CHAPTER 20

1. (*a*) The maximum force will be produced when the wire and the magnetic field are perpendicular, so we have

   $F_{max} = ILB$, or

   $F_{max}/L = IB = (9.80 \text{ A})(0.80 \text{ T}) =$ 7.8 N/m.

   (*b*) We find the force per unit length from

   $F/L = IB \sin 45.0° = (F_{max}/L) \sin 45.0° = (7.8 \text{ N/m}) \sin 45.0° =$ 5.5 N/m.

2. The force on the wire is produced by the component of the magnetic field perpendicular to the wire:

   $F = ILB \sin 40°$

   $= (5.5 \text{ A})(1.5 \text{ m})(5.5 \times 10^{-5} \text{ T}) \sin 40° =$ 2.9×10^{-4} N perpendicular to the wire and to **B**.

3. For the maximum force the wire is perpendicular to the field, so we find the current from

   $F = ILB$;

   $0.900 \text{ N} = I(4.20 \text{ m})(0.0800 \text{ T})$, which gives $I =$ 2.68 A.

4. The maximum force will be produced when the wire and the magnetic field are perpendicular, so we have

   $F_{max} = ILB$;

   $4.14 \text{ N} = (25.0 \text{ A})(0.220 \text{ m})B$, which gives $B =$ 0.753 T.

5. To find the direction of the force on the electron, we point our fingers west and curl them upward into the magnetic field. Our thumb points north, which would be the direction of the force on a positive charge. Thus the force on the electron is south.

   $F = qvB = (1.60 \times 10^{-19} \text{ C})(3.58 \times 10^{6} \text{ m/s})(1.30 \text{ T}) =$ 7.45×10^{-13} N south.

6. To find the direction of the force on the electron, we point our fingers upward and curl them forward into the magnetic field. Our thumb points left, which would be the direction of the force on a positive charge. Thus the force on the electron is right. As the electron deflects to the right, the force will always be perpendicular, so the electron will travel in a clockwise vertical circle.

   The magnetic force provides the radial acceleration, so we have

   $F = qvB = mv^2/r$, so the radius of the path is

   $r = mv/qB$;

   $= (9.11 \times 10^{-31} \text{ kg})(1.80 \times 10^{6} \text{ m/s})/(1.60 \times 10^{-19} \text{ C})(0.250 \text{ T}) =$ 4.10×10^{-5} m.

7. To find the direction of the force on the electron, we point our fingers in the direction of **v** and curl them into the magnetic field **B**. Our thumb points in the direction of the force on a positive charge. Thus the force on the electron is opposite to our thumb.

   (*a*) Fingers out, curl down, thumb right, force left.

   (*b*) Fingers down, curl back, thumb right, force left.

   (*c*) Fingers in, curl right, thumb down, force up.

   (*d*) Fingers right, curl up, thumb out, force in.

   (*e*) Fingers left, but cannot curl into B, so force is zero.

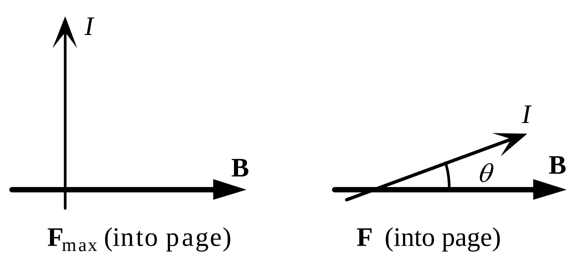
   (*f*) Fingers left, curl out, thumb up, force down.

8. We assume that we want the direction of **B** that produces the maximum force, i. e., perpendicular to **v**. Because the charge is positive, we point our thumb in the direction of **F** and our fingers in the direction of **v**. To find the direction of **B**, we note which way we should curl our fingers, which will be the direction of the magnetic field **B**.
   (*a*) Thumb out, fingers left, curl down.
   (*b*) Thumb up, fingers right, curl in.
   (*c*) Thumb down, fingers in, curl right.

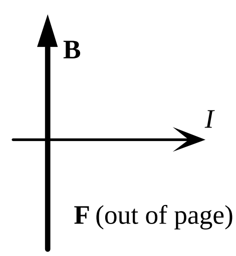
9. To produce a circular path, the magnetic field is perpendicular to the velocity. The magnetic force provides the centripetal acceleration:
   $qvB = mv^2/r$, or
   $r = mv/qB$;
   $0.25\text{ m} = (6.6 \times 10^{-27}\text{ kg})(1.6 \times 10^7\text{ m/s})/2(1.60 \times 10^{-19}\text{ C})\,B$, which gives $B =$ 1.3 T.

10. The greatest force will be produced when the velocity and the magnetic field are perpendicular. We point our thumb down (a negative charge!), and our fingers south. We must curl our fingers to the west, which will be the direction of the magnetic field. We find the magnitude from
    $F = qvB$;
    $2.2 \times 10^{-12}\text{ N} = (1.60 \times 10^{-19}\text{ C})(1.8 \times 10^6\text{ m/s})B$, which gives $B =$ 7.6 T west.

11. The force is maximum when the current and field are perpendicular:
    $F_{max} = ILB$.
    When the current makes an angle θ with the field, the force is
    $F = ILB \sin \theta$.
    Thus we have
    $F/F_{max} = \sin \theta = 0.45$, or $\theta =$ 27°.



12. (*a*) We see from the diagram that the magnetic field is up, so the top pole face is a south pole.
    (*b*) We find the current from
    $F = ILB$;
    $5.30\text{ N} = I(0.10\text{ m})(0.15\text{ T})$, which gives $I =$ 3.5×10^2 A.
    (*c*) The new force is
    $F' = ILB \sin \theta = F \sin \theta = (5.30\text{ N}) \sin 80° =$ 5.22 N.
    Note that the wire could be tipped either way.



13. The magnetic force provides the centripetal acceleration:
    $qvB = mv^2/r$, or $mv = qBr$.
    The kinetic energy of the electron is
    $\text{KE} = !mv^2 = !(qBr)^2/m$
    $= ![(1.60 \times 10^{-19}\text{ C})(1.15\text{ T})(8.40 \times 10^{-3}\text{ m})]^2/(1.67 \times 10^{-27}\text{ kg})$
    $= 7.15 \times 10^{-16}\text{ J} = (7.15 \times 10^{-16}\text{ J})/(1.60 \times 10^{-19}\text{ J/eV}) = 4.47 \times 10^3\text{ eV} =$ 4.47 keV.

14. The magnetic force provides the centripetal acceleration:
 $qvB = mv^2/r$, or $mv = qBr$.
 The kinetic energy of the electron is
 $KE = !mv^2 = !(qBr)^2/m = (q^2B^2/2m)r^2$.

15. The magnetic force provides the centripetal acceleration:
 $qvB = mv^2/r$, or $mv = p = qBr$.

16. The magnetic force provides the centripetal acceleration:
 $qvB = mv^2/r$, or $mv = p = qBr$.
 The angular momentum is
 $L = mvr = qBr^2$.

17. We find the required acceleration from
 $v^2 = v_0^2 + 2ax$;
 $(30\text{ m/s})^2 = 0 + 2a(1.0\text{ m})$, which gives $a = 450\text{ m/s}^2$.
 This acceleration is provided by the force from the magnetic field:
 $F = ILB = ma$;
 $I(0.20\text{ m})(1.7\text{ T}) = (1.5 \times 10^{-3}\text{ kg})(450\text{ m/s}^2)$, which gives $I =$ 2.0 A.
 The force is away from the battery, fingers in the direction of I would have to curl down; thus the field points down.

