Chapter 28

Sources of Magnetic Field

PowerPoint® Lectures for
University Physics, Thirteenth Edition
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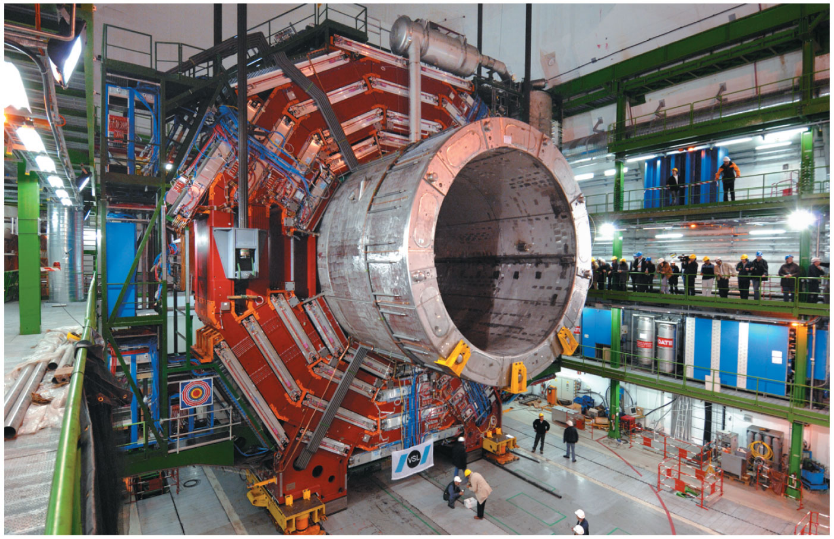
Goals for Chapter 28

- **Magnetic field produced by a moving charge**
- **Magnetic field of an element of a current-carrying conductor**
- **Magnetic field of a long, straight, current-carrying conductor**
- **Magnetic force between current-carrying wires**
- **Magnetic field of a circular loop**
- **Ampere’s Law and 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.



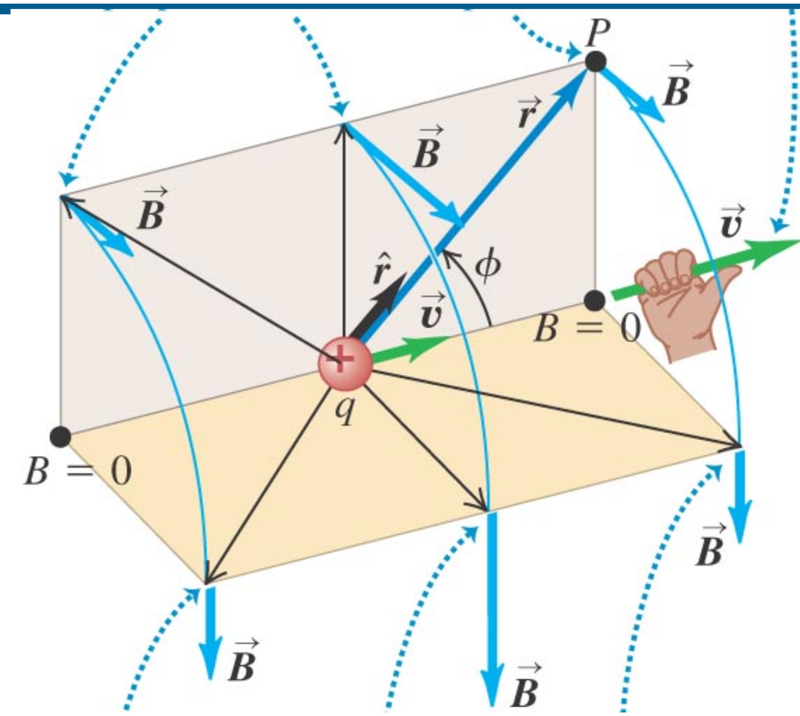
The magnetic field of a moving charge

- A moving charge generates a magnetic field that depends on the velocity of the charge.

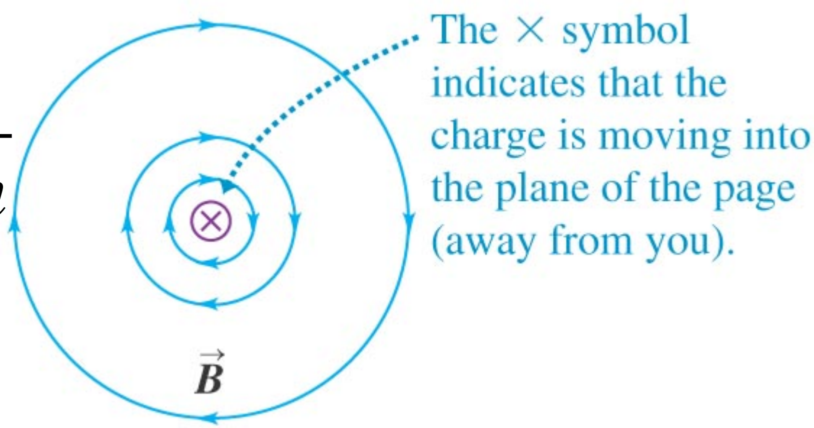
$$\mathbf{B} = \frac{\mu_0}{4\pi}\frac{q\mathbf{v}\times\hat{\mathbf{r}}}{r^2}$$

$$\text{Value of } \mu_0 : 4\pi\times10^{-7} = \frac{1}{\varepsilon_0 c^2}$$

$$\text{Unit of } \mu_0 : \frac{N.s^2}{C^2} \text{ or } \frac{T.m}{A} \text{ or } \frac{Wb}{A.m}$$

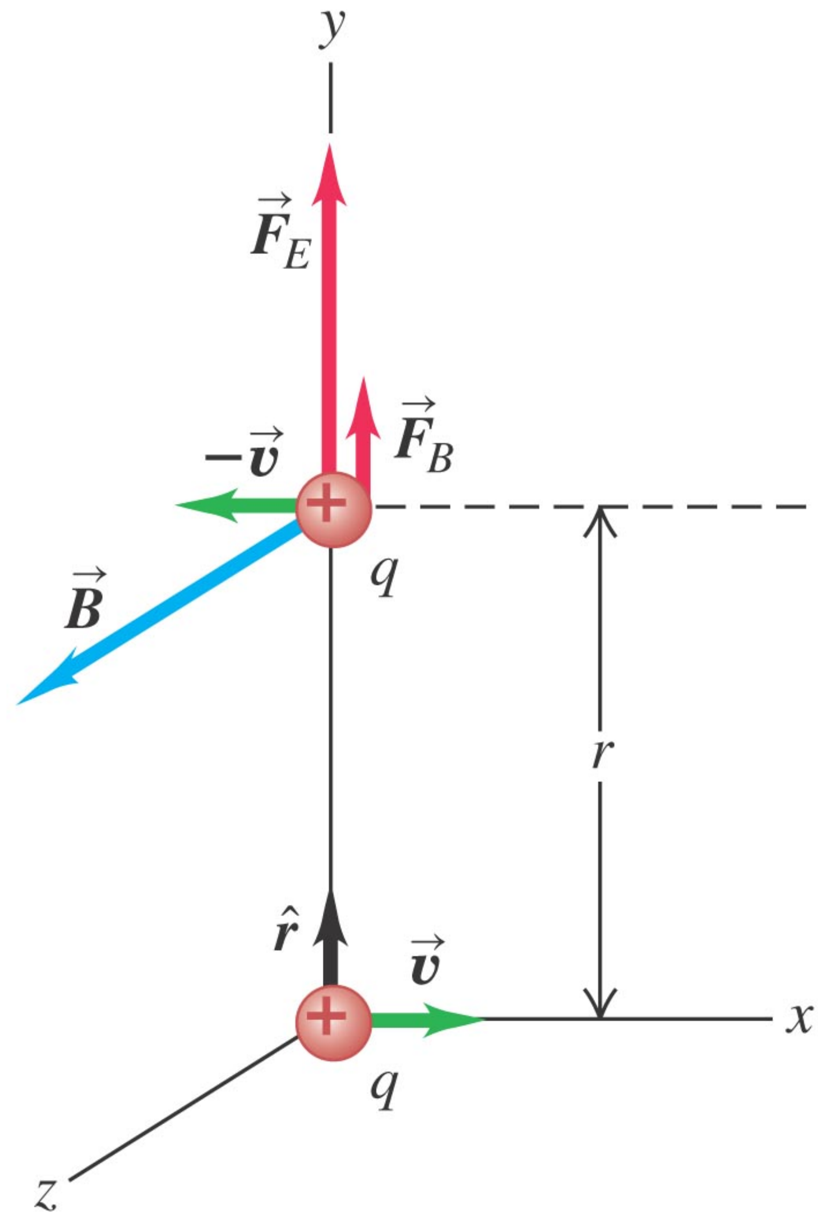


View from behind the charge



Magnetic force between moving protons

- Example 28.1 Two protons move parallel to the x-axis in opposite directions at the speed of v (small compared to the speed of light). At the instant shown, find the electric and magnetic forces on the upper proton and determine ratio of their magnitude.



