

# Chapter 28

# Sources of Magnetic Field

PowerPoint® Lectures for  
*University Physics, Thirteenth Edition*  
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Lectures by Wayne Anderson

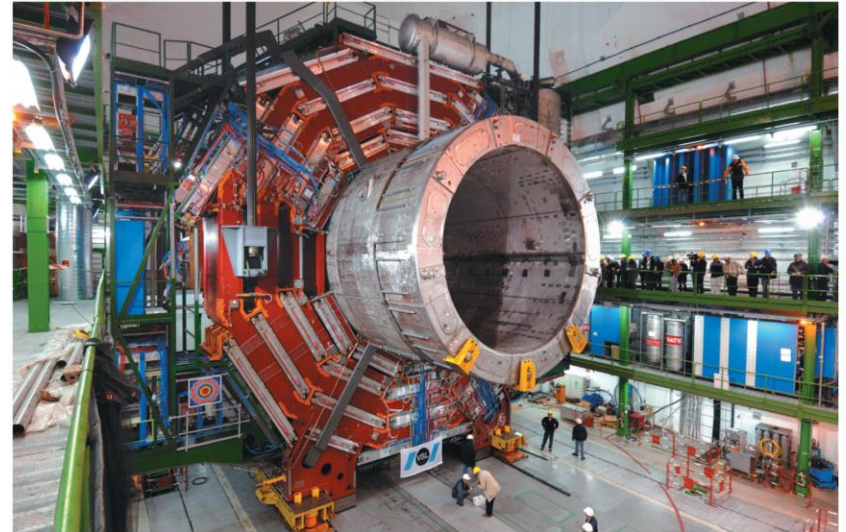
# Goals for Chapter 28

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- To determine the magnetic field produced by a moving charge
- To study the magnetic field of an element of a current-carrying conductor
- To calculate the magnetic field of a long, straight, current-carrying conductor
- To study the magnetic force between current-carrying wires
- To determine the magnetic field of a circular loop
- To use Ampere's Law to calculate magnetic fields

# Introduction

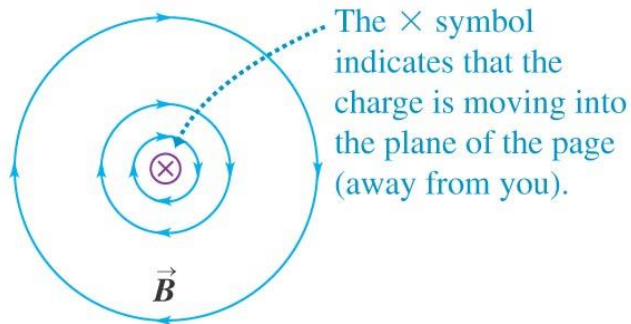
- What can we say about the magnetic field due to a solenoid?
- What actually creates magnetic fields?
- We will introduce Ampere's law to calculate magnetic fields.



# The magnetic field of a moving charge

- A moving charge generates a magnetic field that depends on the velocity of the charge.
- Figure 28.1 shows the direction of the field.

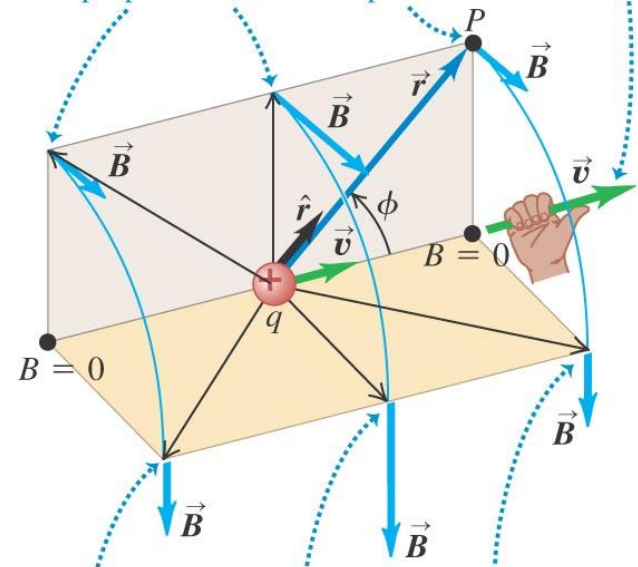
View from behind the charge



Perspective view

**Right-hand rule for the magnetic field due to a positive charge moving at constant velocity:** Point the thumb of your right hand in the direction of the velocity. Your fingers now curl around the charge in the direction of the magnetic field lines. (If the charge is negative, the field lines are in the opposite direction.)

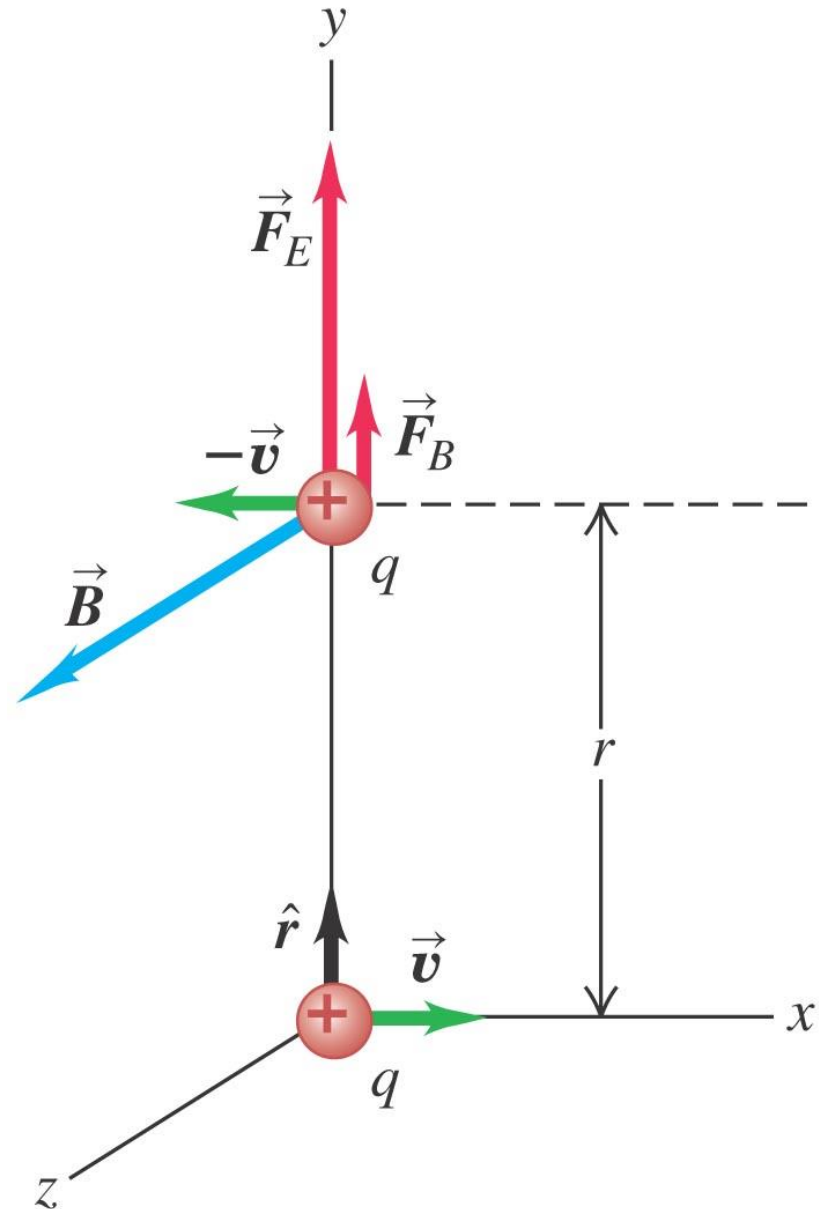
For these field points,  $\vec{r}$  and  $\vec{v}$  both lie in the beige plane, and  $\vec{B}$  is perpendicular to this plane.



