Section 8.1: Magnets and Electromagnets

Section 8.1 Questions, page 385

1. A permanent magnet is a magnet that always behaves as a magnet, unlike some materials that only act as magnets in response to an applied magnetic field.

2. (a) Earth's magnetic field is directed slightly off from Earth's axis. The south magnetic pole attracts the north pole of a bar magnet. This means that, from a physical standpoint, the north pole of Earth's magnetic field is located near Earth's south geographic pole.

(b) Charged particles from the Sun are directed downward toward Earth's surface by Earth's magnetic field. They are deflected near the equator and channelled along magnetic field lines toward the poles. These particles energize gas atoms in the upper atmosphere, causing the gas atoms to release the extra energy as rays of light, producing the beautiful colours of the auroras.

(c) Magnetic compasses align with Earth's magnetic field. A hiker can use a compass to identify a northerly direction.

3. (a) I would hold the conductor in my right hand with my thumb pointing along its length. The direction of the magnetic field is in the direction of my curled fingers.

(b) I would hold the loop of wire in my right hand with my thumb pointing along the loop. The direction of the magnetic field is in the direction of my curled fingers.

(c) I would make a fist and hold my hand so that my fingers curl in the direction of the electric current. My thumb then points in the direction of the magnetic field lines in the core.

4. The field lines inside the coils are straight and directed along the length of the solenoid. The field lines outside the coils curve around from one end to the other.

5. The doorbell contains an electromagnet, which is a solenoid with a core of a magnetic metal. When the switch is closed, current flows through the coils of the electromagnet, producing a magnetic field according to the principle of electromagnetism. By the right-hand rule for a solenoid, the magnetic field attracts the metal plate away from the contact. When contact is broken, the hammer hits the doorbell.

6. To demonstrate the principle of electromagnetism, I would follow these steps:

Make an electromagnet from an iron rod in a solenoid. Have the wires of the solenoid connected to a circuit with a battery. Using various types of batteries, experiment with how the electromagnet can attract paper clips as the voltage changes.

7. Answers may vary. Students' paragraphs should note that each crystal, called a magnetosome, is composed of a single magnetic domain. Bacteria use the magnetic areas like a compass to direct them downward, away from oxygen.

Section 8.2: Magnetic Force on Moving Charges

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1. (a) Given: $q = 1.60 \times 10^{-19}$ C; $v = 9.4 \times 10^4$ m/s; $B = 1.8$ T; $\theta = 90°$

Required: F_M

Analysis: $F_M = qvB \sin \theta$; by the right-hand rule, the direction of the electric force is south.

Solution:
$$\begin{aligned} F_M &= qvB\sin\theta \\ &= \left(1.60\times10^{-19}\ \cancel{C}\right)\left(9.4\times10^4\ \frac{m}{s}\right)\left(1.8\ \frac{kg}{\cancel{C}\cdot s}\right)\sin 90° \\ &= 2.707\times10^{-14}\ kg\cdot m/s^2 \\ &= 2.707\times10^{-14}\ N\ \text{(two extra digits carried)} \\ F_M &= 2.7\times10^{-14}\ N \end{aligned}$$

Statement: The magnetic force on the proton is 2.7×10^{-14} N [S].

(b) Given: $m = 1.67 \times 10^{-27}$ kg; $g = 9.8$ m/s^2

Required: F_g

Analysis: $F_g = mg$

Solution:
$$\begin{aligned} F_g &= mg \\ &= (1.67\times10^{-27}\ kg)(9.8\ m/s^2) \\ &= 1.637\times10^{-26}\ N\ \text{(two extra digits carried)} \\ F_g &= 1.6\times10^{-26}\ N \end{aligned}$$

Statement: The gravitational force on the proton is 1.6×10^{-26} N.

(c) Determine the ratio of the two forces on the proton:

$$\frac{F_g}{F_M} = \frac{1.637\times10^{-26}\ \cancel{N}}{2.707\times10^{-14}\ \cancel{N}}$$

$$\frac{F_g}{F_M} = \frac{6.0\times10^{-13}}{1}$$

The gravitational force on the proton is 6.0×10^{-13} times the magnetic force on the proton.

2. Given: $q = -1.60 \times 10^{-19}$ C; $v = 3.5 \times 10^5$ m/s; $F_M = 7.5 \times 10^{-14}$ N; $\theta = 90°$

Required: B

Analysis: by the right-hand rule, the direction of the electric field is into the page;

$$F_M = qvB\sin\theta$$

$$B = \frac{F_M}{qv\sin\theta}$$

Solution:
$$\begin{aligned} B &= \frac{F_M}{qv\sin\theta} \\ &= \frac{\left(7.5\times10^{-14}\ kg\cdot\frac{\cancel{m}}{s^{\cancel{2}}}\right)}{\left(-1.60\times10^{-19}\ C\right)\left(3.5\times10^5\ \frac{\cancel{m}}{\cancel{s}}\right)\sin 90°} \\ B &= 1.3\ T \end{aligned}$$

Statement: The magnitude of the electric field is 1.3 T and it is directed into the page.

3. (a) Given: $q = 1.60 \times 10^{-19}$ C; $v = 2.24 \times 10^8$ m/s; $B = 0.56$ T; $\theta = 90°$

Required: $\vec{F}_\text{M}$

Analysis: $F_\text{M} = qvB \sin \theta$; by the right-hand rule, the direction of the force is outward from the spiral.

Solution: $F_\text{M} = qvB\sin\theta$

$$= \left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(2.24\times10^{8}\ \text{m/s}\right)\left(0.56\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$

$$F_\text{M} = 2.0\times10^{-11}\ \text{N}$$

Statement: The magnetic force on the electron is 2.0×10^{-11} N, outward from the spiral.

(b) Given: $q = 1.60 \times 10^{-19}$ C; $v = 2.24 \times 10^8$ m/s; $B = 5.5 \times 10^{-5}$ T; $\theta = 90°$

Required: F_M

Analysis: $F_\text{M} = qvB \sin \theta$

Solution: $F_\text{M} = qvB\sin\theta$

$$= \left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(2.24\times10^{8}\ \text{m/s}\right)\left(5.5\times10^{-5}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$

$$F_\text{M} = 2.0\times10^{-15}\ \text{N}$$

Statement: The magnetic force on the electron after it leaves the spiral is 2.0×10^{-15} N.

4. (a) Given: $q = -1.60 \times 10^{-19}$ C; $\vec{v} = 6.7 \times 10^6$ m/s [E]; $\vec{B} = 2.3$ T; $\theta = 47°$

Required: $\vec{F}_\text{M}$

Analysis: $F_\text{M} = qvB \sin \theta$; by the right-hand rule, the direction of the electric field is north.

Solution: $F_\text{M} = qvB\sin\theta$

$$= \left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(6.7\times10^{6}\ \text{m/s}\right)\left(2.3\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 47°$$

$$= -1.803\times10^{-12}\ \text{N (two extra digits carried)}$$

$$F_\text{M} = -1.8\times10^{-12}\ \text{N}$$

Statement: The magnetic force on the electron is 1.8×10^{-12} N [N].

(b) Given: $m = 9.11 \times 10^{-31}$ kg; $F_\text{M} = 1.803 \times 10^{12}$ N

Required: a

Analysis: $F_\text{M} = ma$

$$a = \frac{F_\text{M}}{m}$$

Solution: $a = \dfrac{F_\text{M}}{m}$

$$= \frac{\left(1.803\times10^{-12}\ \cancel{\text{kg}}\cdot\dfrac{\text{m}}{\text{s}^2}\right)}{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)}$$

$$a = 2.0\times10^{18}\ \text{m/s}^2$$

Statement: The acceleration of the electron is 2.0×10^{18} m/s^2.