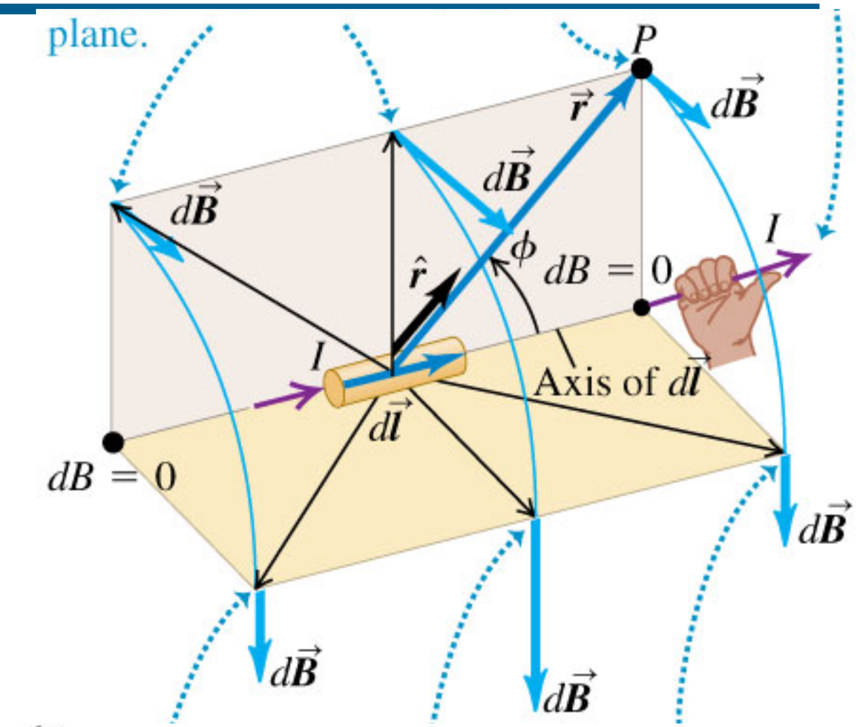
Magnetic field of a current element

- Principle of superposition: The total magnetic field of several moving charges is the vector sum of each field.

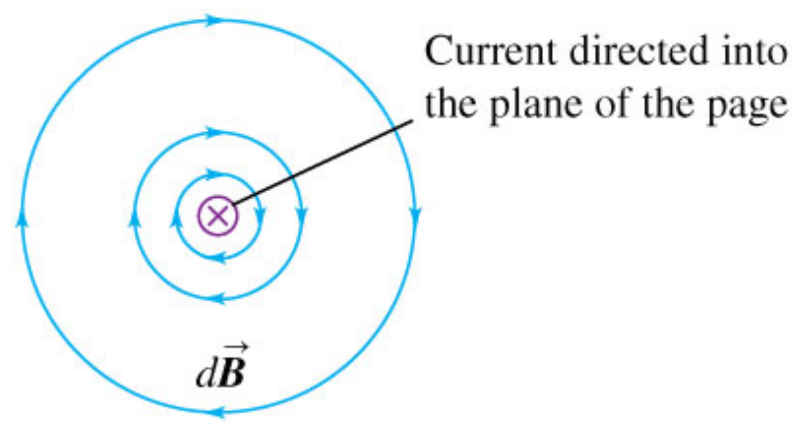
$$\mathbf{B} = \sum_{i=\text{all charges}} \mathbf{B}_i$$

- The *law of Biot and Savart: magnetic field around a current carrying conductor is:*

$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I\, d\mathbf{l}\times\hat{\mathbf{r}}}{r^2}$$

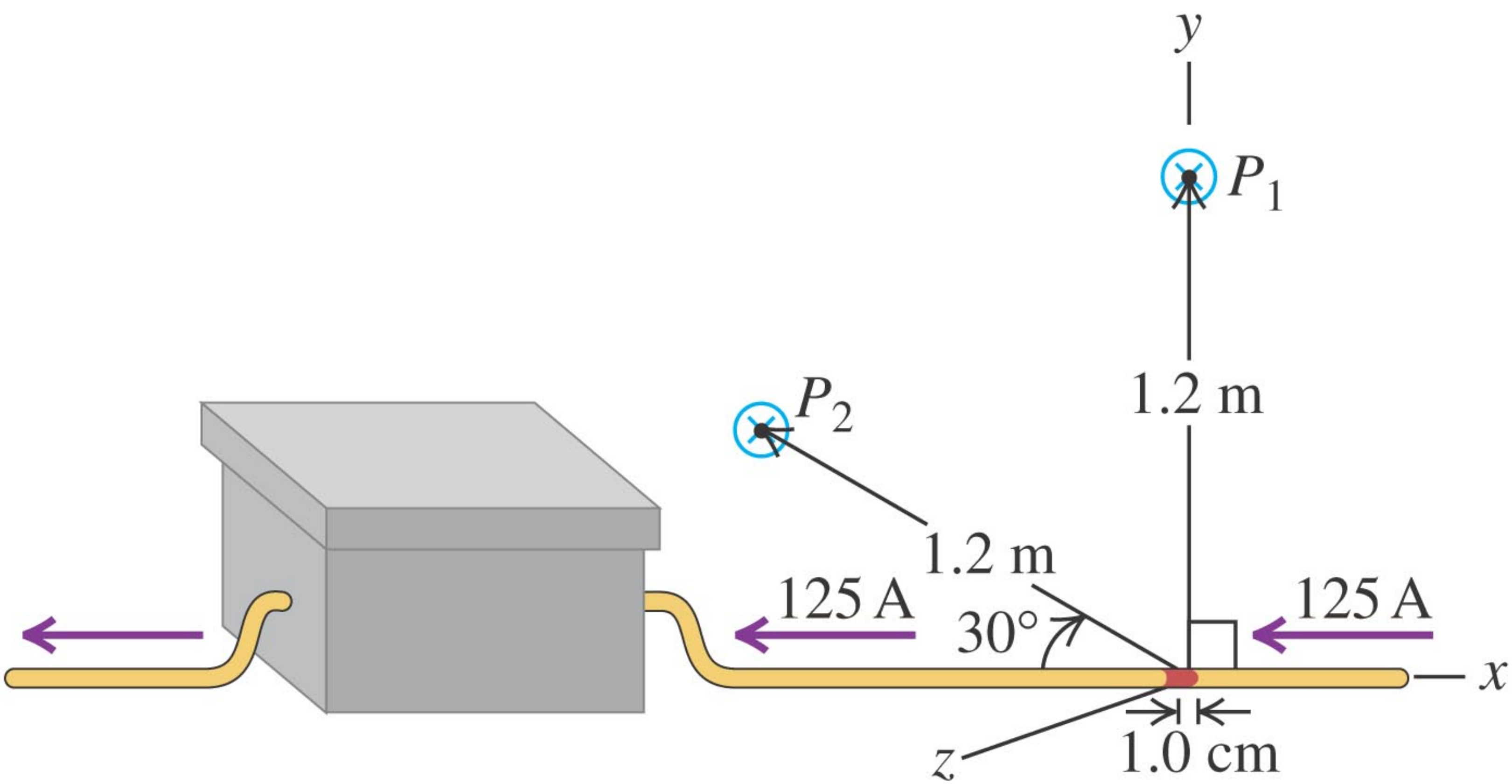


(b) View along the axis of the current element



Magnetic field of a current segment

- Example 28.2 A cupper wire carries a steady current of 12.5A to an electroplating tank. Find the magnetic field caused by a 1.0 cm of the wire at points P_1 and P_2

