Lecture 10.1:
The Magnetic Field

Lecture Outline:
Magnetism
Magnetic Field of Moving Charges
Magnetic Field of a Current

Textbook Reading:
Ch. 32.1 - 32.4

March 19, 2013
Announcements

• Homework #8 due on Monday, March 25 in Mastering Physics.
• Quiz #4 on Thursday. Covers Ch.30-31 material.
Equivalent Resistance for Resistors in Parallel:

\[
\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \cdots + \frac{1}{R_N}
\]
RC Circuit, with open switch.

An exponential decay curve

The charge has decreased to 37% of its initial value at \( t = \tau \).

The charge has decreased to 13% of its initial value at \( t = 2\tau \).

The current has decreased to 37% of its initial value at \( t = \tau \).
Last Lecture...

RC Circuit, with open switch.

Current flows after the switch is closed.
Magnets are objects that create magnetic fields, and can exert forces on other magnets. Magnetism appears distinct from electric force since all objects involved can be electrically neutral.
Magnetism

Some Properties of Magnets:

Magnets have two poles (north and south). Like poles repel, opposites attract.

If allowed to rotate, like in a compass, a magnet will align itself in a north-south direction.

Some materials are attracted to magnets, some are not.
Earth itself is a large magnet, with its magnetic poles offset from geographic poles. Earth’s magnetic field is due to motion of its molten iron core.

Earth’s Magnetic Poles Aren’t Fixed!
A brief interruption:
Conventions for drawing vectors/currents

Vectors into page

Current into page

Vectors out of page

Current out of page
Magnetism

Oersted noted in early 1800s that a compass needle would turn if brought near a current-carrying wire.

North pole of compasses points along magnetic field direction.

Right-hand rule to determine direction of magnetic field.
Magnetism

Properties of Magnetic Field

• Magnetic field exists at all points in space around current-carrying wire.
• Magnetic field is a vector with strength ($B$) and direction determined using right-hand rule.
• Magnetic field exerts forces on magnetic poles. Force on north pole is parallel to $B$, force on south pole is opposite $B$. 

![Diagram of forces on magnetic poles](image)
Clicker Question #1

If the bar magnet is flipped over and the south pole is brought near the hanging ball, the ball will be

A. Attracted to the magnet.
B. Repelled by the magnet.
C. Unaffected by the magnet.
D. I’m not sure.
If the bar magnet is flipped over and the south pole is brought near the hanging ball, the ball will be

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Biot-Savart law

\[ \vec{B}_{\text{point charge}} = \frac{\mu_0}{4\pi} \frac{q \cdot \vec{v} \cdot \sin\theta}{r^2} \]

Direction from right-hand rule.

1 tesla = 1 T \equiv 1 \text{ N/ A m}

Permeability Constant: \( \mu_0 = 4\pi \times 10^{-7} \text{ T m/ A} = 1.257 \times 10^{-6} \text{ T m/ A} \)
To give you some scale for magnetic field strength...

<table>
<thead>
<tr>
<th>Field source</th>
<th>Field strength (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface of the earth</td>
<td>$5 \times 10^{-5}$</td>
</tr>
<tr>
<td>Refrigerator magnet</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Laboratory magnet</td>
<td>0.1 to 1</td>
</tr>
<tr>
<td>Superconducting magnet</td>
<td>10</td>
</tr>
</tbody>
</table>

NASA satellite view of earth’s magnetic field in action...we’ll talk more about this behavior soon.
Magnetic Field of Moving Charges

Biot-Savart law rewritten using vector cross product:

\[ \vec{B}_{\text{point charge}} = \frac{\mu_0}{4\pi} \frac{q\vec{v} \times \hat{r}}{r^2} \]

The Cross Product: \( \vec{C} \times \vec{D} = CD\sin\alpha \)  
Direction from right-hand rule.
Clicker Question #2

What is the direction of the magnetic field at the position of the dot?

A. Into the screen.
B. Out of the screen.
C. Up.
D. Down.
E. Left.
What is the direction of the magnetic field at the position of the dot?

A. Into the screen.
B. Out of the screen.
C. Up. Direction of $\vec{v} \times \hat{r}$
D. Down.
E. Left.

$\vec{B}$
$\hat{r}$
$\vec{v}$ into screen
Example Problem: What is the magnetic field at the position of the dot?
Magnetic Field of a Current

Biot-Savart law applies to a point charge, but we want to know about the magnetic field of many charges, such as in a current.

\[ \vec{B}_{\text{current segment}} = \frac{\mu_0}{4\pi} \frac{I\Delta\vec{s} \times \hat{r}}{r^2} \]

Charge \( \Delta Q \) in a small length \( \Delta s \) of a current-carrying wire

\[ (\Delta Q)\vec{v} = \Delta Q \frac{\Delta\vec{s}}{\Delta t} = \frac{\Delta Q}{\Delta t} \Delta\vec{s} = I\Delta\vec{\sigma} \]

The magnetic field of the short segment of current is in the direction of \( \Delta\vec{s} \times \hat{r} \).
Magnetic Field of a Current

Magnetic Field at a distance $d$ away from a long, straight wire carrying current $I$ (see Example 32.3 for derivation)

$$\mathbf{B}_{\text{wire}} = \frac{\mu_0 I}{2\pi d}$$

Use right-hand rule to determine direction.
Clicker Question #3

Compared to the magnetic field at point A, the magnetic field at point B is

A. Half as strong, same direction.
B. Half as strong, opposite direction.
C. One-quarter as strong, same direction.
D. One-quarter as strong, opposite direction.
E. Can’t compare without knowing $I$. 
Clicker Question #3

Compared to the magnetic field at point A, the magnetic field at point B is

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D. One-quarter as strong, opposite direction.
E. Can’t compare without knowing $I$. 

![Diagram of a current-carrying wire with magnetic field lines at points A and B]
A loop with radius $R$ carries a current $I$. What is the magnetic field at distance $z$ on the axis of the loop?
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