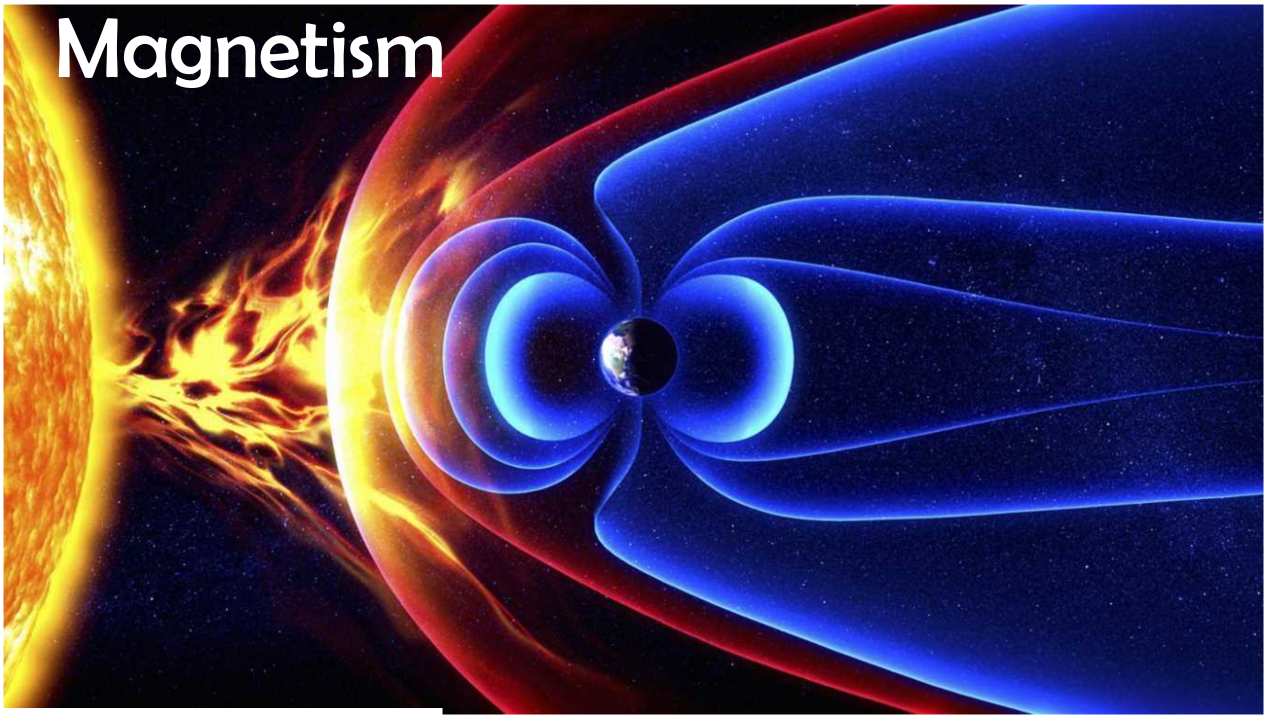
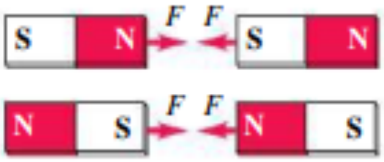
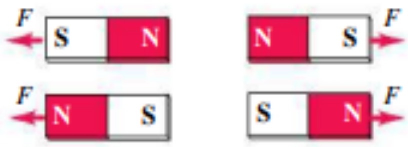
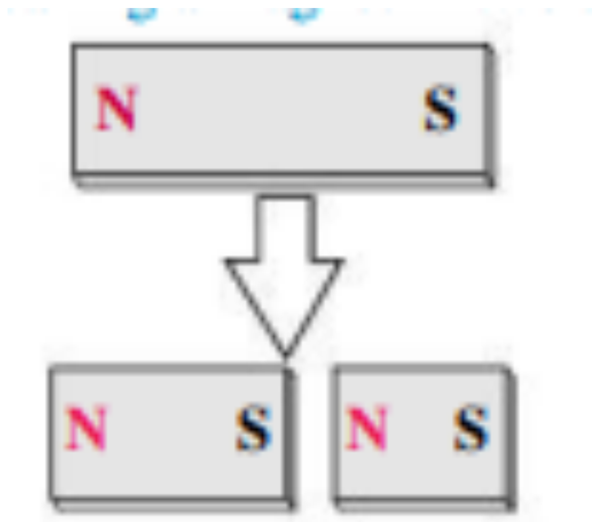
7/21 will be on test 3



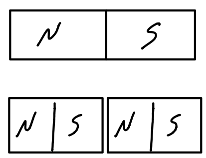




Unlike electrical charges
magnetic charges always have a N/S end




Cutting a magnetic make two new magnets

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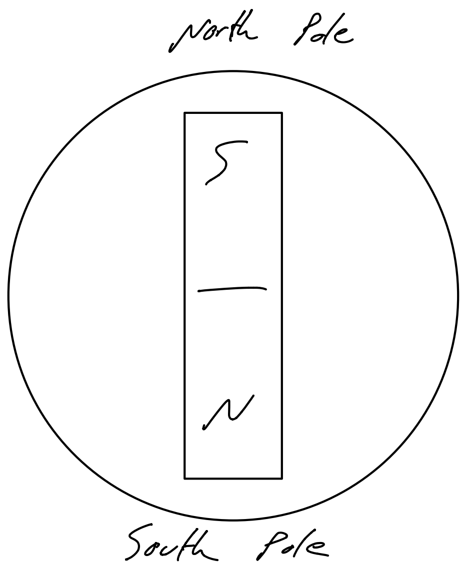
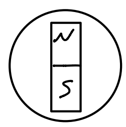
Earth




