Phys 102 – Lecture 10

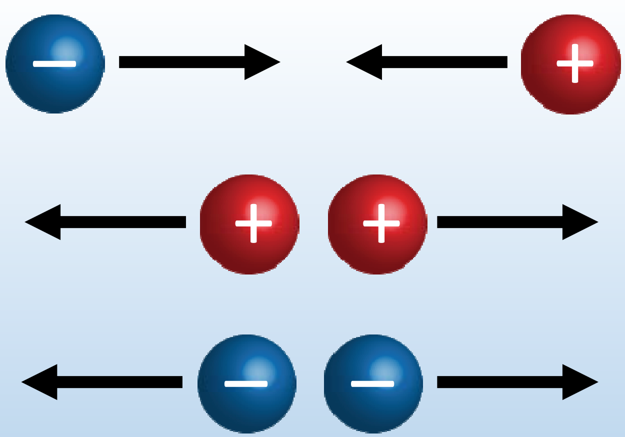
Magnetic fields & forces

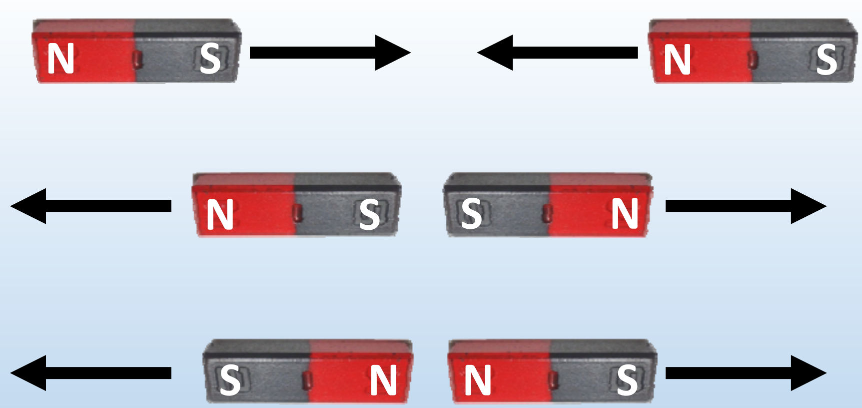
Today we will...

- 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



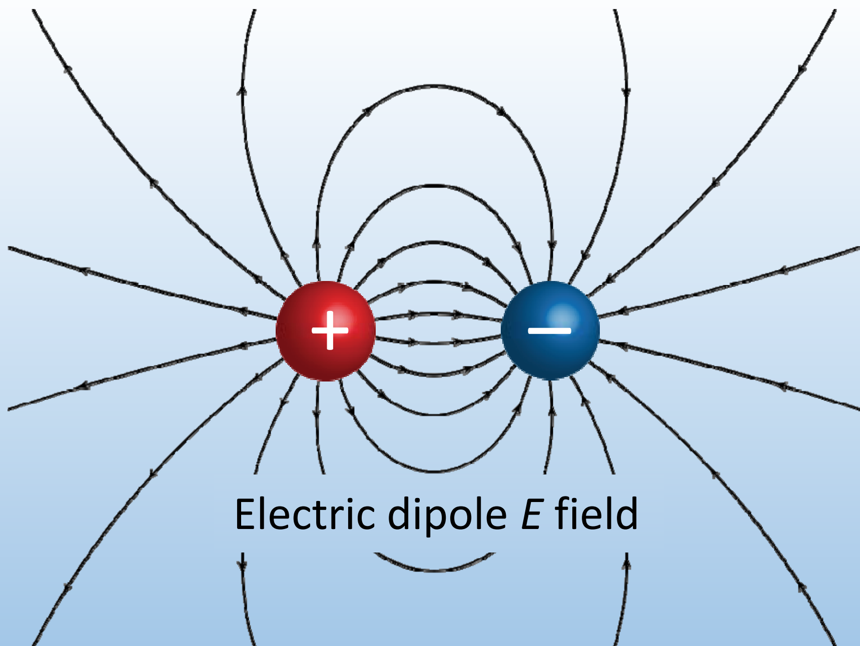


DEMO

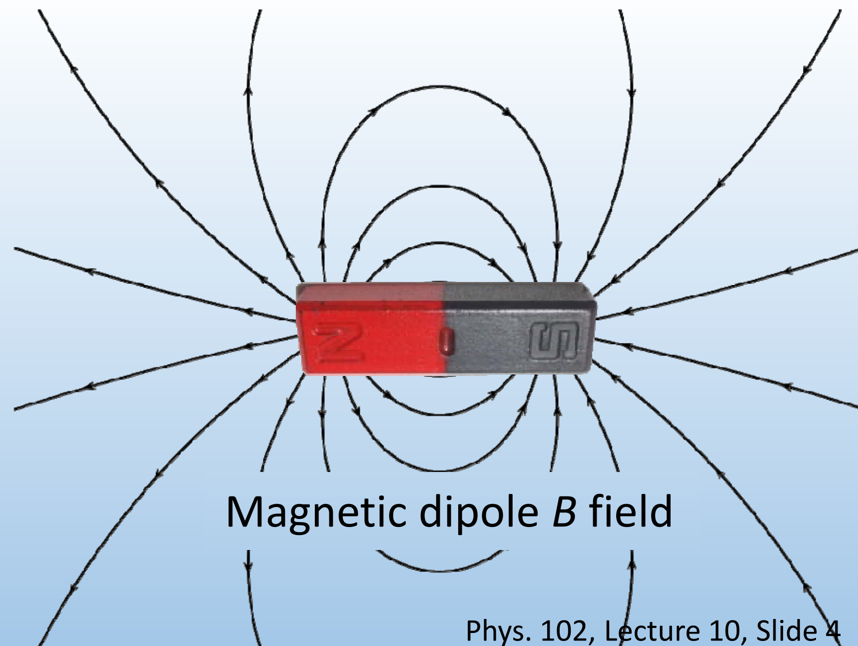
Electricity vs. magnetism

- Electric field $\vec{E}$
  - Vector at location in space
  - Points from positive & negative *Q*
  - Units: N/C = V/m