(c) Given: $m = 1.67 \times 10^{-27}$ kg; $F_M = 1.803 \times 10^{12}$ N
Required: a
Analysis: $F_M = ma$

$$a = \frac{F_M}{m}$$

Solution: $a = \frac{F_M}{m}$

$$= \frac{\left(1.803 \times 10^{-12}\ \cancel{\text{kg}} \cdot \frac{\text{m}}{\text{s}^2}\right)}{\left(1.67 \times 10^{-27}\ \cancel{\text{kg}}\right)}$$

$$a = 1.1 \times 10^{15}\ \text{m/s}^2$$

Statement: The acceleration of the proton is 1.1×10^{15} m/s^2.

Section 8.2 Questions, page 391

1. The right-hand rule for a straight conductor and the right-hand rule for a solenoid both describe how to determine the direction of the magnetic field if you know the direction of a current. The right-hand rule for a moving charge in a magnetic field allows you to determine the direction of the resulting magnetic force.
2. The particle has a positive charge, since it acts in the same direction as that determined by the right-hand rule.
3. The particle has a negative charge according to the right-hand rule. If the charge tripled while the velocity was halved, the magnitude of the force would be 1.5 that of the original situation:

$$F_M = (3q)\left(\frac{1}{2}v\right)B\sin\theta$$

$$F_M = \frac{3}{2}qvB\sin\theta$$

4. (a) Given: $q = 1.60 \times 10^{-19}$ C; $v = 1.4 \times 10^3$ m/s; $B = 0.85$ T; $\theta = 90°$
Required: F_M
Analysis: $F_M = qvB \sin \theta$
Solution: $F_M = qvB\sin\theta$

$$= \left(1.60 \times 10^{-19}\ \cancel{\text{C}}\right)\left(1.4 \times 10^3\ \text{m/s}\right)\left(0.85\ \frac{\text{kg}}{\cancel{\text{C}} \cdot \text{s}}\right)\sin 90°$$

$$F_M = 1.9 \times 10^{-16}\ \text{N}$$

Statement: The magnetic force on the proton is 1.9×10^{-16} N.
(b) The magnitude of the magnetic force on the electron is also 1.9×10^{-16} N because the proton and electron have the same magnitude of charge.

5. Given: $q = -1.60 \times 10^{-19}$ C; $v = 235$ m/s; $B = 2.8$ T; $F_M = 5.7 \times 10^{-17}$ C
Required: θ
Analysis: $F_M = qvB\sin\theta$

$$\sin\theta = \frac{F_M}{qvB}$$

Solution: $\sin\theta = \dfrac{F_M}{qvB}$

$$= \frac{\left(5.7\times10^{-17}\ \cancel{\text{kg}}\cdot\dfrac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}{\left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(235\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\left(2.8\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)}$$

$$= -0.5414$$

$$\theta = \sin^{-1}(-0.5414)$$

$$\theta = -33°$$

Statement: The angle between the path of the electron and the electric field is 33°.
6. By the right-hand rule, the particle is deflected downward on the plane of the page.
7. (a) Given: $q = 6.4\ \mu\text{C} = 6.4 \times 10^{-6}$ C; $\theta = 27°$; $v = 170$ m/s; $B = 0.85$ T
Required: F_M
Analysis: $F_M = qvB \sin \theta$
Solution: $F_M = qvB\sin\theta$

$$= \left(6.4\times10^{-6}\ \cancel{\text{C}}\right)(170\ \text{m/s})\left(0.85\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 27°$$

$$F_M = 4.2\times10^{-4}\ \text{N}$$

Statement: The magnitude of the magnetic force on the particle is 4.2×10^{-4} N.
(b) By the right-hand rule, the magnetic force is in the $-z$ direction.
(c) 0 N; there would be no force because the angle between the velocity and the magnetic field is 0°.
8. By the right-hand rule, the magnetic force is in the $+z$ direction.
9. Given: $q = -7.9\ \mu\text{C} = -7.9 \times 10^{-6}$ C; $v = 580$ m/s; $\theta = 55°$; $B = 1.3$ T [$+y$ direction]
Required: $\vec{F}_M$
Analysis: $F_M = qvB \sin \theta$; by the right-hand rule, the magnetic force is in the $-z$ direction; the given angle is with respect to the x-axis, so subtract it from 90° to get the angle between the velocity and the magnetic field.
Solution: $F_M = qvB\sin\theta$

$$= \left(-7.9\times10^{-6}\ \cancel{\text{C}}\right)(580\ \text{m/s})\left(1.3\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin(90° - 55°)$$

$$F_M = -3.4\times10^{-3}\ \text{N}$$

Statement: The magnitude of the magnetic force on the particle is 3.4×10^{-3} N [$-z$ direction].

10. (a) Given: $m = 6.644 \times 10^{-27}$ kg; $a = 2.4 \times 10^{3}$ m/s^2
Required: F_M
Analysis: $F_M = ma$
Solution: $F_M = ma$

$$= (6.644 \times 10^{-27}\ \text{kg})(2.4 \times 10^{3}\ \text{m/s}^2)$$
$$= 1.595 \times 10^{-23}\ \text{N (two extra digits carried)}$$
$$F_M = 1.6 \times 10^{-23}\ \text{N}$$

Statement: The magnitude of the magnetic force on the alpha particle is 1.6×10^{-23} N.
(b) Given: $q = 2(1.60 \times 10^{-19}$ C); $\theta = 90°$; $B = 1.4$ T; $F_M = 1.595 \times 10^{-23}$ N
Required: v
Analysis: $F_M = qvB \sin \theta$

$$v = \frac{F_M}{qB \sin \theta}$$

Solution: $v = \dfrac{F_M}{qB \sin \theta}$

$$= \frac{\left(1.595 \times 10^{-23}\ \cancel{\text{kg}} \cdot \dfrac{\text{m}}{\text{s}^2}\right)}{2(1.60 \times 10^{-19}\ \cancel{\text{C}})\left(1.4\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}} \cdot \cancel{\text{s}}}\right) \sin 90°}$$

$$v = 3.6 \times 10^{-5}\ \text{m/s}$$

Statement: The speed of the alpha particle is 3.6×10^{-5} m/s.

Section 8.3: Magnetic Force on a Current-Carrying Conductor

Tutorial 1 Practice, page 395

1. Given: L = 155 mm = 0.155 m; I = 3.2 A; B = 1.8 T; θ = 90°

Required: $F_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$

Solution:
$$\begin{aligned} F_{\text{on wire}} &= ILB\sin\theta \\ &= \left(3.2\ \frac{\cancel{\text{C}}}{\text{s}}\right)(0.155\ \text{m})\left(1.8\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90^\circ \\ F_{\text{on wire}} &= 0.89\ \text{N} \end{aligned}$$

Statement: The magnitude of the force on the wire is 0.89 N.

(b) By the right-hand rule, the magnetic force is in the $-x$ direction.

2. Given: $F_{\text{on wire}}$ = 0.75 N; I = 15 A; θ = 90°; B = 0.20 T

Required: L

Analysis:
$$\begin{aligned} F_{\text{on wire}} &= ILB\sin\theta \\ L &= \frac{F_{\text{on wire}}}{IB\sin\theta} \end{aligned}$$

Solution:
$$\begin{aligned} L &= \frac{F_{\text{on wire}}}{IB\sin\theta} \\ &= \frac{\left(0.75\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\cancel{\text{s}^2}}\right)}{\left(15\ \frac{\cancel{\text{C}}}{\cancel{\text{s}}}\right)\left(0.20\ \frac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)\sin 90^\circ} \\ &= 0.25\ \text{m} \\ L &= 25\ \text{cm} \end{aligned}$$

Statement: The length of the wire is 25 cm.

3. Given: $F_{\text{on wire}} = 1.4 \times 10^{-5}$ N; L = 0.045 m; θ = 18°; $B = 5.3 \times 10^{-5}$ T

Required: I

Analysis:
$$\begin{aligned} F_{\text{on wire}} &= ILB\sin\theta \\ I &= \frac{F_{\text{on wire}}}{LB\sin\theta} \end{aligned}$$

Solution:
$$\begin{aligned} I &= \frac{F_{\text{on wire}}}{LB\sin\theta} \\ &= \frac{\left(1.4\times10^{-5}\ \cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\text{s}^{\cancel{2}}}\right)}{(0.045\ \cancel{\text{m}})\left(5.3\times10^{-5}\ \frac{\cancel{\text{kg}}}{\text{C}\cdot\cancel{\text{s}}}\right)\sin 18^\circ} \\ I &= 19\ \text{A} \end{aligned}$$

Statement: The current in the wire is 19 A.

