Chapter 28

Sources of Magnetic Field

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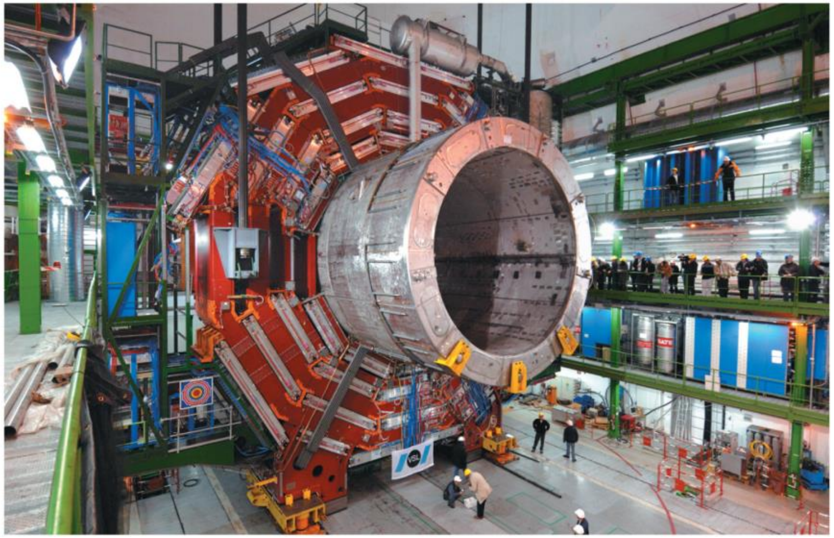
Lectures by Wayne Anderson

Goals for Chapter 28

- 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

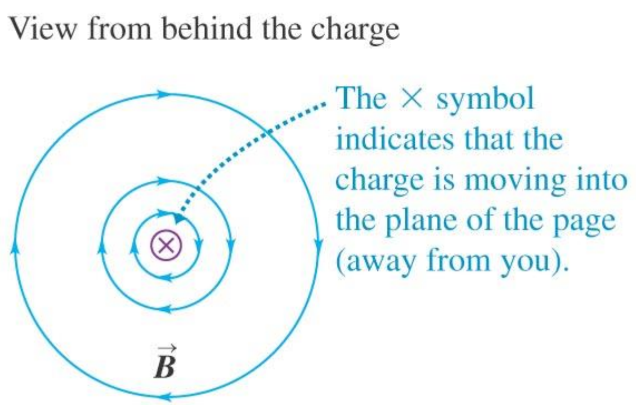
Introduction

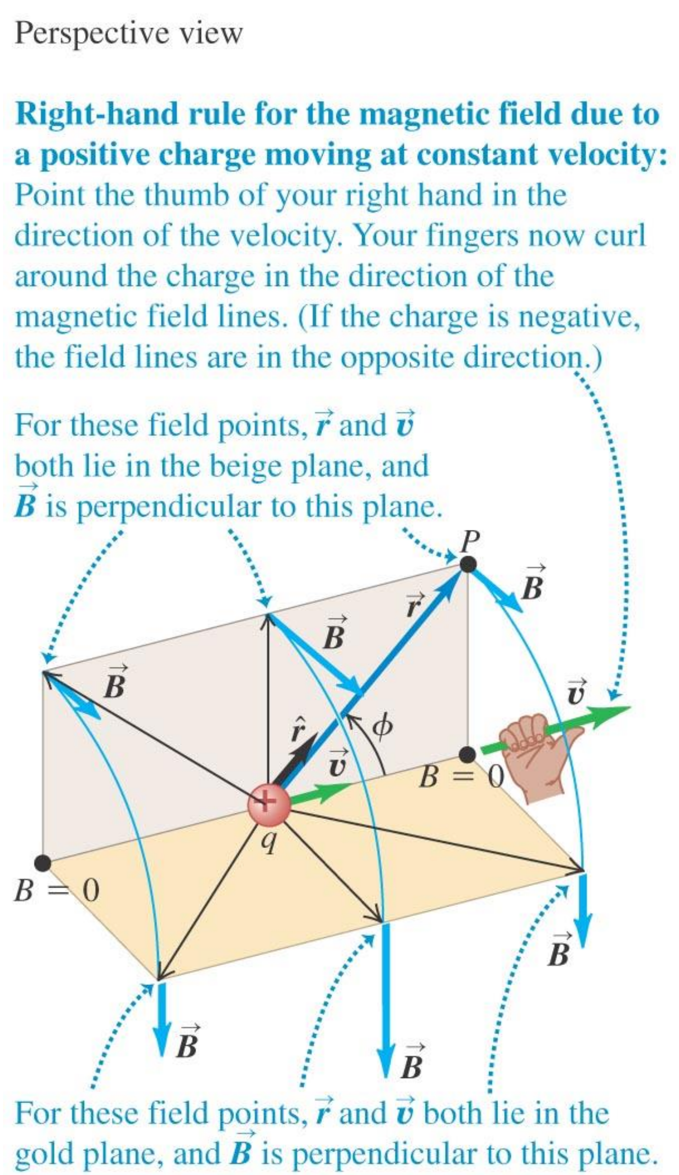
- What can we say about the magnetic field due to a solenoid?
- What actually creates magnetic fields?
- We will introduce Ampere's law to calculate magnetic fields.



