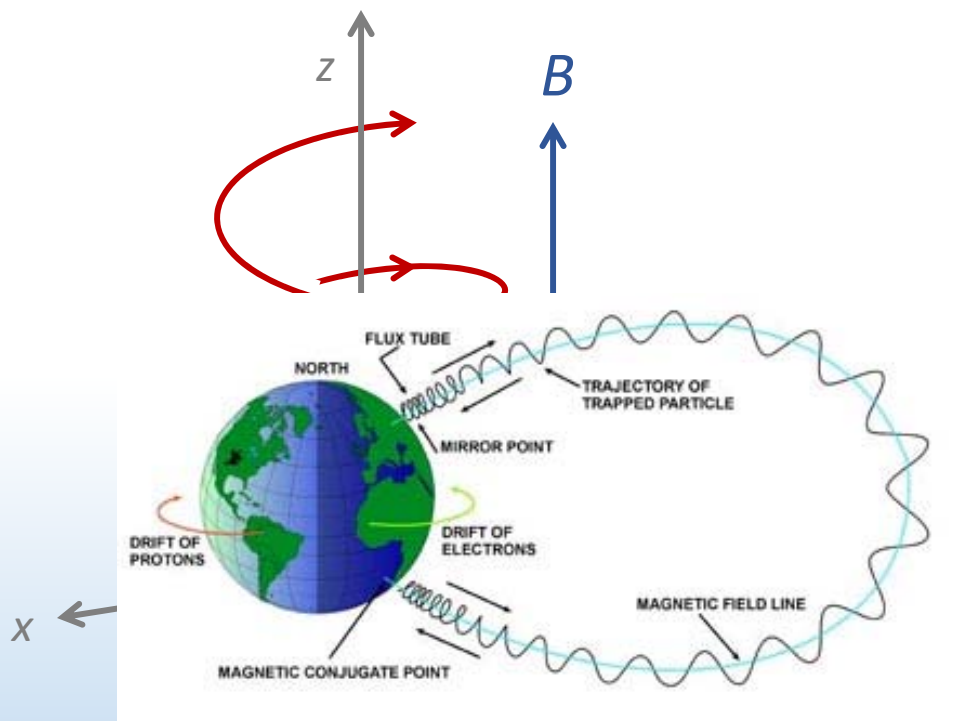
$$F = qBv_{\perp}$$

Component  $\perp$  to  $B$   
rotates in a circle

Charge moves in a *helical* trajectory

# *Aurora borealis & australis*

Earth's  $B$  field protects against stream of ions from sun ("solar wind")



$B$  field directs ions to atmosphere in north and south hemispheres.  
Ions collide with particles in atmosphere and emit light: "*aurora*"

# ***Summary of today's lecture***

## *Electric vs. magnetic forces*

Force:	Electric	Magnetic
Source:	Charge	Moving charge
Act on:	Charge	Moving charge
Magnitude:	$F_E = q E$	$F_B = q v B \sin(\theta)$
Direction:	to $E$	$\perp$ to $v, B$
Work:	$W_E = qEd \cos(\theta)$	$W_B = 0$



KEEP  
CALM  
AND USE

THE RIGHT  
HAND RULE