Compass

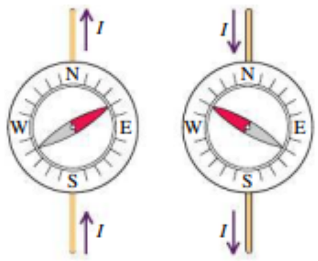



North ends of compasses attracted to the south end of Earth's magnetic field (in geographical north)

Earths magnetism can shift (from iron core) + can flip

Hans Christian Oersted

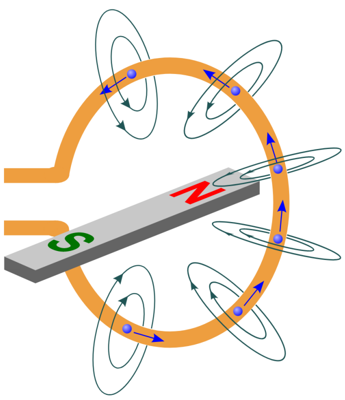
electrical current generates a magnetic field & ∴ effects a compass

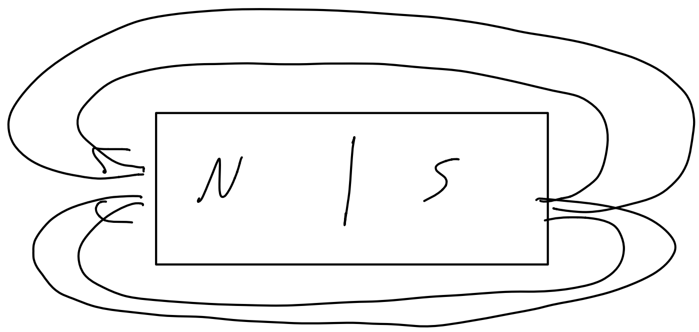


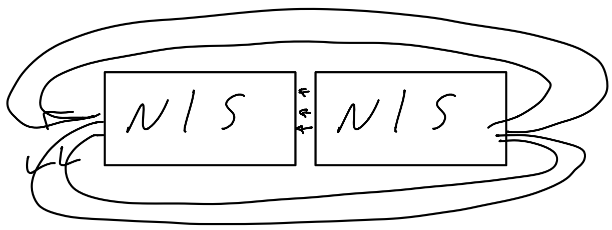

← Direction of current changes orientation of the field

Michael Faraday and Joseph Henry

Moving a magnet creates an electrical current (electrical generator)



Magnetic force on a moving charged particle

$$\vec{F} = q\vec{v} \times \vec{B}$$

Particle's charge ($q$)

Particle's velocity ($\vec{v}$)

Magnetic field ($\vec{B}$)

$$F = |q|v_{\perp}B = |q|vB\sin\phi$$

angle off of the magnetic field

is perpendicular

$\therefore \sin\phi = 1$

$\sin(90°) = 1$

$$1 \text{ tesla} = 1\text{ T} = 1\text{ N/A}\cdot\text{m}$$

$\text{Amp} = \frac{\text{Coulomb}}{\text{Second}}$

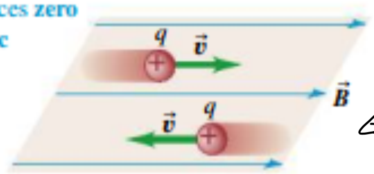
$A = C/s$

$$\text{gauss } (1\text{ G} = 10^{-4}\text{ T})$$

$0.0001\ T$

$T = N/A\cdot m$

A charge moving **parallel** to a magnetic field experiences **zero magnetic force.**



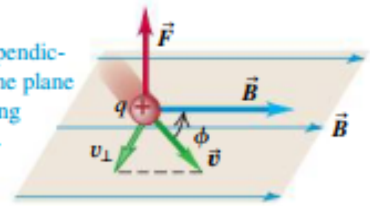

← No resistance on either

$\sin\phi = \sin(0°) = 0$

A charge moving at an angle $\phi$ to a magnetic field experiences a magnetic force with magnitude $F = |q|v_\perp B = |q|vB\sin\phi$.

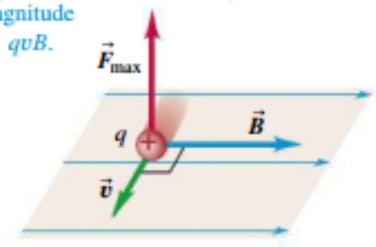
$V_\perp = v\sin\phi$

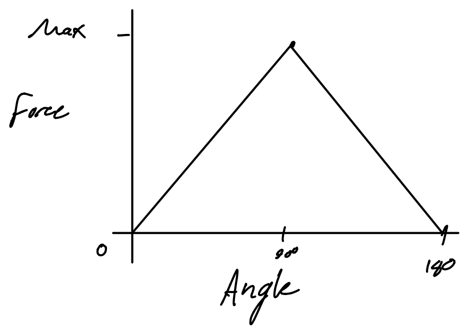
$\vec{F}$ is perpendicular to the plane containing $\vec{v}$ and $\vec{B}$.




$\vec{F}$, $\vec{B}$, & $\vec{V}$ are all perp ∴ 3D

A charge moving **perpendicular** to a magnetic field experiences a maximal magnetic force with magnitude $F_{max} = qvB$.



