Today

- Announcements:
  - HW#5 is due by 8:00 am tomorrow, Wednesday February 20th. HW#6 is due next week.
  - The third extra credit problem is due tomorrow at 8:00am
- Entropy and the Second Law of Thermodynamics
- Electric and Magnetic Forces

Energy and Entropy - Pendulum Example

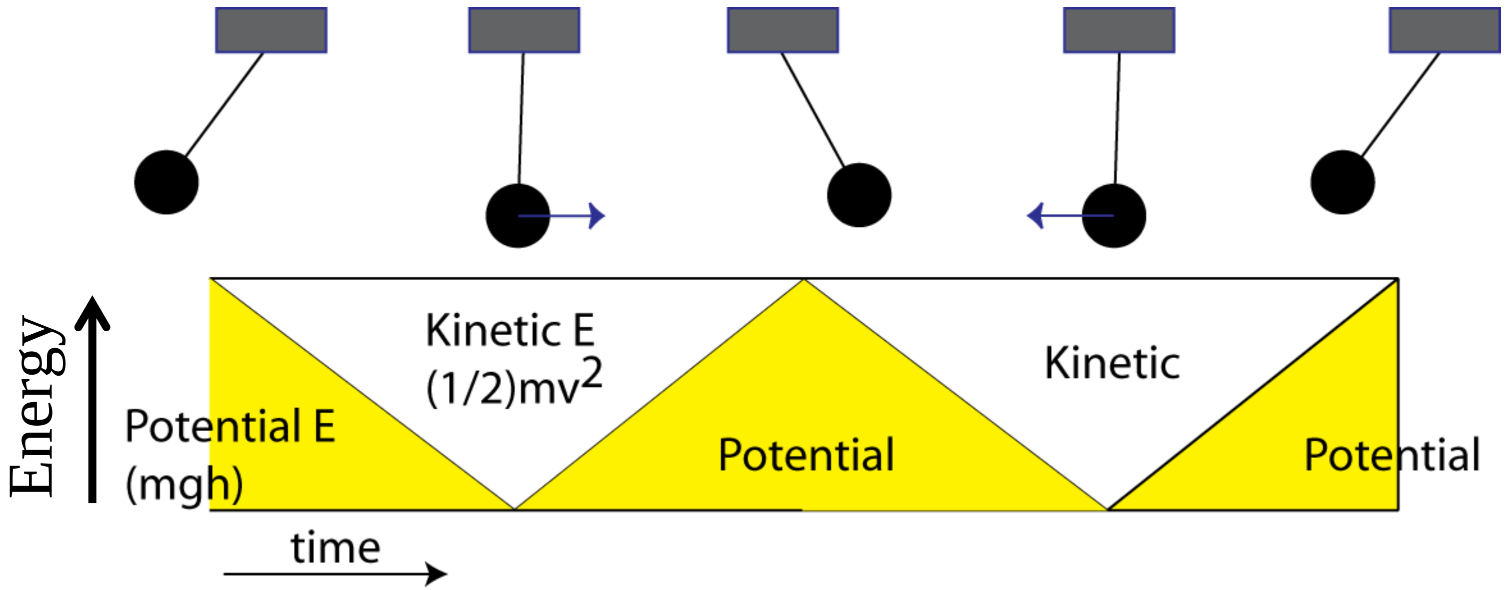
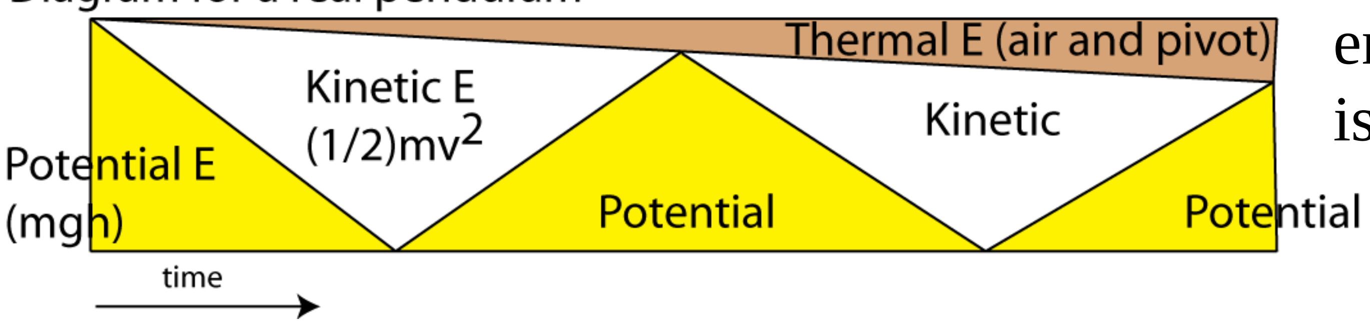


Diagram for a real pendulum



The thermal energy (heat) is "lost"

Entropy

- Entropy is a measure of the number of ways a system can be arranged.
- S = 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?

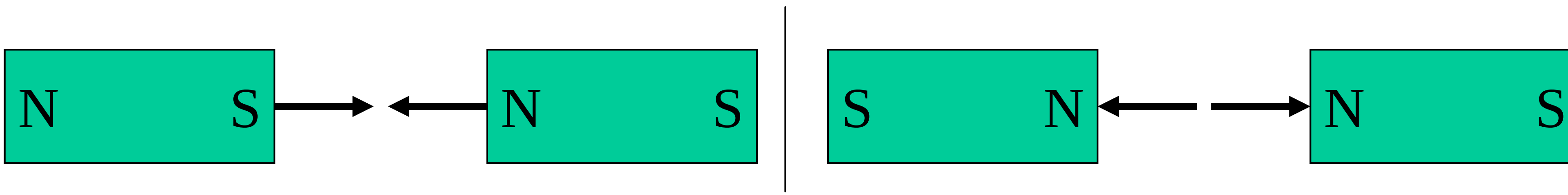
Why does the entropy of a system always have to increase?

For now, lets say because that's the way it seems to work. It probably has to do with how the Universe was formed, but that discussion is for later in the term.

A new force – Magnetic force

Certain objects in nature have magnetic poles. They always come in pairs, north and south.

