***P22.7** For each electron, $|q|vB\sin 90.0° = \frac{mv^2}{r}$ and $v = \frac{eBr}{m}$.

The electrons have no internal structure to absorb energy, so the collision must be perfectly elastic:

$$K = \frac{1}{2}mv_{1i}^2 + 0 = \frac{1}{2}mv_{1f}^2 + \frac{1}{2}mv_{2f}^2$$

$$K = \frac{1}{2}m\left(\frac{e^2B^2R_1^2}{m^2}\right) + \frac{1}{2}m\left(\frac{e^2B^2R_2^2}{m^2}\right) = \frac{e^2B^2}{2m}\left(R_1^2 + R_2^2\right)$$

$$K = \frac{e\left(1.60\times10^{-19}\ \text{C}\right)\left(0.044\,0\ \text{N}\cdot\text{s/C}\cdot\text{m}\right)^2}{2\left(9.11\times10^{-31}\ \text{kg}\right)}\left[\left(0.010\,0\ \text{m}\right)^2 + \left(0.024\,0\ \text{m}\right)^2\right] = \boxed{115\ \text{keV}}$$

P22.10 $F_B = F_e$

so $qvB = qE$

where $v = \sqrt{\frac{2K}{m}}$ and K is kinetic energy of the electron.

$$E = vB = \sqrt{\frac{2K}{m}}B = \sqrt{\frac{2(750)\left(1.60\times10^{-19}\right)}{9.11\times10^{-31}}}\left(0.015\,0\right) = \boxed{244\ \text{kV/m}}$$

P22.13 $\theta = \tan^{-1}\left(\frac{25.0}{10.0}\right) = 68.2°$ and $R = \frac{1.00\ \text{cm}}{\sin 68.2°} = 1.08\ \text{cm}$.

Ignoring relativistic correction, the kinetic energy of the electrons is

$\frac{1}{2}mv^2 = q\Delta V$ so $v = \sqrt{\frac{2q\Delta V}{m}} = 1.33\times10^{8}\ \text{m/s}$.

From Newton's second law $\frac{mv^2}{R} = qvB$, we find the magnetic field

$$B = \frac{mv}{|q|R} = \frac{\left(9.11\times10^{-31}\ \text{kg}\right)\left(1.33\times10^{8}\ \text{m/s}\right)}{\left(1.60\times10^{-19}\ \text{C}\right)\left(1.08\times10^{-2}\ \text{m}\right)} = \boxed{70.1\ \text{mT}}.$$

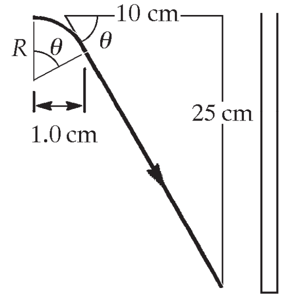


FIG. P22.13

P22.14 (a) If the charge carriers are negative, to carry current in the x direction they move with drift velocity v_d in the $-x$ direction. The magnetic force $q\vec{\mathbf{v}}\times\vec{\mathbf{B}}$ is in the $-\left(-\hat{\mathbf{i}}\right)\times\hat{\mathbf{j}} = \hat{\mathbf{k}}$ direction, so the negative charges are deflected to the top of the ribbon, point c. Some accumulate there to make V_c negative with respect to V_a, until ...

(b) ... an upward electric field $\vec{\mathbf{E}}=\frac{|V_c-V_a|}{d}\hat{\mathbf{k}}$ exerts a downward force on the other charge carriers to let them drift in equilibrium according to

$\Sigma F_z=0$: $$|q|\frac{|V_c-V_a|}{d}\left(-\hat{\mathbf{k}}\right)+|q||\vec{\mathbf{v}}_d||\vec{\mathbf{B}}|\hat{\mathbf{k}}=0$$

$$v_d=\frac{|\Delta V_H|}{dB}.$$

Since the measured current is $I=n|q|v_d t\,d$

we have $$I=n|q|\frac{|\Delta V_H|}{dB}t\,d$$

$$n=\frac{IB}{|q||\Delta V_H|t}.$$

Since we have shown that ΔV_H is negative if q is negative, this expression simplifies to

$$\boxed{n=\frac{IB}{q\Delta V_H t}}.$$

P22.15 $\vec{\mathbf{F}}_B=I\vec{\ell}\times\vec{\mathbf{B}}=(2.40\text{ A})(0.750\text{ m})\hat{\mathbf{i}}\times(1.60\text{ T})\hat{\mathbf{k}}=\boxed{\left(-2.88\hat{\mathbf{j}}\right)\text{N}}$

P22.17 The magnetic force on each bit of ring is $Id\vec{\mathbf{s}}\times\vec{\mathbf{B}}=IdsB$ radially inward and upward, at angle θ above the radial line. The radially inward components tend to squeeze the ring but all cancel out as forces. The upward components $IdsB\sin\theta$ all add to $\boxed{I2\pi rB\sin\theta\text{ up}}$.