18. The magnetic force produces an acceleration perpendicular to the original motion:
 $a_\perp = qvB/m = (8.10 \times 10^{-9}\text{ C})(180\text{ m/s})(5.00 \times 10^{-5}\text{ T})/(3.80 \times 10^{-3}\text{ kg}) = 1.92 \times 10^{-8}\text{ m/s}^2$.
 The time the bullet takes to travel 1.00 km is
 $t = L/v = (1.00 \times 10^3\text{ m})/(180\text{ m/s}) = 5.56\text{ s}$.
 The small acceleration will produce a small deflection, so we assume the perpendicular acceleration is constant. We find the deflection of the electron from
 $y = v_{0y}t + !at^2 = 0 + !(1.92 \times 10^{-8}\text{ m/s}^2)(5.56\text{ s})^2 =$ 3.0×10^{-7} m.
 This justifies our assumption of constant acceleration.

19. The magnetic field of a long wire depends on the distance from the wire:
 $B = (\mu_0/4^1)2I/r$
 $= (10^{-7}\text{ T}\cdot\text{m/A})2(15\text{ A})/(0.15\text{ m}) =$ 2.0×10^{-5} T.
 When we compare this to the Earth's field, we get
 $B/B_{Earth} = (2.0 \times 10^{-5}\text{ T})/(5.5 \times 10^{-5}\text{ T}) = 0.36 =$ 36%.

20. We find the current from
 $B = (\mu_0/4^1)2I/r$;
 $5.5 \times 10^{-5}\text{ T} = (10^{-7}\text{ T}\cdot\text{m/A})2I/(0.30\text{ m})$, which gives $I =$ 83 A.

21. The two currents in the same direction will be attracted with a force of
 $F = I_1(\mu_0 I_2/2^1 d)L = \mu_0 I_1 I_2 L/2^1 d$
 $= (4^1 \times 10^{-7}\text{ T}\cdot\text{m/A})(35\text{ A})(35\text{ A})(45\text{ m})/2^1(0.060\text{ m}) =$ 0.18 N attraction.

22. Because the force is attractive, the second current must be in the same direction as the first. We find the magnitude from

$F/L = \mu_0 I_1 I_2/2^1 d$

8.8×10^{-4} N/m = ($4^1 \times 10^{-7}$ T·m/A)(12 A)$I_2/2^1$(0.070 m), which gives I_2 = 26 A upward.

23. The magnetic field produced by the wire must be less than 1% of the magnetic field of the Earth. We find the current from

$B = (\mu_0/4^1)2I/r$;

0.01(5.5×10^{-5} T) > (10^{-7} T·m/A)$2I$/(1.0 m), which gives $I <$ 3 A.

24. The magnetic field produced by the wire is

$B = (\mu_0/4^1)2I/r$ = (10^{-7} T·m/A)2(30 A)/(0.086 m) = 6.98×10^{-5} T,

and will be perpendicular to the motion of the airplane.

We find the acceleration produced by the magnetic force from

$F = qvB = ma$;

(18.0 C)(1.8 m/s)(6.98×10^{-5} T) = (175×10^{-3} kg)a, which gives $a = 1.29 \times 10^{-2}$ m/s² = 1.3×10^{-3} g.

25. The magnetic field from the wire at a point south of a downward current will be to the west, with a magnitude:

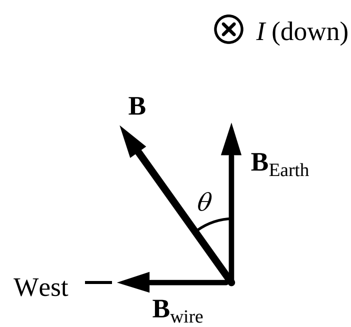
$B_{wire} = (\mu_0/4^1)2I/r$

= (10^{-7} T·m/A)2(30 A)/(0.20 m) = 3.0×10^{-5} T.

Because this is perpendicular to the Earth's field, we find the direction of the resultant field, and thus of the compass needle, from

$\tan\theta = B_{wire}/B_{Earth}$ = (3.0×10^{-5} T)/(0.45×10^{-4} T) = 0.667, or

θ = 34° W of N.



26. The magnetic field to the west of a wire with a current to the north will be up, with a magnitude:

$B_{wire} = (\mu_0/4^1)2I/r$

= (10^{-7} T·m/A)2(12.0 A)/(0.200 m) = 1.20×10^{-5} T.

The net downward field is

$B_{down} = B_{Earth} \sin 40° - B_{wire}$ = (5.0×10^{-5} T) sin 40° – 1.20×10^{-5} T = 2.01×10^{-5} T.

The northern component is $B_{north} = B_{Earth} \cos 40°$ = 3.83×10^{-5} T.

We find the magnitude from

$B = [(B_{down})^2 + (B_{north})^2]^{1/2}$ = [(2.01×10^{-5} T)² + (3.83×10^{-5} T)²]$^{1/2}$ = 4.3×10^{-5} T.

We find the direction from

$\tan\theta = B_{down}/B_{north}$ = (2.01×10^{-5} T)/(3.83×10^{-5} T) = 0.525, or θ = 28° below the horizontal.

27. Because a current represents the amount of charge that passes a given point, the effective current of the proton beam is

I = Æq/Æt = (10^9 protons/s)(1.60×10^{-19} C/proton) = 1.60×10^{-10} A.

The magnetic field from this current will be

$B = (\mu_0/4^1)2I/r$

= (10^{-7} T·m/A)2(1.60×10^{-10} A)/(2.0 m) = 1.6×10^{-17} T.

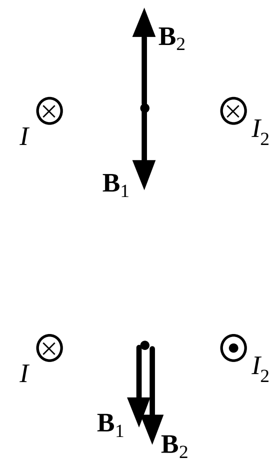
28. (*a*) When the currents are in the same direction, the fields between the currents will be in opposite directions, so at the midpoint we have

$B_a = B_2 - B_1 = [(\mu_0/4^1)2I_2/r] - [(\mu_0/4^1)2I/r]$

$= [(\mu_0/4^1)2/r](I_2 - I)$

$= (10^{-7}\ \mathrm{T\cdot m/A})2/(0.010\ \mathrm{m})(15\ \mathrm{A} - I)$

$=$ $(2.0 \times 10^{-5}\ \mathrm{T/A})(15\ \mathrm{A} - I)$ up, with the currents as shown.



(*b*) When the currents are in opposite directions, the fields between the currents will be in the same direction, so at the midpoint we have

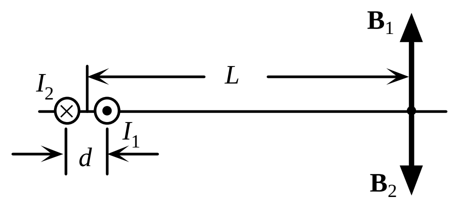
$B_b = B_2 + B_1 = [(\mu_0/4^1)2I_2/r] + [(\mu_0/4^1)2I/r]$

$= [(\mu_0/4^1)2/r](I_2 + I)$

$= (10^{-7}\ \mathrm{T\cdot m/A})2/(0.010\ \mathrm{m})(15\ \mathrm{A} + I)$

$=$ $(2.0 \times 10^{-5}\ \mathrm{T/A})(15\ \mathrm{A} + I)$ down, with the currents as shown.

