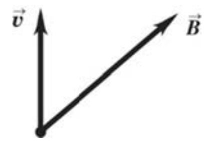
***20.3. Set Up:** The directions of $\vec{\boldsymbol{v}}$ and $\vec{\boldsymbol{B}}$ are shown in the figure below. A proton has charge $e = +1.60 \times 10^{-19}$ C. $F = |q|vB\sin\phi.$ In part (a), $\phi = 55.0°.$ An electron has charge $-e$.



Solve: **(a)** The right-hand rule says $\vec{\boldsymbol{F}}$ is into the page in the figure above.

$$F = |q|vB\sin\phi = (1.60\times10^{-19}\text{ C})(3.60\times10^{3}\text{ m/s})(0.750\text{ T})\sin 55.0° = 3.54\times10^{-16}\text{ N}.$$

(b) F is maximum when $\phi = 90°$, when $\vec{\boldsymbol{v}}$ is perpendicular to $\vec{\boldsymbol{B}}$. $F_{\text{max}} = |q|vB = 4.32\times10^{-16}$ N. F is minimum when $\phi = 0°$ or $180°$, when $\vec{\boldsymbol{v}}$ is either parallel or antiparallel to $\vec{\boldsymbol{B}}$. $F_{\text{min}} = 0.$

(c) $|q|$ is the same for an electron and a proton, so $F = 3.45\times10^{-16}$ N, the same as for a proton. Since the proton and electron have charges of opposite sign, the forces on them are in opposite directions. The force on the electron is directed out of the page in the figure above.

Reflect: Only the component of $\vec{\boldsymbol{v}}$ perpendicular to $\vec{\boldsymbol{B}}$ contributes to the magnetic force. Therefore, this force is zero when the charged particle moves along the direction of $\vec{\boldsymbol{B}}$ and the force is maximum when the particle moves in a direction perpendicular to $\vec{\boldsymbol{B}}$. When the sign of the charge changes, the force reverses direction. And, even though the force magnitude is the same for the electron and proton, the effect of the force (the acceleration) for the electron would be much greater, because of its smaller mass.

***20.13. Set Up:** Eq. (20.4) says $R = \dfrac{mv}{|q|B}$. A proton has mass $m = 1.67 \times 10^{-27}$ kg and charge $q = +e = 1.60 \times 10^{-19}$ C.

Solve: $v = \dfrac{R|q|B}{m} = \dfrac{(0.0613\text{ m})(1.60 \times 10^{-19}\text{ C})(0.250\text{ T})}{1.67 \times 10^{-27}\text{ kg}} = 1.47 \times 10^{6}\text{ m/s}.$

***20.53. Set Up:** $F = \frac{\mu_0 lII'}{2\pi r}$. $\mu_0 = 4\pi \times 10^{-7}\ \text{N/A}^2$. Parallel conductors carrying currents in opposite directions repel each other. Parallel conductors carrying currents in the same direction attract each other.

Solve: $F = \frac{(4\pi \times 10^{-7}\ \text{N/A}^2)(15\ \text{m})(25\ \text{A})(75\ \text{A})}{2\pi(0.35\ \text{m})} = 0.0161\ \text{N}$. Since the currents are in the same direction the force is attractive.

Reflect: The currents are large but the force per meter on each wire is very small.

20.54. Set Up: Label wires 1 and 2. Find the direction of the magnetic field of one wire at the location of the other. Then use the right-hand rule to find the direction of the force on the second wire due to this magnetic field.

Solve: Figure (a) below shows the magnetic fields at the wires for the case where the currents are both to the left. The directions of the forces on the wires exerted by these fields are also shown. The wires attract.

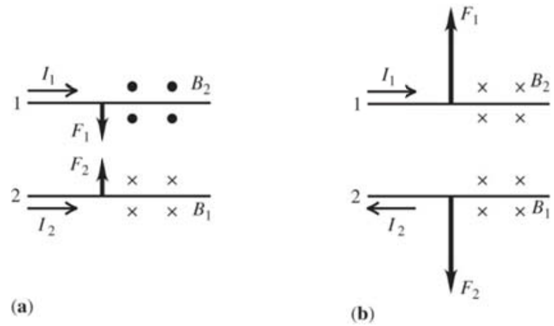


Figure (b) above shows the magnetic fields at the wires for the case where one current is to the left and the other is to the right. The directions of the forces on the wires exerted by these fields are also shown. The wires repel.

20.73. Set Up: Assume that the tightly bound wires have negligible diameters. By symmetry the field lines are circles centered on the wires and the magnitude of the field depends only on the distance from the wires. Ampere's law says $\sum B_{\parallel} \Delta s = \mu_0 I_{\text{encl}}$. Apply this law to a circular path with radius $r = 10$ m and with the wires at its center.

Solve: As we move along the chosen circular path $\vec{\boldsymbol{B}}$ has a constant magnitude and is tangent to the path. If we face southward as we look at the circular path, the net current points toward us and (according to the right-hand rule) the magnetic field circulates in a counterclockwise direction around the circular path. Thus, if we traverse the circular path in the counterclockwise direction we have $\sum B_{\parallel} \Delta s = B \sum \Delta s = B(2\pi r)$, with $I_{\text{encl}} = 17.5\text{ A} + 11.3\text{ A} - 23.0\text{ A} = 5.8\text{ A}$. Ampere's law therefore gives $B(2\pi r) = \mu_0 I_{\text{encl}}$ and $B = \frac{\mu_0 I_{\text{encl}}}{2\pi r} = \frac{(4\pi \times 10^{-7}\text{ T}\cdot\text{m/A})(5.8\text{ A})}{2\pi(10.0\text{ m})} = \underline{1.1}6 \times 10^{-7} = 0.17\ \mu\text{T}$.

Reflect: We could also obtain this result by using the superposition principle since each current I produces a known magnetic field equal to $B = \frac{\mu_0 I}{2\pi r}$. As we face southward, northbound currents create counterclockwise magnetic field and southbound currents create clockwise fields. Thus, the net magnetic field has a magnitude equal to $B = \frac{\mu_0 | I_{\text{north}} - I_{\text{south}} |}{2\pi r}$, with the direction of circulation determined by the larger current.