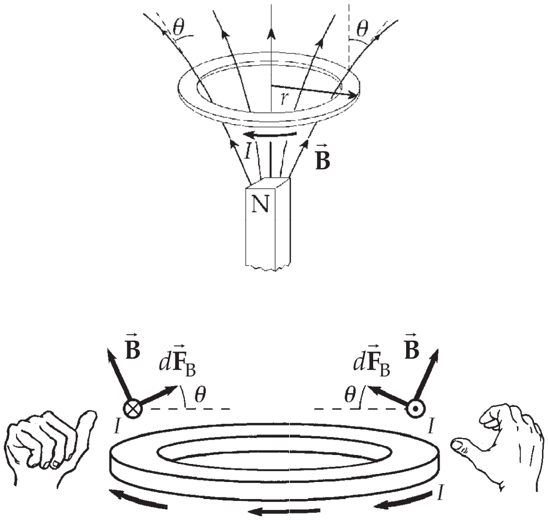


FIG. P22.17

P22.19 (a) $2\pi r=2.00\text{ m}$

so $r=0.318\text{ m}$

$$\mu=IA=\left(17.0\times10^{-3}\text{ A}\right)\left[\pi(0.318)^2\text{ m}^2\right]=\boxed{5.41\text{ mA}\cdot\text{m}^2}$$

(b) $\vec{\tau} = \vec{\mu} \times \vec{\mathbf{B}}$

so $\tau = \left(5.41 \times 10^{-3}\ \text{A}\cdot\text{m}^2\right)(0.800\ \text{T}) = \boxed{4.33\ \text{mN}\cdot\text{m}}$

P22.23 $B = \dfrac{\mu_0 I}{2R} = \dfrac{\mu_0 q(v/2\pi R)}{2R} = \boxed{12.5\ \text{T}}$

P22.27 We can think of the total magnetic field as the superposition of the field due to the long straight wire (having magnitude $\dfrac{\mu_0 I}{2\pi R}$ and directed into the page) and the field due to the circular loop (having magnitude $\dfrac{\mu_0 I}{2R}$ and directed into the page). The resultant magnetic field is: $\boxed{\vec{\mathbf{B}} = \left(1 + \dfrac{1}{\pi}\right)\dfrac{\mu_0 I}{2R}\ (\text{directed into the page})}$.

***P22.29** Wire 1 creates at the origin magnetic field

$\vec{\mathbf{B}}_1 = \dfrac{\mu_0 I}{2\pi r}$ right hand rule $= \dfrac{\mu_0 I_1}{2\pi a}$  $= \dfrac{\mu_0 I_1}{2\pi a}\hat{\mathbf{j}}$

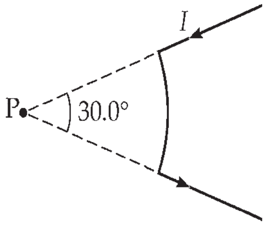
(a) If the total field at the origin is $\dfrac{2\mu_0 I_1}{2\pi a}\hat{\mathbf{j}} = \dfrac{\mu_0 I_1}{2\pi a}\hat{\mathbf{j}} + \vec{\mathbf{B}}_2$ then the second wire must create field according to $\vec{\mathbf{B}}_2 = \dfrac{\mu_0 I_1}{2\pi a}\hat{\mathbf{j}} = \dfrac{\mu_0 I_2}{2\pi(2a)}$ .

Then $I_2 = \boxed{2I_1 \text{ out of the paper}}$.

(b) The other possibility is $\vec{\mathbf{B}}_1 + \vec{\mathbf{B}}_2 = \dfrac{2\mu_0 I_1}{2\pi a}\left(-\hat{\mathbf{j}}\right) = \dfrac{\mu_0 I_1}{2\pi a}\hat{\mathbf{j}} + \vec{\mathbf{B}}_2$. Then

$\vec{\mathbf{B}}_2 = \dfrac{3\mu_0 I_1}{2\pi a}\left(-\hat{\mathbf{j}}\right) = \dfrac{\mu_0 I_2}{2\pi(2a)}$  $I_2 = \boxed{6I_1 \text{ into the paper}}$

P22.31 We use the Biot-Savart law. For bits of wire along the straight-line sections, $d\vec{\mathbf{s}}$ is at 0° or 180° to $\hat{\mathbf{r}}$, so $d\vec{\mathbf{s}} \times \hat{\mathbf{r}} = 0$. Thus, only the curved section of wire contributes to $\vec{\mathbf{B}}$ at P. Hence, $d\vec{\mathbf{s}}$ is tangent to the arc and $\hat{\mathbf{r}}$ is radially inward; so $d\vec{\mathbf{s}} \times \hat{\mathbf{r}} = |ds|\ell \sin 90° = |ds|\otimes$. All points along the curve are the same distance $r = 0.600\ \text{m}$ from the field point, so



$$B = \int_{\text{all current}} |d\vec{\mathbf{B}}| = \int \frac{\mu_0}{4\pi}\frac{I|d\vec{\mathbf{s}} \times \hat{\mathbf{r}}|}{r^2} = \frac{\mu_0}{4\pi}\frac{I}{r^2}\int |ds| = \frac{\mu_0}{4\pi}\frac{I}{r^2}s$$

FIG. P22.31

where s is the arc length of the curved wire,

$$s = r\theta = (0.600\ \text{m})(30.0°)\left(\frac{2\pi}{360°}\right) = 0.314\ \text{m}$$

Then, $B=\left(10^{-7}\ \mathrm{T\cdot m/A}\right)\dfrac{(3.00\ \mathrm{A})}{(0.600\ \mathrm{m})^2}(0.314\ \mathrm{m})$ $\qquad B=\boxed{261\ \mathrm{nT\ \ into\ the\ page}}$

P22.34 Let both wires carry current in the x direction, the first at $y=0$ and the second at $y=10.0\ \mathrm{cm}$.

