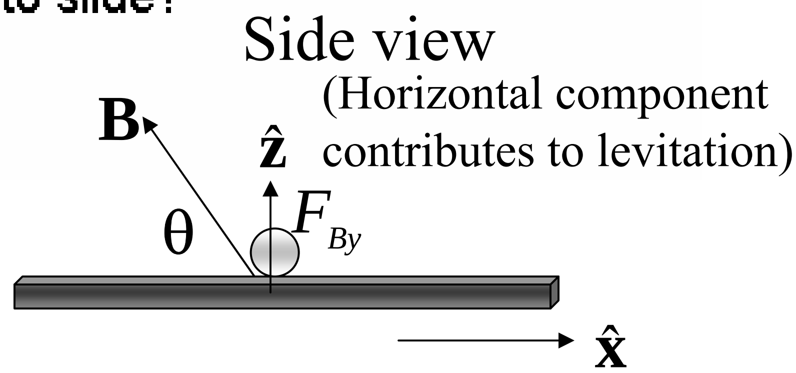
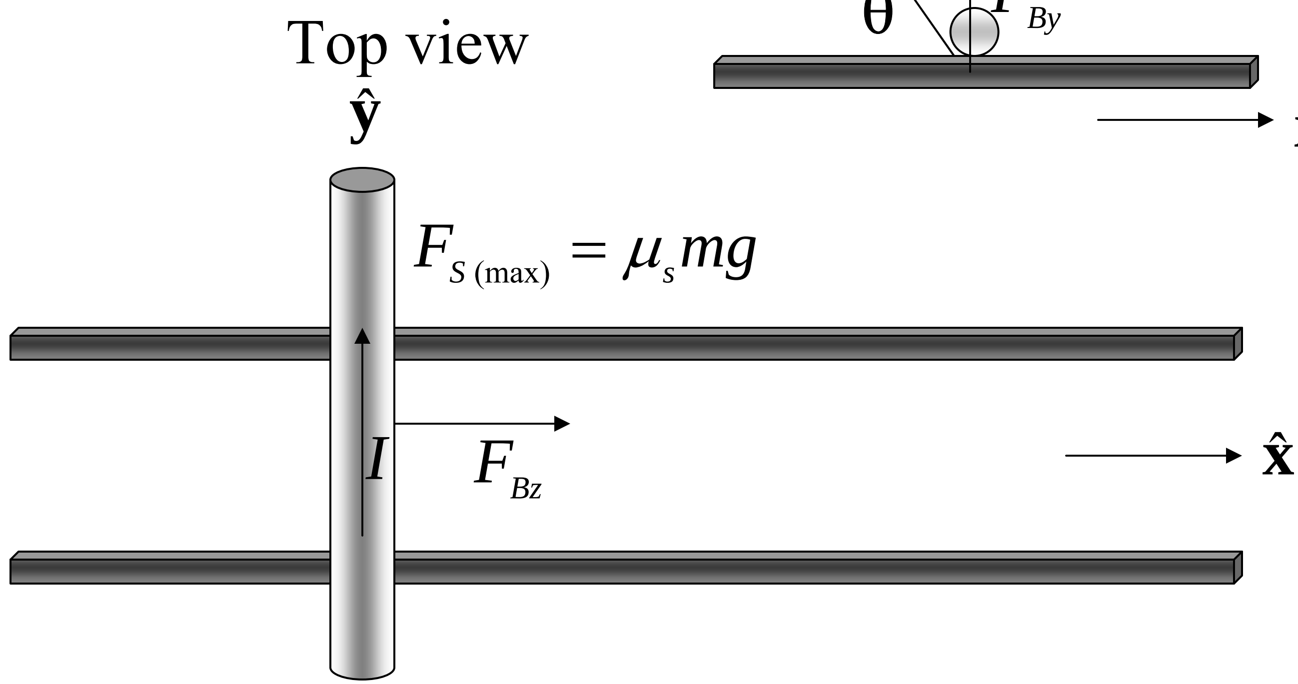
Announcements

1. Reminders
    - Homework is important! If you need more time for your homework, extensions are possible if you ask.
    - Rework exam for ≤ 10 extra credit points (goes in general "extra credit" accumulation) -- due 2/14/05
2. Comment on HW #3 for Assignment 10
3. Continue discussion of magnetic forces and sources of magnetic fields

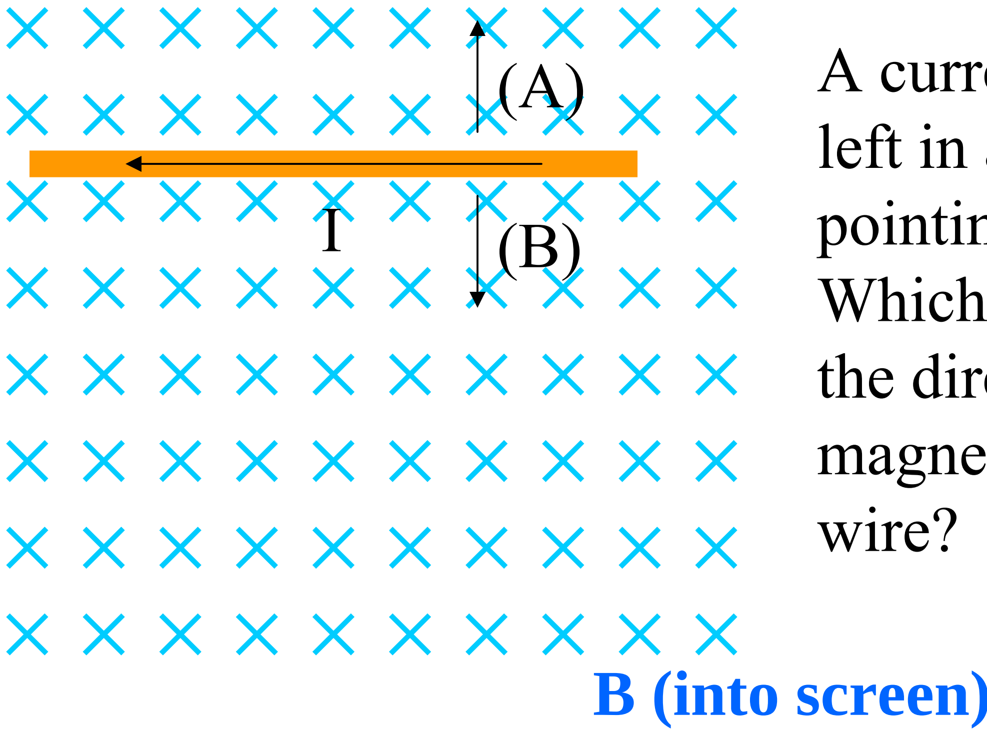
3. [HRW6 29.P.037.] A 2.4 kg copper rod rests on two horizontal rails 2.4 m apart and carries a current of 41 A from one rail to the other. The coefficient of static friction between rod and rails is 0.47. What is the smallest magnetic field (not necessarily vertical) that would cause the rod to slide?

