PHY 114 A General Physics II
11 AM-12:15 PM TR Olin 101

Plan for Lecture 12 (Chapters 30):

Sources of Magnetic fields

1. “Permanent” magnets
2. Biot-Savart Law; magnetic fields from a current-carrying wire
3. Ampere’ Law
4. Magnetic fields in a solenoid

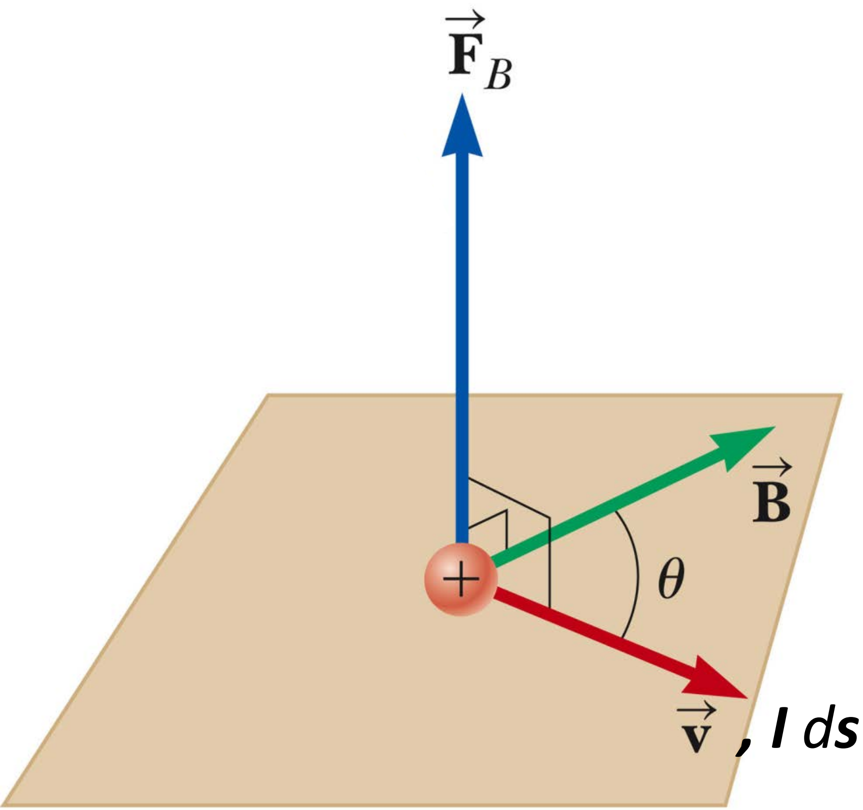
Remember to send in your chapter reading questions…

	02/07/2012	Exam			
6	02/09/2012	Capacitance and dielectrics	26.1-26.7	26.4,26.13,26.30	02/14/2012
7	02/14/2012	Current and resistance	27.1-27.6	27.3,27.12,27.29	02/16/2012
8	02/16/2012	Direct current circuits	28.1-28.2	28.3,28.7,28.19	02/21/2012
9	02/21/2012	Direct current circuits	28.3-28.5	28.23,28.25,28.34	02/23/2012
10	02/23/2012	Review	26.1-28.5	(Review for exam)	
	02/28/2012	Exam			
11	03/01/2012	Magnetic fields	29.1-29.6	29.5,29.12,29.47	03/06/2012
12	03/06/2012	Magnetic field sources	30.1-30.6	30.5,30.21,30.29	03/08/2012
13	03/08/2012	Faraday's law	31.1-31.5	31.12,31.23,31.40	03/20/2012
	03/13/2012	*No class (Spring Break)*			
	03/15/2012	*No class (Spring Break)*			
14	03/20/2012	Induction and AC circuits	32.1-32.6		
15	03/22/2012	AC circuits	33.1-33.9		
16	03/27/2012	Electromagnetic waves	34.1-34.3		

Review of magnetic forces:

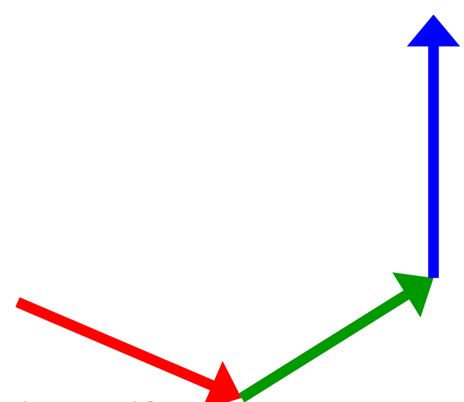
$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