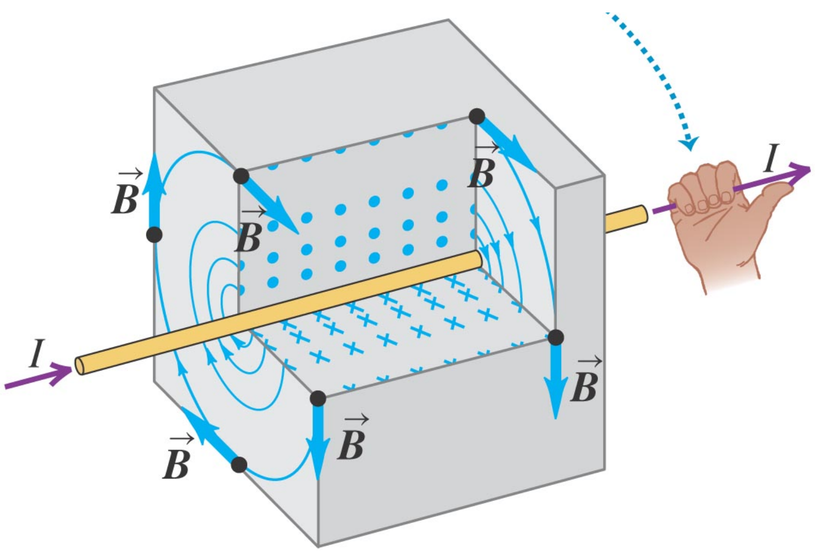


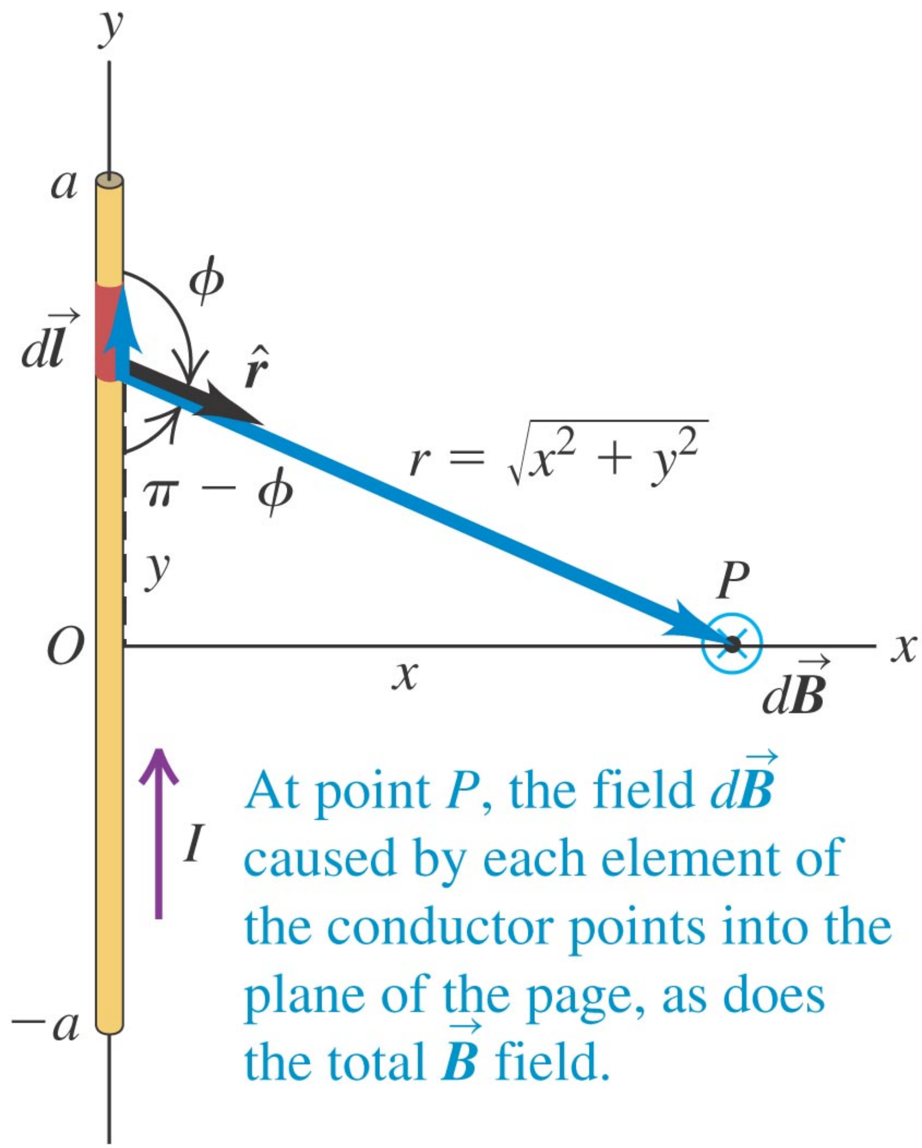
Magnetic field of a straight current-carrying conductor

- If we apply the law of Biot and Savart to a long straight conductor, the result is

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

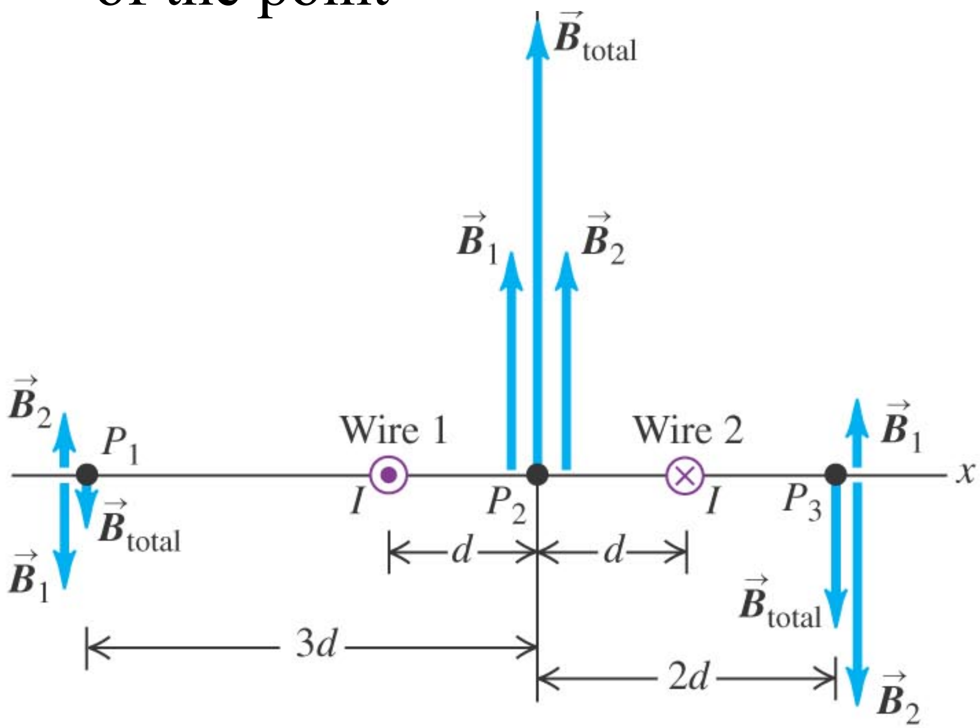
- The right-hand rule for the direction of the force.