- Magnetic field $\vec{B}$
  - Vector at location in space
  - Points from N to S pole
  - Units: T ("Tesla")



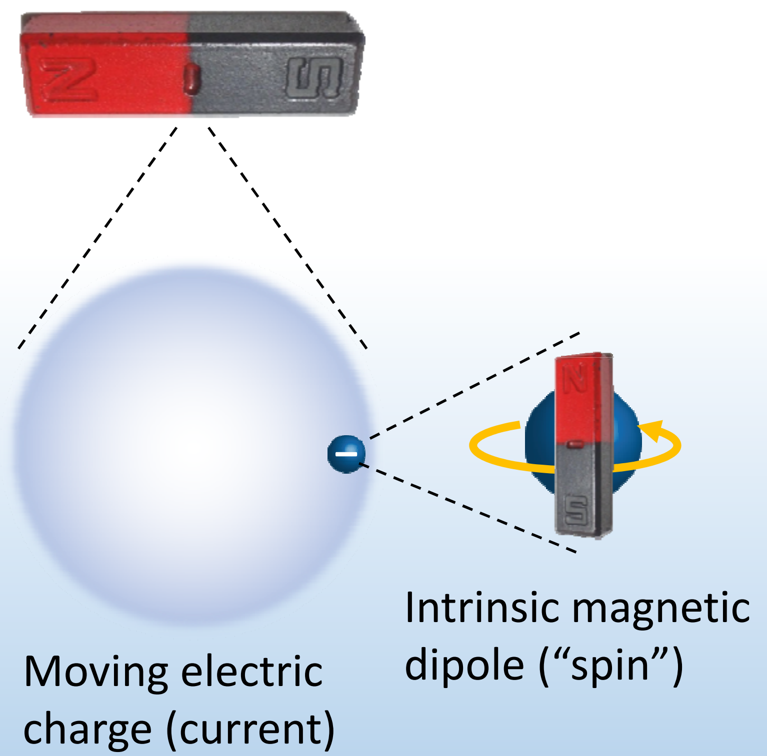
Electric dipole *E* field

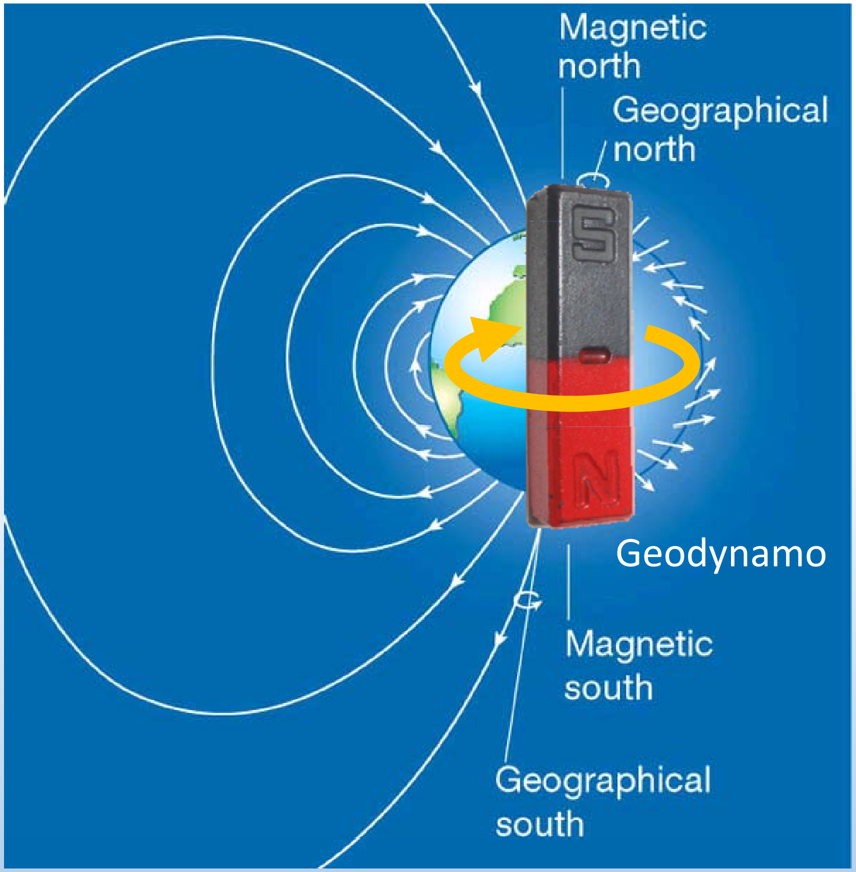


Magnetic dipole *B* field

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 <u>*moving*</u> charge *q*:

Magnitude

$$F = |q| vB \sin\theta$$

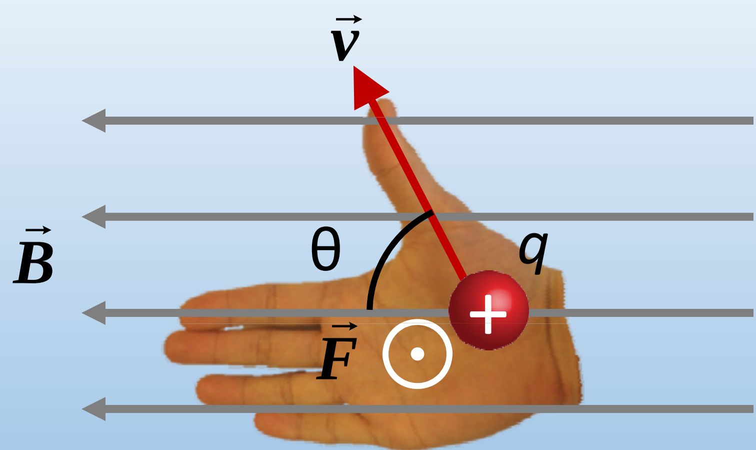
Angle between *v* and *B*

Speed of charge *q*

Magnetic field strength

Direction

“Right-hand rule” (RHR)



Thumb along $\vec{v}$

Fingers along $\vec{B}$

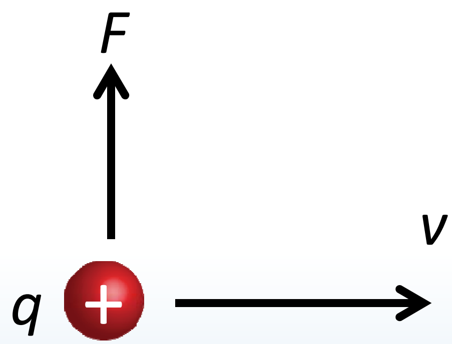
$\vec{F}$ on + *q* is *out of palm*

$\vec{F}$ on – *q* is *into palm*

F is ⊥ to both v and B

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

ACT: Right hand rule practice

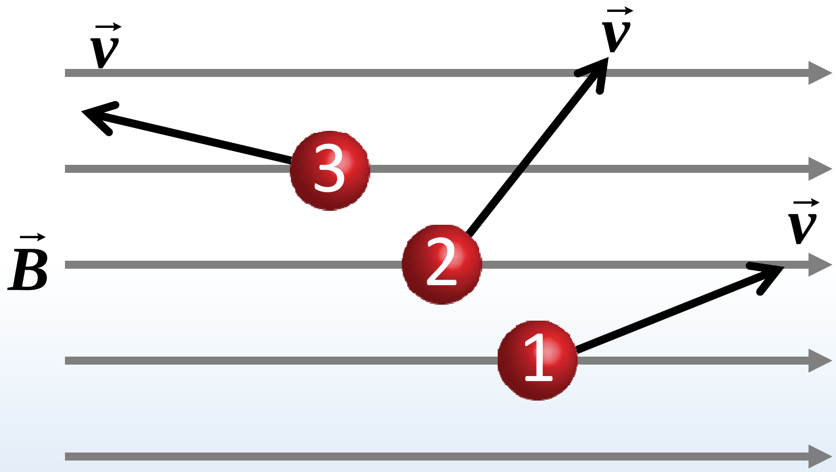
A – charge moving out of the page in a uniform *B* field to the left experiences a force *F* in which direction?

A. Up
B. Down
C. Into the page
D. Out of the page

DEMO

ACT: Moving charges

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



Which particle experiences the greatest magnetic force?

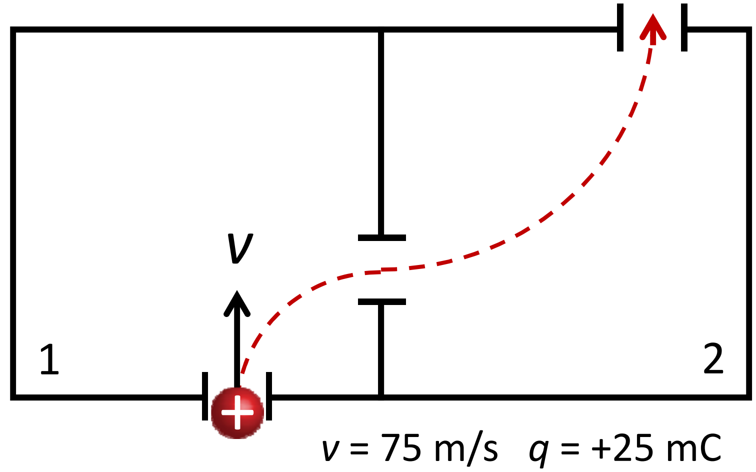
A. 1 B. 2 C. 3 D. All same

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.

