PHYS 104
1^{ST} semester 1439-1440

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Lecture 20

Chapter 29

Magnetic Field

29.1 Magnetic Fields and Forces

29.2 Magnetic Force Acting on a Current-Carrying Conductor

29.4 Motion of a Charged Particle in a Uniform Magnetic Field

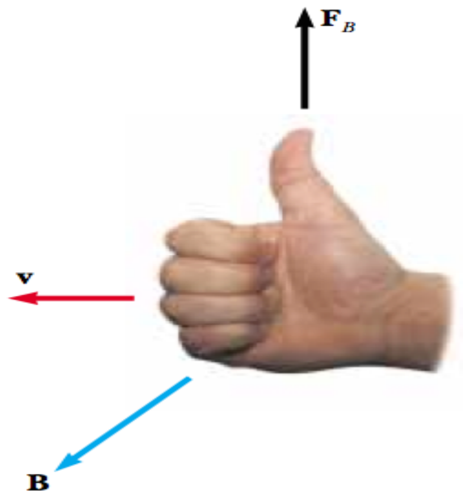
29.5 Applications Involving Charged Particles Moving in a Magnetic Field

29.1 Magnetic Fields and Forces

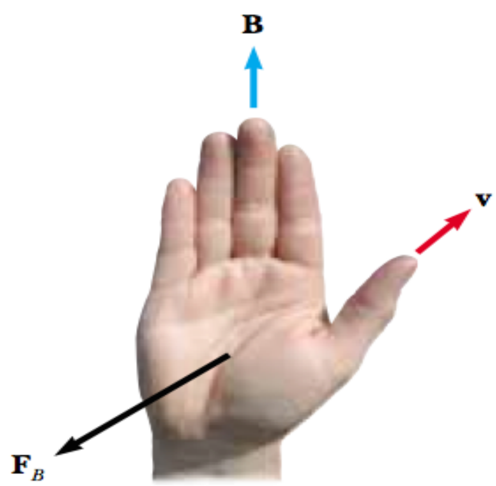
- Vector expression for the magnetic force acting on a particle with charge *q* moving with a velocity **v** in a magnetic field **B**.

$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

- Two **right-hand rules** for determining the direction of the magnetic force $\mathbf{F}_B$:
  - **a)** The fingers point in the direction of **v**, with **B** coming out of your palm, so that you can curl your fingers in the direction of **B**. The direction of **v** x **B**, and the force on a positive charge, is the direction in which the thumb points.
  - **b)** The vector **v** is in the direction of your thumb and **B** in the direction of your fingers. The force $\mathbf{F}_B$ on a positive charge is in the direction of your palm, as if you are pushing the particle with your hand.



(a)



(b)

29.1 Magnetic Fields and Forces

- The magnitude of the magnetic force on a charged particle is

$$F_B = |q|vB \sin \theta$$

- Differences between electric and magnetic forces:
  - The electric force acts along the direction of the electric field, whereas the magnetic force acts perpendicular to the magnetic field.
  - The electric force acts on a charged particle regardless of whether the particle is moving, whereas the magnetic force acts on a charged particle only when the particle is in motion.
  - The electric force does work in displacing a charged particle, whereas the magnetic force associated with a steady magnetic field does no work when a particle is displaced because the force is perpendicular to the displacement.

29.1 Magnetic Fields and Forces

- The SI unit of magnetic field is the newton per coulomb-meter per second, which is called the **tesla** (T):

$$1\ \mathrm{T} = 1\ \frac{\mathrm{N}}{\mathrm{C \cdot m/s}}$$

- Because a coulomb per second is defined to be an ampere, we see that

$$1\ \mathrm{T} = 1\ \frac{\mathrm{N}}{\mathrm{A \cdot m}}$$

- A non-SI magnetic-field unit in common use, called the *gauss* (G), is related to the tesla through the conversion $1\ \mathrm{T} = 10^4\ \mathrm{G}$.

