PHYS12 CH22: Magnetism

Sections 22.1-22.8

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Learning Objectives

By the end of this presentation, you should be able to:

- Describe the basic properties of magnets and magnetic fields
- Explain ferromagnetism and how electromagnets work
- Understand magnetic field lines and their properties
- Calculate the force on a moving charge in a magnetic field
- Apply the right-hand rule to determine the direction of magnetic forces
- Explain the Hall effect and its applications
- Calculate the force on a current-carrying conductor in a magnetic field
- Determine the torque on a current loop in a magnetic field

Outline

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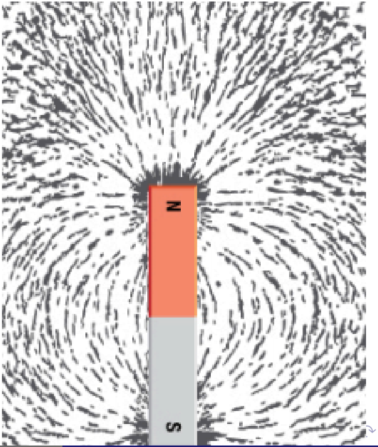
Basic Concepts of Magnetism

Magnetism

Properties of magnets, effect of magnetic force on moving charges and currents, and creation of magnetic fields by currents.

- Two types of magnetic poles:
  - North magnetic pole
  - South magnetic pole
- North magnetic poles are attracted toward Earth's geographic north pole
- Like poles repel, unlike poles attract
- Magnetic poles always occur in pairs—cannot be isolated



Ferromagnetic Materials

- Materials exhibiting strong magnetic effects (e.g., iron)
- Atoms act like small magnets (due to internal currents)
- Form millimeter-sized regions called **domains**
- Domains can align to create permanent magnets
- Above Curie temperature, thermal agitation destroys alignment

Electromagnets

- Use electric currents to make magnetic fields
- Often aided by induced fields in ferromagnetic materials
- Field strength depends on current and number of turns
- Field can be turned on and off

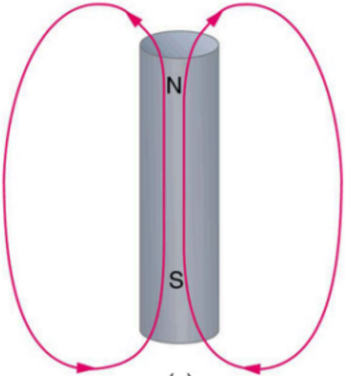
Magnetic Field Lines

Magnetic Field Representation

Magnetic fields can be pictorially represented by magnetic field lines.

Properties of magnetic field lines:

1. The field is tangent to the magnetic field line
2. Field strength is proportional to line density
3. Field lines cannot cross
4. Field lines are continuous loops



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Force on Moving Charge in Magnetic Field

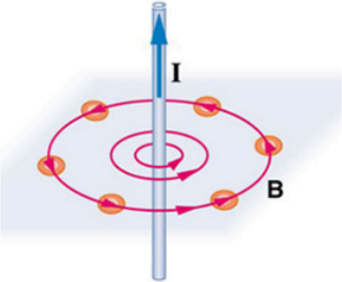
Magnetic Force Formula

The magnitude of the magnetic force on a moving charge q is:

$$F = qvB\sin\theta \tag{1}$$

where θ is the angle between the directions of $\vec{v}$ and $\vec{B}$.

- SI unit for magnetic field B: tesla (T)
- $1\ \mathrm{T} = \frac{1\ \mathrm{N}}{\mathrm{A{\cdot}m/s}} = \frac{1\ \mathrm{N}}{\mathrm{A{\cdot}m}}$
- Force direction given by right hand rule 1 (RHR-1)
- Force is perpendicular to plane formed by $\vec{v}$ and $\vec{B}$
- Force is zero if $\vec{v}$ is parallel to $\vec{B}$



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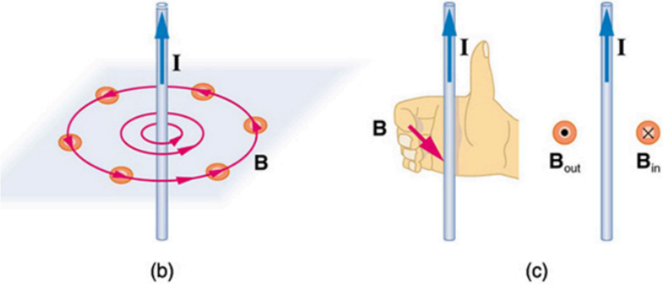