4. Given: I = 1.5 A; L = 5.7 cm = 0.057 m; θ = 90°; $F_{\text{on wire}} = 5.7 \times 10^{-6}$ N
Required: B
Analysis: $F_{\text{on wire}} = ILB\sin\theta$

$$B = \frac{F_{\text{on wire}}}{IL\sin\theta}$$

Solution: $B = \frac{F_{\text{on wire}}}{IL\sin\theta}$

$$= \frac{\left(5.7\times10^{-6}\ \text{kg}\cdot\frac{\cancel{\text{m}}}{\text{s}^2}\right)}{\left(3.2\ \frac{\text{C}}{\cancel{\text{s}}}\right)(0.057\ \cancel{\text{m}})\sin 90°}$$

$$B = 6.7\times10^{-5}\ \text{T}$$

Statement: The magnitude of Earth's magnetic field around the lamp is 6.7×10^{-5} T.

Section 8.3 Questions, page 396

1. (a) Given: B = 1.4 T; L = 2.3 m; $F_{\text{on wire}}$ = 1.8 N; θ = 90°
Required: I
Analysis: $F_{\text{on wire}} = ILB\sin\theta$

$$I = \frac{F_{\text{on wire}}}{LB\sin\theta}$$

Solution: $I = \frac{F_{\text{on wire}}}{LB\sin\theta}$

$$= \frac{\left(1.8\ \cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\text{s}^2}\right)}{(2.3\ \cancel{\text{m}})\left(1.4\ \frac{\cancel{\text{kg}}}{\text{C}\cdot\cancel{\text{s}}}\right)\sin 90°}$$

$$I = 0.56\ \text{A}$$

Statement: The current in the conductor is 0.56 A.
(b) When the magnetic force is a maximum, the angle is 90° because that is when sin θ is a maximum.
2. (a) Given: L = 120 mm = 0.120 m; θ = 56°; B = 0.40 T; I = 2.3 A
Required: $F_{\text{on wire}}$
Analysis: $F_{\text{on wire}} = ILB\sin\theta$
Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(2.3\ \frac{\cancel{\text{C}}}{\text{s}}\right)(0.120\ \text{m})\left(0.40\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 45°$$

$$F_{\text{on wire}} = 7.8\times10^{-2}\ \text{N}$$

Statement: The magnitude of the force on the wire is 7.8×10^{-2} N.
(b) By the right-hand rule, the direction of the magnetic force is upward.

3. (a) Given: L = 2.6 m; I = 2.5 A; B = 5.0 × 10^{-5} T; θ = 90°
Required: $\vec{F}_{\text{on wire}}$
Analysis: $F_{\text{on wire}} = ILB \sin \theta$; by the right-hand rule, the magnetic force is downward.
Solution:
$$F_{\text{on wire}} = ILB\sin\theta$$
$$= \left(2.5\ \frac{\cancel{\text{C}}}{\text{s}}\right)(2.6\ \text{m})\left(5.0\times10^{-5}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$
$$F_{\text{on wire}} = 3.2\times10^{-4}\ \text{N}$$
Statement: The force on the wire is 3.2 × 10^{-4} N [down].
(b) Given: L = 2.6 m; I = 2.5 A; B = 5.0 × 10^{-5} T; θ = 72°
Required: $F_{\text{on wire}}$
Analysis: $F_{\text{on wire}} = ILB \sin \theta$
Solution:
$$F_{\text{on wire}} = ILB\sin\theta$$
$$= \left(2.5\ \frac{\cancel{\text{C}}}{\text{s}}\right)(2.6\ \text{m})\left(5.0\times10^{-5}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 72°$$
$$F_{\text{on wire}} = 3.1\times10^{-4}\ \text{N}$$
Statement: The magnitude of the force on the wire is 3.1 × 10^{-4} N.
4. Given: L = 1.4 m; I = 3.5 A; B = 1.5 T; θ = 90°
Required: $F_{\text{on wire}}$
Analysis: $F_{\text{on wire}} = ILB \sin \theta$
Solution:
$$F_{\text{on wire}} = ILB\sin\theta$$
$$= \left(3.5\ \frac{\cancel{\text{C}}}{\text{s}}\right)(1.4\ \text{m})\left(1.5\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$
$$F_{\text{on wire}} = 7.4\ \text{N}$$
Statement: The magnitude of the force on the wire is 7.4 N.
5. (a) The magnetic field is in the same direction as the wire, so the force is 0 N.
(b) Write the length of each segment in terms of L and θ:
$$\cos\theta = \frac{L}{L_{\text{hypotenuse}}}$$
$$L_{\text{hypotenuse}} = \frac{L}{\cos\theta}$$

$$\tan\theta = \frac{L_{\text{opposite}}}{L}$$
$$L_{\text{opposite}} = L\tan\theta$$

Write the magnetic force on each segment in terms of L and θ:

$$\begin{aligned}
F_{\text{on wire}} &= ILB\sin\theta \\
F_{\text{hypotenuse}} &= IL_{\text{hypotenuse}}B\sin\theta \\
&= I\left(\frac{L}{\cos\theta}\right)B\sin\theta \\
F_{\text{hypotenuse}} &= ILB\tan\theta
\end{aligned}$$

$$\begin{aligned}
F_{\text{on wire}} &= ILB\sin\theta \\
F_{\text{opposite}} &= IL_{\text{opposite}}B\sin 90^\circ \\
&= I(L\tan\theta)B \\
F_{\text{opposite}} &= ILB\tan\theta
\end{aligned}$$

The magnitudes of the two forces are equal. By the right-hand rule, the force on the hypotenuse is into the page and the force on the opposite side is out of the page. That means that the sum of the forces is 0 N.

(c) The magnetic force on a closed loop in a uniform magnetic field is zero.

Section 8.4: Motion of Charged Particles in Magnetic Fields

Tutorial 1 Practice, page 401

1. Given: $q = 3.2 \times 10^{-19}$ C; $m = 6.7 \times 10^{-27}$ kg; $B = 2.4$ T; $v = 1.5 \times 10^7$ m/s

Required: r

Analysis: $r = \dfrac{mv}{qB}$

Solution: $r = \dfrac{mv}{qB}$

$$= \frac{\left(6.7 \times 10^{-27}\ \cancel{\text{kg}}\right)\left(1.5 \times 10^{7}\ \dfrac{\text{m}}{\cancel{\text{s}}}\right)}{\left(3.2 \times 10^{-19}\ \cancel{\text{C}}\right)\left(2.4\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}} \cdot \cancel{\text{s}}}\right)}$$

$r = 0.13$ m

Statement: The radius of the ion's path is 0.13 m.

2. Given: $q = 1.60 \times 10^{-19}$ C; $m = 1.67 \times 10^{-27}$ kg; $B = 1.5$ T; $r = 8.0$ cm $= 0.080$ m

Required: v

Analysis: $r = \dfrac{mv}{qB}$

$v = \dfrac{rqB}{m}$

Solution: $v = \dfrac{rqB}{m}$

$$= \frac{(0.080\ \text{m})\left(1.60 \times 10^{-19}\ \cancel{\text{C}}\right)\left(1.5\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}} \cdot \text{s}}\right)}{\left(1.67 \times 10^{-27}\ \cancel{\text{kg}}\right)}$$

$v = 1.1 \times 10^7$ m/s

Statement: The speed of the proton is 1.1×10^7 m/s.