[ ] T





Peer instruction question



A current is flowing to left in a magnetic field pointing into the screen. Which arrow represents the direction of the magnetic force on the wire?

Example

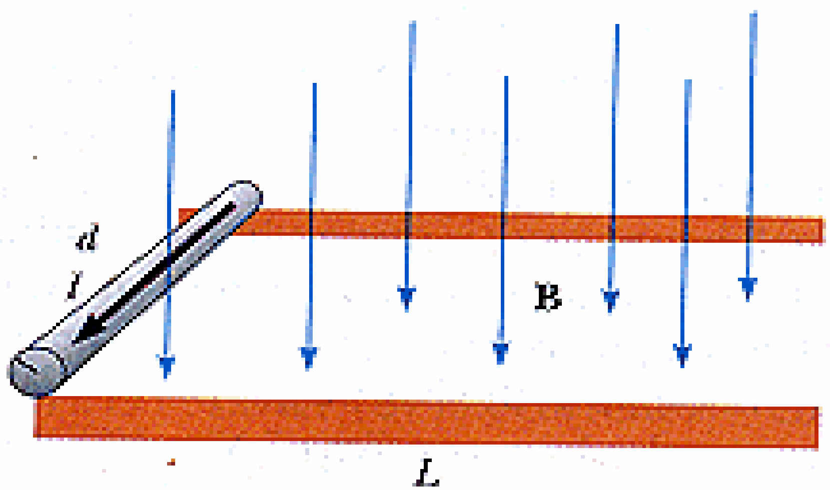


Figure P29.19.

What is the direction of the magnetic force?

Example

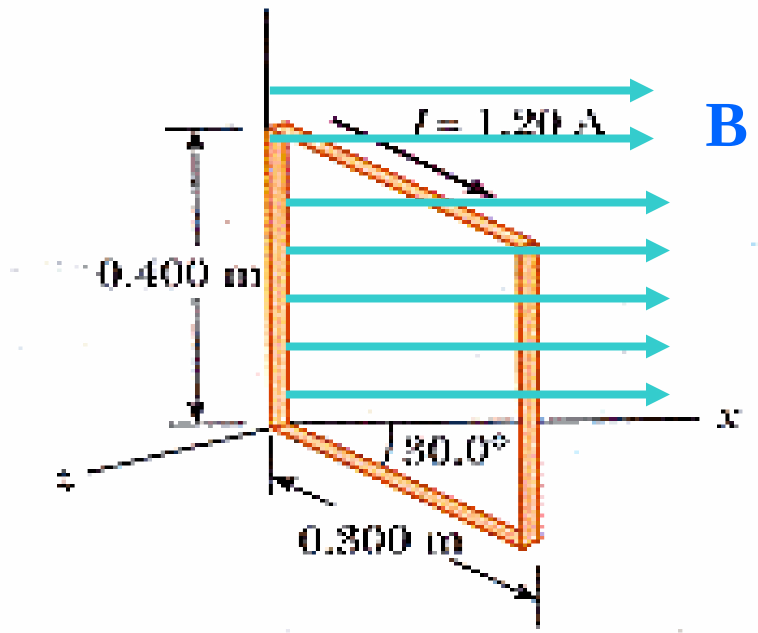
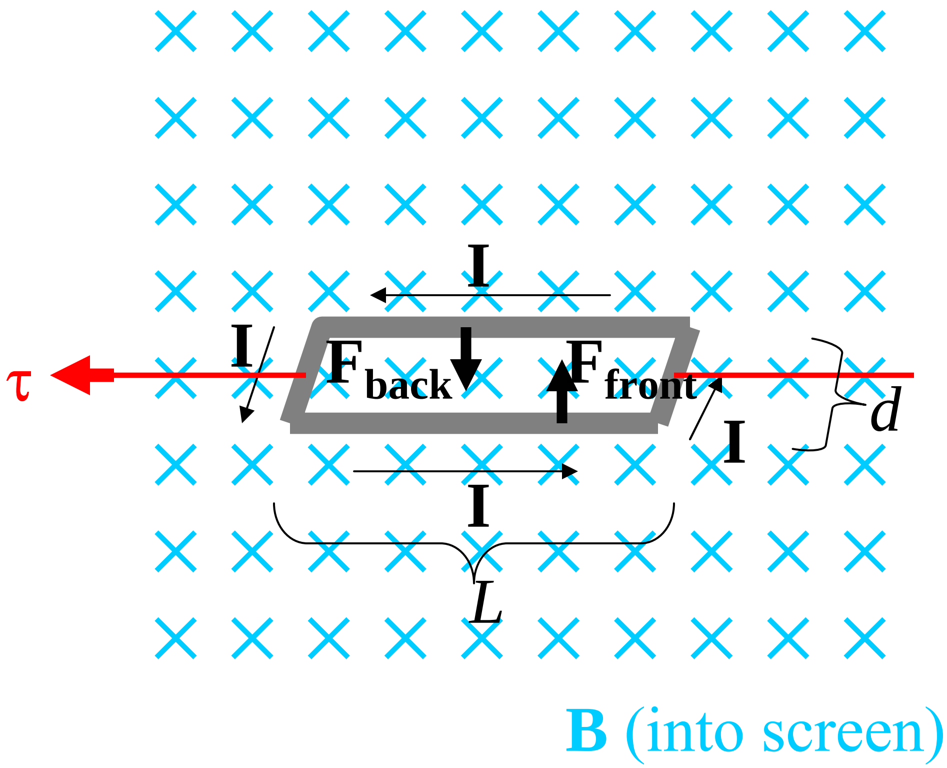


Figure P29.25.

Net forces on a current loop:



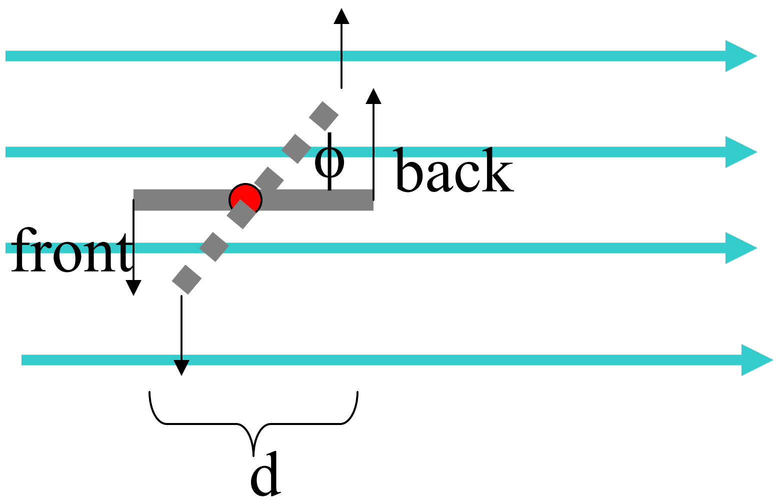
$\mathbf{F_{front}} = L\ \mathbf{IB}$ **(up)**

