33.5. The magnetic field is into the page on the left of the wire and it is out of the page on the right of the wire. Grab the wire with your right hand in such a way that your fingers point out of the page to the right of the wire. Since the thumb now points down, the current in the wire is down.

33.6. **(a)** The force on a charge moving in a magnetic field is

$$\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B} = (qvB\sin\alpha, \text{ direction of right-hand rule})$$

A *positive* charge moving to the right with $\vec{B}$ into the page gives a force that is *up*.
(b) The direction of the force on a negative charge is opposite the direction determined by the right-hand rule. A *negative* charge moving up with $\vec{B}$ out of the page gives a force to the left.

33.7. (a) The force on a charge moving in a magnetic field is

$$\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B} = (qvB\sin\alpha, \text{ direction of right-hand rule})$$

A *positive* charge moving to the right with $\vec{B}$ down gives a force *into the page*.
(b) The direction of the force on a negative charge is opposite the direction determined by the right-hand rule. Any charge moving parallel to the field has *no* force and *no* deflection.

33.8. **(a)** The force on a charge moving in a magnetic field is

$$\vec{F}_{\text{on q}} = q\vec{v} \times \vec{B} = (qvB\sin\alpha, \text{ direction of right-hand rule})$$

The magnetic field must be in a plane perpendicular to both the $\vec{v}$ and $\vec{F}$ vectors. Using the right-hand rule for a *positive* charge moving to the right, the $\vec{B}$ field must be *out* of the page.
(b) The direction of the force on a negative charge is opposite the direction determined by the right-hand rule. The force $\vec{F}$ on the *negative* charge is into the page. Since the velocity is to the right, the magnetic field $\vec{B}$ must be *up*.

33.13. The magnet is repelled. The current loop produces a magnetic dipole with the north pole on the left and the south pole on the right. The approaching south pole of the magnet is repelled by the south pole of the current loop.

33.14. Model: Assume the wires are infinitely long.

Visualize: Please refer to Figure EX33.14.

Solve: The magnetic field strength at point a is

$$\vec{B}_{\text{at a}} = \vec{B}_{\text{top}} + \vec{B}_{\text{bottom}} = \left(\frac{\mu_0 I}{2\pi d}, \text{ out of page}\right)_{\text{top}} + \left(\frac{\mu_0 I}{2\pi d}, \text{ into page}\right)_{\text{bottom}}$$

$$\Rightarrow B_{\text{at a}} = \frac{\mu_0 I}{2\pi}\left(\frac{1}{2.0\text{ cm}} - \frac{1}{(4.0+2.0)\text{ cm}}\right) = \left(2\times10^{-7}\text{ T m/A}\right)(10\text{ A})\left(\frac{1}{2.0\times10^{-2}\text{ m}} - \frac{1}{6.0\times10^{-2}\text{ m}}\right)$$

$$\Rightarrow \vec{B}_{\text{at a}} = \left(6.7\times10^{-5}\text{ T, out of page}\right)$$

At points b and c,

$$\vec{B}_{\text{at 2}} = \left(\frac{\mu_0 I}{2\pi d}, \text{ into page}\right) + \left(\frac{\mu_0 I}{2\pi d}, \text{ into page}\right) = \left(2.0\times10^{-4}\text{ T, into page}\right)$$

$$\vec{B}_{\text{at 3}} = \left(\frac{\mu_0 I}{2\pi d}, \text{ into page}\right) + \left(\frac{\mu_0 I}{2\pi d}, \text{ out of page}\right) = \left(6.7\times10^{-5}\text{ T, out of page}\right)$$

33.16. Solve: (a) The magnetic dipole moment of the superconducting ring is

$$\mu = \left(\pi R^2\right) I = \pi\left(1.0\times10^{-3}\ \text{m}\right)^2 (100\ \text{A}) = 3.1\times10^{-4}\ \text{A m}^2$$

(b) From Example 33.5, the on-axis magnetic field of the superconducting ring is

$$B_{\text{ring}} = \frac{\mu_0}{2}\frac{IR^2}{\left(z^2+R^2\right)^{3/2}} = \frac{2\pi\left(10^{-7}\ \text{T m/A}\right)(100\ \text{A})\left(1.0\times10^{-3}\ \text{m}\right)^2}{\left[(0.050\ \text{m})^2+(0.0010\ \text{m})^2\right]^{3/2}} = 5.0\times10^{-7}\ \text{T}$$