3. Given: $q = 1.60 \times 10^{-19}$ C; $v = 6.0 \times 10^5$ m/s; $m_1 = 1.67 \times 10^{-27}$ kg;
$m_2 = 2(1.67 \times 10^{-27}\text{ kg}) = 3.34 \times 10^{-27}$ kg; $\Delta d = 1.5$ mm $= 0.0015$ m

Required: B

Analysis: $r = \dfrac{mv}{qB}$

In a mass spectrometer, the difference between the entry point and the ion detector is $2r$. The greater the mass of an ion, the greater the radius. So, the deuterium ion is detected at $2r + 0.0015$ m from the entry point, where r is the radius of the path of the hydrogen ion:

$\Delta d = 2r_{\text{deuterium}} - 2r_{\text{hydrogen}}$

Solution: $\Delta d = 2r_{\text{deuterium}} - 2r_{\text{hydrogen}}$

$$= \frac{2m_{\text{deuterium}}v}{qB} - \frac{2m_{\text{hydrogen}}v}{qB}$$

$$= \frac{2v\left(2m_{\text{hydrogen}} - m_{\text{hydrogen}}\right)}{qB}$$

$$B = \frac{2vm_{\text{hydrogen}}}{q\Delta d}$$

$$= \frac{2\left(6.0\times10^{5}\ \frac{\cancel{\text{m}}}{\text{s}}\right)\left(1.67\times10^{-27}\ \text{kg}\right)}{\left(1.60\times10^{-19}\ \text{C}\right)\left(0.0015\ \cancel{\text{m}}\right)}$$

$$B = 8.4\ \text{T}$$

Statement: The magnitude of the magnetic field is 8.4 T.

4. (a) Since the electric force is up, the balancing magnetic force must be down. By the right-hand rule, the magnetic field should be directed out of the page.

(b) The magnetic force is $F_{\text{M}} = qvB$ since the angle is 90°. The electric force is $F_{\text{E}} = \varepsilon q$. These forces are equal when the speed is proper:

$$F_{\text{E}} = F_{\text{M}}$$

$$\varepsilon q = qvB$$

$$\varepsilon = vB$$

$$v = \frac{\varepsilon}{B}$$

The proper velocity is $v = \dfrac{\varepsilon}{B}$.

(c) Since speed only affects the magnetic force, an ion moving too fast will experience a greater magnetic force and be pushed downward. An ion moving too slowly will experience a greater electric force and move upward.

Mini Investigation: Simulating a Mass Spectrometer, page 401

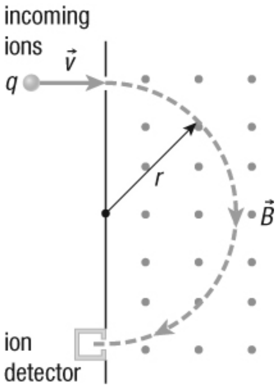
Answers may vary. Sample answers:

A. The ball bearings experience a magnetic force and deflect by different amounts, depending on their masses. This effect is similar to what happens in a mass spectrometer.

B. This activity does not quite model the function of a mass spectrometer because the bearings do not experience a uniform magnetic force. The force gets stronger at the bottom of the ramp, and gravity will have a more significant effect in this simulation than on particles in a mass spectrometer.

Section 8.4 Questions, page 404

1. The mass spectrometer makes use of the magnetic force on a moving charged particle. Atoms are converted into ions and then accelerated into a finely focused beam. The force deflects a particle by an amount depending on its mass and its charge. Electric detectors identify how far the ion travelled in the mass spectrometer.



2. Given: $q = 3(1.60 \times 10^{-19}\text{ C}) = 4.80 \times 10^{-19}\text{ C}$; $m_{\text{U238}} = 3.952 \times 10^{-25}\text{ kg}$; $m_{\text{U235}} = 3.903 \times 10^{-25}\text{ kg}$; $B = 9.5\text{ T}$; $\Delta d = 2.2\text{ mm} = 0.0022\text{ m}$

Required: v

Analysis: $r = \dfrac{mv}{qB}$

In a mass spectrometer, the difference between the entry point and the ion detector is $2r$. The greater the mass of an ion, the greater the radius. So, the U-238 ion is detected at $2r + 0.0022$ m from the entry point where r is the radius of the path of the U-235 ion: $\Delta d = 2r_{\text{U238}} - 2r_{\text{U235}}$

$$\begin{aligned}
\Delta d &= 2r_{\text{U238}} - 2r_{\text{U235}} \\
&= \frac{2m_{\text{U238}}v}{qB} - \frac{2m_{\text{U235}}v}{qB} \\
&= \frac{2v\left(m_{\text{U238}} - m_{\text{U235}}\right)}{qB} \\
v &= \frac{qB\Delta d}{2\left(m_{\text{U238}} - m_{\text{U235}}\right)}
\end{aligned}$$

Solution: $v = \dfrac{qB\Delta d}{2\left(m_{\text{U238}} - m_{\text{U235}}\right)}$

$$= \frac{3\left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(9.5\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\text{s}}\right)\left(0.0022\ \cancel{\text{m}}\right)}{2\left(3.952\times10^{-25}\ \cancel{\text{kg}} - 3.903\times10^{-25}\ \cancel{\text{kg}}\right)}$$

$$v = 1.0\times10^{6}\ \text{m/s}$$

Statement: The initial speed of the ions is 1.0×10^6 m/s.

3. Given: $q = -1.60 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg; $B = 0.424$ T; $E_k = 2.203 \times 10^{-19}$ J
Required: r
Analysis: Use $E_k = \frac{1}{2}mv^2$ to determine the speed of the electron; then use $r = \frac{mv}{qB}$ to determine the radius of the path.
Solution: Determine the speed of the electron:

$$E_k = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E_k}{m}}$$

$$= \sqrt{\frac{2\left(2.203\times10^{-19}\ \cancel{\text{kg}}\cdot\frac{\text{m}}{\text{s}^2}\cdot\text{m}\right)}{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)}}$$

$v = 6.954\times10^5$ m/s (two extra digits carried)

Determine the radius of the path:

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

$$= \frac{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)\left(6.954\times10^5\ \frac{\text{m}}{\cancel{\text{s}}}\right)}{\left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(0.424\ \frac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)}$$

$r = 9.34\times10^{-6}$ m

Statement: The radius of the electron's path is 9.34×10^{-6} m.

4. Given: $q = 4 \times 10^{-9}$ C; $\vec{v}_1 = 3 \times 10^3$ m/s [E 45° N]; $\vec{F}_1$ is upward; $\vec{v}_2 = 2 \times 10^4$ m/s [up]; $\vec{F}_2 = 4 \times 10^{-5}$ N [W]
Required: B
Analysis: The upward force in the first situation means that, by the right-hand rule, the direction of the magnetic field must be in the x–y plane, and somewhere within 180° counterclockwise of E 45° N. The westward force in the second situation means that, by the right-hand rule, the direction of the magnetic field must be in the y–z plane. The only possible direction that fits both scenarios is north. Use this information and $F_M = qvB \sin\theta$ to solve for the magnitude of the field.

$$F_M = qvB\sin\theta$$

$$B = \frac{F_M}{qv\sin\theta}$$

Solution: $B = \dfrac{F_{\text{M}}}{qv\sin\theta}$

$$= \frac{\left(4\times10^{-5}\ \text{kg}\cdot\dfrac{\cancel{\text{m}}}{\text{s}^2}\right)}{\left(4\times10^{-9}\ \text{C}\right)\left(2\times10^{4}\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\sin 90°}$$

$B = 0.5\ \text{T}$

Statement: The magnetic field is 0.5 T [N].

5. Given: $q = -1.60 \times 10^{-19}$ C; $m = 9.11 \times 10^{-31}$ kg; $\Delta V = 100.0$ V; $B = 0.0400$ T

Required: r

Analysis: Use the law of the conservation of energy, $\Delta E_{\text{E}} + \Delta E_{\text{k}} = 0$, along with the equations $E_{\text{k}} = \dfrac{1}{2}mv^2$ and $\Delta V = \dfrac{E_{\text{E}}}{q}$ to determine the speed of the electron. Then calculate the radius using $r = \dfrac{mv}{qB}$.