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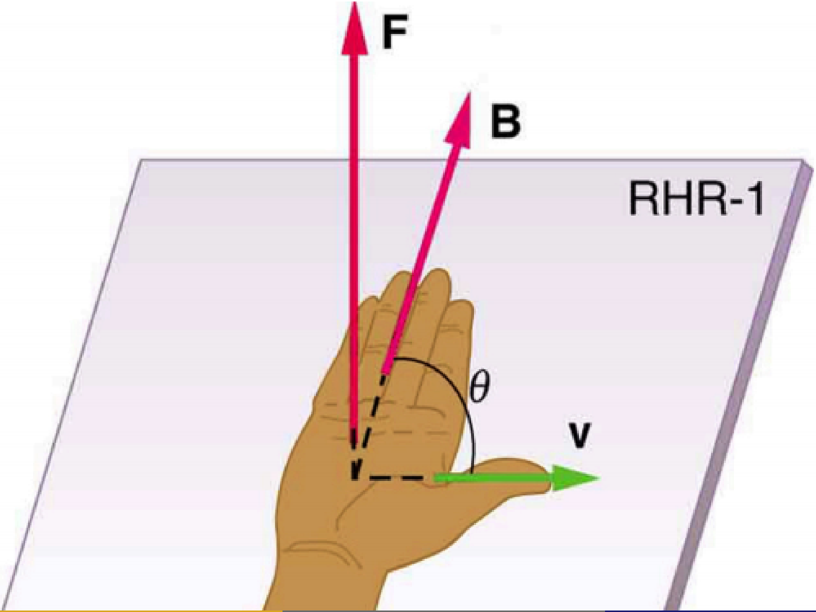


Applications of Force on Moving Charges

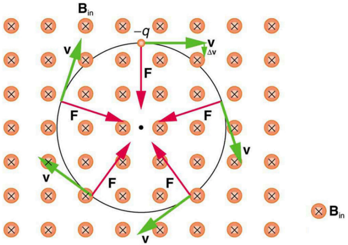
Circular Motion in Magnetic Field

Magnetic force can supply centripetal force causing charged particles to move in circular paths with radius:

$$r = \frac{mv}{qB} \tag{2}$$

where v is the component of velocity perpendicular to $\vec{B}$.

- Basis for many applications:
  - Mass spectrometers
  - Cyclotrons
  - Synchrotrons
  - Particle detectors
- Only affects moving charges
- Direction changes with charge polarity



The Hall Effect

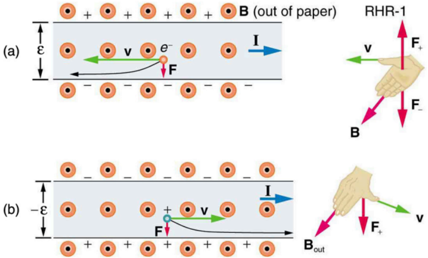
Hall Effect Definition

The creation of voltage ε (Hall emf) across a current-carrying conductor by a magnetic field.

- Hall emf is given by:

$$\varepsilon = Blv \qquad (3)$$

- B, l, and v must be mutually perpendicular
- For conductor of width l with charges moving at speed v
- Applications:
  - Measuring magnetic fields
  - Determining charge carrier type and density
  - Hall effect sensors



Magnetic Force on a Current-Carrying Conductor

Force Formula

The magnetic force on a current-carrying conductor is:

$$F = IlB \sin\theta \tag{4}$$

where I is the current, l is the length of the conductor, B is the magnetic field strength, and θ is the angle between $\vec{I}$ and $\vec{B}$.

- Direction follows RHR-1 with thumb in direction of $\vec{I}$
- Maximum force when conductor is perpendicular to field
- No force when conductor is parallel to field
- Basis for electric motors

Torque on a Current Loop: Motors and Meters

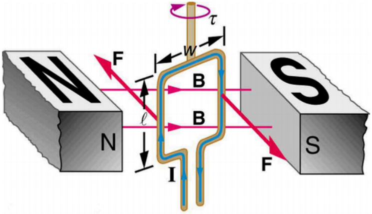
Torque Formula

The torque on a current-carrying loop in a uniform magnetic field is:

$$\tau = NIAB \sin\theta \tag{5}$$

where N is the number of turns, I is the current, A is the loop area, B is the magnetic field strength, and θ is the angle between the perpendicular to the loop and the magnetic field.