$\mathbf{F_{back}} = L\ \mathbf{IB}$ **(down)**

maximum torque on loop:

$\tau = dL\ IB$

Edge view of coil:

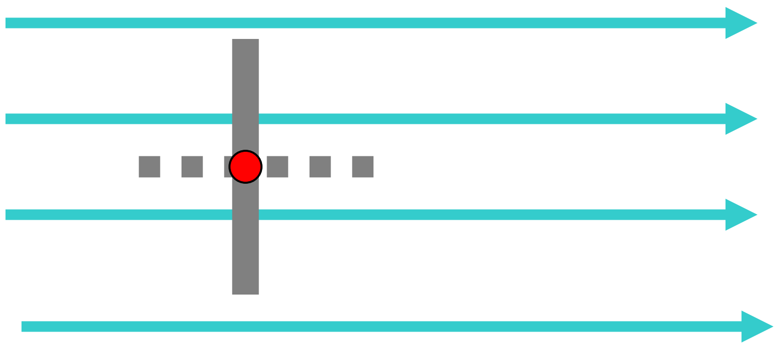


$\tau = dL\,N\,IB\cos\phi$

number of coils

length of coil perpendicular to field and pivot

Edge view of coil:



What is the net torque on the coil when it is in the upright configuration as shown?

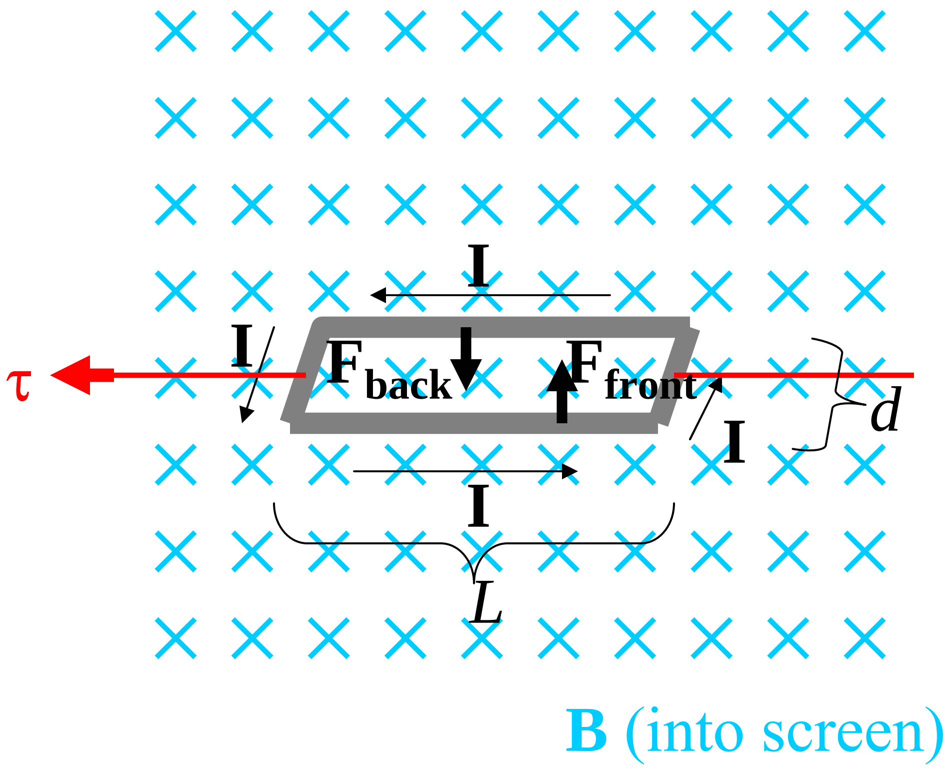
(A) $dL\ N\ IB$

(B) $2dL\ N\ IB$

(C) $\frac{1}{2}\ dL\ N\ IB$

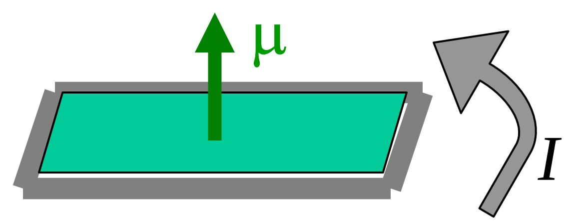
(D) 0

Magnetic "moment" associated with the current loop



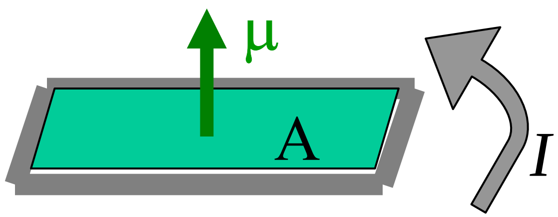
$\tau = dL\ N\ IB \cos\phi$

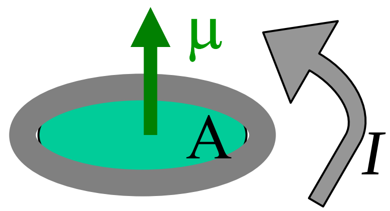
$\mu = ANI$



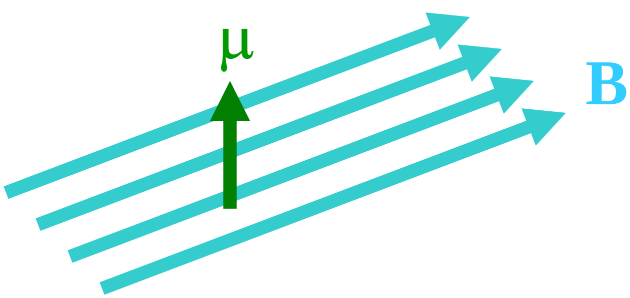
$\tau = \mu \times \mathbf{B}$

Magnetic moment associated with current loop:





$\mu = NI\,\mathbf{A}$



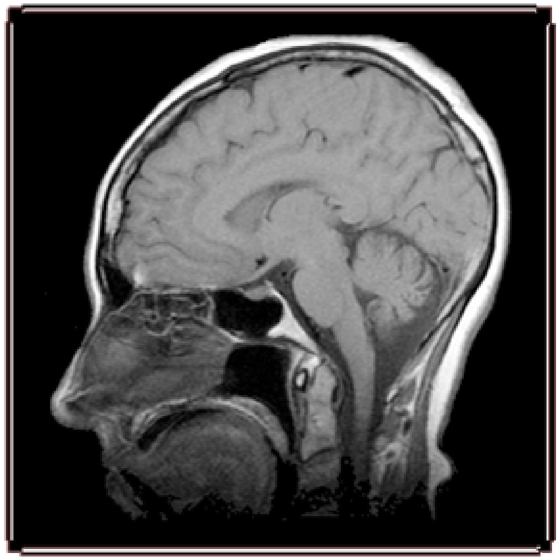
Torque:

$\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B}$

Potential energy:

$U = -\boldsymbol{\mu} \cdot \mathbf{B}$

MRI – Magnetic resonance imaging



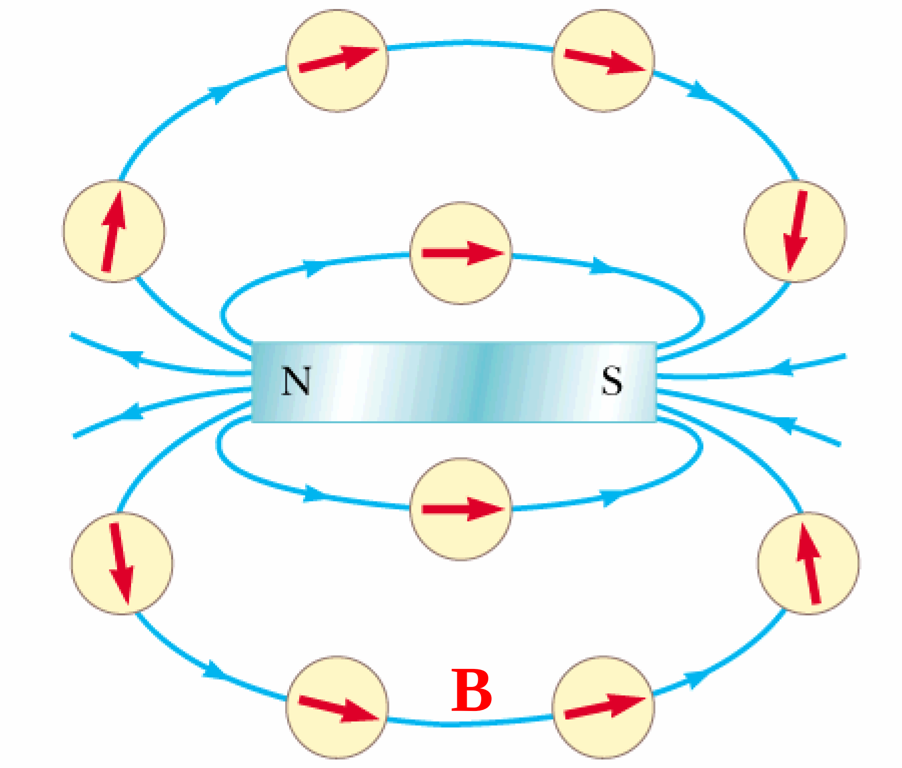
$U = -\mu \cdot \mathbf{B}$ plus time varying B_1 ➔ signal from μ of protons

Ref: http://www.cis.rit.edu/htbooks/mri/inside.htm

Sources of magnetic field:

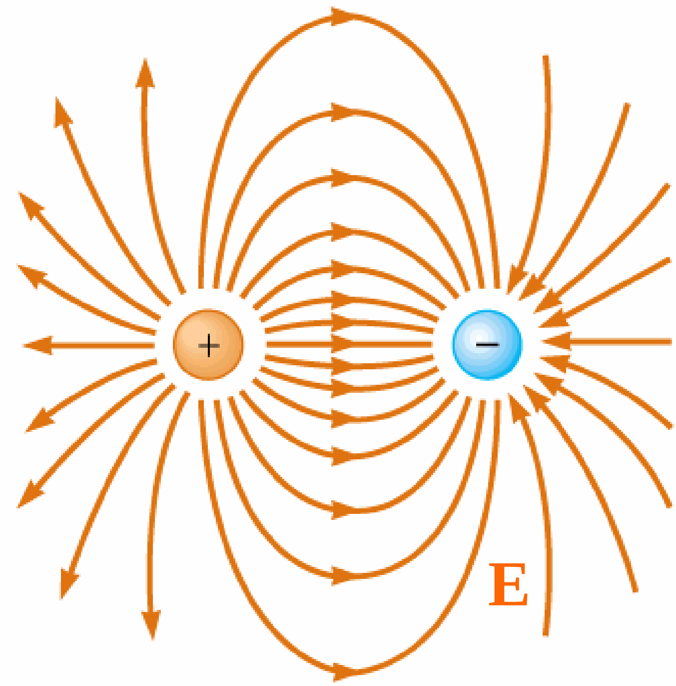
1. Ferromagnetic materials -- bar magnet
2. Currents and moving charges

Magnetic dipoles



Magnetic field lines associated with bar magnet

Electric dipole

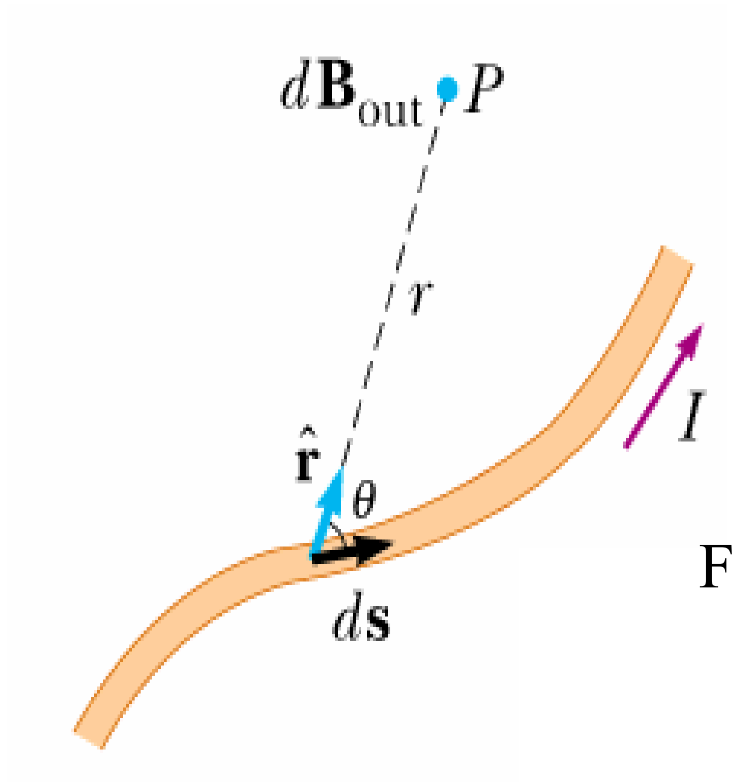


Electric field lines

There are no magnetic "charges" (monopoles)

