Physics 202, Lecture 14

Today’s Topics

- Midterm 2 announcements
- Sources of the Magnetic Field (Ch 30)
  - Review: The Biot-Savart Law
  - The Ampere’s Law
  - Applications And Exercises of ampere’s Law
    - Straight line, Loop, Solenoid, Toroid
- Magnetism in Matter
About Midterm 2

- **When and where**
  - Monday March 21st 5:30-7:00 pm
  - Will be announced later

- **Format**
  - Closed book
  - One 8x11 formula sheet allowed, **must be self prepared, no photo copy of solutions, no photo copy of lecture slides, etc**
  - 20 – 25 questions
  - Bring a calculator (but no computer). Only basic calculation functionality can be used.
  - B2 pencil for Scantron

- **Special Arrangements:**
  - All alternative time tests must be preapproved. **Deadline: 6 PM Monday (March 7).**
  - All specially arranged tests (e.g. those at alternative time) are held in our 202 lab rooms (**for approved requests only**).
Midterm 2: Chapters Covered

- Ch 27: Current and Resistance
- Ch 28: Direct-Current Circuits
- Ch 29: Magnetic Fields
- Ch 30: Sources of Magnetic Field

Suggested preparations:
- Go over homework problems
- Additional problems at the end of chapters
- Pay special attention to signs and directions!

Reviews:
- Lecture next Thursday
- There will be additional office hours next week (look for an email about this).
Ampere’s Law

- It applies to any closed path
- It applies to any static B field
- It is practically useful only in symmetric cases

- Ampere’s Law can be derived from Biot-Savart Law
Magnetic Field Around Infinite Straight Current

Use Ampere’s Law

\[ \oint \vec{B} \cdot ds = \mu_0 I \]

for any closed path

to show that

\[ B = \frac{\mu_0 I}{2\pi R} \]

around an infinite straight current.
Recall: Force On Current Carrying Wire

- Magnetic force on a current segment of length $L$ in uniform field $\mathbf{B}$:

$$\mathbf{F}_B = \Sigma q\mathbf{v}_d \times \mathbf{B} = I\mathbf{L} \times \mathbf{B}$$
Exercise/Demo:
Magnetic Forces Between Two Parallel Current

Tips:
Parallel currents attract each other
Anti-Parallel currents repel each other

\[
\frac{F_B}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi a}
\]
Example: Solenoid

The B field inside an ideal solenoid is:

$$B = \mu_0 n I$$

$\ n=N/L\ 

ideal solenoid

segment 3 at $\infty$
Compare Solenoid and Bar Magnet

http://www.societyofrobots.com/actuators_solenoids.shtml
More on this in Ch. 31.
Exercise: Toroid

Show the B field inside a toroid (donut shape) is (example 30.6):

hint: Use Ampere’s Law
(See board)

\[ B = \frac{\mu_0 NI}{2\pi r} \]

A transformer from Radio Shack.
More on this in Ch. 31.
Quick reminder: Electric Dipole Moments

- Electric dipole moment $\mathbf{p}$.

Dielectric material contains electric dipoles at atomic level.

In an external field $E_0$, the dipoles line up $E_{\text{ind}}$ is always opposite to $E_0$.

$E = E_0 / \kappa < E_0$, $C = \kappa C_0$

(dielectric constant $\kappa > 1$)

\[ \sum \mathbf{F} = 0 \]
\[ \vec{\tau} = \mathbf{p} \times \mathbf{E} \]
\[ U = -\mathbf{p} \cdot \mathbf{E} \]
Quick reminder: Magnetic Dipole Moments

- Magnetic dipole moment $\mu$.

  **Macroscopic**
  $\mu = I A$

  **Microscopic**
  $\mu \propto L$

  angular momentum of orbiting or spin

  definition of magnetic moment

Note: $B$ produced (at the center) is always in the same direction as $\mu$.
Magnetism in Matter

- Induced field $B_{\text{ind}}$ in response to an external $B_0$: $B_{\text{ind}} = \chi B_0$
- the net field inside: $B = B_0 + B_{\text{ind}} = (1 + \chi) B_0 = (\mu_m/\mu_0) B_0$

$\mu_m$: magnetic permeability, $\chi$: magnetic susceptibility

### Classification of Magnetic Matter

<table>
<thead>
<tr>
<th>Type</th>
<th>Direction of $B_{\text{ind}}$</th>
<th>Strength of $B_{\text{ind}}$</th>
<th>$\chi=\mu_m/\mu_0-1$</th>
<th>Contributing Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferromagnetic (e.g. Fe, Co, Ni...)</td>
<td>Same as $B_0$</td>
<td>Strong</td>
<td>$&gt;&gt;0$ ($\sim 10^3$)</td>
<td>Domain of Magnetic Dipole</td>
</tr>
<tr>
<td>Paramagnetic (e.g. Al, Ca,...)</td>
<td>Same as $B_0$</td>
<td>Weak</td>
<td>$&gt;0$ ($\sim 10^{-5}$)</td>
<td>$\mu_{\text{atoms}}$</td>
</tr>
<tr>
<td>Diamagnetic (e.g. Cu, Au,...)</td>
<td>Opposite</td>
<td>Weak</td>
<td>$&lt;0$ ($\sim -10^{-5}$)</td>
<td>Magnetic Quadruple</td>
</tr>
<tr>
<td>Superconductor</td>
<td>Opposite</td>
<td>$=-B_0$</td>
<td>-1</td>
<td>Quantum eff.</td>
</tr>
</tbody>
</table>
Permanent Magnetic Moments (domains)  
Inside Ferromagnetic Material

No external B field, permanent mag. moments exist, but oriented randomly  
→ no induced B field

B\(_0\) applied, permanent magnetic moments line up in the direction of B\(_0\)  
→ strong induced B field
Meissner Effect

- Certain superconductors (type I) exhibit perfect diamagnetism in superconducting state:
  no magnetic field allowed inside (Meissner Effect)
Additional Resources

- Field visualization tools:
  - http://www.falstad.com/vector3dm/

- Floating frog and other objects:
  - http://www.ru.nl/hfml/research/levitation/diamagnetic/