Solution: Determine the speed of the electron:

$$\Delta E_{\text{E}} + \Delta E_{\text{k}} = 0$$

$$q\Delta V + \frac{1}{2}mv^2 = 0$$

$$\frac{1}{2}mv^2 = -q\Delta V$$

$$v = \sqrt{\frac{-2q\Delta V}{m}}$$

$$= \sqrt{\frac{-2\left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(100.0\ \cancel{\text{kg}}\cdot\dfrac{\text{m}}{\text{s}^2}\cdot\dfrac{\text{m}}{\cancel{\text{C}}}\right)}{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)}}$$

$v = 5.9267\times10^{6}$ m/s (two extra digits carried)

Determine the radius of the path:

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

$$= \frac{\left(9.11\times10^{-31}\ \cancel{\text{kg}}\right)\left(5.9267\times10^{6}\ \dfrac{\text{m}}{\cancel{\text{s}}}\right)}{\left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(0.0400\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)}$$

$r = 8.44\times10^{-4}$ m

Statement: The radius of the path described by the electron is 8.44×10^{-4} m = 0.844 mm.

6. (a) Given: $\theta = 90°$; $v = 5.0 \times 10^2$ m/s; $B = 0.050$ T
Required: ε
Analysis: $F_E = F_M$; $F_M = qvB \sin \theta$; $F_E = \varepsilon q$

$$F_E = F_M$$

$$\varepsilon q = qvB\sin\theta$$

Solution: $\varepsilon = vB\sin 90°$

$$= \left(5.0\times10^2\ \frac{\text{m}}{\text{s}}\right)\left(0.050\ \frac{\text{kg}}{\text{C}\cdot\text{s}}\right)$$

$$\varepsilon = 25\ \text{N/C}$$

Statement: The strength of the electric field is 25 N/C.
(b) Given: $q = 1.60 \times 10^{-19}$ C; $m = 1.67 \times 10^{-27}$ kg; $B = 0.050$ T; $v = 5.0 \times 10^2$ m/s
Required: r
Analysis: $r = \dfrac{mv}{qB}$

Solution: $r = \dfrac{mv}{qB}$

$$= \frac{(1.67\times10^{-27}\ \cancel{\text{kg}})\left(5.0\times10^2\ \dfrac{\text{m}}{\cancel{\text{s}}}\right)}{(1.60\times10^{-19}\ \cancel{\text{C}})\left(0.050\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)}$$

$$r = 1.0\times10^{-4}\ \text{m}$$

Statement: The radius of the proton’s path to point P is 1.0×10^{-4} m.

Chapter 8 Review, pages 416–421

Knowledge

1. (a)
2. (b)
3. (d)
4. (c)
5. (a)
6. (d)
7. (d)

8. True

9. True

10. True

11. True

12. False. Field theory does not include the study of the principles of spectral fields.

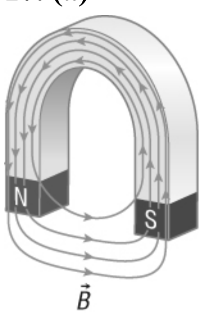
13. True

14. False. *Current research indicates that* exposure to high-voltage electrical fields *does not* increase the risk of developing cancers.

15. True

Understanding

16. (a) Iron filings align in parallel with the magnetic field of the bar magnet.
(b) Magnetic field lines point from the north pole to the south pole.
17. (a)



(b) The magnetic field is strongest directly between the poles.
18. The iron filings act like tiny bar magnets. The strong magnetic force will cause the iron filings to align with the field of the magnet that produces the force.
19. The compass needle N shows the direction of geographic north pole because the north pole of the needle is attracted toward Earth's magnetic south pole (geographic north pole).
20. It may be caused by electric currents in Earth's liquid core. The spin of Earth about its axis causes the liquid to circulate in a complicated pattern that varies with time.
21. When the lamp is turned on, the compass needle may move because the current in the lamp's cord creates a magnetic field. The orientation of the compass and the cord will determine which way the compass needle will deflect.
22. The batteries are the same, so the solenoid on the right, which has more windings, has a stronger magnetic field.

23. Placing an iron core (or any other magnetic material) in the middle of the coil makes a solenoid's magnetic field stronger.
24. Students should use the right-hand rule to determine that the magnetic field inside the solenoid in their drawings points left.
25. The direction of the force is perpendicular, or 90°, relative to the velocity and magnetic field.
26. (a) Given: $B = 1.2 \times 10^{-3}$ T; $q = 1.60 \times 10^{-19}$ C; $v = 3.2 \times 10^{7}$ m/s; $\theta = 90°$
Required: F_M
Analysis: $F_M = qvB \sin \theta$
Solution:

$$F_M = qvB\sin\theta$$
$$= \left(1.60\times10^{-19}\ \cancel{C}\right)\left(3.2\times10^{7}\ \text{m/s}\right)\left(1.2\times10^{-3}\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$
$$F_M = 6.1\times10^{-15}\ \text{N}$$

Statement: The magnetic force on the proton is 6.1×10^{-15} N.
(b) Using the right-hand rule, the force on the proton points east.
27. (a) If an electron enters parallel to the field direction, it continues in the same direction since there is no magnetic force.
(b) Using the right-hand rule, if an electron enters perpendicular to the field direction, it moves in a circle that is always perpendicular to the magnetic field, at a constant speed.
(c) Using the right-hand rule, if an electron enters at some other angle to the field direction, it moves in a helix with an axis in the same direction as the magnetic field, at a constant speed.
28. (a) Since the electron has a negative charge and the direction of Earth's magnetic field near the equator is south to north, using the right-hand rule, the electron is deflected west.
(b) Since the electron has a negative charge and the direction of Earth's magnetic field near the equator is south to north, using the right-hand rule, the electron is deflected vertically upward.
(c) The electron is travelling in the same direction as Earth's magnetic field, so there is no deflection.
29. (a) Given: $q = 1.60 \times 10^{-19}$ C; $m = 1.67 \times 10^{-27}$ kg; $B = 1.50$ T; $v = 6 \times 10^{6}$ m/s
Required: F_M
Analysis: $F_M = qvB \sin \theta$; the maximum magnitude is when $\theta = 90°$.
Solution:

$$F_M = qvB\sin\theta$$
$$= \left(1.60\times10^{-19}\ \cancel{C}\right)\left(6\times10^{6}\ \text{m/s}\right)\left(1.50\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$
$$F_M = 1.44\times10^{-12}\ \text{N}$$

Statement: The maximum magnetic force on the proton is 1.44×10^{-12} N.
(b) Given: $m = 1.67 \times 10^{-27}$ kg; $F_M = 1.44 \times 10^{-12}$ N
Required: a
Analysis: $F_M = ma;\ a = \dfrac{F_M}{m}$

Solution: $a = \frac{F_M}{m}$

$$= \frac{\left(1.44 \times 10^{-12}\ \cancel{\text{kg}} \cdot \frac{\text{m}}{\text{s}^2}\right)}{\left(1.67 \times 10^{-27}\ \cancel{\text{kg}}\right)}$$

$a = 8.62 \times 10^{14}\ \text{m/s}^2$

Statement: The maximum acceleration of the proton is 8.62×10^{14} m/s^2.

30. Given: B = 0.08 T; $q = 2.0 \times 10^{-11}$ C; θ = 90°; v = 4.8 cm/s = 4.8×10^{-2} m/s

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(2.0 \times 10^{-11}\ \cancel{\text{C}}\right)\left(4.8 \times 10^{-2}\ \text{m/s}\right)\left(0.080\ \frac{\text{kg}}{\cancel{\text{C}} \cdot \text{s}}\right)\sin 90°$$

$F_M = 7.7 \times 10^{-14}\ \text{N}$

Statement: The magnitude of the magnetic force is 7.7×10^{-14} N.

31. The magnetic field is directed right to left (from the north pole to the south pole), so by the right-hand rule, the force is directed out of the page.