Like poles repel
Unlike poles attract



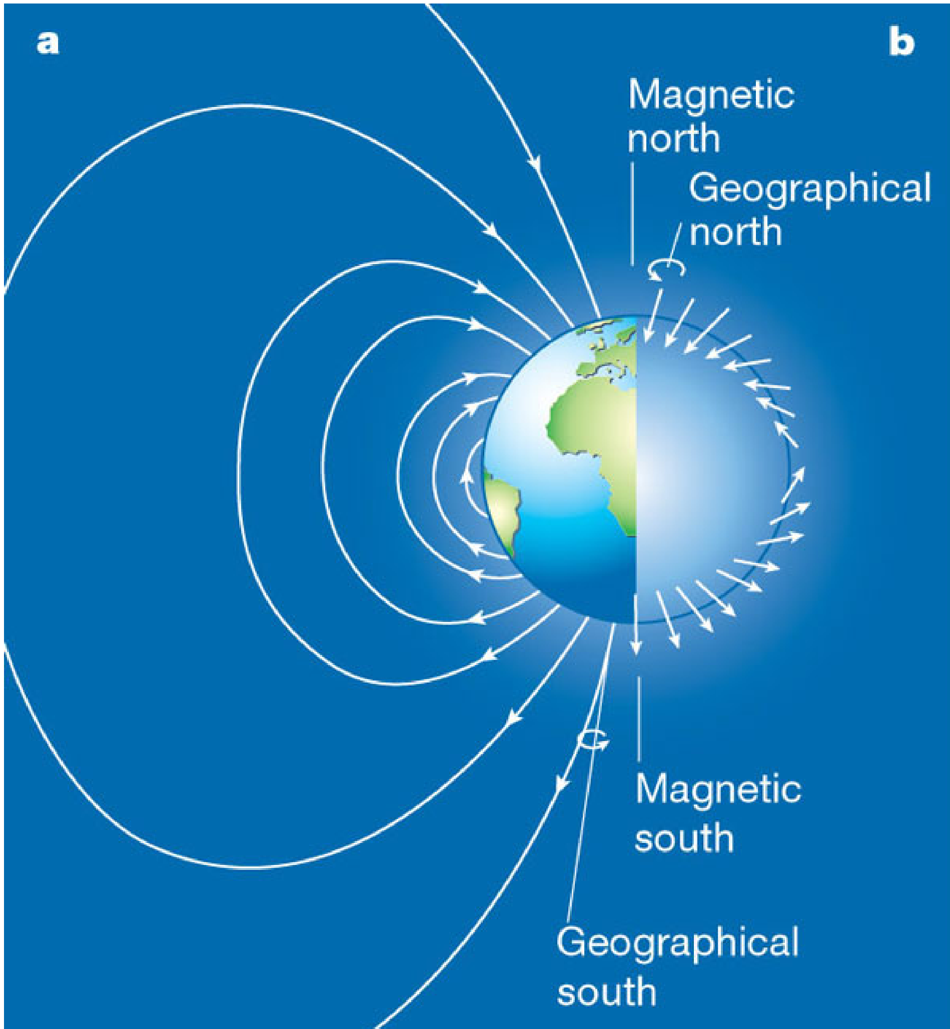
Near the pole, the strength of the force decreases with the square of the distance.

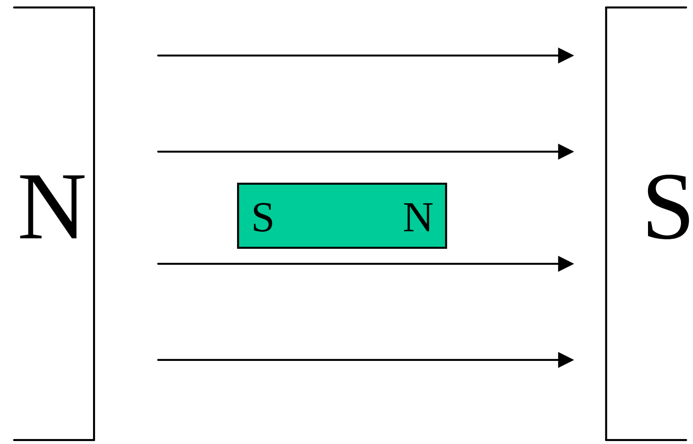
$$F \propto 1/r^2$$

What causes the magnetic force?

- 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 give the Earth a magntic field. The exact nature is not known.
- The Earth's changing magnetic field: http://science.nasa.gov/headlines/y2003/29dec_magneticfield.htm