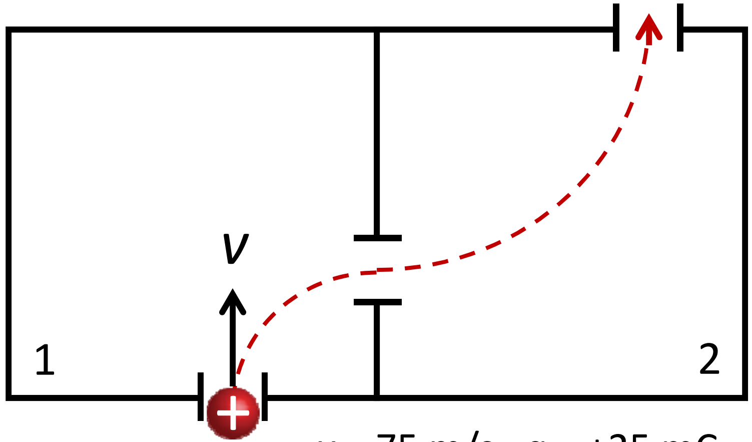


What is the direction of the *force* on the particle just as it enters region 1?

A. up
B. down
C. left
D. right
E. into page
F. out of page

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.

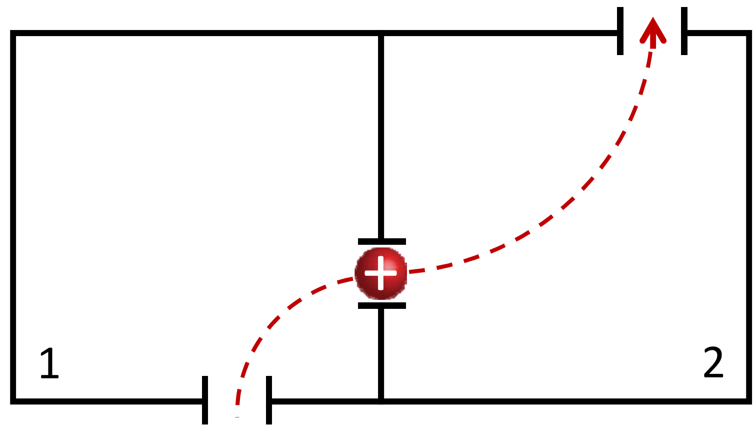


What is the direction of the *magnetic field* in region 1?

A. up
B. down
C. left
D. right
E. into page
F. out of page

ACT: 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.

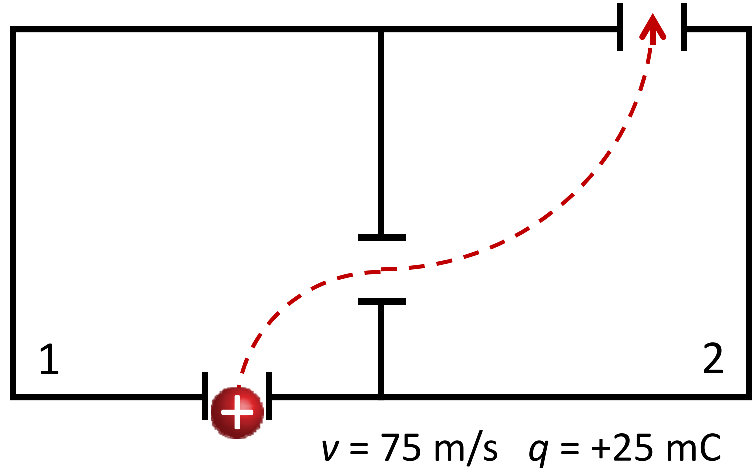


What is the direction of the *magnetic field* in <u>region 2</u>?

A. up
B. down
C. left
D. right
E. into page
F. 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.



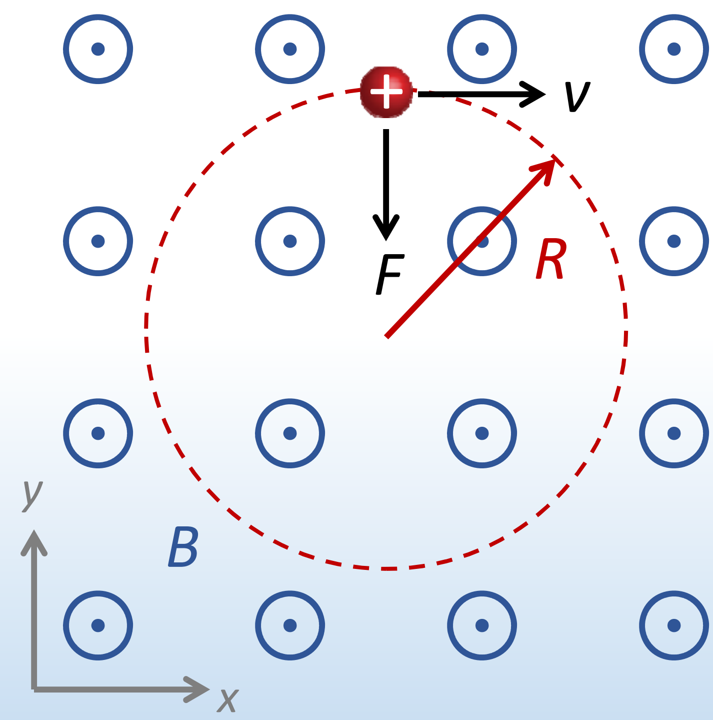
How do the *magnitudes* of the *B* fields in region 1 and 2 compare?