32. The set should such be placed so that the beam is moving either toward the east or toward the west.

33. Given: I = 10.0 A; B = 0.300 T; L = 5.00 m; θ = 30.0°

Required: $F_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(10.0\ \frac{\cancel{\text{C}}}{\text{s}}\right)(5.00\ \text{m})\left(0.300\ \frac{\text{kg}}{\cancel{\text{C}} \cdot \text{s}}\right)\sin 30.0°$$

$F_{\text{on wire}} = 7.50\ \text{N}$

Statement: The magnitude of the force on the wire is 7.50 N.

34. Given: $q = 1.60 \times 10^{-19}$ C; $v = 1.0 \times 10^7$ m/s; $r = 6.4 \times 10^6$ m; $m = 1.67 \times 10^{-27}$ kg

Required: B

Analysis: $r = \frac{mv}{qB}$; $B = \frac{mv}{qr}$

Solution: $B = \frac{mv}{qr}$

$$= \frac{\left(1.67 \times 10^{-27}\ \cancel{\text{kg}}\right)\left(1.0 \times 10^7\ \frac{\cancel{\text{m}}}{\text{s}}\right)}{\left(1.60 \times 10^{-19}\ \cancel{\text{C}}\right)\left(6.4 \times 10^6\ \cancel{\text{m}}\right)}$$

$B = 1.6 \times 10^{-8}\ \text{T}$

Statement: The magnetic field is 1.6×10^{-8} T.

35. Given: $q_{\text{proton}} = 1.60 \times 10^{-19}$ C; $m_{\text{proton}} = 1.67 \times 10^{-27}$ kg; $m_{\text{neutron}} = m_{\text{proton}}$
Required: r for H^+, $^2H^+$, and $^3H^+$
Analysis: Express r in terms of v and B using $r = \dfrac{mv}{qB}$. Assume H^+ has the mass of one proton, $^2H^+$ has the mass of one proton and one neutron, and $^3H^+$ has the mass of one proton and two neutrons.
Solution:

$$r = \frac{mv}{qB} \qquad r = \frac{mv}{qB} \qquad r = \frac{mv}{qB}$$

$$r_1 = \frac{m_{\text{proton}}v}{q_{\text{proton}}B} \qquad r_2 = \frac{2m_{\text{proton}}v}{q_{\text{proton}}B} \qquad r_3 = \frac{3m_{\text{proton}}v}{q_{\text{proton}}B}$$

$$= \frac{(1.67\times10^{-27}\ \text{kg})v}{(1.60\times10^{-19}\ \text{C})B} \qquad = \frac{2(1.67\times10^{-27}\ \text{kg})v}{(1.60\times10^{-19}\ \text{C})B} \qquad = \frac{3(1.67\times10^{-27}\ \text{kg})v}{(1.60\times10^{-19}\ \text{C})B}$$

$$r_1 = (1.04\times10^{-8})\frac{v}{B} \qquad r_2 = (2.09\times10^{-8})\frac{v}{B} \qquad r_3 = (3.13\times10^{-8})\frac{v}{B}$$

Statement: The radius of the H^+ ion's path is $(1.04 \times 10^{-8})\dfrac{v}{B}$. The radius of the $^2H^+$ ion's path is $(2.09 \times 10^{-8})\dfrac{v}{B}$. The radius of the $^3H^+$ ion's path is $(3.13 \times 10^{-8})\dfrac{v}{B}$.

36. (a) Given: $\varepsilon = 510$ V/m; $B = 0.025$ T
Required: v
Analysis: The magnetic force is $F_M = qvB$ since the angle is 90°. The electric force is $F_E = \varepsilon q$. These forces are equal when an ion has the selected speed: $F_M = F_E$.

$$\begin{aligned} F_E &= F_M \\ \varepsilon \cancel{q} &= \cancel{q}vB \\ \varepsilon &= vB \\ v &= \frac{\varepsilon}{B} \end{aligned}$$

Solution: $v = \dfrac{\varepsilon}{B}$

$$= \frac{510\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}}\cdot\dfrac{\text{m}}{\text{s}^{\cancel{2}}}}{0.025\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}}$$

$$v = 2.0\times10^4\ \text{m/s}$$

Statement: The speed selected for protons is 2.0×10^4 m/s.
(b) The speed selected is independent of mass or charge, so the speed selected for Ca^{2+} ions is also 2.0×10^4 m/s.
(c) Both forces would reverse directions since the charge is now negative.

Analysis and Application

37. (a) Using the right-hand rule, if your fingers curl in the direction of the magnetic field, your thumb points right, the direction of the current.

(b) To reverse the magnetic field direction, reverse the current direction: left.

38. (a) Using the right-hand rule, the field points into the page.

(b) Using the right-hand rule, the field points right.

(c) Using the right-hand rule, the field points down.

39. (a) An electron with no velocity experiences no force: 0 N.

(b) Given: $q = -1.60 \times 10^{-19}$ C; $v = 2.0$ m/s; $B = 3.0$ T; $\theta = 90°$

Required: $\vec{F}_M$

Analysis: $F_M = qvB \sin \theta$; by the right-hand rule, the force on a positive charge is into the page.

Solution: $F_M = qvB\sin\theta$

$$= \left(-1.60\times10^{-19}\ \cancel{C}\right)\left(2.0\ \text{m/s}\right)\left(3.0\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$

$$F_M = -9.6\times10^{-19}\ \text{N}$$

Statement: The magnetic force on the proton is 9.6×10^{-19} N [out of the page].

(c) An electron moving in the same direction as the magnetic field experiences no force: 0 N.

40. Using the right-hand rule, the electron will experience a force down or south as it enters the magnetic field. This deflection to the left of its path will cause the electron to move in a semicircle until it exits the magnetic field. It will curve downward.

41. Given: $B = 0.3$ T; $q = 0.006$ C; $v = 400$ m/s; $\theta = 90°$

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(0.006\ \cancel{C}\right)\left(400\ \text{m/s}\right)\left(0.3\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$

$$F_M = 0.72\ \text{N}$$

Statement: The magnitude of the magnetic force on the particle is 0.72 N.

42. Given: $q = 1.60 \times 10^{-19}$ C; $B = 5.4 \times 10^{-2}$ m/s; $\theta = 90°$; $v = 4.8 \times 10^{5}$ m/s

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(1.60\times10^{-19}\ \cancel{C}\right)\left(4.8\times10^{5}\ \text{m/s}\right)\left(5.4\times10^{-2}\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$

$$F_M = 4.1\times10^{-15}\ \text{N}$$

Statement: The magnitude of the magnetic force on the proton is 4.1×10^{-15} N.

43. Given: $q = -1.60 \times 10^{-19}$ C; $v = 6.9 \times 10^{3}$ m/s; $\theta = 90°$; $B = 1.3 \times 10^{-2}$ T

Required: $\vec{F}_M$

Analysis: $F_M = qvB \sin \theta$; by the right-hand rule, the force on a positive charge is down.

Solution: $F_M = qvB\sin\theta$

$$= \left(-1.60\times10^{-19}\ \cancel{C}\right)\left(6.9\times10^{3}\ \text{m/s}\right)\left(1.3\times10^{-2}\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$

$$F_M = -1.4\times10^{-17}\ \text{N}$$

Statement: The magnetic force on the electron is 1.4×10^{-17} N [up].

44. Given: $q = 5.0 \times 10^{-16}$ C; $B = 2.4 \times 10^{-2}$ T; $\theta = 90°$; $v = 4.9 \times 10^5$ m/s

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(5.0\times10^{-16}\ \cancel{\text{C}}\right)\left(4.9\times10^{5}\ \text{m/s}\right)\left(2.4\times10^{-2}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$

$$F_M = 5.9\times10^{-12}\ \text{N}$$

Statement: The magnitude of the magnetic force on the particle is 5.9×10^{-12} N.

45. Given: $q = -1.60 \times 10^{-19}$ C; $v = 3.0 \times 10^3$ m/s; $\theta = 90°$; $B = 2.4 \times 10^{-2}$ T

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(3.0\times10^{3}\ \text{m/s}\right)\left(2.4\times10^{-2}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90°$$

$$F_M = -1.2\times10^{-17}\ \text{N}$$

Statement: The magnitude of the magnetic force on the electron is 1.2×10^{-17} N.