$$d\mathbf{F}_B = I\, d\mathbf{s} \times \mathbf{B}$$

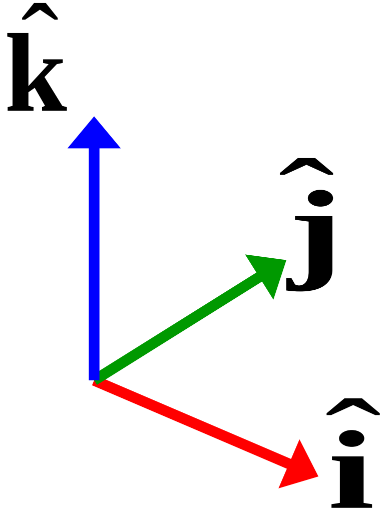


Right hand rule

http://www.fotosearch.com/CSP760/k7601927/



Vector cross product



$$\hat{\mathbf{i}} \times \hat{\mathbf{j}} = \hat{\mathbf{k}}$$

$$\hat{\mathbf{j}} \times \hat{\mathbf{k}} = \hat{\mathbf{i}}$$

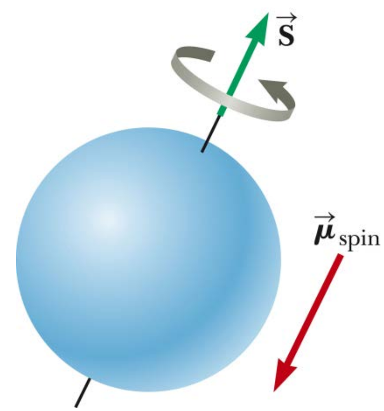
$$\hat{\mathbf{k}} \times \hat{\mathbf{i}} = \hat{\mathbf{j}}$$

$$\hat{\mathbf{j}} \times \hat{\mathbf{i}} = -\hat{\mathbf{k}}$$

Sources of magnetic fields **B**
Permanent magnet materials – Fe, Fe_2O_3 , Co, Ni, alloys

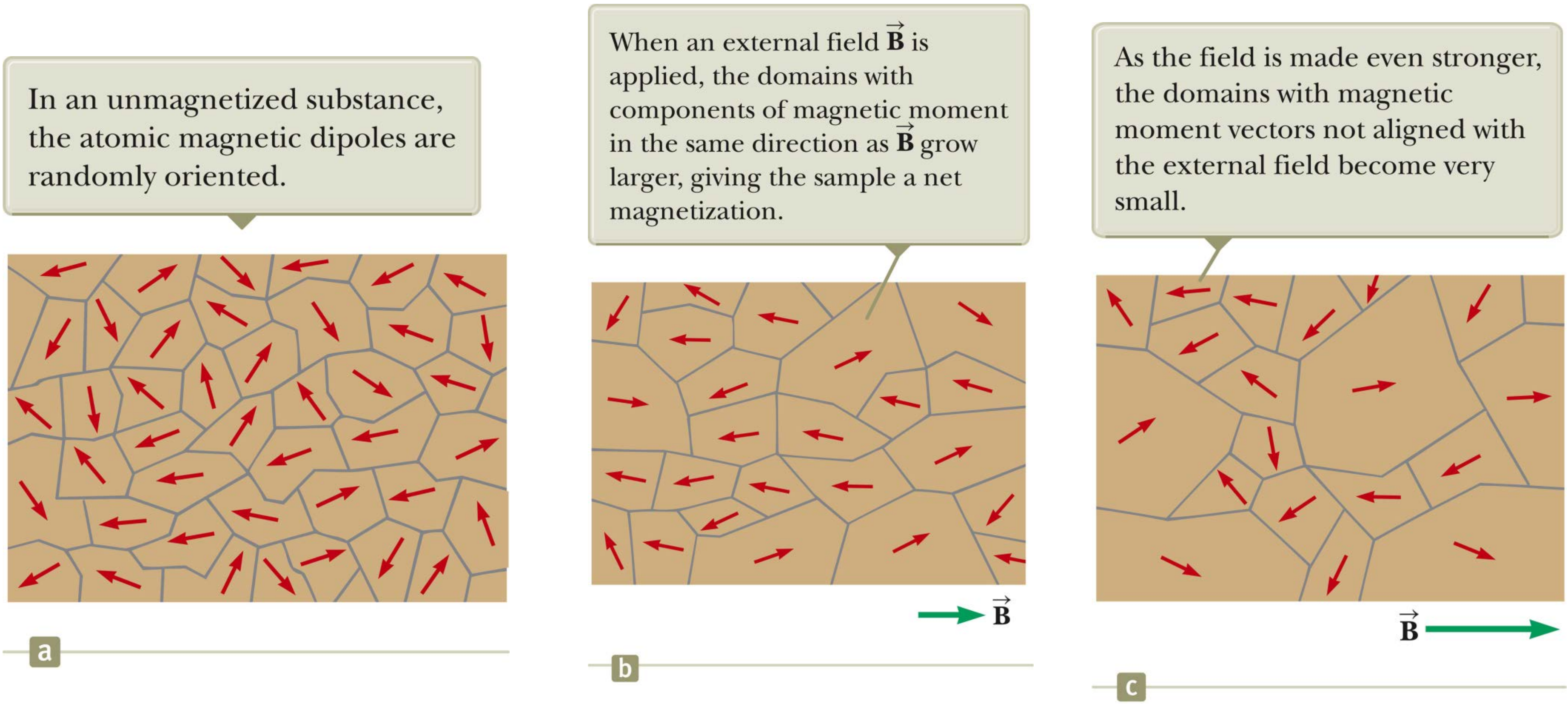
Internal atomic level magnet dipole moments $\vec{\mu}$
$\Rightarrow$ Energy incentive for neighboring magnetic dipoles to align at temperatures below Curie termperature.

