Physics 202, Lecture 11

Today’s Topics

- Magnetic Forces (Ch. 29)
- Review: magnetic force
- Motion of charge in uniform B field:
  Applications: cyclotron, velocity selector, Hall effect
Magnetic Fields and Forces: Recap

**Magnetic Force:** experienced by moving charges

\[ \vec{F} = q \vec{v} \times \vec{B} \]  
(point charges)

\[ \vec{F} = \int I d\vec{l} \times \vec{B} \]  
(currents)

**Magnetic Field B:** sourced by moving charges  
*direction:* as indicated by north pole of compass

Units: 1 Tesla (T) = 1 N/(A m)

Field lines: closed loops!  
Outside magnet: N to S  
Inside magnet: S to N
Suppose charge $q$ enters a uniform $B$-field with velocity $v$. What will be the path that $q$ follows?

Force perpendicular to velocity: uniform circular motion

Note: magnetic force does no work on the charge!
Kinetic energy constant
Trajectory in Uniform B Field

- **Force:**
  \[ F = qvB \]

- **centripetal acc:**
  \[ a = \frac{v^2}{R} \]

- **Newton's 2nd Law:**
  \[ F = ma \quad \Rightarrow \quad qvB = m\frac{v^2}{R} \]

  \[ \Rightarrow \quad R = \frac{mv}{qB} = \frac{p}{qB} \]

  (an important result, with useful experimental consequences!)

- **“Cyclotron” frequency:**
  \[ \omega = \frac{v}{R} = \frac{qB}{m} \quad T = \frac{2\pi}{\omega} = \frac{2\pi m}{qB} \]
Application: Cyclotron

First Modern Particle Accelerator

First Cyclotron (1934)
Lawrence & Livingston
Trajectory in Uniform B Field: 3D case

General 3D case:

- In the plane perpendicular to B:
  \[ R = \frac{mv_{\perp}}{qB} \quad T = \frac{2\pi m}{qB} \]

- Parallel to B: spacing b/w turns of helix
  \[ d = v_{\parallel}T = \frac{v_{\parallel}2\pi m}{qB} \]
Application: Velocity, Mass Selectors

Velocity and mass selector:

speed selected:

\[ v = \frac{E}{B} \]

mass selected:

\[ \frac{m}{q} = \frac{rB_0}{v} = \frac{rB_0}{(E/B)} \]
Magnetic Force On A Current Carrying Wire

Top View

(a) 

(b) 
$I = 0$

(c) 
$I$

(d) 
$I$

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For forces on a current loop, in a uniform magnetic field as shown, what is the direction of the force on each side?

Case 1: 
1. Upward force on side 1.
2. Downward force on side 3.
3. No force on side 2.

Case 2: 
1. Upward force on side 1.
2. Downward force on side 3.
3. No force on side 2.

Recall: \( \sum F_B = 0 \)
Torque on a Current Loop

(a) Axis of rotation

(b) $\vec{F}_1$, $\vec{F}_2$,

(c) $\vec{F}_1$ (perpendicular to coil face)

$\vec{\mu} = NIA$
The Galvanometer
The Hall Effect

Potential difference on current-carrying conductor in B field:

Equilibrium between electrostatic & magnetic forces:

\[ F_{\text{up}} = qv_d B \quad F_{\text{down}} = qE_{\text{ind}} = q \frac{V_H}{W} \quad V_H = v_d Bw = "\text{Hall Voltage}" \]

(first evidence that electrons are charge carriers in most metals)