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

Motion in uniform B field

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

Particle moves in a circle



B field does <u>*no*</u> work (since $F \perp d$)

Kinetic energy is constant

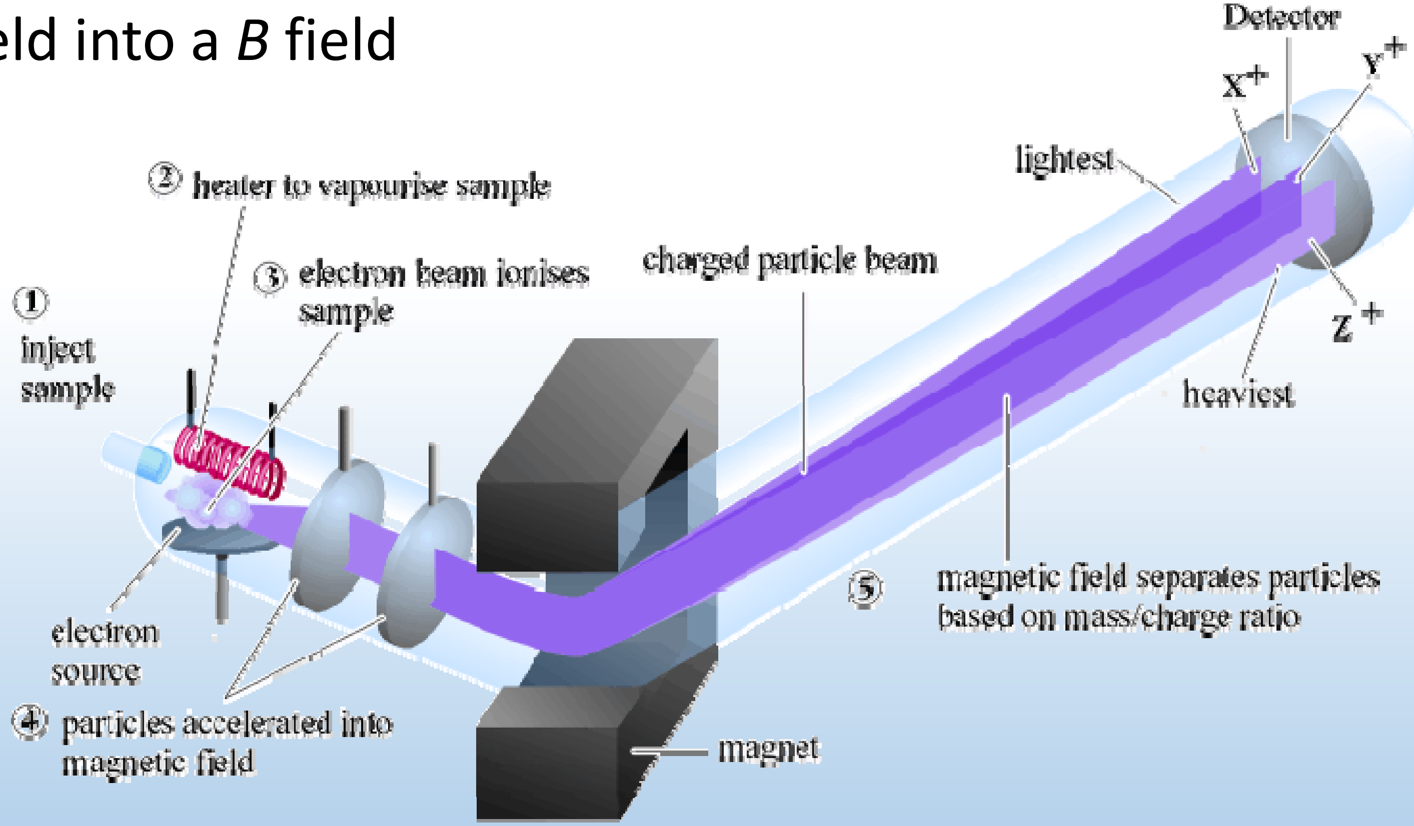
Speed is constant

DEMO

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

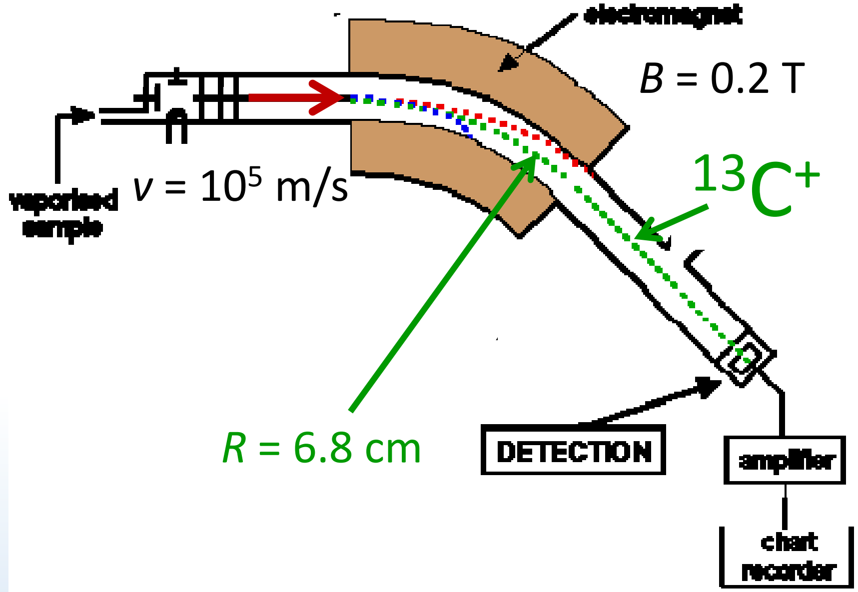


Fragments separate according to mass to charge ratio (*m*/*q*)

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 $+1e = 1.6\times10^{-19}$ C.

