Chapter 22    Magnetism

Outline

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The Motion of Charges Particles in Magnetic Field

Electric versus Magnetic Forces

Let us compare two cases in Fig (a) and (b).

The work done $W = F \Delta S$

(a) Electric force does work on the particle:

(b) No work done by the magnetic force.

Figure 22-10
Differences Between Motion in Electric and Magnetic Fields
CONCEPTUAL CHECKPOINT 22–3

In a device called a velocity selector, charged particles move through a region of space with both an electric and a magnetic field. If the speed of the particle has a particular value, the net force acting on it is zero. Assume that a positively charged particle moves in the positive x direction, as shown in the sketch, and the electric field is in the positive y direction. Should the magnetic field be in (a) the positive z direction, (b) the negative y direction, or (c) the negative z direction in order to give zero net force?
CONCEPTUAL CHECKPOINT 22–3

In a device called a velocity selector, charged particles move through a region of space with both an electric and a magnetic field. If the speed of the particle has a particular value, the net force acting on it is zero. Assume that a positively charged particle moves in the positive $x$ direction, as shown in the sketch, and the electric field is in the positive $y$ direction. Should the magnetic field be in (a) the positive $z$ direction, (b) the negative $y$ direction, or (c) the negative $z$ direction in order to give zero net force?

**Reasoning and Discussion**

The force exerted by the electric field is in the positive $y$ direction; hence, the magnetic force must be in the negative $y$ direction if it is to cancel the electric force. If we simply try the three possible directions for $\mathbf{B}$ one at a time, applying the magnetic force RHR in each case, we find that only a magnetic field along the positive $z$ axis gives rise to a force in the negative $y$ direction, as desired.

**Answer:**
(a) $\mathbf{B}$ should point in the positive $z$ direction.
Circular Motion

Assume a particle with a velocity that is perpendicular to the magnetic field, as shown in Fig. 22-12.

At every points, the force is vertical to the velocity and point to a common center.
For centripetal motion, one has

\[ m \frac{v^2}{r} = |q| vB \]

Therefore, we have the radius

\[ r = \frac{mv}{|q| B} \]

\[ 22 - 3 \]
Problem 22-17

An electron accelerated from rest through a voltage of 410 V enters a region of constant magnetic field. If the electron follows a circular path with radius of 17 cm, what is the magnitude of the magnetic field?
Solution:

(1) Apply energy conservation:

\[ e\Delta V = \frac{1}{2}mv^2 \Rightarrow \]

\[ v = \sqrt{\frac{2e\Delta V}{m}} = \sqrt{\frac{2\left(1.60 \times 10^{-19} \text{ C}\right)\left(410 \text{ V}\right)}{\left(9.11 \times 10^{-31} \text{ kg}\right)}} \]

\[ = 1.2 \times 10^7 \text{ m/s} \]

(2) Solve Eq(22-3) for B:

\[ r = \frac{mv}{|q|B} \Rightarrow \]

\[ B = \frac{mv}{er} = \frac{\left(9.11 \times 10^{-31} \text{ kg}\right)\left(1.2 \times 10^7 \text{ m/s}\right)}{\left(1.60 \times 10^{-19} \text{ C}\right)\left(0.17 \text{ m}\right)} = 4.0 \times 10^{-4} \text{ T} = \boxed{0.40 \text{ mT}} \]
Helical Motion

Figure 22-14
Helical Motion in a Magnetic Field

Why?
22-4 The Magnetic Force Exert on a Current-Carrying Wire

How to derive the force?

Assume a wire with current is located in a magnetic field. The wire has a length $L$, and the charge is moving at a speed of $v$.

The time require the charge to go through the wire $L$ is

$$\Delta t = \frac{L}{v}$$

Therefore, the amount of charge is

$$q = I \Delta t = \frac{IL}{v}$$

Thus, the force exerted on the wire is

$$F = qvB \sin \theta = \left(\frac{IL}{v}\right)vB \sin \theta = ILB \sin \theta$$

Figure 22-15
The Magnetic Force on a Current-Carrying Wire
Magnetic Force on a Current-Carrying Wire

\[ F = ILB \sin \theta \quad \text{(22 – 4)} \]

SI unit: Newton, N

The direction of the force is determined by “Right-hand-Rule”.
CONCEPTUAL CHECKPOINT 22–4

When the switch is closed in the circuit shown in the sketch, the wire between the poles of the horseshoe magnet deflects downward. Is the left end of the magnet (a) a north magnetic pole or (b) a south magnetic pole?
CONCEPTUAL CHECKPOINT 22–4

When the switch is closed in the circuit shown in the sketch, the wire between the poles of the horseshoe magnet deflects downward. Is the left end of the magnet (a) a north magnetic pole or (b) a south magnetic pole?

Reasoning and Discussion
Once the switch is closed, the current in the wire is into the page, as shown in the second sketch.

Applying the magnetic force RHR, we see that the magnetic field must point from left to right in order for the force to be downward. Since magnetic field lines leave from north poles and enter at south poles, it follows that the left end of the magnet must be a north magnetic pole.

Answer:
(a) The left end of the magnet is a north magnetic pole.
Problem 22-25

The magnetic force exerted on a 1.2-m straight wire is 1.6 N. The wire carries a current of 3.0 A in an region with constant magnetic field of 0.50 T. what is the angle between the wire and the magnetic field?
Solution:

Solve Eq (22-4) for $\theta$

\[
F = ILB \sin \theta \implies \\
\sin \theta = \frac{F}{ILB} \\
\theta = \sin^{-1} \left( \frac{F}{ILB} \right) = \sin^{-1} \left( \frac{1.6 \text{ N}}{(3.0 \text{ A})(1.2 \text{ m})(0.50 \text{ T})} \right) = 63^\circ
\]
Summary

Magnetic Force on a Current-Carrying Wire

\[ F = ILB \sin \theta \]  

SI unit: Newton, N

The direction of the magnetic force is determined by Right-Hand Rule
Exercise 22-1

An electron moving perpendicular to a magnetic field of $4.60 \times 10^{-3}$ T follows a circular path of radius $2.80$ mm. What is the electron’s speed?

Solution:

Since 

$$r = \frac{mv}{|q|B}$$

Therefore,

$$v = \frac{r|q|B}{m} = \frac{(2.80 \times 10^{-3} m)(1.60 \times 10^{-19} C)(4.60 \times 10^{-3} T)}{9.11 \times 10^{-31} \text{ kg}}$$

$$= 2.26 \times 10^6 \text{ m/s}$$

Figure 22-13
The Operating Principle of a Mass Spectrometer
Active Example 22-1  Find the time for one orbit

Calculate the time $T$ required for a particle of mass $m$ with charge $q$ to complete a circular orbit in a magnetic field.

**Solution**

Since for a circular motion, one has

$$T = \frac{2\pi r}{v} \quad (1)$$

Also, we have

$$r = \frac{mv}{|q|B} \quad (2)$$

Solving (1) and (2) for $T$: 

$$T = \frac{2\pi m}{|q|B}$$
Example 22-4  Magnetic Levity

A copper rod 0.150m long and with a mass 0.0500kg is suspended from two thin wire. At right angle to the rod is a uniform magnetic field of 0.550 T pointing into the page. Find

(a) The direction and (b) magnitude of the electric current to levitate the copper rod’s gravitation force.
Solution

Part (b)

The magnetic force must cancel the force of the gravity,

\[ ILB = mg \]

\[ I = \frac{mg}{LB} = \frac{(0.0500\, \text{kg})(9.81\, \text{m/s}^2)}{(0.150\, \text{m})(0.550\, \text{T})} = 5.95 \, \text{A} \]