Today’s Topics

- RC circuit (ch. 28.4)
- Magnetic Field (ch. 29.1)
  - Magnetic Field
  - Magnetic Forces
    - Between Bar Magnets
    - On A Charged Particle
    - On Current Carrying Wire
- Earth Magnetic Field
  - South Pole or North Pole? (Confusing!)
- Preview for next time: magnetic force on a current carrying conductor (ch. 29.4)

- Expected from preview: north and south poles, Tesla, magnetic field lines, magnetic force......
Charging A Capacitor in RC Circuit

- Find $I$ and $q$ when a capacitor is being charged in a RC circuit.

$$q(t) = \mathcal{E}C(1 - e^{-t/RC})$$

$$I(t) = \frac{\mathcal{E}}{R} e^{-t/RC}$$

Note: $\tau \equiv RC$ is called time constant
Discharging A Capacitor in RC Circuit

- Find I and q when a capacitor is being discharged in a RC circuit (After class exercise).

\[ q(t) = Qe^{-t/RC} \]

\[ I(t) = -\frac{Q}{RC}e^{-t/RC} \]

Note the time constant \( \tau = RC \)
Demo: RC Circuit
Demo: Magnetism

- **Bar magnets** (Permanent magnetic material)
  - Two type of poles
    (like poles repel, opposite pole attractive)
  - Produce a magnetic field

- **Ferromagnetic material** (e.g. iron)
  - Does not produce magnetic field by itself.
  - Always attracted by magnets (temporarily magnetized)

- **Materials of Weak/Non magnetism**
  (e.g. copper, aluminum, wood, plastics etc.)
  - Does not produce magnetic field by itself.
  - Not (or very weakly) attracted by bar magnets
Bar Magnets and Compass

- A magnet always has two opposite magnetic poles. The two poles are conventionally named “north” and “south”
  - like poles repel, opposite poles attract each other.
  - both poles attract iron (ferromagnetic material)
  - The two poles are not separable. (i.e. no mono-pole)

- A compass is essentially a bar magnet.
  - Its “north” pole, as conventionally defined, points towards the north direction.

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Magnets | Modern compasses | An ancient Chinese compass (~220BC)
The Magnetic Field

- The magnetic field ($\mathbf{B}$) is a field which can exert forces on magnetic objects
  - It is a vector field:
    - Magnitude: Unit Tesla (T)
    - Direction: as pointed by the “north” pole of a compass

\[ 1 \text{T} = 1 \frac{\text{N}}{\text{C} \cdot \text{m/s}} = 1 \frac{\text{N}}{\text{A} \cdot \text{m}} \]

Tips
- Outside magnet: $\text{N} \rightarrow \text{S}$
- Inside magnet: $\text{S} \rightarrow \text{N}$
- Each line forms a closed loop
Demo: Magnetic Field Lines

(a) (b) (c)

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## Typical Magnetic Field Strength

### Table 29.1

<table>
<thead>
<tr>
<th>Source of Field</th>
<th>Field Magnitude (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strong superconducting laboratory magnet</td>
<td>30</td>
</tr>
<tr>
<td>Strong conventional laboratory magnet</td>
<td>2</td>
</tr>
<tr>
<td>Medical MRI unit</td>
<td>1.5</td>
</tr>
<tr>
<td>Bar magnet</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Surface of the Sun</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>Surface of the Earth</td>
<td>$0.5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Inside human brain (due to nerve impulses)</td>
<td>$10^{-13}$</td>
</tr>
</tbody>
</table>

1 Gauss = $10^{-4}$ Tesla
Magnetic Force

- A moving charged particle in a magnetic field is subject to a magnetic force: \( \mathbf{F} = q \mathbf{v} \times \mathbf{B} \)
  - direction: “right hand rule” for positive charge
  - magnitude: \( F_B = |q| v B \sin \theta \).
Exercise: Direction of Magnetic Force

- Indicate the direction of $F_B$ in the following situations:

(a) $B$ out of page:

(b) $B$ into page:
Quick Quiz 1: Direction of Magnetic Force

Which fig has the correct direction of $\mathbf{F}_B$?
Quick Quiz 2: Direction of Magnetic Force

Which fig has the correct direction of $\mathbf{F}_B$?
Properties of Magnetic Force

- Magnetic Force: \( F_B = qv \times B \).  \( F_B = |q|vB \sin \theta \)
  - \( F_B = 0 \) if \( v = 0 \)
  - \( F_B = 0 \) if \( v \) and \( B \) in 0° or 180°
  - \( F_B \) is normal to \( v \)
  - \( F_B \) is normal to \( B \)

- work done by \( F_B \) is always zero!

- direction of \( F_B \) are opposite for positive charge and negative charges.
The Earth Magnetic Field

North/South? Magnetic Pole

Geographic North Pole

The Earth’s Magnetic Field

North Magnetic Pole

Geographic North Pole

Geographic South Pole

South Magnetic Pole

Peter Reid (SCI-FUN), 2003
Magnetic Force On Current Carrying Wire (1)

- Magnetic force on a current segment of length L in uniform field \( B \):
  \[
  \mathbf{F}_B = \sum q \mathbf{v} \times \mathbf{B} = I \mathbf{L} \times \mathbf{B}
  \]

  - Key steps to derive:
    - Current: moving charges. \( I = q n v_d A \)
    - Magnetic force on charge \( q \): \( q \mathbf{v}_d \times \mathbf{B} \)
    - \( \mathbf{F}_B = q \mathbf{v}_d \times \mathbf{B} \) (ALn) = \( I \mathbf{L} \times \mathbf{B} \)