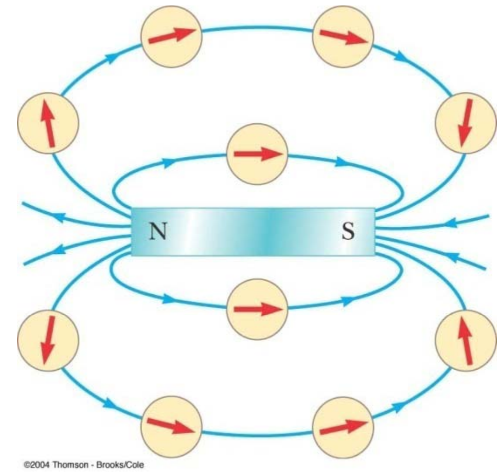
Magnetic Fields

Magnetic Poles

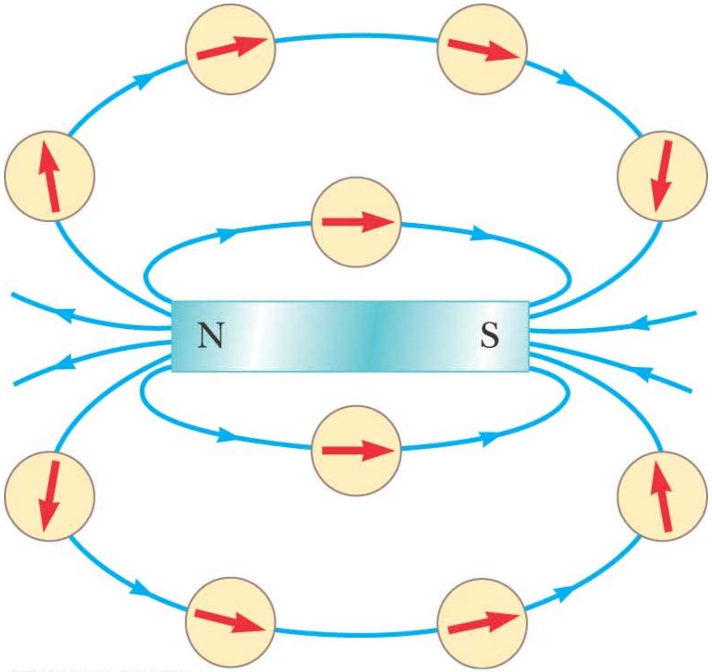
- Every magnet, regardless of its shape, has two poles
  - Called ***north*** and ***south*** poles
  - Poles exert forces on one another
    - **Similar to the way electric charges exert forces on each other**
    - ***Like poles repel each other***
      - N-N or S-S
    - ***Unlike poles attract each other***
      - N-S



- The force between two poles varies as the **inverse square** of the distance between them
- A single magnetic pole has never been isolated

Magnetic Fields

- Magnetic Field is Created by the Magnets
- A vector quantity, Symbolized by **B**
- Direction is given by the direction a *north pole* of a compass needle points in that location
- ***Magnetic field lines*** can be used to show how the field lines, as traced out by a compass, would look



©2004 Thomson - Brooks/Cole

Magnetic Field

- The SI unit of magnetic field is the **tesla** (T)

$$T = \frac{N}{C \cdot (m/s)} = \frac{N}{A \cdot m}$$

Table 29.1

Some Approximate Magnetic Field Magnitudes

Source of Field	Field Magnitude (T)
Strong superconducting laboratory magnet	30
Strong conventional laboratory magnet	2
Medical MRI unit	1.5
Bar magnet	10^{-2}
Surface of the Sun	10^{-2}
Surface of the Earth	0.5×10^{-4}
Inside human brain (due to nerve impulses)	10^{-13}

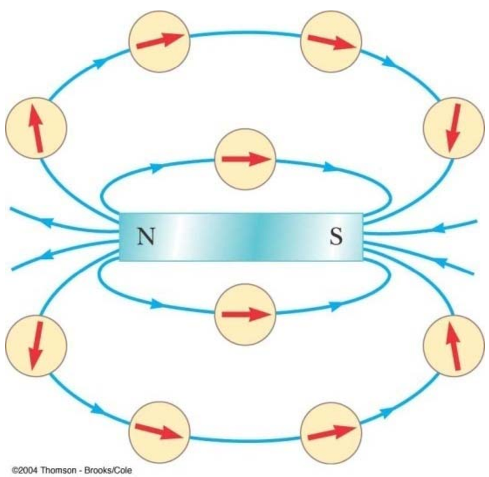
Chapter 24

Sources of the Magnetic Field

Sources of Magnetic Field

Real source of Magnetic Field –

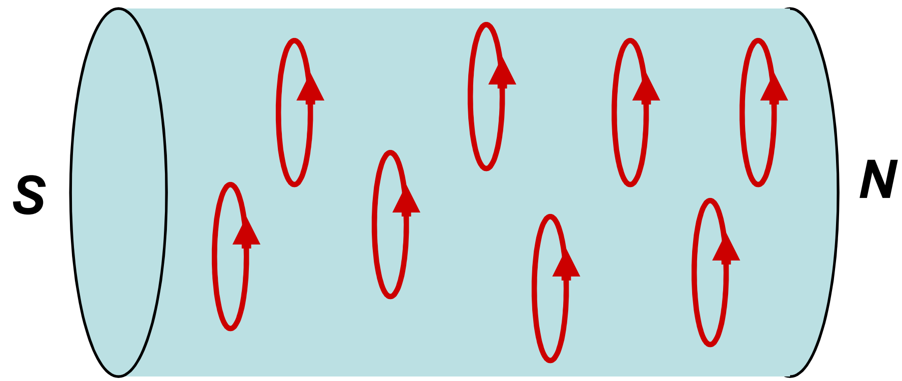
- moving electric charges or
- electric current

