Physics 2112
Unit 12

Today’s Concept:
Magnetic Force on Moving Charges

\[
\vec{F} = q \vec{v} \times \vec{B}
\]
Where we are......

E fields

B fields
This is crazy. But also really cool.

What is that "K" = p^2/2m? I saw it in the prelecture question but I didn't see it in the actual prelecture slide.

Need to go over Question 3 in Pre-Lecture. If R=mv/qB then wouldn't a particle with 2x the charge and 4x the mass have 2x the R??????

The derived equations were difficult for me units units units.... how well do we have to know prefixes for the upcoming test?

Would like to see examples of cross product

I got confused comparing the magnitude of the magnetic field at chamber 1 and 2.

I need to review cross products & also are we using the vector from the electric field generated by the particle as the 2nd vector? Because that makes more sense.
Magnetic Force

Electric Field
- Any particle can cause \( \vec{E} \) field
- Any particle affected by \( \vec{E} \) field

Magnetic Field
- Only moving particle can cause \( \vec{B} \) field
- Only moving particle affected by \( \vec{B} \) field

\[
\vec{F} = q\vec{v} \times \vec{B}
\]
Units: Tesla (N/(Cm/sec))

Extremely large field so sometimes use Gauss = (10^{-4}T)

- Earth ~ 0.6 Gauss
- Frig Magnet ~ 0.01T (100 Gauss)
- MRI 1.5 -> 5.0 Tesla (15,000 – 30,000 Gauss)
- LHC 8.4 Tesla
- World’s Record 45 Tesla (National High Magnetic Field Laboratory at Florida State)
Cross Product Review

Cross Product different from Dot Product

\[ \vec{A} \cdot \vec{B} \] is a scalar; \[ \vec{A} \times \vec{B} \] is a vector
\[ \vec{A} \cdot \vec{B} \] proportional to the component of \( B \) parallel to \( A \)
\[ \vec{A} \times \vec{B} \] proportional to the component of \( B \) perpendicular to \( A \)

Definition of \( \vec{A} \times \vec{B} \)

Magnitude: \( |A||B|\sin\theta \)
Direction: perpendicular to plane defined by \( A \) and \( B \) with sense given by right-hand-rule
Remembering Directions: The Right Hand Rule

\[ \vec{F} = q\vec{v} \times \vec{B} \]
A permanent magnet has field lines as shown above. An electron moves out of the slide toward you at point A. The magnetic force on the electron is best represented by:
A proton moves to the right at point B. The magnetic force on the proton is best represented by:

- A
- B
- C
- D
- E

D
Zero

E
None of the above
An electron moves vertically upward at point C. The magnetic force on the electron is represented by:

A  B  C
D  E  Zero

None of the above
A proton is at rest at point D. The magnetic force on the proton is best represented by:

A. 
B. 
C. 
D. Zero
E. None of the above
Example 12.1 (Acceleration of proton)

The earth’s magnetic field is pointed roughly 70° from the horizontal in Chicago.

What would the acceleration of a proton be if it were moving at 10% of the speed of light in the horizontal direction?
A particle enters a magnetic field \( \vec{B} = -0.2 \hat{k} T \).

The particle had charge of 1\( \mu \)C and a velocity of \( \vec{v} = (-0.3 \hat{i} + 0.7 \hat{j}) m/\text{sec} \).

What is the force on the particle?
Three points are arranged in a uniform magnetic field. The \textbf{B} field points into the screen.

A positively charged particle is located at point A and is stationary.

The direction of the magnetic force on the particle is:

A. right
B. left
C. into the screen
D. out of the screen
E. zero
Three points are arranged in a uniform magnetic field. The \( \mathbf{B} \) field points into the screen.

A positively charged particle is located at point A and is stationary.

The direction of the magnetic force on the particle is:

A. right  
B. left  
C. into the screen  
D. out of the screen  
E. zero
Three points are arranged in a uniform magnetic field. The B field points into the screen.

Now the positive charge moves from point A toward B.

The direction of the magnetic force on the particle is:

A. right
B. left
C. into the screen
D. out of the screen
E. zero
The positive charge moves from point A toward B.

The direction of the magnetic force on the particle is:

A. right
B. left
C. into the screen
D. out of the screen
E. zero

A. We point our thumb in the direction of movement and our fingers in direction of the magnetic field. The way your palm points is the answer.

