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 magnets, magnetic fields, and magnetism
- Understand magnetic field lines and their properties
- Calculate the force on charges and currents in magnetic fields
- Apply the right-hand rule for magnetic forces
- Explain the Hall effect and practical applications
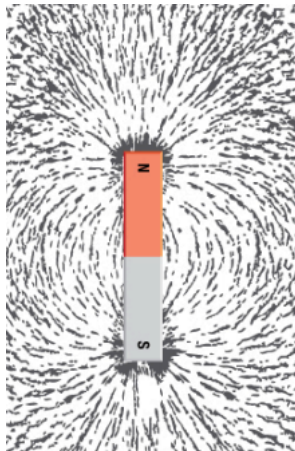- Calculate torque on current loops in magnetic fields

Outline

Basic Concepts of Magnetism

Magnetism

Properties of magnets and their interaction with moving charges and currents.

- Magnetic poles: North and South
- Like poles repel, unlike poles attract
- Poles always occur in pairs—cannot be isolated
- North poles point toward Earth's geographic north

Ferromagnets and Electromagnets

Ferromagnetic Materials

- Materials with strong magnetic effects (iron)
- Form regions called **domains**
- Domains align to create permanent magnets
- Lose magnetism above Curie temperature

Electromagnets

- Use electric currents to create magnetic fields
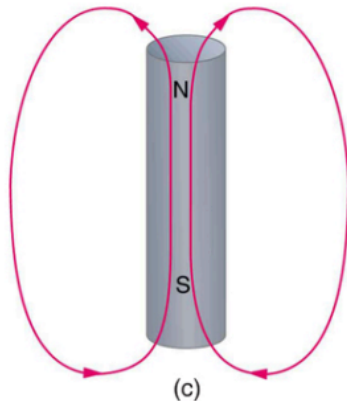- Field strength depends on current and coil turns
- Can be turned on and off

Magnetic Field Lines

Magnetic Field Representation

Magnetic fields are represented by field lines.

Properties of magnetic field lines:

- Field is tangent to the field line
- Line density shows field strength
- Lines never cross
- Lines form continuous loops
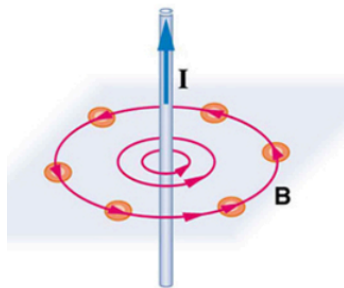

(c)

Force on Moving Charge in Magnetic Field

Magnetic Force Formula

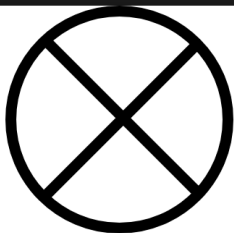The magnitude of the magnetic force on a moving charge:

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

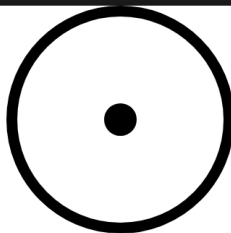where θ is the angle between velocity and field.

- SI unit: tesla (T)
- Force direction given by right-hand rule
- Force is perpendicular to v and B
- No force when v is parallel to B
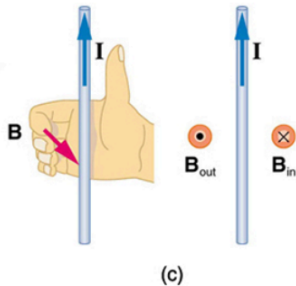
Force on Moving Charge in Magnetic Field

Notation for vector pointing into the page

Notation for vector pointing out of the page

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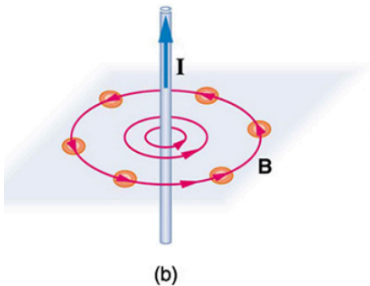
Force on Moving Charge in Magnetic Field
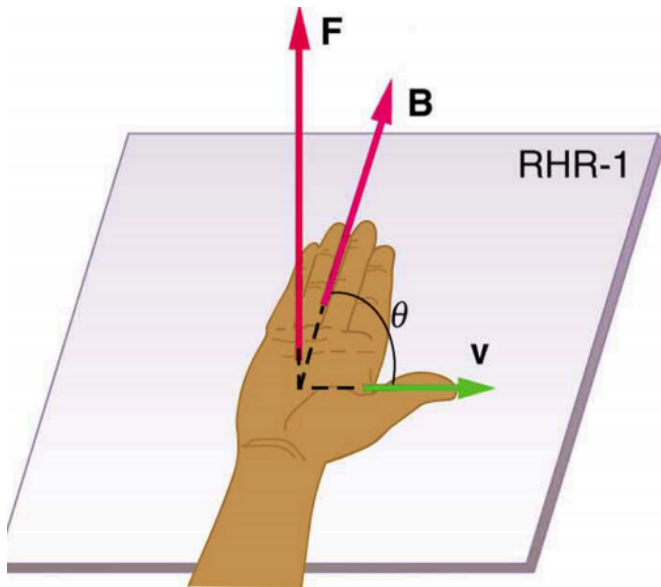
Applications of Force on Moving Charges