The magnetic field of a moving charge

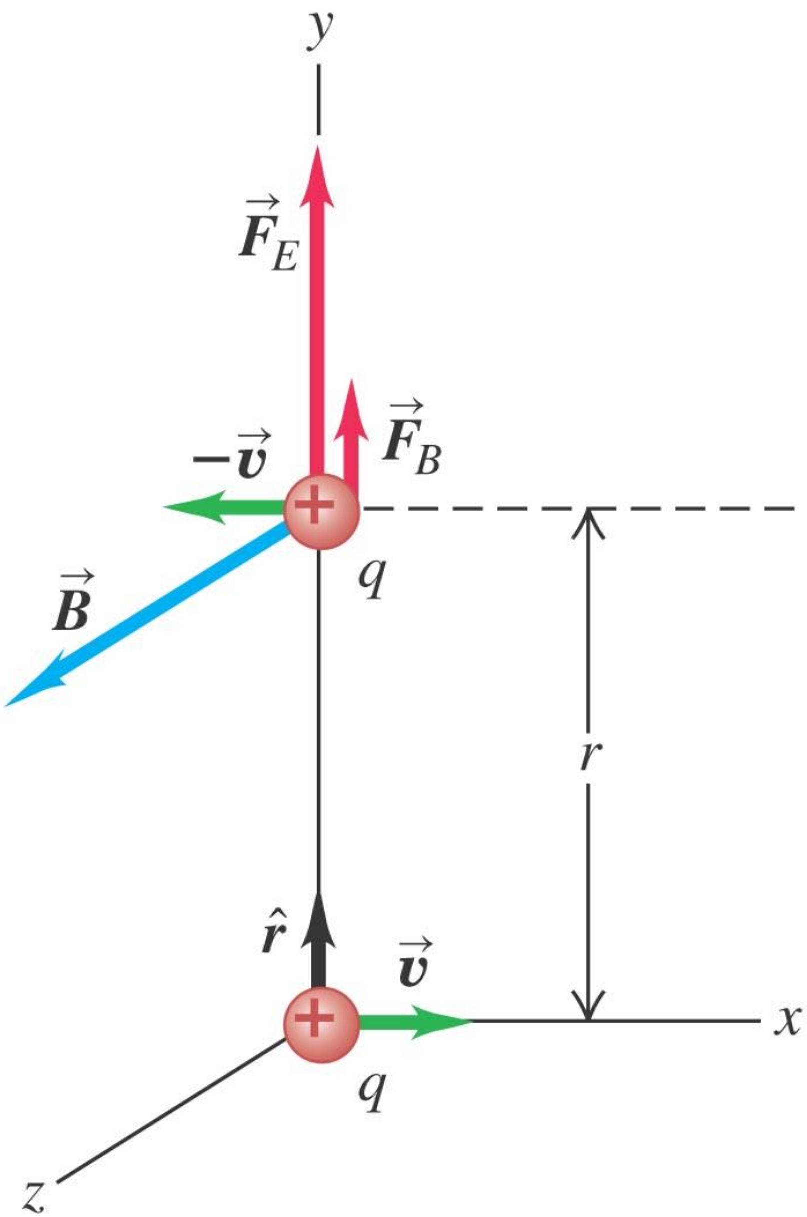
- A moving charge generates a magnetic field that depends on the velocity of the charge.
- Figure 28.1 shows the direction of the field.





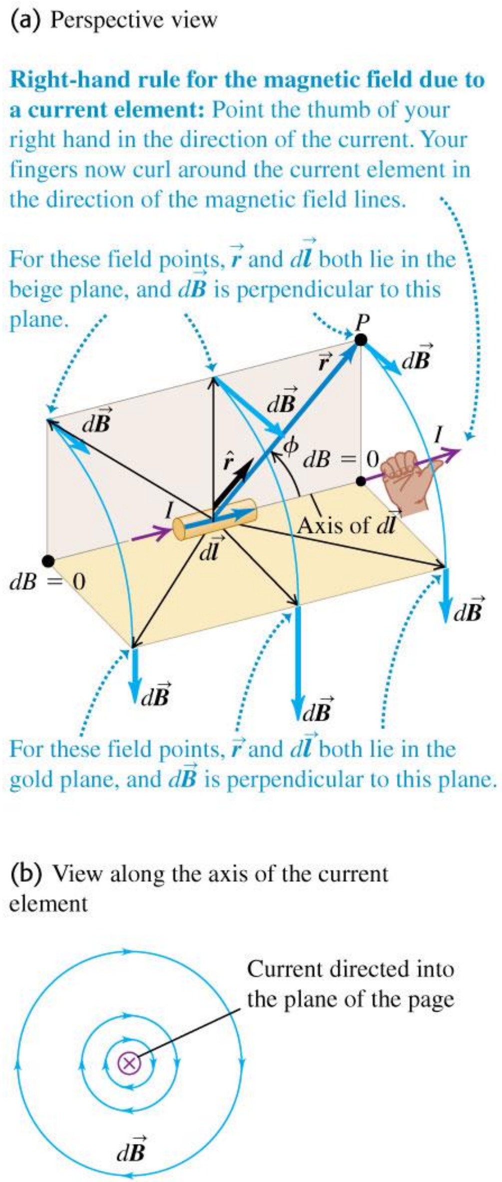
Magnetic force between moving protons

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



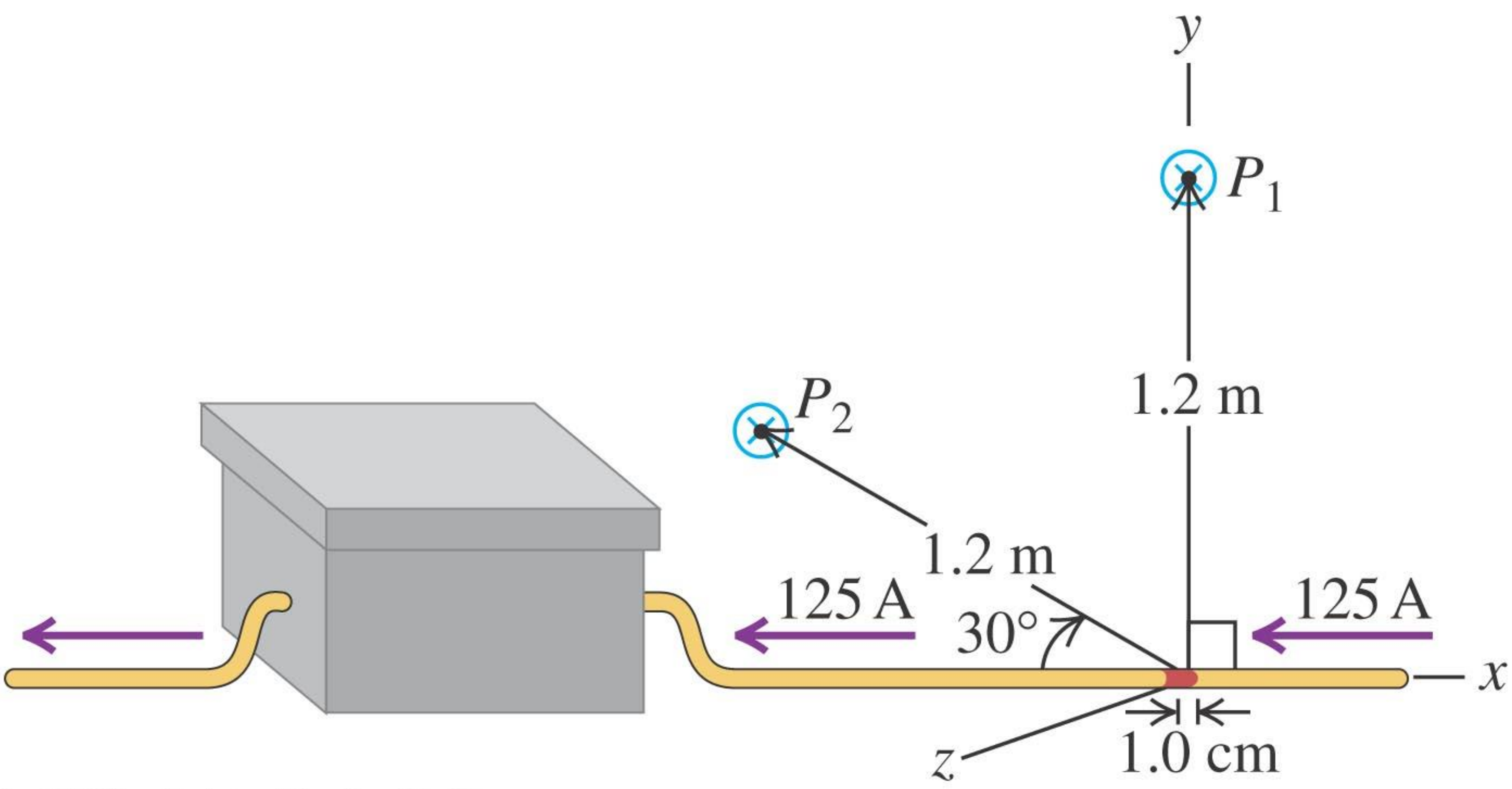
Magnetic field of a current element

- 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*.