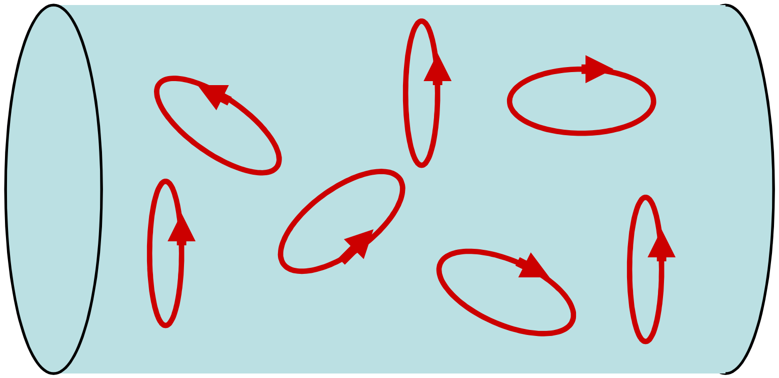


Inside every magnet – electric currents

Sources of Magnetic Field

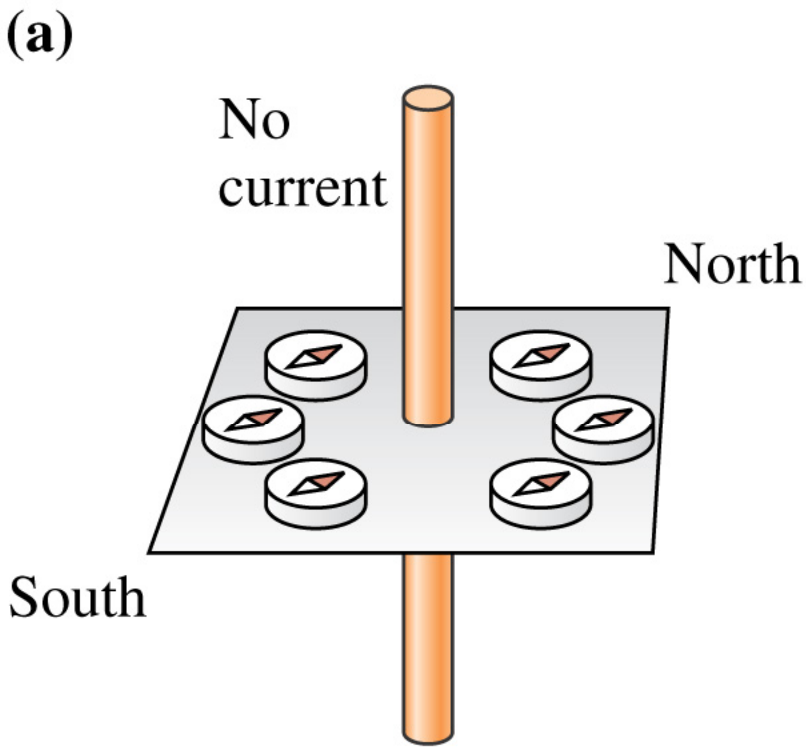
Inside every magnet – electric currents

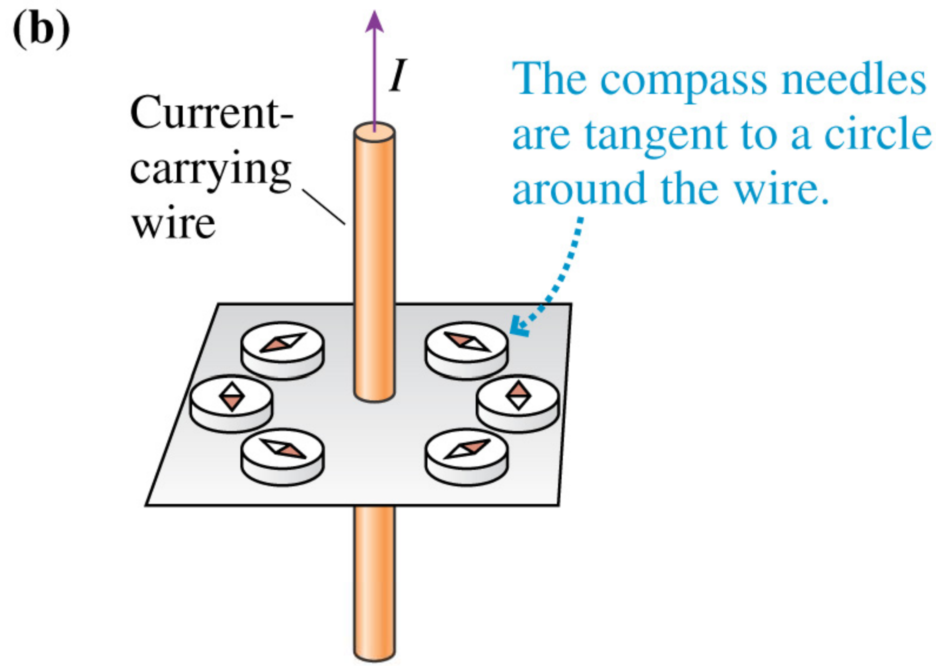




no magnetic field

Magnetic Field of a Long Straight Conductor

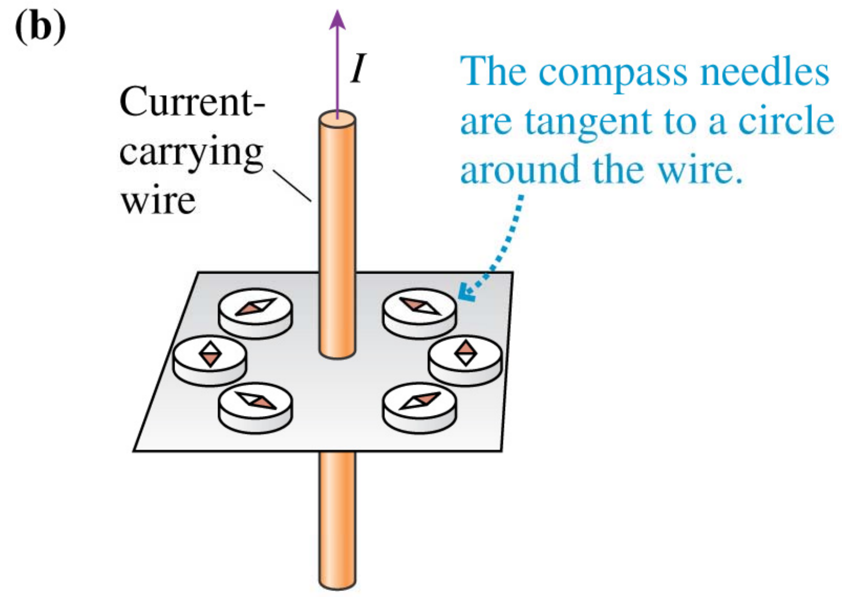




Magnetic Field of a Long Straight Conductor

- Magnetic field due to a long straight conductor, carrying current I:

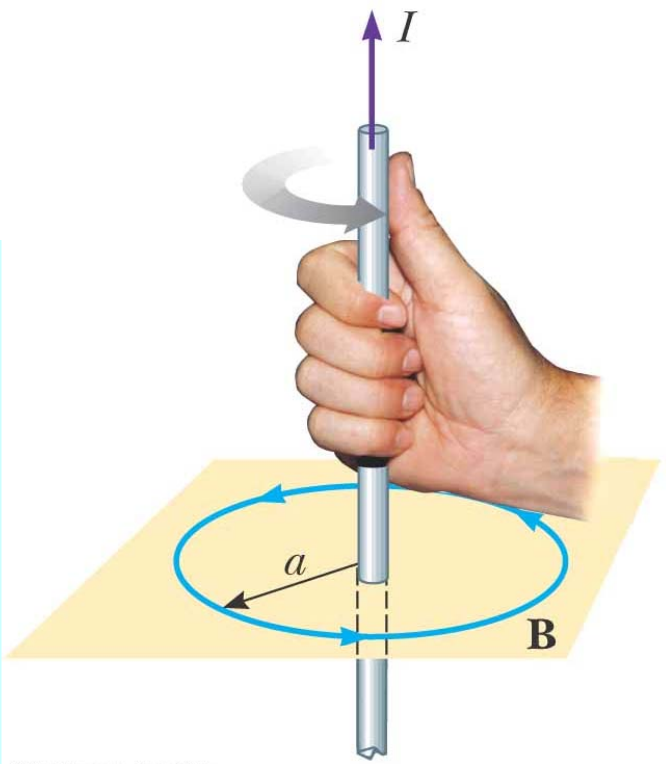
$$B = \frac{\mu_o I}{2\pi a}$$



Magnetic Field of a Long Straight Conductor

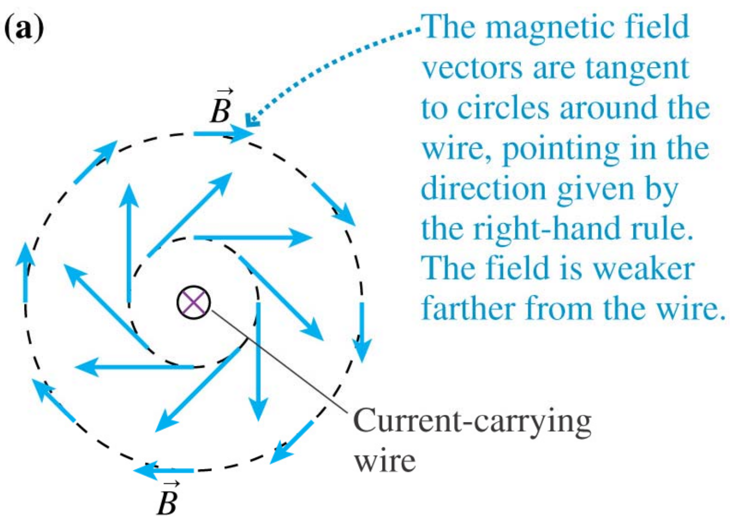
$$B = \frac{\mu_o I}{2\pi a}$$

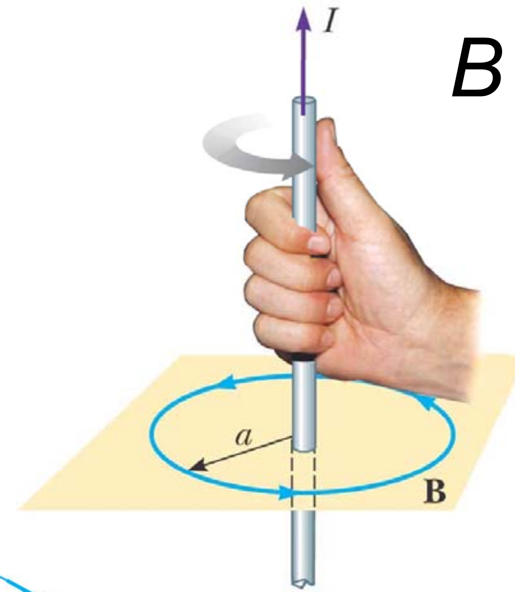
- The magnetic field lines are circles concentric with the wire
- The field lines lie in planes perpendicular to to wire
- The magnitude of **B** is constant on any circle of radius ***a***

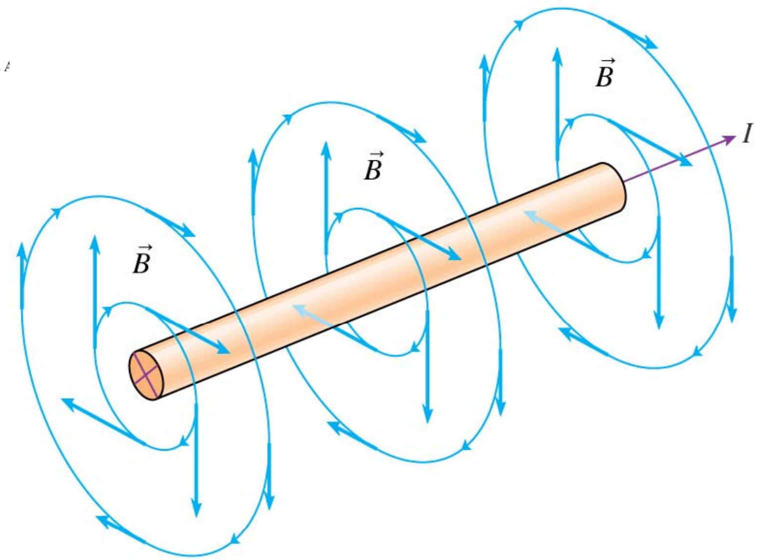


Magnetic Field of a Long Straight Conductor

$$B = \frac{\mu_o I}{2\pi a}$$



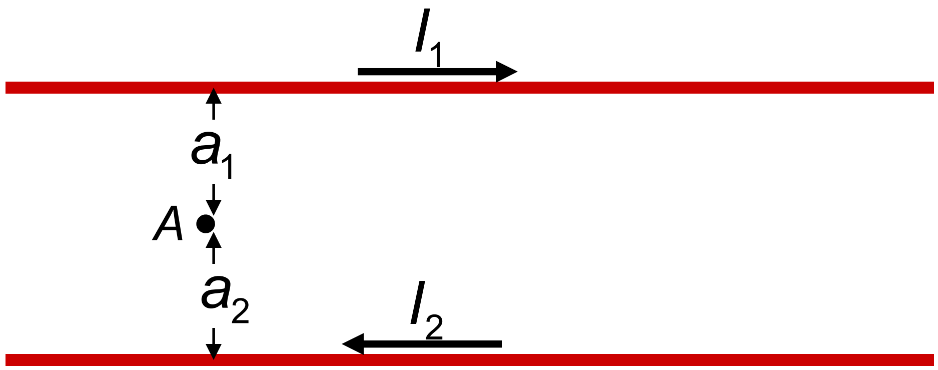




Example 1

Determine the magnetic field at point *A*.

$$B_1 = \frac{\mu_o I_1}{2\pi a_1}$$



$$B_2 = \frac{\mu_o I_2}{2\pi a_2}$$

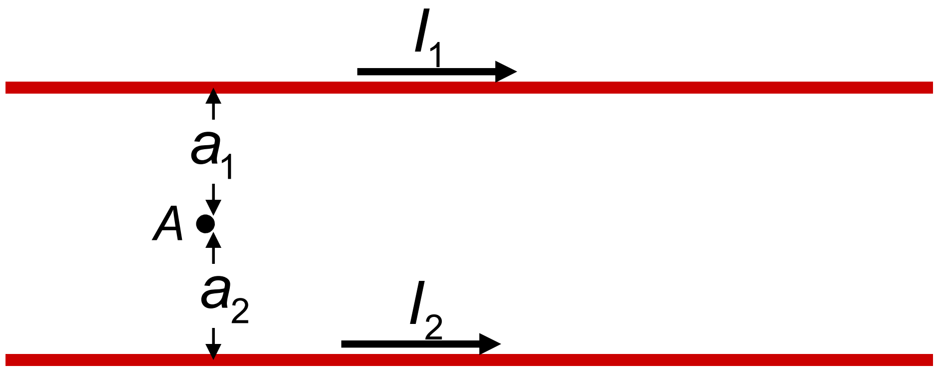
$$B = B_1 + B_2 = \frac{\mu_o I_1}{2\pi a_1} + \frac{\mu_o I_2}{2\pi a_2}$$

Example 2

Determine the magnetic field at point *A*.

