Your questions/comments

IMPORTANT ANNOUNCEMENTS:

This week: I will be out of town after Monday's Lect. 10 (so, no office hour) & Bryce Gadway will give Wednesday's Lect. 11.

Exam scores are in! Class mean was 75%.
Due to a printing error, we gave everyone credit for Q8.

"I'd like more examples of right hand rule problems and how to approach them."

"I did not see a connection between the checkpoint and what was taught in the pre-lecture. I really did not know how to approach the problem based on what we learned."

"EVERYTHING! Kinda completely lost"

"I don't really understand how to determine the direction of a magnetic field other than the right hand rule. It's very confusing."

Phys 102 – Lecture 10

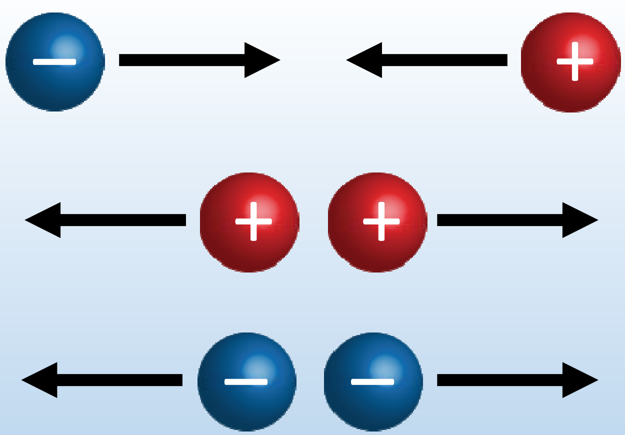
Magnetic fields & forces

Today we will...

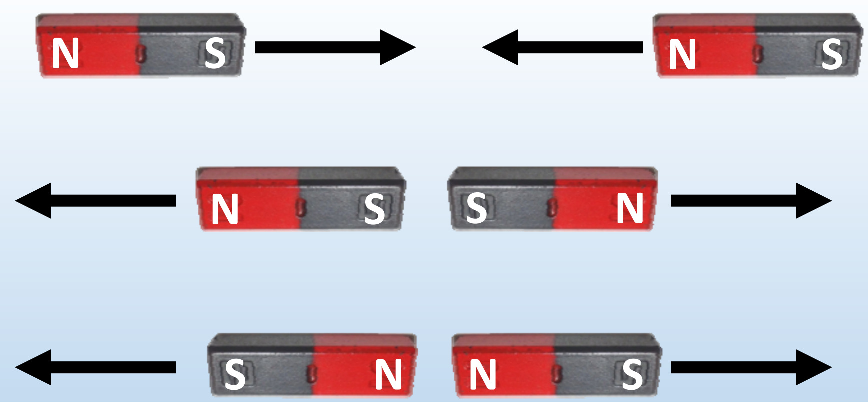
- Learn about the magnetism
  - Magnetic field *B*
  - Magnetic force *F* on moving charge
- Apply these concepts!
  - Charged particle motion in a magnetic field
  - Mass spectrometry
  - Earth's magnetic field & northern/southern lights

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



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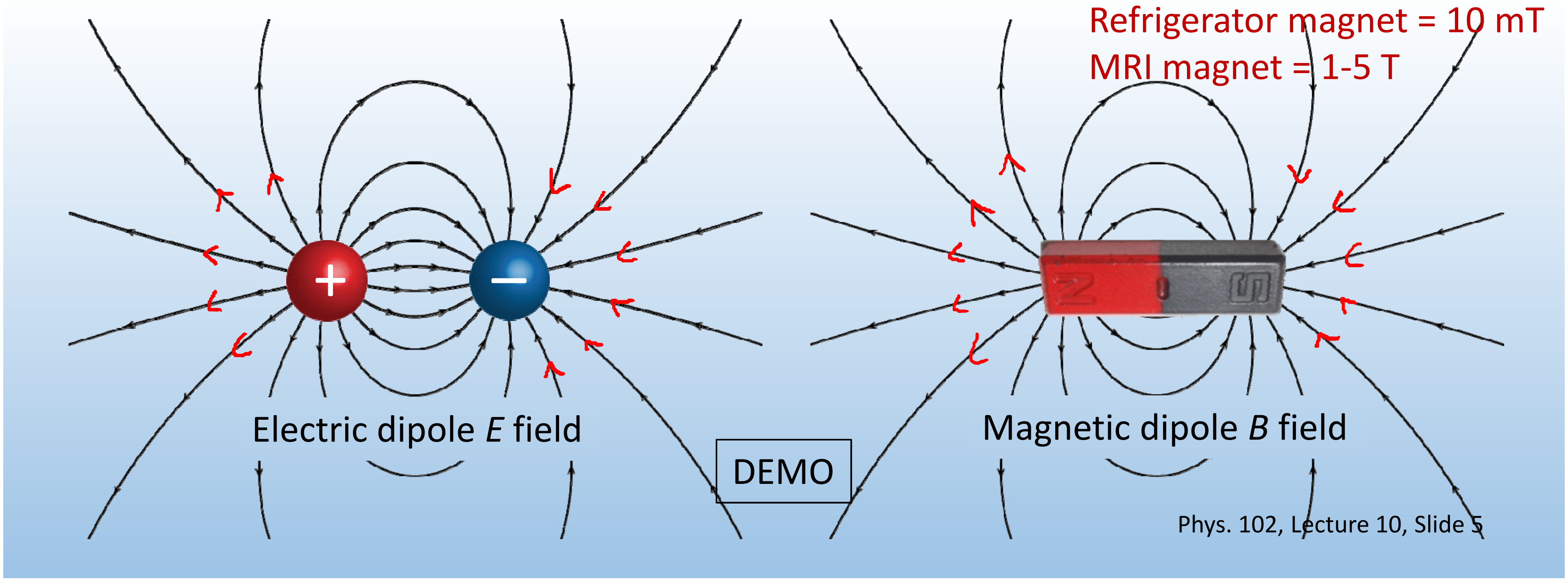
Electricity vs. magnetism