For these field points,  $\vec{r}$  and  $\vec{v}$  both lie in the gold plane, and  $\vec{B}$  is perpendicular to this plane.

# Magnetic force between moving protons

- Follow the text discussion of the vector magnetic field.
- Follow Example 28.1 using Figure 28.2 at the right.



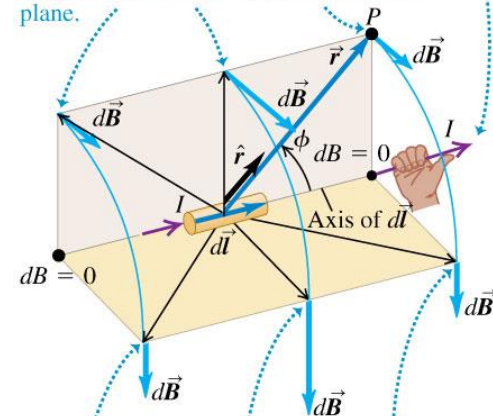
# Magnetic field of a current element

- The total magnetic field of several moving charges is the vector sum of each field.
- Follow the text discussion of the vector magnetic field due to a current element. Refer to Figure 28.3 at the right. The formula derived is called the *law of Biot and Savart*.

(a) Perspective view

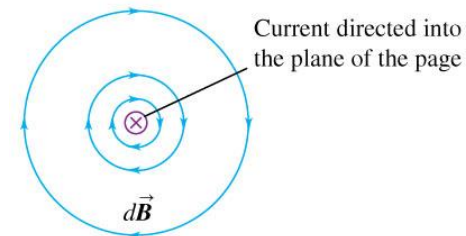
**Right-hand rule for the magnetic field due to a current element:** Point the thumb of your right hand in the direction of the current. Your fingers now curl around the current element in the direction of the magnetic field lines.

For these field points,  $\vec{r}$  and  $d\vec{l}$  both lie in the beige plane, and  $d\vec{B}$  is perpendicular to this plane.



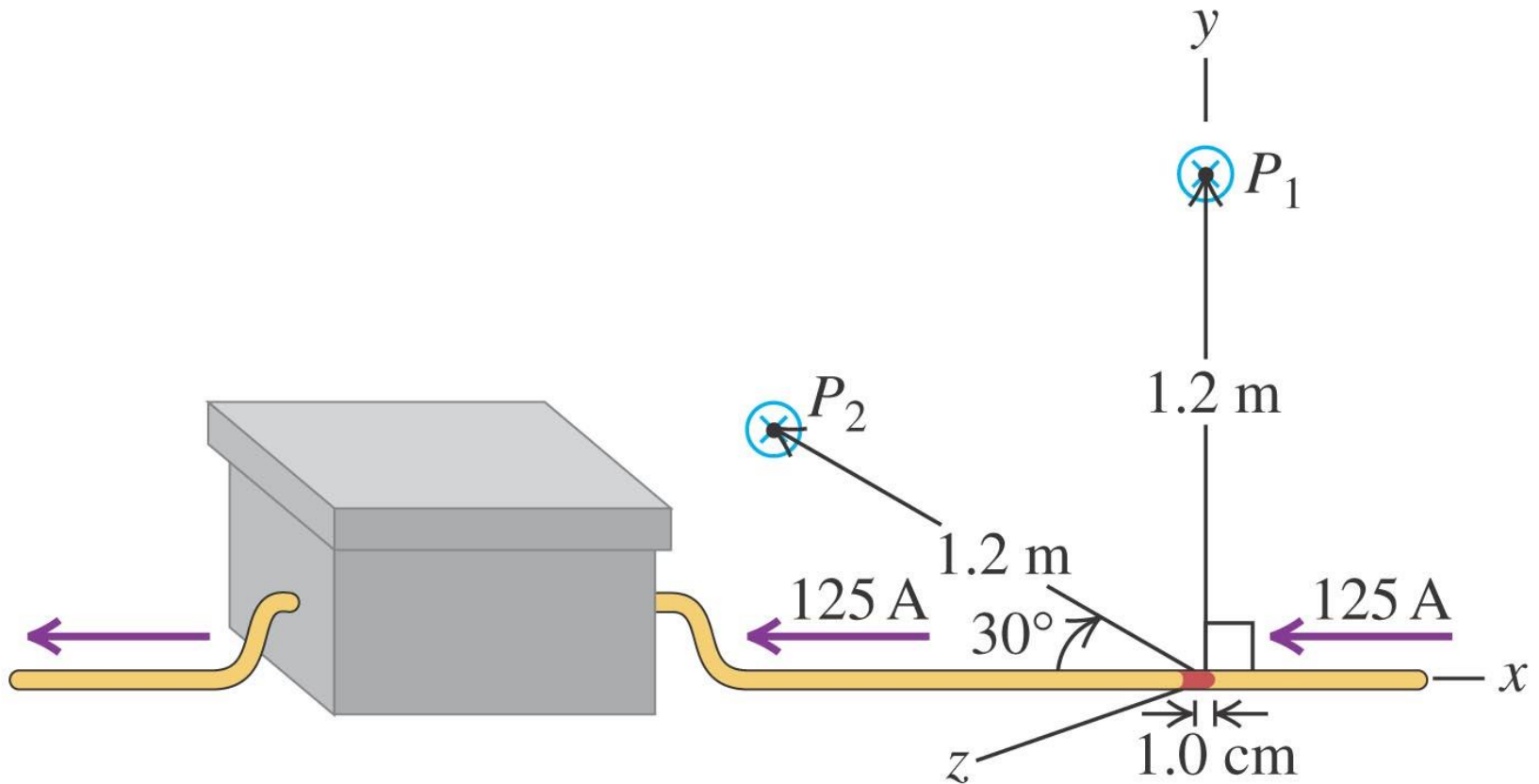
For these field points,  $\vec{r}$  and  $d\vec{l}$  both lie in the gold plane, and  $d\vec{B}$  is perpendicular to this plane.