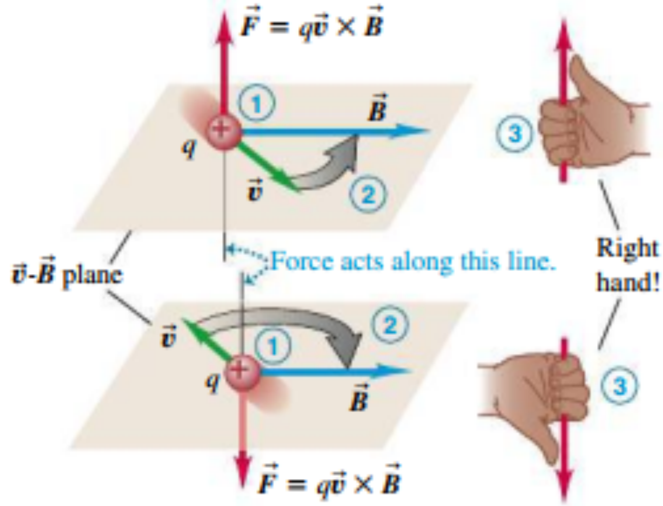



**Right-hand rule** for the direction of magnetic force on a **positive** charge moving in a magnetic field:

1. Place the $\vec{v}$ and $\vec{B}$ vectors tail to tail.

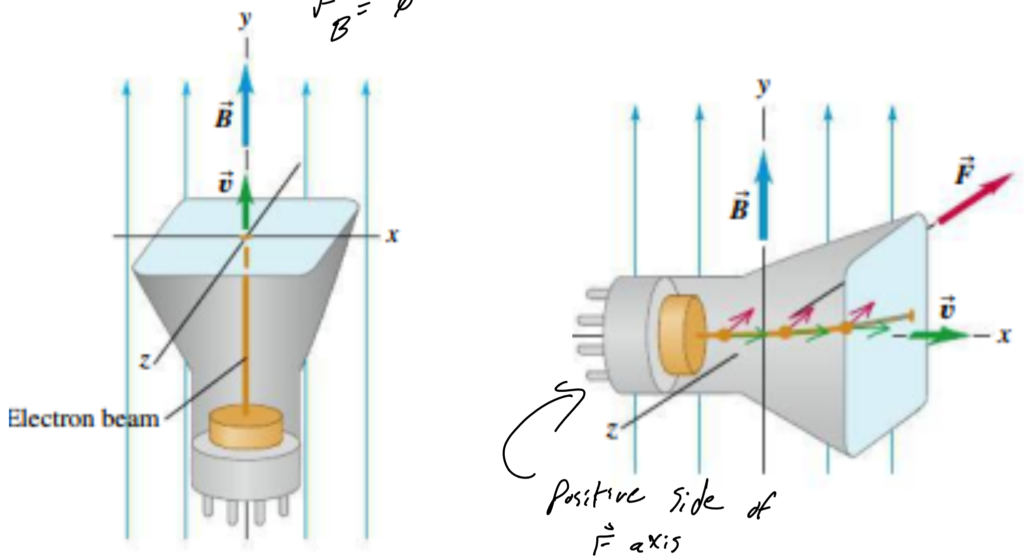
2. Imagine turning $\vec{v}$ toward $\vec{B}$ in the $\vec{v}$-$\vec{B}$ plane (through the smaller angle).

3. The force acts along a line perpendicular to the $\vec{v}$-$\vec{B}$ plane. Curl the fingers of your *right hand* around this line in the same direction you rotated $\vec{v}$. Your thumb now points in the direction the force acts.



**27.9** Determining the direction of a magnetic field by using a cathode-ray tube. Because electrons have a negative charge, the magnetic force $\vec{F} = q\vec{v} \times \vec{B}$ in part (b) points opposite to the direction given by the right-hand rule (see Fig. 27.7b).

$\vec{F}_B = \emptyset$




$\vec{F} = -N$

Positive side of $\vec{F}$ axis

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

force from electric field: $\vec{F}_E = q\vec{E}$

force from magnetic field: $\vec{F}_B = q(\vec{v} \times \vec{B})$

force from both: $\vec{F}_{total} = (q\vec{E}) + (q(\vec{v} \times \vec{B}))$

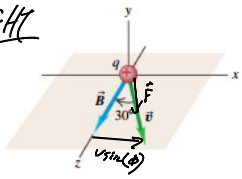
$$= q(\vec{E} + (\vec{v} \times \vec{B}))$$

A beam of protons ($q = 1.6 \times 10^{-19}$ C) moves at $3.0 \times 10^{5}$ m/s through a uniform 2.0-T magnetic field directed along the positive $z$-axis (Fig. 27.10). The velocity of each proton lies in the $xz$-plane and is directed at 30° to the $+z$-axis. Find the force on a proton.

RIGHT Hand

B: Palm
v: Fingers

Thumb down
$\therefore \vec{F}$ in negative direction




$F = |q|\, v B \sin(\phi)$

$\vec{F} = (1.6 \times 10^{-27})(3 \times 10^{5})(2) \sin(30°)$

$\vec{F} = 4.8 \times 10^{-14}$ N

$\vec{F} = -4.8 \times 10^{-14}$ N

**SOLUTION**

**IDENTIFY and SET UP:** This problem uses the expression $\vec{F} = q\vec{v} \times \vec{B}$ for the magnetic force $\vec{F}$ on a moving charged particle. The target variable is $\vec{F}$.