33.19. Visualize: Please refer to Figure EX33.19.

Solve: Because $\vec{B}$ is in the same direction as the integration path $\vec{s}$ from i to f, the dot product of $\vec{B}$ and $d\vec{s}$ is simply Bds. Hence the line integral

$$\int_{\mathrm{i}}^{\mathrm{f}} \vec{B} \cdot d\vec{s} = \int_{\mathrm{i}}^{\mathrm{f}} Bds = B\int_{\mathrm{i}}^{\mathrm{f}} ds = B\left(\sqrt{(0.50\text{ m})^2 + (0.50\text{ m})^2}\right) = (0.10\text{ T})\sqrt{2}(0.50\text{ m}) = 0.071\text{ T m}$$

33.20. Visualize: Please refer to Figure EX33.20.

Solve: The line integral of $\vec{B}$ between points i and f is

$$\int_{\mathrm{i}}^{\mathrm{f}} \vec{B} \cdot d\vec{s}$$

Because $\vec{B}$ is perpendicular to the integration path from i to f, the dot product is zero at all points and the line integral is zero.

33.23. Model: The magnetic field is that of a current flowing into the plane of the paper. The current-carrying wire is very long.

Visualize: Please refer to Figure EX33.23.

Solve: Divide the line integral into three parts:

$$\int_{\mathrm{i}}^{\mathrm{f}} \vec{B}\cdot d\vec{s} = \int_{\text{left line}} \vec{B}\cdot d\vec{s} + \int_{\text{semicircle}} \vec{B}\cdot d\vec{s} + \int_{\text{right line}} \vec{B}\cdot d\vec{s}$$

The magnetic field of the current-carrying wire is tangent to clockwise circles around the wire. $\vec{B}$ is everywhere perpendicular to the left line and to the right line, thus the first and third parts of the line integral are zero. Along the semicircle, $\vec{B}$ is tangent to the path *and* has the same magnitude $B = \mu_0 I/2\pi d$ at every point. Thus

$$\int_{\mathrm{i}}^{\mathrm{f}} \vec{B}\cdot d\vec{s} = 0 + BL + 0 = \frac{\mu_0 I}{2\pi d}(\pi d) = \frac{\mu_0 I}{2} = \frac{(4\pi\times10^{-7}\ \text{T m/A})(2.0\ \text{A})}{2} = 1.26\times10^{-6}\ \text{T m}$$

where $L = \pi d$ is the length of the semicircle, which is half the circumference of a circle of radius d.

33.24. Model: Assume that the solenoid is an ideal solenoid.

Solve: We can use Equation 33.16 to find the current that will generate a 3.0 mT field inside the solenoid:

$$B_{\text{solenoid}} = \frac{\mu_0 NI}{l} \Rightarrow I = \frac{B_{\text{solenoid}} l}{\mu_0 N}$$

Using $l = 0.15$ m and $N = 0.15\ \text{m}/0.0010\ \text{m} = 150$,

$$I = \frac{(3.0\times10^{-3}\ \text{T})(0.15\ \text{m})}{(4\pi)(10^{-7}\ \text{T m/A})(150)} = 2.4\ \text{A}$$

Assess: This is a reasonable current to pass through a good conducting wire of diameter 1 mm.

33.27. Model: A magnetic field exerts a magnetic force on a moving charge.
Visualize: Please refer to Figure EX33.27.
Solve: **(a)** The force is

$$\vec{F}_{\text{on q}} = q\vec{v}\times\vec{B} = \left(-1.60\times10^{-19}\ \text{C}\right)\left(-1.0\times10^{7}\,\hat{j}\ \ \text{m/s}\right)\times\left(0.50\hat{i}\ \text{T}\right) = -8.0\times10^{-13}\,\hat{k}\ \text{N}$$

(b) The force is

$$\vec{F}_{\text{on q}} = \left(-1.60\times10^{-19}\ \text{C}\right)\left(1.0\times10^{7}\ \text{m/s}\right)\left(-\cos45^\circ\,\hat{j}+\sin45^\circ\hat{k}\right)\times\left(0.50\hat{i}\ \text{T}\right) = 5.7\times10^{-13}\left(-\hat{j}-\hat{k}\right)\ \text{N}$$

33.36. Model: Two parallel wires carrying currents in opposite directions exert repulsive magnetic forces on each other. Two parallel wires carrying currents in the same direction exert attractive magnetic forces on each other.