29. Because the currents are in opposite directions, the fields will be in opposite directions. For the net field we have



$B = B_1 - B_2 = [(\mu_0/4^1)2I_1/r_1] - [(\mu_0/4^1)2I_2/r_2]$

$= [(\mu_0/4^1)2I]\{[1/(L - !d)] - [1/(L + !d)]\}$

$= [(\mu_0/4^1)2I/L]\{[1/(1 - !d/L)] - [1/(1 + !d/L)]\}.$

Because $d \ll L$, we can use the approximation $1/(1 \pm x)$ Å $1 — x$:

$B = [(\mu_0/4^1)2I/L][(1 + !d/L) - (1 - !d/L)]$

$= [(\mu_0/4^1)2I/L](d/L) = (\mu_0/4^1)2Id/L^2$

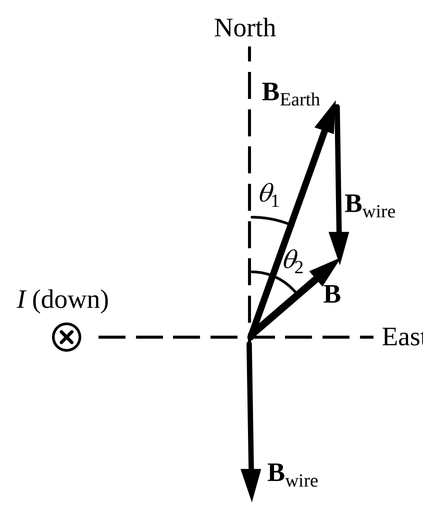
$= [(10^{-7}\ \mathrm{T\cdot m/A})2(25\ \mathrm{A})(2.0 \times 10^{-3}\ \mathrm{m})/(0.100\ \mathrm{m})^2$

$=$ $1.0 \times 10^{-6}\ \mathrm{T}$ up, with the currents as shown.

This is

$(1.0 \times 10^{-6}\ \mathrm{T})/(5.0 \times 10^{-5}\ \mathrm{T}) = 0.02 =$ 2% of the Earth's field.

30. The magnetic field of the Earth points in the original direction of the compass needle. The field of the wire will be tangent to a circle centered at the wire. We see from the diagram that the field of the wire must be to the south to produce a greater angle for the resultant field. Thus the current in the wire must be down. From the vector diagram, we have



$B \sin \theta_2 = B_{Earth} \sin \theta_1;$

$B \cos \theta_2 = B_{Earth} \cos \theta_1 - B_{wire}.$

When we divide the two equations, we get

$\tan \theta_2 = B_{Earth} \sin \theta_1)/(B_{Earth} \cos \theta_1 - B_{wire});$

$\tan 55° = [(0.50 \times 10^{-4}\ \mathrm{T}) \sin 20°]/[(0.50 \times 10^{-4}\ \mathrm{T}) \cos 20° - B_{wire}],$

which gives $B_{wire} = 3.50 \times 10^{-4}\ \mathrm{T}$.

We find the current from

$B_{wire} = (\mu_0/4^1)2I/r;$

$3.50 \times 10^{-4}\ \mathrm{T} = (10^{-7}\ \mathrm{T\cdot m/A})2I/(0.080\ \mathrm{m})$, which gives $I =$ 14 A.

31. Because the currents and the separations are the same, we find the force per unit length between any two wires from

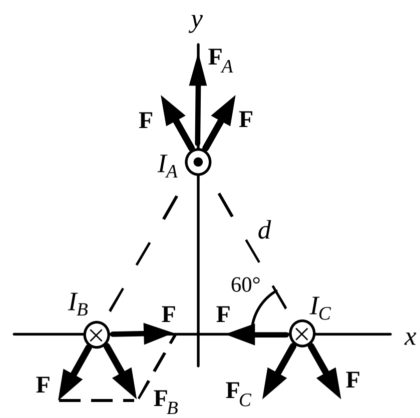
$F/L = I_1(\mu_0 I_2/2^1 d) = \mu_0 I^2/2^1 d$
$= (4^1 \times 10^{-7}\ \text{T}\cdot\text{m/A})(8.0\ \text{A})^2/2^1(0.380\ \text{m})$
$= 3.37 \times 10^{-5}\ \text{N/m}.$

The directions of the forces are shown on the diagram. The symmetry of the force diagrams simplifies the vector addition, so we have

$F_A/L = 2(F/L)\cos 30°$
$= 2(3.37 \times 10^{-5}\ \text{N/m})\cos 30° =$ 5.8×10^{-5} up.

$F_B/L = F/L$
$=$ 3.4×10^{-5} N/m 60° below the line toward *C*.

$F_C/L = F/L$
$=$ 3.4×10^{-5} N/m 60° below the line toward *B*.



32. The Coulomb force between the charges provides the centripetal acceleration:

$ke^2/r^2 = mv^2/r$, which gives $v = (ke^2/mr)^{1/2}$.

The period of the electron's orbit is

$T = 2^1 r/v = 2^1 r/(ke^2/mr)^{1/2} = 2^1(mr^3/ke^2)^{1/2}$
$= 2^1[(9.11 \times 10^{-31}\ \text{kg})(5.3 \times 10^{-11}\ \text{m})^3/(9.0 \times 10^9\ \text{N}\cdot\text{m}^2/\text{C}^2)(1.60 \times 10^{-19}\ \text{C})^2]^{1/2}$
$= 1.52 \times 10^{-16}\ \text{s}.$

Thus the effective current of the electron is

$I = e/T = (1.60 \times 10^{-19}\ \text{C})/(1.52 \times 10^{-16}\ \text{s}) = 1.05 \times 10^{-3}\ \text{A}.$

The magnitude of the magnetic field is

$B = (\mu_0/2^1)I/r = (\mu_0/4^1)2I/r$
$= (10^{-7}\ \text{T}\cdot\text{m/A})2(1.05 \times 10^{-3}\ \text{A})/(5.3 \times 10^{-11}\ \text{m}) =$ 12 T.

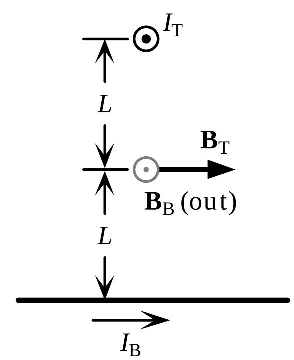
33. We find the direction of the field for each wire from the tangent to the circle around the wire, as shown. For their magnitudes, we have

$B_T = (\mu_0/4^1)2I_T/L$
$= (10^{-7}\ \text{T}\cdot\text{m/A})2(20.0\ \text{A})/(0.100\ \text{m}) = 4.00 \times 10^{-5}\ \text{T}.$

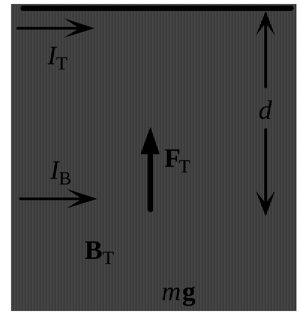
$B_B = (\mu_0/4^1)2I_B/L$
$= (10^{-7}\ \text{T}\cdot\text{m/A})2(5.0\ \text{A})/(0.100\ \text{m}) = 1.00 \times 10^{-5}\ \text{T}.$

Because the fields are perpendicular, we find the magnitude from

$B = (B_T^2 + B_B^2)^{1/2}$
$= [(4.00 \times 10^{-5}\ \text{T})^2 + (1.00 \times 10^{-5}\ \text{T})^2]^{1/2} =$ 4.1×10^{-5} T.