**EXECUTE:** The charge is positive, so the force is in the same direction as the vector product $\vec{v} \times \vec{B}$. From the right-hand rule, this direction is along the negative $y$-axis. The magnitude of the force, from Eq. (27.1), is

$$
\begin{aligned}
F &= qvB\sin\phi \\
&= (1.6 \times 10^{-19}\ \text{C})(3.0 \times 10^{5}\ \text{m/s})(2.0\ \text{T})(\sin 30°) \\
&= 4.8 \times 10^{-14}\ \text{N}
\end{aligned}
$$

**EVALUATE:** To check our result, we evaluate the force by using vector language and Eq. (27.2). We have

$$
\vec{v} = (3.0 \times 10^{5}\ \text{m/s})(\sin 30°)\hat{\imath} + (3.0 \times 10^{5}\ \text{m/s})(\cos 30°)\hat{k}
$$

$$
\vec{B} = (2.0\ \text{T})\hat{k}
$$

$$
\begin{aligned}
\vec{F} &= q\vec{v} \times \vec{B} \\
&= (1.6 \times 10^{-19}\ \text{C})(3.0 \times 10^{5}\ \text{m/s})(2.0\ \text{T}) \\
&\quad \times (\sin 30°\hat{\imath} + \cos 30°\hat{k}) \times \hat{k} \\
&= (-4.8 \times 10^{-14}\ \text{N})\hat{\jmath}
\end{aligned}
$$

(Recall that $\hat{\imath} \times \hat{k} = -\hat{\jmath}$ and $\hat{k} \times \hat{k} = \mathbf{0}$.) We again find that the force is in the negative $y$-direction with magnitude $4.8 \times 10^{-14}$ N.

If the beam consists of *electrons* rather than protons, the charge is negative ($q = -1.6 \times 10^{-19}$ C) and the direction of the force is reversed. The force is now directed along the ***positive*** $y$-axis, but the magnitude is the same as before, $F = 4.8 \times 10^{-14}$ N.

**27.1** • A particle with a charge of $-1.24 \times 10^{-8}$ C is moving with instantaneous velocity $\vec{v} = (4.19 \times 10^4 \text{ m/s})\hat{\imath} + (-3.85 \times 10^4 \text{ m/s})\hat{\jmath}$. What is the force exerted on this particle by a magnetic field (a) $\vec{B} = (1.40 \text{ T})\hat{\imath}$ and (b) $\vec{B} = (1.40 \text{ T})\hat{k}$?

a) $q = -1.24 \times 10^{-8} C$

$V_\perp = -3.85 \times 10^4 \text{ m/s } \hat{j}$

$\vec{B} = 1.40 T \hat{\imath}$

$$\vec{V} \times \vec{B} \quad \begin{vmatrix} \hat{\imath} & \hat{j} & \hat{k} \\ 4.19\times10^{-9} & -3.85\times10^{4} & \phi \\ 1.40 & \phi & \phi \end{vmatrix} \begin{matrix} \hat{\imath} & \hat{j} \\ 4.16\times10^{4} & -3.85\times10^{4} \\ \phi & \phi \end{matrix}$$

$\vec{F} = q \vec{v} \times \vec{B}$

$\vec{F} = (-1.24\times10^{-8} c)(-53{,}900 \hat{k})$

$[(\phi\hat{\imath} + \phi\hat{j} + 0\hat{k}) + (0\hat{\imath} + 0\hat{j} - 53{,}900 \hat{k})]$

$\vec{F} = -668 \mu N \hat{k}$

$= -6.68\times10^{-9} N \hat{k}$

b)

$\vec{F} = q(\vec{v} \times \vec{B})$

$$\vec{V} \times \vec{B} \quad \begin{vmatrix} \hat{\imath} & \hat{j} & \hat{k} \\ 4.19\times10^{-9} & -3.85\times10^{4} & \phi \\ \phi & \phi & 1.40 \end{vmatrix} \begin{matrix} \hat{\imath} & \hat{j} \\ 4.16\times10^{4} & -3.85\times10^{4} \\ \phi & \phi \end{matrix}$$

$= (-1.24\times10^{-8} c) \left[ \left( ((1.40)(-3.85\times10^4)\hat{\imath}) + \phi\hat{j} + \phi\hat{k} \right) + \left( \phi\hat{\imath} + ((1.40)(4.16\times10^4)\hat{j}) + \phi\hat{k} \right) \right]$

$= (-1.24\times10^{-8} c)[-53{,}900\hat{\imath} + 58{,}240\hat{j}]$

$= 668\times10^{-6} \hat{\imath} - 722\times10^{-6} \hat{j}$

$\vec{F} = 668 \mu N \hat{\imath} + 722 \mu N \hat{j}$

Check

$Accel = Force / mass$

**27.4** • A particle with mass $1.81 \times 10^{-3}$ kg and a charge of $1.22 \times 10^{-8}$ C has, at a given instant, a velocity $\vec{v} = (3.00 \times 10^4 \text{ m/s})\hat{j}$. What are the magnitude and direction of the particle's acceleration produced by a uniform magnetic field $\vec{B} = (1.63 \text{ T})\hat{\imath} + (0.980 \text{ T})\hat{j}$?