The Earth's magnetic field

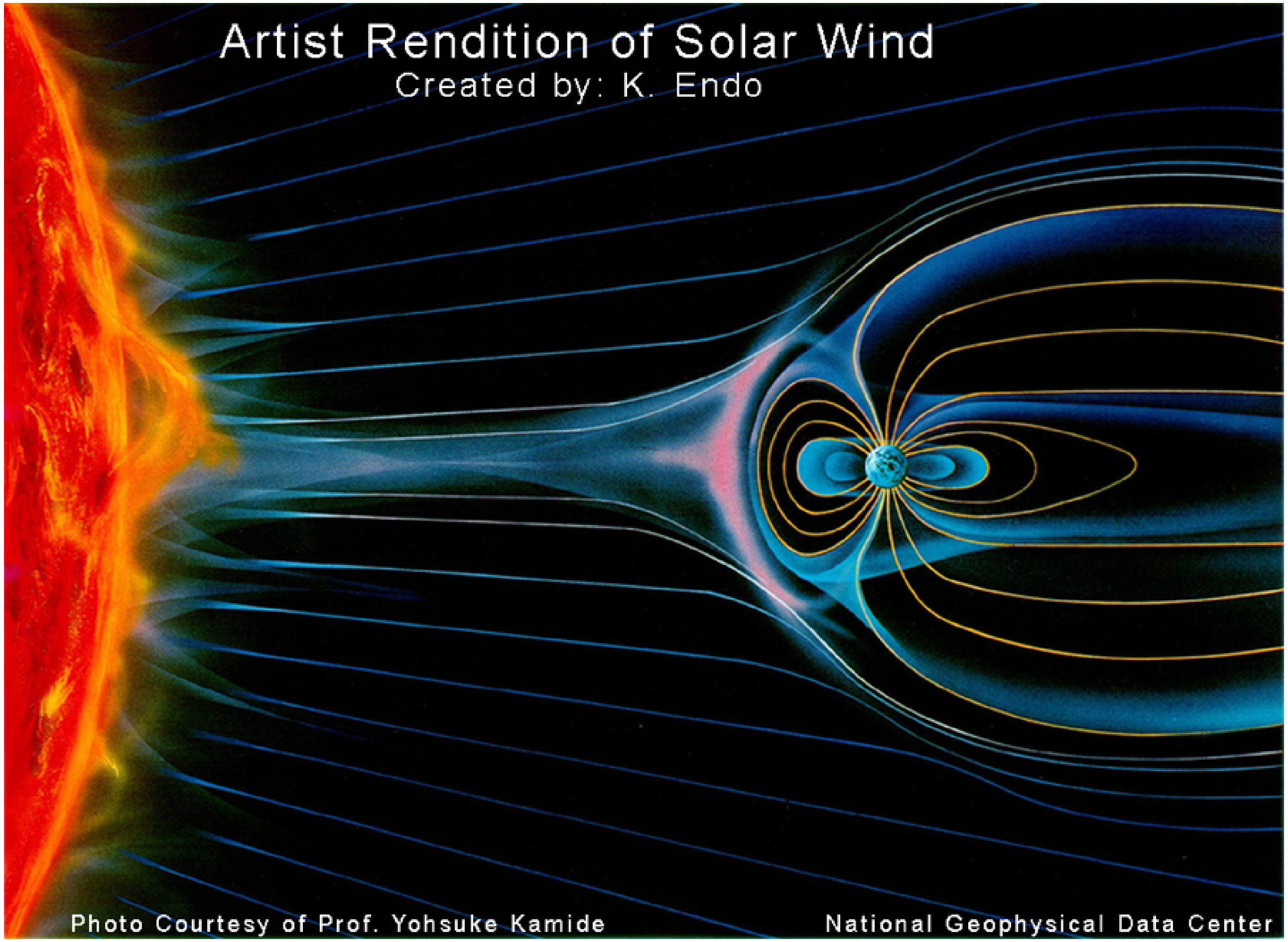




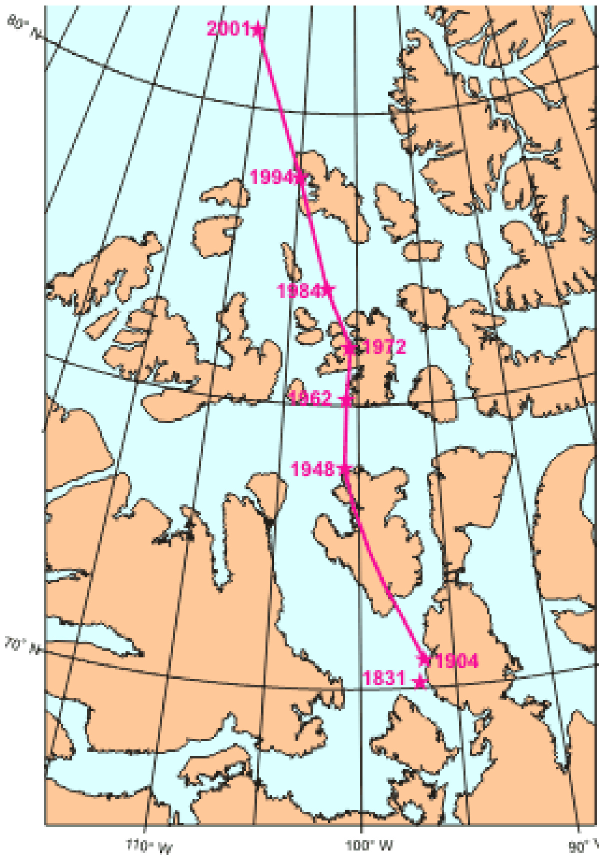
Magnetic field lines point from North magnetic poles to South magnetic poles.

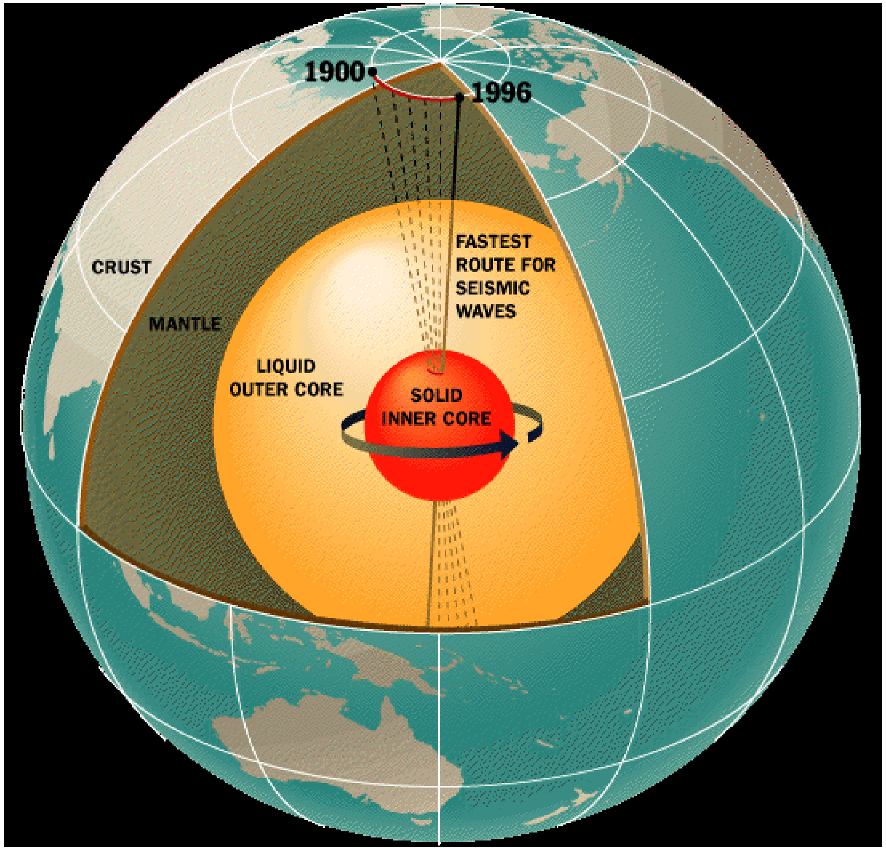
Thomas Alerstam Nature 421, 27-28(2 January 2003)