Visualization of intrinsic spin magnetic moment of electron.



http://littlegreenfootballs.com/weblog/img/bobibutu/2011/10/04/magnet.jpg

$\mathbf{B} = 0$ $\mathbf{B} > 0$ $\mathbf{B} >> 0$



"Permanent" magnets controlled by temperature and external magnetic fields.

Magnetic fields generated by moving charge:

Electrical field generated by charge distribution

$$\rho(\mathbf{r}) = \sum_{i;\mathbf{r}_i \approx \mathbf{r}} \frac{Q_i}{\Delta V_i}$$

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0} \int \rho(\mathbf{r}') \frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3} d^3r'$$

Magnetic field generated by current distribution

$$\mathbf{J}(\mathbf{r}) = \sum_{i;\mathbf{r}_i \approx \mathbf{r}} \frac{Q_i v_i}{\Delta V_i}$$

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi} \int \mathbf{J}(\mathbf{r}') \times \frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3} d^3r'$$

Biot-Savart Law:

Units: B ➔ T (Tesla)

$J = I/\text{area}$ ➔ A/m^2

Constant: μ_0 "permeability" of free space

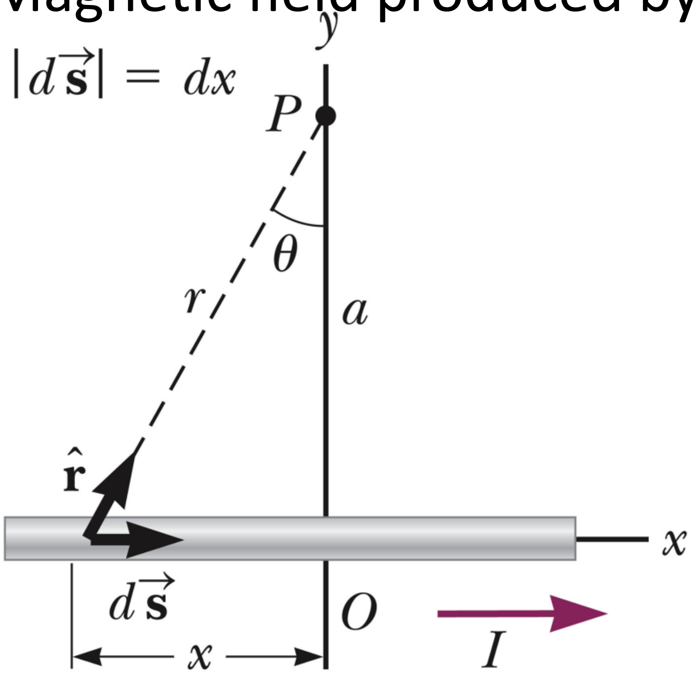
$4\pi\ 10^{-7}$ Tm/A

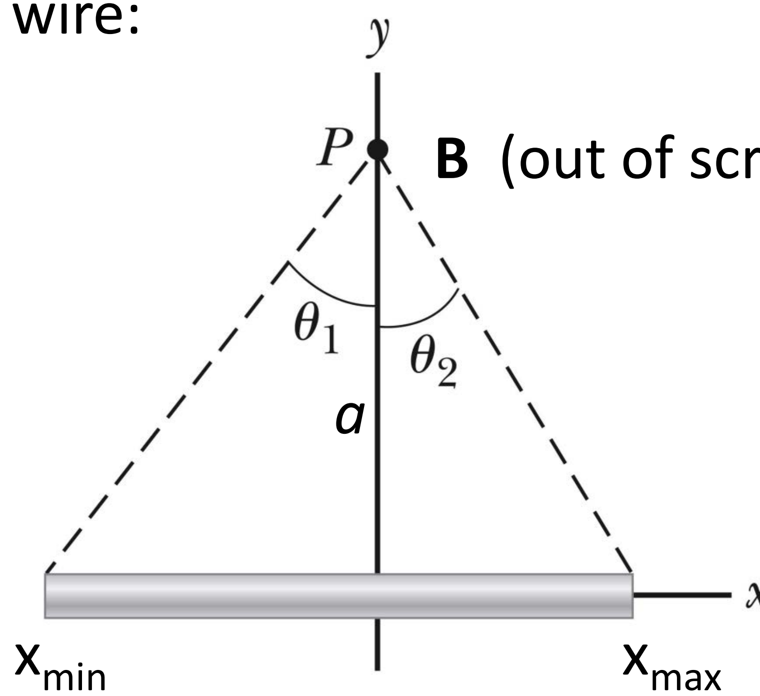
$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0}{4\pi}\int \mathbf{J}(\mathbf{r}')\times\frac{\mathbf{r}-\mathbf{r}'}{|\mathbf{r}-\mathbf{r}'|^3}\,d^3r'$$

For thin wire of constant current I, where $\mathbf{s}$ denotes direction along wire:

$$\mathbf{B}(\mathbf{r}) = \frac{\mu_0 I}{4\pi}\int d\mathbf{s}\times\frac{\mathbf{r}-\mathbf{s}}{|\mathbf{r}-\mathbf{s}|^3}$$

Magnetic field produced by straight wire:

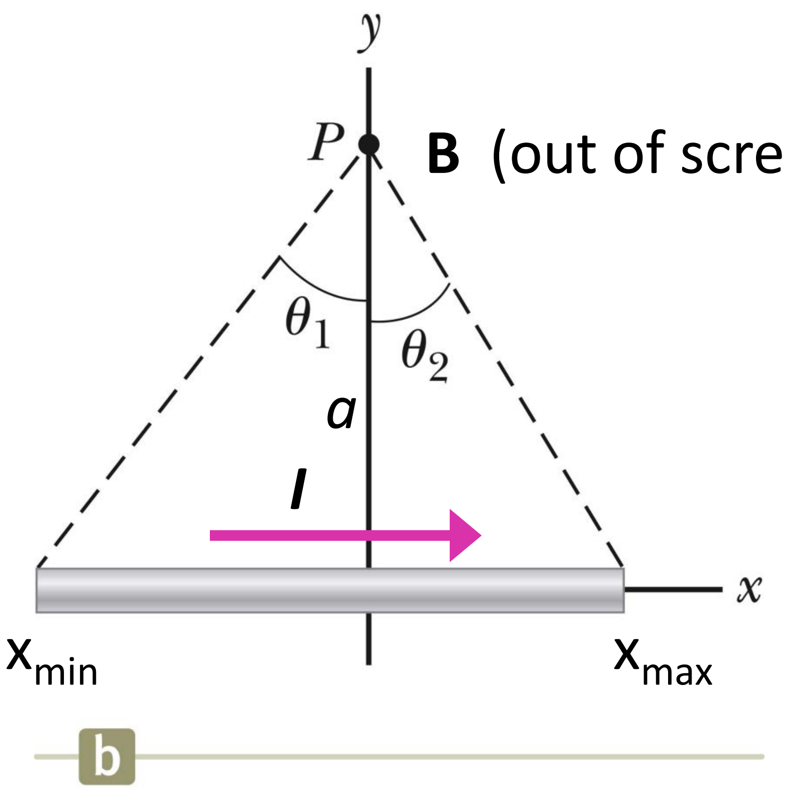




$$\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{z}}\frac{\mu_0 I}{4\pi}\int_{x_{\min}}^{x_{\max}} \frac{a\,dx}{\left(a^2 + x^2\right)^{3/2}}$$

$$= \hat{\mathbf{z}}\frac{\mu_0 I}{4\pi a}\int_{\theta_1}^{\theta_2} \cos\theta\, d\theta$$

$$\boxed{\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{z}}\frac{\mu_0 I}{4\pi a}\left(\sin\theta_1 - \sin\theta_2\right)}$$

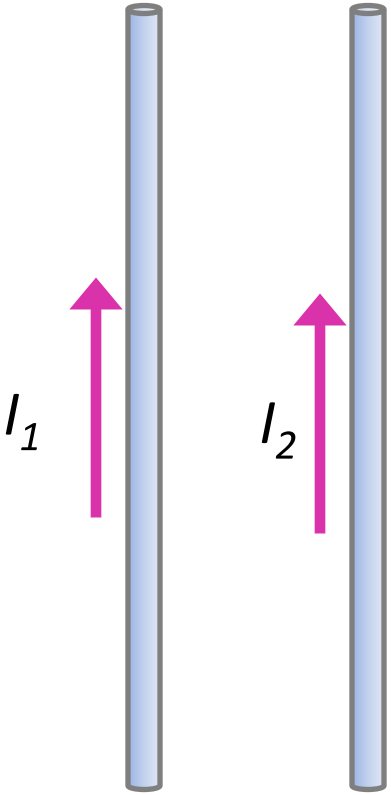


$$\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{z}}\frac{\mu_0 I}{4\pi a}\left(\sin\theta_1 - \sin\theta_2\right)$$

$$\text{For } x_{\min} \to -\infty,\; x_{\max} \to \infty:$$

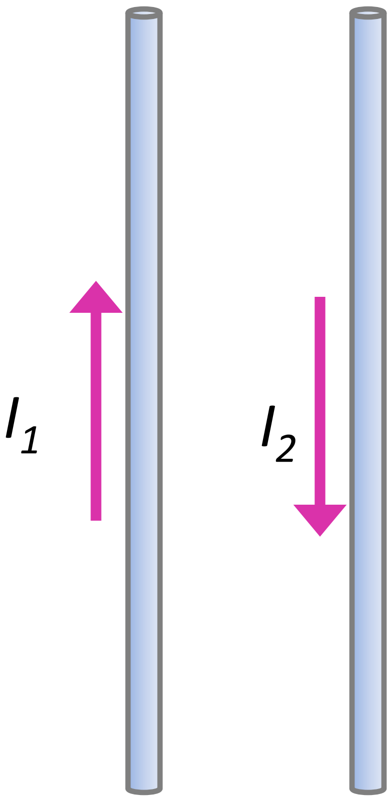
$$\theta_1 \to -90^o, \theta_2 \to 90^o$$

$$\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{z}}\frac{\mu_0 I}{2\pi a}$$



Consider 2 (infinitely long) wires.
Vote for the least incorrect answer:

A. The two wires cancel each other completely
B. The two wires generate exactly twice the magnet field compared to a single wire
C. The two wires attract each other.
D. The two wires repel each other.