Visualize: Please refer to Figure EX33.36.

Solve: The magnitudes of the various forces between the parallel wires are

$$F_{2\text{ on }1} = \frac{\mu_0 L I_1 I_2}{2\pi d} = \frac{\left(2\times10^{-7}\ \text{T m/A}\right)\left(0.50\ \text{m}\right)\left(10\ \text{A}\right)\left(10\ \text{A}\right)}{0.02\ \text{m}} = 5.0\times10^{-4}\ \text{N} = F_{2\text{ on }3} = F_{3\text{ on }2} = F_{1\text{ on }2}$$

$$F_{3\text{ on }1} = \frac{\mu_0 L I_1 I_3}{2\pi d} = \frac{\left(2\times10^{-7}\ \text{T m/A}\right)\left(0.50\ \text{m}\right)\left(10\ \text{A}\right)\left(10\ \text{A}\right)}{0.04\ \text{m}} = 2.5\times10^{-4}\ \text{N} = F_{1\text{ on }3}$$

Now we can find the net force each wire exerts on the other as follows:

$$\vec{F}_{\text{on }1} = \vec{F}_{2\text{ on }1} + \vec{F}_{3\text{ on }1} = \left(5.0\times10^{-4}\,\hat{j}\right)\ \text{N} + \left(-2.5\times10^{-4}\,\hat{j}\right)\ \text{N} = 2.5\times10^{-4}\,\hat{j}\,\text{N} = \left(2.5\times10^{-4}\ \text{N, up}\right)$$

$$\vec{F}_{\text{on }2} = \vec{F}_{1\text{ on }2} + \vec{F}_{3\text{ on }2} = \left(-5.0\times10^{-4}\,\hat{j}\right)\ \text{N} + \left(+5.0\times10^{-4}\,\hat{j}\right)\ \text{N} = 0\ \text{N}$$

$$\vec{F}_{\text{on }3} = \vec{F}_{1\text{ on }3} + \vec{F}_{2\text{ on }3} = \left(2.5\times10^{-4}\,\hat{j}\right)\ \text{N} + \left(-5.0\times10^{-4}\,\hat{j}\right)\ \text{N} = -2.5\times10^{-4}\,\hat{j}\ \text{N} = \left(2.5\times10^{-4}\ \text{N, down}\right)$$

33.39. Solve: From Equation 33.28, the torque on the loop exerted by the magnetic field is

$$\vec{\tau} = \vec{\mu} \times \vec{B} \Rightarrow \tau = \mu B \sin\theta = IAB\sin\theta = (0.500 \text{ A})(0.050 \text{ m} \times 0.050 \text{ m})(1.2 \text{ T})\sin 30° = 7.5 \times 10^{-4} \text{ N m}$$

33.45. Model: Assume that the superconducting niobium wire is very long.

Solve: The magnetic field of a long wire carrying current I is

$$B_{\text{wire}} = \frac{\mu_0 I}{2\pi d}$$

We're interested in the magnetic field of the current right at the surface of the wire, where d = 1.5 mm. The maximum field is 0.10 T, so the maximum current is

$$I = \frac{(2\pi d)B_{\text{wire}}}{\mu_0} = \frac{2\pi(1.5\times10^{-3}\text{ m})(0.10\text{ T})}{4\pi\times10^{-7}\text{ T m/A}} = 750\text{ A}$$

Assess: The current density in this superconducting wire is of the order of 1×10^8 A/m^2. This is a typical value for conventional superconducting materials.