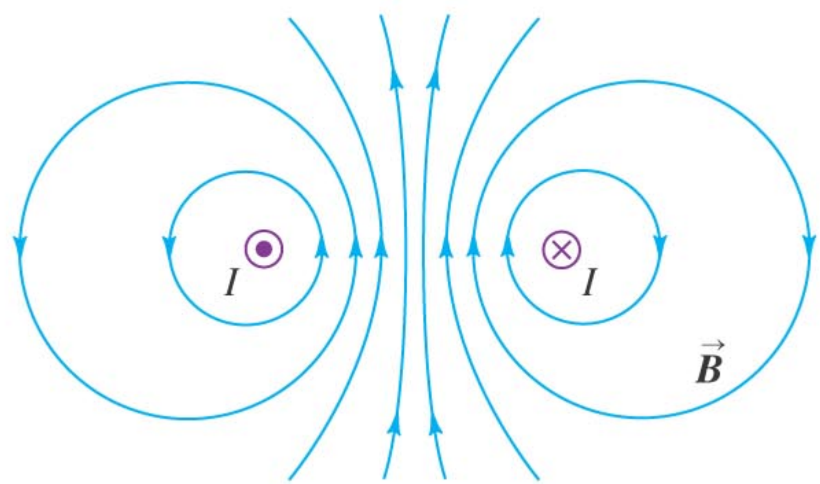




Magnetic fields of long wires

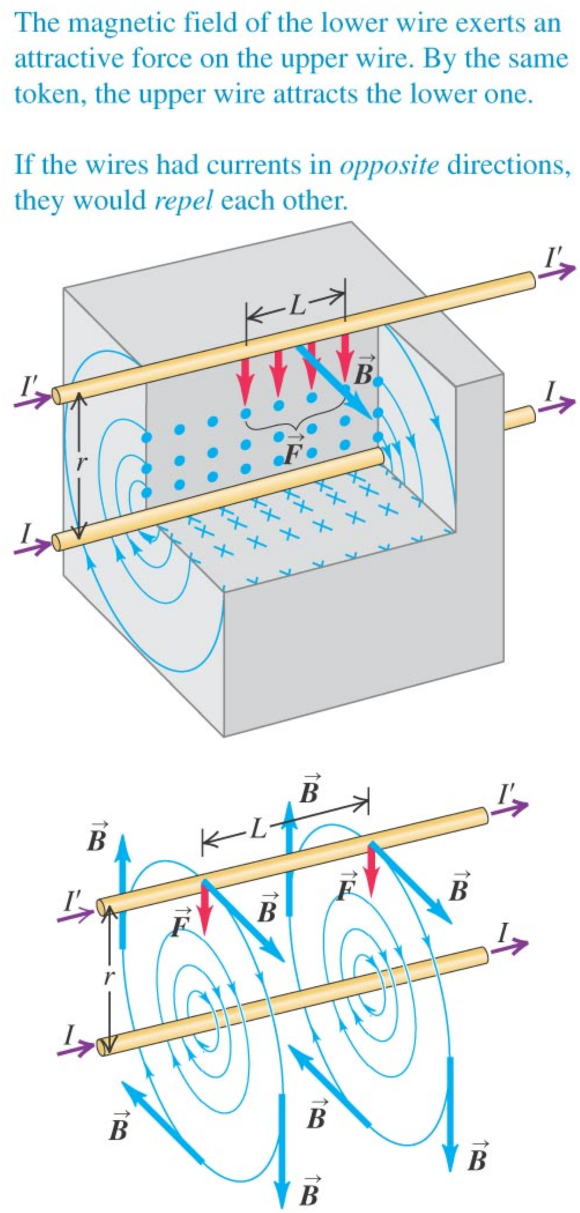
- 28.3 At what distance from a wire carrying a 1.0A current the magnetic field is: 0.5E-4T (B of earth in Pittsburg).
- 28.4 Two long straight parallel wires each carrying current I in opposite directions. A) Find the magnitude and direction of B at points P_1 and P_2 and P_3 . B) Find the magnitude and direction of B at any point on x-axis to the right of wire 2 in terms of the x-coordinate of the point





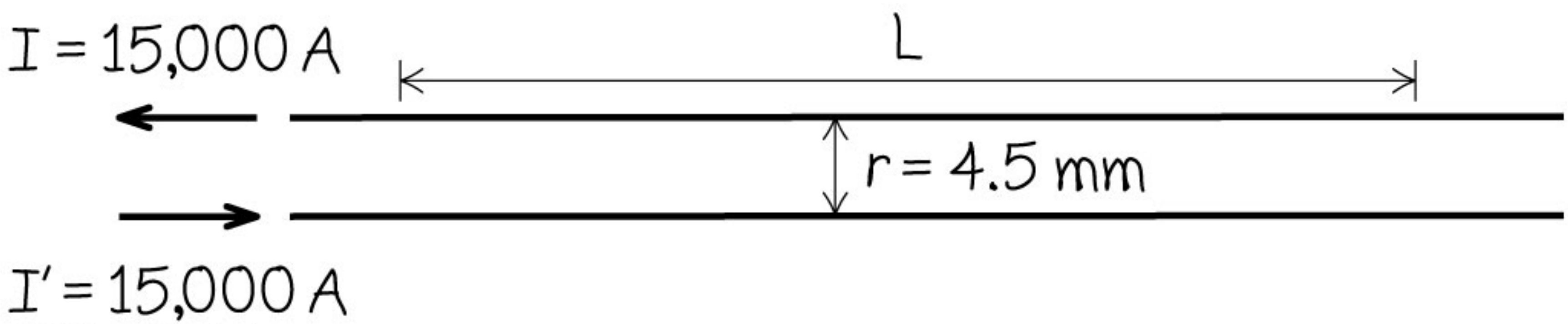
Force between parallel conductors

- The force per unit length on each conductor is $F/L = \mu_0 I I' L/2\pi r$. (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.



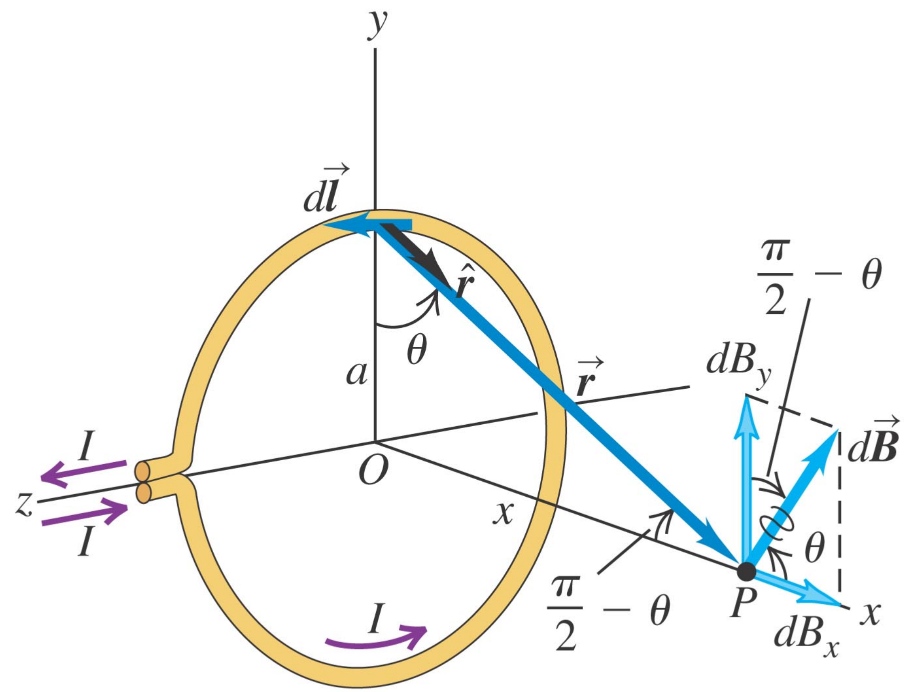
Forces between parallel wires

- Follow Example 28.5 using Figure 28.10 below.



Magnetic field of a circular current loop

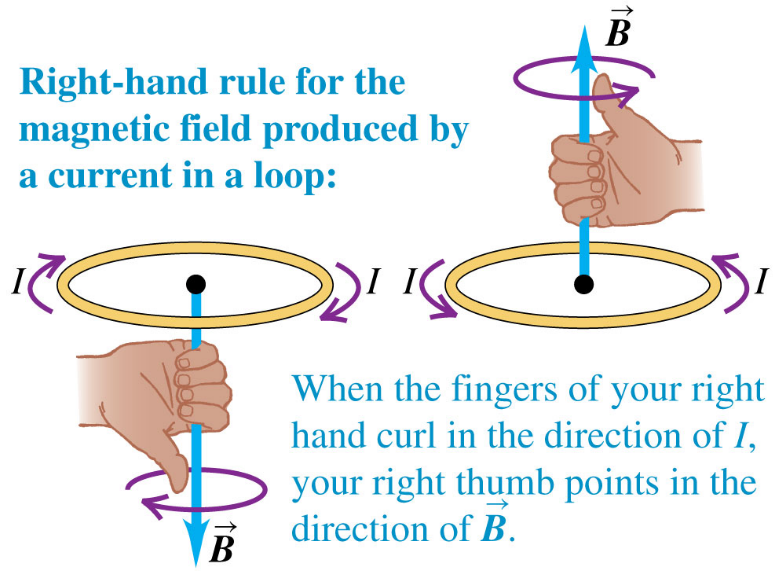
- The Biot Savart law gives $B_x = \mu_0 I a^2/2(x^2 + a^2)^{3/2}$ on the axis of the loop. Follow the text derivation using Figure 28.12 at the right.

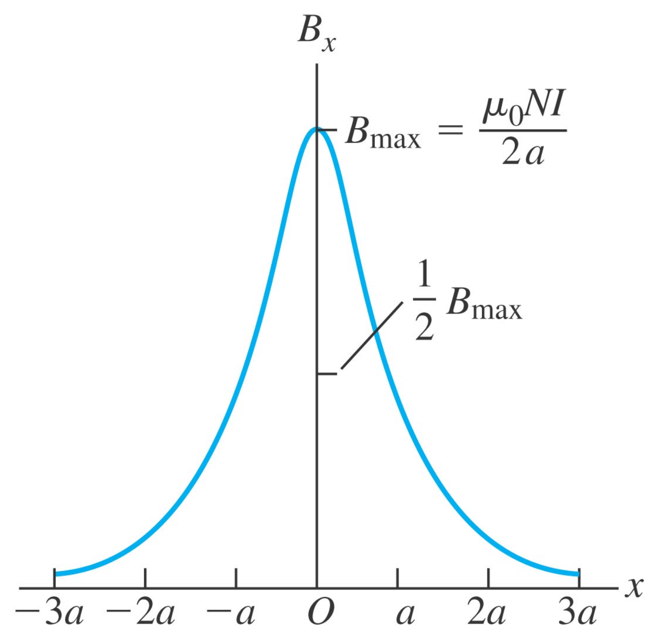


- At the center of N loops, the field on the axis is $B_x = \mu_0 NI/2a$.