Circular Motion in Magnetic Field

Radius of a charged particle's circular path:

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

- Applications:
  - Mass spectrometers
  - Particle accelerators
  - Particle detectors
- Only affects moving charges
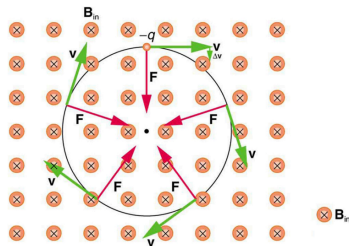
The Hall Effect

Hall Effect

Voltage created across a current-carrying conductor by a magnetic field.

- Hall voltage:

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

- B, I, and v must be perpendicular
- Applications:
  - Measuring magnetic fields
  - Hall effect sensors
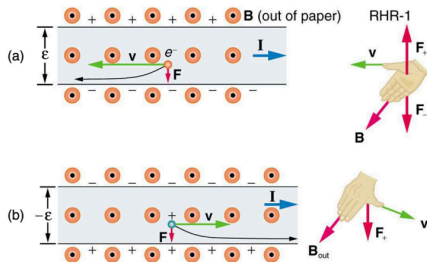
Magnetic Force on a Current-Carrying Conductor

Force Formula

The magnetic force on a current-carrying conductor:

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

where I is current, l is length, B is field strength, and θ is the angle.

- Direction follows right-hand rule
- 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:

$$\tau = NIAB\sin\theta \qquad (5)$$

where N is turns, I is current, A is area, B is field strength.

- Maximum torque: loop parallel to field
- Zero torque: loop perpendicular to field
- Applications:
  - Electric motors
  - Measuring instruments
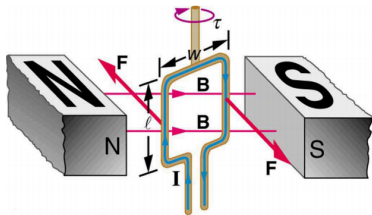
Example 1: "I do"

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: -1.60×10^{-19} C
- Velocity: 5.0×10^6 m/s
- Magnetic field: 0.50 T
- Angle: 90 (perpendicular)

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Solution

Given:

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Using $F = qvB \sin \theta$:

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Solution

Given:

- Charge of electron: -1.60×10^{-19} C
- Velocity: 5.0×10^6 m/s
- Magnetic field: 0.50 T
- Angle: 90 (perpendicular)

Using $F = qvB \sin \theta$:

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

$$F = -4.0 \times 10^{-13} \text{ N} \tag{7}$$

The negative sign indicates force direction opposite to the right-hand rule.

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: 1.67×10^{-27} kg
- Charge of proton: 1.60×10^{-19} C
- Velocity: 3.0×10^6 m/s
- Magnetic field: 0.75 T

Example 2: "We do"

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Solution

Given:

- Mass of proton: 1.67×10^{-27} kg
- Charge of proton: 1.60×10^{-19} C
- Velocity: 3.0×10^6 m/s
- Magnetic field: 0.75 T

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

Example 2: "We do"

Solution

Given:

- Mass of proton: 1.67×10^{-27} kg
- Charge of proton: 1.60×10^{-19} C
- Velocity: 3.0×10^6 m/s
- Magnetic field: 0.75 T

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

$$r = \frac{(1.67 \times 10^{-27} \text{ kg})(3.0 \times 10^6 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(0.75 \text{ T})} \tag{8}$$

$$r = 4.2 \times 10^{-2} \text{ m} = 4.2 \text{ cm} \tag{9}$$

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?

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?

Hints

- Use $F = IlB \sin \theta$
- Convert length to meters
- Calculate sin(30)

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?

Hints

- Use $F = IlB \sin \theta$
- Convert length to meters
- Calculate sin(30)

Answer (to check your work)

$F = 0.125$ N

Key Equations

Magnetic Forces

$$F = qvB\sin\theta \qquad \text{(Force on moving charge)} \qquad (10)$$

$$r = \frac{mv}{qB} \qquad \text{(Radius of circular path)} \qquad (11)$$

$$\varepsilon = Blv \qquad \text{(Hall emf)} \qquad (12)$$

$$F = IlB\sin\theta \qquad \text{(Force on current-carrying conductor)} \qquad (13)$$

$$\tau = NIAB\sin\theta \qquad \text{(Torque on current loop)} \qquad (14)$$

Right-Hand Rule

Thumb: velocity/current direction, Fingers: magnetic field, Palm: force direction

Summary

- Magnets have north and south poles that cannot be isolated
- Like poles repel, unlike poles attract
- All magnetism arises from electric current
- Magnetic fields affect moving charges and currents
- The Hall effect creates voltage in conductors in magnetic fields
- Torque on current loops enables motors and meters

Applications

Electromagnets, motors, generators, particle accelerators, MRI, sensors

References

Textbook

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