(b) View along the axis of the current element



# Magnetic field of a current segment

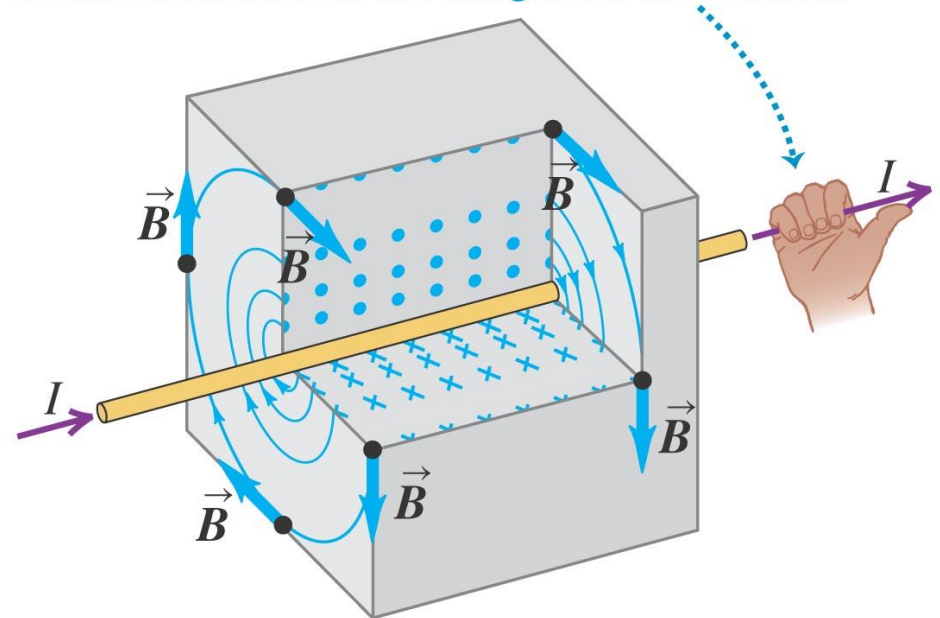
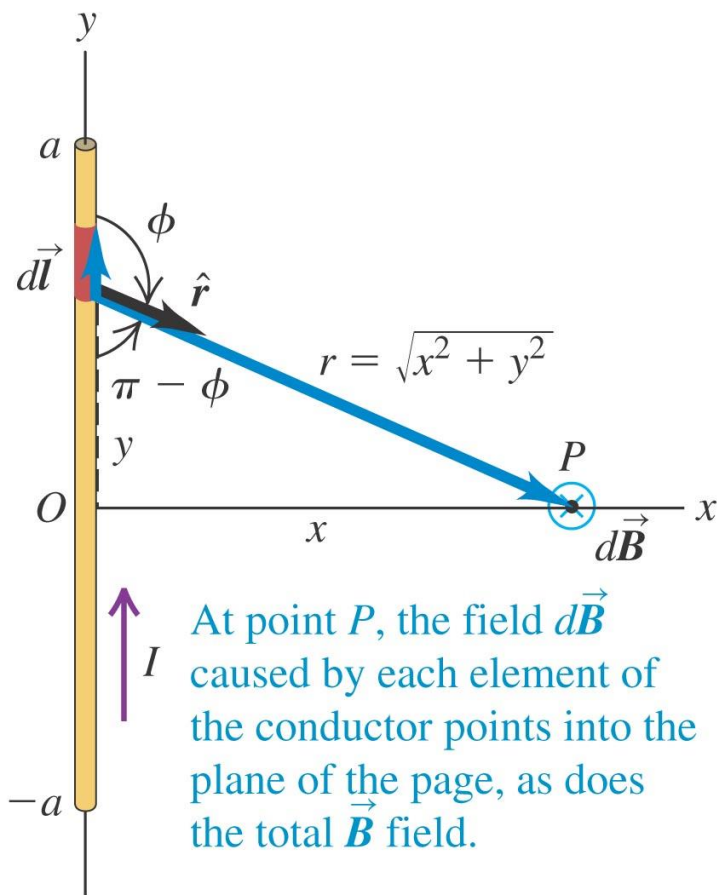
- Read Problem-Solving Strategy 28.1.
- Follow Example 28.2 using Figure 28.4 below.



# Magnetic field of a straight current-carrying conductor

- If we apply the law of Biot and Savart to a long straight conductor, the result is  $B = \mu_0 I / 2\pi x$ . See Figure 28.5 below left. Figure 28.6 below right shows the right-hand rule for the direction of the force.