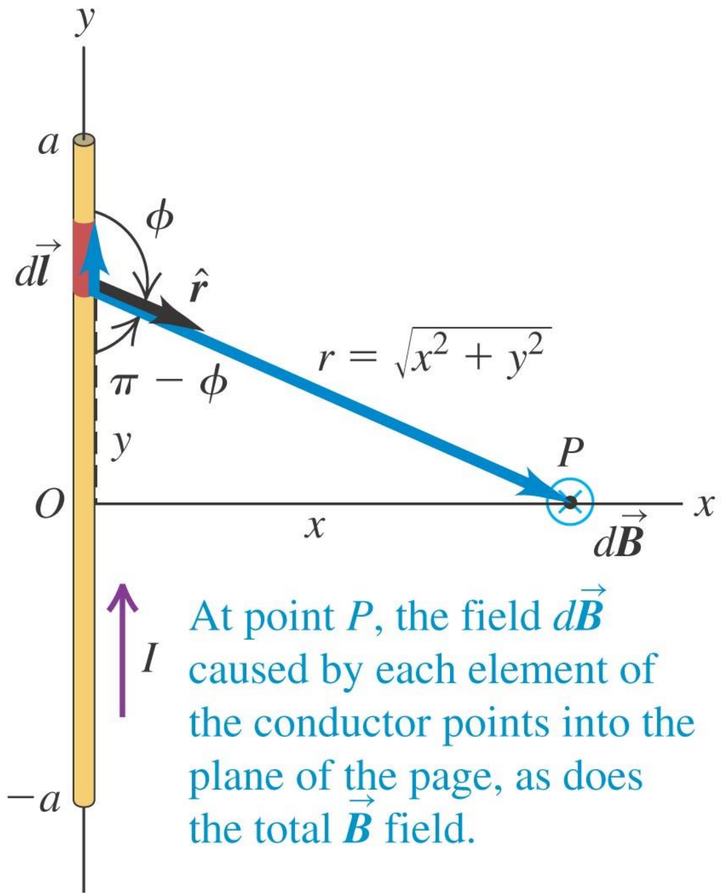
Magnetic field of a current segment

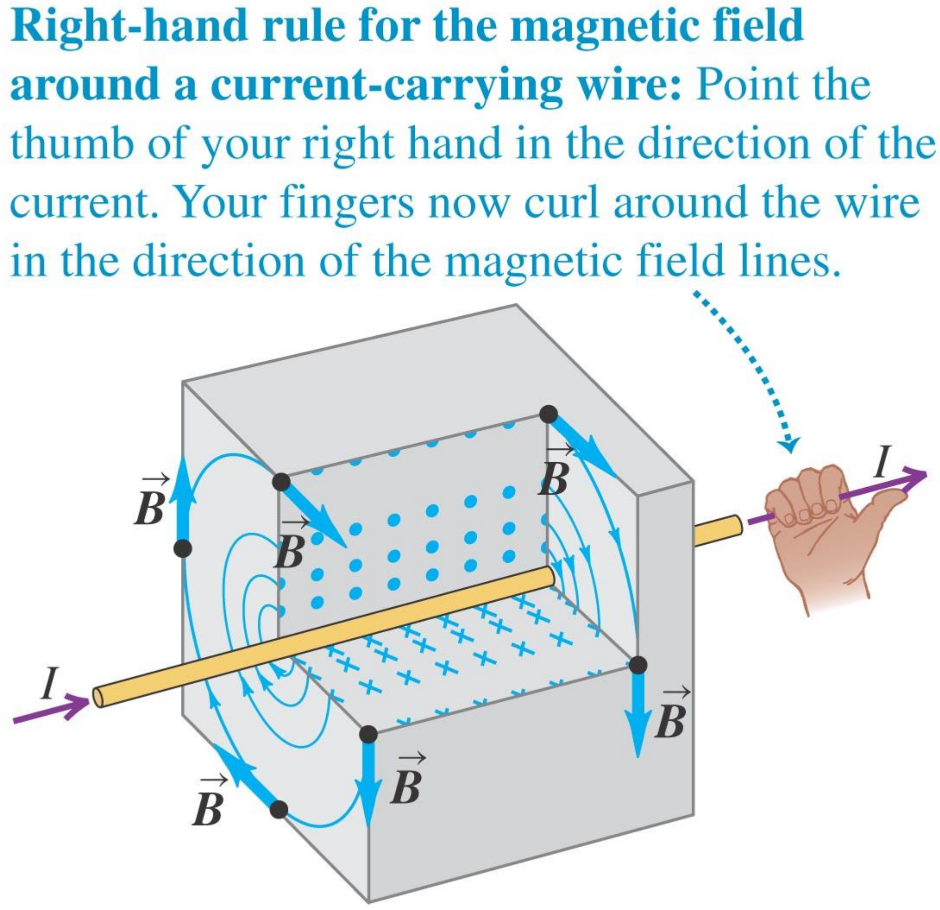
- Read Problem-Solving Strategy 28.1.
- Follow Example 28.2 using Figure 28.4 below.



