

Chapter 28

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(a) The magnitude of the magnetic force on the proton is given by $F_B = evB \sin \phi$, where v is the speed of the proton, B is the magnitude of the magnetic field, and ϕ is the angle between the particle velocity and the field when they are drawn with their tails at the same point. Thus

$$v = \frac{F_B}{eB \sin \phi} = \frac{6.50 \times 10^{-17} \text{ N}}{(1.60 \times 10^{-19} \text{ C})(2.60 \times 10^{-3} \text{ T}) \sin 23.0^\circ} = 4.00 \times 10^5 \text{ m/s}.$$

(b) The kinetic energy of the proton is

$$K = \frac{1}{2}mv^2 = \frac{1}{2}(1.67 \times 10^{-27} \text{ kg})(4.00 \times 10^5 \text{ m/s})^2 = 1.34 \times 10^{-16} \text{ J}.$$

This is $(1.34 \times 10^{-16} \text{ J})/(1.60 \times 10^{-19} \text{ J/eV}) = 835 \text{ eV}$.

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(a) Since the kinetic energy is given by $K = \frac{1}{2}mv^2$, where m is the mass of the electron and v is its speed,

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2(1.20 \times 10^3 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})}{9.11 \times 10^{-31} \text{ kg}}} = 2.05 \times 10^7 \text{ m/s}.$$

(b) The magnitude of the magnetic force is given by evB and the acceleration of the electron is given by v^2/r , where r is the radius of the orbit. Newton's second law is $evB = mv^2/r$, so

$$B = \frac{mv}{er} = \frac{(9.11 \times 10^{-31} \text{ kg})(2.05 \times 10^7 \text{ m/s})}{(1.60 \times 10^{-19} \text{ C})(25.0 \times 10^{-2} \text{ m})} = 4.68 \times 10^{-4} \text{ T} = 468 \mu\text{T}.$$

(c) The frequency f is the number of times the electron goes around per unit time, so

$$f = \frac{v}{2\pi r} = \frac{2.05 \times 10^7 \text{ m/s}}{2\pi(25.0 \times 10^{-2} \text{ m})} = 1.31 \times 10^7 \text{ Hz} = 13.1 \text{ MHz}.$$

(d) The period is the reciprocal of the frequency:

$$T = \frac{1}{f} = \frac{1}{1.31 \times 10^7 \text{ Hz}} = 7.63 \times 10^{-8} \text{ s} = 76.3 \text{ ns}.$$

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(a) If v is the speed of the positron, then $v \sin \phi$ is the component of its velocity in the plane that is perpendicular to the magnetic field. Here ϕ is the angle between the velocity and the field (89°). Newton's second law yields $eBv \sin \phi = m(v \sin \phi)^2/r$, where r is the radius of the orbit. Thus $r = (mv/eB) \sin \phi$. The period is given by

$$T = \frac{2\pi r}{v \sin \phi} = \frac{2\pi m}{eB} = \frac{2\pi(9.11 \times 10^{-31} \text{ kg})}{(1.60 \times 10^{-19} \text{ C})(0.100 \text{ T})} = 3.58 \times 10^{-10} \text{ s}.$$

The expression for r was substituted to obtain the second expression for T .

(b) The pitch p is the distance traveled along the line of the magnetic field in a time interval of one period. Thus $p = vT \cos \phi$. Use the kinetic energy to find the speed: $K = \frac{1}{2}mv^2$ yields

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2(2.0 \times 10^3 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})}{9.11 \times 10^{-31} \text{ kg}}} = 2.651 \times 10^7 \text{ m/s}.$$

Thus

$$p = (2.651 \times 10^7 \text{ m/s})(3.58 \times 10^{-10} \text{ s}) \cos 89.0^\circ = 1.66 \times 10^{-4} \text{ m}.$$

(c) The orbit radius is

$$r = \frac{mv \sin \phi}{eB} = \frac{(9.11 \times 10^{-31} \text{ kg})(2.651 \times 10^7 \text{ m/s}) \sin 89.0^\circ}{(1.60 \times 10^{-19} \text{ C})(0.100 \text{ T})} = 1.51 \times 10^{-3} \text{ m}.$$