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



FA13 EX2

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

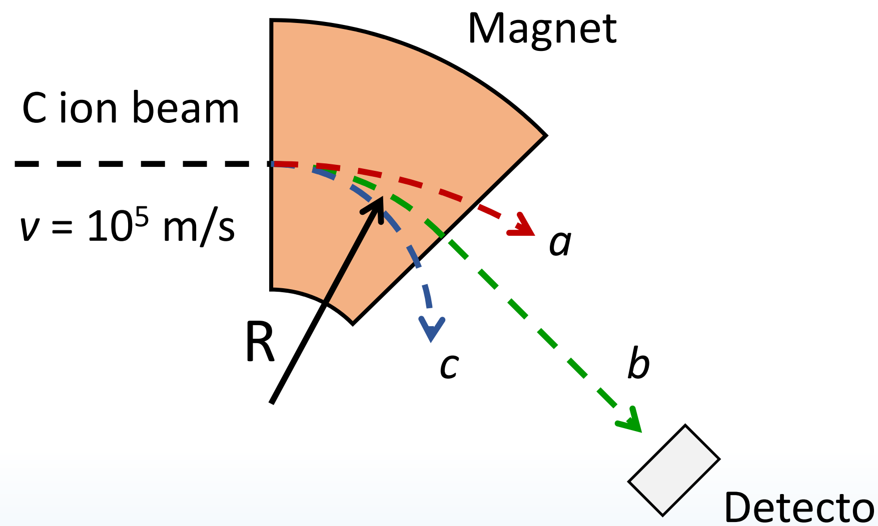
$$m = \frac{qBR}{v} = \frac{1.6\times10^{-19}\cdot 0.2 \cdot 0.068}{10^5} = 2.18\times10^{-26}\text{ kg} = 13\,\text{amu} \qquad {}^{13}C^+$$

$$1\,\text{amu} = 1.67\times10^{-27}\text{ kg}$$

Which way does the B field point?

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?

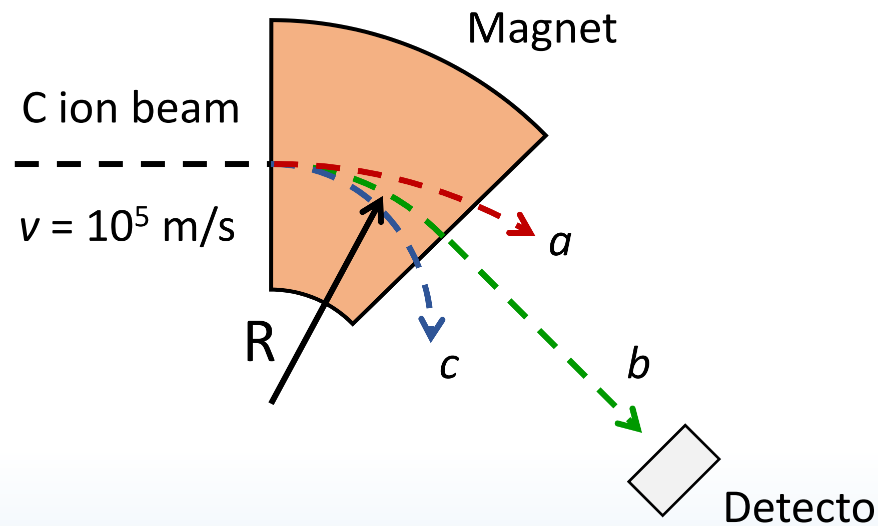
A. $v_a > v_b > v_c$

B. $v_a = v_b = v_c$

C. $v_a < v_b < v_c$

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.



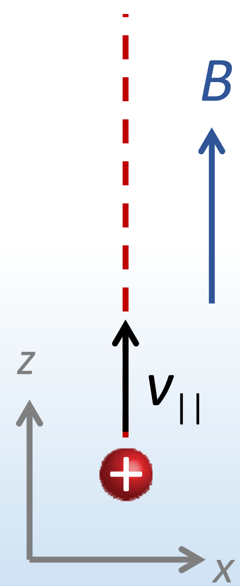
How do the masses of the different isotopes *a*, *b*, *c* compare?

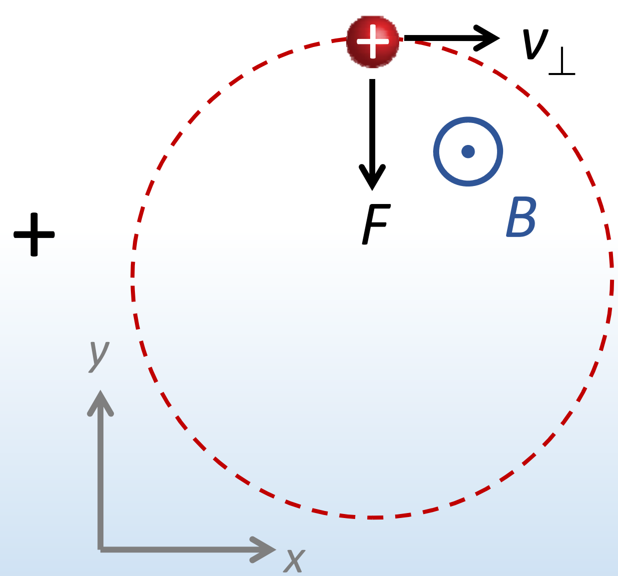
A. $m_a > m_b > m_c$
B. $m_a = m_b = m_c$
C. $m_a < m_b < m_c$