$$B_1 = \frac{\mu_o I_1}{2\pi a_1}$$

$$B_2 = \frac{\mu_o I_2}{2\pi a_2}$$



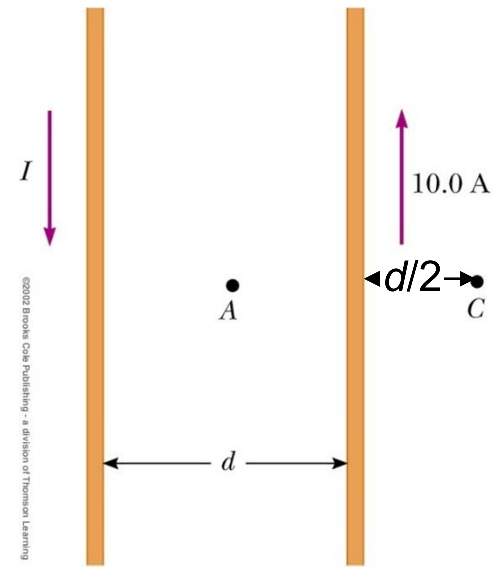
$$B = B_1 - B_2 = \frac{\mu_o I_1}{2\pi a_1} - \frac{\mu_o I_2}{2\pi a_2}$$

Example 3

Two parallel conductors carry current in opposite directions. One conductor carries a current of 10.0 A. Point *A* is at the midpoint between the wires, and point *C* is a distance *d*/2 to the right of the 10.0-A current. If *d* = 18.0 cm and *I* is adjusted so that the magnetic field at *C* is zero, find (a) the value of the current *I* and (b) the value of the magnetic field at *A*.

$$B_A = B_{1,A} + B_{2,A} = \frac{\mu_o I_1}{2\pi a_1} + \frac{\mu_o I_2}{2\pi a_2} = \frac{\mu_o I}{\pi d} + \frac{\mu_o I_0}{\pi d}$$

$$a_1 = d/2 \qquad a_2 = d/2$$



$$B_C = B_{1,C} - B_{2,C} = \frac{\mu_o I_1}{2\pi a_1} - \frac{\mu_o I_2}{2\pi a_2} = \frac{\mu_o I}{3\pi d} - \frac{\mu_o I_0}{\pi d}$$

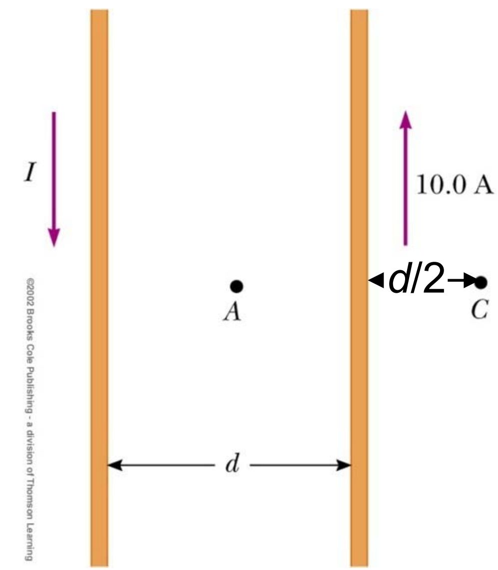
$$a_1 = 3d/2 \qquad a_2 = d/2$$

$$B_C = 0 \qquad \frac{\mu_o I}{3\pi d} = \frac{\mu_o I_0}{\pi d} \qquad I = 3I_0 = 30A$$

Example 3

Two parallel conductors carry current in opposite directions. One conductor carries a current of 10.0 A. Point *A* is at the midpoint between the wires, and point *C* is a distance *d*/2 to the right of the 10.0-A current. If *d* = 18.0 cm and *I* is adjusted so that the magnetic field at *C* is zero, find (a) the value of the current *I* and (b) the value of the magnetic field at *A*.

$$I = 3I_0 = 30A$$



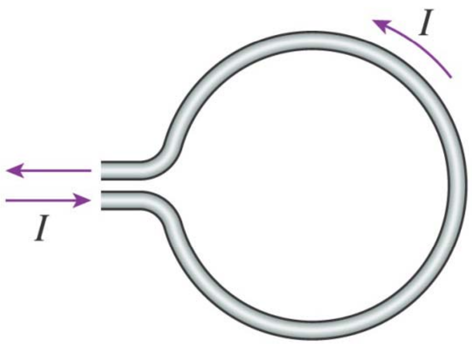
$$B_A = B_{1,A} + B_{2,A} = \frac{\mu_o I_1}{2\pi a_1} + \frac{\mu_o I_2}{2\pi a_2} = \frac{\mu_o I}{\pi d} + \frac{\mu_o I_0}{\pi d}$$

$$a_1 = d/2 \qquad a_2 = d/2$$

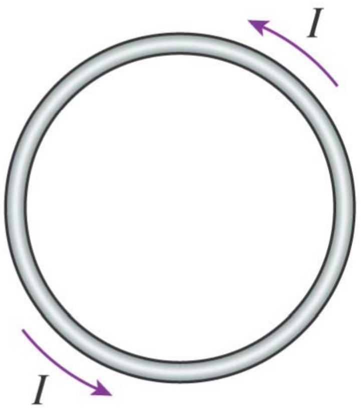
$$B_A = \frac{\mu_o 3I_0}{\pi d} + \frac{\mu_o I_0}{\pi d} = 4\frac{\mu_o I_0}{\pi d} = 88.9\,\mu T$$