- 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")

Earth = 25-50 μT
Refrigerator magnet = 10 mT
MRI magnet = 1-5 T



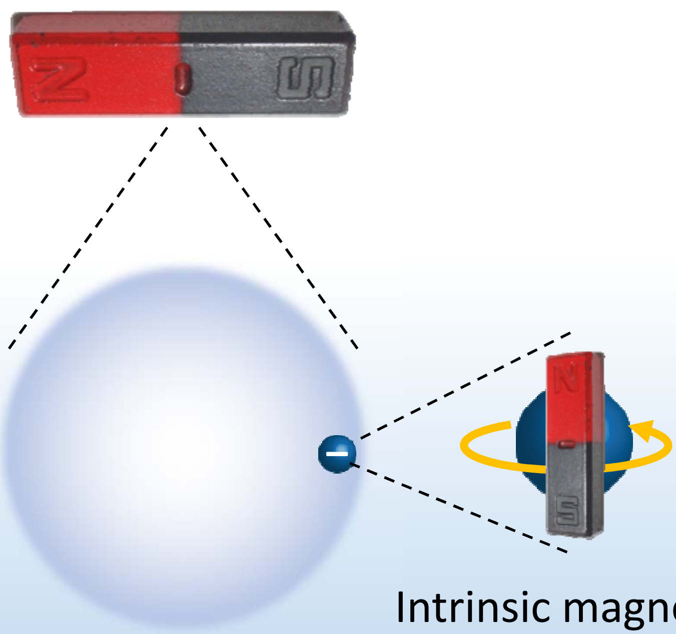
Electric dipole *E* field

Magnetic dipole *B* field

DEMO

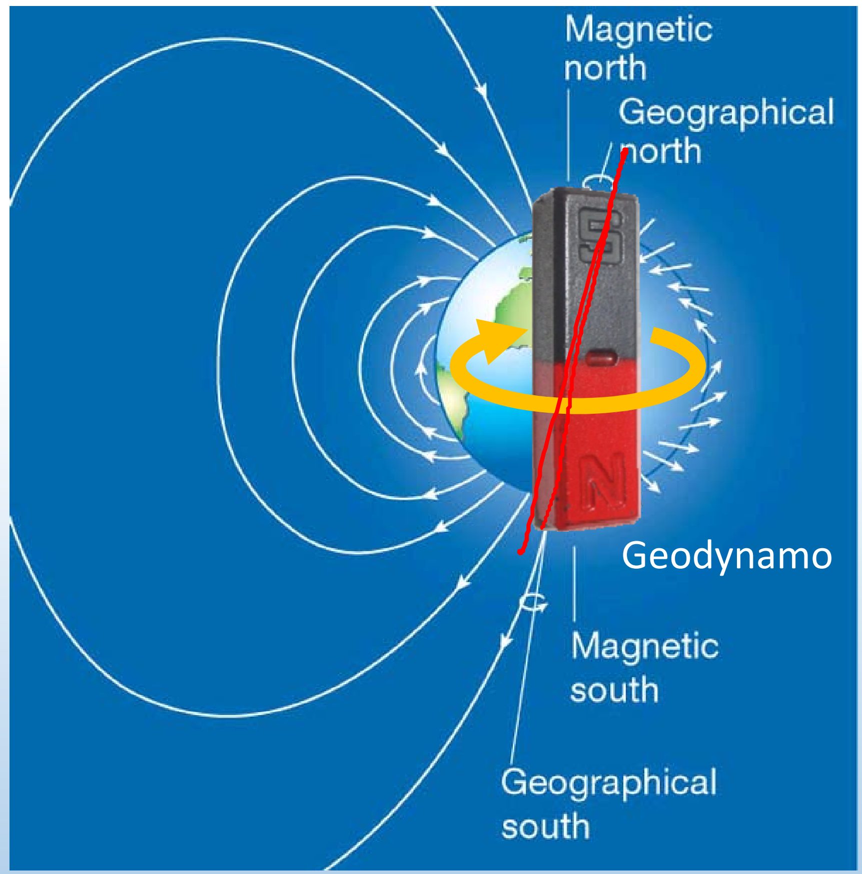
Sources of magnetic fields

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



Moving electric charge (current)
Lecture 12

Intrinsic magnetic dipole ("spin")
Lecture 25



Magnetic force

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

Magnitude

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

Angle between *v* and *B*

Speed of charge *q*

Magnetic field strength

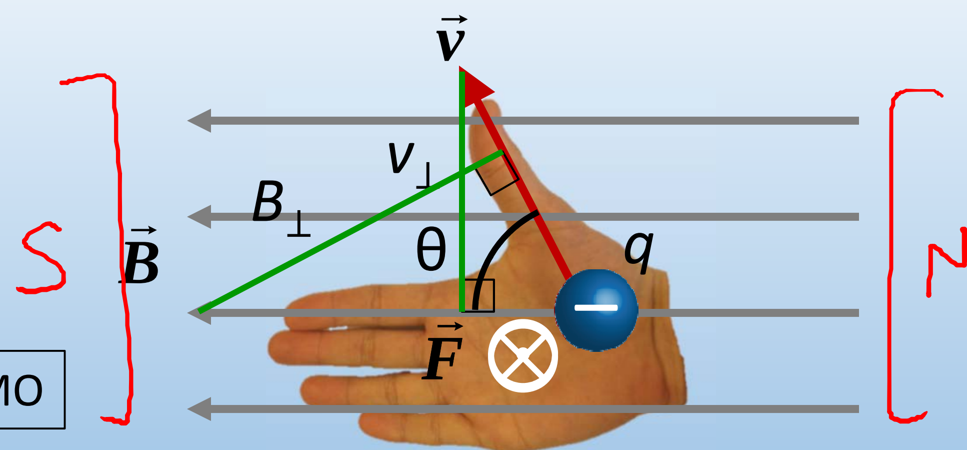
Only component of v ⊥ to B (or B ⊥ to v) matters