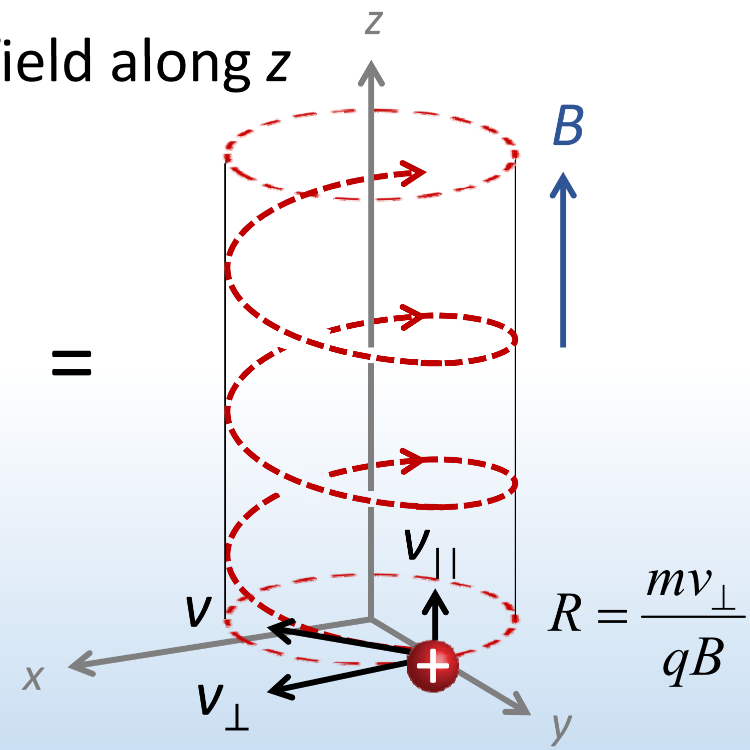
3-D motion in uniform B field

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

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







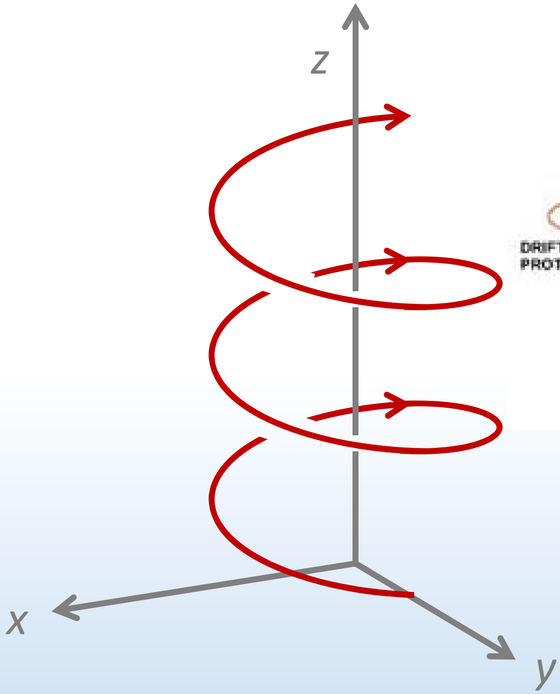
$F = 0$
Component || to *B*
remains constant

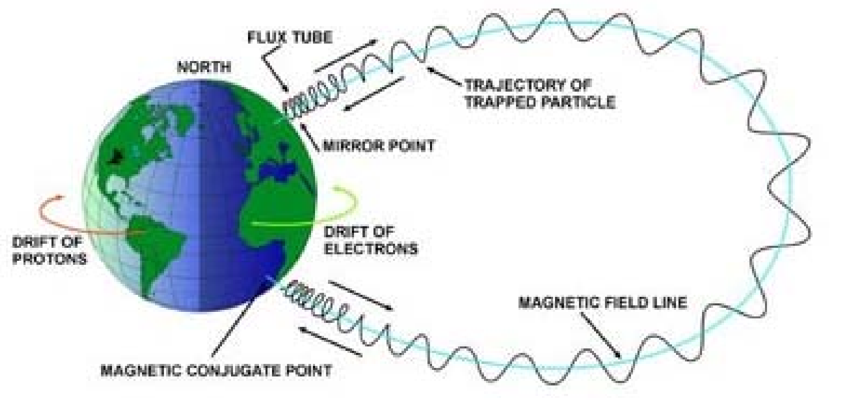
$F = qBv_\perp$
Component $\perp$ to *B*
rotates in a circle

