PROBLEMS

1. SSM ***REASONING AND SOLUTION*** According to Equation 21.1, the magnitude B of the magnetic field is

$$B = \frac{F}{q_0 v \sin\theta} = \frac{8.7\times10^{-3}\ \text{N}}{(12\times10^{-6}\ \text{C})(9.0\times10^{6}\ \text{m/s})\sin 90.0°} = \boxed{8.1\times10^{-5}\ \text{T}}$$

2. ***REASONING AND SOLUTION*** The magnitude of the force can be determined using Equation 21.1, $F = qvB \sin\theta$, where θ is the angle between the velocity and the magnetic field. The direction of the force is determined by using Right-Hand Rule No. 1.

a. $F = qvB \sin 30.0° = (8.4\times10^{-6}\ \text{C})(45\ \text{m/s})(0.30\ \text{T})\sin 30.0° = \boxed{5.7\times10^{-5}\ \text{N}}$, directed $\boxed{\text{into the paper}}$.

b. $F = qvB \sin 90.0° = (8.4\times10^{-6}\ \text{C})(45\ \text{m/s})(0.30\ \text{T})\sin 90.0° = \boxed{1.1\times10^{-4}\ \text{N}}$, directed $\boxed{\text{into the paper}}$.

c. $F = qvB \sin 150° = (8.4\times10^{-6}\ \text{C})(45\ \text{m/s})(0.30\ \text{T})\sin 150° = \boxed{5.7\times10^{-5}\ \text{N}}$, directed $\boxed{\text{into the paper}}$.

3. ***REASONING AND SOLUTION***

a. The magnitude of the magnetic force is given by $F = qvB \sin\theta$. We have, therefore,

$$B = \frac{F}{qv\sin\theta} = \frac{7.31\times10^{-3}\ \text{N}}{(25.0\times10^{-6}\ \text{C})(4.50\times10^{3}\ \text{m/s})\sin 90.0°} = \boxed{6.50\times10^{-2}\ \text{T}}$$

b. For the second charge,

$$v_2 = \frac{F}{qB\sin\theta} = \frac{1.90\times10^{-3}\ \text{N}}{(5.00\times10^{-6}\ \text{C})(6.50\times10^{-2}\ \text{T})\sin 40.0°} = \boxed{9.10\times10^{3}\ \text{m/s}}$$

4. ***REASONING*** According to Equation 21.1, the magnetic force has a magnitude of $F = qvB \sin \theta$. The field B and the directional angle θ are the same for each particle. Particle 1, however, travels faster than particle 2. By itself, a faster speed v would lead to a greater force magnitude F. But the force on each particle is the same. Therefore, particle 1 must have a smaller charge to counteract the effect of its greater speed.

SOLUTION Applying Equation 21.1 to each particle, we have

$$\underbrace{F = q_1 v_1 B \sin\theta}_{\text{Particle 1}} \quad \text{and} \quad \underbrace{F = q_2 v_2 B \sin\theta}_{\text{Particle 2}}$$

Dividing the equation for particle 1 by the equation for particle 2 and remembering that $v_1 = 3v_2$ gives

$$\frac{F}{F} = \frac{q_1 v_1 B \sin\theta}{q_2 v_2 B \sin\theta} \quad \text{or} \quad 1 = \frac{q_1 v_1}{q_2 v_2} \quad \text{or} \quad \frac{q_1}{q_2} = \frac{v_2}{v_1} = \frac{v_2}{3v_2} = \boxed{\tfrac{1}{3}}$$

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5. **SSM** ***REASONING*** According to Equation 21.1, the magnitude of the magnetic force on a moving charge is $F = q_0 vB \sin\theta$. Since the magnetic field points due north and the proton moves eastward, $\theta = 90.0°$. Furthermore, since the magnetic force on the moving proton balances its weight, we have $mg = q_0 vB \sin\theta$, where m is the mass of the proton. This expression can be solved for the speed v.

SOLUTION Solving for the speed v, we have

$$v = \frac{mg}{q_0 B \sin\theta} = \frac{(1.67 \times 10^{-27}\ \text{kg})(9.80\ \text{m/s}^2)}{(1.6 \times 10^{-19}\ \text{C})(2.5 \times 10^{-5}\ \text{T}) \sin 90.0°} = \boxed{4.1 \times 10^{-3}\ \text{m/s}}$$

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6. ***REASONING*** According to Equation 21.1, the magnetic force has a magnitude of $F = qvB \sin \theta$, where q is the magnitude of the charge, B is the magnitude of the magnetic field, v is the speed, and θ is the angle of the velocity with respect to the field. As θ increases from 0° to 90°, the force increases. Therefore, the angle we seek must lie between 25° and 90°.

