Physics 202, Lecture 11

Today’s Topics

- Magnetic Fields and Forces (Ch. 29)
  - 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 $E$:
  $$\vec{F}_E = q\vec{E}$$

Now: magnetism (first, magnetostatics)
(historically: magnetic materials, Oersted effect)
- Forces and field due to moving charges (currents)
- Magnetic Force $F_B$, magnetic field $B$:
  $$\vec{F}_B = qv \times \vec{B}$$  (charges: Lorentz force)
  $$\vec{F}_B = \int Id\vec{l} \times \vec{B}$$  (currents)

Magnetic Materials (1)

Focus first on bar magnets (permanent magnets):
  Two types of poles: N and S

Magnetic forces: like poles repel, opposite poles attract

Magnetic field: $B$  (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
**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

**Earth’s Magnetic Field**

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: \( \perp \) to direction of \( q \)'s velocity
- c) direction: \( \perp \) to direction of \( B \)

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

- direction: “right hand rule”
- magnitude: $F = qvB \sin \theta$

**Magnetic Force**

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

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

If also electric field $E$: Lorentz Force Law

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

**Exercise: Direction of Magnetic Force**

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

**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

$$dF_B = nAdl(q\vec{v}_d \times \vec{B}) = Idl \times \vec{B}$$

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

(for uniform field)

Magnetic Force On Current Carrying Wire (2)

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

$$\int_a^b \vec{d}l = \vec{L}_{ba}$$

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.

Magnetic Force On Current Carrying Wire (3)
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