33.10. Solve: From Example 33.5, the on-axis magnetic field of a current loop is

$$B_{\text{loop}}(z) = \frac{\mu_0}{2}\frac{IR^2}{\left(z^2+R^2\right)^{\frac{3}{2}}}.$$

We want to find the value of z such that $B(z) = 2B(0)$.

$$\frac{\mu_0}{2}\frac{IR^2}{\left(z^2+R^2\right)^{\frac{3}{2}}} = 2\frac{\mu_0}{2}\frac{IR^2}{\left(R^2\right)^{\frac{3}{2}}}$$

$$\Rightarrow \left(z^2+R^2\right)^{\frac{3}{2}} = \frac{R^3}{z} \Rightarrow z^2+R^2 = \frac{R^2}{2^{\frac{2}{3}}} \Rightarrow z = R\left(2^{-\frac{2}{3}}-1\right)^{\frac{1}{2}} = 0.77\text{ R}$$

33.12. Model: The magnetic field is the superposition of the magnetic fields of three wire segments.
Visualize: Please refer to Figure EX33.12.
Solve: The magnetic field of the horizontal wire, with current *I*, encircles the wire. Because the dot is on the axis of the wire, the input current creates no magnetic field at this point. The current divides at the junction, with *I*/2 traveling upward and *I*/2 traveling downward. The right-hand rule tells us that the upward current creates a field at the dot that is into the page; the downward current creates a field that is out of the page. Although we could calculate the strength of each field, the symmetry of the situation (the dot is the same distance and direction from the base of each wire) tells us that the fields of the upward and downward current must have the same strength. Since they are in opposite directions, their sum is $\vec{0}$. Altogether, then, the field at the dot is $\vec{B} = \vec{0}\ \text{T}$.

33.22. Model: Only the two currents enclosed by the closed path contribute to the line integral.
Visualize: Please refer to Figure EX33.22.
Solve: Ampere's law gives the line integral of the magnetic field around the closed path:

$$\oint \vec{B} \cdot d\vec{s} = \mu_0 I_{\text{through}} = 1.38 \times 10^{-5} \text{ T m } = \mu_0 (I_2 + I_3) = (4\pi \times 10^{-7} \text{ T m/A})(8.0 \text{ A} + I_3)$$

$$\Rightarrow (I_3 + 8.0 \text{ A}) = \frac{1.38 \times 10^{-5} \text{ T m}}{4\pi \times 10^{-7} \text{ T m/A}} \Rightarrow I_3 = 3.0 \text{ A, out of the page.}$$

Assess: The right-hand rule was used above to assign a positive sign to I_2. Since I_3 is also positive, it is in the same direction as I_2.

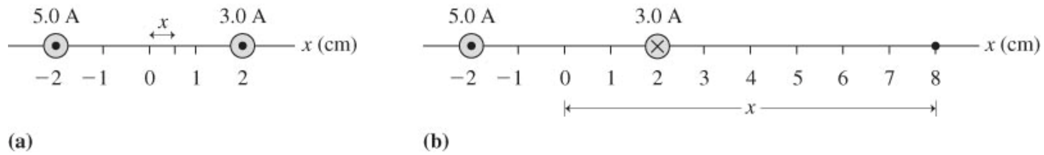
33.26. **Model:** A magnetic field exerts a magnetic force on a moving charge.
Visualize: Please refer to Figure EX33.26.
Solve: **(a)** The force on the charge is

$$\vec{F}_{\text{on q}} = q\vec{v}\times\vec{B} = \left(1.60\times10^{-19}\ \text{C}\right)\left(1.0\times10^{7}\ \text{m/s}\right)\left(\cos45°\hat{i}+\sin45°\hat{k}\right)\times\left(0.50\hat{i}\ \text{T}\right)$$

$$= \left(1.60\times10^{-19}\ \text{C}\right)\left(0.50\ \text{T}\right)\frac{\left(1.0\times10^{7}\ \text{m/s}\right)}{\sqrt{2}}\left(\hat{i}\times\hat{i}+\hat{k}\times\hat{i}\right) = +5.7\times10^{-13}\,\hat{j}\ \text{N}$$

(b) Because the cross product $\hat{i}\times\hat{i}$ in the equation for the force is zero, $\vec{F}_{\text{on q}} = \vec{0}$ N.

33.42. Model: The magnetic field is that of two long wires that carry current.
Visualize:



Solve: **(a)** For $x > +2$ cm and for $x < -2$ cm, the magnetic fields due to the currents in the two wires add. The point where the two magnetic fields cancel lies on the x-axis in between the two wires. Let that point be a distance x away from the origin. Because the magnetic field of a long wire is $B = \mu_0 I/2\pi r$, we have

$$\frac{\mu_0}{2\pi}\frac{(5.0\text{ A})}{(0.020\text{ m}+x)} = \frac{\mu_0}{2\pi}\frac{(3.0\text{ A})}{(0.020\text{ m}-x)} \Rightarrow 5(0.020\text{ m} - x) = 3(0.020\text{ m} + x) \Rightarrow x = 0.0050\text{ m} = 0.50\text{ cm}$$

(b) The magnetic fields due to the currents in the two wires add in the region -2.0 cm $< x < 2.0$ cm. For $x <$ -2.0 cm, the magnetic fields subtract, but the field due to the 5.0 A current is always larger than the field due to the 3.0 A current. However, for $x > 2.0$ m, the two fields will cancel at a point on the x-axis. Let that point be a distance x away from the origin, so

$$\frac{\mu_0}{2\pi}\frac{5.0\text{ A}}{x+0.020\text{ m}} = \frac{\mu_0}{2\pi}\frac{3.0\text{ A}}{x-0.020\text{ m}} \Rightarrow 5(x - 0.020\text{ m}) = 3(x + 0.020\text{ m}) \Rightarrow x = 8.0\text{ cm}$$

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

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

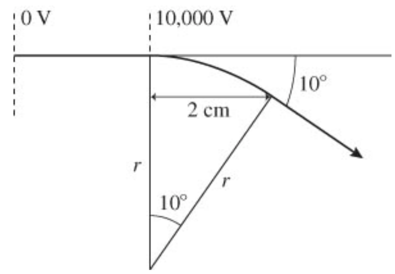
where $L = R\theta$ is the length of the arc.
(b) Substituting $\theta = 2\pi$ in the above expression,

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

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

33.59. Model: Energy is conserved as the electron moves between the two electrodes. Assume the electron starts from rest. Once in the magnetic field, the electron moves along a circular arc.

Visualize:



The electron is deflected by 10° after moving along a circular arc of angular width 10°.

Solve: Energy is conserved as the electron moves from the 0 V electrode to the 10,000 V electrode. The potential energy is $U = qV$ with $q = -e$, so

$$K_f + U_f = K_i + U_i \Rightarrow \tfrac{1}{2}mv^2 - eV = 0 + 0$$

$$v = \sqrt{\frac{2eV}{m}} = \sqrt{\frac{2(1.60\times10^{-19}\ \text{C})(10{,}000\ \text{V})}{9.11\times10^{-31}\ \text{kg}}} = 5.93\times10^{7}\ \text{m/s}$$

The radius of cyclotron motion in a magnetic field is $r = mv/eB$. From the figure we see that the radius of the circular arc is $r = (2.0\ \text{cm})/\sin10°$. Thus

$$B = \frac{mv}{er} = \frac{(9.11\times10^{-31}\ \text{kg})(5.93\times10^{7}\ \text{m/s})}{(1.60\times10^{-19}\ \text{C})(0.020\ \text{m})/\sin10°} = 2.9\times10^{-3}\ \text{T}$$