SOLUTION Letting $\theta_1 = 25°$ and θ_2 be the desired angle, we can apply Equation 21.1 to both situations as follows:

$$\underbrace{F = qvB \sin\theta_1}_{\text{Situation 1}} \quad \text{and} \quad \underbrace{2F = qvB \sin\theta_2}_{\text{Situation 2}}$$

Dividing the equation for situation 2 by the equation for situation 1 gives

$$\frac{2F}{F} = \frac{qvB\sin\theta_2}{qvB\sin\theta_1} \quad \text{or} \quad \sin\theta_2 = 2\sin\theta_1 = 2\sin 25° = 0.85$$

$$\theta_2 = \sin^{-1}(0.85) = \boxed{58°}$$

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7. ***REASONING*** The angle θ between the electron's velocity and the magnetic field can be found from Equation 21.1,

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

According to Newton's second law, the magnitude F of the force is equal to the product of the electron's mass m and the magnitude a of its acceleration, $F = ma$.

SOLUTION The angle θ is

$$\theta = \sin^{-1}\left(\frac{ma}{qvB}\right) = \sin^{-1}\left[\frac{(9.11\times10^{-31}\ \text{kg})(3.50\times10^{14}\ \text{m/s}^2)}{(1.60\times10^{-19}\ \text{C})(6.80\times10^{6}\ \text{m/s})(8.70\times10^{-4}\ \text{T})}\right] = \boxed{19.7°}$$

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8. ***REASONING AND SOLUTION*** Equation 21.1 gives the magnitude F of the maximum force on the particle as $F = q_0vB\sin 90.0° = q_0vB$, where B is the magnitude of the net magnetic field. Since the two field components B_x and B_y are perpendicular, the Pythagorean theorem indicates that $B = \sqrt{B_x^2 + B_y^2}$. Therefore, we find that $B = \sqrt{B_x^2 + B_y^2} = \frac{F}{q_0v}$. Squaring this result and solving for the y component of the magnetic field gives

$$B_y = \sqrt{\frac{F^2}{(q_0v)^2} - B_x^2} = \sqrt{\frac{(0.455\ \text{N})^2}{\left[(6.50\times10^{-5}\ C)(2.00\times10^{4}\ \text{m/s})\right]^2} - (0.200\ \text{T})^2} = \boxed{0.287\ \text{T}}$$

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9. SSM WWW ***REASONING*** The direction in which the electrons are deflected can be determined using Right-Hand Rule No. 1 and reversing the direction of the force (RHR-1 applies to positive charges, and electrons are negatively charged).

Each electron experiences an acceleration a given by Newton's second law of motion, $a = F/m$, where F is the net force and m is the mass of the electron. The only force acting on the electron is the magnetic force, $F = q_0vB\sin\theta$, so it is the net force. The speed v of the electron is related to its kinetic energy KE by the relation KE = $\frac{1}{2}mv^2$. Thus, we have enough information to find the acceleration.

SOLUTION

a. According to RHR-1, if you extend your right hand so that your fingers point along the direction of the magnetic field **B** and your thumb points in the direction of the velocity **v** of a *positive* charge, your palm will face in the direction of the force **F** on the positive charge.

For the electron in question, the fingers of the right hand should be oriented downward (direction of **B**) with the thumb pointing to the east (direction of **v**). The palm of the right hand points due north (the direction of **F** on a positive charge). Since the electron is negatively charged, it will be deflected $\boxed{\text{due south}}$.

b. The acceleration of an electron is given by Newton's second law, where the net force is the magnetic force. Thus,

$$a = \frac{F}{m} = \frac{q_0 vB\sin\theta}{m}$$

Since the kinetic energy is $\mathrm{KE} = \frac{1}{2}mv^2$, the speed of the electron is $v = \sqrt{2(\mathrm{KE})/m}$. Thus, the acceleration of the electron is

$$a = \frac{q_0 vB\sin\theta}{m} = \frac{q_0\sqrt{\dfrac{2(\mathrm{KE})}{m}}\,B\sin\theta}{m}$$

$$= \frac{(1.60\times10^{-19}\ \mathrm{C})\sqrt{\dfrac{2(2.40\times10^{-15}\ \mathrm{J})}{9.11\times10^{-31}\ \mathrm{kg}}}\,(2.00\times10^{-5}\ \mathrm{T})\sin 90.0^\circ}{9.11\times10^{-31}\ \mathrm{kg}} = \boxed{2.55\times10^{14}\ \mathrm{m/s^2}}$$