Magnetic Field for a Current Loop

(a) A practical current loop

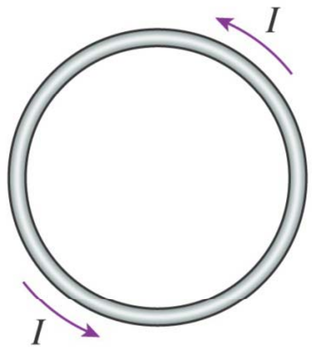


(b) An ideal current loop

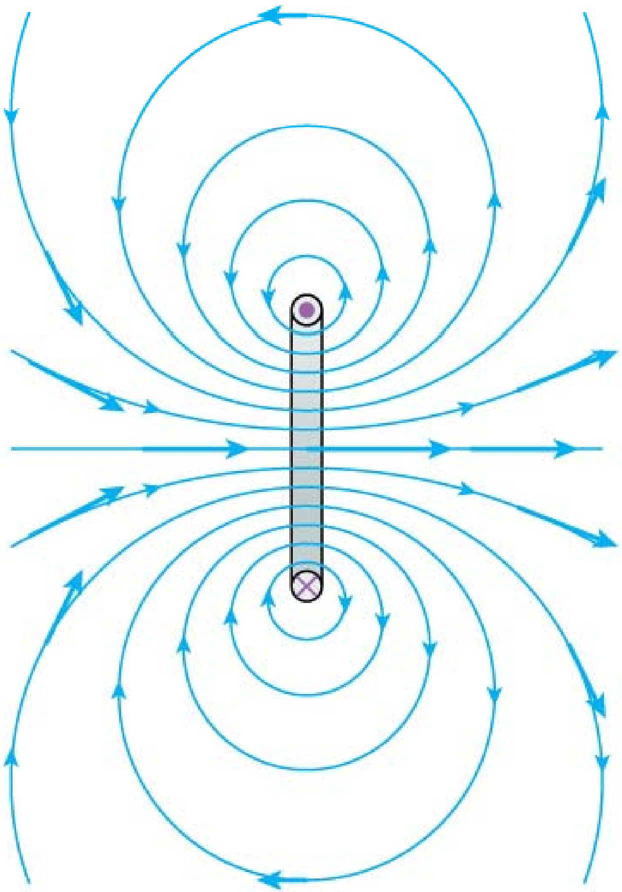


Magnetic Field for a Current Loop

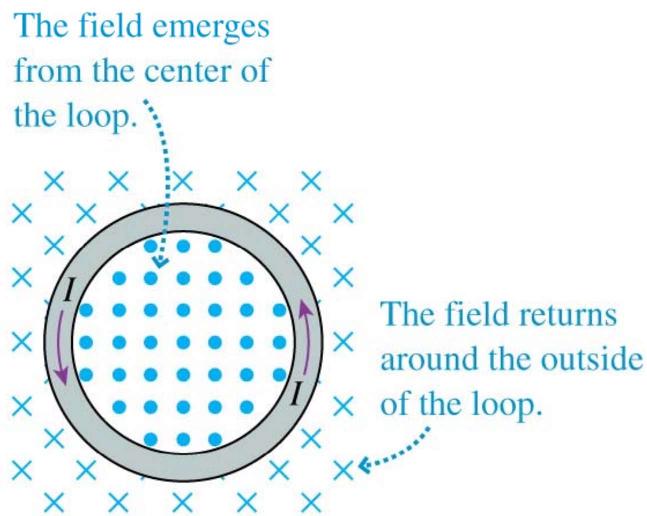
(b) An ideal current loop



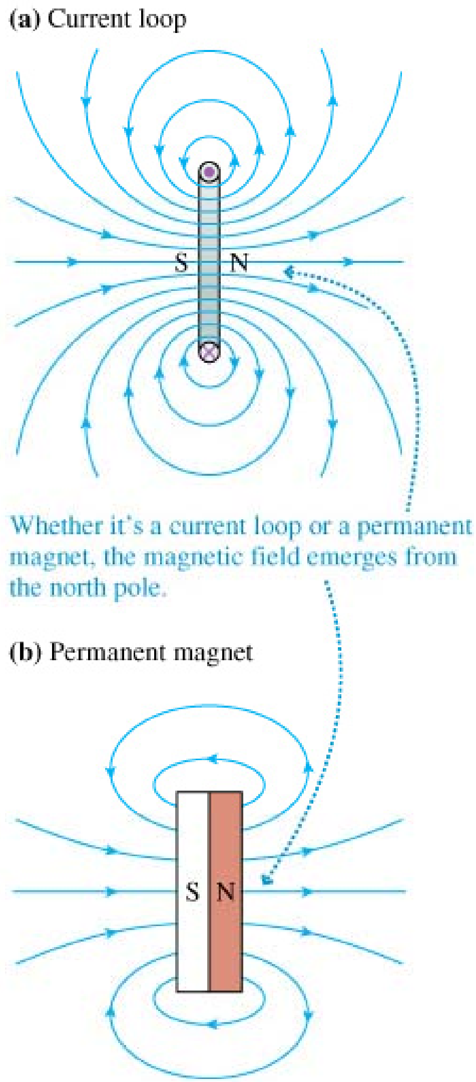
(a) Cross section through the current loop