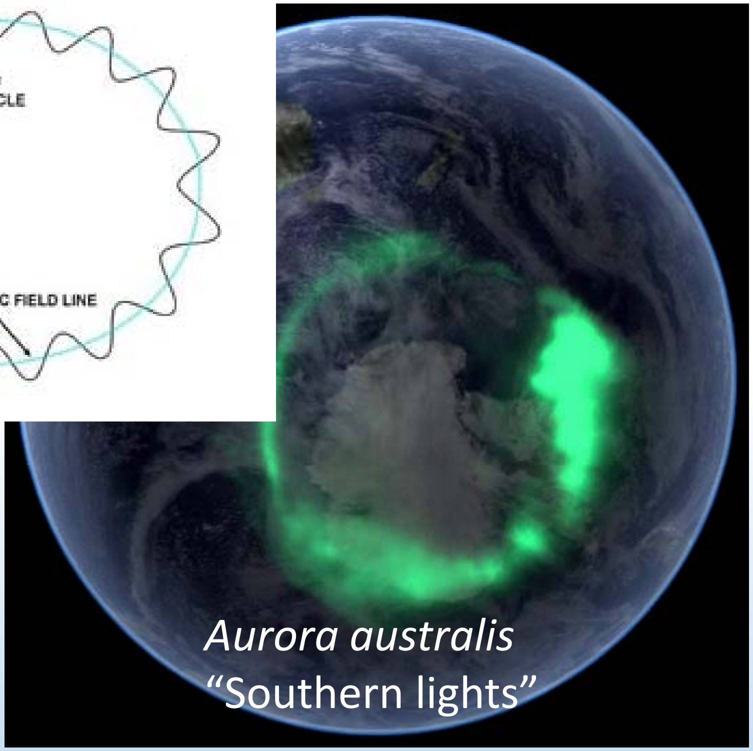
Charge moves in a *helical* trajectory

Aurora borealis & australis

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





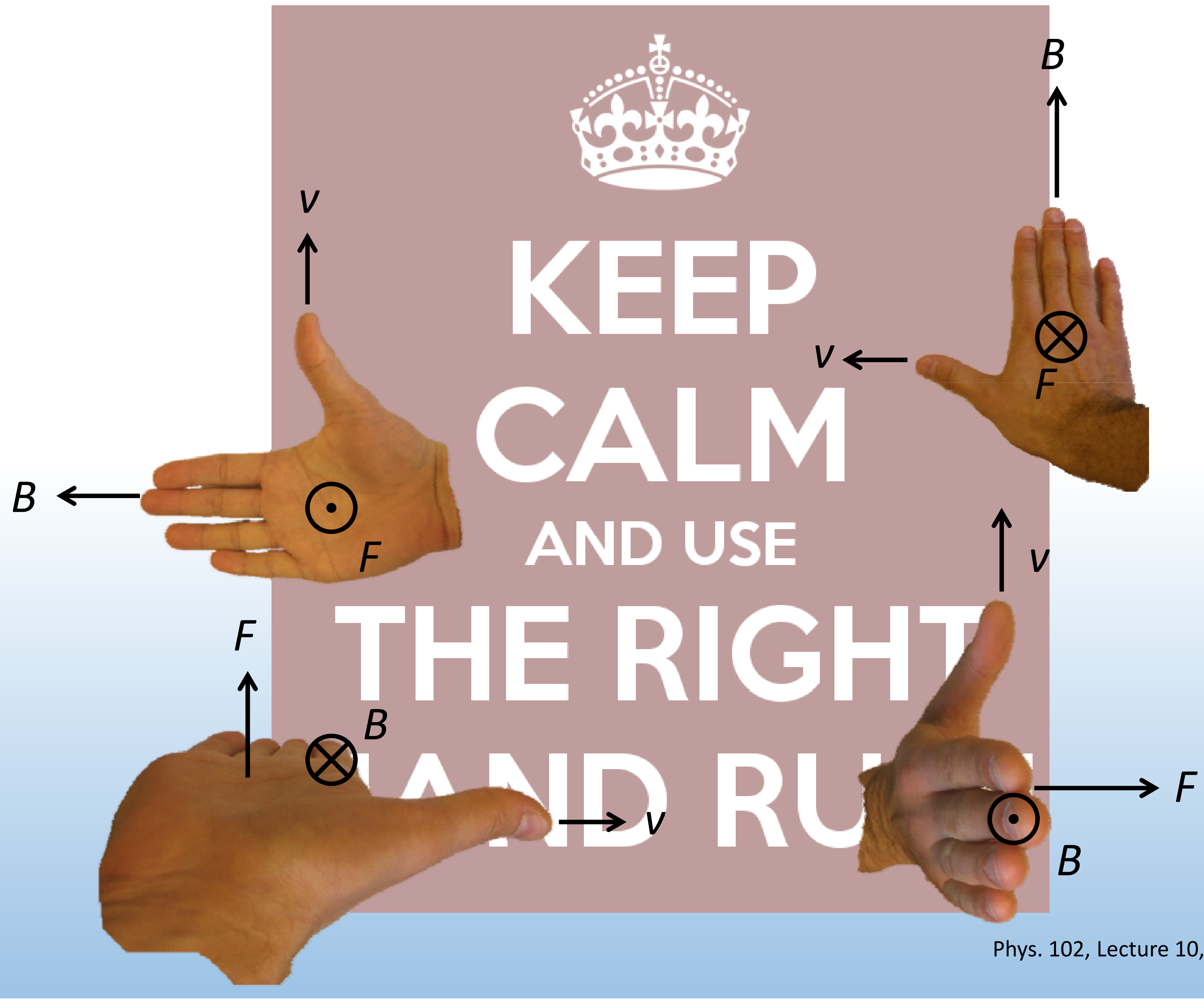


B field directs ions to atmosphere in north and south hemispheres.
Ions collide with particles in atmosphere and emit light: "*aurora*"

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:	$W_E = qEd\cos(\theta)$	$W_B = 0$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