34. (*a*) For the force produced by the magnetic field of the upper wire to balance the weight, it must be up, i. e., an attractive force. Thus the currents must be in the same direction. When we equate the magnitudes of the two forces for a length L, we get



$I_B B_T L = mg;$

$(\mu_0/4^1)2I_B I_T L/d = \rho(^1 r^2 L)g;$

$(4^1 \times 10^{-7}\ \mathrm{T\cdot m/A})2I_B(48\ \mathrm{A})/(0.15\ \mathrm{m}) =$

$(8.9 \times 10^3\ \mathrm{kg/m^3})^1(1.25\ \mathrm{m})^2(9.80\ \mathrm{m/s^2}),$

which gives $I_B =$ 6.7×10^3 A to the right.

(*b*) The magnetic force will decrease with increasing separation. If the wire is moved a small distance above or below the equilibrium position, there will be a net force, away from equilibrium, and the wire will be unstable.

(*c*) If the second wire is above the first, there must be a repulsive magnetic force between the two wires to balance the weight, which means the currents must be opposite. Because the separation is the same, the magnitude of the current is the same:

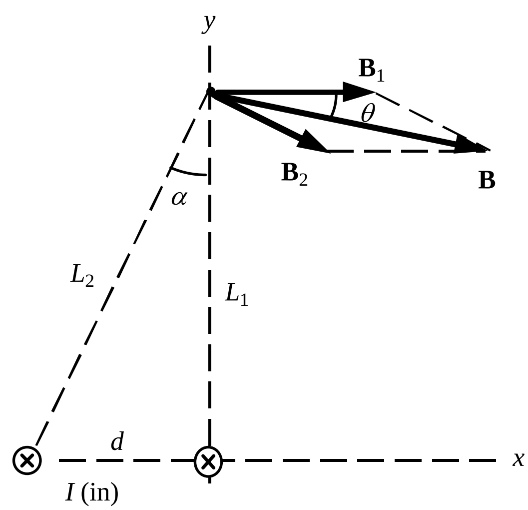
$I_2 =$ 6.7×10^3 A to the left.

The magnetic force will decrease with increasing separation. If the wire is moved a small distance above or below the equilibrium position, there will be a net force back toward equilibrium, and the wire will be stable for vertical displacements.

35. Because $(12)^2 + (5)^2 = (13)^2$, we have a right triangle, so

$\tan\alpha = d/L_1 = (5.00\ \mathrm{cm})/(12.0\ \mathrm{cm}) = 0.417,\ \ \alpha = 22.6°.$

We find the direction of the field for each wire from the tangent to the circle around the wire, as shown.



For their magnitudes, we have

$B_1 = (\mu_0/4^1)2I/L_1$

$= (10^{-7}\ \mathrm{T\cdot m/A})2(16.5\ \mathrm{A})/(0.120\ \mathrm{m}) = 2.75 \times 10^{-5}\ \mathrm{T}.$

$B_2 = (\mu_0/4^1)2I_B/L_2$

$= (10^{-7}\ \mathrm{T\cdot m/A})2(16.5\ \mathrm{A})/(0.130\ \mathrm{m}) = 2.54 \times 10^{-5}\ \mathrm{T}.$

From the vector diagram, we have

$B_x = B_1 + B_2 \cos\alpha$

$= 2.75 \times 10^{-5}\ \mathrm{T} + (2.54 \times 10^{-5}\ \mathrm{T}) \cos 22.6°$

$= 5.09 \times 10^{-5}\ \mathrm{T}.$

$B_y = -B_2 \cos\alpha;$

$= -(2.54 \times 10^{-5}\ \mathrm{T}) \cos 22.6° = -0.976 \times 10^{-5}\ \mathrm{T}.$

For the direction of the field, we have

$\tan\theta = B_y/B_x = (0.976 \times 10^{-5}\ \mathrm{T})/(5.09 \times 10^{-5}\ \mathrm{T}) = 0.192,\ \ \theta = 10.9°.$

We find the magnitude from

$B_x = B\cos\theta;$

$5.09 \times 10^{-5}\ \mathrm{T} = B \cos 10.9°,$

which gives $B =$ 5.18×10^{-5} T 10.9° below the plane parallel to the two wires.

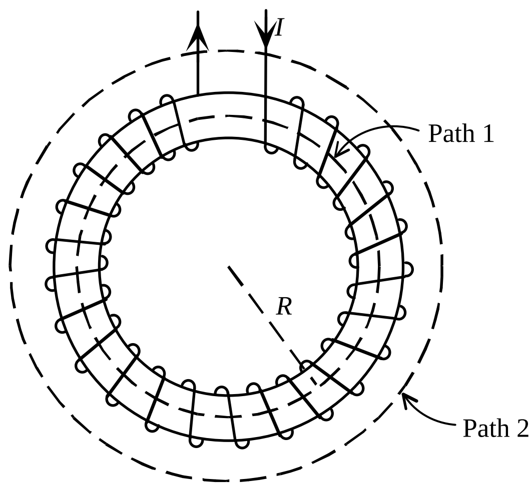
36. We find the current in the solenoid from

$B = \mu_0 nI = \mu_0 NI/L;$

$0.385\ \mathrm{T} = (4^1 \times 10^{-7}\ \mathrm{T\cdot m/A})[(1000\ \mathrm{turns})/(0.300\ \mathrm{m})]I$, which gives $I =$ 91.9 A.

37. The mass, and thus the volume, of the wire is fixed, so we have ¹$r^2L = k$; a smaller radius will give a greater length. If we assume a given current (a variable voltage supply), the magnetic field of the solenoid will be determined by the density of turns: $B = \mu_0 nI$. The greatest density will be when the wires are closely wound. In this case, the separation of turns is $2r$, so the density of turns is $1/2r$, which would indicate that the radius should be very small.
If D is the diameter of the solenoid, the number of turns is
$N = L/$¹D,
so the length of the solenoid is $N2r = 2Lr/$¹$D = 2k/$¹²rD.
The length of the solenoid must be much greater than the diameter, which will be true for small r, as long as the diameter is not large, which is the only restriction on the diameter. These considerations indicate that a long and thin wire should be used. However, we must be concerned with the resistance of the wire, because the thermal power generation, I^2R, must be dissipated in the solenoid. The resistance is
$R = \rho L/$¹$r^2 = \rho k/$¹r^4.
Thus a very thin wire will create thermal dissipation problems, which means that the insulation and/or wire could melt. Thus the wire should be something between long, thin and short, fat.

38. (*a*) Each loop will produce a field along its axis.
For path 1, the symmetry means that the magnetic field will have the same magnitude anywhere on the path and be circular, so that B is parallel to the path.
We apply Ampere's law to path 1, which is a circle with radius R. One side of every turn of the coil passes through the area enclosed by this path, so we have

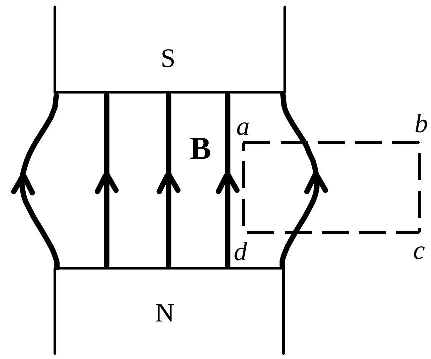


· $B_{||}$ Æ¬ = μ_0 · I.
Because $B_{||} = B$ is the same for all segments of the path, and each turn has the same current, we get
B · Æ¬ = B(2¹R) = $\mu_0 NI$, or $B = \mu_0 NI/2$¹R.

