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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

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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

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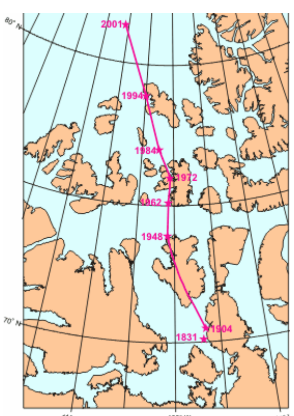
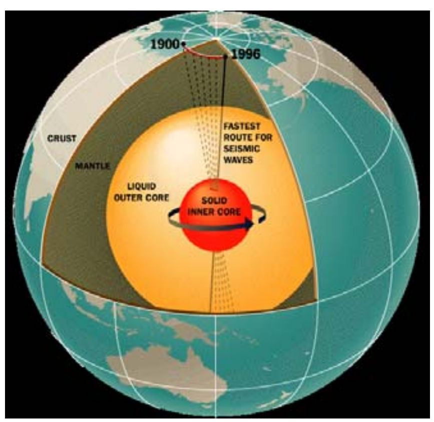
The Changing Earth's Magnetic Field





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

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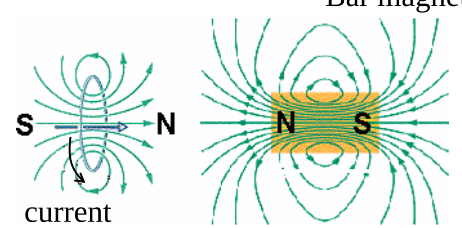
The correspondence of a loop of current and magnet

Magnets have an internal structure were the motion of the electrons creates small regions with currents.

Bar magnet



Important observations

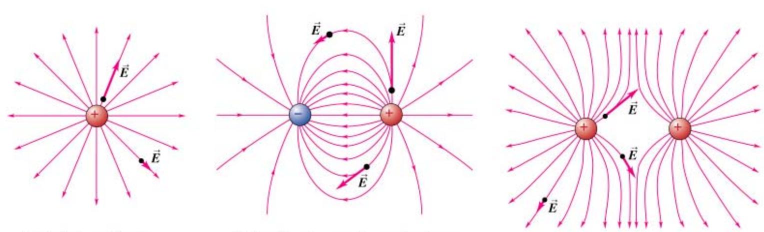
- The magnetic force and the electric force are related. They are two manifestations of what we call the **electromagnetic** force.
- There are four equations that give the relationship. These are Maxwell's Equations; more about them later.
- The electric force is much stronger than the gravitational force.
  - $k = 8.99E+9\ N\text{-}m^2/C^2$
  - $G = 6.67E\text{-}11\ N\text{-}m^2/kg^2$
- 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 = electric field times charge in the field

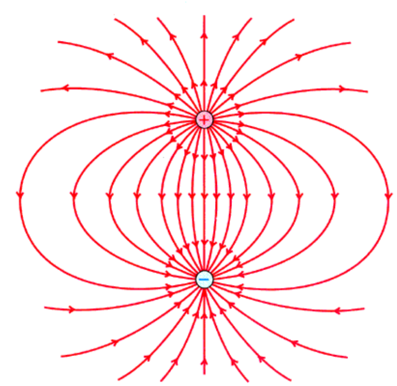
Samples



(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

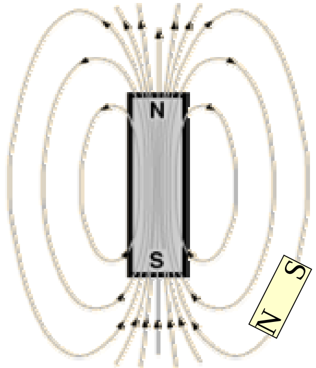
- Electric field lines point away from positive charge and toward negative charge.
- Charge generates an electric field.

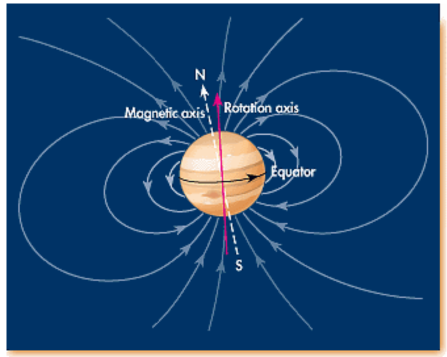
Example of two point charges



(a)