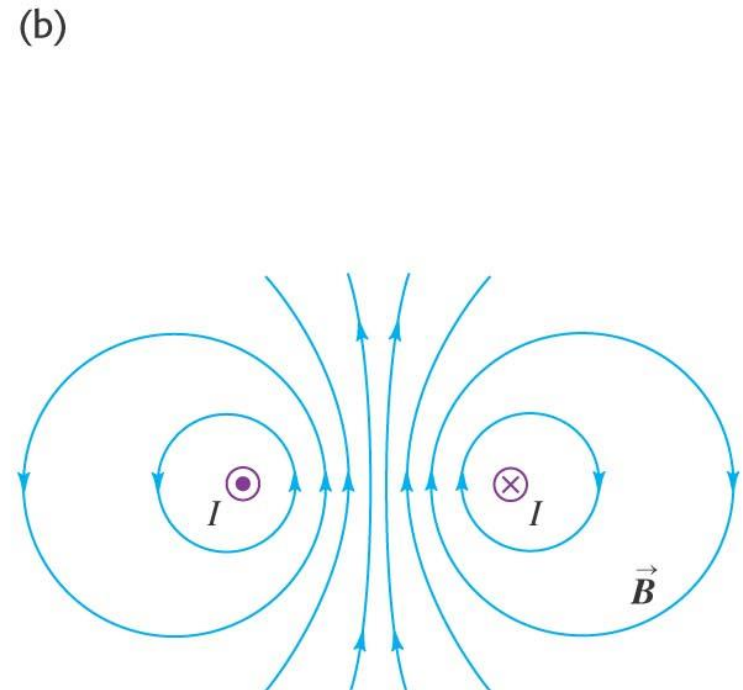
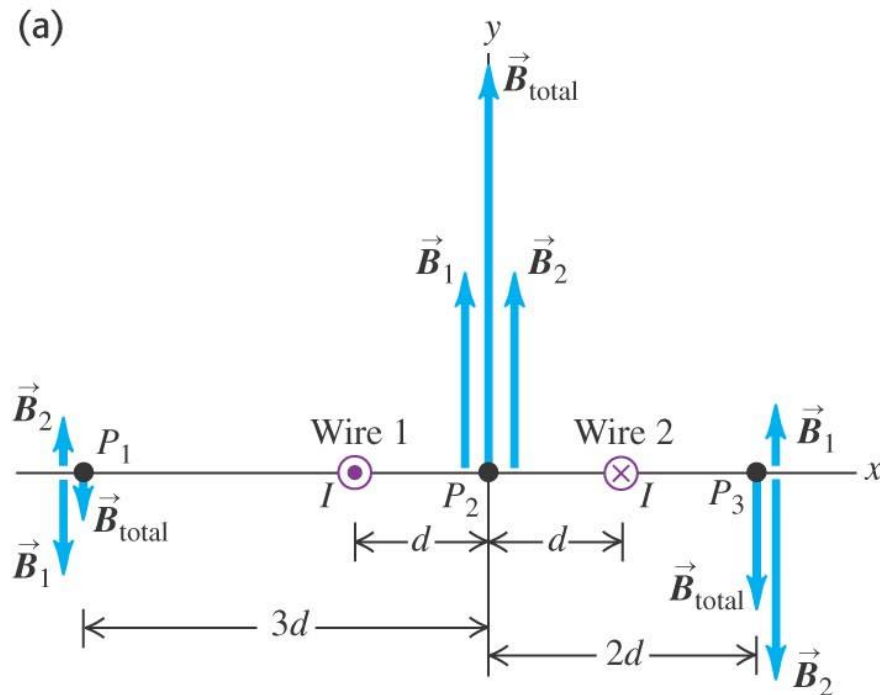
**Right-hand rule for the magnetic field around a current-carrying wire:** Point the thumb of your right hand in the direction of the current. Your fingers now curl around the wire in the direction of the magnetic field lines.





# Magnetic fields of long wires

- Follow Example 28.3 for one wire.
- Follow Example 28.4 for two wires. Use Figure 28.7 below.

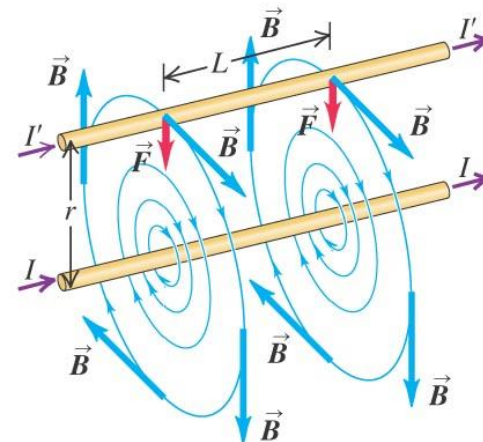
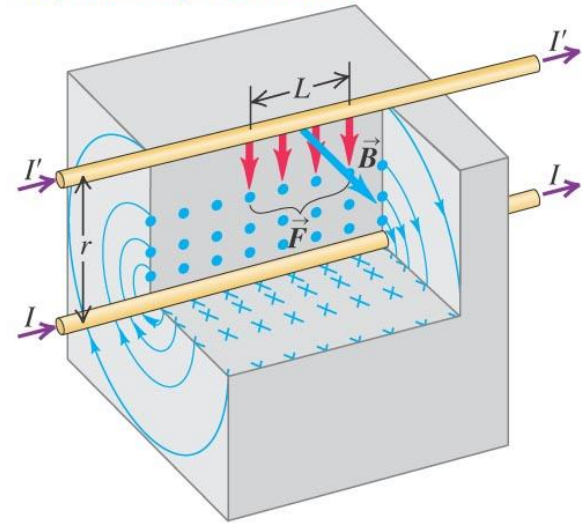


# Force between parallel conductors

- The force per unit length on each conductor is  $F/L = \mu_0 I I' / 2\pi r$ . (See Figure 28.9 at the right.)
- The conductors attract each other if the currents are in the same direction and repel if they are in opposite directions.

The magnetic field of the lower wire exerts an attractive force on the upper wire. By the same token, the upper wire attracts the lower one.

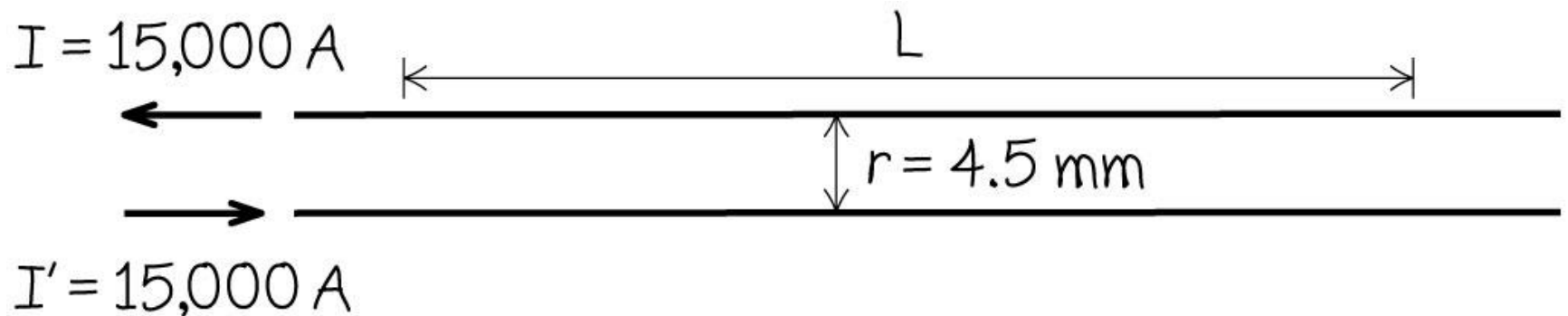
If the wires had currents in *opposite* directions, they would *repel* each other.



