Today

• Announcements:
  – Up to 4 people can collaborate on the homework essay questions.
  – HW#5 on electric and magnetic forces will be due after the exam on October 19th.
  – The exam #1 review sheet has been posted.
• Electric and Magnetic Forces
• Electric and Magnetic Fields

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

The correspondence of a loop of current and magnet

Magnets have an internal structure were 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 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 \( E = F/q \)
• Electric field is a vector. Its units are N/C or V/m (volts/meter)
• Once we know the electric field we can calculate the force: \( F = qE \)
  \( F = \text{electric field times charge in the field} \)

Samples

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

Example of two point charges
The SI unit for magnetic field is Tesla, T. At East Lansing the Earth’s magnetic field strength is 0.7E-4 T.
The Earth has an electric field

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

Lightning

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

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.

\[ |E(1.5m)| = \frac{\Delta V}{\Delta x} = \frac{(100V - 0V)}{(2m - 1m)} = 100 \frac{V}{m} \]
Electric fields and potential

- In equilibrium the electric field in a metal conductor (electrons to move) is zero.
- This means that inside a metal the electric potential is flat, like the flat top of a table.
- Sitting inside a metal cage is like sitting on top of a large, flat table. As long as you are in the center, there is no danger of falling off.

Maxwell’s Equations - 1864

- These 4 equations describe the full relationship between the electric and magnetic field.

\[ \nabla \cdot \mathbf{E} = 4\pi \rho \] 
Charge makes an electric field.

\[ \nabla \times \mathbf{B} = \frac{4\pi}{c} \mathbf{j} + \frac{1}{c} \frac{\partial \mathbf{E}}{\partial t} \] 
Moving charge makes a magnetic field.

\[ \nabla \times \mathbf{E} = -\frac{1}{c} \frac{\partial \mathbf{B}}{\partial t} \] 
Changing magnetic field makes an electric field

\[ \nabla \cdot \mathbf{B} = 0 \] 
Magnets always have a north and a south pole

- 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.