Earth’s Magnetic Field and the sun



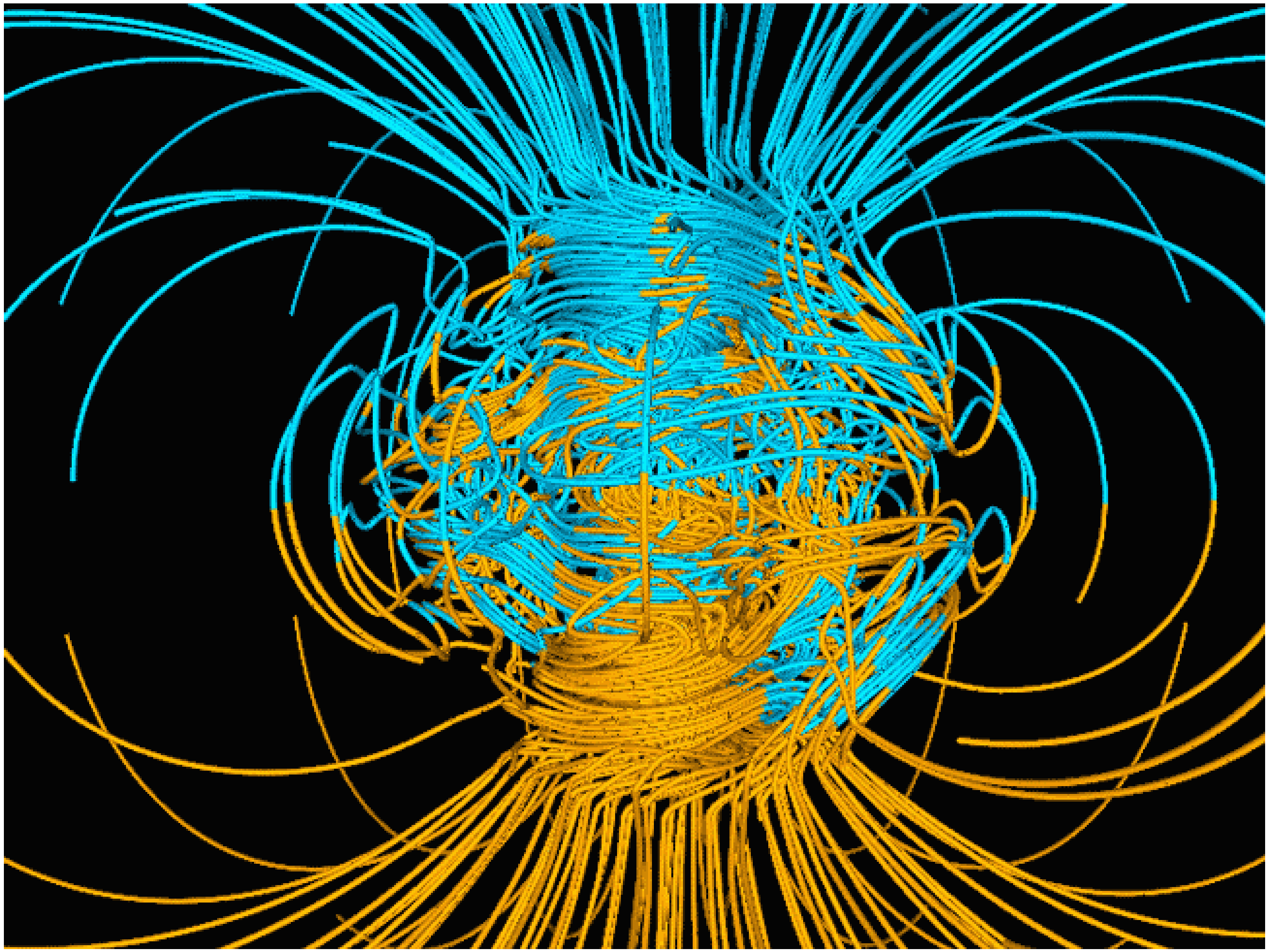
The Changing Earth's Magnetic Field





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

The Earth's Magnetic field - Really



Super computer calculation of field lines

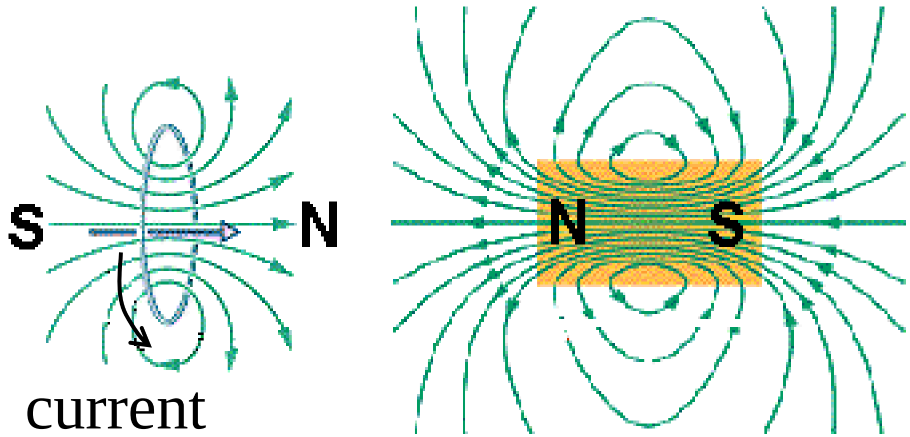
Cyan – in
Gold - out

Gary A. Glatzmaier (UCSC)

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.

Bar magnet



current

MICHIGAN STATE UNIVERSITY

The electric and magnetic forces

- 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.
  - Charge creates the electric force
  - Moving charge creates the magnetic force
- Maxwell's equations "unified" the electric and magnetic forces.
- The electric force is what allows us to sit and stand.

Maxwell's Equations - 1864

$$\nabla \cdot \vec{E} = 4\pi\rho$$

Charge makes an electric field.

$$\nabla \times \vec{B} = \frac{4\pi}{c}\vec{J} + \frac{1}{c}\frac{\partial \vec{E}}{\partial t}$$

Moving charge makes a magnetic field.

$$\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$$

Changing magnetic field makes an electric field

$$\nabla \cdot \vec{B} = 0$$

Magnets always have a north and a south pole

The equations predict the existence of an wave that travels with speed c, the speed of light.

Electric Charge

- Electric charge is a property of matter.
- It is measured in Coulombs
- The charge on one electron is 1.602E-19 C
- How many electrons in a charge of 1 C?

$$\#\text{Electrons} = \frac{\text{Total Charge}}{\text{Charge}/\text{electron}} = \frac{1\text{C}}{1.602\text{E}-19\ \text{C}/\text{electron}}$$

$$\#\text{Electrons} = 6.215\text{E}18$$

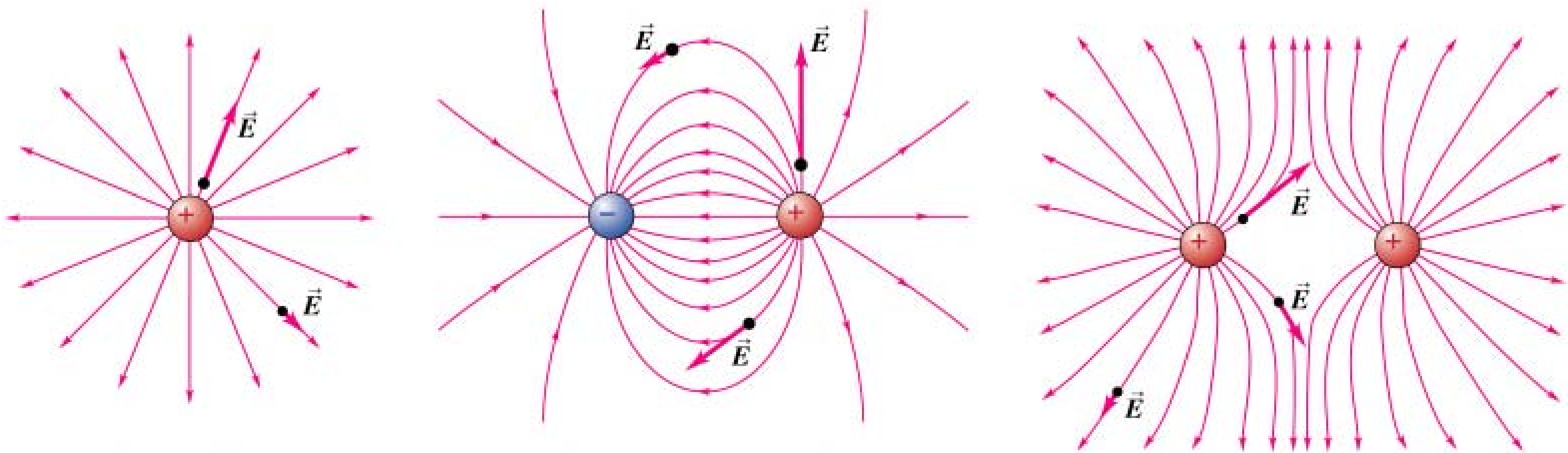
Electric and Magnetic Fields

- 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 **E = F/q**
- Electric field is a vector. Its units are N/C or V/m (volts/meter). It points in the direction of the force.
- Once we know the electric field we can calculate the force: F=qE

F = electric field times charge of the object in the field

Which is underlying reality, the force or the field?