# Forces between parallel wires

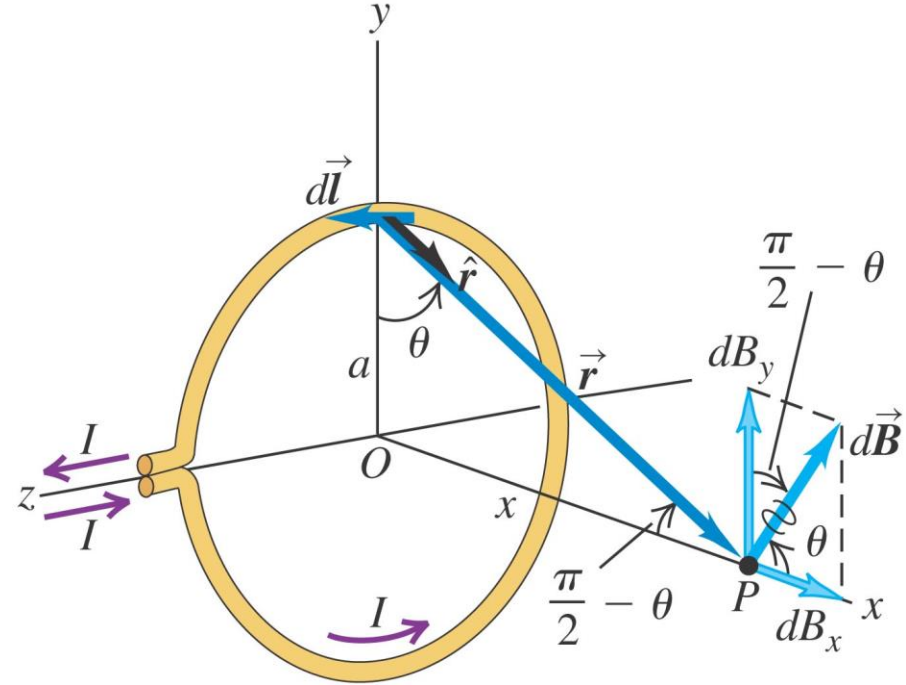
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- Follow Example 28.5 using Figure 28.10 below.



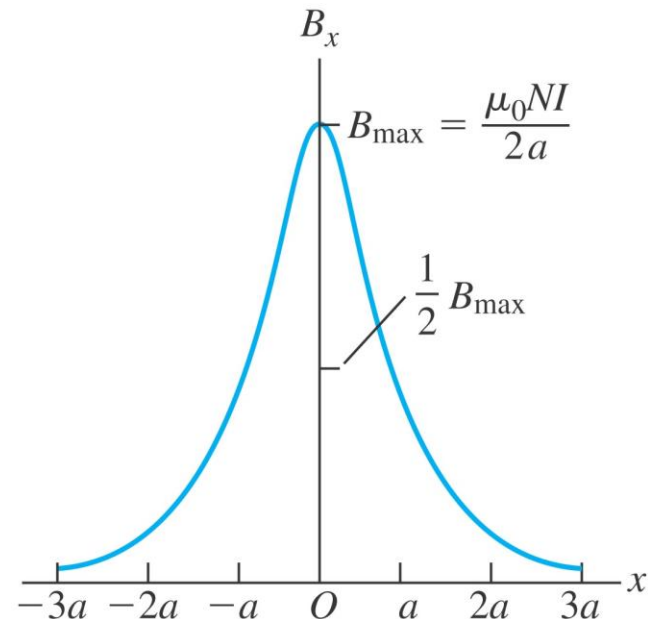
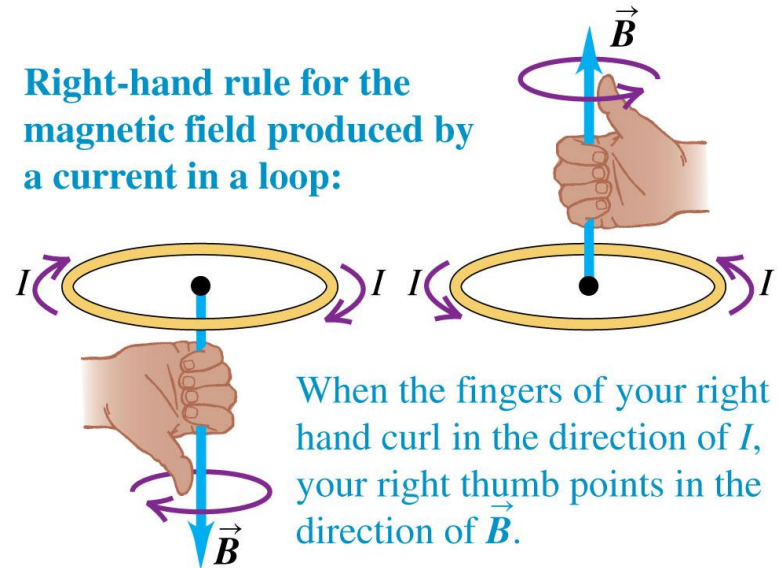
# Magnetic field of a circular current loop

- The Biot Savart law gives  $B_x = \mu_0 I a^2 / 2(x^2 + a^2)^{3/2}$  on the axis of the loop. Follow the text derivation using Figure 28.12 at the right.
- At the center of  $N$  loops, the field on the axis is  $B_x = \mu_0 N I / 2a$ .



# Magnetic field of a coil

- Figure 28.13 (top) shows the direction of the field using the right-hand rule.
- Figure 28.14 (below) shows a graph of the field along the  $x$ -axis.
- Follow Example 28.6.

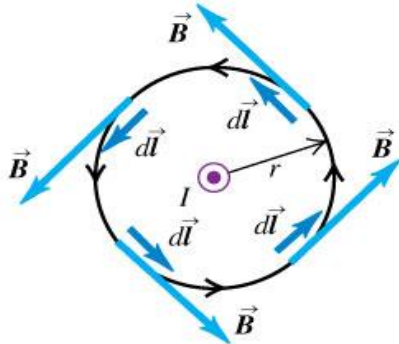


# Ampere's law (special case)

- Follow the text discussion of Ampere's law for a circular path around a long straight conductor, using Figure 28.16 below.

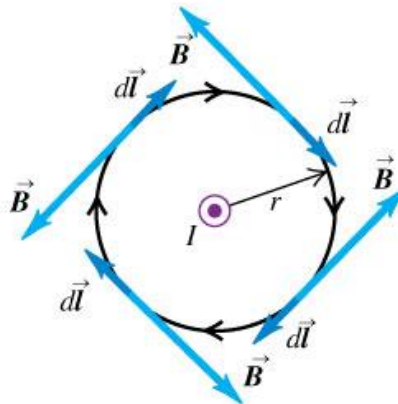
(a) Integration path is a circle centered on the conductor; integration goes around the circle counterclockwise.