33.46. Model: Use the Biot-Savart law for a current carrying segment.
Visualize: Please refer to Figure P33.46.
Solve: **(a)** The Biot-Savart law (Equation 33.6) for the magnetic field of a current segment $\Delta\vec{s}$ is

$$\vec{B} = \frac{\mu_0}{4\pi}\frac{I\Delta\vec{s}\times\hat{r}}{r^2}$$

where the unit vector $\hat{r}$ points from current segment Δs to the point, a distance r away, at which we want to evaluate the field. For the two linear segments of the wire, $\Delta\vec{s}$ is in the same direction as $\hat{r}$, so $\Delta\vec{s}\times\hat{r} = 0$. For the curved segment, $\Delta\vec{s}$ and $\hat{r}$ are always perpendicular, so $\Delta\vec{s}\times\hat{r} = \Delta s$. Thus

$$B = \frac{\mu_0}{4\pi}\frac{I\Delta s}{r^2}$$

Now we are ready to sum the magnetic field of all the segments at point P. For all segments on the arc, the distance to point P is $r = R$. The superposition of the fields is

$$B = \frac{\mu_0}{4\pi}\frac{I}{R^2}\int_{\text{arc}} ds = \frac{\mu_0}{4\pi}\frac{IL}{R^2} = \frac{\mu_0 I\theta}{4\pi R}$$

where $L = R\theta$ is the length of the arc.
(b) Substituting $\theta = 2\pi$ in the above expression,

$$B_{\text{loop center}} = \frac{\mu_0 I 2\pi}{4\pi R} = \frac{\mu_0}{2}\frac{I}{R}$$

This is Equation 33.7, which is the magnetic field at the center of a 1-turn coil.

33.48. Model: Assume that the wire is infinitely long.

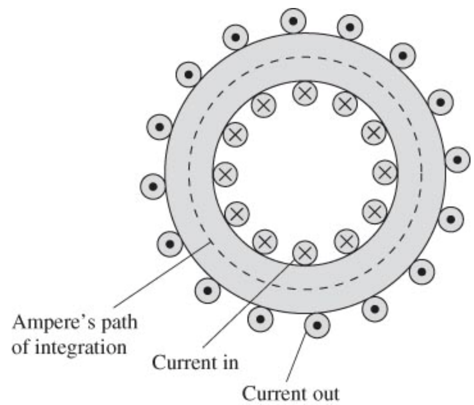
Visualize: Please refer to Figure P33.48. The wire, looped as it is, consists of a circular part and a linear part.

Solve: Using Equation 33.7 and Example 33.3, the magnetic field at P is

$$B_{\text{P}} = B_{\text{loop center}} + B_{\text{wire}} = \frac{\mu_0 I}{2R} + \frac{\mu_0 I}{2\pi R}$$

$$= \frac{4\pi\left(10^{-7}\text{ T m/A}\right)\left(5.0\text{ A}\right)}{2\left(0.010\text{ m}\right)} + \frac{4\pi\left(10^{-7}\text{ T m/A}\right)\left(5.0\text{ A}\right)}{2\pi\left(0.010\text{ m}\right)} = 4.1\times10^{-4}\text{ T}$$

33.54. Model: The toroid may be viewed as a solenoid that has been bent into a circle.
Visualize: Please refer to Figure P33.54.
Solve: (a) A long solenoid has a uniform magnetic field inside and it is roughly parallel to the axis. If we bend the solenoid to make it circular, we will have circular magnetic field lines around the inside of the toroid. However, as explained in part (c) the field is not uniform.
(b)



A top view of the toroid is shown. Current is into the page for the inside windings and out of the page for the outside windings. The closed Ampere's path of integration thus contains a current NI where I is the current flowing through the wire and N is the number of turns. Applied to the closed line path, the Ampere's law is

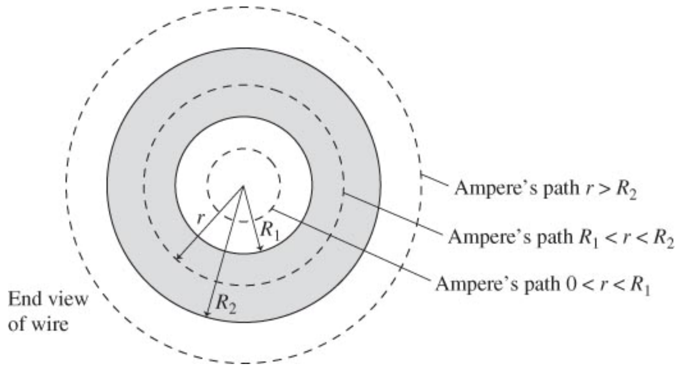
$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} = \mu_0 NI$$