Consider 2 (infinitely long) wires.

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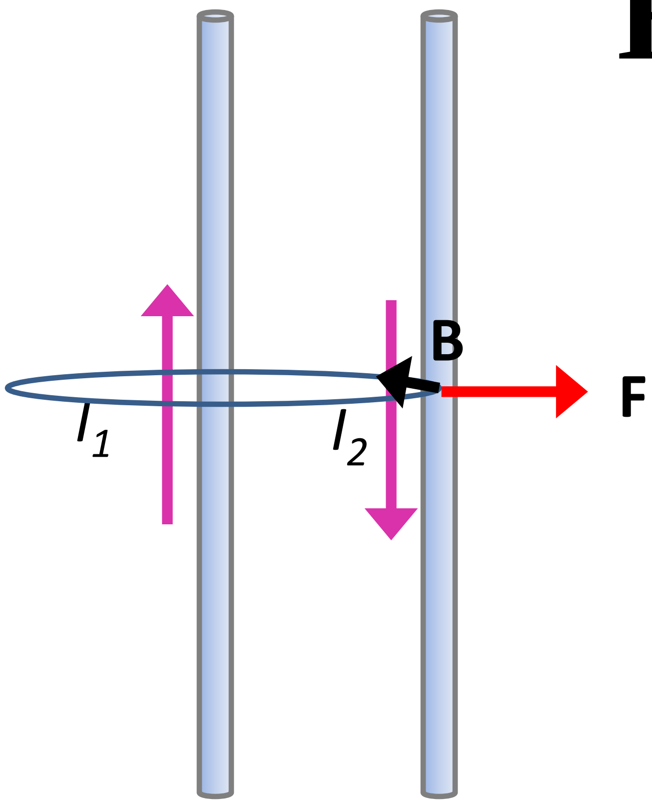
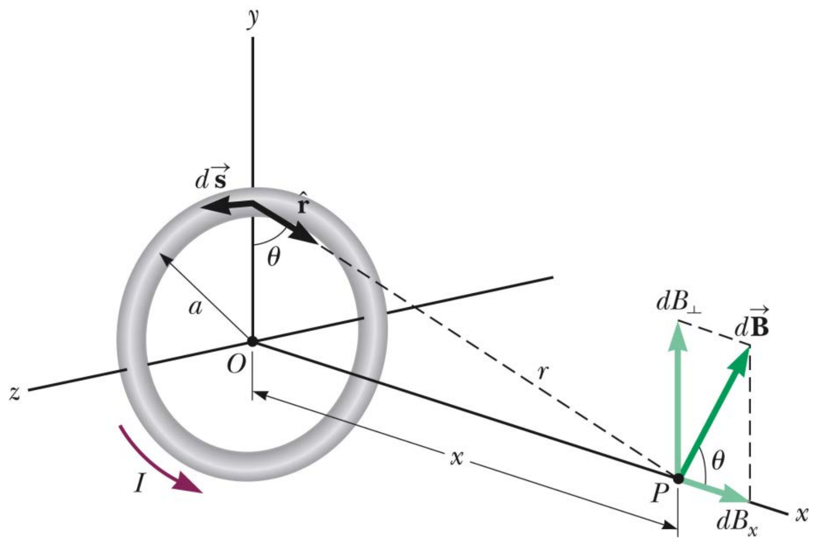
D. The two wires repel each other.

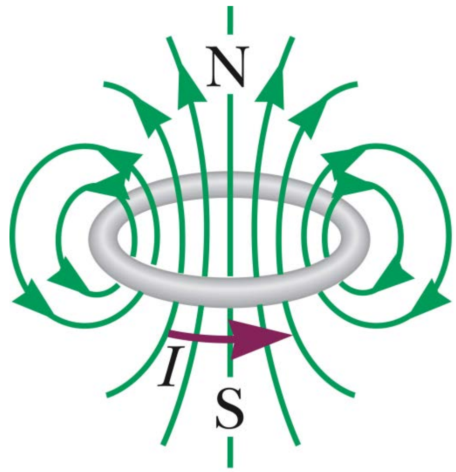
$$\mathbf{F} = \ell \mathbf{I} \times \mathbf{B}$$



➔wires repel each other

Magnetic field produced by wire loop:



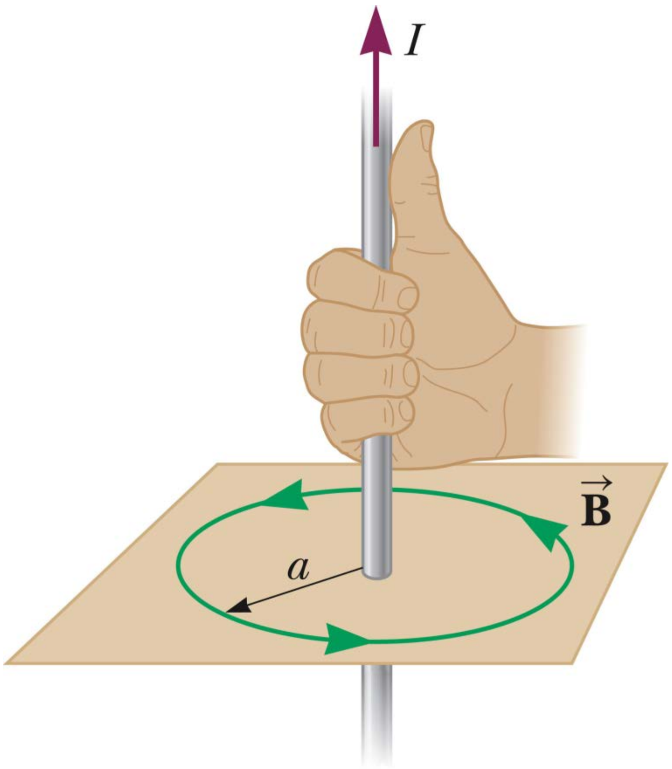


$$\mathbf{B}(\mathbf{r}_P) = \hat{\mathbf{x}} \frac{\mu_0 I}{4\pi} \int_0^{2\pi} \frac{a^2 d\theta}{\left(a^2 + x^2\right)^{3/2}}$$

$$= \hat{\mathbf{x}} \frac{\mu_0 I}{4\pi} \frac{2\pi a^2}{\left(a^2 + x^2\right)^{3/2}} = \hat{\mathbf{x}} \frac{\mu_0 I a^2}{2\left(a^2 + x^2\right)^{3/2}}$$