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10. ***REASONING AND SOLUTION***

b. The magnitude of the magnetic field is $B = mv/qr$ (see Equation 21.2). Therefore,

$$B = \frac{(9.11\times10^{-31}\ \mathrm{kg})(6.0\times10^{6}\ \mathrm{m/s})}{(1.60\times10^{-19}\ \mathrm{C})(1.3\times10^{-3}\ \mathrm{m})} = \boxed{2.6\times10^{-2}\ \mathrm{T}}$$

c. From Newton's second law, the electron's acceleration is $a = F/m$, where the force can be obtained using Equation 21.1:

$F = qvB \sin\theta$

$= (1.60 \times 10^{-19}\ \text{C})(6.0 \times 10^{6}\ \text{m/s})(2.6 \times 10^{-2}\ \text{T}) \sin 90.0° = 2.5 \times 10^{-14}\ \text{N}$

The acceleration is, therefore,

$$a = \frac{F}{m} = \frac{2.5 \times 10^{-14}\ \text{N}}{9.11 \times 10^{-31}\ \text{kg}} = \boxed{2.7 \times 10^{16}\ \text{m/s}^2}$$

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11. ***REASONING AND SOLUTION*** The charge can be found from Equation 21.2 as

$$q = \frac{mv}{Br} = \frac{(6.6 \times 10^{-27}\ \text{kg})(4.4 \times 10^{5}\ \text{m/s})}{(0.75\ \text{T})(0.012\ \text{m})} = 3.2 \times 10^{-19}\ \text{C}$$

Since $e = 1.6 \times 10^{-19}$ C, we see that the charge of the ionized helium is $\boxed{+2e}$.

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16. ***REASONING AND SOLUTION*** The magnitudes of the magnetic and electric forces are equal. Therefore, $F_B = F_E$, or $qvB = qE$. Solving for v yields,

$$v = \boxed{E/B}$$

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7. ***REASONING AND SOLUTION*** The radius of curvature for a particle in a mass spectrometer is given by (see Section 21.4)

$$r = \sqrt{\frac{2mV}{qB^2}} = \sqrt{\frac{2\left(3.27 \times 10^{-25}\ \text{kg}\right)\left(1.00 \times 10^{3}\ \text{V}\right)}{\left(3.2 \times 10^{-19}\ \text{C}\right)\left(0.500\ \text{T}\right)^2}} = \boxed{0.0904\ \text{m}}$$

21. ***REASONING AND SOLUTION*** The proton will miss the opposite plate if the distance between the plates is equal to the radius of the circular orbit of the proton. Therefore,

$$B=\frac{mv}{qr}=\frac{\left(1.67\times 10^{-27}\ \text{kg}\right)\left(2.2\times 10^{6}\ \text{m/s}\right)}{\left(1.6\times 10^{-19}\ \text{C}\right)\left(0.18\ \text{m}\right)}=\boxed{0.13\ \text{T}}$$

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26. ***REASONING*** According to Equation 21.3, the magnetic force has a magnitude of $F = ILB \sin \theta$, where I is the current, B is the magnitude of the magnetic field, L is the length of the wire, and $\theta = 90°$ is the angle of the wire with respect to the field.

SOLUTION Using Equation 21.3, we find that

$$L = \frac{F}{IB \sin\theta} = \frac{7.1 \times 10^{-5}\text{ N}}{(0.66\text{ A})(4.7 \times 10^{-5}\text{ T})\sin 58°} = \boxed{2.7\text{ m}}$$

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27. SSM ***REASONING AND SOLUTION*** The magnetic force exerted on the power line is given by Equation 21.3,

$$F = ILB\sin\theta = (1400\text{ A})(120\text{ m})(5.0 \times 10^{-5}\text{ T})(\sin 75°) = \boxed{8.1\text{ N}}$$

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28. ***REASONING AND SOLUTION*** The magnitude F of the force on a current I is given by Equation 21.3 as $F = ILB \sin \theta$, where L is the length of the wire and θ is the angle between the wire and a magnetic field that has a magnitude B. Applying this equation in the two situations described in this problem and recognizing that L, B, and θ are the same in each, we find that

$$\frac{F_1}{F_2} = \frac{I_1 LB \sin\theta}{I_2 LB \sin\theta} = \frac{I_1}{I_2} \quad \text{so} \quad \frac{0.030\text{ N}}{0.047\text{ N}} = \frac{2.7\text{ A}}{I_2} \quad \text{or} \quad I_2 = (2.7\text{ A})\left(\frac{0.047\text{ N}}{0.030\text{ N}}\right) = \boxed{4.2\text{ A}}$$