Samples



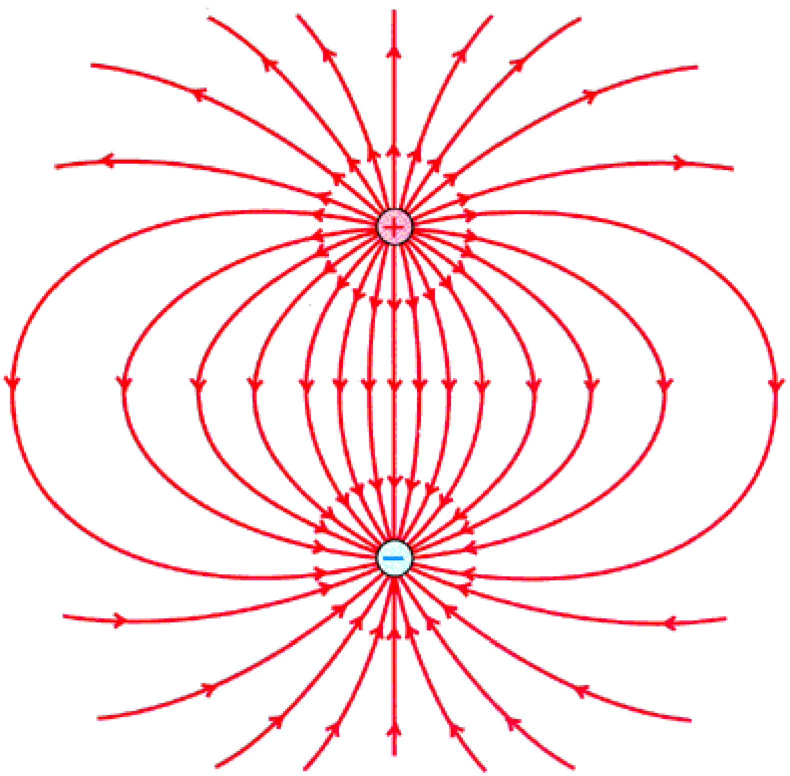
(a) A single positive charge (compare Figure 21.16)

(b) A positive charge and a negative charge of equal magnitude (an electric dipole)

(c) Two equal positive charges

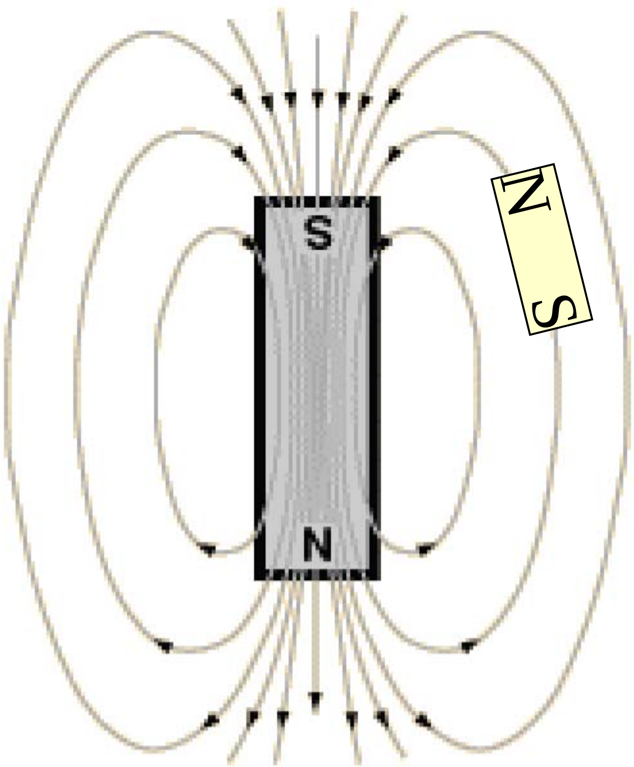
- Electric field lines point away from positive charge and toward negative charge.
- Charge generates an electric field.

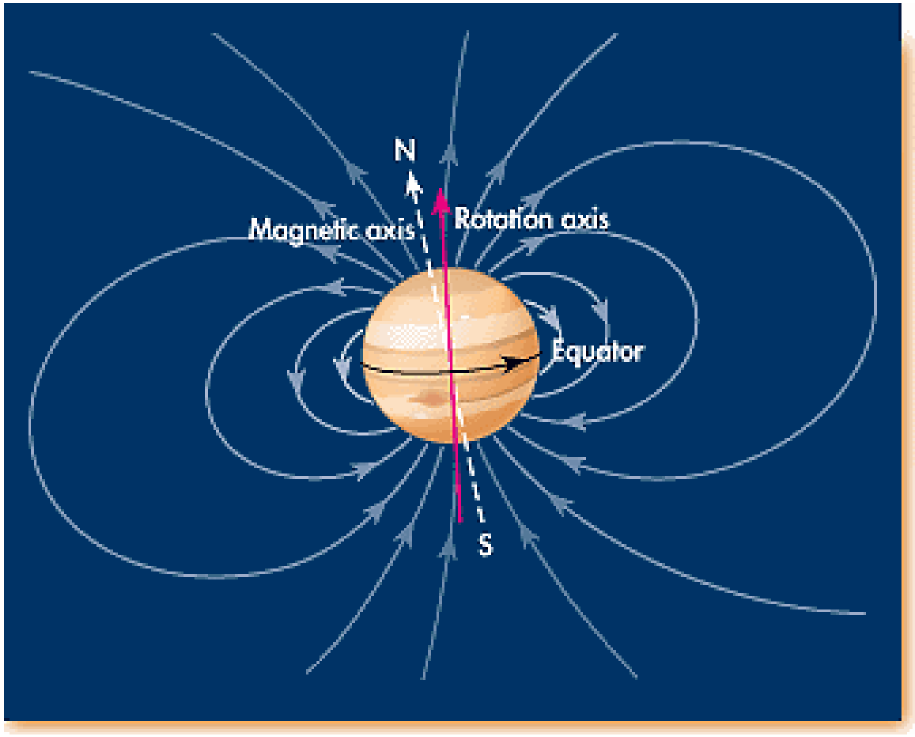
Example of two point charges



(a)

