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

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

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

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

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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: $F_M = qvB\sin\theta$

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

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

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

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

$$= -0.5414$$

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

$$\theta = -33°$$

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: $F_\text{M} = ma$
Solution:
$$\begin{aligned} F_\text{M} &= ma \\ &= (6.644 \times 10^{-27}\ \text{kg})(2.4 \times 10^{3}\ \text{m/s}^2) \\ &= 1.595 \times 10^{-23}\ \text{N (two extra digits carried)} \\ F_\text{M} &= 1.6 \times 10^{-23}\ \text{N} \end{aligned}$$
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; $F_\text{M} = 1.595 \times 10^{-23}$ N
Required: v
Analysis:
$$F_\text{M} = qvB \sin \theta$$
$$v = \frac{F_\text{M}}{qB \sin \theta}$$
Solution:
$$v = \frac{F_\text{M}}{qB \sin \theta}$$
$$= \frac{\left(1.595 \times 10^{-23}\ \cancel{\text{kg}} \cdot \dfrac{\text{m}}{\text{s}^2}\right)}{2(1.60 \times 10^{-19}\ \cancel{\text{C}})\left(1.4\ \dfrac{\cancel{\text{kg}}}{\cancel{\text{C}} \cdot \cancel{\text{s}}}\right)\sin 90°}$$
$$v = 3.6 \times 10^{-5}\ \text{m/s}$$
Statement: The speed of the alpha particle is 3.6×10^{-5} m/s.