Magnetic field of a straight current-carrying conductor

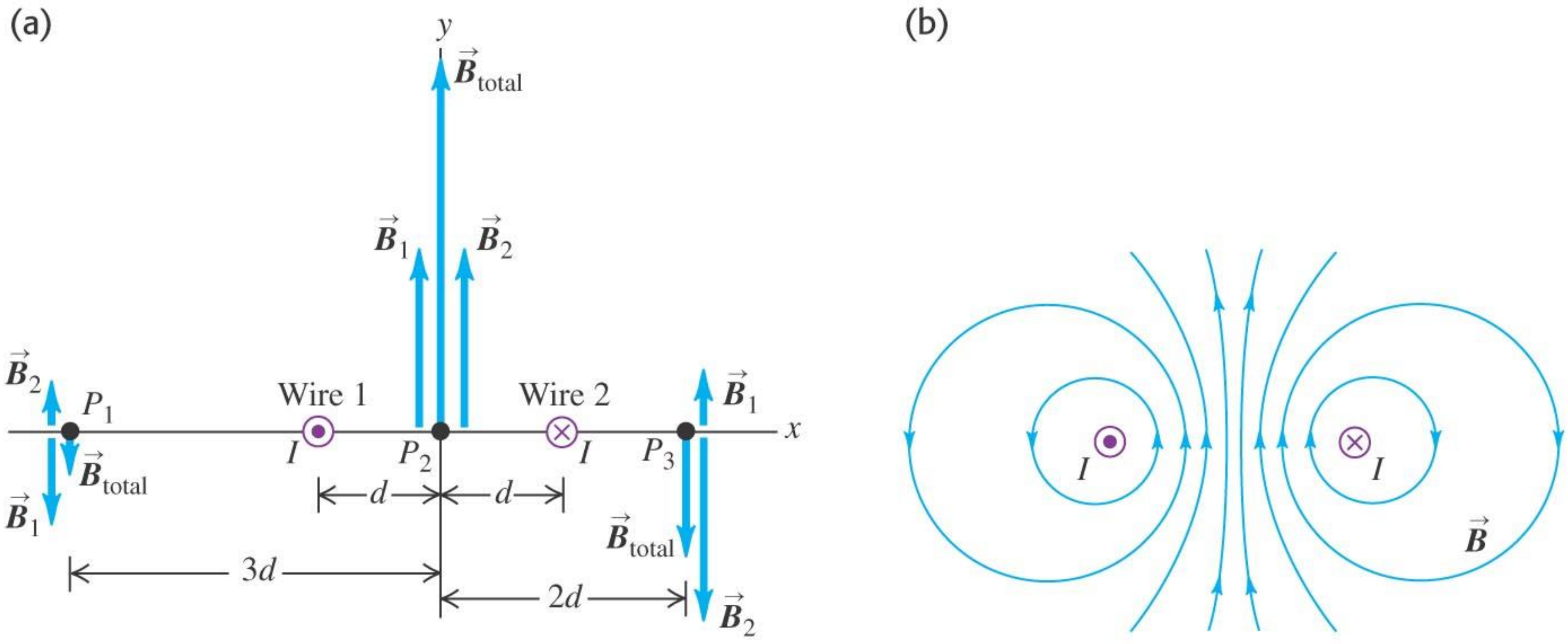
- If we apply the law of Biot and Savart to a long straight conductor, the result is $B = \mu_0 I/2\pi x$. See Figure 28.5 below left. Figure 28.6 below right shows the right-hand rule for the direction of the force.





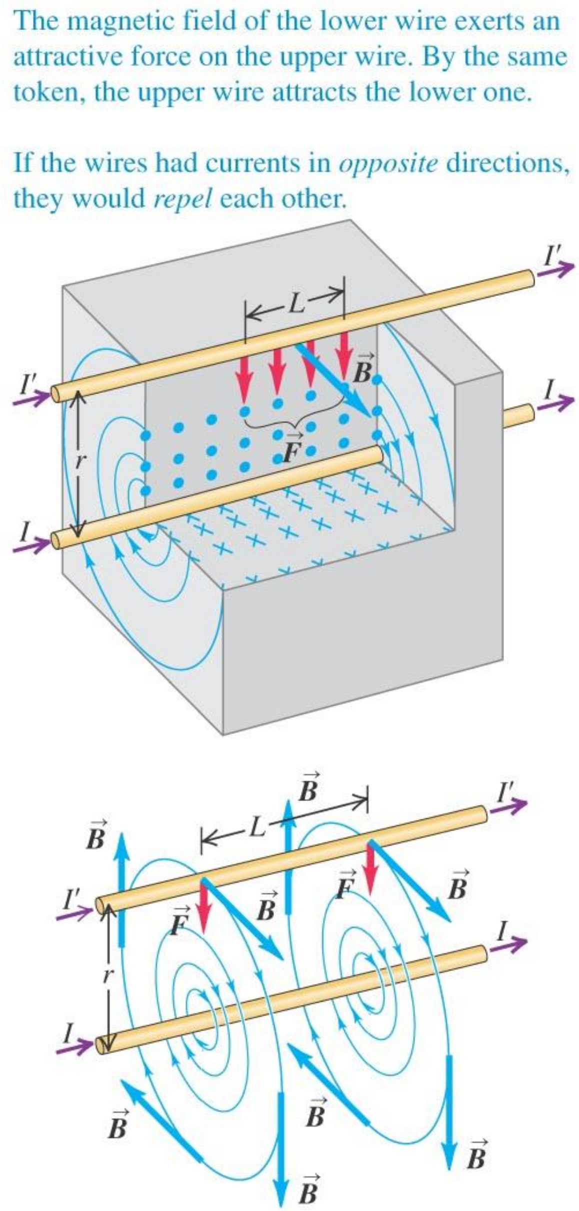
Magnetic fields of long wires

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



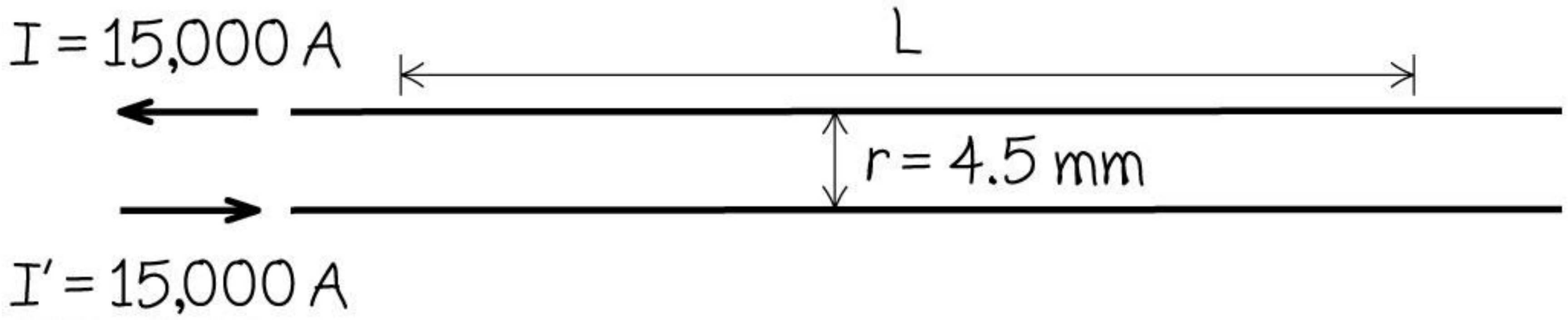
Force between parallel conductors

- 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.