Because $\vec{B}$ and $d\vec{s}$ are along the same direction and B is the same along the line integral, the above simplifies to

$$B\oint ds = B2\pi r = \mu_0 NI \Rightarrow B = \frac{\mu_0 NI}{2\pi r}$$

(c) The magnetic field for a toroid depends inversely on r which is the distance from the center of the toroid. As r increases from the inside of the toroid to the outside, B_{toroid} decreases. Thus the field is not uniform.

33.55. **Model:** The magnetic field is that of the current which is distributed uniformly in the hollow wire.
Visualize:



Ampere's integration paths are shown in the figure for the regions 0 m $< r < R_1$, $R_1 < r < R_2$, and $R_2 < r$.

Solve: For the region 0 m $< r < R_1$, $\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}}$. Because the current inside the integration path is zero, $B = 0$ T. To find I_{through} in the region $R_1 < r < R_2$, we multiply the current density by the area inside the integration path that carries the current. Thus,

$$I_{\text{through}} = \frac{I}{\pi\left(R_2^2 - R_1^2\right)}\pi\left(r^2 - R_1^2\right)$$

where the current density is the first term. Because the magnetic field has the same magnitude at every point on the circular path of integration, Ampere's law simplifies to

$$\oint \vec{B} \cdot d\vec{s} = B\int ds = B\left(2\pi r\right) = \mu_0 \frac{I\left(r^2 - R_1^2\right)}{\left(R_2^2 - R_1^2\right)} \Rightarrow B = \frac{\mu_0 I}{2\pi r}\left(\frac{r^2 - R_1^2}{R_2^2 - R_1^2}\right)$$

For the region $R_2 < r$, I_{through} is simply I because the loop encompasses the entire current. Thus,

$$\oint \vec{B} \cdot d\vec{s} = B\int ds = B2\pi r = \mu_0 I \Rightarrow \; B = \frac{\mu_0 I}{2\pi r}$$

Assess: The results obtained for the regions $r > R_2$ and $R_1 < r < R_2$ yield the same result at $r = R_2$. Also note that a hollow wire and a regular wire have the same magnetic field outside the wire.

33.58. Visualize: Please refer to Figure P33.58.

Solve: The electric field is

$$\vec{E} = \left(\frac{200\ \text{V}}{1\ \text{cm}}, \text{down}\right) = \left(20{,}000\ \text{V/m, down}\right)$$

The force this field exerts on the electron is $\vec{F}_{\text{elec}} = q\vec{E} = -e\vec{E} = \left(3.2\times10^{-15}\ \text{N, up}\right)$. The electron will pass through without deflection *if* the magnetic field also exerts a force on the electron such that $\vec{F}_{\text{net}} = \vec{F}_{\text{elec}} + \vec{F}_{\text{mag}} = 0\ \text{N}$. That is, $\vec{F}_{\text{mag}} =$ $(3.2\times10^{-15}$ N, 3.2×10^{-15} N, down). In this case, the electric and magnetic forces cancel each other. For a *negative* charge with $\vec{v}$ to the right to have $\vec{F}_{\text{mag}}$ down requires, from the right-hand rule, that $\vec{B}$ point *into* the page. The magnitude of the magnetic force on a moving charge is $F_{\text{mag}} = qvB$, so the needed field strength is

$$B = \frac{F_{\text{mag}}}{ev} = \frac{3.2\times10^{-15}\ \text{N}}{\left(1.60\times10^{-19}\ \text{C}\right)\left(1.0\times10^{7}\ \text{m/s}\right)} = 2.0\times10^{-3}\ \text{T} \ = \ 2.0\ \text{mT}$$

Thus, the required magnetic field is $\vec{B}$ = (2.0 mT, into page).

33.60. Model: Charged particles moving perpendicular to a uniform magnetic field undergo uniform circular motion at a constant speed.