⊙ = out of the page

⊗ = into page

Direction

"Right-hand rule" (RHR)



DEMO

Thumb along $\vec{v}$

Fingers along $\vec{B}$

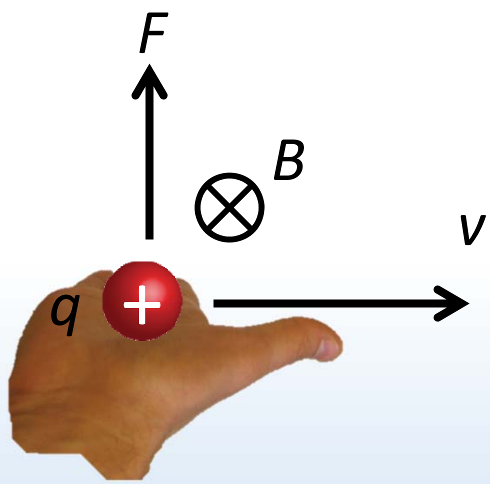
$\vec{F}$ on + *q* is *out of palm*

$\vec{F}$ 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

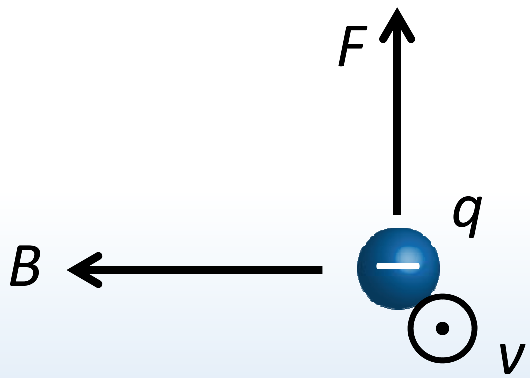
Thumb along $\vec{v}$

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?



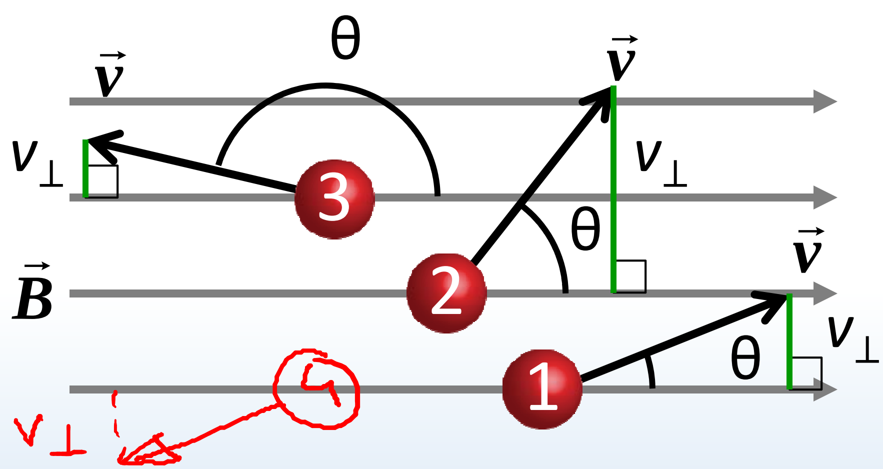
A. Up
B. Down
C. Into the page
D. Out of the page

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

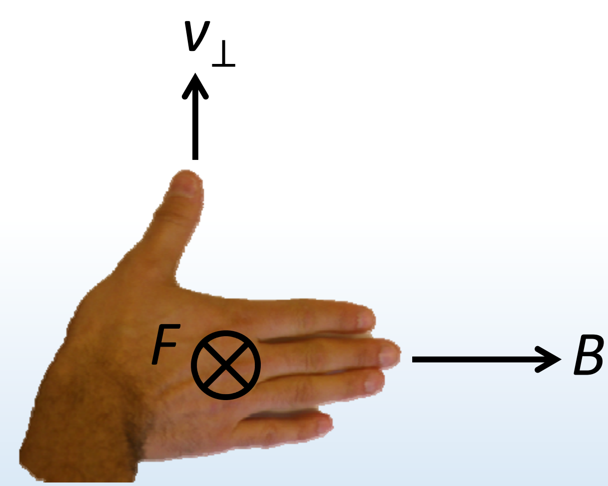
DEMO

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?

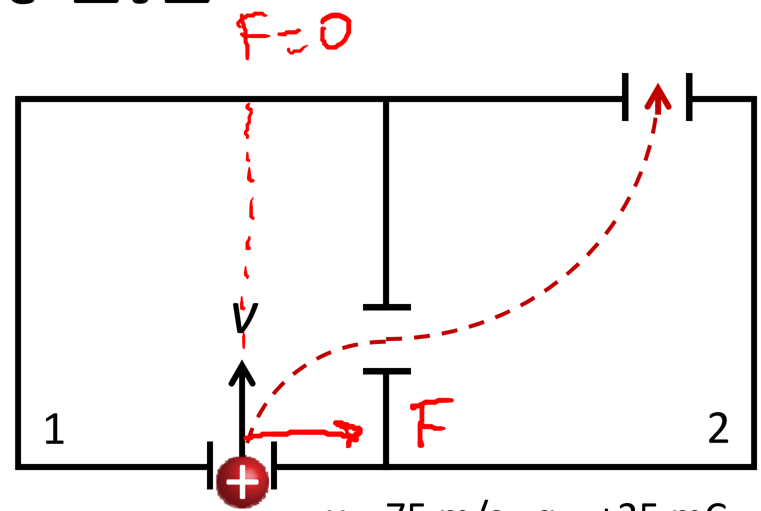
A. 1 B. 2 C. 3 D. All same

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.



