

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

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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		

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Review of magnetic forces:

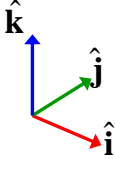
$$\mathbf{F}_B = q\mathbf{v} \times \mathbf{B}$$

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

Right hand rule

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Vector cross product



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


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

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

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

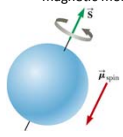
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Sources of magnetic fields **B**
 Permanent magnet materials – Fe, Fe₂O₃, Co, Ni, alloys



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

Visualization of intrinsic spin magnetic moment of electron.



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

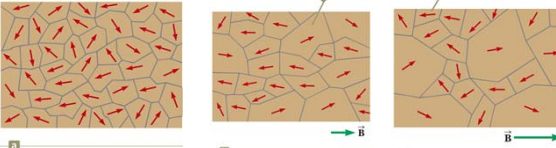
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B = 0 **B > 0** **B >> 0**

In an unmagnetized substance, the atomic magnetic dipoles are randomly oriented.

When an external field **B** is applied, the domains with components of magnetic moment in the same direction as **B** grow larger, giving the sample a net magnetization.

As the field is made even stronger, the domains with magnetic moment vectors not aligned with the external field become very small.



“Permanent” magnets controlled by temperature and external magnetic fields.

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Magnetic fields generated by moving charge:

Electrical field generated by charge distribution

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

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\epsilon_0} \int \rho(\mathbf{r}') \frac{\mathbf{r} - \mathbf{r}'}{|\mathbf{r} - \mathbf{r}'|^3} d^3r'$$

Magnetic field generated by current distribution

$$\mathbf{J}(\mathbf{r}) = \sum_{i, \mathbf{r}_i} \frac{Q_i \mathbf{v}_i}{\Delta V_i}$$

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

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Biot-Savart Law:

Units: $\mathbf{B} \rightarrow \text{T (Tesla)}$
 $\mathbf{J} = I/\text{area} \rightarrow \text{A/m}^2$

Constant: μ_0 "permeability" of free space
 $4\pi \cdot 10^{-7} \text{ Tm/A}$

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

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

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

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Magnetic field produced by straight wire:

$|d\mathbf{s}| = dx$

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

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

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

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

For $x_{\min} \rightarrow -\infty, x_{\max} \rightarrow \infty$:
 $\theta_1 \rightarrow -90^\circ, \theta_2 \rightarrow 90^\circ$

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

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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.

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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.

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

→ wires repel each other

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Magnetic field produced by wire loop:

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

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

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Easier way for situations with high symmetry
– Ampere's Law

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

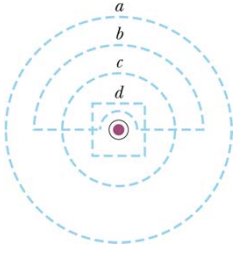
In this case

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

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

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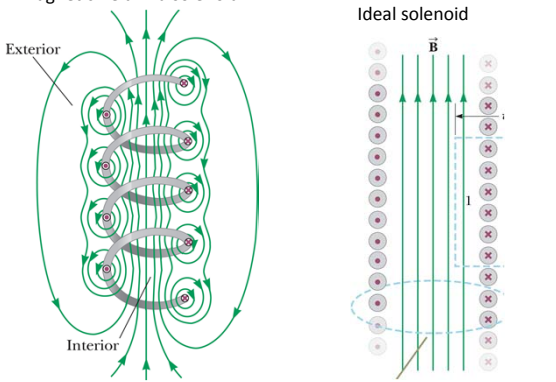
Example of Ampere's law:
 The figure below shows a wire coming out of the screen. Which of the paths for $\oint \mathbf{B} \cdot d\mathbf{s}$ has the smallest magnitude?



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

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Magnetic field in a solenoid



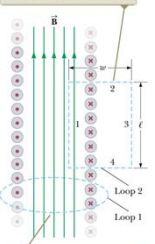
Exterior
 Interior

Ideal solenoid

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Magnetic field inside ideal solenoid:

Ampère's law applied to the rectangular dashed path can be used to calculate the magnitude of the interior field.



Ampère's law applied to the circular path whose plane is perpendicular to the page can be used to show that there is a weak field outside the solenoid.

Ampere's Law :

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

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

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

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

MRI Scanner Cutaway

Radio Frequency Coil

Gradient Coils

Magnet

Scanner

Patient

Patient Table

$B \approx 21 \text{ T}$
(experimental MRI at FSU)

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

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

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

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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 : $\oint \mathbf{E}(\mathbf{r}) \cdot d\mathbf{A} = \frac{Q_m}{\epsilon_0}$ Note : $\oint \mathbf{B}(\mathbf{r}) \cdot d\mathbf{A} = 0$

Differential form : $\nabla \cdot \mathbf{E} = \frac{\rho}{\epsilon_0}$ $\nabla \cdot \mathbf{B} = 0$

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