Forces between parallel wires

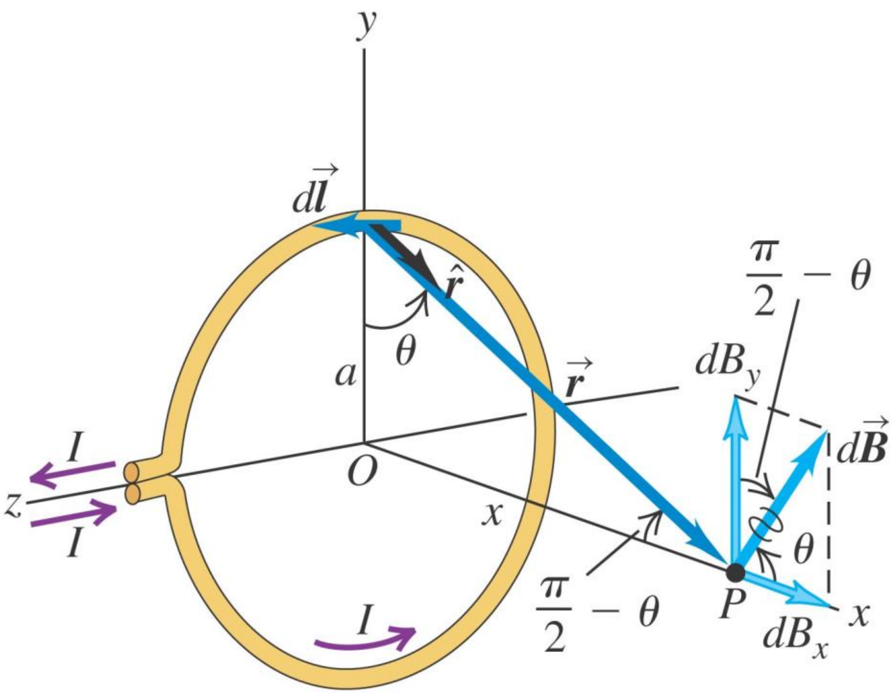
- Follow Example 28.5 using Figure 28.10 below.



Magnetic field of a circular current loop

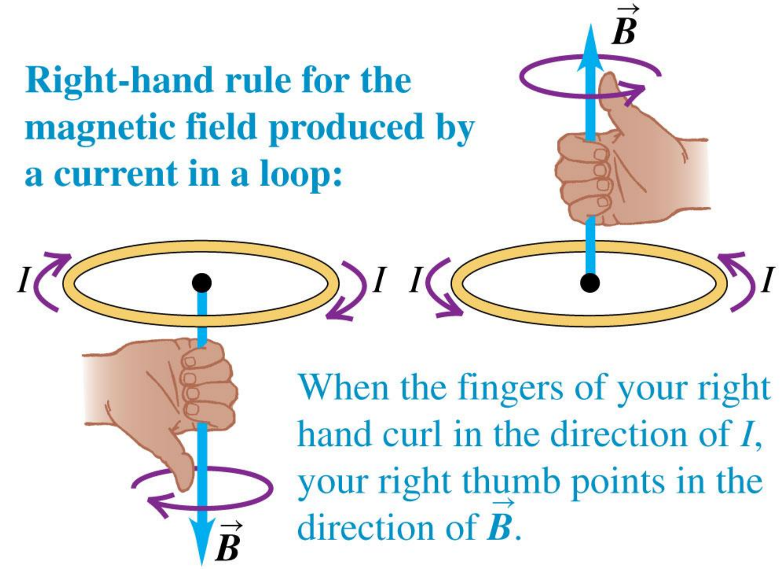
- The Biot Savart law gives $B_x = \mu_0 I a^2 / 2(x^2 + a^2)^{3/2}$ on the axis of the loop. Follow the text derivation using Figure 28.12 at the right.

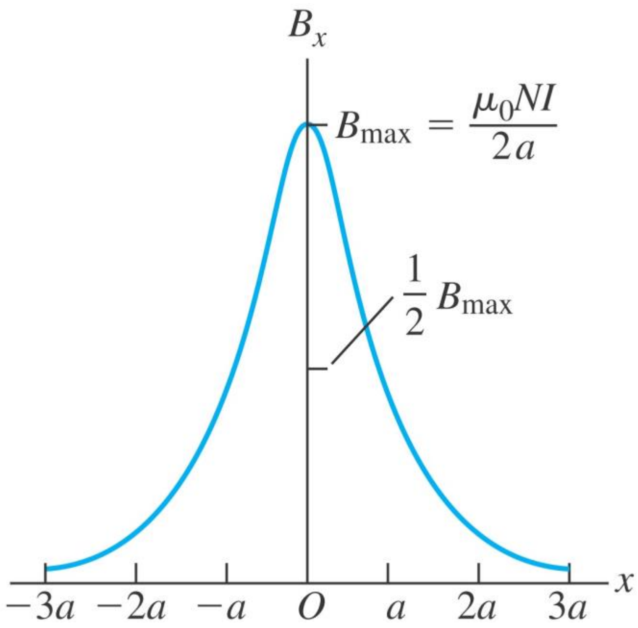
- At the center of N loops, the field on the axis is $B_x = \mu_0 N I / 2a$.



Magnetic field of a coil

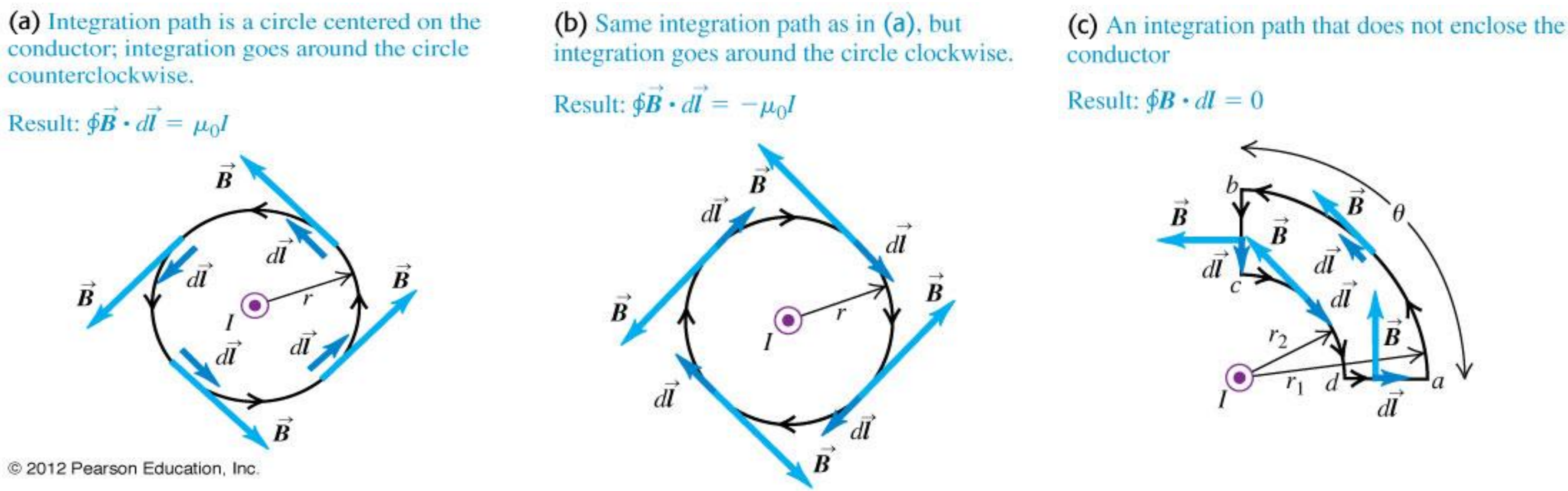
- Figure 28.13 (top) shows the direction of the field using the right-hand rule.
- Figure 28.14 (below) shows a graph of the field along the *x*-*a*xis.
- Follow Example 28.6.