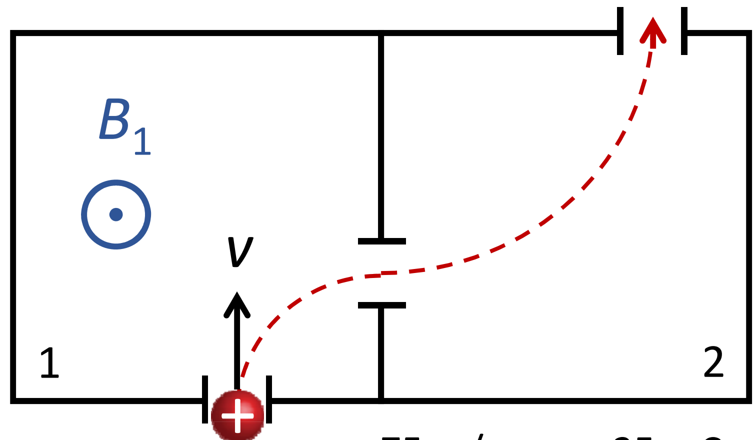
What is the direction of the *force* on the particle just as it enters region 1?

A. up — 32%
B. down — 8%
C. left — 7%
D. right — 38%

Particle is moving straight upwards then veers to the right

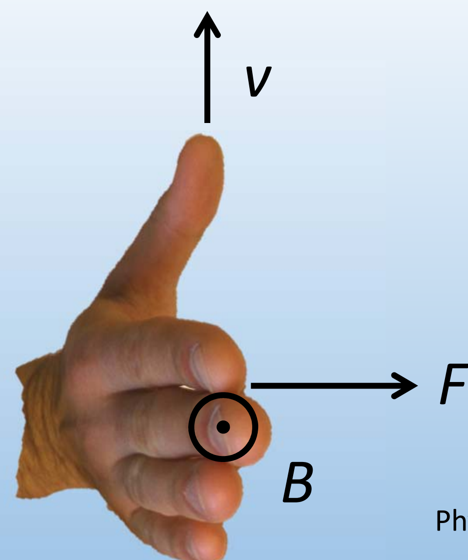
ACT: Checkpoint 1.2

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.



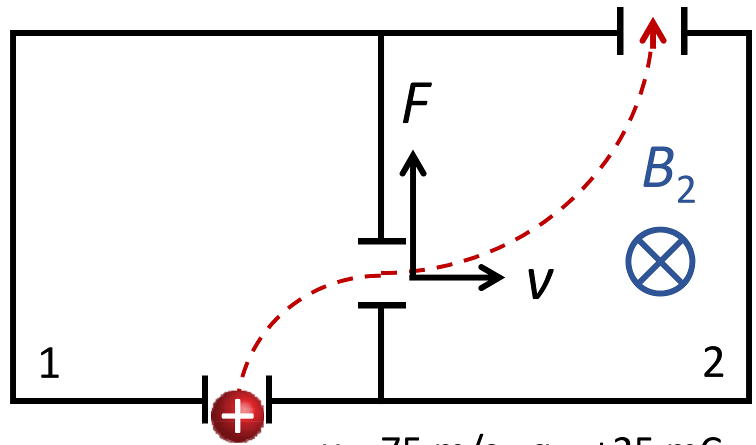
What is the direction of the *magnetic field* in region 1?

A. up 17%
B. down 9%
C. into page 11%
D. out of page 24%



Checkpoint 1.4

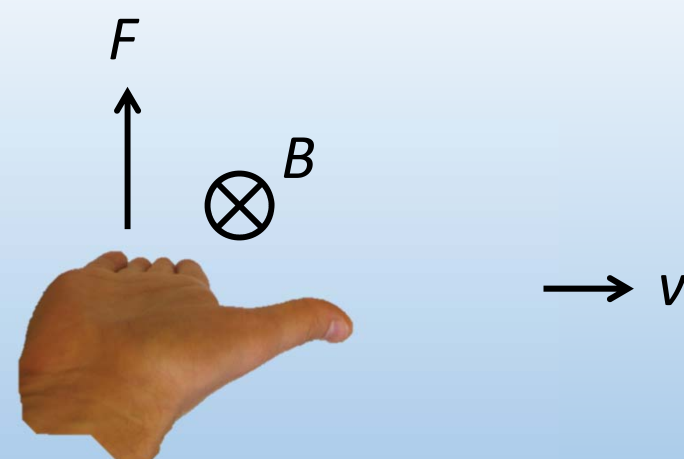
Each chamber has a unique magnetic field. A *positively* charged particle enters chamber 1 with velocity 75 m/s up, and follows the dashed trajectory.



v = 75 m/s q = +25 mC

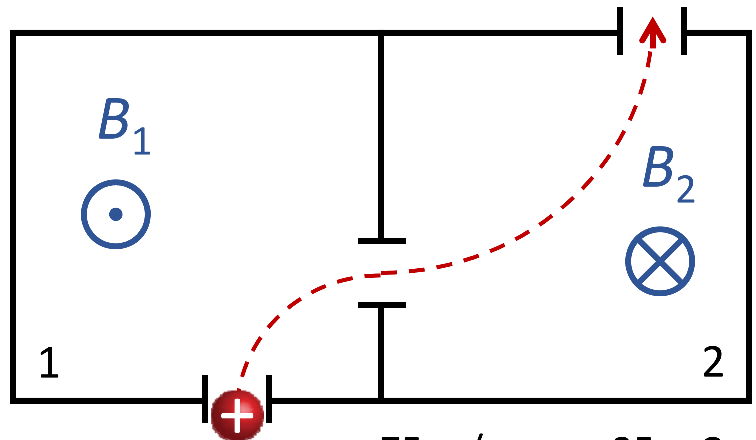
What is the direction of the *magnetic field* in region 2?