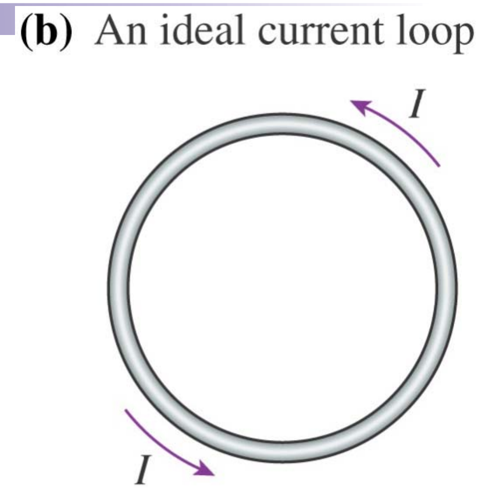


(b) The current loop seen from the right



Magnetic Field for a Current Loop

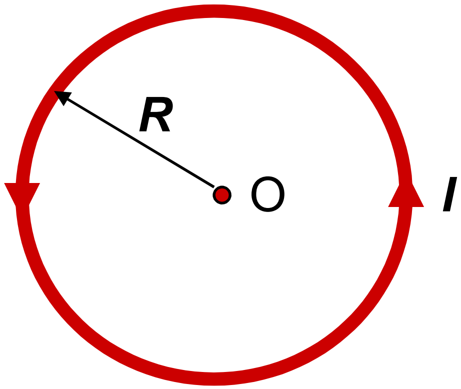




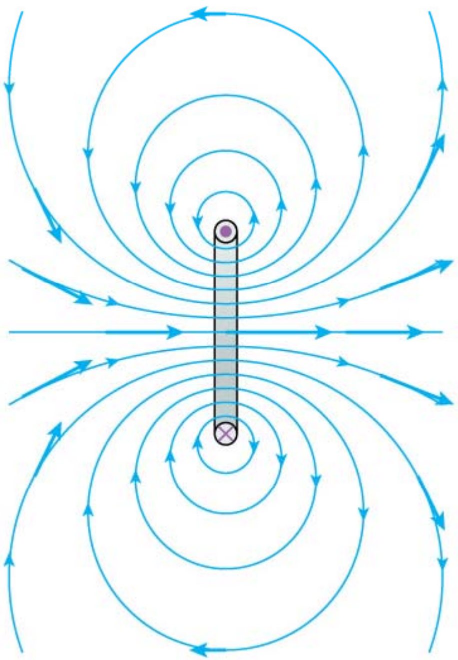
Magnetic Field for a Current Loop

- Magnetic field at the *center* of the loop

$$B = \frac{\mu_o I}{2R}$$

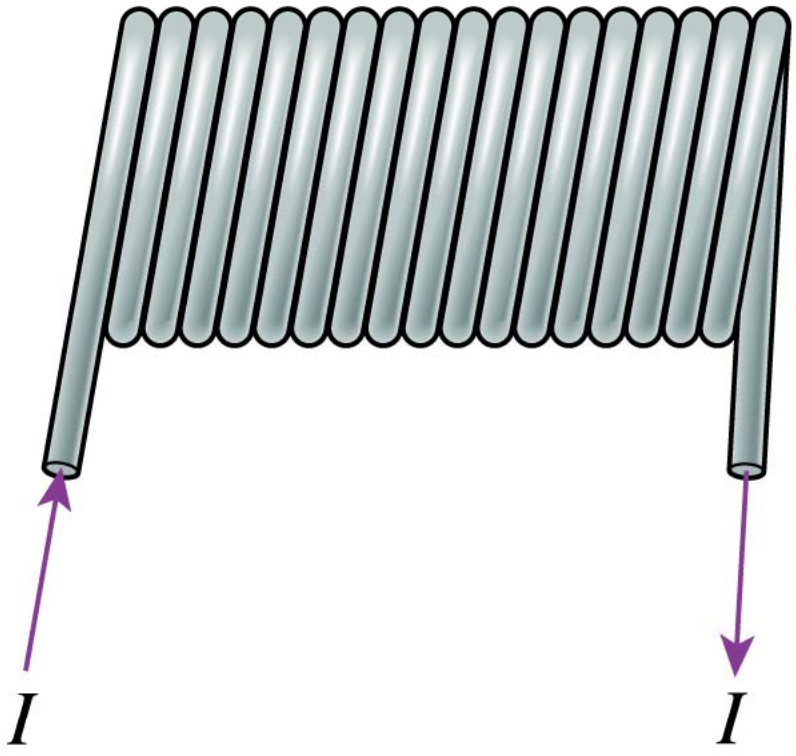


(a) Cross section through the current loop



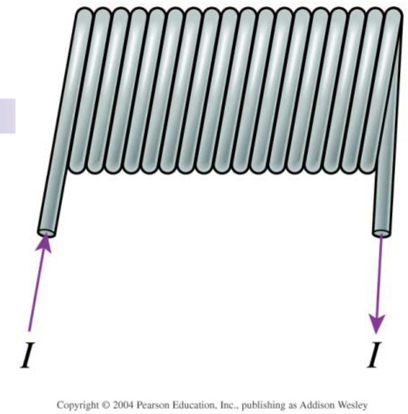
Magnetic Field of a Solenoid

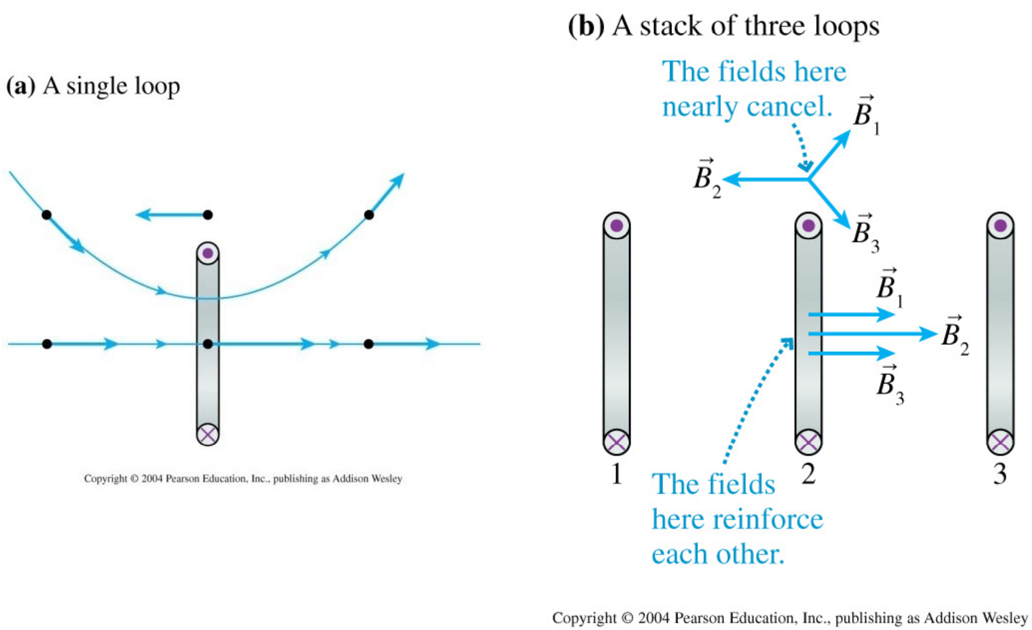
- A **solenoid** is a long wire wound in the form of a helix

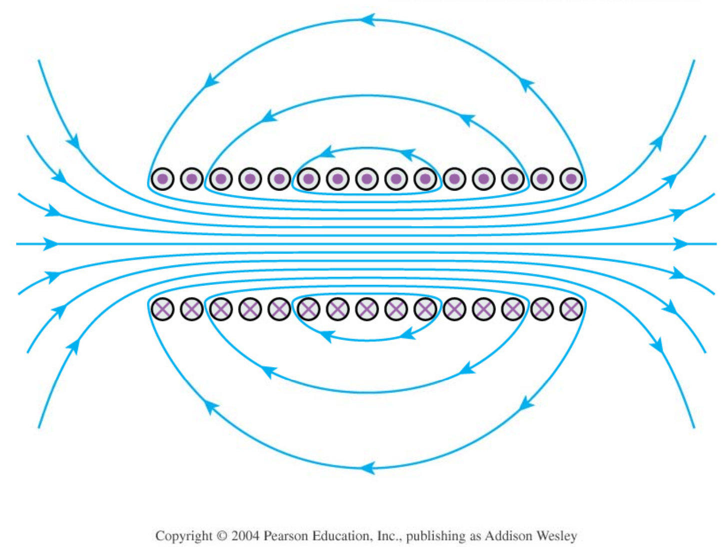


Magnetic Field of a Solenoid

- A **solenoid** is a long wire wound in the form of a helix



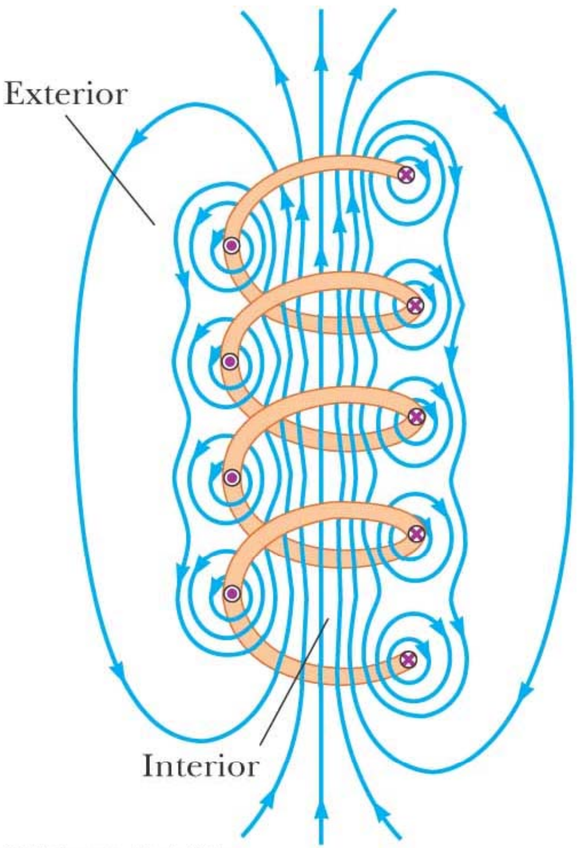




A reasonably uniform magnetic field can be produced in the space surrounded by the turns of the wire