$\vec{F} = q(\vec{v} \times \vec{B})$

| | $\hat{i}$ | $\hat{j}$ | $\hat{k}$ | $\hat{i}$ | $\hat{j}$ |
|---|---|---|---|---|---|
| $\vec{v}$ | $\emptyset$ | $3\times10^4$ | $\emptyset$ | $\emptyset$ | $3\times10^4$ |
| $\vec{B}$ | 1.63 | 0.98 | $\emptyset$ | 1.63 | 0.98 |

$\hat{j}$ $\vec{v}$ $\vec{F}$ $\vec{B}$ $\hat{i}$

$\vec{F} = (1.22\times10^{-8} C)(4.89\times10^4 \ N/C)$

$\vec{F} = 5.97\times10^{-4} N \ \hat{k}$

right hand rule ⊗

$\therefore$ $\vec{F}$ negative

$\boxed{\vec{F} = -5.97\times10^{-4} N \ \hat{k}}$

$4.89\times10^4 \ \hat{k} \ \frac{Tm}{s}$

$\left(\frac{N}{A \cdot \cancel{m}}\right)\left(\frac{\cancel{m}}{s}\right)$

$\left(\frac{N}{C/\cancel{s}}\right)\left(\frac{1}{\cancel{s}}\right)$

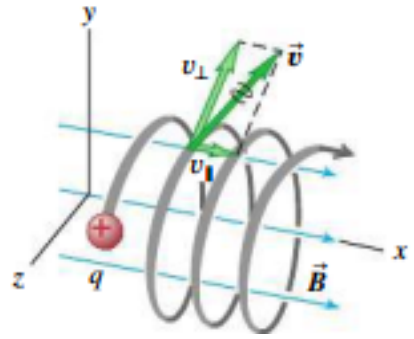
$N/C$

$Accell = m/F$

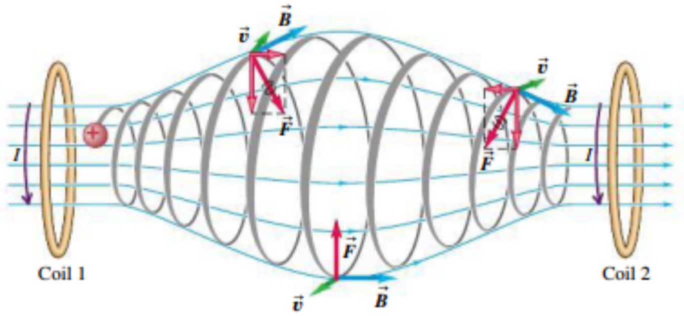
$= \frac{(1.81\times10^{-3} kg)}{(-5.97\times10^{-4} N \ \hat{k})}$

$A = 3.034 \ m/s \ \hat{k}$

This particle's motion has components both parallel ($v_\parallel$) and perpendicular ($v_\perp$) to the magnetic field, so it moves in a helical path.




27.19 A magnetic bottle. Particles near either end of the region experience a magnetic force toward the center of the region. This is one way of containing an ionized gas that has a temperature of the order of $10^6$ K, which would vaporize any material container.



$$F = |q|v_{\perp}B = m\frac{v_{\perp}^2}{R}$$

$$a_c = \frac{v^2}{r}$$

$\omega$ = angular frequency (velocity) rad/s

$\omega = v/r$

$$\omega = \frac{2\pi}{T} = 2\pi f$$

period

f = frequency (1/s = Hertz)

T = period (s)

## EXAMPLE 27.3 ELECTRON MOTION IN A MAGNETRON

A magnetron in a microwave oven emits electromagnetic waves with frequency $f = 2450$ MHz. What magnetic field strength is required for electrons to move in circular paths with this frequency?

$$\vec{F}_B = ma$$

$$|q|vB = m\frac{v^2}{r}$$

$$v/r = w = 2\pi f$$

$$|q|B = \frac{mv}{r}$$

$$|q|B = m\,2\pi f$$

$$B = 2\pi f \frac{m}{|q|}$$

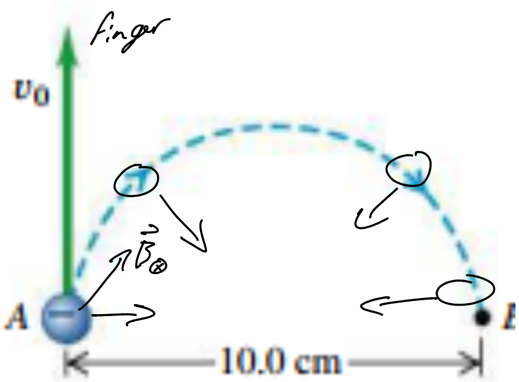
mass/charge of $e^-$

$$B = 2\pi(2450\times10^6)\left(\frac{9.11\times10^{-31}}{1.609\times10^{-19}}\right)$$

$$B = 0.0872\ T = 87.2\ mT$$

**27.15** •• An electron at point $A$ in Fig. E27.15 has a speed $v_0$ of $1.41 \times 10^6$ m/s. Find (a) the magnitude and direction of the magnetic field that will cause the electron to follow the semicircular path from $A$ to $B$, and (b) the time required for the electron to move from $A$ to $B$.