Easier way for situations with high symmetry

– Ampere's Law



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

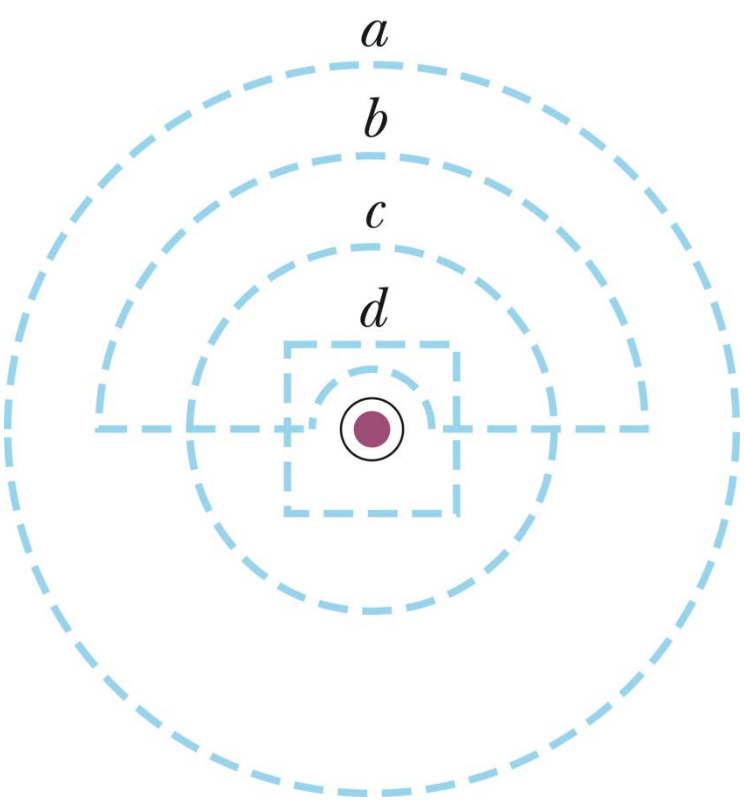
In this case

$$\oint \mathbf{B} \cdot d\mathbf{s} = 2\pi a B = \mu_0 I$$

$$\Rightarrow B = \frac{\mu_0 I}{2\pi a}$$

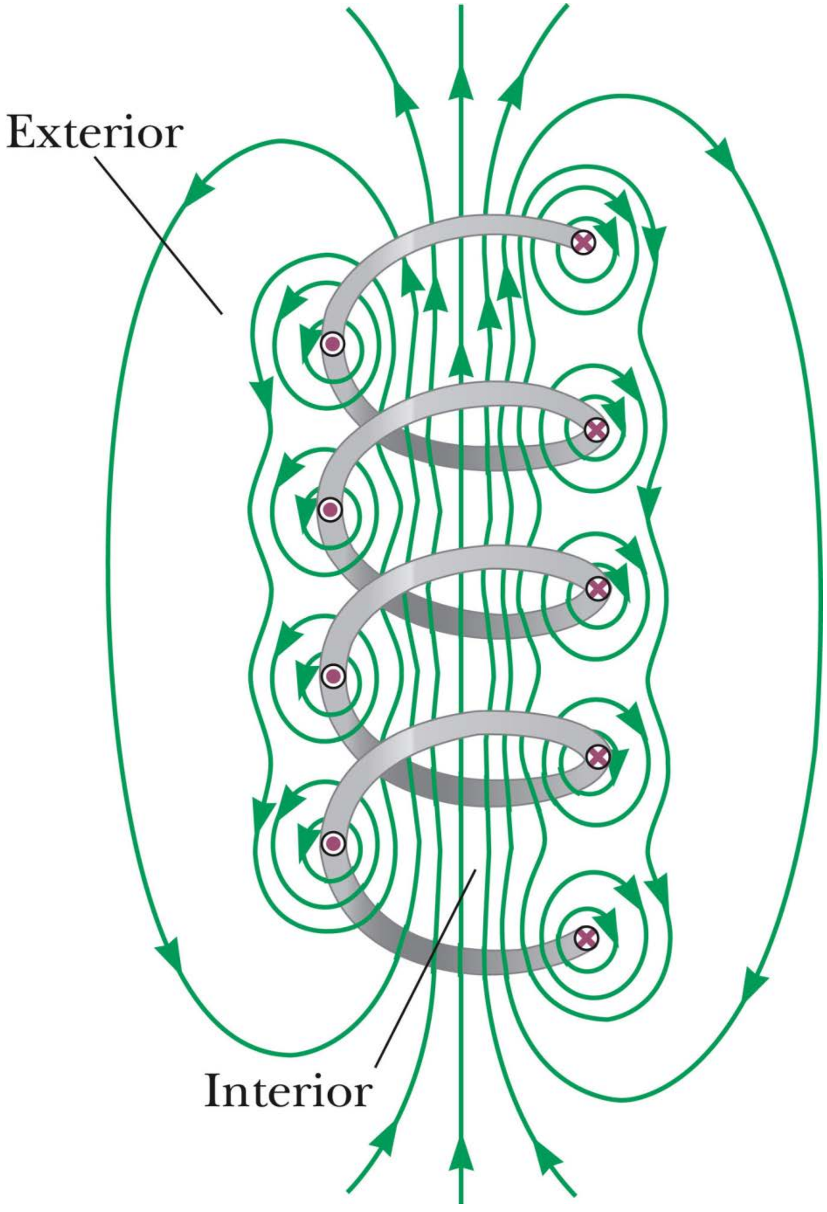
Example of Ampere's law:

The figure below shows a wire coming out of the screen. Which of the paths for $\oint \mathbf{B} \cdot d\mathbf{s}$ has the smallest magnitude?