Sources of magnetic field – currents

Biot-Savart law

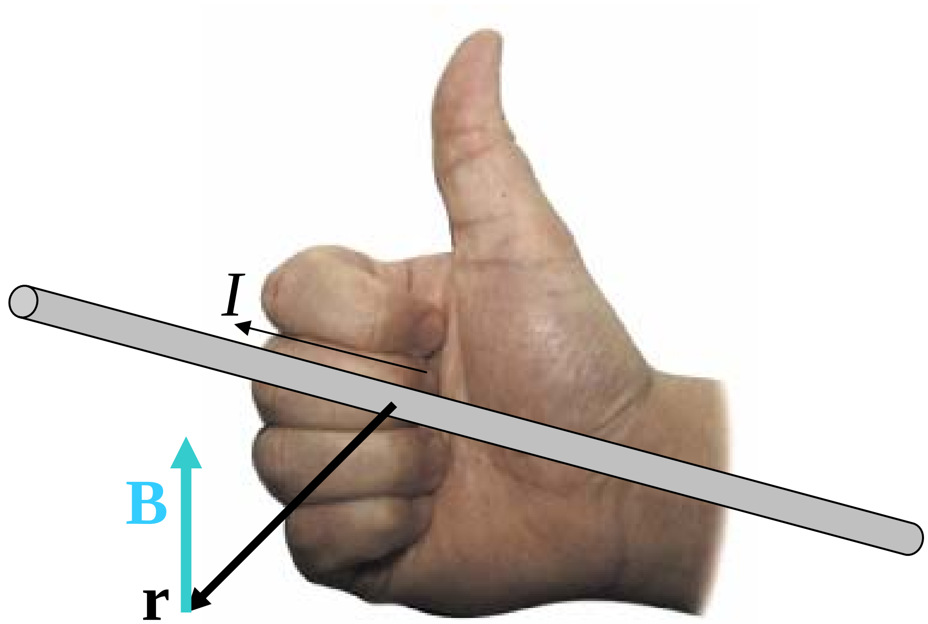


$$d\mathbf{B} = \frac{\mu_0}{4\pi}\frac{I d\mathbf{s}\times\hat{\mathbf{r}}}{r^2}$$

Field from a single moving charge:

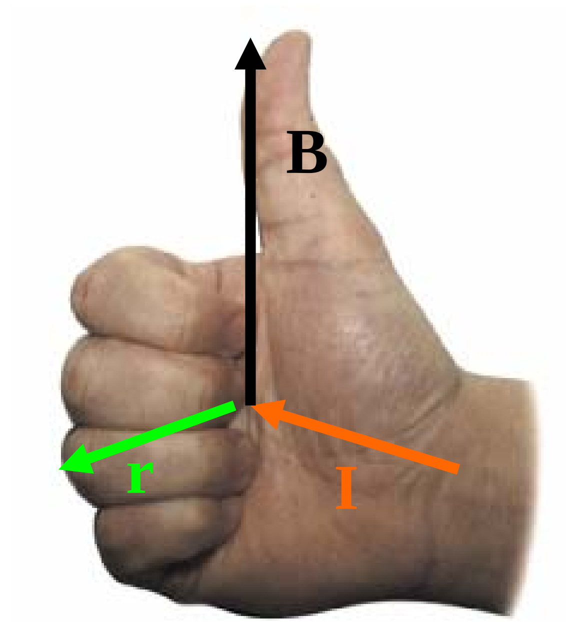
$$\mathbf{B} \approx \frac{\mu_0}{4\pi}\frac{q\mathbf{v}\times\hat{\mathbf{r}}}{r^2}$$

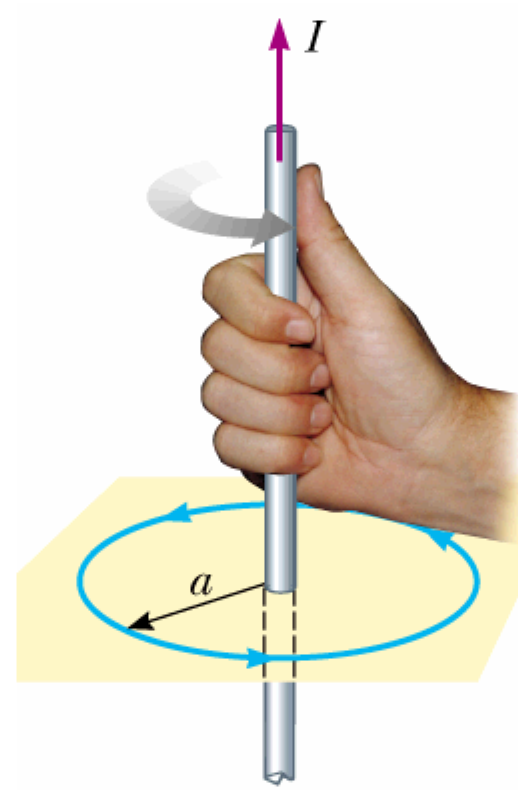
$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I d\mathbf{s} \times \hat{\mathbf{r}}}{r^2}$$



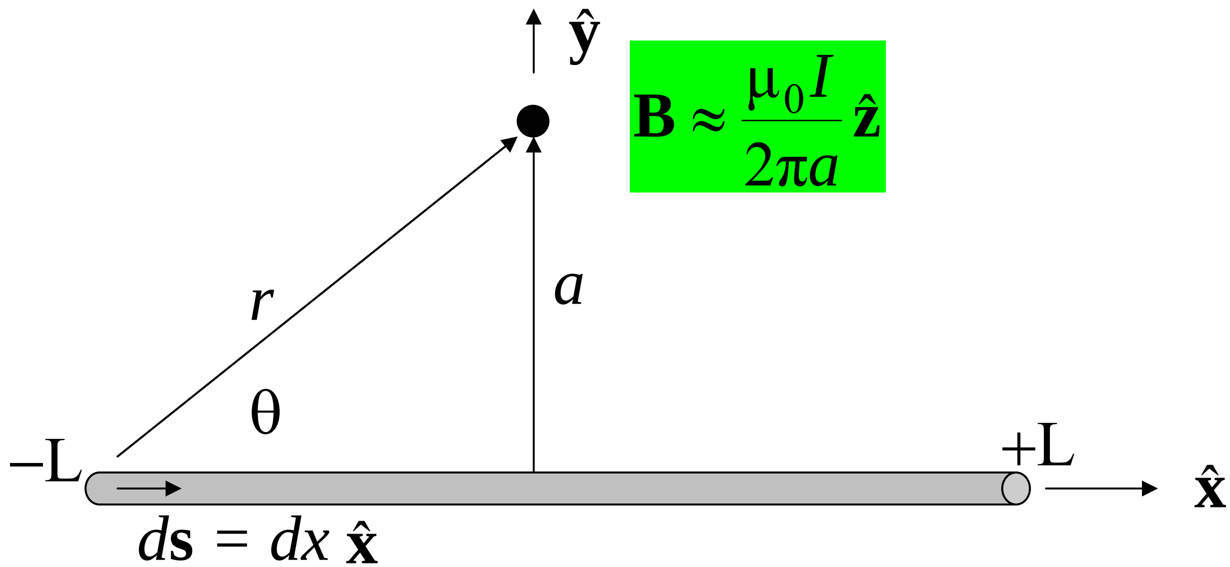
Digression on the right-hand rule:

B	➔ I	×	r
thumb	palm		fingers
palm	fingers		thumb
fingers	thumb		palm





Integrating the Biot-Savart equation

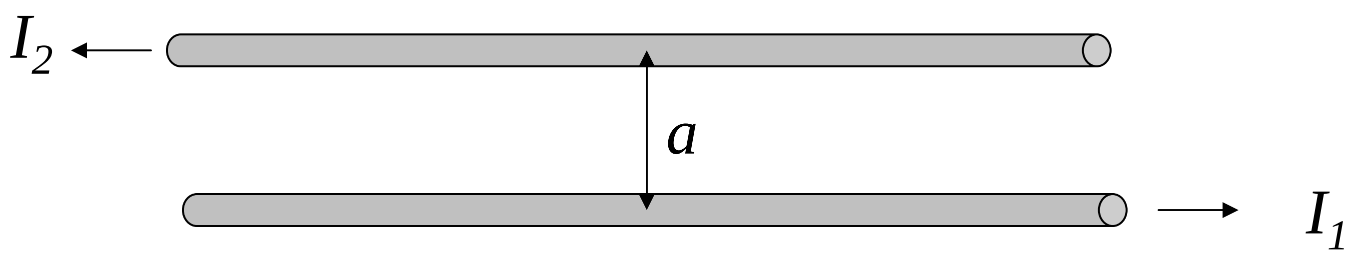


$$\mathbf{B} \approx \frac{\mu_0 I}{2\pi a}\,\hat{\mathbf{z}}$$

$$\mathbf{B} = \frac{\mu_0}{4\pi}\int \frac{I d\mathbf{s} \times \hat{\mathbf{r}}}{r^2} = \frac{\mu_0 I}{4\pi}\,\hat{\mathbf{z}} \int_{-L}^{+L} dx \frac{1}{x^2 + a^2}\underbrace{\left(\frac{a}{\sqrt{x^2 + a^2}}\right)}_{\sin\theta} = \frac{\mu_0 I}{2\pi a}\,\hat{\mathbf{z}}\underbrace{\left(\frac{L}{\sqrt{L^2 + a^2}}\right)}_{\approx 1}$$

(when L → ∞)

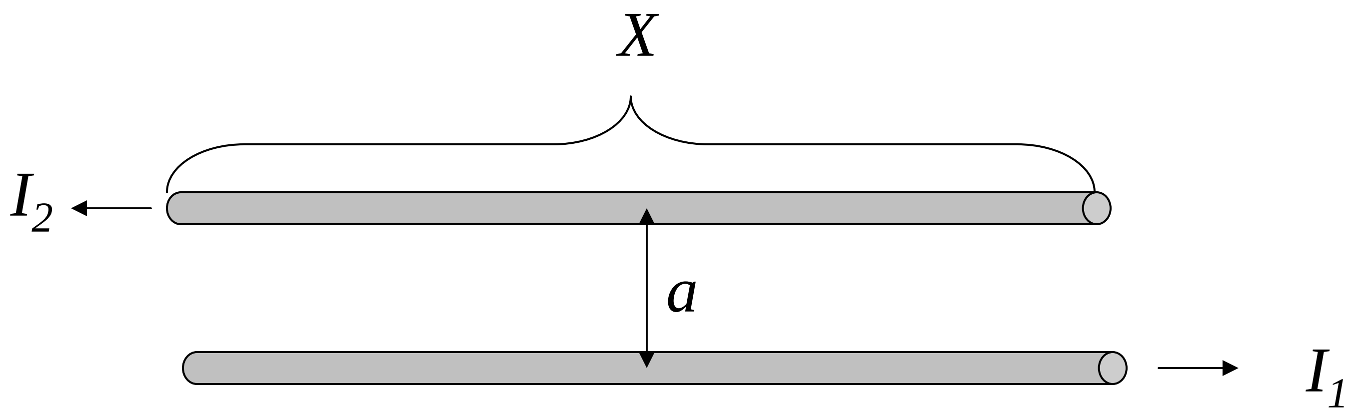
Peer instruction question



Two long wires with currents I_1 and I_2 are separated by a vertical distance a as shown. What is the direction of the magnetic force that I_1 exerts on I_2?

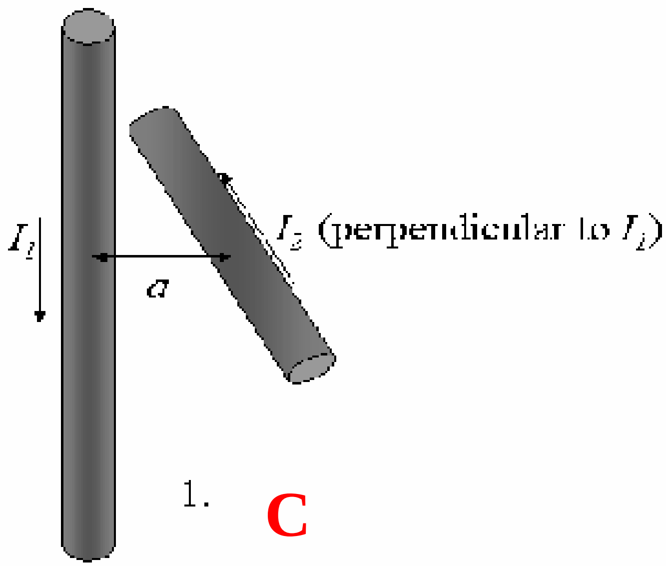
(A) upward (B) downward (C) out of the screen

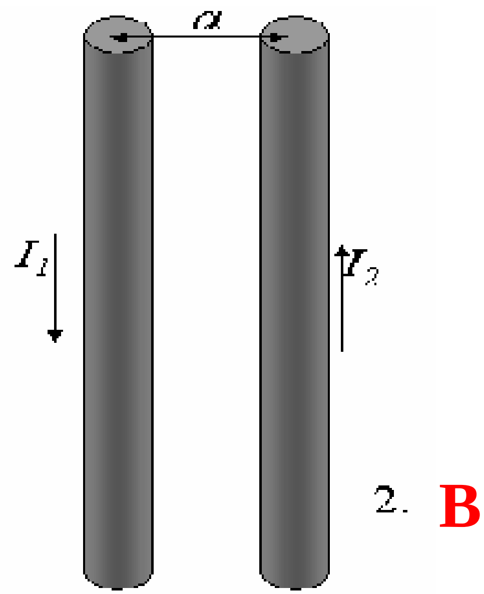
(D) to the left

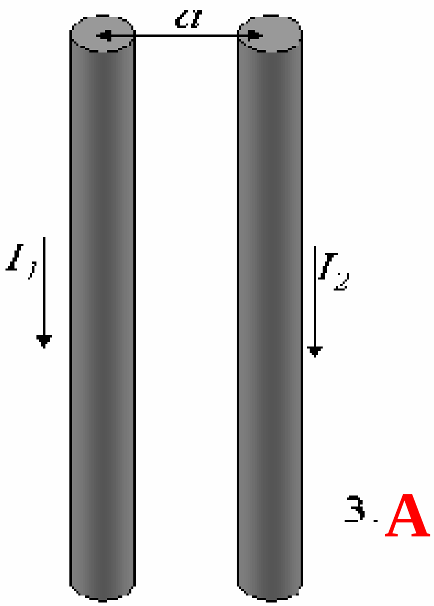


Magnitude of the magnetic force between two parallel wires:

$$F = \frac{\mu_0 I_1 I_2 X}{2\pi a}$$







Online Quiz for Lecture 11
Sources for magnetic fields -- Feb. 11, 2005

In your text, there is a formula for the force between two current-carrying wires of the form:

$$\frac{F_B}{l} = \frac{\mu_0 I_1 I_2}{2\pi a}$$

Match the following statements (A), (B), and (C) with the diagrams 1., 2., and 3.

A. The wires I_1 and I_2 attract eachother.
B. The wires I_1 and I_2 repel eachother.
C. The wires I_1 and I_2 exert no force on eachother.

2. [HRW6 30.P.025.] Four long copper wires are parallel to each other, their cross sections forming the corners of a square with sides *a* = 58 cm. A 25 A current exists in each wire in the direction shown in Fig. 30-53. What are the magnitude and direction of **B** at the center of the square?

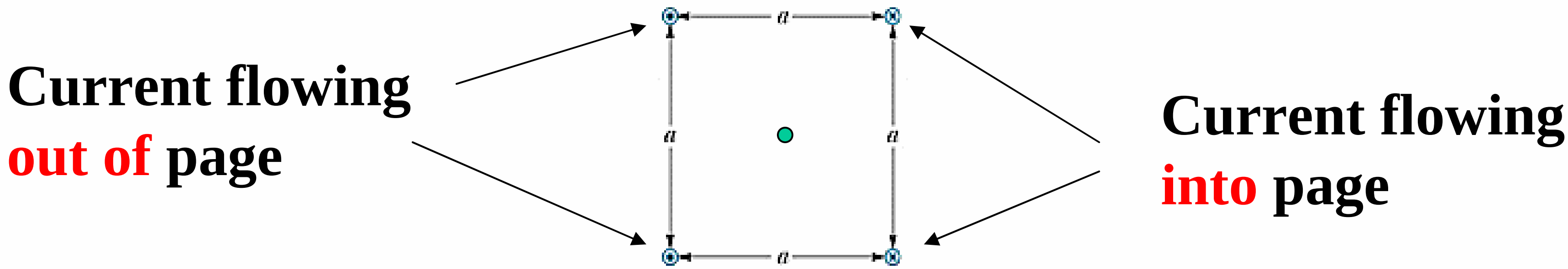
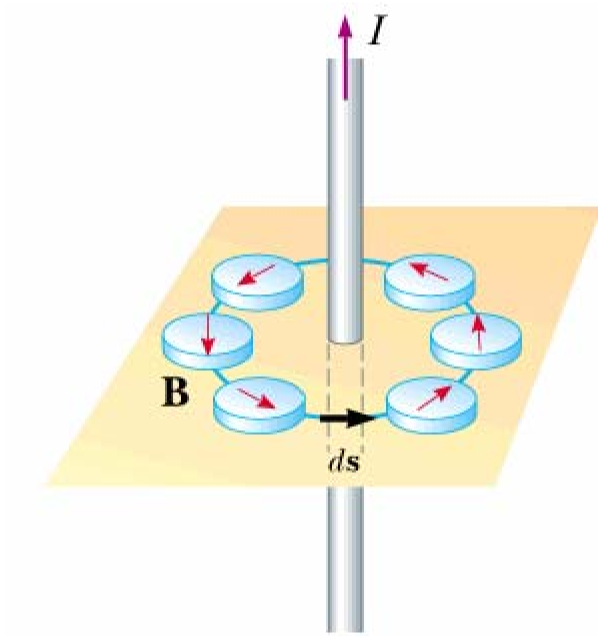


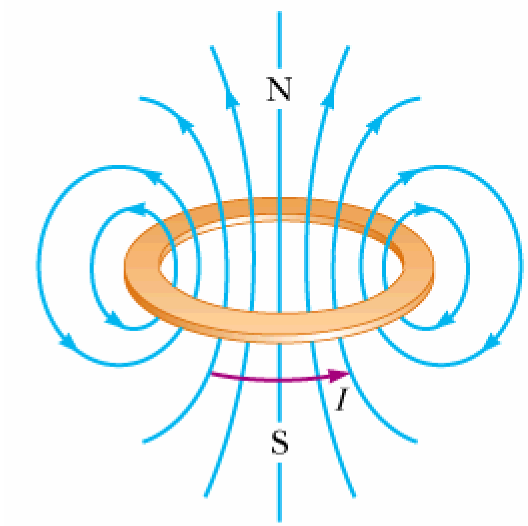
Figure 30-53.