Solve: **(a)** From Equation 33.20, the magnetic field is

$$B = \frac{2\pi fm}{e} = \frac{2\pi\left(2.4\times10^{9}\ \text{Hz}\right)\left(9.11\times10^{-31}\ \text{kg}\right)}{1.6\times10^{-19}\ \text{C}} = 0.086\ \text{T} = 86\ \text{mT}$$

(b) The maximum kinetic energy is for an orbit with radius 1.25 cm.

$$K = \tfrac{1}{2}mv^2 = \tfrac{1}{2}m\left(2\pi rf\right)^2 = \tfrac{1}{2}\left(9.11\times10^{-31}\ \text{kg}\right)\left[2\pi\left(0.0125\ \text{m}\right)\left(2.4\times10^{9}\ \text{Hz}\right)\right]^2 = 1.62\times10^{-14}\ \text{J}$$

33.64. Model: Charged particles moving perpendicular to a uniform magnetic field undergo circular motion at constant speed.
Visualize: Please refer to Figure P33.64.
Solve: The potential difference causes an ion of mass m to accelerate from rest to a speed v. Upon entering the magnetic field, the ion follows a circular trajectory with cyclotron radius $r = mv/eB$. To be detected, an ion's trajectory must have radius $d = 2r = 8$ cm. This means the ion needs the speed

$$v = \frac{eBr}{m} = \frac{eBd}{2m}$$

This speed was acquired by accelerating from potential V to potential 0. We can use the conservation of energy equation to find the voltage that will accelerate the ion:

$$K_1 + U_1 = K_2 + U_2 \Rightarrow 0 \text{ J} + e\Delta V = \tfrac{1}{2}mv^2 + 0 \text{ J} \Rightarrow \Delta V = \frac{mv^2}{2e}$$

Using the above expression for v, the voltage that causes an ion to be detected is

$$\Delta V = \frac{mv^2}{2e} = \frac{m}{2e}\left(\frac{eBd}{2m}\right)^2 = \frac{eB^2d^2}{8m}$$

An ion's mass is the sum of the masses of the two atoms *minus* the mass of the missing electron. For example, the mass of N_2^+ is

$$m = m_N + m_N - m_{elec} = 2(14.0031 \text{ u})(1.661 \times 10^{-27} \text{ kg/u}) - 9.11 \times 10^{-31} \text{ kg} = 4.65174 \times 10^{-26} \text{ kg}$$

Note that we're given the atomic masses very accurately in Exercise 28. We need to retain this accuracy to tell the difference between N_2^+ and CO^+. The voltage for N_2^+ is

$$\Delta V = \frac{(1.6\times10^{-19} \text{ C})(0.200 \text{ T})^2(0.08 \text{ m})^2}{8(4.65174\times10^{-26} \text{ kg})} = 110.07 \text{ V}$$

Ion	Mass (kg)	Accelerating voltage (V)
N_2^+	4.65174×10^{-26}	110.07
O_2^+	5.31341×10^{-26}	96.36
CO^+	4.64986×10^{-26}	110.11

Assess: The difference between N_2^+ and CO^+ is not large but is easily detectable.

33.66. Model: The loop will not rotate about the axle if the torque due to the magnetic force on the loop balances the torque of the weight.

Visualize: Please refer to Figure P33.66.

Solve: The rotational equilibrium condition $\Sigma \vec{\tau}_{\text{net}} = 0 \text{ N m}$ is about the axle and means that the torque from the weight is equal and opposite to the torque from the magnetic force. We have

$$\left(50\times10^{-3}\text{ kg}\right)g\left(0.025\text{ m}\right) = \mu B\sin 90° = \left(NIA\right)B$$

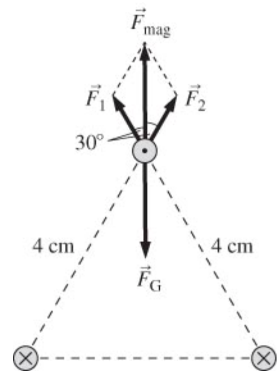
$$\Rightarrow B = \frac{\left(50\times10^{-3}\text{ kg}\right)\left(9.8\text{ m/s}^2\right)\left(0.025\text{ m}\right)}{\left(10\right)\left(2.0\text{ A}\right)\left(0.050\text{ m}\right)\left(0.100\text{ m}\right)} = 0.123\text{ T}$$

Assess: The current in the loop must be clockwise for the two torques to be equal.