Quick Quiz 29.1 The north-pole end of a bar magnet is held near a positively charged piece of plastic. Is the plastic (a) attracted, (b) repelled, or (c) unaffected by the magnet?

Quick Quiz 29.2 A charged particle moves with velocity $\mathbf{v}$ in a magnetic field $\mathbf{B}$. The magnetic force on the particle is a maximum when $\mathbf{v}$ is (a) parallel to $\mathbf{B}$, (b) perpendicular to $\mathbf{B}$, (c) zero.

Quick Quiz 29.3 An electron moves in the plane of this paper toward the top of the page. A magnetic field is also in the plane of the page and directed toward the right. The direction of the magnetic force on the electron is (a) toward the top of the page, (b) toward the bottom of the page, (c) toward the left edge of the page, (d) toward the right edge of the page, (e) upward out of the page, (f) downward into the page.

Example 29.1 An Electron Moving in a Magnetic Field

An electron in a television picture tube moves toward the front of the tube with a speed of 8.0×10^6 m/s along the x axis (Fig. 29.5). Surrounding the neck of the tube are coils of wire that create a magnetic field of magnitude 0.025 T, directed at an angle of 60° to the x axis and lying in the xy plane.

(A) Calculate the magnetic force on the electron using Equation 29.2.

Solution Using Equation 29.2, we find the magnitude of the magnetic force:

$$\begin{aligned} F_B &= |q|vB \sin\theta \\ &= (1.6 \times 10^{-19}\ \text{C})(8.0 \times 10^6\ \text{m/s})(0.025\ \text{T})(\sin 60°) \\ &= \boxed{2.8 \times 10^{-14}\ \text{N}} \end{aligned}$$

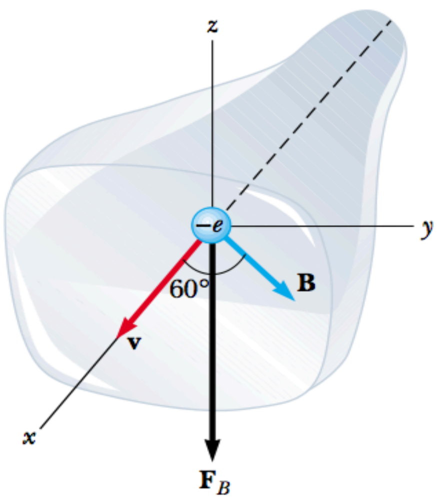


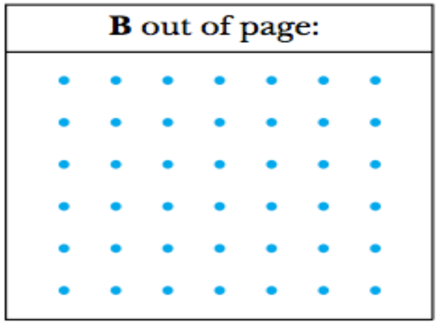
Figure 29.5 (Example 29.1) The magnetic force $\mathbf{F}_B$ acting on the electron is in the negative z direction when **v** and **B** lie in the xy plane.

Because $\mathbf{v} \times \mathbf{B}$ is in the positive z direction (from the right-hand rule) and the charge is negative, $\mathbf{F}_B$ is in the negative z direction.

29.2 Magnetic Force Acting on a Current-Carrying Conductor

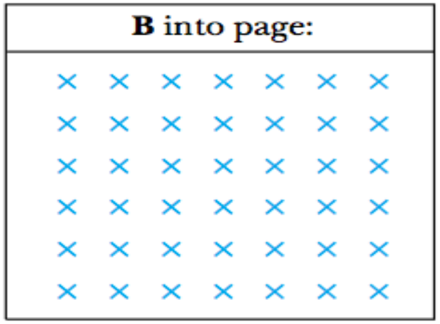
- The current-carrying wire experiences a force when placed in a magnetic field.
- The current is a collection of many charged particles in motion; hence, the resultant force exerted by the field on the wire is the vector sum of the individual forces exerted on all the charged particles making up the current.