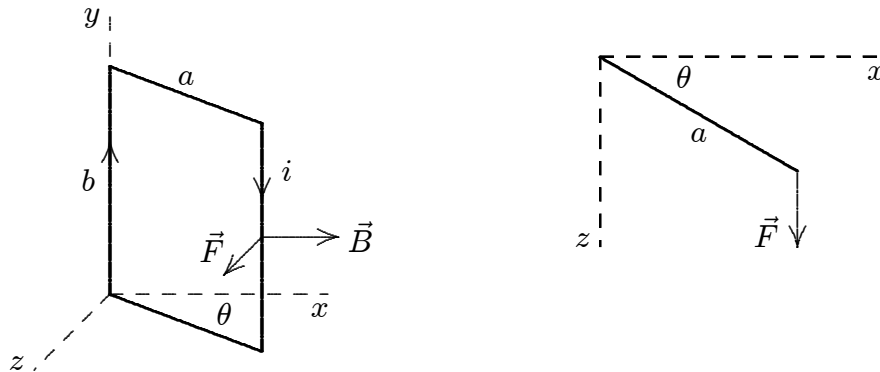
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(a) The magnitude of the magnetic force on the wire is given by $F_B = iLB \sin \phi$, where i is the current in the wire, L is the length of the wire, B is the magnitude of the magnetic field, and ϕ is the angle between the current and the field. In this case $\phi = 70^\circ$. Thus

$$F_B = (5000 \text{ A})(100 \text{ m})(60.0 \times 10^{-6} \text{ T}) \sin 70^\circ = 28.2 \text{ N}.$$

(b) Apply the right-hand rule to the vector product $\vec{F}_B = i\vec{L} \times \vec{B}$ to show that the force is to the west.

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The situation is shown in the left diagram above. The y axis is along the hinge and the magnetic field is in the positive x direction. A torque around the hinge is associated with the wire opposite the hinge and not with the other wires. The force on this wire is in the positive z direction and has magnitude $F = NibB$, where N is the number of turns.

The right diagram shows the view from above. The magnitude of the torque is given by

$$\begin{aligned} \tau &= Fa \cos \theta = NibBa \cos \theta \\ &= 20(0.10 \text{ A})(0.10 \text{ m})(0.50 \times 10^{-3} \text{ T})(0.050 \text{ m}) \cos 30^\circ \\ &= 4.3 \times 10^{-3} \text{ N} \cdot \text{m}. \end{aligned}$$

Use the right-hand rule to show that the torque is directed downward, in the negative y direction. Thus $\vec{\tau} = -(4.3 \times 10^{-3} \text{ N} \cdot \text{m})\hat{j}$.

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(a) The magnitude of the magnetic dipole moment is given by $\mu = NiA$, where N is the number of turns, i is the current in each turn, and A is the area of a loop. In this case the loops are circular, so $A = \pi r^2$, where r is the radius of a turn. Thus

$$i = \frac{\mu}{N\pi r^2} = \frac{2.30 \text{ A} \cdot \text{m}^2}{(160)(\pi)(0.0190 \text{ m})^2} = 12.7 \text{ A}.$$

(b) The maximum torque occurs when the dipole moment is perpendicular to the field (or the plane of the loop is parallel to the field). It is given by $\tau = \mu B = (2.30 \text{ A} \cdot \text{m}^2)(35.0 \times 10^{-3} \text{ T}) = 8.05 \times 10^{-2} \text{ N} \cdot \text{m}$.

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The magnitude of a magnetic dipole moment of a current loop is given by $\mu = iA$, where i is the current in the loop and A is the area of the loop. Each of these loops is a circle and its area is given by $A = \pi R^2$, where R is the radius. Thus the dipole moment of the inner loop has a magnitude of $\mu_i = i\pi r_1^2 = (7.00 \text{ A})\pi(0.200 \text{ m})^2 = 0.880 \text{ A} \cdot \text{m}^2$ and the dipole moment of the outer loop has a magnitude of $\mu_o = i\pi r_2^2 = (7.00 \text{ A})\pi(0.300 \text{ m})^2 = 1.979 \text{ A} \cdot \text{m}^2$.

(a) Both currents are clockwise in Fig. 28–51 so, according to the right-hand rule, both dipole moments are directed into the page. The magnitude of the net dipole moment is the sum of the magnitudes of the individual moments: $\mu_{\text{net}} = \mu_i + \mu_o = 0.880 \text{ A} \cdot \text{m}^2 + 1.979 \text{ A} \cdot \text{m}^2 = 2.86 \text{ A} \cdot \text{m}^2$. The net dipole moment is directed into the page.