(*b*) For path 2, the symmetry means that the magnetic field will have the same magnitude anywhere on the path and be circular, so that B is parallel to the path.
We apply Ampere's law to path 2, which is a circle with radius R. For each coil the current on one side will be opposite to the current on the other, so the net current through the area enclosed by this path is zero, so we have
· $B_{||}$ Æ¬ = μ_0 · I;
B · Æ¬ = B(2¹R) = 0, or $B = 0$.

(*c*) The field inside the torus is not uniform. If we vary the radius of path 1, the analysis does not change, so the magnetic field inside the torus varies as $1/R$.

39. We choose a clockwise rectangular path shown in the diagram. Because there are no currents through the rectangle, for Ampere's law we have



   · $B_{\|}$ Æ¬ = μ_0 · I = 0.

   The sum on the left-hand side consists of four parts:

   (· $B_{\|}$ Æ¬$)_{left}$ + (· $B_{\|}$ Æ¬$)_{top}$ + (· $B_{\|}$ Æ¬$)_{right}$ + (· $B_{\|}$ Æ¬$)_{bottom}$ = 0.

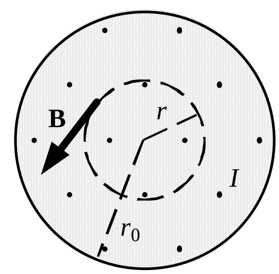
   The field on the left side is constant and parallel to the path; the field on the right is zero. Thus we have

   Bh + (· $B_{\|}$ Æ¬$)_{top}$ + 0 + (· $B_{\|}$ Æ¬$)_{bottom}$ = 0, or

   Bh = – [(· $B_{\|}$ Æ¬$)_{top}$ + (· $B_{\|}$ Æ¬$)_{bottom}$].

   Thus there must be a component of B parallel to the paths on top and bottom, as shown, so there must be a fringing field.
   Note that the contributions to the sum from the top and bottom have the same signs.

40. (*a*) We choose a circular path with radius r, centered on the axis of the cylinder, so the symmetry means that the magnetic field will have the same magnitude anywhere on the path and be circular; B is parallel to the path. Because the current is uniform across the cross section, we find the current through the path from the area:



   I' = (¹r^2/¹r_0^2)I = (r^2/r_0^2)I.

   We apply Ampere's law to the path:

   · $B_{\|}$ Æ¬ = μ_0 · I.

   B · Æ¬ = B(2¹r) = $\mu_0(r^2/r_0^2)I$, or $B = \mu_0 Ir/$2¹r_0^2.

   (*b*) At the surface of the wire, $r = r_0$, so we have

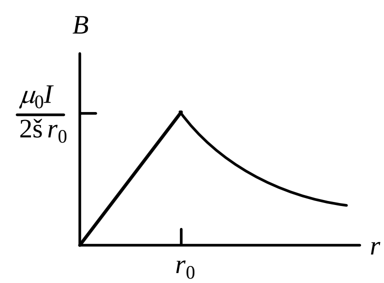
   $B = \mu_0 Ir/$2¹r_0^2 = $\mu_0 Ir_0/$2¹r_0^2 = $\mu_0 I/$2¹r_0,

   which is the expression for the magnetic field outside the wire.

   (*c*) The field is zero at the center of the wire, and outside the wire it decreases with distance, so the maximum is

   at the surface of the wire.

   For the given data, we have



   B_{max} = $\mu_0 I/$2¹r_0 = (μ_0/4¹)2I/r_0
   = (10^{-7} T ·m/A)2(15.0 A)/(0.50 × 10^{-3} m)
   = 6.0×10^{-3} T.

   (*d*) Inside the wire we have

   $B/B_{max} = r/r_0 = 0.10$, or $r = 0.10r_0$.

   Outside the wire we have

   $B/B_{max} = r_0/r = 0.10$, or $r = 10r_0$.

41. When the coil comes to rest, the magnetic torque is balanced by the restoring torque:

   $NIAB = k\phi$.

   Because the deflection is the same, we have

   $I_1B_1 = I_2B_2$;

   (63.0 μA)$B_1 = I_2(0.860B_1)$, which gives I_2 = 73.3 μA.

42. When the coil comes to rest, the magnetic torque is balanced by the restoring torque:

   $NIAB = k\phi$.

   Because the deflection is the same, we have

$I_1/k_1 = I_2/k_2$;
$(36\ \mu A)/k_1 = I_2/(0.80k_1)$, which gives $I_2 = 29\ \mu A$.

43. If we assume that the magnetic field is constant, we have

$\tau_2/\tau_1 = I_2/I_1 = 0.85,$

so the torque will decrease by 15%.

If we assume that the magnetic field is produced by the current, it will be proportional to the current and will also decrease by 15%, so we have

$\tau_2/\tau_1 = (I_2/I_1)(B_2/B_1) = (0.85)(0.85) = 0.72,$

so the torque will decrease by 28%.

44. When the coil is parallel to the magnetic field, the torque is maximum, so we have

$\tau = NIAB;$

$0.325\ \text{m}\cdot\text{N} = (1)(6.30\ \text{A})(0.220)^2 B$, which gives $B =$ 1.07 T.

45. The angular momentum of the electron for the circular orbit is

$L = mvr.$

The time for the electron to go once around the orbit is

$T = 2^1 r/v,$

so the effective current is

$I = e/T = ev/2^1 r.$

The magnetic dipole moment is

$M = IA = (ev/2^1 r)^1 r^2 = evr/2 = (e/2m)L.$

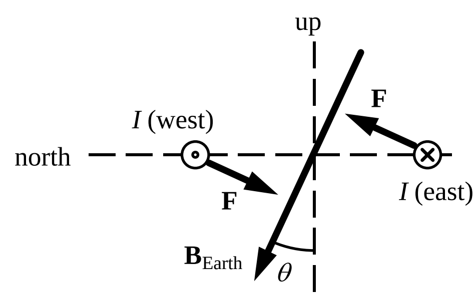
46. (*a*) The angle between the normal to the coil and the field is 34.0°, so the torque is

$\tau = NIAB \sin\theta$

$= (11)(7.70\ \text{A})^1(0.090\ \text{m})^2(5.50\ \text{T}) \sin 34.0°$

$=$ $6.63 \times 10^{-5}\ \text{m}\cdot\text{N}.$

(*b*) From the directions of the forces shown on the diagram, the south edge of the coil will rise.



47. (*a*) The Hall emf is across the width of the sample, so the Hall field is

$E_H = å_H/w = (6.5 \times 10^{-6}\ \text{V})/(0.030\ \text{m}) =$ $2.2 \times 10^{-4}\ \text{V/m}.$

(*b*) The forces from the electric field and the magnetic field balance. We find the drift speed from

$E_H = v_d B;$

$2.2 \times 10^{-4}\ \text{V/m} = v_d(0.80\ \text{T})$, which gives $v_d =$ $2.7 \times 10^{-4}\ \text{m/s}.$

(*c*) We find the density from

$I = neAv_d;$

$30\ \text{A} = n(1.60 \times 10^{-19}\ \text{C})(0.030\ \text{m})(500 \times 10^{-6}\ \text{m})(2.7 \times 10^{-4}\ \text{m/s}),$

which gives $n =$ $4.6 \times 10^{28}\ \text{electrons/m}^3.$

48. The Hall field is

 $E_{\rm H} = \text{å}_{\rm H}/w = (2.42 \times 10^{-6}\ \text{V})/(0.015\ \text{m}) = 1.613 \times 10^{-4}\ \text{V/m}.$

 To determine the drift speed, we first find the density of free electrons:

 $n = [(0.971)(1000\ \text{kg/m}^3)(10^3\ \text{g/kg})/(23\ \text{g/mol})](6.02 \times 10^{23}\ \text{free electrons/mol})$

 $= 2.543 \times 10^{28}\ \text{electrons/m}^3.$

 We find the drift speed from

 $I = neAv_{\rm d};$

 $12.0\ \text{A} = (2.543 \times 10^{28}\ \text{electrons/m}^3)(1.60 \times 10^{-19}\ \text{C})(0.015\ \text{m})(1.00 \times 10^{-3}\ \text{m})(2.7 \times 10^{-4}\ \text{m/s})v_{\rm d},$

 which gives $v_{\rm d} = 1.967 \times 10^{-4}\ \text{m/s}.$

 The forces from the electric field and the magnetic field balance, so we have

 $E_{\rm H} = v_{\rm d}B;$

 $1.613 \times 10^{-4}\ \text{V/m} = (1.967 \times 10^{-4}\ \text{m/s})B$, which gives $B =$ 0.820 T.