Figure E27.15




**27.16** •• Repeat Exercise 27.15 for the case in which the particle is a proton rather than an electron.

$$F_B = m a_c$$

a)

$$|q| v B = m \frac{v^2}{r}$$

$$B = \frac{m v}{|q| r}$$

$$B = \frac{(9.11 \times 10^{-31} \text{ kg})(1.41 \times 10^6 \text{ m/s})}{(-1.609 \times 10^{-19} \text{ C})(0.05 \text{ m})}$$

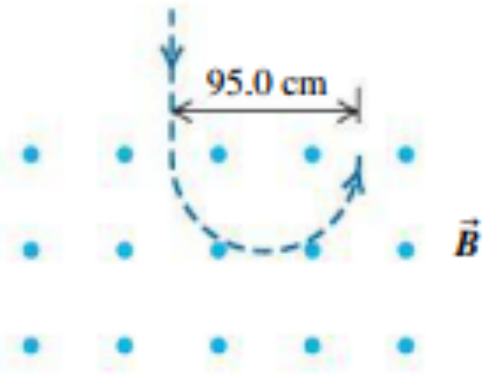
$$B = 0.00016 \text{ T}$$

$$\vec{B} = -160 \,\mu\text{T} \; \hat{k}$$

Hw

**27.19** • In an experiment with cosmic rays, a vertical beam of particles that have charge of magnitude $3e$ and mass 12 times the proton mass enters a uniform horizontal magnetic field of 0.250 T and is bent in a semicircle of diameter 95.0 cm, as shown in Fig. E27.19. (a) Find the speed of the particles and the sign of their charge. (b) Is it reasonable to ignore the gravity force on the particles? (c) How does the speed of the particles as they enter the field compare to their speed as they exit the field?

Figure E27.19



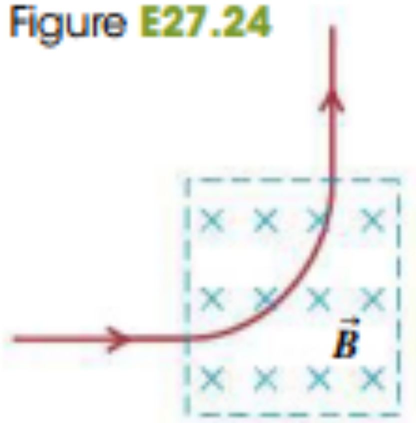
Hw

**27.23** • An electron in the beam of a cathode-ray tube is accelerated by a potential difference of 2.00 kV. Then it passes through a region of transverse magnetic field, where it moves in a circular arc with radius 0.180 m. What is the magnitude of the field?

Hw

**27.24** •• A beam of protons traveling at 1.20 km/s enters a uniform magnetic field, traveling perpendicular to the field. The beam exits the magnetic field, leaving the field in a direction perpendicular to its original direction (Fig. E27.24). The beam travels a distance of 1.18 cm *while in the field*. What is the magnitude of the magnetic field?

Figure E27.24



HW

**27.25** •• A proton ($q = 1.60 \times 10^{-19}$ C, $m = 1.67 \times 10^{-27}$ kg) moves in a uniform magnetic field $\vec{B} = (0.500\ \text{T})\hat{\imath}$. At $t = 0$ the proton has velocity components $v_x = 1.50 \times 10^5$ m/s, $v_y = 0$, and $v_z = 2.00 \times 10^5$ m/s (see Example 27.4). (a) What are the magnitude and direction of the magnetic force acting on the proton? In addition to the magnetic field there is a uniform electric field in the $+x$-direction, $\vec{E} = (+2.00 \times 10^4\ \text{V/m})\hat{\imath}$. (b) Will the proton have a component of acceleration in the direction of the electric field? (c) Describe the path of the proton. Does the electric field affect the radius of the helix? Explain. (d) At $t = T/2$, where $T$ is the period of the circular motion of the proton, what is the $x$-component of the displacement of the proton from its position at $t = 0$?

Hw

**27.26** • A singly charged ion of $^7Li$ (an isotope of lithium) has a mass of $1.16 \times 10^{-26}$ kg. It is accelerated through a potential difference of 220 V and then enters a magnetic field with magnitude 0.874 T perpendicular to the path of the ion. What is the radius of the ion's path in the magnetic field?

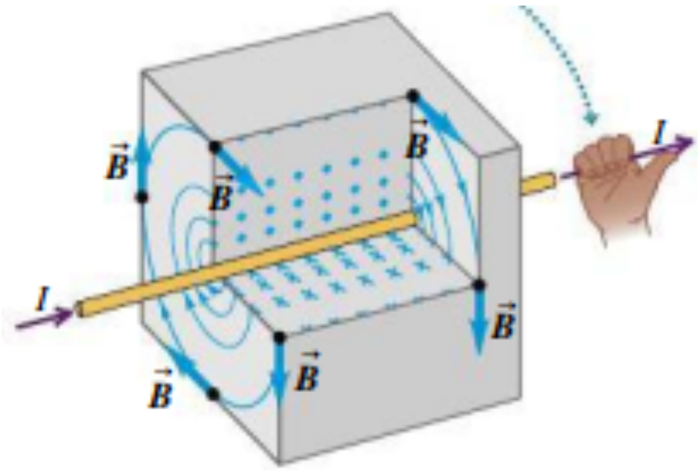
Magnetic constant

**Magnetic field near a long, straight, current-carrying conductor**

$$B = \frac{\mu_0 I}{2\pi r}$$

Current

Distance from conductor



## EXAMPLE 28.3 MAGNETIC FIELD OF A SINGLE WIRE

A long, straight conductor carries a 1.0-A current. At what distance from the axis of the conductor does the resulting magnetic field have magnitude $B = 0.5 \times 10^{-4}$ T (about that of the earth's magnetic field in Pittsburgh)?