Result:  $\oint \vec{B} \cdot d\vec{l} = \mu_0 I$



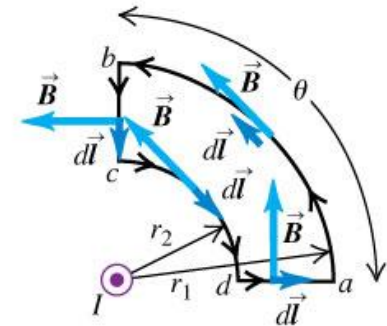
(b) Same integration path as in (a), but integration goes around the circle clockwise.

Result:  $\oint \vec{B} \cdot d\vec{l} = -\mu_0 I$



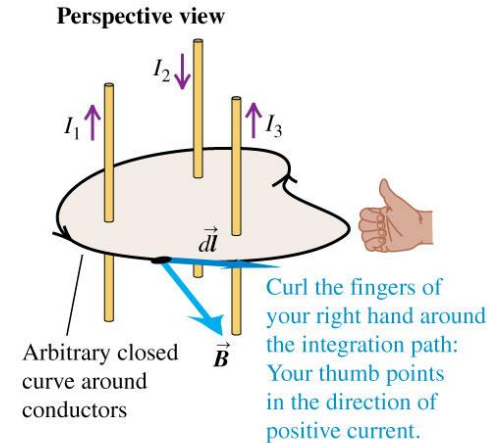
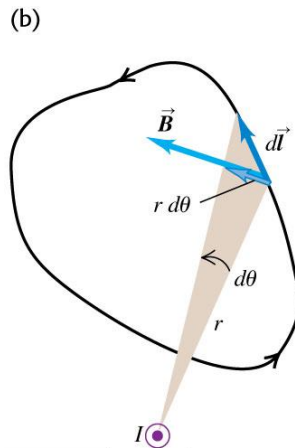
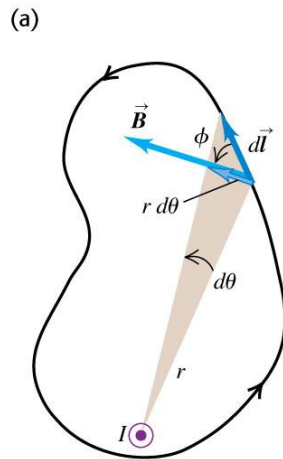
(c) An integration path that does not enclose the conductor

Result:  $\oint \vec{B} \cdot d\vec{l} = 0$

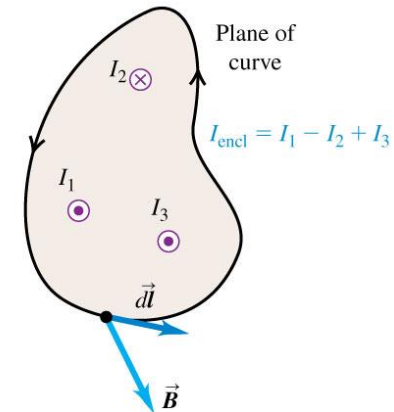


# Ampere's law (general statement)

- Follow the text discussion of the general statement of Ampere's law, using Figures 28.17 and 28.18 below.



**Top view**

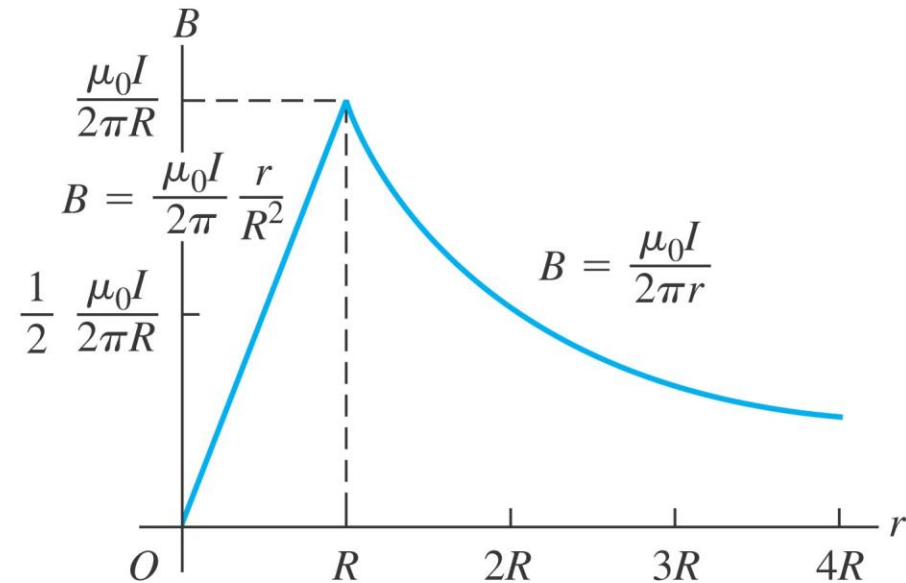
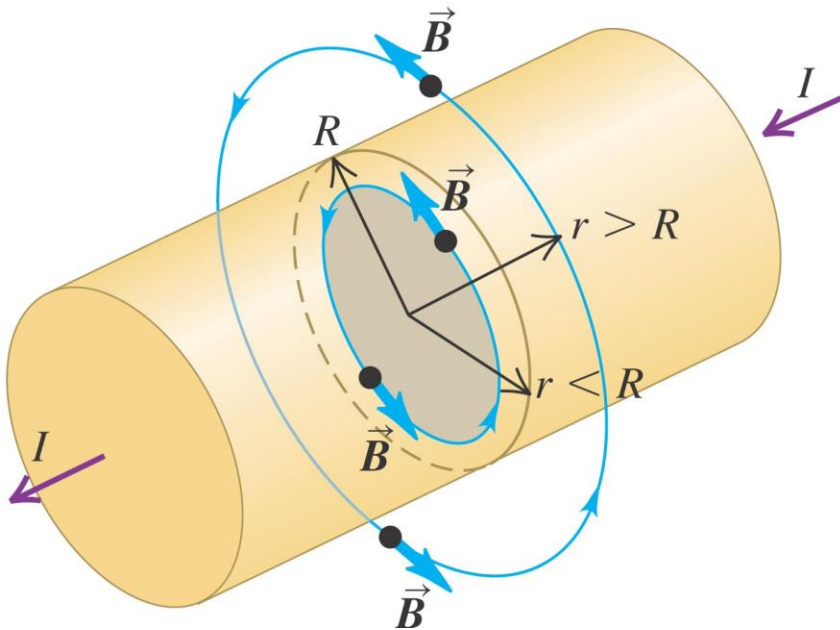


**Ampere's law:** If we calculate the line integral of the magnetic field around a closed curve, the result equals  $\mu_0$  times the total enclosed current:

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{encl}}$$

# Magnetic fields of long conductors

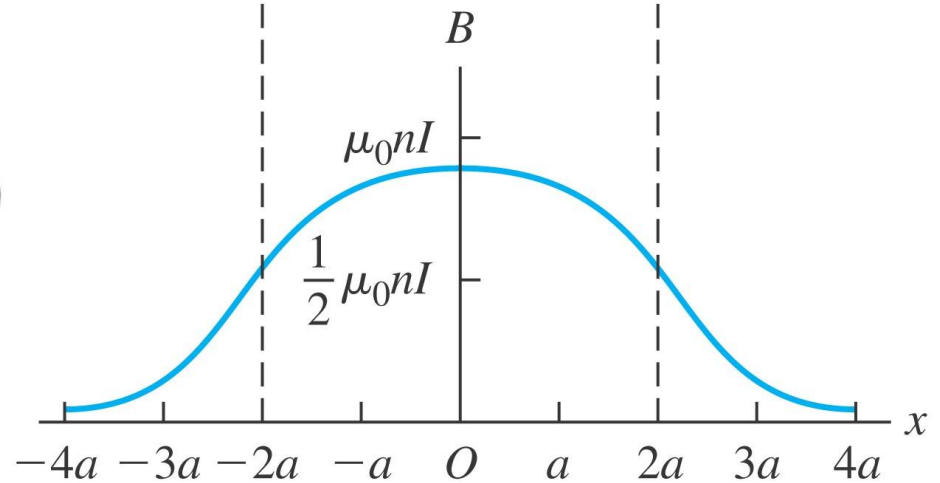
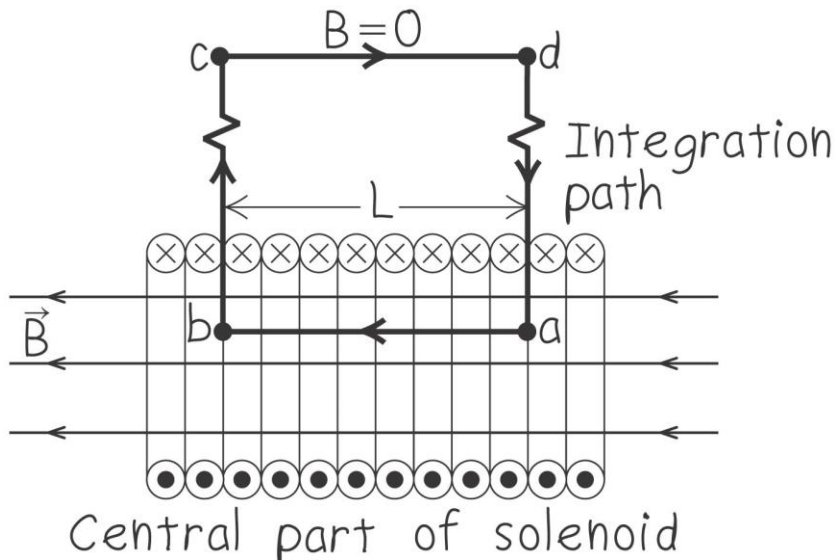
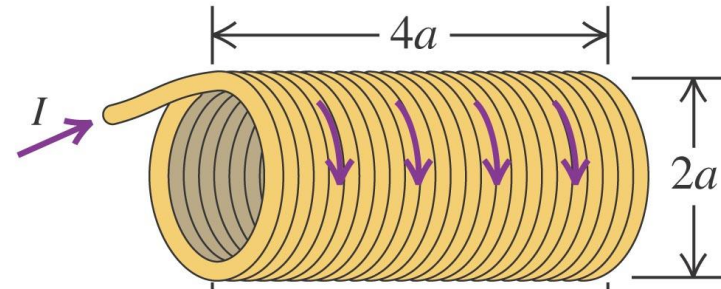
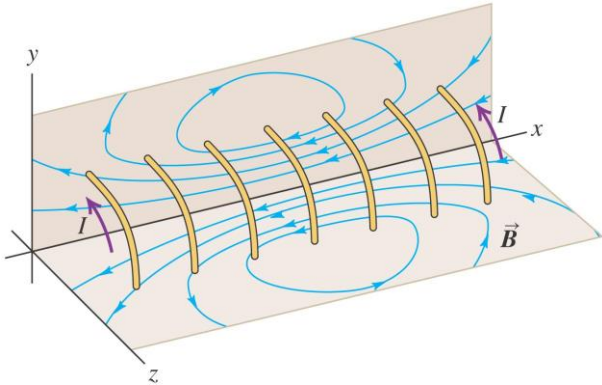
- Read Problem-Solving Strategy 28.2.
- Follow Example 28.7 for a long straight conductor.
- Follow Example 28.8 for a long cylinder, using Figures 28.20 and 28.21 below.