- Maximum torque when loop is parallel to field
- Zero torque when loop is perpendicular to field
- Applications:
    - Electric motors
    - Galvanometers
    - Ammeters



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Example 1: "I do"

Problem

Calculate the force on an electron moving at 5.0×10^6 m/s perpendicular to a magnetic field of 0.50 T.

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Solution

Given:

- Charge of electron: $q = -1.60 \times 10^{-19}$ C
- Velocity: $v = 5.0 \times 10^6$ m/s
- Magnetic field: $B = 0.50$ T
- Angle: $\theta = 90$ (perpendicular)

The negative sign indicates the force is in the direction opposite to that given by RHR-1 for a positive charge.

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Using the formula $F = qvB \sin\theta$:

$$F = (-1.60 \times 10^{-19}\ \text{C})(5.0 \times 10^{6}\ \text{m/s})(0.50\ \text{T})(\sin 90) \tag{6}$$
$$F = (-1.60 \times 10^{-19})(5.0 \times 10^{6})(0.50)(1) \tag{7}$$
$$F = -4.0 \times 10^{-13}\ \text{N} \tag{8}$$

The negative sign indicates the force is in the direction opposite to that given by RHR-1 for a positive charge.

Example 2: "We do"

Problem

Find the radius of the circular path of a proton with speed 3.0×10^6 m/s in a magnetic field of 0.75 T when the proton velocity is perpendicular to the field.

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Find the radius of the circular path of a proton with speed 3.0×10^6 m/s in a magnetic field of 0.75 T when the proton velocity is perpendicular to the field.

Solution

Given:

- Mass of proton: $m = 1.67 \times 10^{-27}$ kg
- Charge of proton: $q = 1.60 \times 10^{-19}$ C
- Velocity: $v = 3.0 \times 10^6$ m/s
- Magnetic field: $B = 0.75$ T

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Using the formula $r = \frac{mv}{qB}$:

$$r = \frac{(1.67 \times 10^{-27}\ \text{kg})(3.0 \times 10^{6}\ \text{m/s})}{(1.60 \times 10^{-19}\ \text{C})(0.75\ \text{T})} \tag{9}$$

$$r = \frac{5.01 \times 10^{-21}}{1.20 \times 10^{-19}} \tag{10}$$

$$r = 4.2 \times 10^{-2}\ \text{m} = 4.2\ \text{cm} \tag{11}$$

Example 3: "You do"

Problem

A straight wire carrying a 5.0 A current is placed in a uniform magnetic field of 0.25 T. If the wire is 10 cm long and makes an angle of 30° with the field, what is the magnetic force on the wire?

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Hints

- Use the formula $F = IlB \sin\theta$
- Convert all units to SI
- Remember to calculate the sine of the angle

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A straight wire carrying a 5.0 A current is placed in a uniform magnetic field of 0.25 T. If the wire is 10 cm long and makes an angle of 30° with the field, what is the magnetic force on the wire?

Hints

- Use the formula $F = IlB \sin\theta$
- Convert all units to SI
- Remember to calculate the sine of the angle

Answer (to check your work)

$F = 0.125$ N

Key Equations

Magnetic Forces

$$F = qvB\sin\theta \qquad \text{(Force on moving charge)} \qquad (12)$$

$$r = \frac{mv}{qB} \qquad \text{(Radius of circular path)} \qquad (13)$$

$$\varepsilon = Blv \qquad \text{(Hall emf)} \qquad (14)$$

$$F = IlB\sin\theta \qquad \text{(Force on current-carrying conductor)} \qquad (15)$$

$$\tau = NIAB\sin\theta \qquad \text{(Torque on current loop)} \qquad (16)$$

Right-Hand Rules

- RHR-1 for force direction: thumb in direction of $\vec{v}$ (or $\vec{I}$), fingers in direction of $\vec{B}$, palm indicates force direction

Summary

- Magnets have north and south poles; like poles repel, unlike poles attract
- Magnetic poles always come in pairs and cannot be isolated
- All magnetism is created by electric current
- Ferromagnetic materials contain domains of aligned atomic magnets
- Magnetic fields are represented by field lines with specific properties
- Magnetic forces act on moving charges and current-carrying conductors
- The Hall effect creates voltage across a current-carrying conductor in a magnetic field
- Torque on current loops in magnetic fields is the basis for motors and meters

Applications

Electromagnets, electric motors, generators, particle accelerators, mass spectrometers, Hall effect sensors, magnetic resonance imaging (MRI)

References

Textbook

OpenStax Physics, Chapter 22: Magnetism, Sections 22.1-22.8