B. Now we have a velocity vector and a magnetic field vector. The cross product of this velocity with the magnetic field creates a force to the left.

C. The field still points in the same direction, meaning the resultant cross product still points into the screen.

\[ \vec{F} = q\vec{v} \times \vec{B} \]
A particle of charge $+q$ and velocity $v$ enters a vacuum containing a uniform magnetic field, $B$. The particle’s velocity is perpendicular to the direction of the field.

After the particle enters the magnetic field, its path is

A. a parabola.
B. circular.
C. spiral.
D. a straight line
E. a hyperbola
Motion of Charge $q$ in Uniform $B$ Field

**Force is perpendicular to $v$**
- Speed does not change
- Uniform Circular Motion

**Solve for $R$:**

\[ \vec{F} = q\vec{v} \times \vec{B} \implies F = qvB \]

\[ a = \frac{v^2}{R} \]

\[ qvB = m \frac{v^2}{R} \quad \Rightarrow \quad R = \frac{mv}{qB} \]
Pre-lecture 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?

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.
A proton enters the magnetic field of an analysis magnet at Fermilab and it deflected by an angle of $\Theta = 10^\circ$. The field has a strength of 0.2T and a length of 2meters. What is the speed of the incoming proton?
Follow up

The analysis magnet

Question: In the previous example how did you know it was a proton?
Example 12.3 (Effect of $v$ on $R$ and $f$)

A proton moving in a circle with a radius $R$ inside a constant magnetic field. It completes the circle with some frequency, $f$.

If you double velocity of the particle, how does the radius change?

How does the frequency change?
What good is this?

Two Copper “D”s

Alternating E Field Btwn “D” (to increase v)

E.O. Lawrence
1939 Nobel Prize in Physics for “cyclotron”

Circular Magnetic Field (to steer)
How big are these things?
How big are these things?

LHC
Swiss-French Border
17 miles diameter
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?

A. up
B. down
C. into the screen
D. out of the screen
E. zero
What we thought......

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

A. up
B. down
C. into the screen
D. out of the screen
E. zero

B) to attract the positive charge it must be down.

C) Since the particle is moving in a clockwise direction, the field would be into the page because of the right hand rule.

D) If the magnetic field in chamber 1 points out of the screen, based on the right hand rule, the magnetic force points to the right, which fits the trajectory of the particle in chamber 1.
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.

A. $|B_1| > |B_2|$
B. $|B_1| = |B_2|$
C. $|B_1| < |B_2|$
What we thought.....

Compare the magnitude of the magnetic field in chamber 1 to the magnitude of the magnetic field in chamber 2.

A. \( |B_1| > |B_2| \)
B. \( |B_1| = |B_2| \)
C. \( |B_1| < |B_2| \)

Motion in a Magnetic Field: Question 1 (N = 34)

A. c  t  l
B. k

Observation: \( R_2 > R_1 \)

\[
R = \frac{mv}{qB} \quad \Rightarrow \quad |B_1| > |B_2|
\]
Example 12.4 (mass spectrometer)

Using a velocity selector, singly ionized $^{235}\text{U}$ and $^{238}\text{U}$ atoms are injected in a 0.3T magnetic field at 100m/sec. If they are allowed to travel $180^\circ$, how far from will the two isotopes be?
The below velocity selector has the magnetic field pointing into the screen and the electric field pointing down. Ions with a speed of \( v_c \) and a mass of \( m_c \) make it all the way through. If an ion is injected with a speed of twice \( v_c \), the particle will:

a) make it all the way through  
b) hit the bottom of the selector  
c) hit the top of the selector
The below velocity selector has the magnetic field pointing into the screen and the electric field pointing down. Ions with a speed of \( v_c \) and a mass of \( m_c \) make it all the way through. If an ion is injected with a mass of twice \( m_c \), the particle will:

a) make it all the way through  
b) hit the bottom of the selector  
c) hit the top of the selector
An airplane viewed from above flies through a small magnetic field oriented vertically downward toward the ground, as shown to the right. Which of the following statements is true?

A. The plane’s front becomes positively charged.
B. The tip of the left wing becomes positively charged.
C. The top of the plane becomes positively charged.
D. None of the above, there’s no charging mechanism.

**The Hall Effect**