Physics 202, Lecture 14

Today’s Topics

- 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 Exam 2

- When and where
  - Friday March 13th 5:30-7:00 pm
  - 2650, 3650 Humanities (same as exam 1)

- Format
  - Closed book
  - 1+1 8x11 formula sheet allowed, must be self prepared, no photo copy of solutions, no photo copy of lecture slides.
  - Four full problems. (~20 questions)
  - Bring a calculator (but no computer). Only basic calculation functionality can be used.

- Special Arrangements:
  - All alternative time tests must be preapproved.
  - No early test before Friday Mar 13th possible.
  - Alternative test available in earlier afternoon (~ 4pm) in lab rooms (for approved requests only)

Review Sessions

- There will be two identical review sessions:
  - Saturday, March 7th, 2-4 pm
  - Sunday, March 8th, 7-9 pm
  - Both are in 2103 Chamberlin. (this room)

  Each session = ~70 min lecturing + Q&A

Review: Ampere’s Law

- Ampere’s Law:

\[ \oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 I \]

- 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
- It has also a generalized form: Ampere-Maxwell law (later in the lecture)
Exercise: Solenoid

- The B field inside an ideal solenoid is:
  \[ B = \mu_0 nI \]
  where \( n = \frac{N}{L} \).

Compare Solenoid and Bar Magnet

- Loose Solenoid
- Tight Solenoid
- Bar Magnet

Exercise: Toroid

- Text example 30.5: Show the B field inside a toroid is:
  \[ B = \frac{\mu_0 NI}{2\pi r} \]
  hint: Use Ampere’s Law
  (See board)

Dielectric material contains electric dipoles at atomic level.

Review: Electric Dipole Moments

- Electric dipole moment \( p \).
- \( \sum F = 0 \)
  \( \vec{F} = \vec{p} \times \vec{E} \)
  \( U = -\vec{p} \cdot \vec{E} \)

In an external field \( E_0 \), the dipoles line up:
- \( \vec{E}_{ind} \) is always opposite to \( \vec{E}_0 \)
- \( \vec{E}_0 \) is parallel to \( \vec{E}_{ind} \)
- \( C = \kappa C_0 \)
  (dielectric constant \( \kappa < 1 \))
Review: Magnetic Dipole Moments

Magnetic dipole moment $\mu$.

- Macroscopic $\mu = |I| A$
- Microscopic $\mu \propto L$

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

$\sum F = 0$

$\vec{r} = \vec{\mu} \times \vec{B}$

$U = -\vec{\mu} \cdot \vec{B}$

$\mu$ in $B$ Field

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: $B = B_0 + B_{\text{ind}} = (1 + \chi) B_0 = \left(\frac{\mu_m}{\mu_0}\right) B_0$

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

<table>
<thead>
<tr>
<th>Classification of Magnetic Matter</th>
<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</td>
<td>Same as $B_0$</td>
<td>Strong</td>
<td>$&gt;0$</td>
<td>$\sim 10^3$</td>
<td>Domain of Magnetic Dipole</td>
</tr>
<tr>
<td>(e.g. Fe, Co, Ni…...)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\mu_{\text{atoms}}$</td>
</tr>
<tr>
<td>Paramagnetic</td>
<td>Same as $B_0$</td>
<td>Weak</td>
<td>$&lt;0$</td>
<td>$\sim 10^{-5}$</td>
<td>$\mu_{\text{atoms}}$</td>
</tr>
<tr>
<td>(e.g. Al, Ca,…...)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Magnetic Quadrupole</td>
</tr>
<tr>
<td>Diamagnetic</td>
<td>Opposite</td>
<td>Weak</td>
<td>$&lt;0$</td>
<td>$\sim 10^{-5}$</td>
<td>$\mu_{\text{atoms}}$</td>
</tr>
<tr>
<td>(e.g. Cu, Au,…...)</td>
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<tr>
<td>Superconductor</td>
<td>Opposite</td>
<td>Weak</td>
<td>$&gt;0$</td>
<td>$\sim 10^{-5}$</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 $\Rightarrow$ no induced $B$ field
- $B_0$ applied, permanent magnetic moments line up in the direction of $B_0$ $\Rightarrow$ strong induced $B$ field

Note: Inductance with a ferromagnetic core: $L = \frac{\mu_m}{\mu_0}L_0 >> L_0$

Demo: Meissner Effect

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