(a) Magnetic field lines coming out of the paper are indicated by dots, representing the tips of arrows coming outward.



(a)

(b) Magnetic field lines going into the paper are indicated by crosses, representing the feathers of arrows going inward.



(b)

29.2 Magnetic Force Acting on a Current-Carrying Conductor

- One can demonstrate the magnetic force acting on a current-carrying conductor by hanging a wire between the poles of a magnet.

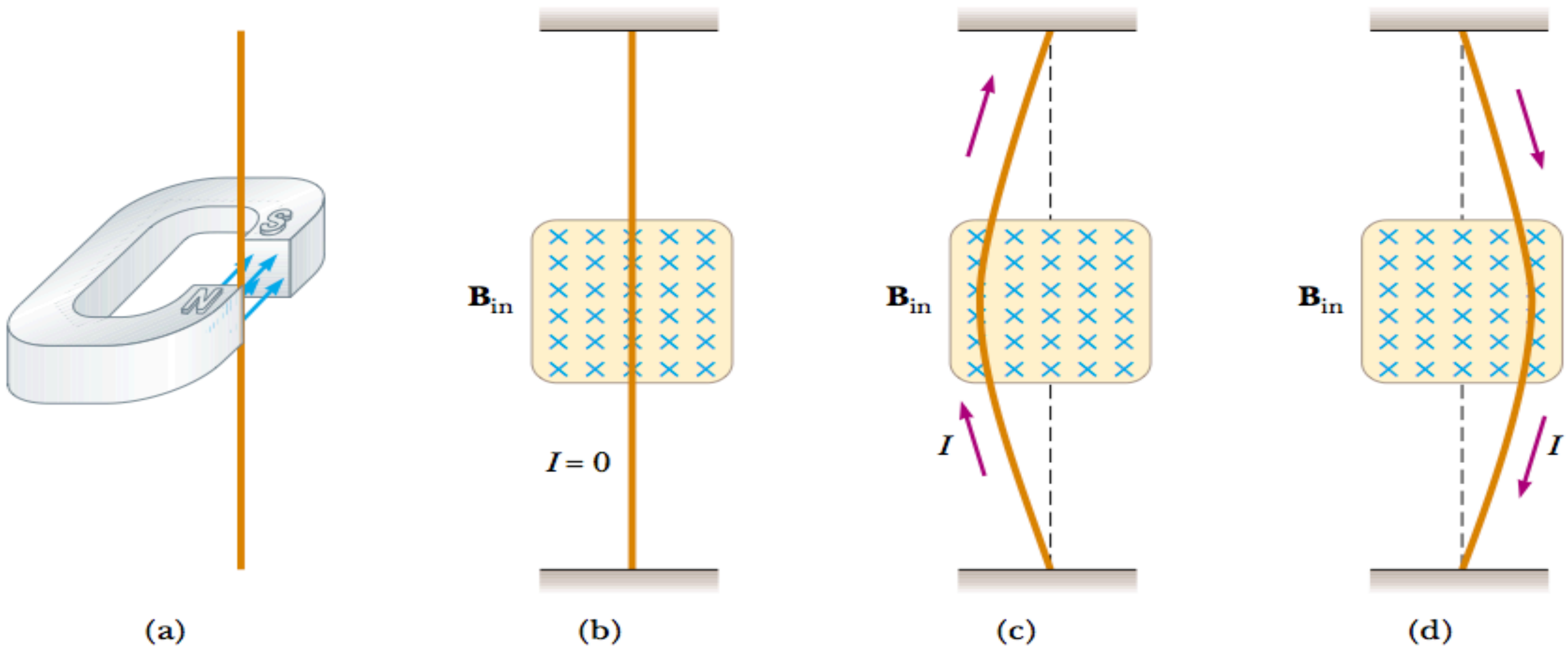


Figure 29.7 (a) A wire suspended vertically between the poles of a magnet. (b) The setup shown in part (a) as seen looking at the south pole of the magnet, so that the magnetic field (blue crosses) is directed into the page. When there is no current in the wire, it remains vertical. (c) When the current is upward, the wire deflects to the left. (d) When the current is downward, the wire deflects to the right.