A. up 26%
B. down 9%
C. into page 20%
D. out of page 15%



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. $|B_1| > |B_2|$ 37%

B. $|B_1| = |B_2|$ 41%

C. $|B_1| < |B_2|$ 22%

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

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

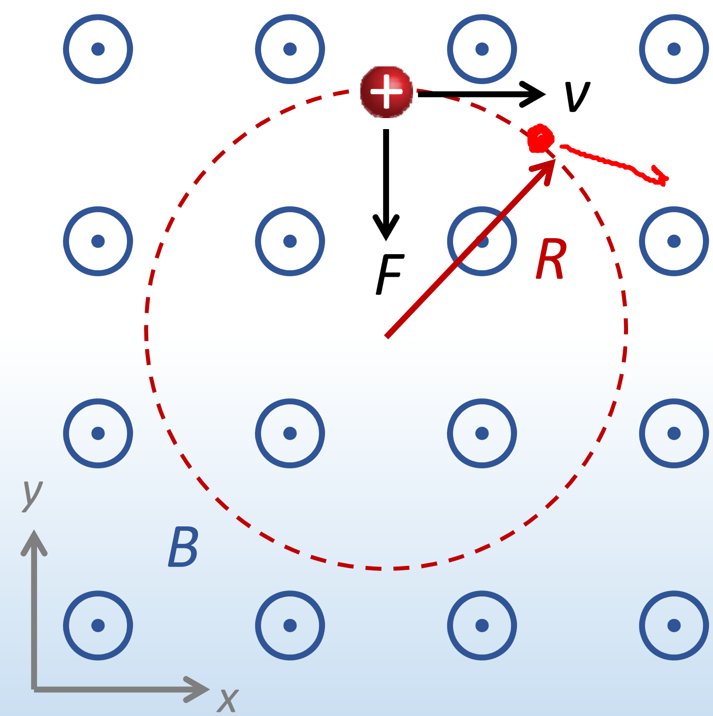
Motion in uniform B field

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

Particle moves in a circle

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

Principle of mass spectrometer



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

$$W_B = Fd\cos\theta = 0$$

Kinetic energy is constant

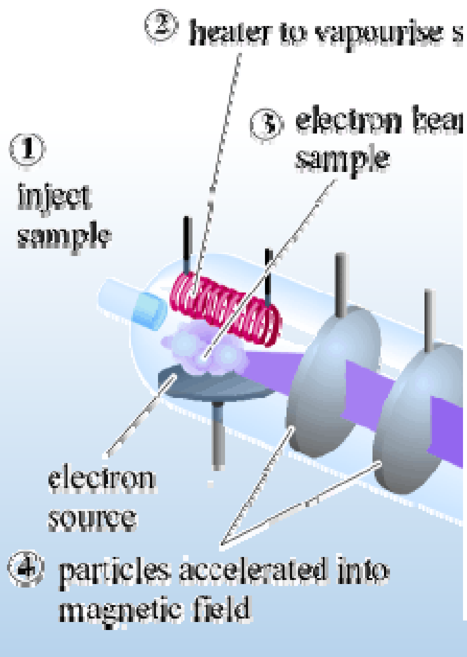
Speed is constant