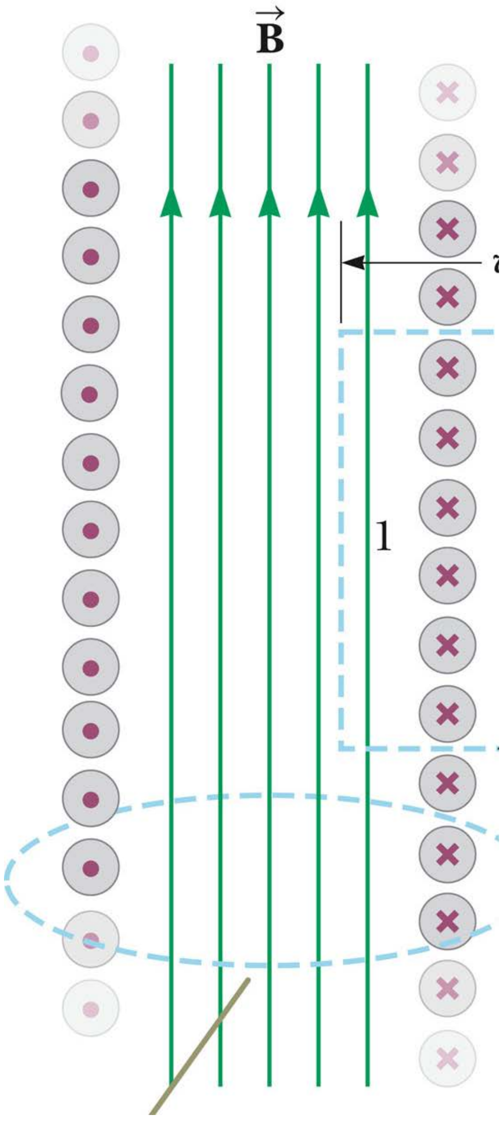


A. a
B. b
C. c
D. d

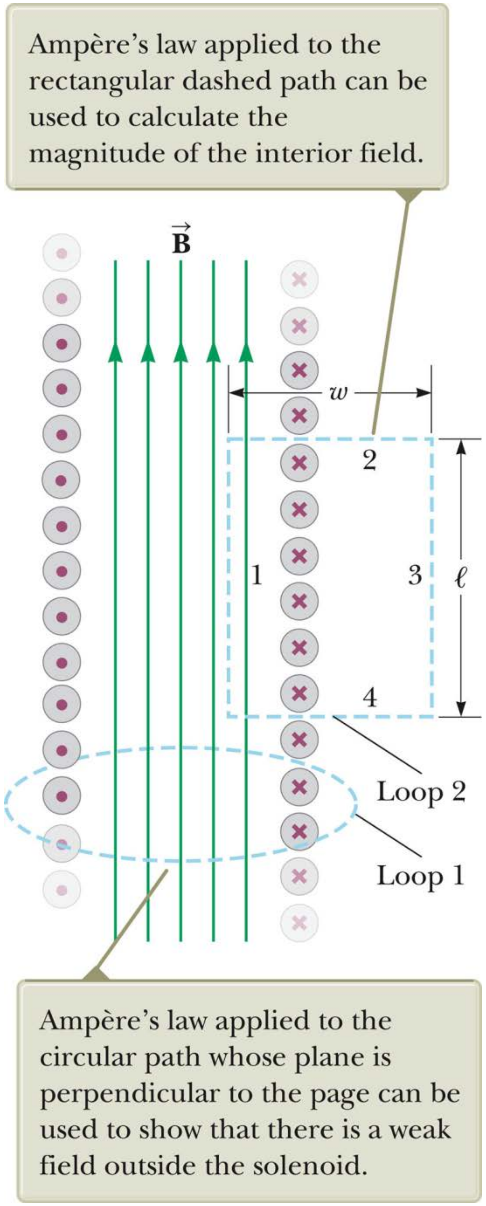
Magnetic field in a solenoid



Ideal solenoid



Magnetic field inside ideal solenoid:



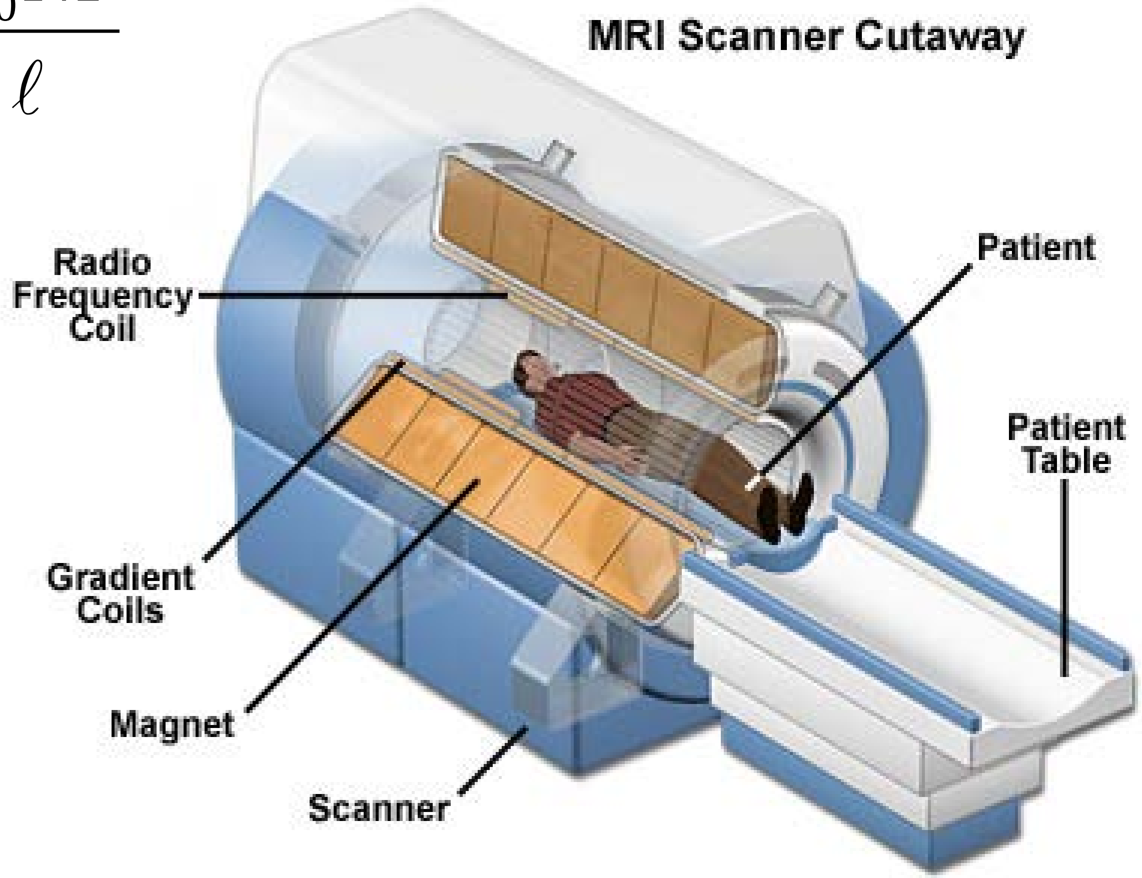
Ampere's Law :

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

$$\oint \mathbf{B} \cdot d\mathbf{s} = B\ell = \mu_0 NI$$

$$\Rightarrow B = \frac{\mu_0 NI}{\ell}$$

$$B = \frac{\mu_0 N I}{\ell}$$



B ≈ 21 T
(experimental MRI at FSU)

http://www.magnet.fsu.edu/education/tutorials/magnetacademy/mri/images/mri-scanner.jpg

MRI signal – detects H nuclei using the magnetic moment of H – μ_H.

$$E = -\mu_H \cdot \mathbf{B}$$

Summary:

Ampere's law:

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

Differential form: $\nabla \times \mathbf{B} = \mu_0 \mathbf{J}$

Gauss's law:

Integral form: $\oint \mathbf{E}(\mathbf{r}) \cdot d\mathbf{A} = \frac{Q_{in}}{\varepsilon_0}$

Differential form: $\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$

Note:

$\oint \mathbf{B}(\mathbf{r}) \cdot d\mathbf{A} = 0$

$\nabla \cdot \mathbf{B} = 0$