29.2 Magnetic Force Acting on a Current-Carrying Conductor

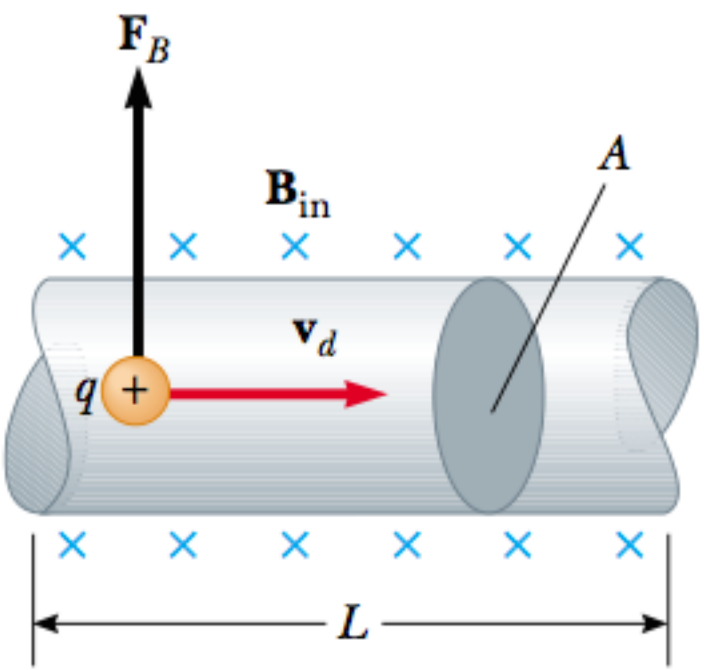
- Consider a straight segment of wire of length L and cross-sectional area A, carrying a current I in a uniform magnetic field **B**.
- The magnetic force exerted on a charge q moving with a drift velocity $\mathbf{v}_d$ is $q\mathbf{v}_d \times \mathbf{B}$.
- To find the total force acting on the wire, we multiply the force by the number of charges in the segment nAL, where n is the number of charges per unit volume.
- The total magnetic force on the wire of length L is

$$\mathbf{F}_B = (q\mathbf{v}_d \times \mathbf{B})nAL$$

- The current in the wire is $I = nqv_dA$.

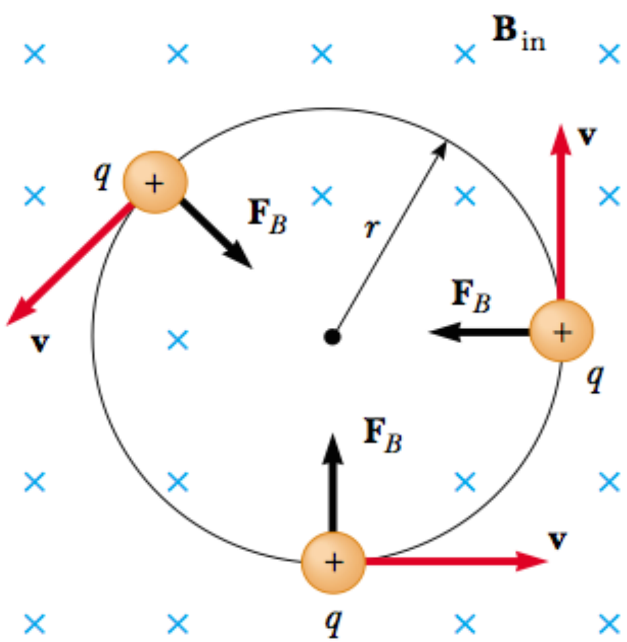
$$\mathbf{F}_B = I\mathbf{L} \times \mathbf{B}$$

- where **L** is a vector that points in the direction of the current I and has a magnitude equal to the length L of the segment.



