Physics 202, Lecture 11

Today’s Topics

- Magnetic Fields and Forces
  - Magnetic materials
  - Magnetic forces on moving point charges
  - Magnetic forces on currents, current loops
  - Motion of charge in uniform B field
Magnetism: Overview

Previously: electrostatics

- Forces and fields due to stationary charges
- Coulomb force $F_E$, Electrostatic field $E$:

$$F_E = qE$$

Now: magnetism (first, magnetostatics)
(historically: magnetic materials, Oersted effect)

- Forces and field due to moving charges (currents)
- Magnetic Force $F_B$, magnetic field $B$:

$$F_B = qv \times B$$  \hspace{1cm} \text{(charges: Lorentz force)}$$

$$F_B = \int Idl \times B$$  \hspace{1cm} \text{(currents)}$$
Focus first on bar magnets (permanent magnets):
Two types of poles: N and S

Magnetic forces: like poles repel, opposite poles attract

Magnetic field: \( \mathbf{B} \) (vector field).
Units: 1 Tesla (T) = 1 N/(A m)

Direction: as indicated by compass’s “north” pole

Field lines:
Outside magnet: N to S
Inside magnet: S to N
## Typical Magnetic Field Strengths

<table>
<thead>
<tr>
<th>Source of Field</th>
<th>Field Magnitude (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong superconducting laboratory magnet</td>
<td>30</td>
</tr>
<tr>
<td>Strong conventional laboratory magnet</td>
<td>2</td>
</tr>
<tr>
<td>Medical MRI unit</td>
<td>1.5</td>
</tr>
<tr>
<td>Bar magnet</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Surface of the Sun</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Surface of the Earth</td>
<td>$0.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Inside human brain (due to nerve impulses)</td>
<td>$10^{-13}$</td>
</tr>
</tbody>
</table>

1 Gauss = $10^{-4}$ Tesla
Magnetic Field Lines of a bar magnet

Electric Field Lines of an Electric Dipole

Dipole field only
No monopoles

Electrostatics analogy:

Magnetic Field Lines of a bar magnet
Bar Magnets and Compass

Recap: 2 magnetic poles, N and S
- like poles repel, opposite poles attract
- both poles attract iron (ferromagnetic material)
- Two poles not separable

Compass: a bar magnet
- Its “north” pole (conventionally defined) points towards the northern direction

Magnets  Modern compasses  An ancient Chinese compass (~220BC)
Magnetic Force

We know about the existence of magnetic fields by the force they exert on moving charges.

What is the "magnetic force"?
How is it distinguished from the "electric" force?

Experimental observations about the magnetic force $F_B$:

a) magnitude: $\propto$ to velocity of $q$

b) direction: ⊥ to direction of $q$'s velocity

c) direction: ⊥ to direction of $B$

$B$ is the magnetic field vector
Cross product review (board):

- **direction**: “right hand rule”
- **magnitude**: \( \vec{F} = q\vec{v} \times \vec{B} \)

\[ F = qvB \sin \theta \]
Magnetic Force

Force $F$ on charge $q$ moving with velocity $v$ through region of space with magnetic field $B$:

$$\vec{F} = q\vec{v} \times \vec{B}$$

If also electric field $E$: Lorentz Force Law

$$\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$$
Exercise: Direction of Magnetic Force

Indicate the direction of $\mathbf{F}_B$ in the following situations:

(a) B out of page:

(b) B into page:
Question: Direction of Magnetic Force

Which fig has the correct direction of $\mathbf{F}_B$?
Question: Direction of Magnetic Force

Which fig has the correct direction of $\mathbf{F}_B$?
Magnetic Force On Current Carrying Wire(1)

Now you know how a single charged particle moves in a magnetic field. What about a group?

In a portion of current-carrying conducting wire:

- \( n \) number of charges per unit volume
- \( A \) area of the conductor
- \( dl \) length of the element
- \( \vec{v}_d \) drift velocity of a charge

Then

\[
dF_B = nA dl (q \vec{v}_d \times \vec{B}) = I dl \times \vec{B}
\]

\[
\Rightarrow I \int dl \times \vec{B} = I \vec{L} \times \vec{B}
\]

(for uniform field)
Magnetic Force On A Current Carrying Wire (2)
Magnetic Force On Current Carrying Wire(3)

For a **uniform** magnetic field:

To get the sum of a number of vectors - put them all head to tail and connect the initial \((a)\) and final point \((b)\):

\[
\int_{a}^{b} d\vec{l} = \vec{L}_{ba}
\]

If the initial and final points are the same, the integral is **zero**!

There is **no net magnetic force** on a **closed current loop** in a uniform magnetic field.
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