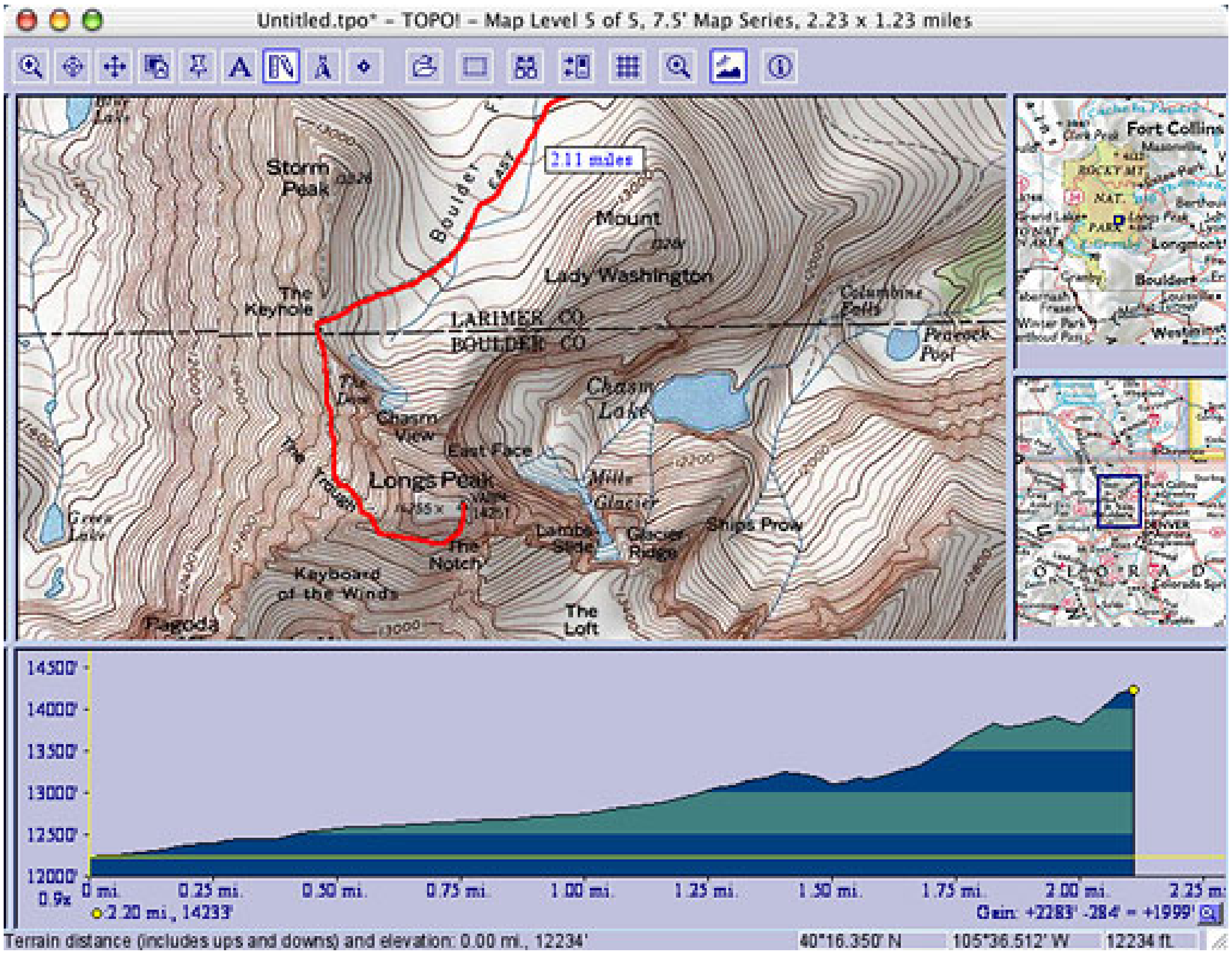
Magnetic Fields





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

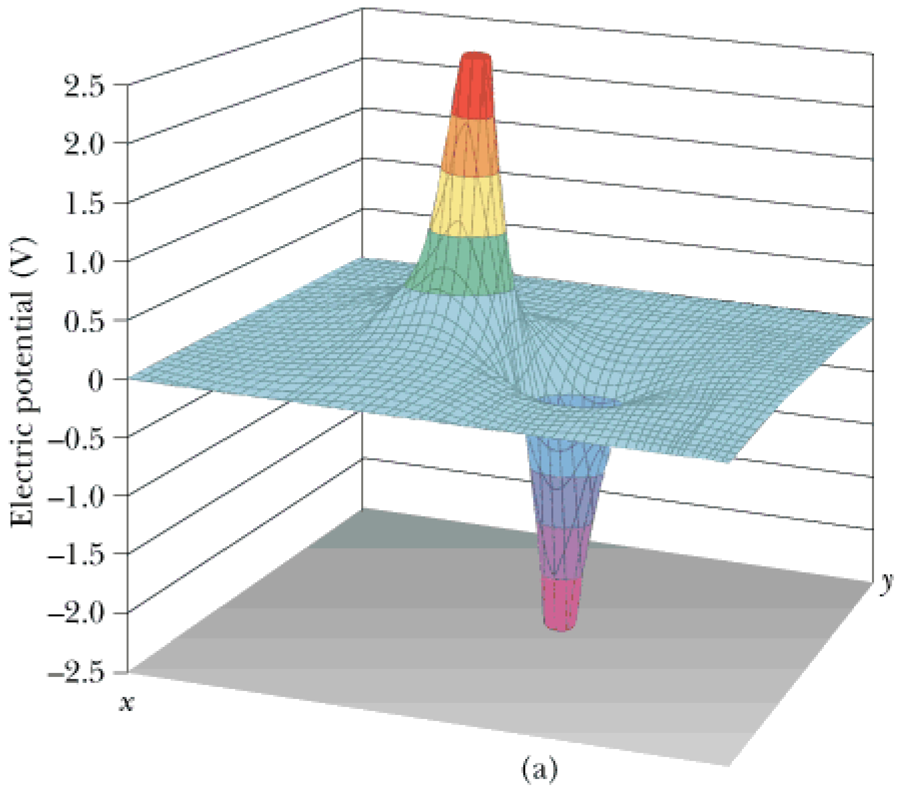
Topographical Maps



Sample from TOPO Maps

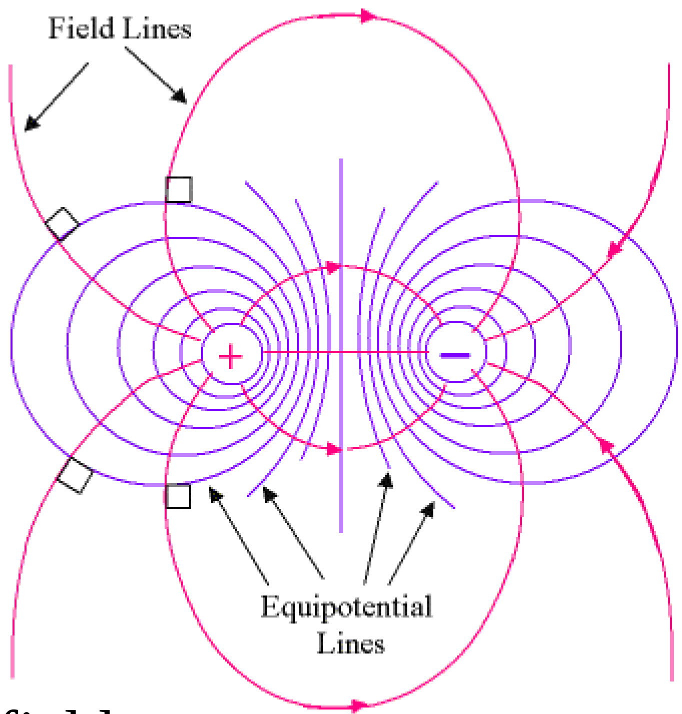
The slope gives a measure of the force and direction on a ball.