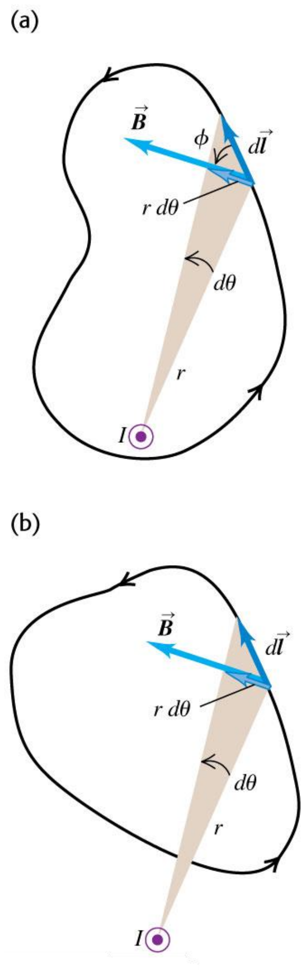
Ampere's law (special case)

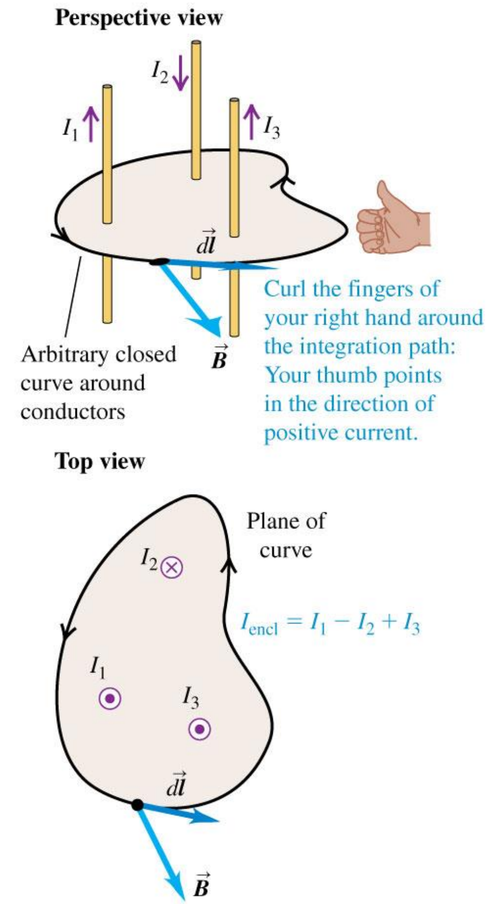
- Follow the text discussion of Ampere's law for a circular path around a long straight conductor, using Figure 28.16 below.



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.

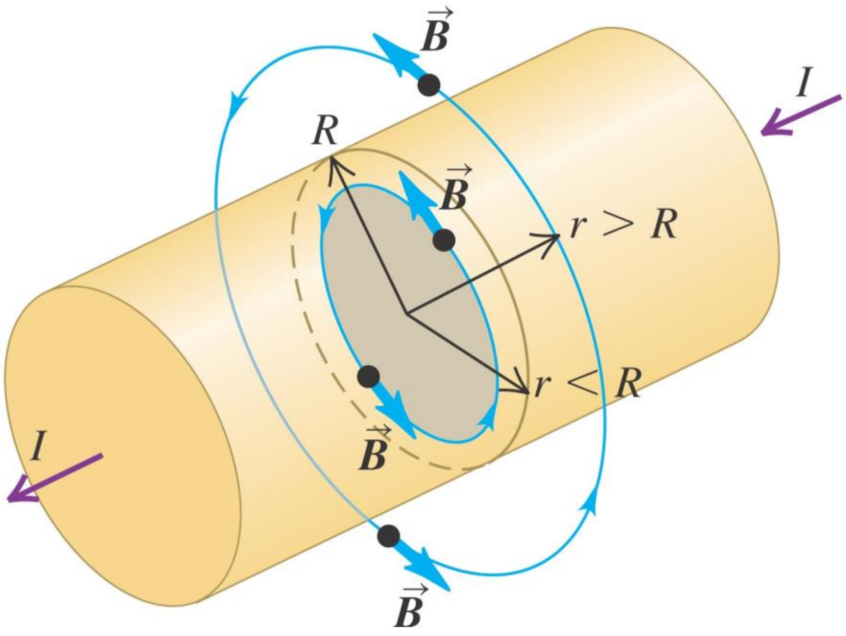


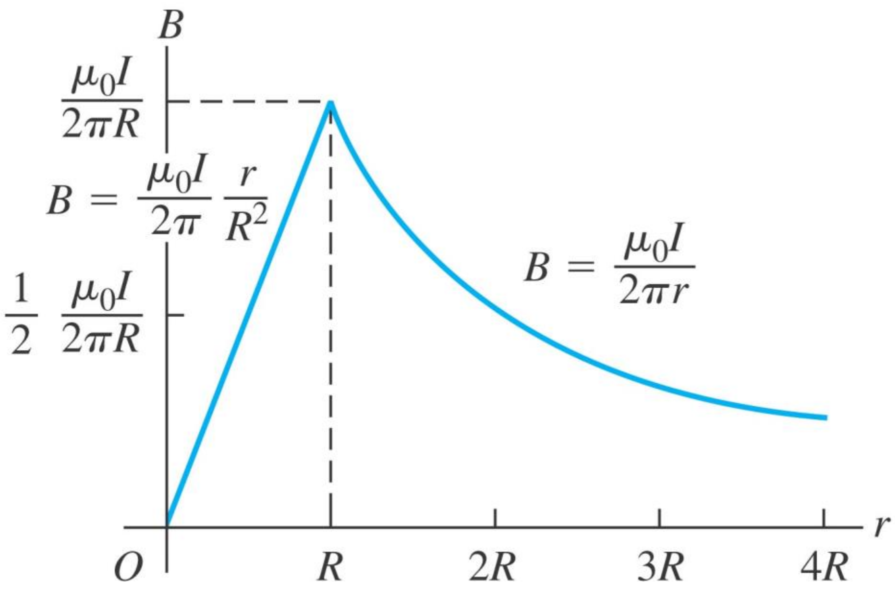


Ampere's law: If we calculate the line integral of the magnetic field around a closed curve, the result equals μ_0 times the total enclosed current: $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{encl}$.