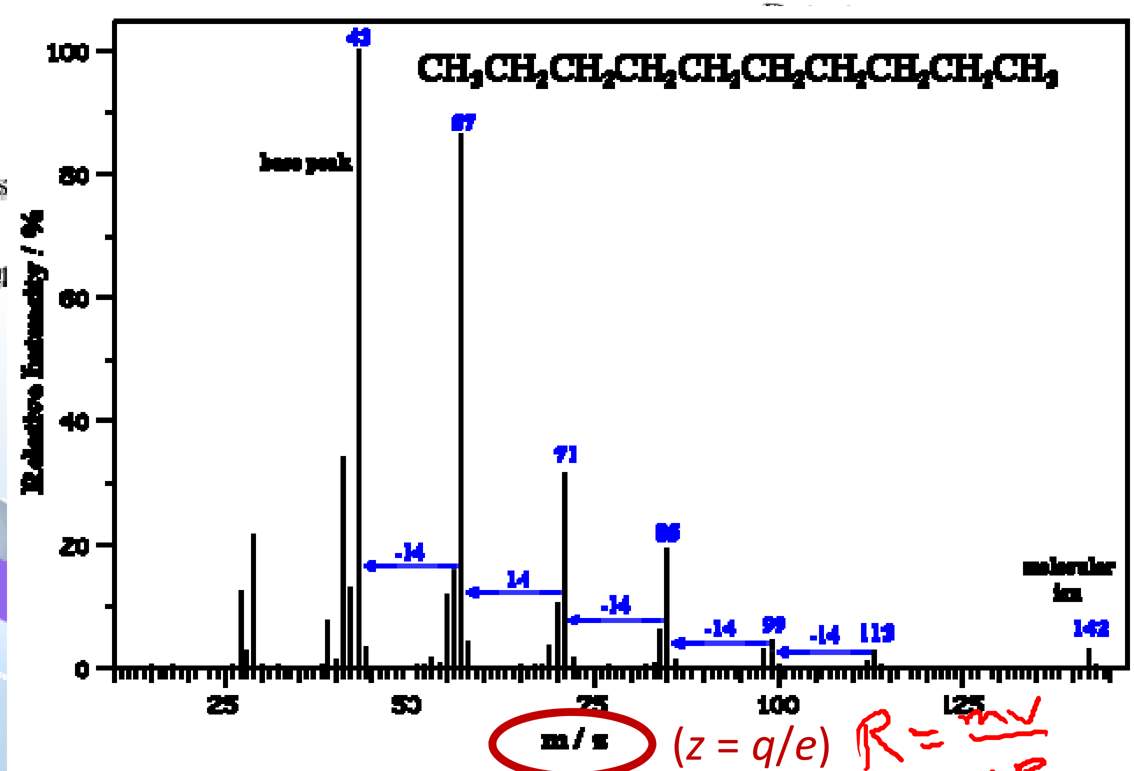
DEMO

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





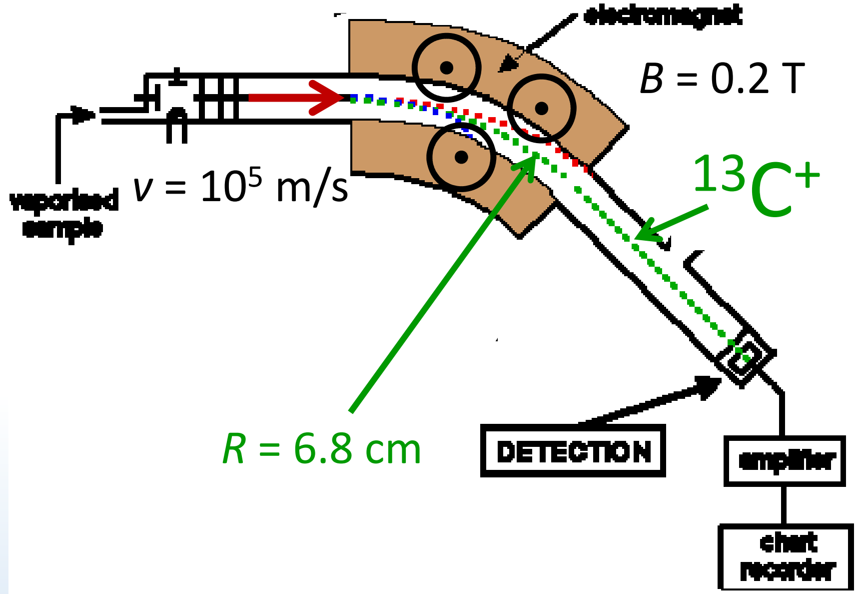
(z = q/e) $R = \frac{mv}{qB}$

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

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

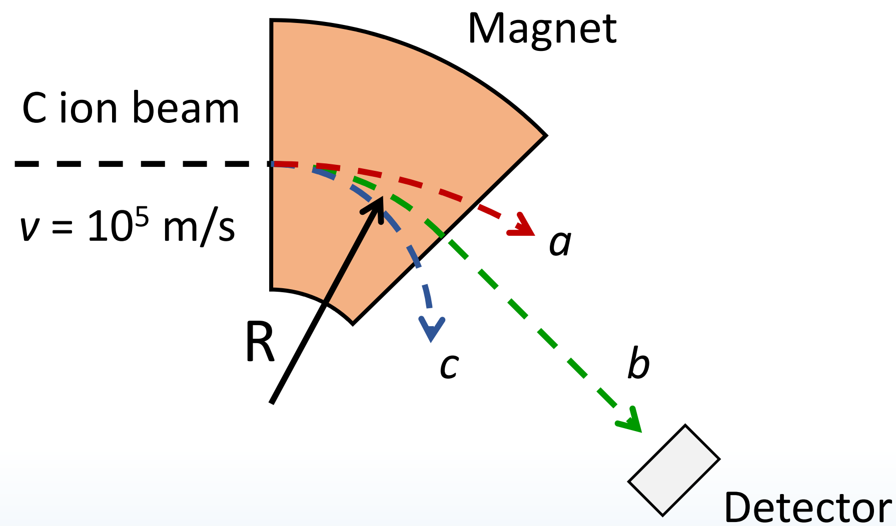
$$m = \frac{qBR}{v} = \frac{1.6\times10^{-19}\cdot 0.2\cdot 0.068}{10^5} = 2.18\times10^{-26}\,\mathrm{kg} = 13\,\mathrm{amu} \qquad {}^{13}C^+$$

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

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.



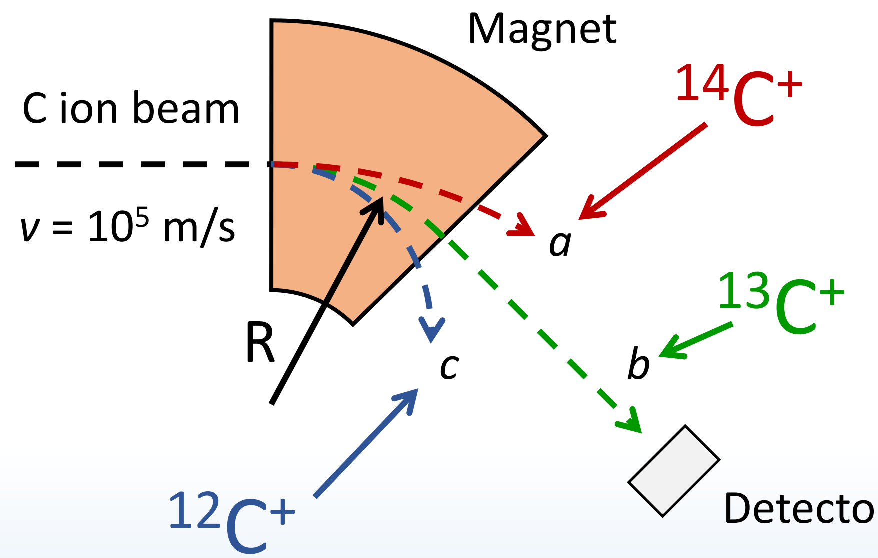
How do the speeds of the different isotopes *a*, *b*, *c* leaving the *B* field compare?