49. (*a*) The sign of the ions will not change the magnitude of the Hall emf, but will determine the polarity of the emf.

 (*b*) The forces from the electric field and the magnetic field balance. We find the flow velocity from

 $\text{å}_{\rm H} = v_{\rm d}Bw;$

 $0.10 \times 10^{-3}\ \text{V} = v_{\rm d}(0.070\ \text{T})(3.3 \times 10^{-3}\ \text{m})$, which gives $v_{\rm d} =$ 0.43 m/s.

50. For the circular motion, the magnetic force provides the centripetal acceleration:

 $qvB = mv^2/r$, or $v = qBr/m.$

 To make the path straight, the forces from the electric field and the magnetic field balance:

 $qE = qvB = q(qBr/m)B$, or

 $E = qB^2r/m = (1.60 \times 10^{-19}\ \text{C})(0.566\ \text{T})^2(0.0510\ \text{m})/(1.67 \times 10^{-27}\ \text{kg}) =$ $1.57 \times 10^6\ \text{V/m}.$

51. For the circular motion, the magnetic force provides the centripetal acceleration:

 $qvB = mv^2/r$, or $r = mv/qB.$

 The velocities are the same because of the velocity selector, so we have

 $m/m_0 = r/r_0;$

 $m_1/(76\ \text{u}) = (21.0\ \text{cm})/(22.8\ \text{cm}) =$ 70 u;

 $m_2/(76\ \text{u}) = (21.6\ \text{cm})/(22.8\ \text{cm}) =$ 72 u;

 $m_3/(76\ \text{u}) = (21.9\ \text{cm})/(22.8\ \text{cm}) =$ 73 u;

 $m_4/(76\ \text{u}) = (22.2\ \text{cm})/(22.8\ \text{cm}) =$ 74 u.

52. We find the velocity of the velocity selector from

 $v = E/B = (2.48 \times 10^4\ \text{V/m})/(0.68\ \text{T}) = 3.65 \times 10^4\ \text{m/s}.$

 For the radius of the path, we have

 $r = mv/qB' = [(3.65 \times 10^4\ \text{m/s})/(1.60 \times 10^{-19}\ \text{C})(0.68\ \text{T})]m = (3.35 \times 10^{23}\ \text{m/kg})m.$

 If we let A represent the mass number, we can write this as

 $r = (3.35 \times 10^{23}\ \text{m/kg})(1.67 \times 10^{-27}\ \text{kg})A = (5.60 \times 10^{-4}\ \text{m})A = (0.560\ \text{mm})A.$

 The separation of the lines is the difference in the diameter, or

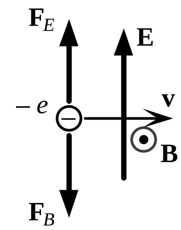
 $\text{Æ}D = 2\ \text{Æ}r = 2(0.560\ \text{mm})\ \text{Æ}A = (1.12\ \text{mm})(1) =$ 1.12 mm.

 If the ions were doubly charged, all radii would be reduced by one-half, so the separation would be 0.56 mm.

53. (*a*) To make the path straight, the forces from the electric field and the magnetic field balance:

$qE = qvB$;

10,000 V/m = (4.8×10^6 m/s)B, which gives B = 2.1×10^{-3} T.



(*b*) Because the electric force is up, the magnetic force must be down, so the magnetic field is out of the page.

(*c*) If there is only the magnetic field, the radius of the circular orbit is

$r = mv/qB$.

The time to complete a circle is

T = 2¹*r*/*v* = 2¹*m*/*qB*, so the frequency is

f = 1/*T* = *qB*/2¹*m* = (1.60×10^{-19} C)(2.08×10^{-3} T)/2¹(9.11×10^{-31} kg) = 5.8×10^7 Hz.

54. The velocity of the velocity selector is

$v = E/B$.

For the radius of the path, we have

$r = mv/qB' = mE/qB'B$, so

r = *km*, and Æ*r* = *k* Æ*m*.

If we form the ratio, we get

Æ*m*/*m* = Æ*r*/*r*;

(28.0134 u – 28.0106 u)/(28.0134 u) = ! (0.50×10^{-3} m)/*r*, which gives *r* = 2.5 m.

55. We find the speed acquired from the accelerating voltage from energy conservation:

0 = ÆKE + ÆPE;

0 = !*mv*² – 0 + *q*(– *V*), which gives $v = (2qV/m)^{1/2}$.

We combine this with the expression for the radius of the path:

$R = mv/qB = m(2qV/m)^{1/2}/qB$, or $m = qB^2R^2/2V$.

56. We find the permeability from

$B = \mu nI$;

1.8 T = μ[(600 turns)/(0.36 m)](40 A), which gives μ = 2.7×10^{-5} T·m/A.

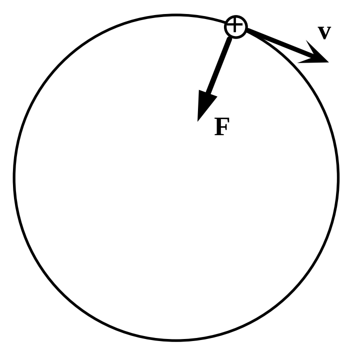
57. The magnetic force must be toward the center of the circular path, so the magnetic field must be up.

The magnetic force provides the centripetal acceleration:

$qvB = mv^2/r$, or $mv = qBr$;

4.8×10^{-16} kg·m/s = (1.60×10^{-19} C)B(1.0×10^3 m),

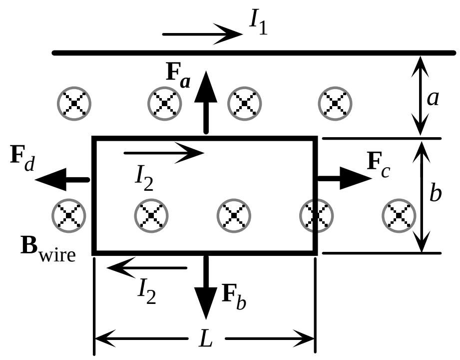
which gives B = 3.0 T up.



58. The magnetic field at the loop from the wire will be into the page, and will depend only on the distance from the wire r:

$B = (\mu_0/4^1)2I_1/r,$

For the two vertical sides of the loop, the currents are in opposite directions so their forces will be in opposite directions. Because the current will be in the same average field, the magnitudes of the forces will be equal, so $\mathbf{F}_c + \mathbf{F}_d = 0$.