Visualizing **B** field lines using iron filings

$\boldsymbol{\tau} = \boldsymbol{\mu} \times \mathbf{B}$

filings move until $\tau = 0$ ➔ filings align along **B** field lines



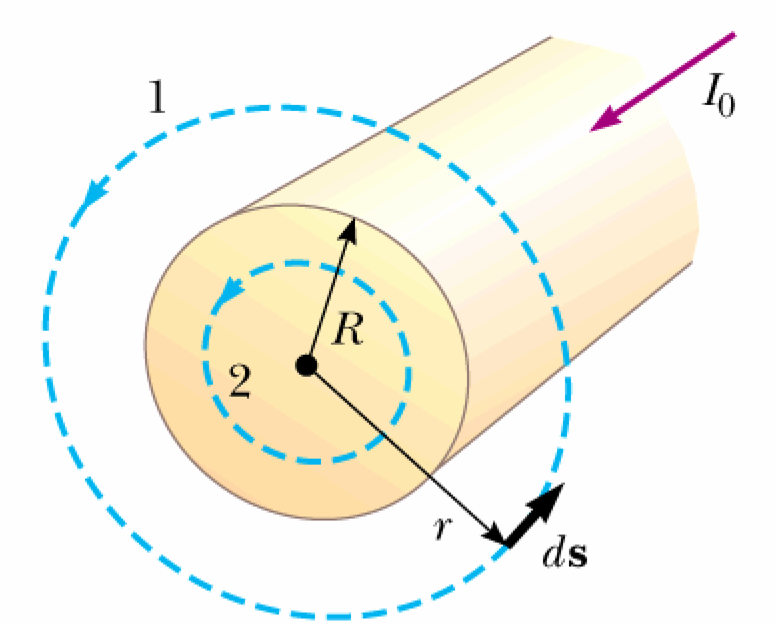


Ampere's law

$$\oint \mathbf{B}\cdot d\mathbf{s} = \mu_0 I_{in}$$

1. For $r > R$:

$$B(2\pi r) = \mu_0 I_0 \qquad \Rightarrow \quad B = \frac{\mu_0 I_0}{2\pi r}$$

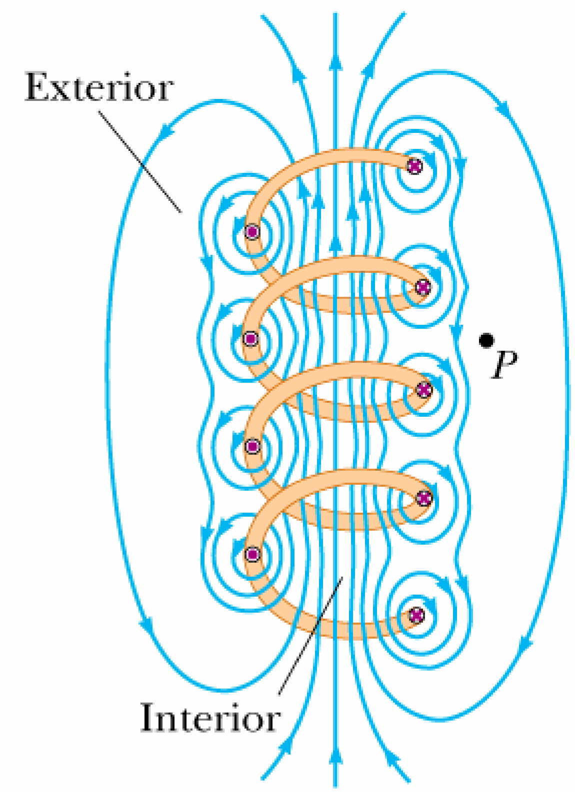


2. For $r < R$:

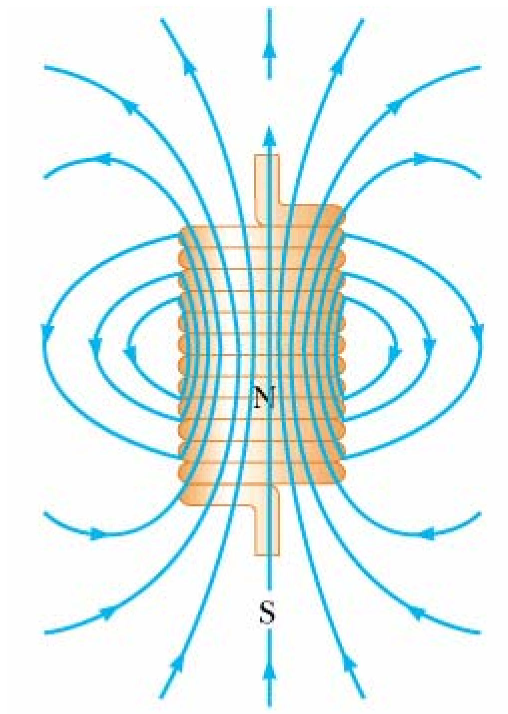
$$B(2\pi r) = \mu_0 I_0 \frac{r^2}{R^2} \qquad \Rightarrow \quad B = \frac{\mu_0 I_0 r}{2\pi R^2}$$

Magnetic field in the solenoid geometry

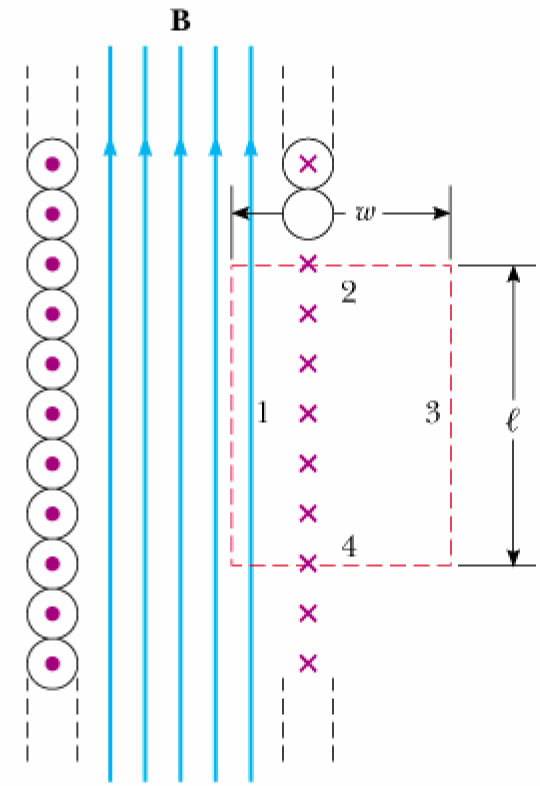
$B_{interior} = \mu_0 n I$ ← n: number of coils/unit length



Helical form

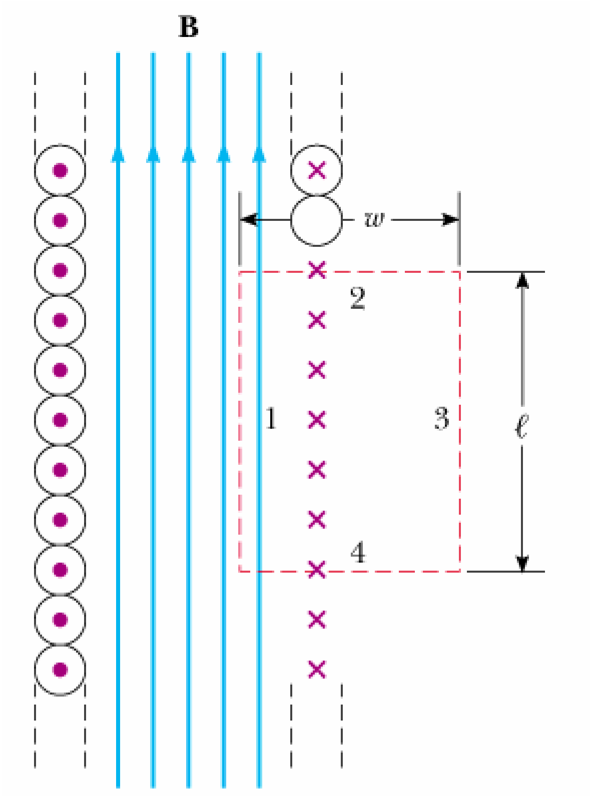


Tight coil form



Ideal form

Details of the solenoid field:



Ampere's law:

$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I_{in}$$

$$B_{in} l + 0w + 0l = \mu_0 N I$$

$$B_{in} = \frac{\mu_0 N I}{l} = \mu_0 n I$$

$$n \equiv N/l$$