Magnetic fields of long conductors

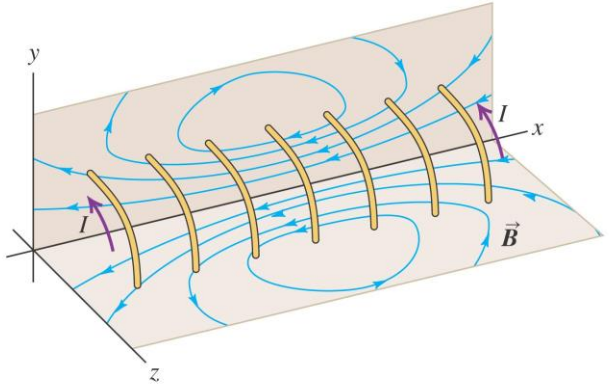
- Read Problem-Solving Strategy 28.2.
- Follow Example 28.7 for a long straight conductor.
- Follow Example 28.8 for a long cylinder, using Figures 28.20 and 28.21 below.

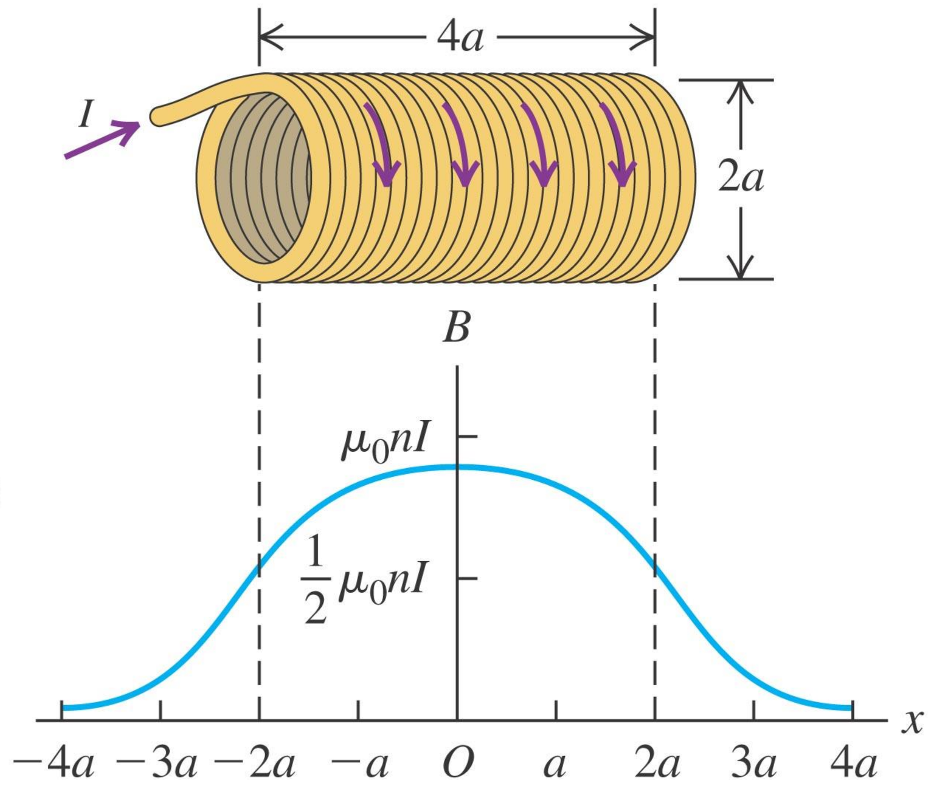


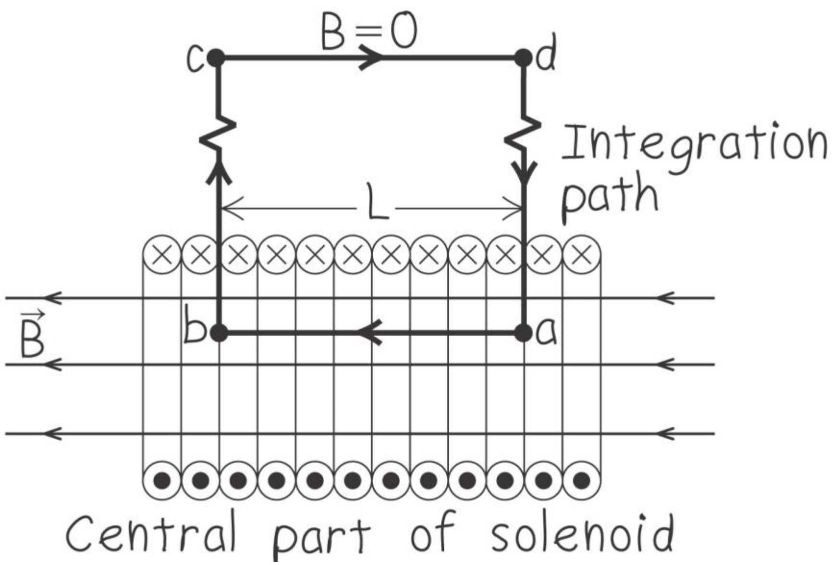


Field of a solenoid

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

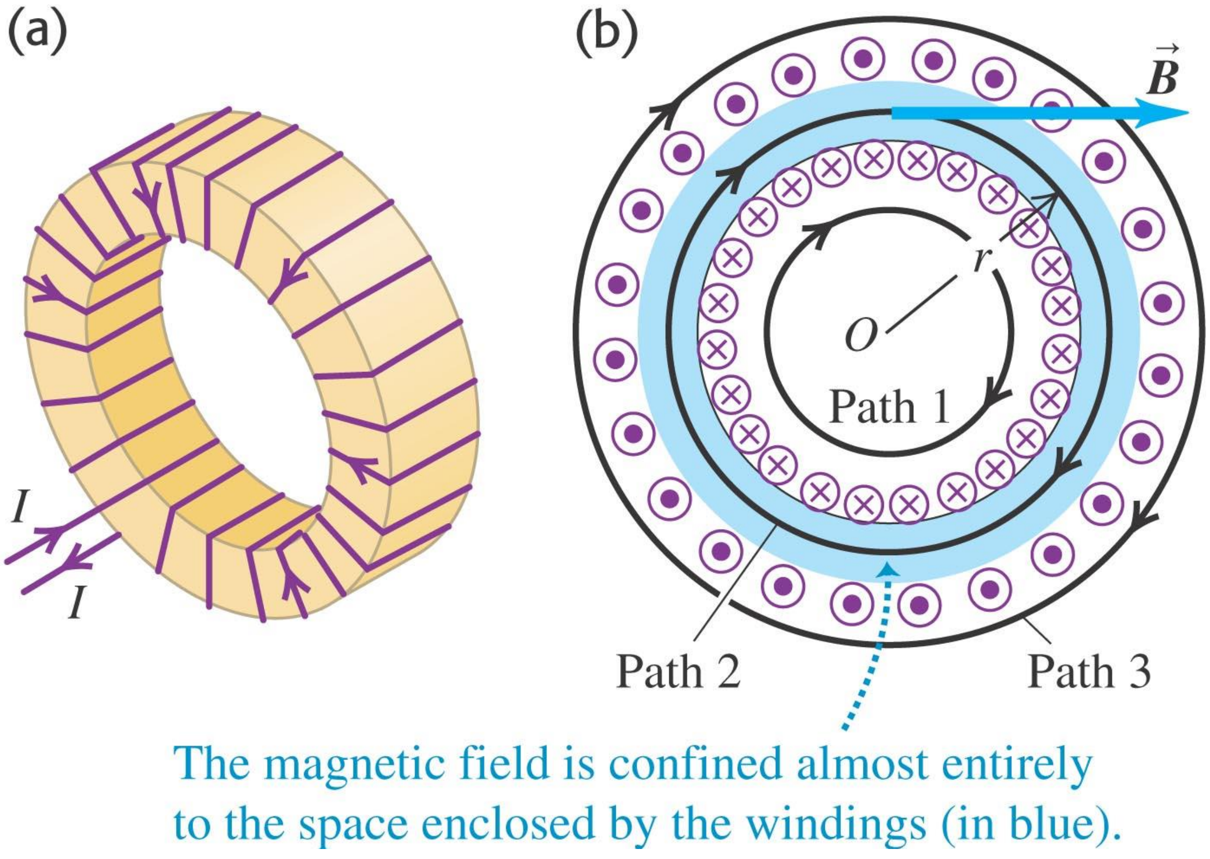






Field of a toroidal solenoid

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