46. Given: $q = -1.60 \times 10^{-19}$ C; $\theta = 90°$; $v = 8.0 \times 10^4$ m/s; $F_M = 3.8 \times 10^{-18}$ N

Required: B

Analysis: $F_M = qvB\sin\theta$

$$B = \frac{F_M}{qv\sin\theta}$$

Solution: $B = \dfrac{F_M}{qv\sin\theta}$

$$= \frac{\left(3.8\times10^{-18}\ \text{kg}\cdot\dfrac{\cancel{\text{m}}}{\text{s}^{\cancel{2}}}\right)}{\left(-1.60\times10^{-19}\ \text{C}\right)\left(8.0\times10^{4}\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\sin 90°}$$

$$B = 3.0\times10^{-4}\ \text{T}$$

Statement: The magnetic field strength is 3.0×10^{-4} T.

47. Given: $q = -2(1.60 \times 10^{-19}$ C); $m = 2.7 \times 10^{-26}$ kg; $v = 310$ m/s; $\theta = 90°$; $a = 1.5 \times 10^9$ m/s^2

Required: B

Analysis: $F_M = qvB\sin\theta$

$$F_M = ma$$

$$ma = qvB\sin\theta$$

$$B = \frac{ma}{qv\sin\theta}$$

Solution: $B = \dfrac{ma}{qv\sin\theta}$

$$= \frac{\left(2.7\times10^{-26}\ \text{kg}\right)\left(1.5\times10^{9}\ \dfrac{\cancel{\text{m}}}{\text{s}^{\cancel{2}}}\right)}{-2\left(1.60\times10^{-19}\ \text{C}\right)\left(310\ \dfrac{\cancel{\text{m}}}{\cancel{\text{s}}}\right)\sin 90^\circ}$$

$B = 0.41\ \text{T}$

Statement: The magnetic field strength is 0.41 T.

48. Given: $q = 1.60 \times 10^{-19}$ C; $v = 520$ m/s; $\theta = 90°$; $B = 5.5 \times 10^{-5}$ T

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(520\ \text{m/s}\right)\left(5.5\times10^{-5}\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90^\circ$$

$F_M = 4.6\times10^{-21}\ \text{N}$

Statement: The magnitude of the magnetic force on the nitrogen ion is 4.6×10^{-21} N.

49. (a) The magnetic field must be pointing either north or south because there is no force when the proton is travelling north. By the right-hand rule, if the proton is moving east and the force is pointed up, then the magnetic field is moving south to north.

(b) Given: $q = 1.60 \times 10^{-19}$ C; $v = 1.00 \times 10^{5}$ m/s; $B = 55.0$ T; $\theta = 90°$

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(1.00\times10^{5}\ \text{m/s}\right)\left(55.0\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90^\circ$$

$F_M = 8.8\times10^{-13}\ \text{N}$

Statement: The magnitude of the magnetic force on the proton is 8.8×10^{-13} N.

50. (a) Given: $q = -1.60 \times 10^{-19}$ C; $v = 2.5 \times 10^{5}$ m/s; $B = 55.0$ T; $\theta = 90°$

Required: F_M

Analysis: $F_M = qvB \sin \theta$

Solution: $F_M = qvB\sin\theta$

$$= \left(-1.60\times10^{-19}\ \cancel{\text{C}}\right)\left(2.5\times10^{5}\ \text{m/s}\right)\left(55.0\ \frac{\text{kg}}{\cancel{\text{C}}\cdot\text{s}}\right)\sin 90^\circ$$

$F_M = -2.2\times10^{-12}\ \text{N}$

Statement: The magnitude of the magnetic force on the electron is 2.2×10^{-12} N.

(b) By the right-hand rule, if an electron is moving west and the field is directed north to south, then the force is directed down.

51. Since the path of the particle is parallel to the magnetic field, there is no magnetic force: 0 N.

52. To maximize the magnetic force, place the conductor perpendicular to the magnetic field.

53. The direction of the magnetic force is perpendicular to the conductor (*x*-axis) and the magnetic field (*z*-axis), so it will be along the *y*-axis.

54. Since the path of the current is parallel to the magnetic field, there is no magnetic force: 0 N.

55. By the right-hand rule, if the current moves in the +*z* direction and the field is in the –*y* direction, then the force is in the –*x* direction.
56. Given: $L = 0.65$ m; $I = 1.7$ A; $B = 1.6$ T; $F_{\text{on wire}} = 1.1$ N
Required: θ
Analysis: $F_{\text{on wire}} = ILB\sin\theta$

$$\sin\theta = \frac{F_{\text{on wire}}}{IBL}$$

$$\theta = \sin^{-1}\left(\frac{F_{\text{on wire}}}{IBL}\right)$$

Solution: $\theta = \sin^{-1}\left(\frac{F_{\text{on wire}}}{IBL}\right)$

$$= \sin^{-1}\left(\frac{\left(1.1\ \cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\cancel{\text{s}^2}}\right)}{\left(1.7\ \frac{\cancel{\text{C}}}{\cancel{\text{s}}}\right)\left(1.6\ \frac{\cancel{\text{kg}}}{\cancel{\text{C}}\cdot\cancel{\text{s}}}\right)(0.65\ \cancel{\text{m}})}\right)$$

$$\theta = 38°$$

Statement: The angle between the magnetic field and the wire is 38°.
57. Using the right-hand rule for a current-carrying conductor, the magnetic field around the wire is in a counterclockwise direction. In the diagram, the field meets the electron as it moves left to right. By the right-hand rule, the direction of the magnetic force on the electron is toward the wire.
58. Given: $L = 10$ cm = 0.1 m; $\theta = 90°$; $B = 1$ T; $F_{\text{on wire}} = 2.5$ N
Required: I
Analysis: $F_{\text{on wire}} = ILB\sin\theta$; $I = \frac{F_{\text{on wire}}}{LB\sin\theta}$

Solution: $I = \frac{F_{\text{on wire}}}{LB\sin\theta}$

$$= \frac{\left(2.5\ \cancel{\text{kg}}\cdot\frac{\cancel{\text{m}}}{\text{s}^{\cancel{2}}}\right)}{(0.01\ \cancel{\text{m}})\left(1\ \frac{\cancel{\text{kg}}}{\text{C}\cdot\cancel{\text{s}}}\right)\sin 90°}$$

$$I = 25\ \text{A}$$

Statement: The current through the wire is 25 A.
59. Reversing the charge on the particle reverses the direction of the magnetic force.
60. (a) Since the wire is parallel to the magnetic field, the magnetic force is 0 N.
(b) Given: $L = 25$ cm = 0.25 m; $I = 50.0$ A; $B = 49$ T; $\theta = 45°$
Required: $F_{\text{on wire}}$
Analysis: $F_{\text{on wire}} = ILB\sin\theta$

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(50.0\ \frac{\cancel{C}}{s}\right)(0.25\ \text{m})\left(49\ \frac{\text{kg}}{\cancel{C}\cdot s}\right)\sin 45°$$

$$F_{\text{on wire}} = 4.3\times10^{2}\ \text{N}$$

Statement: The force on the wire when the angle is 45° is 4.3×10^2 N.

(c) Given: L = 25 cm = 0.25 m; I = 50.0 A; B = 49 T; θ = 90°

Required: $F_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(50.0\ \frac{\cancel{C}}{s}\right)(0.25\ \text{m})\left(49\ \frac{\text{kg}}{\cancel{C}\cdot s}\right)\sin 90°$$

$$F_{\text{on wire}} = 6.1\times10^{2}\ \text{N}$$

Statement: The force on the wire when the angle is 90° is 6.1×10^2 N.

61. Given: L = 5.0 cm = 0.050 m; I = 2.5 A; B = 25 T; θ = 90°

Required: $F_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(2.5\ \frac{\cancel{C}}{s}\right)(0.050\ \text{m})\left(25\ \frac{\text{kg}}{\cancel{C}\cdot s}\right)\sin 90°$$

$$F_{\text{on wire}} = 3.1\ \text{N}$$

Statement: The force on the wire is 3.1 N.