$$B = \frac{\mu_0 I}{2\pi r}$$

$$r = \frac{\mu_0 I}{2\pi B}$$

$$r = \frac{\left(\cancel{4\pi}^{\,2} \times 10^{-7}\ \frac{T m}{\cancel{A}}\right)(1.0\ \cancel{A})}{\cancel{2\pi}\,(0.5 \times 10^{-4}\ \cancel{T})}$$

$$= \frac{2 \times 10^{-7}}{0.5 \times 10^{-4}}\ m$$

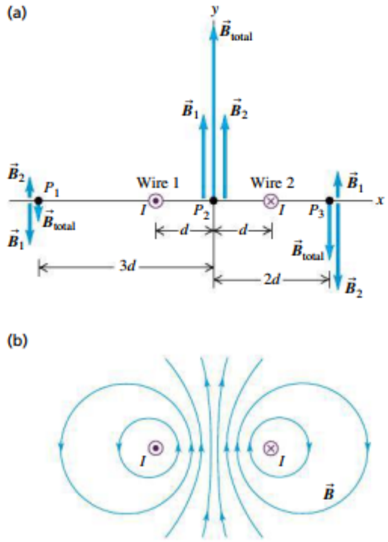
$$r = 0.004\ m$$

$$r = 4\ mm$$

## EXAMPLE 28.4 MAGNETIC FIELD OF TWO WIRES

**Figure 28.7a** is an end-on view of two long, straight, parallel wires perpendicular to the $xy$-plane, each carrying a current $I$ but in opposite directions. (a) Find $\vec{B}$ at points $P_1$, $P_2$, and $P_3$. (b) Find an expression for $\vec{B}$ at any point on the $x$-axis to the right of wire 2.

**28.7** (a) Two long, straight conductors carrying equal currents in opposite directions. The conductors are seen end-on. (b) Map of the magnetic field produced by the two conductors. The field lines are closest together between the conductors, where the field is strongest.




$\otimes$ : In to page

$\odot$ : Out of page

a)

$$B_{P_1} = -\frac{\mu_0 I}{2\pi(2d)} + \frac{\mu_0 I}{2\pi(4d)}$$

$$\boxed{B_{P_1} = \frac{-\mu_0 I}{8\pi d}\hat{j}}$$

$$B_{P_2} = \frac{\mu_0 I}{2\pi(d)} + \frac{\mu_0 I}{2\pi(d)}$$

$$\boxed{B_{P_2} = \frac{\mu_0 I}{\pi d}\hat{j}}$$

$$B_{P_3} = \frac{\mu_0 I}{2\pi(3d)} - \frac{\mu_0 I}{2\pi(d)}$$

$$\boxed{B_{P_3} = -\frac{\mu_0 I}{3\pi d}\hat{j}}$$

b)

$$\vec{B}_x = \frac{\mu_0 I}{2\pi(2d+R)} - \frac{\mu_0 I}{2\pi(R)}$$

$$\vec{B}_d = \left(\frac{1}{2d+R} - \frac{1}{R}\right)\left(\frac{\mu_0 I}{2\pi}\right)\hat{j}$$

Magnetic force per unit length between two long, parallel, current-carrying conductors