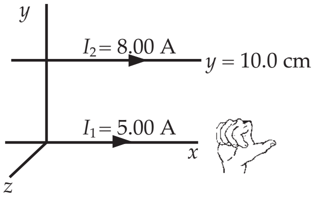


FIG. P22.34(a)

(a) $$\vec{\mathbf{B}}=\frac{\mu_0 I}{2\pi r}\hat{\mathbf{k}}=\frac{\left(4\pi\times10^{-7}\ \mathrm{T\cdot m/A}\right)(5.00\ \mathrm{A})}{2\pi(0.100\ \mathrm{m})}\hat{\mathbf{k}}$$

$$\vec{\mathbf{B}}=\boxed{1.00\times10^{-5}\ \mathrm{T\ out\ of\ the\ page}}$$

(b) $$\vec{\mathbf{F}}_B=I_2\vec{\ell}\times\vec{\mathbf{B}}=(8.00\ \mathrm{A})\left[(1.00\ \mathrm{m})\hat{\mathbf{i}}\times\left(1.00\times10^{-5}\ \mathrm{T}\right)\hat{\mathbf{k}}\right]=\left(8.00\times10^{-5}\ \mathrm{N}\right)\left(-\hat{\mathbf{j}}\right)$$

$$\boxed{\vec{\mathbf{F}}_B=8.00\times10^{-5}\ \mathrm{N\ toward\ the\ first\ wire}}$$

(c) $$\vec{\mathbf{B}}=\frac{\mu_0 I}{2\pi r}\left(-\hat{\mathbf{k}}\right)=\frac{\left(4\pi\times10^{-7}\ \mathrm{T\cdot m/A}\right)(8.00\ \mathrm{A})}{2\pi(0.100\ \mathrm{m})}\left(-\hat{\mathbf{k}}\right)=\left(1.60\times10^{-5}\ \mathrm{T}\right)\left(-\hat{\mathbf{k}}\right)$$

$$\vec{\mathbf{B}}=\boxed{1.60\times10^{-5}\ \mathrm{T\ into\ the\ page}}$$

continued on next page

(d) $$\vec{\mathbf{F}}_B=I_1\vec{\ell}\times\vec{\mathbf{B}}=(5.00\ \mathrm{A})\left[(1.00\ \mathrm{m})\hat{\mathbf{i}}\times\left(1.60\times10^{-5}\ \mathrm{T}\right)\left(-\hat{\mathbf{k}}\right)\right]=\left(8.00\times10^{-5}\ \mathrm{N}\right)\left(+\hat{\mathbf{j}}\right)$$

$$\vec{\mathbf{F}}_B=\boxed{8.00\times10^{-5}\ \mathrm{N\ towards\ the\ second\ wire}}$$

P22.35 By symmetry, we note that the magnetic forces on the top and bottom segments of the rectangle cancel. The net force on the vertical segments of the rectangle is (using Equation 22.27)

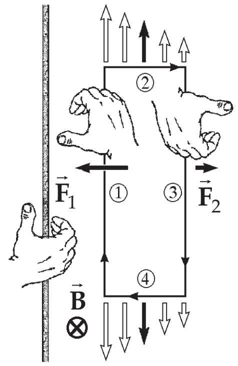


FIG. P22.35

$$\vec{\mathbf{F}}=\vec{\mathbf{F}}_1+\vec{\mathbf{F}}_2=\frac{\mu_0 I_1 I_2\ell}{2\pi}\left(\frac{1}{c+a}-\frac{1}{c}\right)\hat{\mathbf{i}}=\frac{\mu_0 I_1 I_2\ell}{2\pi}\left(\frac{-a}{c(c+a)}\right)\hat{\mathbf{i}}$$

$$\vec{\mathbf{F}}=\frac{\left(4\pi\times10^{-7}\ \mathrm{N/A^2}\right)(5.00\ \mathrm{A})(10.0\ \mathrm{A})(0.450\ \mathrm{m})}{2\pi}\left(\frac{-0.150\ \mathrm{m}}{(0.100\ \mathrm{m})(0.250\ \mathrm{m})}\right)\hat{\mathbf{i}}$$

$$\vec{\mathbf{F}}=\left(-2.70\times10^{-5}\hat{\mathbf{i}}\right)\mathrm{N}$$

or $\quad\vec{\mathbf{F}}=\boxed{2.70\times10^{-5}\ \mathrm{N\ toward\ the\ left}}$.