36. ***REASONING AND SOLUTION*** The maximum torque occurs when $\phi = 90.0°$ so that $\tau = NIAB$. For a square loop, $A = (L/4)^2 = (0.50\text{ m}/4)^2 = 1.6 \times 10^{-2}\text{ m}^2$. So,

$$\tau = NIAB = (1)(12\,A)(1.6 \times 10^{-2}\text{ m}^2)(0.12\text{ T}) = \boxed{0.023\text{ N}\cdot\text{m}}$$

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39. ***REASONING*** The magnetic moment of the current-carrying triangle is the product of the current I and the area A of the triangle. The magnitude τ of the torque exerted on the triangle by the magnetic field is equal to the product of the magnetic moment, the magnitude B of the magnetic field, and the sine of the angle ϕ between the magnetic field and the normal to the plane of the triangle, τ = (*Magnetic moment*) $B \sin \phi$.

SOLUTION

a. The area of a triangle is equal to one-half the base times the height,

$$A = \tfrac{1}{2}(2.00\text{ m})\left[(2.00\text{ m})\tan 55.0°\right] = 2.86\text{ m}^2$$

The magnetic moment is

$$\textit{Magnetic moment} = IA = (4.70\text{ A})(2.86\text{ m}^2) = \boxed{13.4\text{ A}\cdot\text{m}^2}$$

46. ***REASONING AND SOLUTION*** The magnitude B of the magnetic field at a distance r from a long straight wire carrying a current I is $B = \mu_0 I/(2\pi r)$. Thus, the distance is

$$r = \frac{\mu_0 I}{2\pi B} = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(48\ \text{A})}{2\pi(8.0 \times 10^{-5}\ \text{T})} = \boxed{0.12\ \text{m}} \qquad (21.5)$$

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47. ***REASONING AND SOLUTION*** The current associated with the lightning bolt is

$$I = \frac{\Delta q}{\Delta t} = \frac{15\ \text{C}}{1.5 \times 10^{-3}\ \text{s}} = 1.0 \times 10^{4}\ \text{A}$$

The magnetic field near this current is given by

$$B = \frac{\mu_0 I}{2\pi r} = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(1.0 \times 10^{4}\ \text{A})}{2\pi(25\ \text{m})} = \boxed{8.0 \times 10^{-5}\ \text{T}}$$

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48. ***REASONING AND SOLUTION*** The magnetic field at the center of a current loop of radius R is given by $B = \mu_0 I/(2R)$, so that

$$R = \frac{\mu_0 I}{2B} = \frac{(4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})(12\ \text{A})}{2(1.8 \times 10^{-4}\ \text{T})} = \boxed{4.2 \times 10^{-2}\ \text{m}}$$

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49. SSM ***REASONING AND SOLUTION*** The magnetic field inside a long solenoid is given by Equation 21.7:

$$B = \mu_0 n I = (4\pi \times 10^{-7}\ \text{T}\cdot\text{m/A})\left(\frac{1400\ \text{turns}}{0.65\ \text{m}}\right)(4.7\ \text{A}) = \boxed{1.3 \times 10^{-2}\ \text{T}}$$

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64. ***REASONING AND SOLUTION*** The speed of the electron can be determined using $eV = (1/2)mv^2$ so that

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2\left(1.60\times10^{-19}\text{ C}\right)\left(19\,000\text{ V}\right)}{9.11\times10^{-31}\text{ kg}}} = 8.17\times10^{7}\text{ m/s}$$

The magnetic force is given by

$$F = qvB\sin\theta = (1.60\times10^{-19}\text{ C})(8.17\times10^{7}\text{ m/s})(0.28\text{ T})\sin 90.0^\circ = \boxed{3.7\times10^{-12}\text{ N}}$$

72. ***REASONING AND SOLUTION*** The magnetic field due to the circular loop alone is $B_1 = \frac{\mu_0 I_1}{2R}$. The field due to the straight wire is $B_2 = \frac{\mu_0 I_2}{2\pi H}$. These two fields cancel at the center of the loop, so that their magnitudes must be equal:

$$\frac{\mu_0 I_1}{2R} = \frac{\mu_0 (6.6\, I_1)}{2\pi H} \quad \text{or} \quad \boxed{H = 2.1\, R}$$