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. $m_a < m_b < m_c$

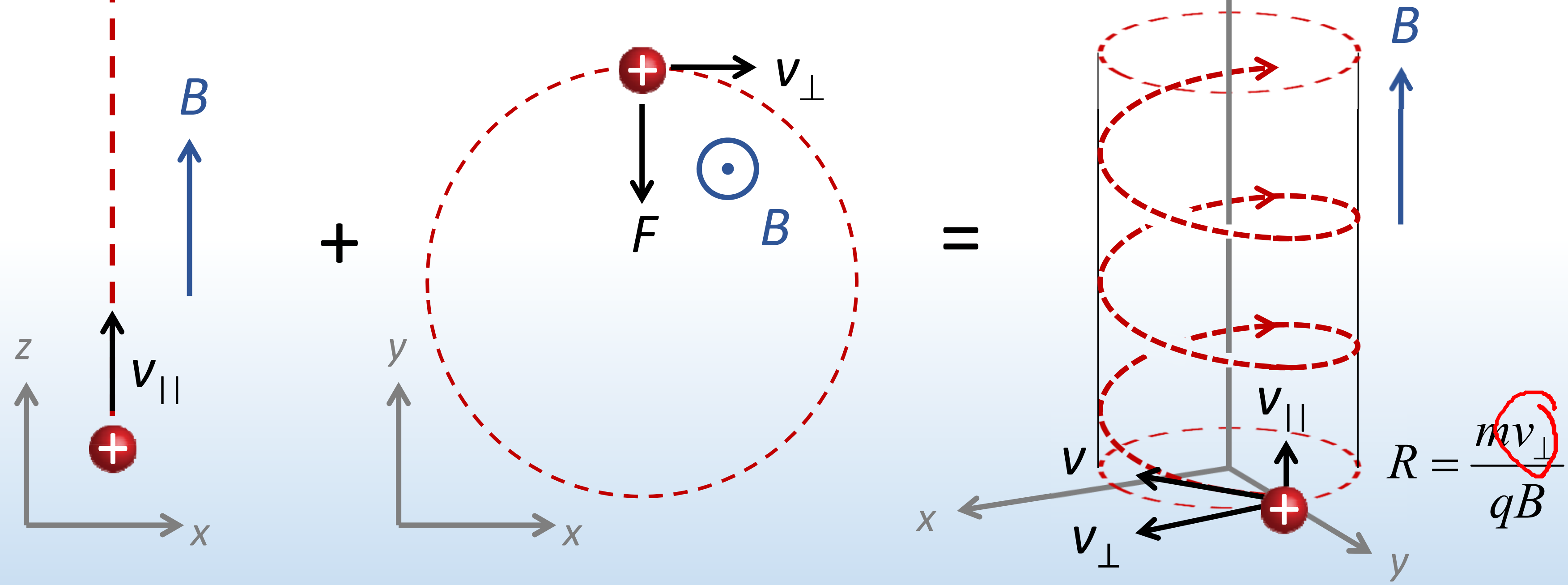
$$R = \frac{mv}{qB}$$

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*



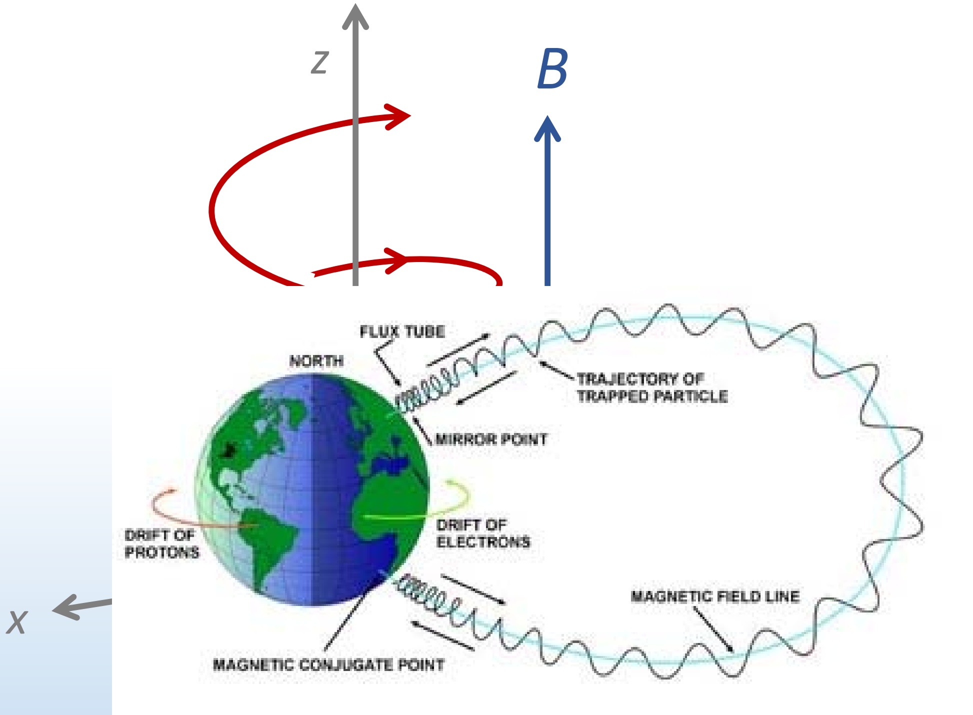
$F = 0$
Component || to *B*
remains constant