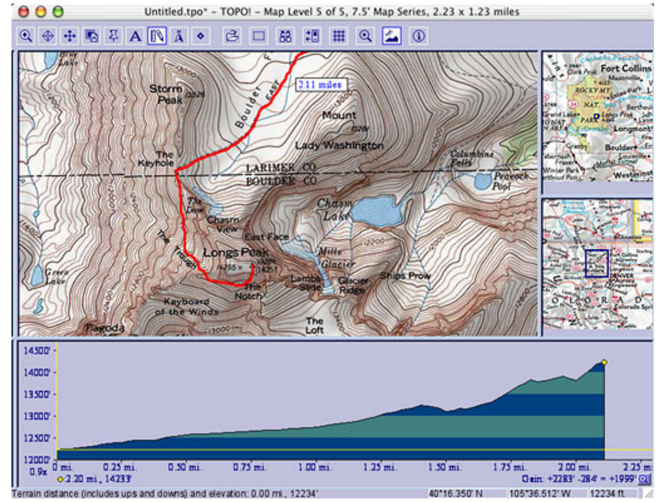
Magnetic Fields





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

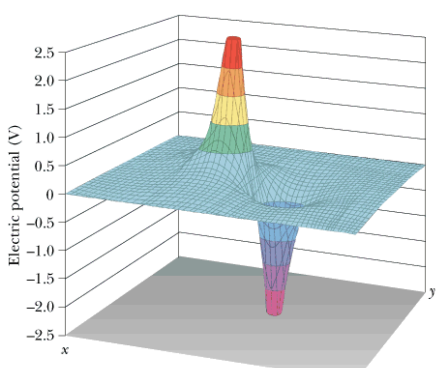
Topographical Maps



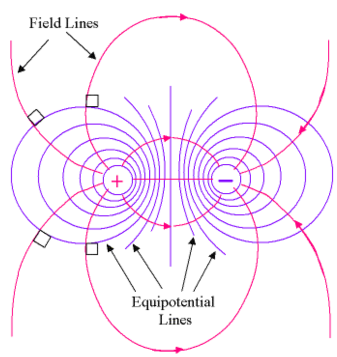
Sample from TOPO Maps

The slope gives a measure of the gravitational field

Map for the Electric Field



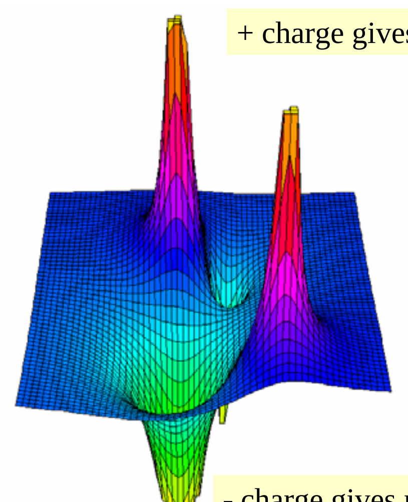
(a)

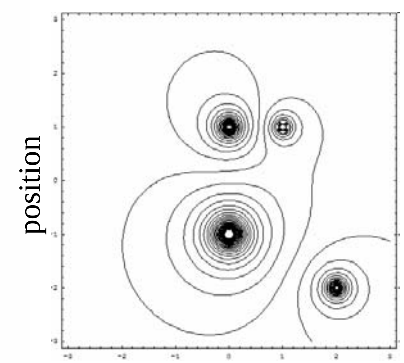


Serway, Physics for Scientists and Engineers, 5/e Figure 25.8a Harcourt, Inc.

Another example- 4 charges

+ charge gives positive potential (V)





position

position

- charge gives negative potential (V)

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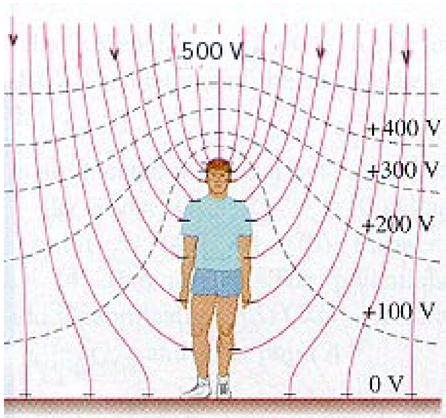
The Earth has an electric field



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

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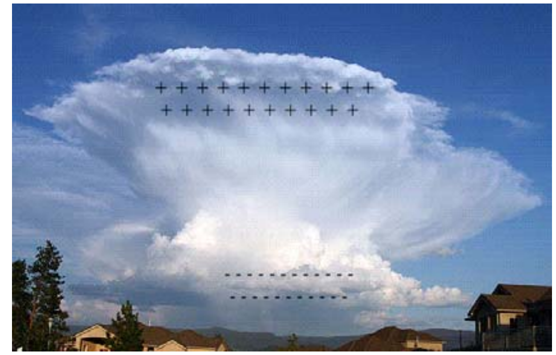
Lightning



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

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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.

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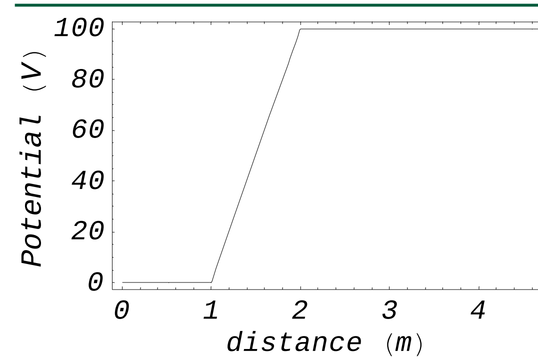
Sample Problem



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.

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

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.

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

- 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