Map for the Electric Field – Electric Potential



Serway, Physics for Scientists and Engineers, 5/e
Figure 25.8a
Harcourt, Inc.

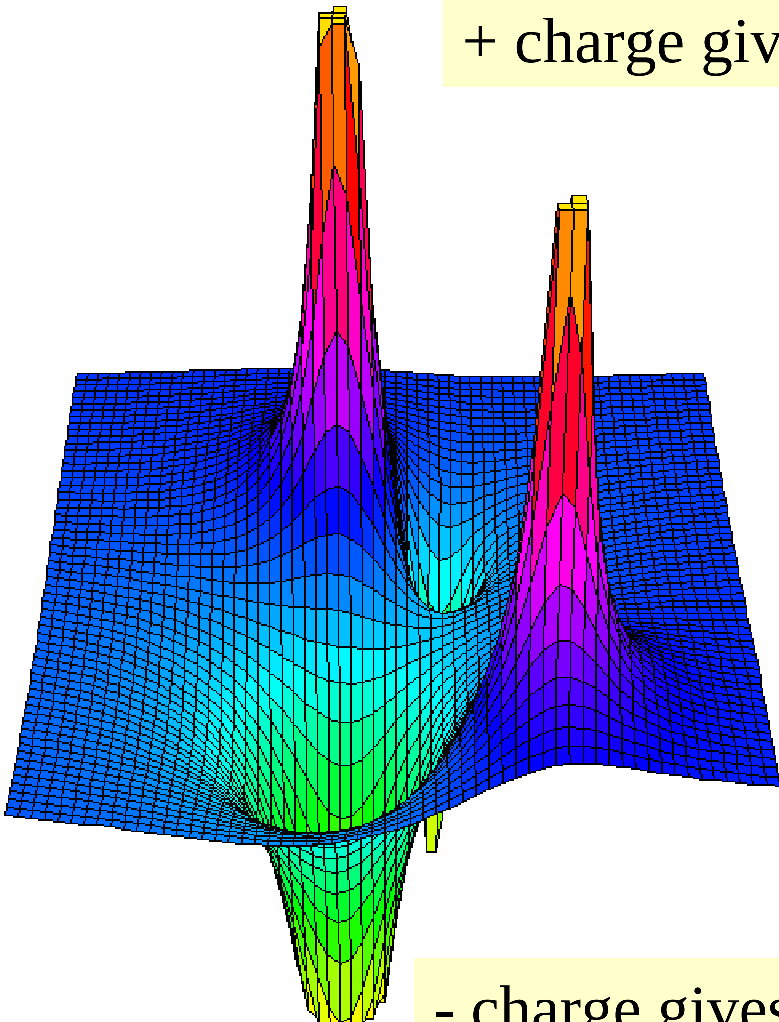
The height is electric potential, V, measured in volts

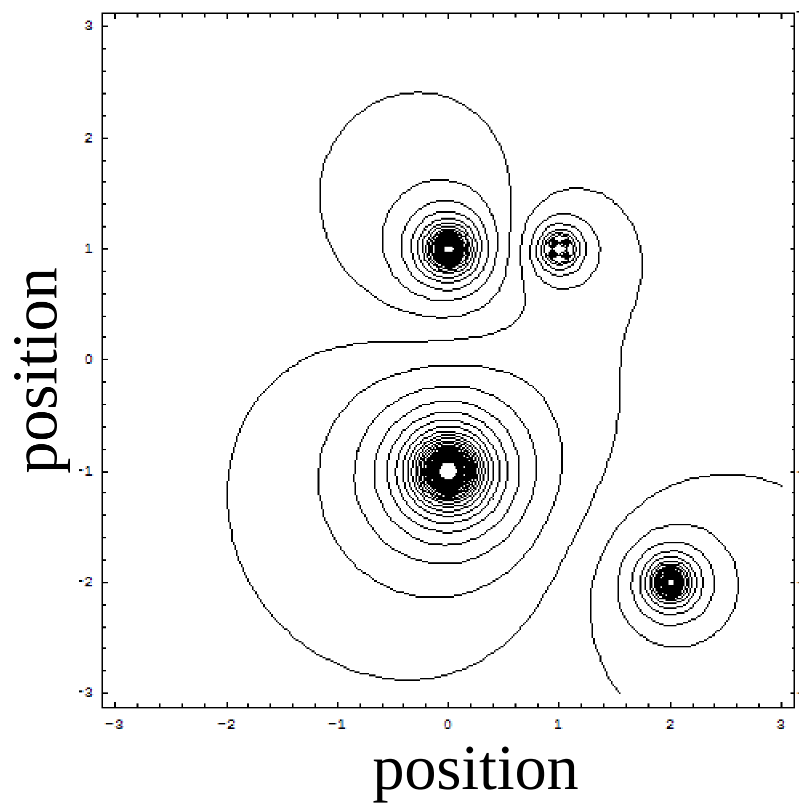


The slope gives a measure of the electric field.