29.4 Motion of a Charged Particle in a Uniform Magnetic Field

- Consider a positively charged particle moving in a uniform magnetic field with the initial velocity vector of the particle perpendicular to the field.
- Assume that the direction of the magnetic field is into the page.
- If the force is always perpendicular to the velocity, the path of the particle is a circle.



29.4 Motion of a Charged Particle in a Uniform Magnetic Field

- The particle moves in a circle because the magnetic force $\mathbf{F}_B$ is perpendicular to **v** and **B** and has a constant magnitude *qvB.*

$$\sum F = ma_c$$

$$F_B = qvB = \frac{mv^2}{r}$$

- The radius of the path r, $$r = \frac{mv}{qB}$$

- The angular speed of the particle $$\omega = \frac{v}{r} = \frac{qB}{m}$$ **Cyclotron frequency**

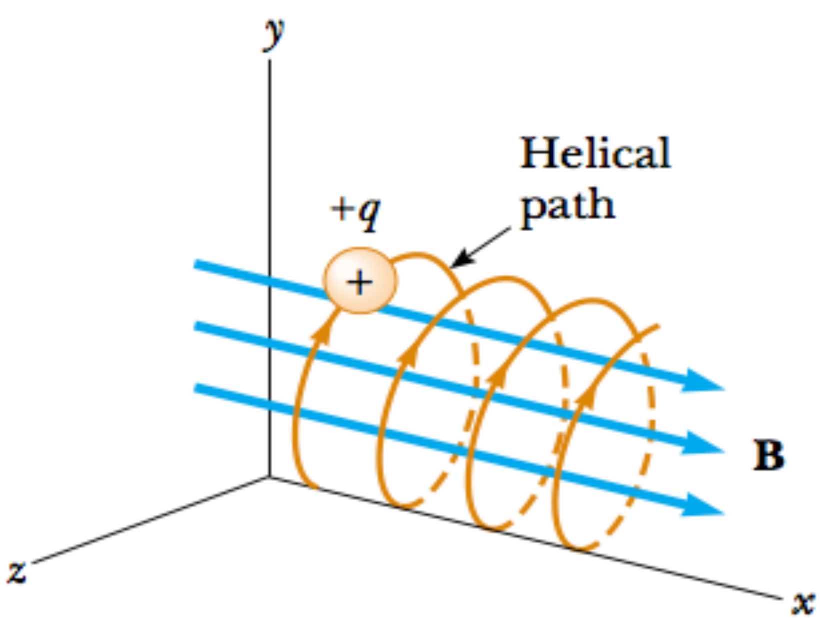
- The period of the motion (the time interval the particle requires to complete one revolution) is

$$T = \frac{2\pi r}{v} = \frac{2\pi}{\omega} = \frac{2\pi m}{qB}$$

29.4 Motion of a Charged Particle in a Uniform Magnetic Field

- If a charged particle moves in a uniform magnetic field with its velocity at some arbitrary angle with respect to **B**, its path is a helix.
- Equations for r, ω, and T still apply, but *v* is replaced by

$$v_\perp = \sqrt{v_y^2 + v_z^2}.$$



Example 29.6 A Proton Moving Perpendicular to a Uniform Magnetic Field

A proton is moving in a circular orbit of radius 14 cm in a uniform 0.35-T magnetic field perpendicular to the velocity of the proton. Find the linear speed of the proton.

Solution From Equation 29.13, we have

$$v = \frac{qBr}{m_p} = \frac{(1.60 \times 10^{-19}\ \mathrm{C})(0.35\ \mathrm{T})(0.14\ \mathrm{m})}{1.67 \times 10^{-27}\ \mathrm{kg}}$$

$$= \boxed{4.7 \times 10^{6}\ \mathrm{m/s}}$$