The 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.

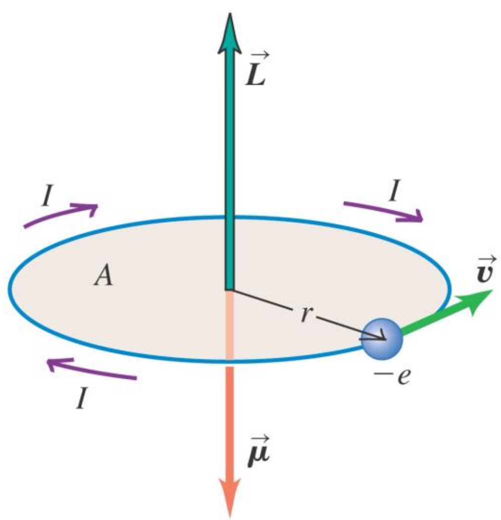
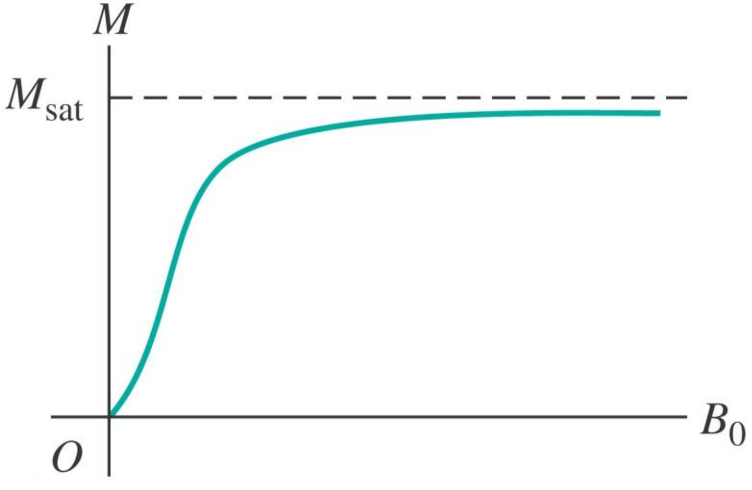


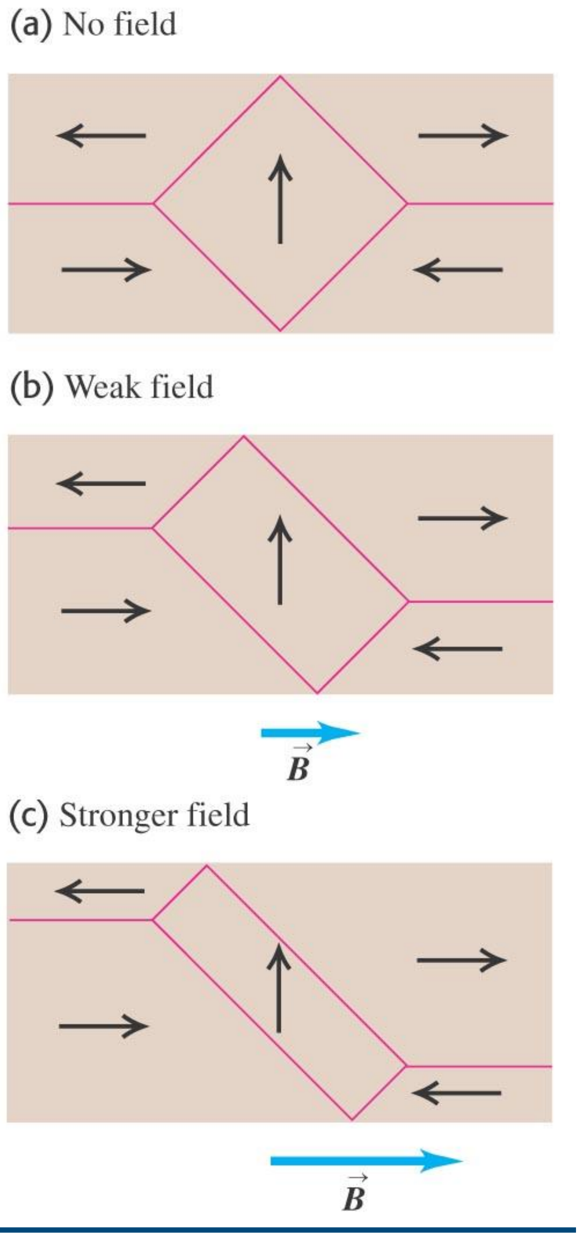
Table 28.1 Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at $T = 20°C$

Material	$\chi_m = K_m - 1\ (\times 10^{-5})$
Paramagnetic	
Iron ammonium alum	66
Uranium	40
Platinum	26
Aluminum	2.2
Sodium	0.72
Oxygen gas	0.19
Diamagnetic	
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.





Hysteresis

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