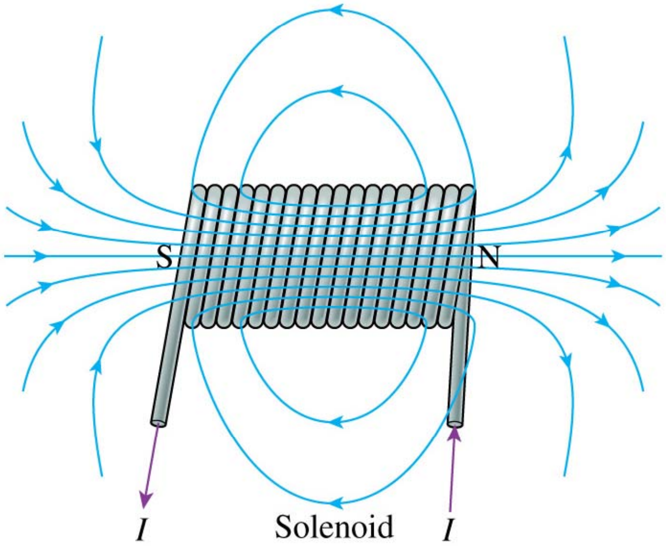
Magnetic Field of a Solenoid

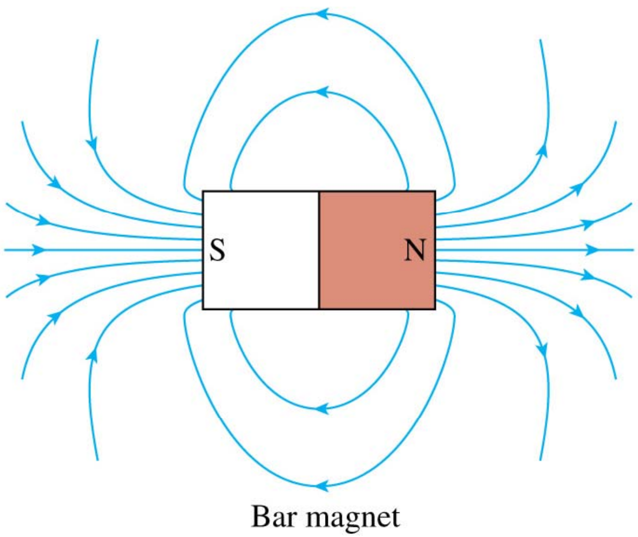
- The field lines in the interior are
  - approximately parallel to each other
  - uniformly distributed
  - close together
- This indicates the field is strong and almost uniform



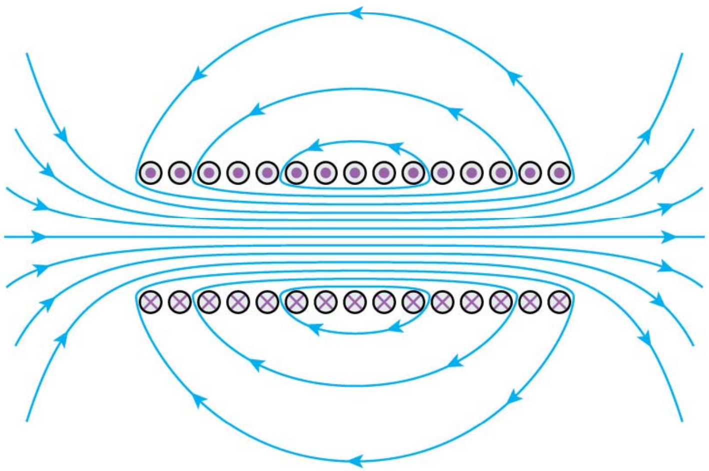
Magnetic Field of a Solenoid

- The field distribution is similar to that of a bar magnet
- As the length of the solenoid increases
  – the interior field becomes more uniform
  – the exterior field becomes weaker





Magnetic Field of a Solenoid



$$B = \mu_o \frac{N}{\ell} I = \mu_o n I$$

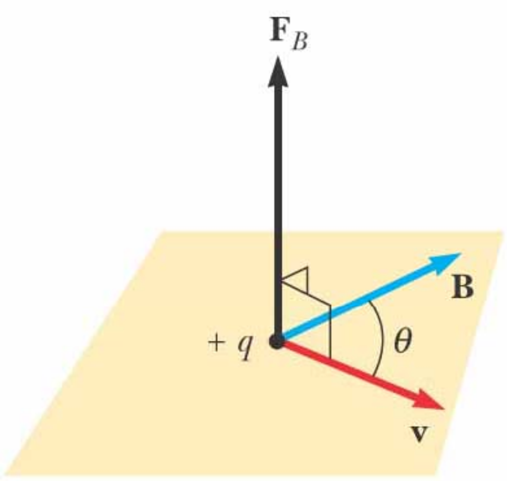
$n = N / \ell$ is the number of turns per unit length

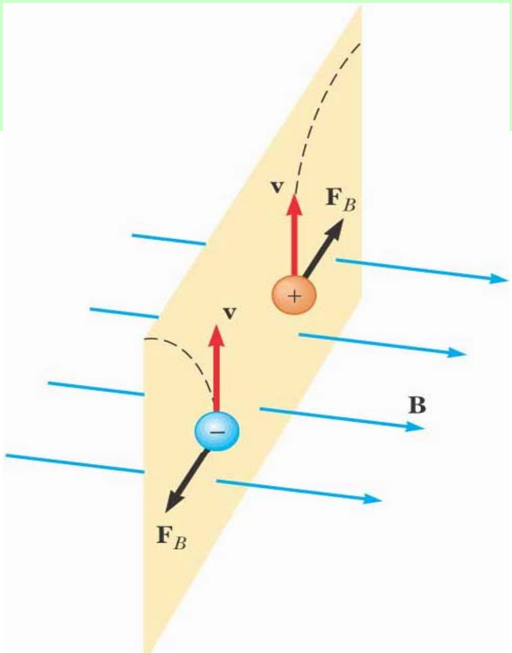
This expression is valid only at points near the center of a very long solenoid

Interaction of Charged Particle with Magnetic Field

Interaction of Charged Particle with Magnetic Field

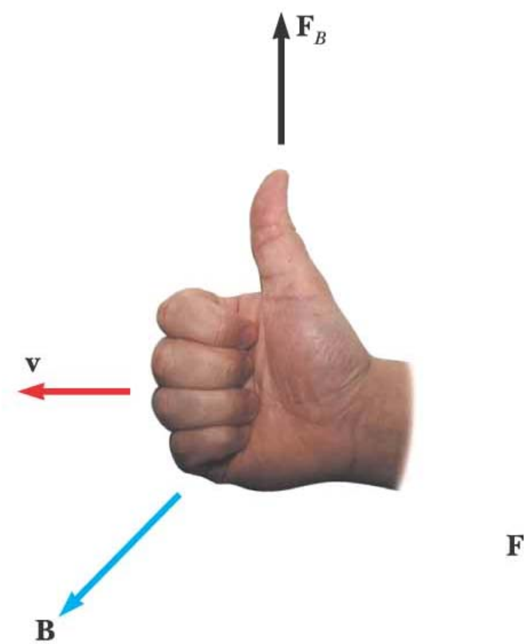
- The magnitude of the magnetic force on a charged particle is $F_B = |q|\, vB \sin\,\theta$
  - ➢ θ is the smallest angle between **v** and **B**
  - – F_B is zero when **v** and **B** are parallel or antiparallel
    - ➢ $\theta = 0$ or 180^o
  - – F_B is a maximum when **v** and **B** are perpendicular
    - ➢ $\theta = 90^o$