Another example- 4 charges

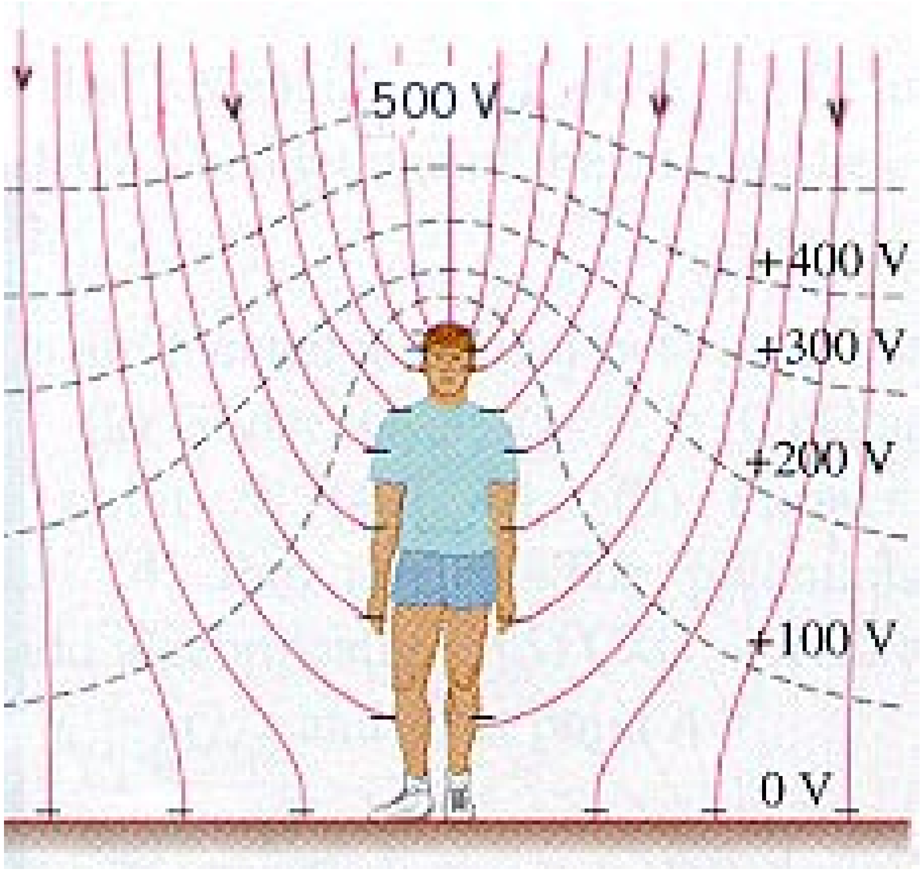
+ charge gives positive potential (V)





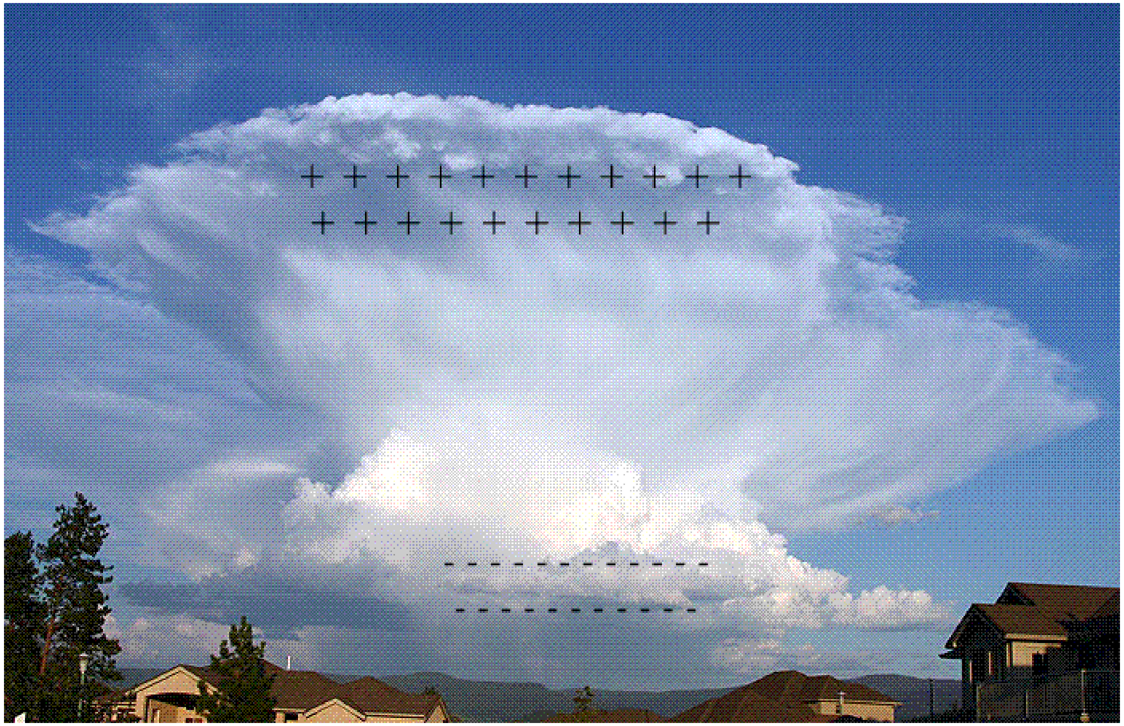
- charge gives negative potential (V)

The Earth has an electric field



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

Lightning



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

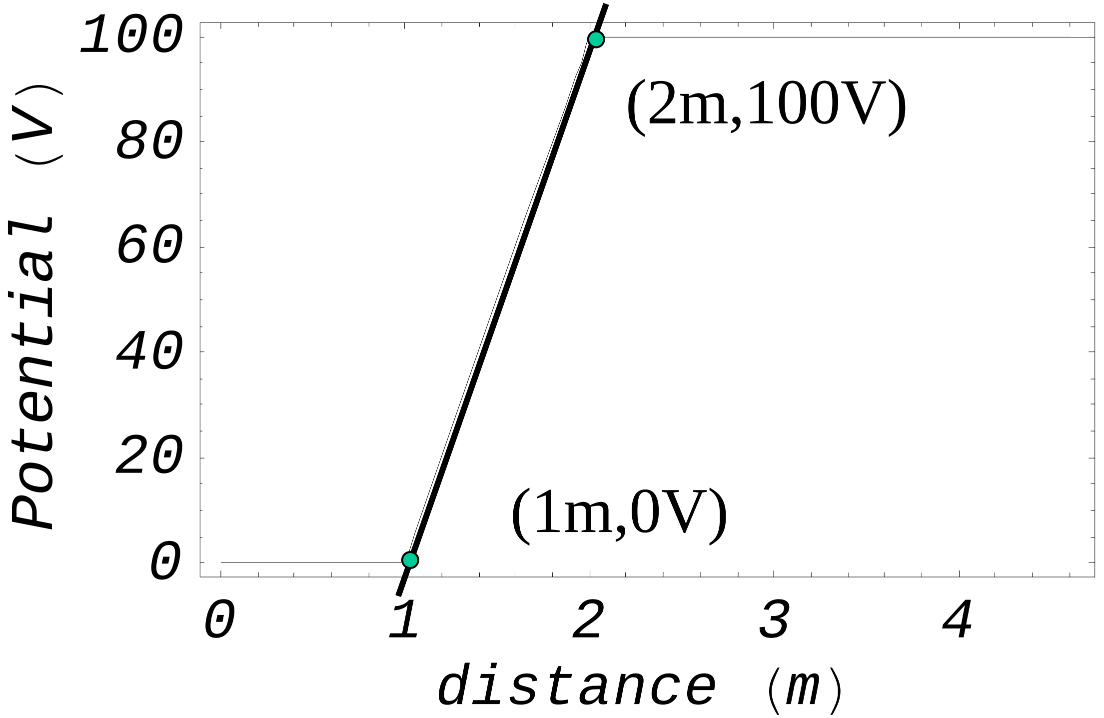
The Strength of the Electric Field

- 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.

$$\left|E(\text{at } 1.5\text{m})\right| = \frac{\Delta \text{V}}{\Delta \text{x}} = \frac{(100V - 0V)}{(2m - 1m)} = 100\frac{V}{m}$$