33.67. Model: A magnetic field exerts a magnetic force on a length of current-carrying wire. We ignore gravitational effects, and focus on the B effects.
Visualize: Please refer to Figure P33.67. The figure shows a wire in a magnetic field that is directed out of the page. The magnetic force on the wire is therefore to the right and will stretch the springs.
Solve: In static equilibrium, the sum of the forces on the wire is zero:

$$F_B + F_{sp\,1} + F_{sp\,2} = 0\text{ N} \Rightarrow ILB + (-k\Delta x) + (-k\Delta x) \Rightarrow I = \frac{2k\Delta x}{LB} = \frac{2(10\text{ N/m})(0.01\text{ m})}{(0.20\text{ m})(0.5\text{ T})} = 2.0\text{ A}$$

33.70. Model: The wire will float in the magnetic field if the magnetic force on the wire points upward and has a magnitude *mg*, allowing it to balance the downward gravitational force.
Visualize:



Solve: Each lower wire exerts a repulsive force on the upper wire because the currents are in opposite directions. The currents are of equal magnitude and the distances are equal, so $F_1 = F_2$. Consider segments of the wires of length L. Then the forces are

$$F_1 = F_2 = \frac{\mu_0 L I^2}{2\pi d}$$

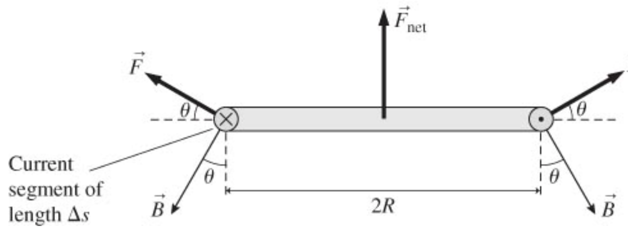
The horizontal components of these two forces cancel, so the net magnetic force is upward and of magnitude

$$F_{\text{mag}} = 2F_1 \cos 30° = \frac{\mu_0 L I^2 \cos 30°}{\pi d}$$

In equilibrium, this force must exactly balance the downward weight of the wire. The wire's linear mass density is $\mu = 0.050$ kg/m, so the mass of this segment is $m = \mu L$ and its weight is $w = mg = \mu L g$. Equating these gives

$$\frac{\mu_0 L I^2 \cos 30°}{\pi d} = \mu L g \Rightarrow I = \sqrt{\frac{\mu g \pi d}{\mu_0 \cos 30°}} = \sqrt{\frac{(0.050 \text{ kg/m})(9.8 \text{ m/s}^2)\pi(0.040 \text{ m})}{(4\pi \times 10^{-7} \text{ T m/A})\cos 30°}} = 238 \text{ A}$$

33.76. Model: A magnetic field exerts a force on a segment of current.
Visualize: The figure shows the forces on two small segments of current, one in which the current enters the plane of the page and one in which the current leaves the plane of the page.



Solve: **(a)** Consider a small segment of the loop of length Δs. The magnetic force on this segment is perpendicular both to the current and to the magnetic field. The figure shows two segments on opposite sides of the loop. The horizontal components of the forces cancel but the vertical components combine to give a force toward the bar magnet. The net force is the sum of the vertical components of the force on all segments around the loop. For a segment of length Δs, the magnetic force is $F = IB\Delta s$ and the vertical component is $F_y = (IB\Delta s)\sin\theta$. Thus the net force on the current loop is

$$F_{net} = \sum F_y = \sum (IB\Delta s)\sin\theta = IB\sin\theta \sum \Delta s$$

We could take $\sin\theta$ outside the summation because θ is the same for all segments. The sum of all the Δs is simply the circumference $2\pi R$ of the loop, so

$$F_{net} = 2\pi RIB\sin\theta$$

(b) The net force is

$$F_{net} = 2\pi(0.020 \text{ m})(\sin 20°)(0.50 \text{ A})(200 \times 10^{-3} \text{ T}) = 4.3 \times 10^{-3} \text{ N}$$