Direction of Magnetic Force

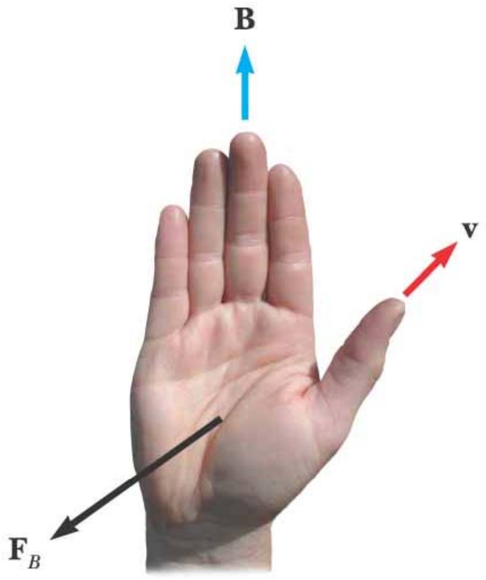
- The fingers point in the direction of **v**
- **B** comes out of your palm
  - Curl your fingers in the direction of **B**
- The thumb points in the direction of $\mathbf{F}_B$



(a)

Direction of Magnetic Force

- Thumb is in the direction of **v**
- Fingers are in the direction of **B**
- Palm is in the direction of $\mathbf{F}_B$
  - On a positive particle
  - You can think of this as your hand pushing the particle



(b)

Differences Between Electric and Magnetic Fields

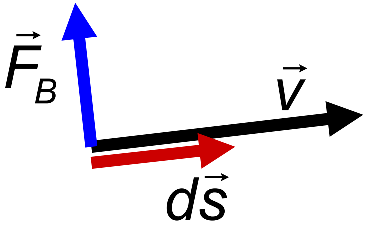
$$\vec{F}_E = q\vec{E} \qquad\qquad F_B = qvB\sin\theta$$

- Direction of force
  - The electric force acts along the direction of the electric field
  - The magnetic force acts perpendicular to the magnetic field
- Motion
  - The electric force acts on a charged particle regardless of whether the particle is moving
  - The magnetic force acts on a charged particle only when the particle is in motion

Differences Between Electric and Magnetic Fields

$$\vec{F}_E = q\vec{E} \qquad \vec{F}_B = q\vec{v} \times \vec{B}$$

- Work
  - The electric force does work in displacing a charged particle
  - The magnetic force associated with a steady magnetic field does no work when a particle is displaced
    - This is because the force is perpendicular to the displacement



$$W = \vec{F}_B \cdot d\vec{s} = 0$$

Work in Magnetic Field

- The kinetic energy of a charged particle moving through a magnetic field cannot be altered by the magnetic field alone
- When a charged particle moves with a velocity **v** through a magnetic field, the field can alter the ***direction*** of the velocity, but **not the speed** or the kinetic energy

Force on a Wire

- The magnetic force is exerted on each moving charge in the wire

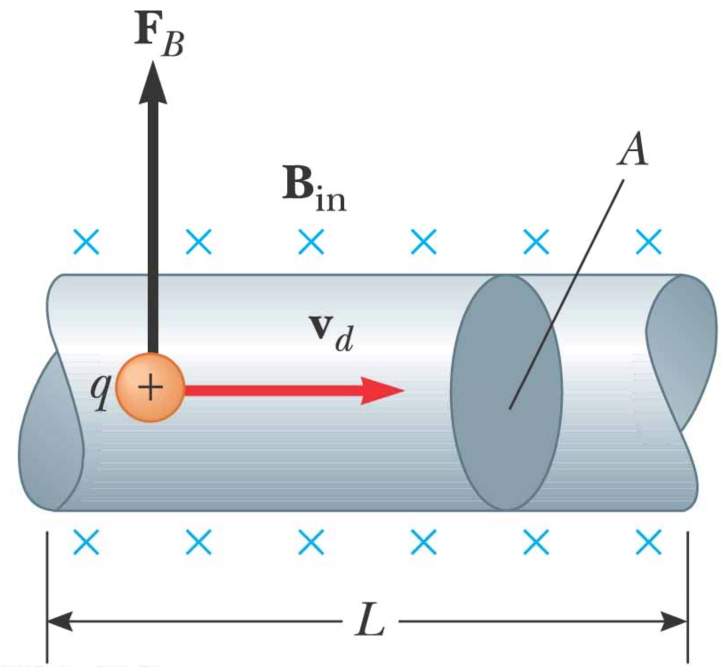
$$F = q\, v_d\, B$$

- The total force is the product of the force on one charge and the number of charges

$$F = (q\, v_d\ B)\, nAL$$

- In terms of current:

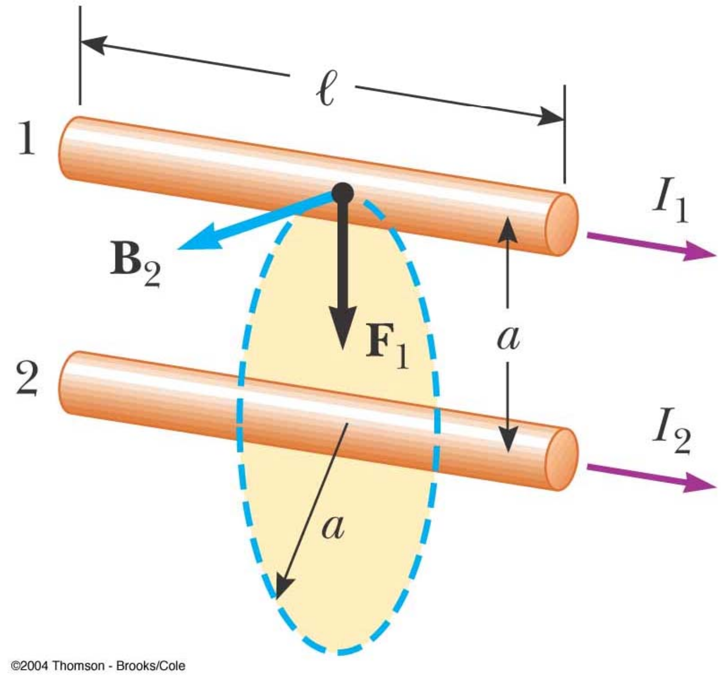
$$F = I\, L\, B$$



Magnetic Force between two parallel conductors

- Two parallel wires each carry a steady current
- The field $\mathbf{B}_2$ due to the current in wire 2 exerts a force on wire 1 of $F_1 = I_1 \ell B_2$
- Substituting the equation for B_2 gives

$$F_1 = \frac{\mu_o I_1 I_2}{2\pi a} \ell$$



Magnetic Force between two parallel conductors

$$F_1 = \frac{\mu_o I_1 I_2}{2\pi a}\ell$$

- Parallel conductors carrying currents in the same direction attract each other
- Parallel conductors carrying current in opposite directions repel each other
- The result is often expressed as the magnetic force *between* the two wires, F_B
- This can also be given as the *force per unit length*:

$$\frac{F_B}{\ell} = \frac{\mu_o I_1 I_2}{2\pi a}$$