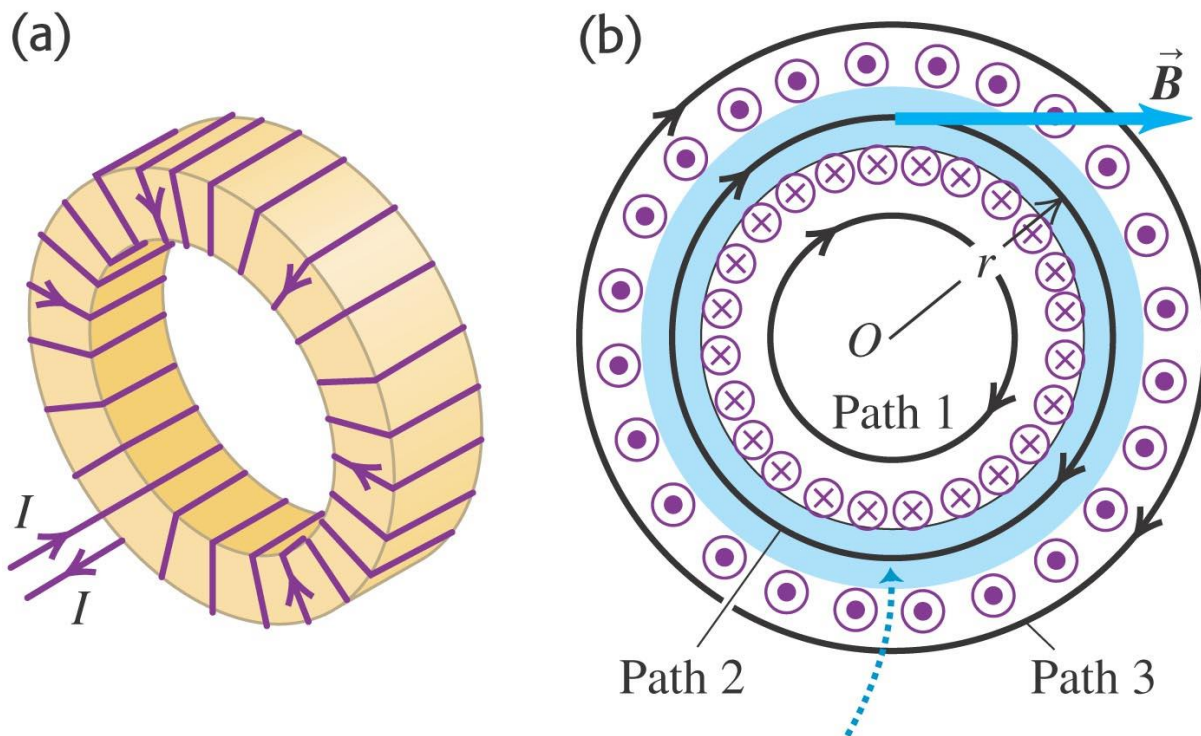
# Field of a solenoid

- A *solenoid* consists of a helical winding of wire on a cylinder.
- Follow Example 28.9 using Figures 28.22–28.24 below.



# Field of a toroidal solenoid

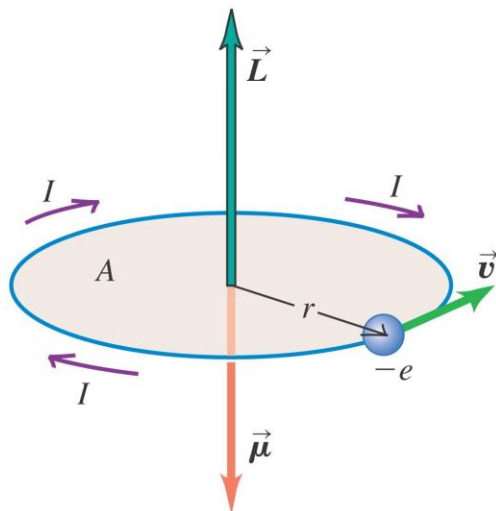
- A *toroidal solenoid* is a doughnut-shaped solenoid.
- Follow Example 28.10 using Figure 28.25 below.



The magnetic field is confined almost entirely to the space enclosed by the windings (in blue).

# The Bohr magneton and paramagnetism

- Follow the text discussions of the *Bohr magneton* and *paramagnetism*, using Figure 28.26 below.
- Table 28.1 shows the magnetic susceptibilities of some materials.
- Follow Example 28.11.

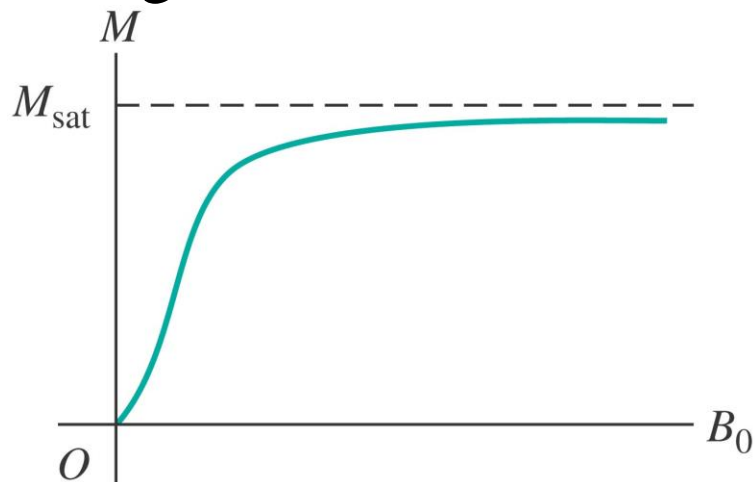


**Table 28.1** Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at  $T = 20^\circ\text{C}$

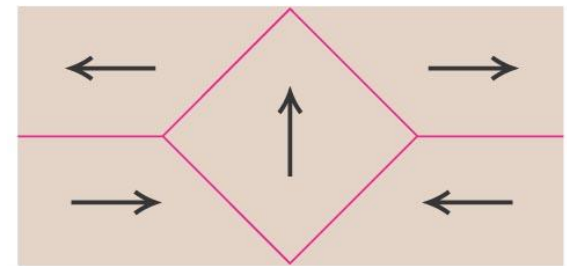
Material	$\chi_m = K_m - 1 (\times 10^{-5})$
<b>Paramagnetic</b>	
Iron ammonium alum	66
Uranium	40
Platinum	26
Aluminum	2.2
Sodium	0.72
Oxygen gas	0.19
<b>Diamagnetic</b>	
Bismuth	-16.6
Mercury	-2.9
Silver	-2.6
Carbon (diamond)	-2.1
Lead	-1.8
Sodium chloride	-1.4
Copper	-1.0

# Diamagnetism and ferromagnetism

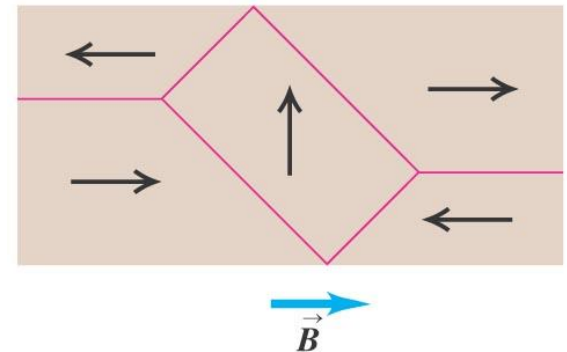
- Follow the text discussion of *diamagnetism* and *ferromagnetism*.
- Figure 28.27 at the right shows how *magnetic domains* react to an applied magnetic field.
- Figure 28.28 below shows a magnetization curve for a ferromagnetic material.



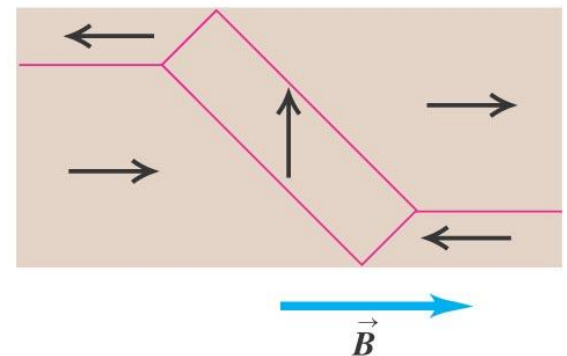
(a) No field



(b) Weak field



(c) Stronger field



# Hysteresis

- Read the text discussion of *hysteresis* using Figure 28.29 below.
- Follow Example 28.12.