62. Given: L = 36.0 m; I = 22.0 A; $B = 5.00 \times 10^{-5}$ T; θ = 90°

Required: $\vec{F}_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$; using the right-hand rule, since the current is direct east and magnetic field is directed north, the force is directed up.

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(22.0\ \frac{\cancel{C}}{s}\right)(36.0\ \text{m})\left(5.00\times10^{-5}\ \frac{\text{kg}}{\cancel{C}\cdot s}\right)\sin 90°$$

$$F_{\text{on wire}} = 4.0\times10^{-2}\ \text{N}$$

Statement: The force on the wire is 4.0×10^{-2} N [up].

63. Given: L = 30 cm = 0.30 m; I = 4.0 A; θ = 90°; B = 0.3 T

Required: $F_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(4.0\ \frac{\cancel{C}}{s}\right)(0.30\ \text{m})\left(0.3\ \frac{\text{kg}}{\cancel{C}\cdot s}\right)\sin 90°$$

$$F_{\text{on wire}} = 0.36\ \text{N}$$

Statement: The force on this segment of the cord is 0.36 N.

64. Given: I = 5.0 A; B = 0.2 T; L = 1.5 m; θ = 90°

Required: $\vec{F}_{\text{on wire}}$

Analysis: $F_{\text{on wire}} = ILB \sin \theta$; using the right-hand rule, since the current is direct east and magnetic field is directed up, the force is directed south.

Solution: $F_{\text{on wire}} = ILB\sin\theta$

$$= \left(5.0\ \frac{\cancel{C}}{\text{s}}\right)(1.5\text{ m})\left(0.2\ \frac{\text{kg}}{\cancel{C}\cdot\text{s}}\right)\sin 90°$$

$$F_{\text{on wire}} = 1.5\text{ N}$$

Statement: The force on the wire is 1.5 N [S].

65. (a) The magnetic field is moving into the page.

(b) (i) There is no force on the wire, so there is no current.

(ii) There is force to the left on the wire, so by the right-hand rule, the current is flowing upward.

(iii) There is force to the right on the wire, so by the right-hand rule, the current is flowing downward.

66. (a) Using the right-hand rule, since the direction of the magnetic field is into the page, the force on a positive charge would be to the left of its direction. This particle has a positive charge.

(b) Substitute $q_{\text{new}} = 3q$ into the equation for the radius of a charged particle's path in a magnetic field:

$$r = \frac{mv}{q_{\text{new}}B}$$

$$= \frac{mv}{(3q)B}$$

$$r = \frac{1}{3}\left(\frac{mv}{qB}\right)$$

The trajectory would have one-third the radius.

(c) Substitute $m_{\text{new}} = \dfrac{m}{10}$ into the equation for the radius of a charged particle's path in a magnetic field:

$$r = \frac{m_{\text{new}}v}{qB}$$

$$= \frac{\left(\frac{m}{10}\right)v}{qB}$$

$$r = \frac{1}{10}\left(\frac{mv}{qB}\right)$$

The trajectory would have one-tenth the radius.

Evaluation

67. (a) First, point the fingers of your right hand in the direction of the magnetic field. Point your thumb in the direction of the current. Your palm faces the direction of the magnetic force.

(b) The formula is $F_M = qvB\sin\theta$.

(c) Using the right-hand rule, the magnetic field reverses direction if the current changes directions from east to west.

68. (a) Electrical signals corresponding to sounds are fed into the speaker as a changing current. This current creates a varying magnetic field around the coil inside the speaker.

(b) The varying magnetic field of the coil and the constant magnetic field of the permanent magnet cause the cone to oscillate back and forth at a particular frequency. These oscillations cause the cone to produce sound waves.
69. (a) Strong solar winds increase the number of charged particles in Earth's atmosphere. Electrically charged electrons and protons spiral along Earth's magnetic field lines and collide with oxygen and nitrogen atoms in the upper atmosphere. These collisions release energy in the form of visible light. The more collisions, the more intense the aurora
(b) Earth's magnetic field is very strong in northern Canada, which is close to Earth's magnetic north pole. The magnetic field gets weaker as you move south toward the equator. There's a higher concentration of charged particles in the regions with a strong magnetic field, so this means more collisions between atoms and molecules take place in northern Canada than south of Manitoba.
(c) Van Allen belts are the source of charged particles that enter the upper atmosphere and collide with oxygen and nitrogen atoms to produce auroras.
70. Sample table:

	Gravitational	Electrical	Magnetic
Affected particles	massive particles	charged particles	charged particles
Factors determining magnitude of force	mass of particle, strength of field	charge of particle, strength of field	charge of particle, speed of particle, strength of field
Factor determining direction of force	field direction	field direction for positive charges and opposite of field direction for negative charges	perpendicular to path and field
Relative strength	very weak but long range	very strong but short range	very strong but short range

71. Answers may vary. Sample answers: Before Ampère, scientists believed that magnetism and electricity were two unconnected areas of study. Ampère changed this opinion when he demonstrated that parallel currents in wires attract and anti-parallel currents repel. The idea that electricity and magnetism are not separate forces but two aspects of the same phenomenon led to, among other things, the discovery of radio waves and the theory of relativity.

Reflect on Your Learning
72. Answers may vary. Students should discuss their favourite topics from the chapter. For example, some students might be interested in the applications of magnetic fields in RFID chips since that is an application they can see.
73. Answers may vary. Students should point out that magnetic field lines are directed from one pole to the other and circular, while electric field lines spread out radially and do not have an endpoint.
74. There are right-hand rules for determine the direction of a magnetic field around a current-carrying conductor, the direction of magnetic field lines in a solenoid, and the direction of a magnetic force on a particle moving in a magnetic field.

75. Answers may vary. For example, an analogy of electricity in magnetism is how the sign and magnitude of the charge on a particle affect the force it experiences in a magnetic field or an electric field.

Research

76. Answers may vary. Students' answers will likely mention that magnetic strips could contain millions of tiny magnets that would be directed either north or south. These magnets would encode information just like 0s and 1s on a computer.

77. Answers may vary. Sample answers:

(a) Scientists can date previous reversals by looking at ancient metal, such as in ancient lava flows, and see how the molten lava was aligned.

(b) Field reversals are a natural result of the spinning iron core of Earth.

(c) Magnetic reversals are irregular and infrequent. The last one was about 780 000 years ago.

(d) Students' answers may relate the reversal to animals that migrate based on magnetic fields, or the effects it would have on humans as compasses would no longer point north.

78. Answers may vary. Sample answers:

(a) Twisting the wires means that the magnetic fields of the two wires are directed into each other and mostly cancel each other out.

(b) Not twisting wires could result in interference by the magnetic fields, especially when working with radio-controlled systems.

79. Answers may vary. Sample answers:

(a) Wireless charging means you do not have to remember to plug in an electric car and reduces the materials needed for maintaining the car (for example, no extra wires and plugs). It also means you can refuel without stopping the vehicle.

(b) Difficulties include the need for infrastructure to allow charging as you travel and the complexity of billing for fuel.

80. Answers may vary. Students should list published articles on both sides of the argument. They may list medical journals and publications by organizations such as the World Health Organization, Lloyds, and the National Cancer Institute.

81. Answers may vary. Sample answers:

(a) The magnetic field is created by running current through superconducting material.

(b) Limitations of early MRIs include availability, expense, and the slow speed at which they worked.

(c) Magnetic resonance elastography (MRE), which is based on MRI technology, can now detect the elasticity of tissue to diagnose liver diseases.

82. Answers may vary. Students' answers may include the understanding of gravitational fields required to get the land rover to Mars and the research into magnetic materials on Mars. Magnetic fields are also important in the electric motors that make the parts of the rover move. Students' answers may include research into the electric fields generated by blowing sand and dust particles rubbing against the planet's surface, which get so large they can produce ground-level sparks.