Magnetic field of a coil

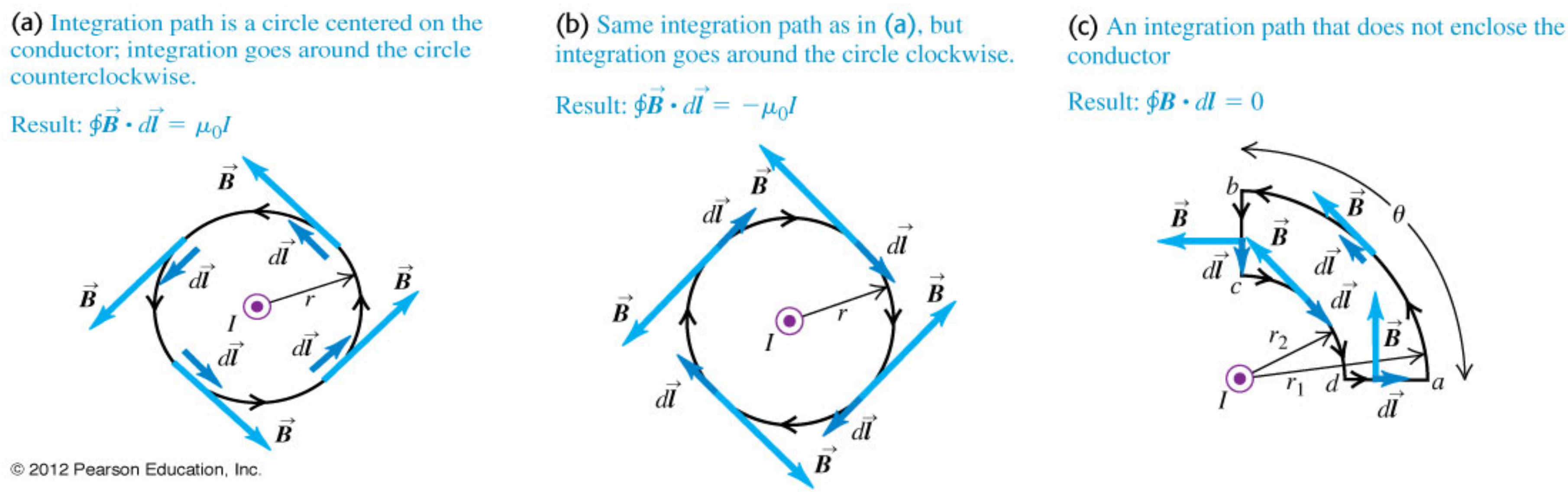
- Figure 28.13 (top) shows the direction of the field using the right-hand rule.
- Figure 28.14 (below) shows a graph of the field along the *x-a*xis.
- Follow Example 28.6.





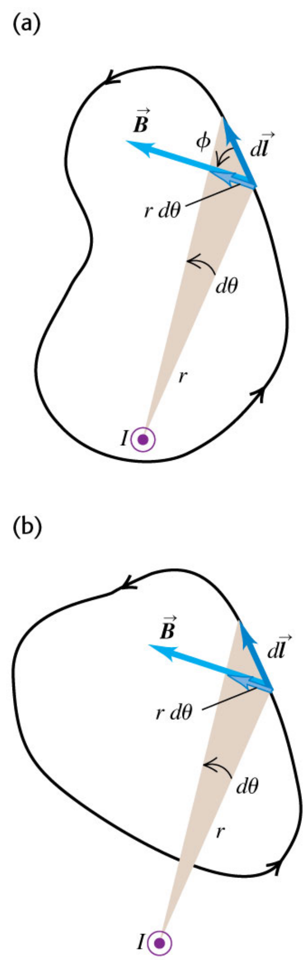
Ampere's law (special case)

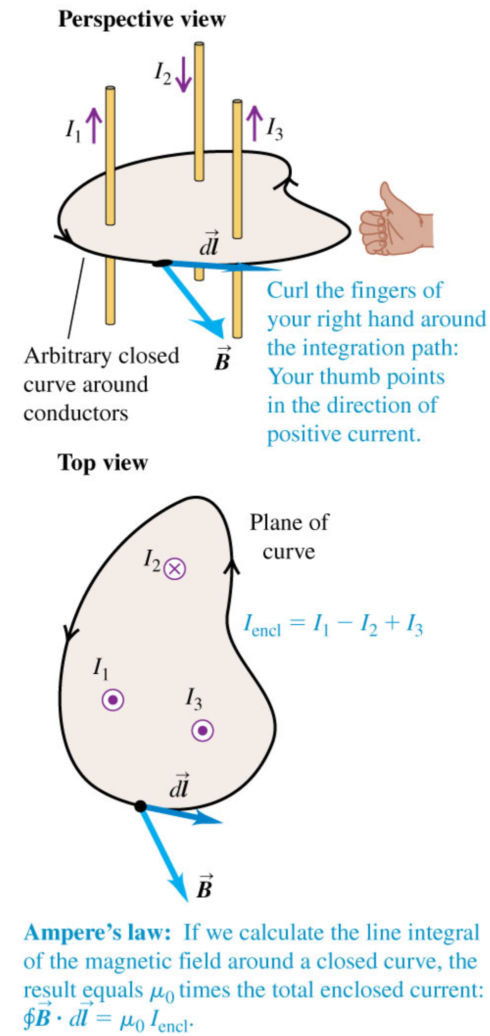
- Follow the text discussion of Ampere's law for a circular path around a long straight conductor, using Figure 28.16 below.



Ampere's law (general statement)

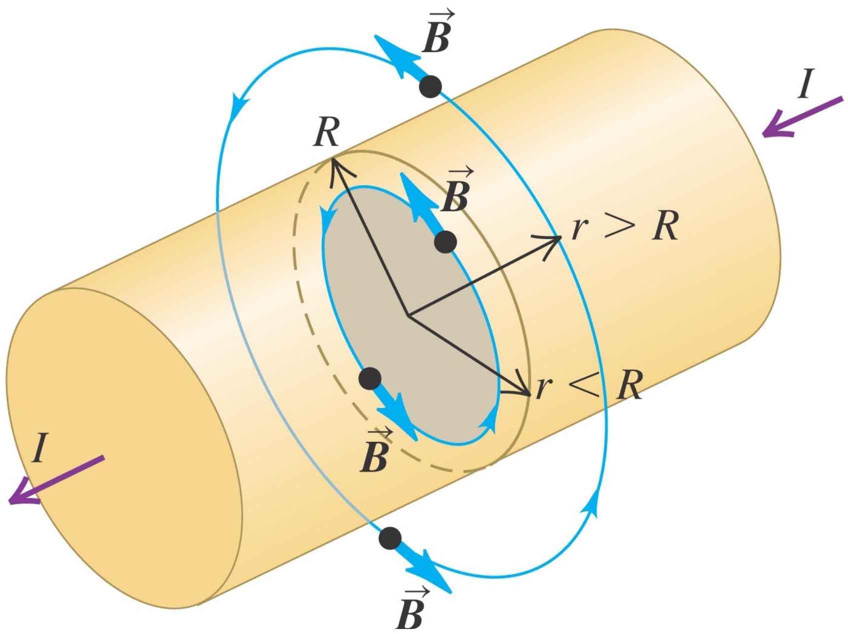
- Follow the text discussion of the general statement of Ampere's law, using Figures 28.17 and 28.18 below.

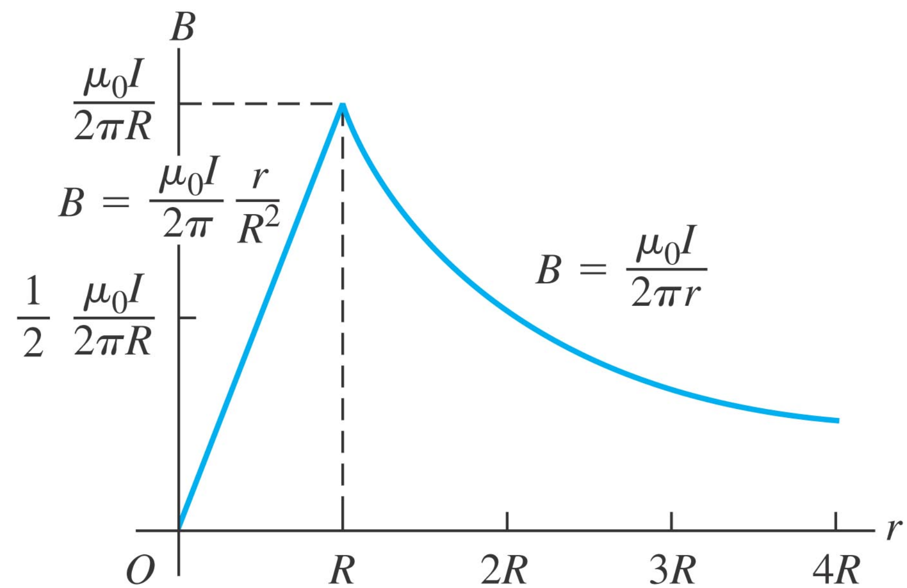




Magnetic fields of long conductors

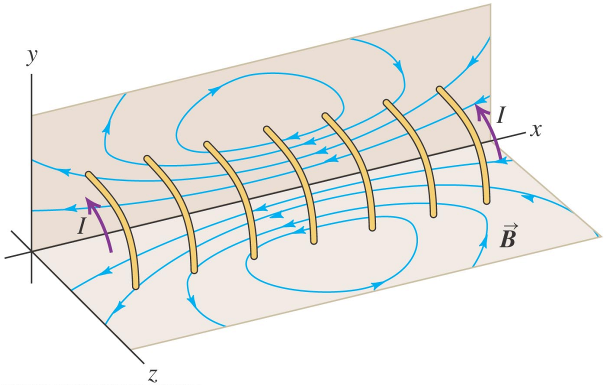
- Read Problem-Solving Strategy 28.2.
- Follow Example 28.7 for a long straight conductor.
- Follow Example 28.8 for a long cylinder, using Figures 28.20 and 28.21 below.