For the sum of the two forces on the top and bottom of the loop, we have

$F_{\text{net}} = F_a - F_b = I_2B_aL - I_2B_bL$

$= I_2[(\mu_0/4^1)2I_1/a]L - I_2[(\mu_0/4^1)2I_1/(a + b)]L$

$= (\mu_0/4^1)(2I_1I_2L)\{(1/a) - [1/(a + b)]\}$

$= (10^{-7}\ \text{T}\cdot\text{m/A})2(2.5\ \text{A})(2.5\ \text{A})(0.100\ \text{m})[(1/0.030\ \text{m}) - (1/0.080\ \text{m})]$

$=$ 2.6×10^{-6} N toward the wire.

59. The radius of the path in the magnetic field is

$r = mv/eB$, or $mv = eBr$.

The kinetic energy is

$\text{KE} = !mv^2 = !(eBr)^2/m$.

If we form the ratio for the two particles, we have

$\text{KE}_p/\text{KE}_e = (r_p/r_e)^2(m_e/m_p)$;

$1 = (r_p/r_e)^2[(9.11 \times 10^{-31}\ \text{kg})/(1.67 \times 10^{-27}\ \text{kg})]$, which gives $r_p/r_e =$ 42.8.

60. The magnetic force on the electron must be up, so the velocity must be toward the west.
For the balanced forces, we have

$mg = qvB$;

$(9.11 \times 10^{-31}\ \text{kg})(9.80\ \text{m/s}^2) = (1.60 \times 10^{-19}\ \text{C})v(0.50 \times 10^{-4}\ \text{T})$,

which gives $v =$ 1.1×10^{-6} m/s west.

61. The force on the airplane is

$F = qvB = (155\ \text{C})(120\ \text{m/s})(5.0 \times 10^{-5}\ \text{T}) =$ 0.93 N.

62. Even though the Earth's field dips, the current and the field are perpendicular. The direction of the force will be perpendicular to both the cable and the Earth's field, so it will be 68° above the horizontal toward the north. For the magnitude, we have

$F = ILB$

$= (330\ \text{A})(10\ \text{m})(5.0 \times 10^{-5}\ \text{T}) =$ 0.17 N 68° above the horizontal toward the north.

63. (*a*) We find the speed acquired from the accelerating voltage from energy conservation:

$0 = \text{ÆKE} + \text{ÆPE}$;

$0 = !mv^2 - 0 + q(-V)$, which gives

$v = (2qV/m)^{1/2} = [2(2)(1.60 \times 10^{-19}\ \text{C})(2400\ \text{V})/(6.6 \times 10^{-27}\ \text{kg})]^{1/2} = 4.82 \times 10^5\ \text{m/s}$.

For the radius of the path, we have

$r = mv/qB = (6.6 \times 10^{-27}\ \text{kg})(4.82 \times 10^5\ \text{m/s})/(2)(1.60 \times 10^{-19}\ \text{C})(0.240\ \text{T})$

$= 4.1 \times 10^{-2}\ \text{m} =$ 4.1 cm.

(*b*) The period of revolution is

$T = 2^1r/v = 2^1m/qB = 2^1(6.6 \times 10^{-27}\ \text{kg})/(2)(1.60 \times 10^{-19}\ \text{C})(0.240\ \text{T}) =$ 5.4×10^{-7} s.

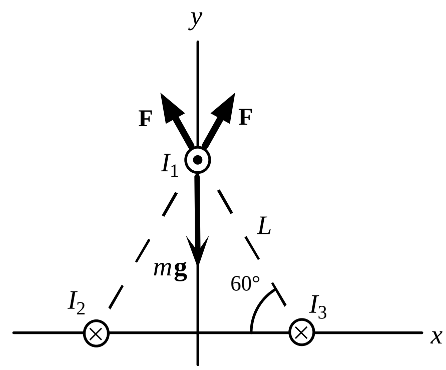
64. If we consider a length L of the wire, for the balanced forces, we have

$mg = \rho^1 r^2 Lg = ILB$;

$(8.9 \times 10^3\ \mathrm{kg/m^3})^1(0.500\ \mathrm{m})^2(9.80\ \mathrm{m/s^2}) = I(5.00 \times 10^{-5}\ \mathrm{T})$,

which gives $I =$ 1.37×10^3 A.

65. Because the currents and the separations are the same, we find the force on a length L of the top wire from either of the two bottom wires from



$F = I_1(\mu_0 I_2/2^1 d)L = \mu_0 I_1 I_2 L/2^1 d$

$= (4^1 \times 10^{-7}\ \mathrm{T \cdot m/A})(20.0\ \mathrm{A})I_1 L/2^1(0.380\ \mathrm{m})$

$= (1.05 \times 10^{-5}\ \mathrm{N/A \cdot m})I_1 L$.

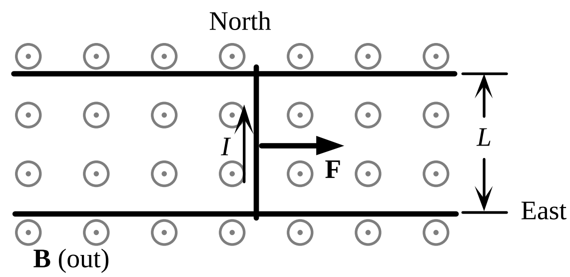
The directions of the forces are shown on the diagram. The symmetry of the force diagrams simplifies the vector addition, so for the net force to be zero, we have

$F_A = 2F \cos 30° = mg = \rho^1 r^2 Lg$;

$2(1.05 \times 10^{-5}\ \mathrm{N/A \cdot m})I_1 L \cos 30° = (8.9 \times 10^3\ \mathrm{kg/m^3})^1(1.00 \times 10^{-3}\ \mathrm{m})^2(9.80\ \mathrm{m/s^2})L$,

which gives $I_1 =$ 1.50×10^4 A.

66. (*a*) The force from the magnetic field will accelerate the rod:



$F = ILB = ma$, which gives $a = ILB/m$.

Because the rod starts from rest and the acceleration is constant, we have

$v = v_0 + at = 0 + (ILB/m)t =$ $ILBt/m$.

(*b*) The total normal force on the rod is mg, so there is a friction force of $\mu_k mg$. For the acceleration, we have

$\cdot F = ILB - \mu_k mg = ma$, which gives $a = (ILB/m) - \mu_k g$.

For the speed we have

$v = at =$ $[(ILB/m) - \mu_k g]t$.

(*c*) For a current toward the north in an upward field, the force will be to the east.

67. We find the speed acquired from the accelerating voltage from energy conservation:

$0 = $ ÆKE + ÆPE;

$0 = !mv^2 - 0 + (-e)(V)$, or $v = (2eV/m)^{1/2}$.

If we assume that the deflection is small, the time the electron takes to reach the screen is

$t = L/v = L(m/2eV)^{1/2}$.

The magnetic force produces an acceleration perpendicular to the original motion:

$a_\perp = evB/m$.

For a small deflection, we can take the force to be constant, so the deflection of the electron is

$d = !a_\perp t^2 = !(evB/m)(L/v)^2 = !eBL^2/mv = !BL^2(e/2mV)^{1/2}$

$= !(5.0 \times 10^{-5}\ \mathrm{T})(0.20\ \mathrm{m})^2[(1.60 \times 10^{-19}\ \mathrm{C})/2(9.11 \times 10^{-31}\ \mathrm{kg})V]^{1/2} = (0.296\ \mathrm{m \cdot V^{1/2}})/V^{1/2}$.