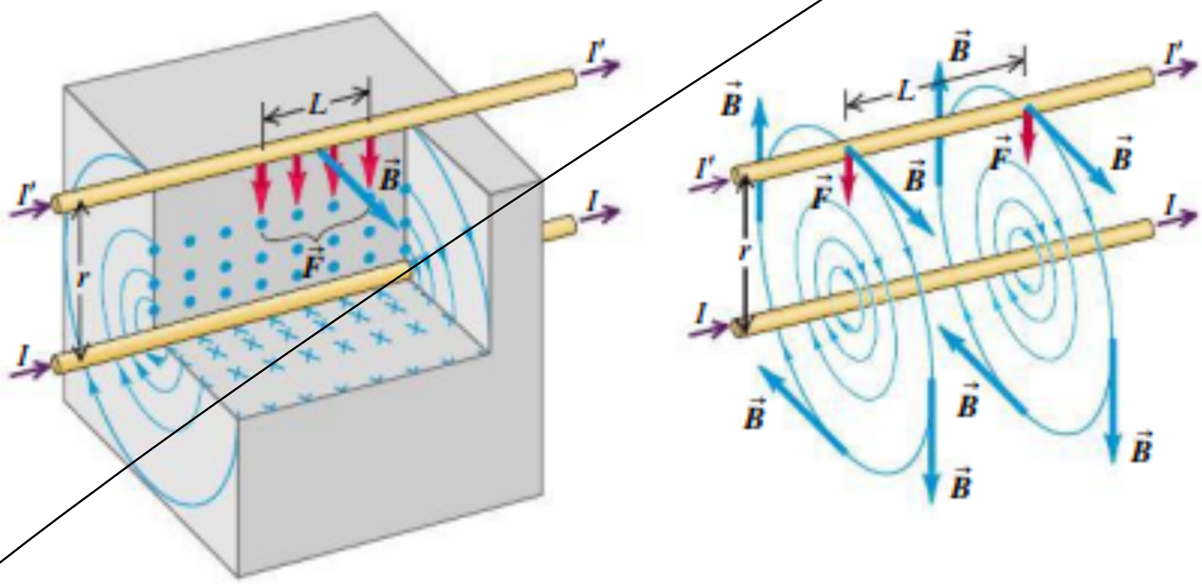
Magnetic constant

Current in first conductor

Current in second conductor

Distance between conductors

$$\frac{F}{L} = \frac{\mu_0 I I'}{2\pi r}$$

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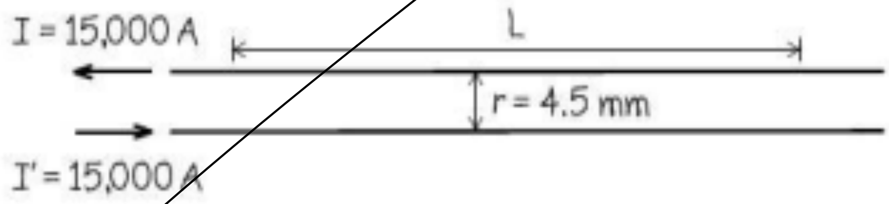
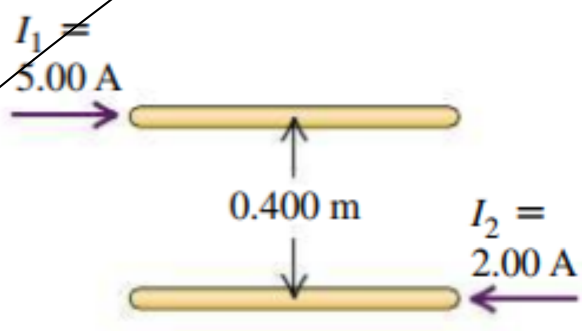
## EXAMPLE 28.5 FORCES BETWEEN PARALLEL WIRES

Two straight, parallel, superconducting wires 4.5 mm apart carry equal currents of 15,000 A in opposite directions. What force, per unit length, does each wire exert on the other?



**28.29** • Two long, parallel wires are separated by a distance of 0.400 m (**Fig. E28.29**). The currents $I_1$ and $I_2$ have the directions shown. (a) Calculate the magnitude of the force exerted by each wire on a 1.20-m length of the other. Is the force attractive or repulsive? (b) Each current is doubled, so that $I_1$ becomes 10.0 A and $I_2$ becomes 4.00 A. Now what is the magnitude of the force that each wire exerts on a 1.20-m length of the other?

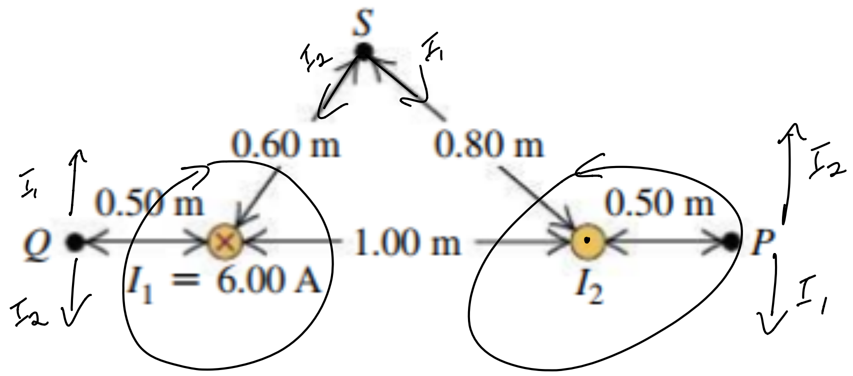
Figure E28.29



**28.30** • Two long, parallel wires are separated by a distance of 2.50 cm. The force per unit length that each wire exerts on the other is $4.00 \times 10^{-5}$ N/m, and the wires repel each other. The current in one wire is 0.600 A. (a) What is the current in the second wire? (b) Are the two currents in the same direction or in opposite directions?

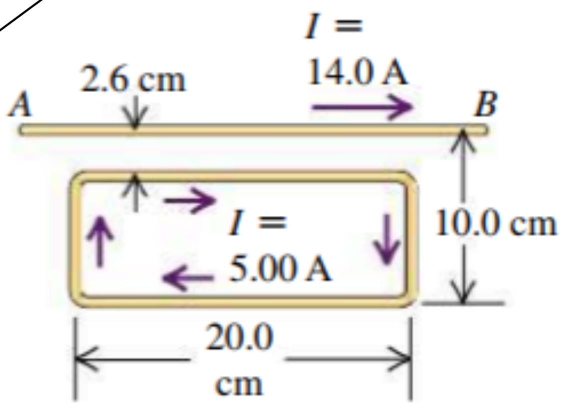
**28.63** • Two long, straight, parallel wires are 1.00 m apart (**Fig. P28.63**). The wire on the left carries a current $I_1$ of 6.00 A into the plane of the paper. (a) What must the magnitude and direction of the current $I_2$ be for the net field at point $P$ to be zero? (b) Then what are the magnitude and direction of the net field at $Q$? (c) Then what is the magnitude of the net field at $S$?

Figure **P28.63**



**28.64** • The long, straight wire *AB* shown in Fig. P28.64 carries a current of 14.0 A. The rectangular loop whose long edges are parallel to the wire carries a current of 5.00 A. Find the magnitude and direction of the net force exerted on the loop by the magnetic field of the wire.

Figure **P28.64**



**28.65** ••• CP Two long, parallel wires hang by 4.00-cm-long cords from a common axis (**Fig. P28.65**). The wires have a mass per unit length of 0.0125 kg/m and carry the same current in opposite directions. What is the current in each wire if the cords hang at an angle of 6.00° with the vertical?

Figure **P28.65**