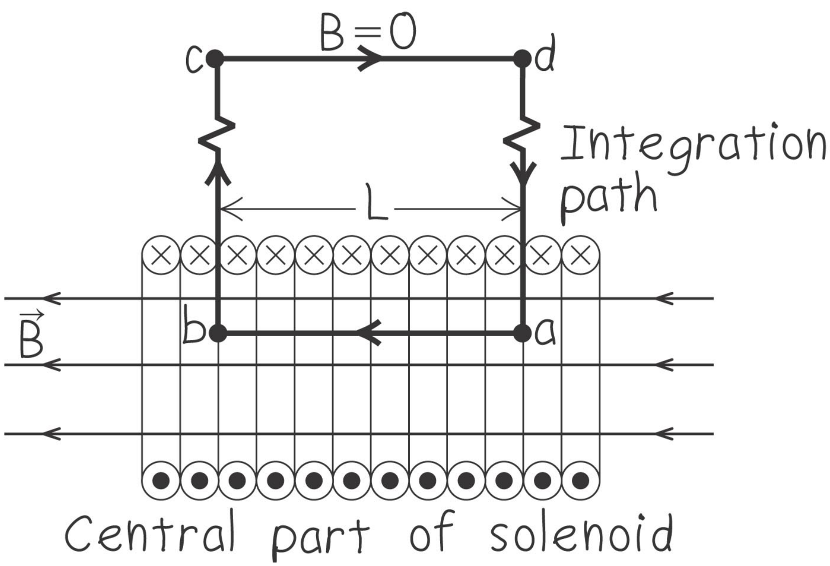


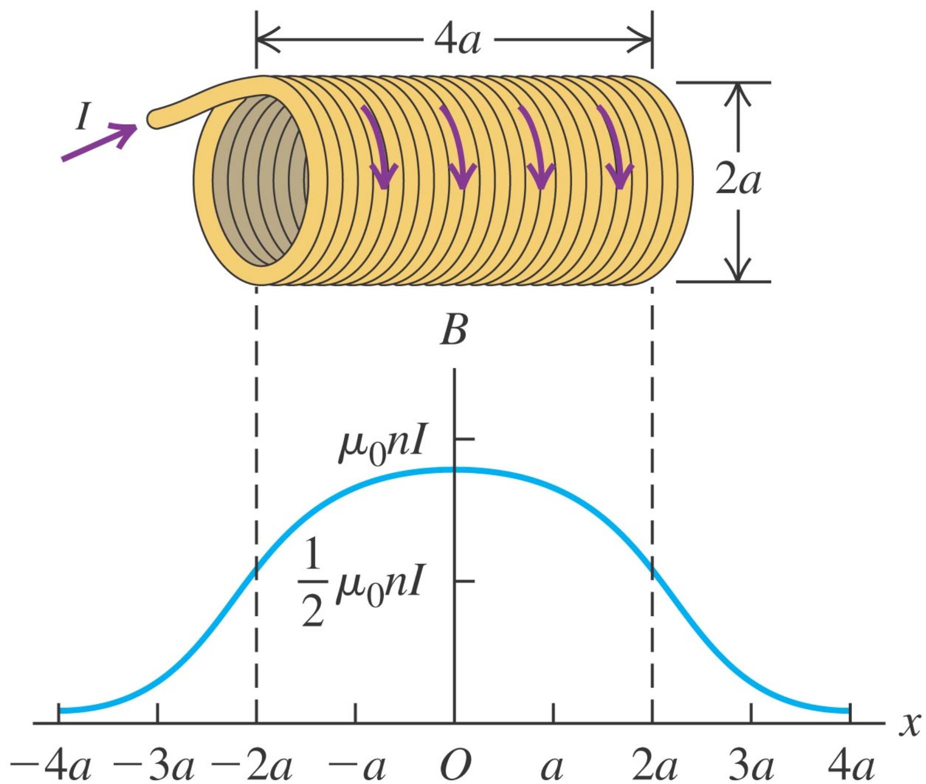


Field of a solenoid

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

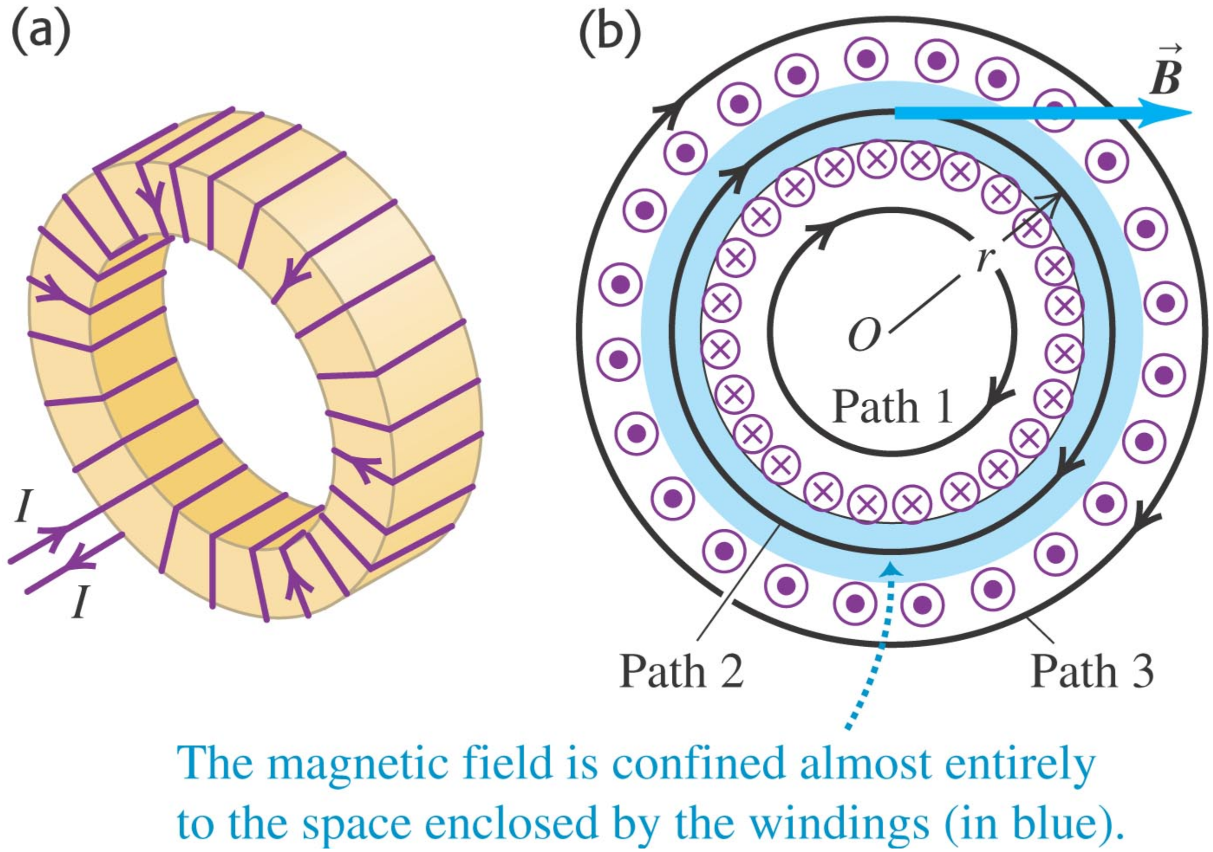






Field of a toroidal solenoid

- 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.

