Today

• Announcements:
  – HW#5 is due by 8:00 am Wednesday February 21th. HW#6 is due next week.
  – The second extra credit problem is due Feb 28 at 8:00am
• Entropy
• Electric and Magnetic Forces

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Entropy

• Entropy is a measure of the number of ways a system can be arranged.
• $S = \text{Heat}/T$ – thermal energy goes toward increasing the entropy
• Second Law of Thermodynamics – The entropy of a closed system always increases.
• As the pendulum swings useful energy is lost to increasing the random motion of the air and pivot
• If this is true, we can’t go back in time. There is no way to recollect the thermal energy and make the pendulum swing higher (that is with a closed system).

Why?

Why does the entropy of a system always have to increase?

For now, lets say because that’s the way it seems to work.
Force and Acceleration

- Force causes acceleration – F = ma
- If you see acceleration, there must be a force responsible
- Where do the forces come from? Gravity is one example, it comes from the nature of space-time and the influence of mass.

Why does the Earth’s magnetic field?

- Moving charge, current, causes a magnetic field.
- Current is the flow of charge (electrons) in a wire, similar to water flowing in a pipe.
- Large scale current in the Earth is due to the liquid core of the earth and its rotation. The exact nature is not known.
- The Earth’s changing magnetic field:
  http://science.nasa.gov/headlines/y2003/29dec_magneticfield.htm

The Changing Earth’s Magnetic Field

http://science.nasa.gov/headlines/y2003/29dec_magneticfield.htm

The correspondence of a loop of current and magnet

Magnets have an internal structure where the motion of the electrons creates small regions with currents.
Important observations

• The magnetic force and the electric force are related. They are two manifestations of what we call the **electromagnetic** force.
• There are four equations that give the relationship. These are Maxwell’s Equations; more about them later.
• The electric force is much stronger than the gravitational force.
  - \( k = 8.99 \times 10^9 \text{ N-m}^2/\text{C}^2 \)
  - \( G = 6.67 \times 10^{-11} \text{ N-m}^2/\text{kg}^2 \)
• The electric force is what allows us to sit and stand.

Electric Charge

• Electric charge is a property of matter.
• It is measured in Coulombs.
• The charge on one electron is \( 1.602 \times 10^{-19} \text{ C} \)
• Charge creates electric fields
• Moving charge creates magnetic fields.
• How many electrons in a charge of 1 C?

\[
\text{# Electrons} = \frac{\text{Total Charge}}{\text{Charge/electron}} = \frac{1 \text{ C}}{1.602 \times 10^{-19} \text{ C/electron}}
\]

\[
\text{# Electrons} = 6.215 \times 10^{18}
\]

Electric and Magnetic Fields

• If we move a test charge, \( q \), (or magnet) in the vicinity of another charge (or magnet) we can make a map of the force.
• Define: Electric field \( \mathbf{E} = \frac{\mathbf{F}}{q} \)
• Electric field is a vector. Its units are \( \text{N/C} \) or \( \text{V/m} \) (volts/meter). It points in the direction of the force.
• Once we know the electric field we can calculate the force: \( \mathbf{F} = q \mathbf{E} \)
  
Which is underlying reality, the force or the field?

Samples

• Electric field lines point away from positive charge and toward negative charge.
• Charge generates an electric field.
Example of two point charges

Magnetic Fields

The SI unit for magnetic field is Tesla, T. At East Lansing the Earth’s magnetic field strength is 0.7E-4 T.

Topographical Maps

Sample from TOPO Maps

The slope gives a measure of the force and direction on a ball.

Map for the Electric Field – Electric Potential

The height is electric potential, V, measured in volts

The slope gives a measure of the electric field.
Another example- 4 charges

+ charge gives positive potential (V)

- charge gives negative potential (V)

The Earth has an electric field

The Earth’s electric field is about 150 N/C (same as V/m)

Potential difference of 100 MV is developed between cloud and ground. In the bolt about 5 C of charge are transferred (on average).

Lightning

The Strength of the Electric Field

- Electric potential – SI unit is the Volt (V)
- Electric field is rate of change of potential

\[ E = -\frac{\Delta V}{\Delta x} \]

- The minus sign means that electric fields point from + to – charge.
Sample Problem

What is the magnitude of the electric field at:
- 0.5 m?
- 1.5 m?
- 3.0 m?

The field is 0 V/m at 0.5 m and 3.0 m since the slope is zero.

\[ |E(1.5\, \text{m})| = \frac{\Delta V}{\Delta x} = \frac{(100V - 0V)}{(2m - 1m)} = 100\, V/m \]

Maxwell’s Equations - 1864

- These 4 equations describe the full relationship between the electric and magnetic field.
- They also predict the existence of an electromagnetic wave that travels with speed c.
- This was possible due to the math of Maxwell and the insight of Faraday.

\[
\begin{align*}
\nabla \cdot \vec{E} &= 4\pi \rho & \text{Charge makes an electric field.} \\
\nabla \times \vec{B} &= \frac{4\pi}{c} \vec{J} + \frac{1}{c} \frac{\partial \vec{E}}{\partial t} & \text{Moving charge makes a magnetic field.} \\
\nabla \times \vec{E} &= -\frac{1}{c} \frac{\partial \vec{B}}{\partial t} & \text{Changing magnetic field makes an electric field} \\
\n\nabla \cdot \vec{B} &= 0 & \text{Magnets always have a north and a south pole}
\end{align*}
\]