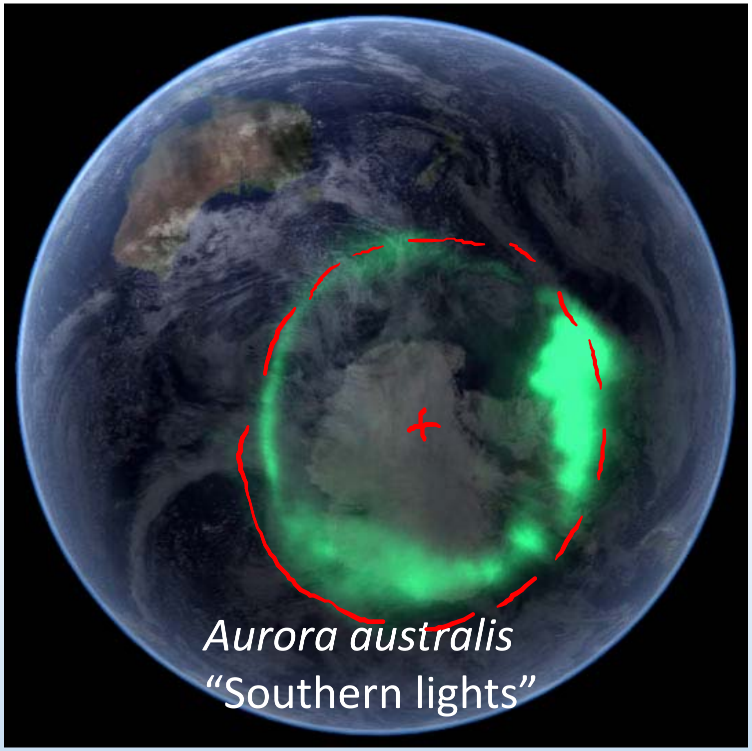
$F = qBv_\perp$
Component $\perp$ to *B*
rotates in a circle

Charge moves in a *helical* trajectory

Aurora borealis & australis

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



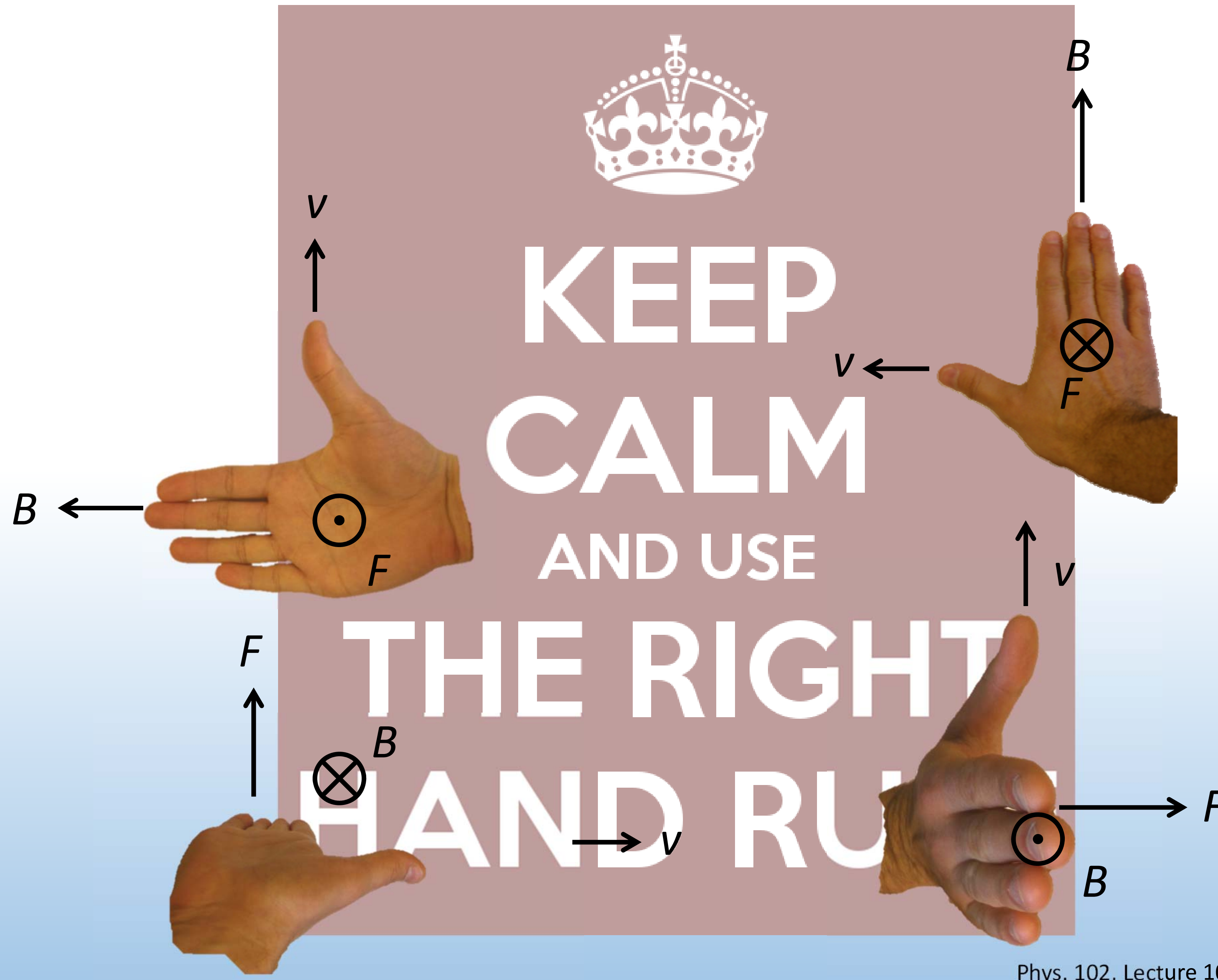


B field directs ions to atmosphere in north and south hemispheres.
Ions collide with particles in atmosphere and emit light: "*aurora*"

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:	$\vert\vert$ to E	$\perp$ to v, B
Work:	$W_E = qEd\cos(\theta)$	$W_B = 0$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