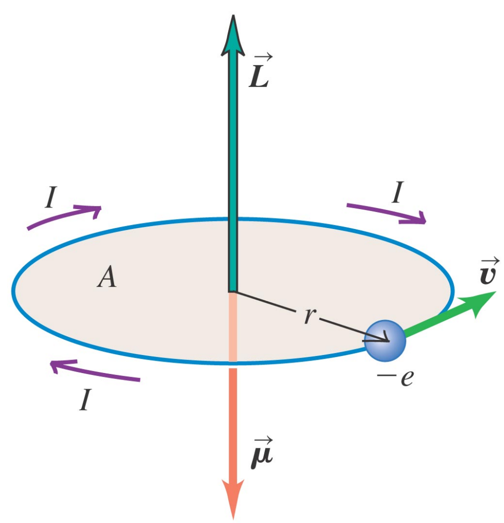
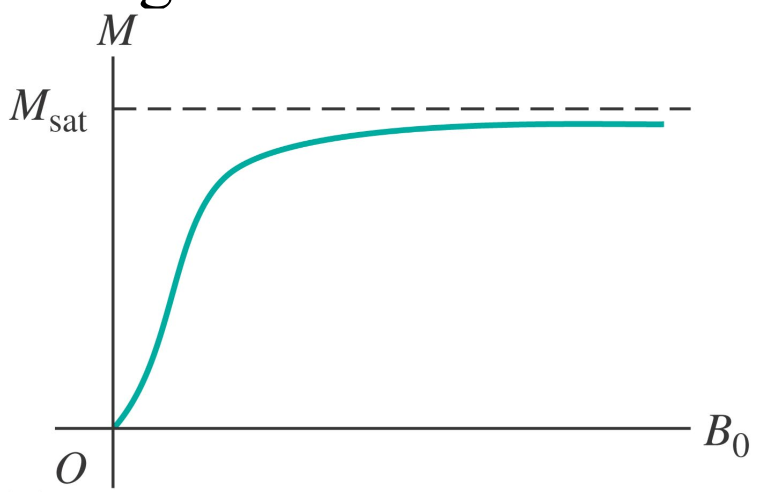


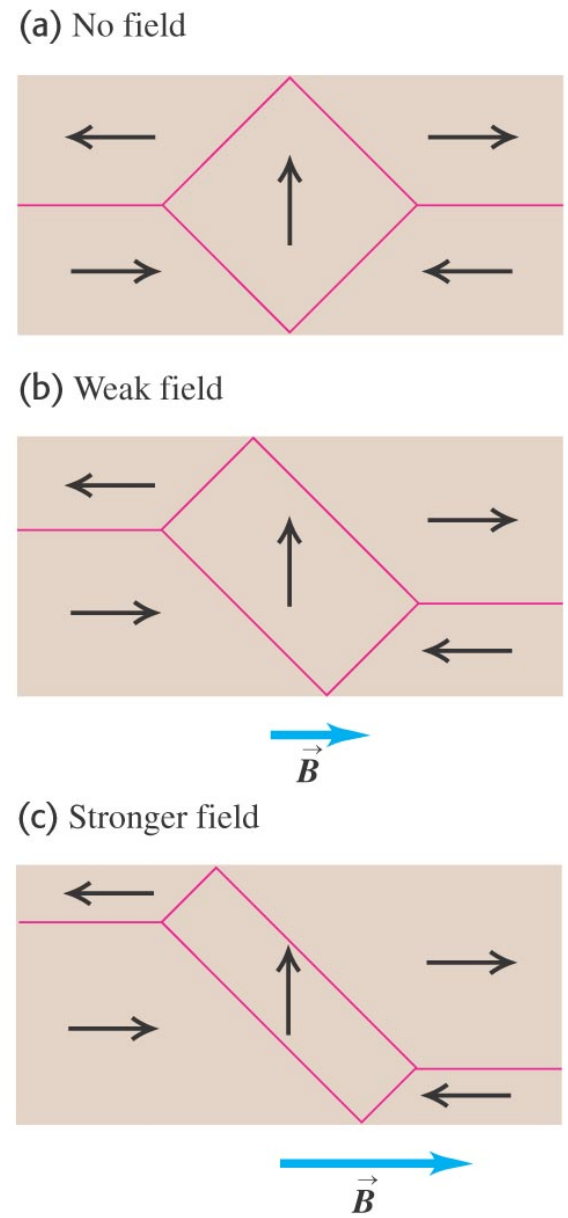
Table 28.1 Magnetic Susceptibilities of Paramagnetic and Diamagnetic Materials at $T = 20°C$

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

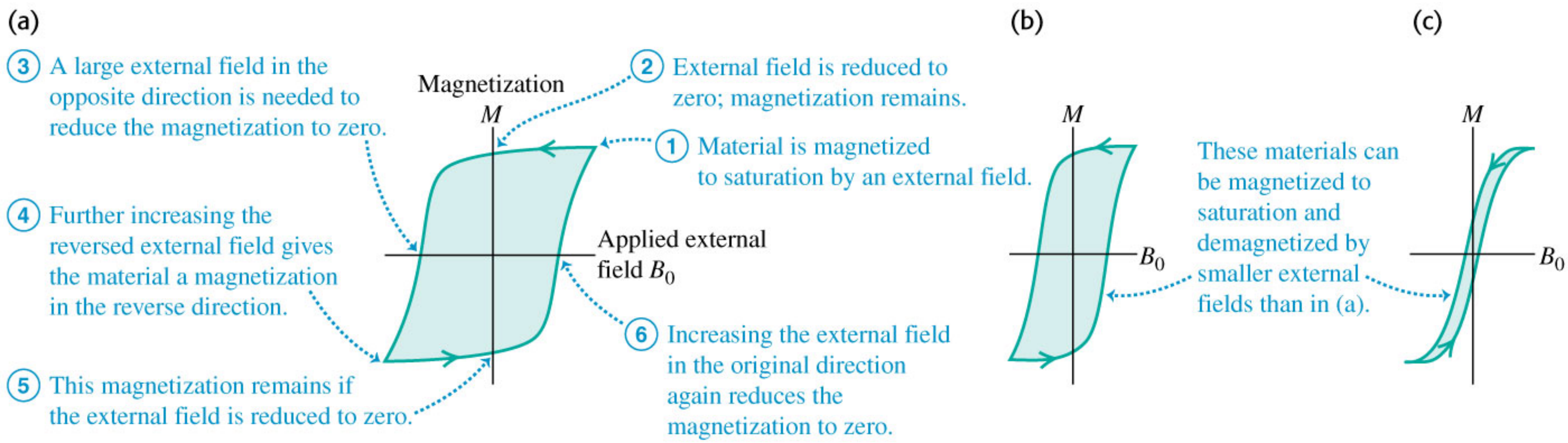
- Follow the text discussion of *diamagnetism* and *ferromagnetism*.
- Figure 28.27 at the right shows how *magnetic domains* react to an applied magnetic field.
- Figure 28.28 below shows a magnetization curve for a ferromagnetic material.





Hysteresis

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



Q28.1

A positive point charge is moving directly toward point *P*. The magnetic field that the point charge produces at point *P*

A. points from the charge toward point *P*.

B. points from point *P* toward the charge.

C. is perpendicular to the line from the point charge to point *P*.

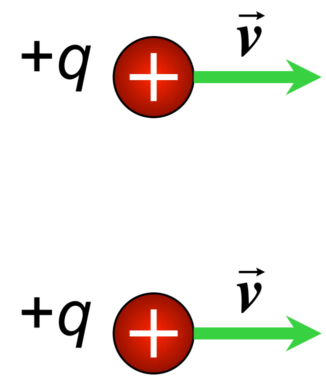
D. is zero.

E. The answer depends on the speed of the point charge.

Q28.2

Two positive point charges move side by side in the same direction with the same velocity.

What is the direction of the magnetic force that the upper point charge exerts on the lower one?



A. toward the upper point charge (the force is attractive)

B. away from the upper point charge (the force is repulsive)

C. in the direction of the velocity

D. opposite to the direction of the velocity

E. none of the above

Q28.3

A long straight wire lies along the *y*-axis and carries current in the positive *y*-direction.

A positive point charge moves along the *x*-axis in the positive *x*-direction. The magnetic force that the wire exerts on the point charge is in

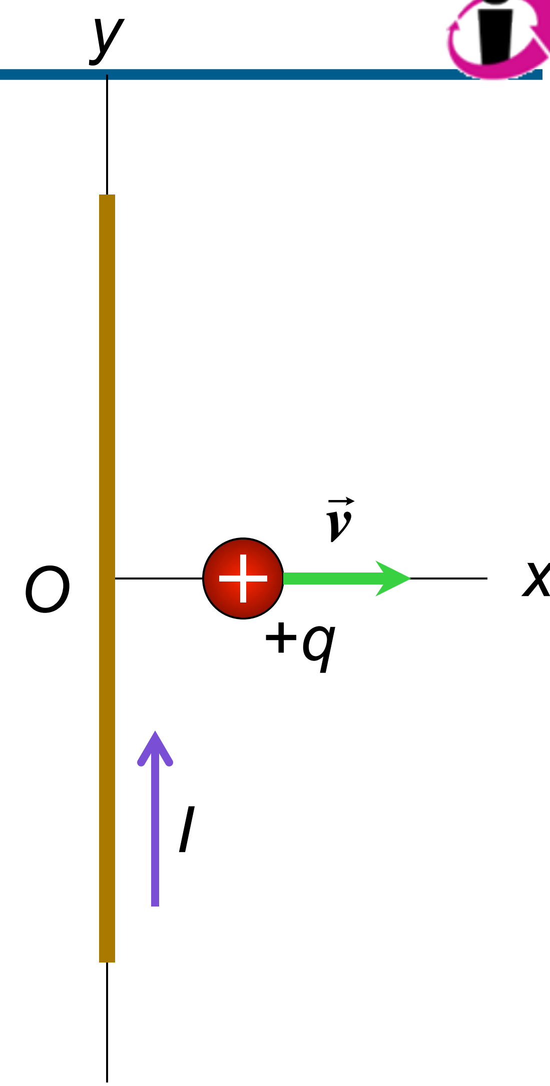
A. the positive *x*-direction.

