MAGNETISM & ELECTROMAGNETISM
Lodestone - magnetite $\text{Fe}_3\text{O}_4$
Magnetic Domains

Domains Before Magnetization

Domains After Magnetization
Earth’s Magnetic Field
Magnetic Field- Bar Magnet
Unlike Poles Attract

Like Poles Repel
Magnetic Field - Horseshoe Magnet
Magnetic Dipole

Magnetic Field (B-Field)
Magnetic Monopoles

Do not exist!

In this way they differ from electric dipoles, which can be separated into electric monopoles.

i.e., No North without a South
Units

- Tesla (SI)
- N/(Cm/s)
- N/(Am)
- Gauss

1 T = 10^4 gauss
Magnetic Fields

- Formed by moving charge
- Affect moving charge
Magnetic Forces can...

- accelerate charged particles by changing their direction
- cause charged particles to move in circular or helical paths
Magnetic Forces cannot...

- change the speed or kinetic energy of charged particles
- do work on charged particles
Magnetic Force on moving Charged Particle

- **magnitude**: $F = qvB\sin\theta$
  - $q$: charge in Coulombs
  - $v$: speed in meters/second
  - $B$: magnetic field in Tesla
  - $\theta$: angle between $v$ and $B$

- **direction**: Right Hand Rule
What orientation is angle $0^\circ$?  
What is $\sin 0^\circ$ equal to?

What orientation is angle $90^\circ$?  
What is $\sin 90^\circ$ equal to?
Right hand Rule #1

Rule applies to + charges
Magnetic Force

Calculate the magnitude and direction of the magnetic force.

\[ v = 300,000 \text{ m/s} \]

\[ B = 200 \text{ mT} \]

\[ q = 3.0 \mu \text{C} \]

\[ \theta = 34^\circ \]
When $v$ and $B$ are at right angles to each other, the magnetic force is a centripetal force. 

$$qvB = \frac{mv^2}{r}$$
Magnetic Force on Current-carrying Wire

\[ F = I L B \sin \theta \]

- \( I \): current in Amps
- \( L \): length in meters
- \( B \): magnetic field in Tesla
- \( \theta \): angle between current and field
Force on a Current-Carrying Wire
Right Hand Rule # 2

Electric current \( I \)

Magnetic field \( B \)
Hand Rule

- Curve your fingers
- Place your thumb (which is presumably pretty straight) in direction of current.
- Curved fingers represent curve of magnetic field.
- Field vector at any point is tangent to field line.
For straight currents
Magnetic Field Created by a Solenoid - RHR #3
Electromagnet
Electric Generator

- How is this similar to an Electric Motor?
Generator Animation
Making Electricity
Making Motion
Magnetic Flux

- The product of magnetic field and area.
- Can be thought of as a total magnetic "effect" on a coil of wire of a given area.
Magnetic Flux

- $\Phi_B = BA\cos\theta$
- $\Phi_B$: magnetic flux in Webers (Tesla meters$^2$)
- $B$: magnetic field in Tesla
- $A$: area in meters$^2$.
- $\theta$: the angle between the area and the magnetic field.
Magnetic Flux

- A system will respond so as to **oppose changes in magnetic flux**.
- Changing the magnetic flux **can generate electrical current**.
Faraday’s Law of Induction

\[ \varepsilon = -N \frac{\Delta \Phi}{\Delta t} \]

- \( \varepsilon \): induced potential (V)
- \( N \): # loops
- \( \Phi_B \): magnetic flux (Webers, Wb)
- \( t \): time (s)
A closer look ...

\[ \varepsilon = -N \frac{\Delta \Phi}{\Delta t} \]

\[ \varepsilon = -\Delta (BA\cos \theta) / \Delta t \]

➢ To generate voltage:
  ➢ Change B
  ➢ Change A
  ➢ Change \( \theta \)
Lenz’s Law

- The current will flow in a direction so as to oppose the change in flux.
- Use in combination with hand rule to predict current direction.
Increasing B-Field

Direction of current in Loop (end view)
Motional emf derivation
Motional Emf

\[ \mathcal{E} = \frac{\Delta BA}{\Delta t} \]

\[ \mathcal{E} = Bl \frac{\Delta x}{\Delta t} \]

\[ \mathcal{E} = Blv \]
Challenge Problem

How large a force is needed to move the rod at a constant speed of 2 m/s? How much power is dissipated in the resistor?

\[ 50 \text{ cm} \]

\[ 3 \, \Omega \]

\[ B = 0.15 \, \text{T} \]

\[ v = 2 \, \text{m/s} \]