(b) Now the dipole moment of the inner loop is directed out of the page. The moments are in opposite directions, so the magnitude of the net moment is $\mu_{\text{net}} = \mu_o - \mu_i = 1.979 \text{ A} \cdot \text{m}^2 - 0.880 \text{ A} \cdot \text{m}^2 = 1.10 \text{ A} \cdot \text{m}^2$. The net dipole moment is again into the page.

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If N closed loops are formed from the wire of length L , the circumference of each loop is L/N , the radius of each loop is $R = L/2\pi N$, and the area of each loop is $A = \pi R^2 = \pi(L/2\pi N)^2 = L^2/4\pi N^2$. For maximum torque, orient the plane of the loops parallel to the magnetic field, so the dipole moment is perpendicular to the field. The magnitude of the torque is then

$$\tau = NiAB = (Ni) \left(\frac{L^2}{4\pi N^2} \right) B = \frac{iL^2 B}{4\pi N}.$$

To maximize the torque, take N to have the smallest possible value, 1. Then

$$\tau = \frac{iL^2 B}{4\pi} = \frac{(4.51 \times 10^{-3} \text{ A})(0.250 \text{ m})^2(5.71 \times 10^{-3} \text{ T})}{4\pi} = 1.28 \times 10^{-7} \text{ N} \cdot \text{m}.$$

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(a) the magnetic potential energy is given by $U = -\vec{\mu} \cdot \vec{B}$, where $\vec{\mu}$ is the magnetic dipole moment of the coil and \vec{B} is the magnetic field. The magnitude of the magnetic moment is $\mu = NiA$,

where i is the current in the coil, A is the area of the coil, and N is the number of turns. The moment is in the negative y direction, as you can tell by wrapping the fingers of your right hand around the coil in the direction of the current. Your thumb is then in the negative y direction. Thus $\vec{\mu} = -(3.00)(2.00 \text{ A})(4.00 \times 10^{-3} \text{ m}^2)\hat{j} = -(2.40 \times 10^{-2} \text{ A} \cdot \text{m}^2)\hat{j}$. The magnetic potential energy is

$$\begin{aligned} U &= -(\mu_y \hat{j}) \cdot (B_x \hat{i} + B_y \hat{j} + B_z \hat{k}) = -\mu_y B_y \\ &= -(-2.40 \times 10^{-2} \text{ A} \cdot \text{m}^2)(-3.00 \times 10^{-3} \text{ T}) = -7.20 \times 10^{-5} \text{ J}, \end{aligned}$$

where $\hat{j} \cdot \hat{i} = 0$, $\hat{j} \cdot \hat{j} = 1$, and $\hat{j} \cdot \hat{k} = 0$ were used.

(b) The magnetic torque on the coil is

$$\begin{aligned} \vec{\tau} &= \vec{\mu} \times \vec{B} = (\mu_y \hat{j}) \times (B_x \hat{i} + B_y \hat{j} + B_z \hat{k}) = \mu_y B_z \hat{i} - \mu_y B_x \hat{k} \\ &= (-2.40 \times 10^{-2} \text{ A} \cdot \text{m}^2)(-4.00 \times 10^{-3} \text{ T})\hat{i} - (-2.40 \times 10^{-2} \text{ A} \cdot \text{m}^2)(2.00 \times 10^{-3} \text{ T})\hat{k} \\ &= (9.6 \times 10^{-5} \text{ N} \cdot \text{m})\hat{i} + (4.80 \times 10^{-5} \text{ N} \cdot \text{m})\hat{k}, \end{aligned}$$

where $\hat{j} \times \hat{i} = -\hat{k}$, $\hat{j} \times \hat{j} = 0$, and $\hat{j} \times \hat{k} = \hat{i}$ were used.

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The net force on the electron is given by $\vec{F} = -e(\vec{E} + \vec{v} \times \vec{B})$, where \vec{E} is the electric field, \vec{B} is the magnetic field, and \vec{v} is the electron's velocity. Since the electron moves with constant velocity you know that the net force must vanish. Thus

$$\vec{E} = -\vec{v} \times \vec{B} = -(v\hat{i}) \times (B\hat{k}) = -vB\hat{j} = -(100 \text{ m/s})(5.00 \text{ T})\hat{j} = (500 \text{ V/m})\hat{j}.$$

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(a) and (b) Suppose the particles are accelerated from rest through an electric potential difference V . Since energy is conserved the kinetic energy of a particle is $K = qV$, where q is the particle's charge. The ratio of the proton's kinetic energy to the alpha particle's kinetic energy is $K_p/K_\alpha = e/2e = 0.50$. The ratio of the deuteron's kinetic energy to the alpha particle's kinetic energy is $K_d/K_\alpha = e/2e = 0.50$.