B. the negative *x*-direction.

C. the positive *y*-direction.

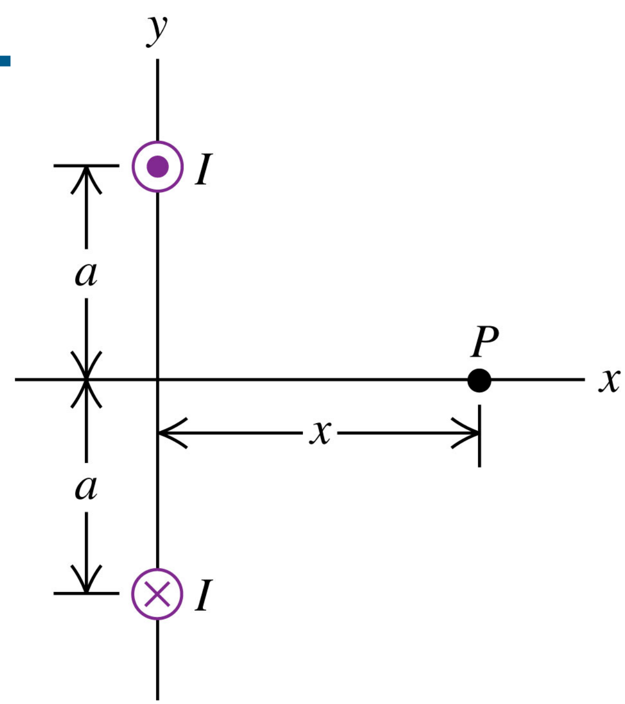
D. the negative *y*-direction.

E. none of the above



Q28.4

Two long, straight wires are oriented perpendicular to the *xy*-plane. They carry currents of equal magnitude *I* in opposite directions as shown. At point *P*, the magnetic field due to these currents is in



A. the positive *x*-direction.

B. the negative *x*-direction.

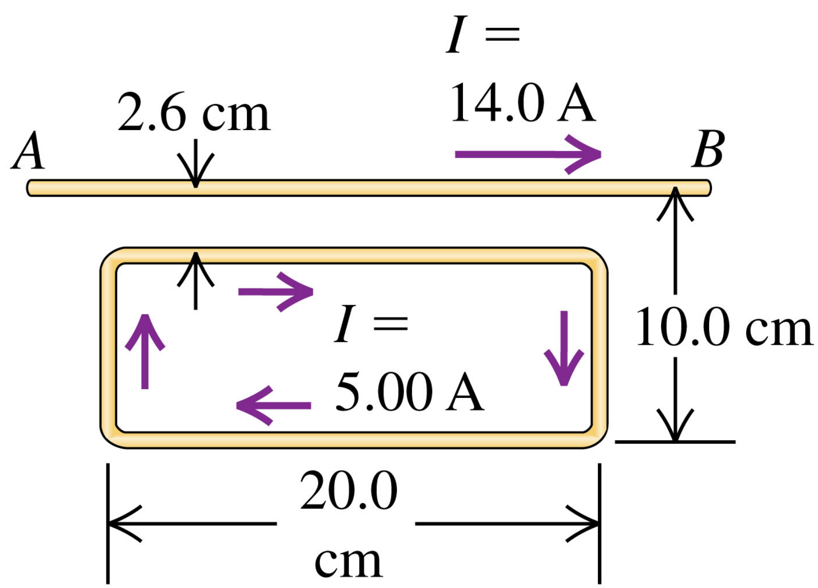
C. the positive *y*-direction.

D. the negative *y*-direction.

E. none of the above

Q28.5

The long, straight wire *AB* carries a 14.0-A current as shown. The rectangular loop has long edges parallel to *AB* and carries a clockwise 5.00-A current.



What is the direction of the net magnetic force that the straight wire *AB* exerts on the loop?

A. to the right

B. to the left

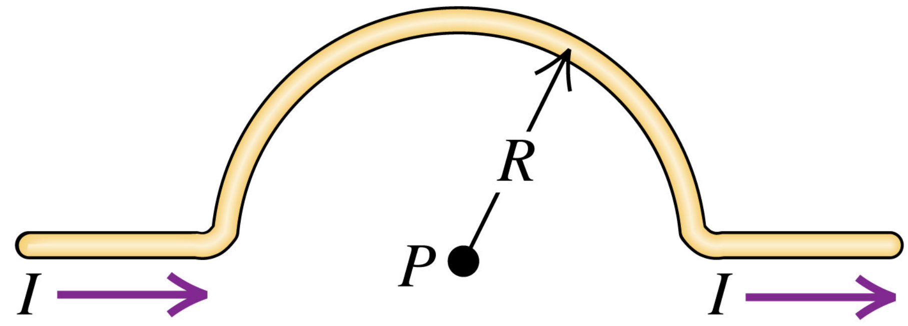
C. upward (toward *AB*)

D. downward (away from *AB*)

E. misleading question—the net magnetic force is zero

Q28.6

A wire consists of two straight sections with a semicircular section between them. If current flows in the wire as shown, what is the direction of the magnetic field at *P* due to the current?



A. to the right

B. to the left

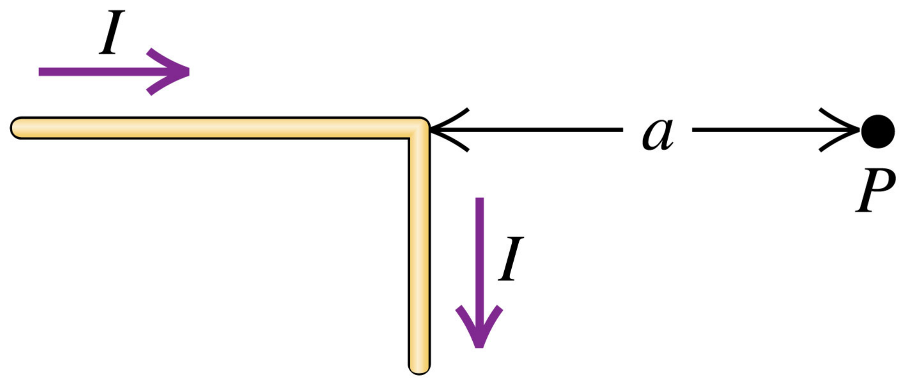
C. out of the plane of the figure

D. into the plane of the figure

E. misleading question—the magnetic field at *P* is zero

Q28.7

The wire shown here is infinitely long and has a 90° bend. If current flows in the wire as shown, what is the direction of the magnetic field at *P* due to the current?



A. to the right

B. to the left

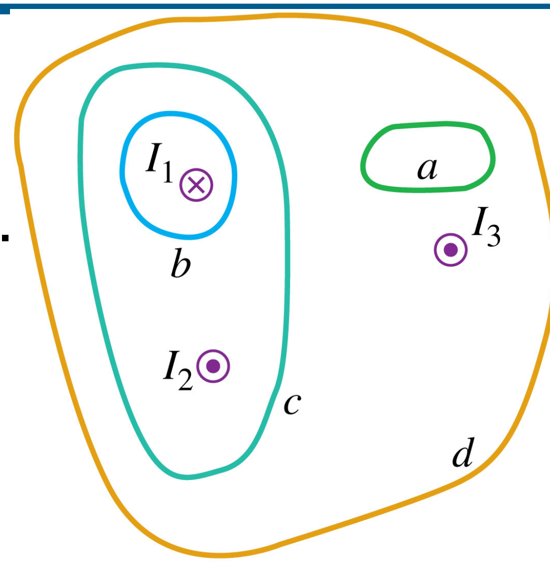
C. out of the plane of the figure

D. into the plane of the figure

E. none of these

Q28.8

The figure shows, in cross section, three conductors that carry currents perpendicular to the plane of the figure.



If the currents I_1, I_2, and I_3 all have the same magnitude, for which path(s) is the line integral of the magnetic field equal to zero?

A. path *a* only

B. paths *a* and *c*

C. paths *b* and *d*

D. paths *a*, *b*, *c*, and *d*

E. The answer depends on whether the integral goes clockwise or counterclockwise around the path.