(*a*) For a voltage of 2.0 kV, we have

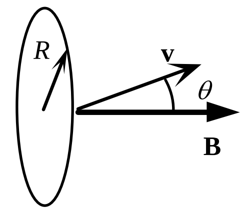
$d = (0.296\ \mathrm{m \cdot V^{1/2}})/V^{1/2} = (0.296\ \mathrm{m \cdot V^{1/2}})/(2.0 \times 10^3\ \mathrm{V})^{1/2} = 6.6 \times 10^{-3}\ \mathrm{m} =$ 6.6 mm.

(*b*) For a voltage of 30 kV, we have

$d = (0.296\ \mathrm{m \cdot V^{1/2}})/V^{1/2} = (0.296\ \mathrm{m \cdot V^{1/2}})/(30 \times 10^3\ \mathrm{V})^{1/2} = 1.7 \times 10^{-3}\ \mathrm{m} =$ 1.7 mm.

These results justify our assumption of small deflection.

68. The component of the velocity parallel to the field does not change. The component perpendicular to the field produces a force which causes the circular motion.



We find the radius of the circular motion from

$R = mv_\perp/qB$

$= (9.11 \times 10^{-31}\ \text{kg})(1.8 \times 10^7\ \text{m/s})(\sin 7.0°)/(1.60 \times 10^{-19}\ \text{C})(3.3 \times 10^{-2}\ \text{T})$

$= 3.78 \times 10^{-4}\ \text{m} =$ 0.38 mm.

We find the time for one revolution:

$T = 2^1R/v_\perp = 2^1(3.78 \times 10^{-4}\ \text{m})/(1.8 \times 10^7\ \text{m/s}) \sin 7.0° = 1.08 \times 10^{-9}\ \text{s}.$

In this time, the distance the electron travels along the field is

$d = v_\parallel T = (1.8 \times 10^7\ \text{m/s})(\cos 7.0°)(1.08 \times 10^{-9}\ \text{s}) = 1.9 \times 10^{-2}\ \text{m} =$ 1.9 cm.

69. (*a*) The radius of the circular orbit is

$r = mv/qB.$

The time to complete a circle is

$T = 2^1r/v = 2^1m/qB$, so the frequency is

$f = 1/T = qB/2^1m.$

Note that this is independent of r.

Because we want the ac voltage to be maximum when the proton reaches the gap and minimum (reversed) when the proton has made half a circle, the frequency of the ac voltage must be the same: $f = 1/T = qB/2^1m$.

(*b*) In a full circle, the proton crosses the gap twice. If the gap is small, the ac voltage will not change significantly from its maximum value while the proton is in the gap.

The energy gain from the two crossings is

ÆKE $= 2qV_0$.

(*c*) From $r = mv/qB$, we see that the maximum speed, and thus the maximum kinetic energy occurs at the maximum radius of the path. The maximum kinetic energy is

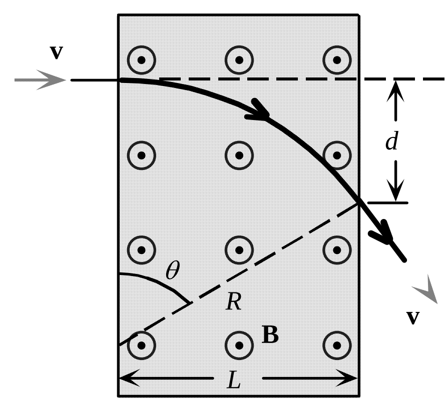
$\text{KE}_{max} = !mv_{max}^2 = !m(qBr_{max}/m)^2 = (qBr_{max})^2/2m$

$= [(1.60 \times 10^{-19}\ \text{C})(0.50\ \text{T})(2.0\ \text{m})]^2/2(1.67 \times 10^{-27}\ \text{kg})$

$= 7.66 \times 10^{-12}\ \text{J} = (7.66 \times 10^{-12}\ \text{J})/(1.60 \times 10^{-13}\ \text{J/MeV}) =$ 48 MeV.

(*d*) The cyclotron is like a swing because a small push is given in resonance with the natural frequency of the motion.

70. If the beam is perpendicular to the magnetic field, the force from the magnetic field is always perpendicular to the velocity, so it will change the direction of the velocity, but not magnitude. The radius of the path in the magnetic field is



$R = mv/qB.$

Protons with different speeds will have paths of different radii. Thus slower protons will deflect more, and faster protons will deflect less, than those with the design speed.

We find the radius of the path from

$R = mv/qB$

$= (1.67 \times 10^{-27}\ \text{kg})(1.0 \times 10^{-7}\ \text{m/s})/(1.60 \times 10^{-19}\ \text{C})(0.33\ \text{T})$

$= 0.316\ \text{m}.$

Because the exit velocity is perpendicular to the radial line from the center of curvature, the exit angle is also the angle the radial line makes with the boundary of the field:

$\sin\theta = L/R = (0.050\ \text{m})/(0.316\ \text{m}) = 0.158$, so $\theta = 9.1°$.

71. (*a*) The force on one side of the loop is

$F = ILB$ = (25.0 A)(0.200 m)(1.65 T) = 8.25 N.

When the loop is perpendicular to the magnetic field, the forces at top and bottom will create a tension in the other two sides of !F. This produces a tensile stress of !$F/A = F/2^1r^2$.

When the loop is parallel to the magnetic field, the forces on right and left will create a shear in the other two sides. This produces a shear stress of !$F/A = F/2^1r^2$.

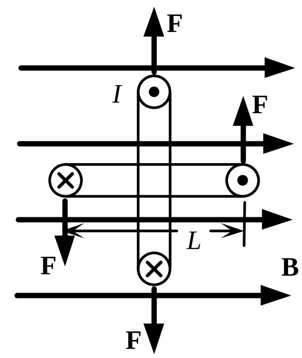
Because the magnitudes are the same and the tensile strength of aluminum is equal to the shear strength, we can use either condition to determine the minimum diameter. With a safety factor of 10, we have

$10(F/2^1r^2)$ < Strength;

$10(8.25\ \text{N})/2^1r^2 < 200 \times 10^6\ \text{N/m}^2$,

which gives $r > 2.56 \times 10^{-4}$ m = 0.256 mm.

Thus the minimum diameter is 0.512 mm.



(*b*) The resistance of a single loop is

$R = \rho L/A = \rho L/^1r^2 = (2.65 \times 10^{-8}\ \Omega\cdot\text{m})(4)(0.200\ \text{m})/^1(2.56 \times 10^{-4}\ \text{m})^2 =$ 0.103 Ω.

72. (*a*) We find the resistance of the coil from

$P = V^2/R$;

$4.0 \times 10^3\ \text{W} = (120\ \text{V})^2/R$, which gives $R = 3.60\ \Omega$.

If the coil is tightly wound, each turn will have a length of ^1D. We find the number of turns from the length of wire required to give this resistance:

$R = \rho L/A = \rho N^1D/w^2$;

$3.60\ \Omega = (1.65 \times 10^{-8}\ \Omega\cdot\text{m})N^1(1.2\ \text{m})/(1.6 \times 10^{-3}\ \text{m})^2$, which gives $N =$ 1.5×10^2 turns.

(*b*) We find the current in the coil from

$I = V/R = (120\ \text{V})/(3.60\ \Omega) = 33.3\ \text{A}$.

We find the magnetic field strength from

$B = \mu_0 NI/2r$

$= (4^1 \times 10^{-7}\ \text{T}\cdot\text{m/A})(1.5 \times 10^2\ \text{turns})(33.3\ \text{A})/2(0.60\ \text{m}) =$ 5.2×10^{-3} T.

(*c*) If we increase the number of turns by a factor k, the resistance will increase by this factor. Because the voltage is constant, the current will decrease by this factor, so the product NI will not change. Thus the magnetic field strength will not change.