(c) The magnitude of the magnetic force on a particle is qvB and, according to Newton's second law, this must equal mv^2/R , where v is its speed and R is the radius of its orbit. Since $v = \sqrt{2K/m} = \sqrt{2qV/m}$,

$$R = \frac{mv}{qB} = \frac{m}{qB} \sqrt{\frac{2K}{m}} = \frac{m}{qB} \sqrt{\frac{2qV}{m}} = \sqrt{\frac{2m}{qB^2}}.$$

The ratio of the radius of the deuteron's path to the radius of the proton's path is

$$\frac{R_d}{R_p} = \sqrt{\frac{2.0 \text{ u}}{1.0 \text{ u}}} \sqrt{\frac{e}{e}} = 1.4.$$

Since the radius of the proton's path is 10 cm, the radius of the deuteron's path is $(1.4)(10 \text{ cm}) = 14 \text{ cm}$.

(d) The ratio of the radius of the alpha particle's path to the radius of the proton's path is

$$\frac{R_\alpha}{R_p} = \sqrt{\frac{4.0 \text{ u}}{1.0 \text{ u}}} \sqrt{\frac{e}{2e}} = 1.4.$$

Since the radius of the proton's path is 10 cm, the radius of the deuteron's path is $(1.4)(10 \text{ cm}) = 14 \text{ cm}$.

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Take the velocity of the particle to be $\vec{v} = v_x \hat{i} + v_y \hat{j}$ and the magnetic field to be $B \hat{i}$. The magnetic force on the particle is then

$$\vec{F} = q\vec{v} \times \vec{B} = q(v_x \hat{i} + v_y \hat{j}) \times (B \hat{i}) = -qv_y B \hat{k},$$

where q is the charge of the particle. We used $\hat{i} \times \hat{i} = 0$ and $\hat{j} \times \hat{i} = -\hat{k}$. The charge is

$$q = \frac{F}{-v_y B} = \frac{0.48 \text{ N}}{-(4.0 \times 10^3 \text{ m/s})(\sin 37^\circ)(5.0 \times 10^{-3} \text{ T})} = -4.0 \times 10^{-2} \text{ C}.$$

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(a) If K is the kinetic energy of the electron and m is its mass, then its speed is

$$v = \sqrt{\frac{2K}{m}} = \sqrt{\frac{2(12 \times 10^3 \text{ eV})(1.60 \times 10^{-19} \text{ J/eV})}{9.11 \times 10^{-31}}} = 6.49 \times 10^7 \text{ m/s}.$$

Since the electron is traveling along a line that is parallel to the horizontal component of Earth's magnetic field, that component does not enter into the calculation of the magnetic force on the electron. The magnitude of the force on the electron is evB and since $F = ma$, where a is the magnitude of its acceleration, $evB = ma$ and

$$a = \frac{evB}{m} = \frac{(1.60 \times 10^{-19} \text{ C})(6.49 \times 10^7 \text{ m/s})(55.0 \times 10^{-6} \text{ T})}{9.11 \times 10^{-31} \text{ kg}} = 6.3 \times 10^{14} \text{ m/s}^2.$$

(b) If the electron does not get far from the x axis we may neglect the influence of the horizontal component of Earth's field and assume the electron follows a circular path. Its acceleration is given by $a = v^2/R$, where R is the radius of the path. Thus

$$R = \frac{v^2}{a} = \frac{(6.49 \times 10^7 \text{ m/s})^2}{6.27 \times 10^{14} \text{ m/s}^2} = 6.72 \text{ m}.$$

The solid curve on the diagram is the path. Suppose it subtends the angle θ at its center. d ($= 0.200 \text{ m}$) is the distance traveled along the x axis and ℓ is the deflection. The right triangle yields $d = R \sin \theta$, so $\sin \theta = d/R$ and $\cos \theta = \sqrt{1 - \sin^2 \theta} = \sqrt{1 - (x/R)^2}$. The triangle also gives $\ell = R - R \cos \theta$, so $\ell = R - R \sqrt{1 - (x/R)^2}$. Substitute $R = 6.72 \text{ m}$ and $d = 0.2 \text{ m}$ to obtain $\ell = 0.0030 \text{ m}$.

