Physics for Scientists & Engineers 2

Spring Semester 2005

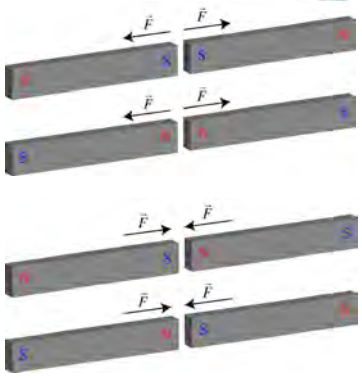
Lecture 20

Permanent Magnets

- Examples of permanent magnets include refrigerator magnets and magnetic door latches
- They are all made of compounds of iron, nickel, or cobalt
- If you touch an iron bar to a piece of magnetic lodestone, the iron bar will be magnetized
- If you then float this iron bar in water, the iron bar will align with the north pole of the Earth
- We call the end of the magnet that points north the north pole of the magnet and the other end the south pole of the magnet

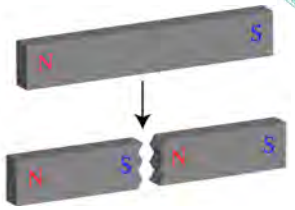
Permanent Magnets - Poles

- If we bring together two permanent magnets such that the two north poles are together or two south poles are together, the magnets will repel each other
- If we bring together a north pole and a south pole, the magnets will attract each other



Broken Permanent Magnets

- If we break a permanent magnet in half, we do not get a separate north pole and south pole
- When we break a bar magnet in half, we always get two new magnets, each with its own north and south pole



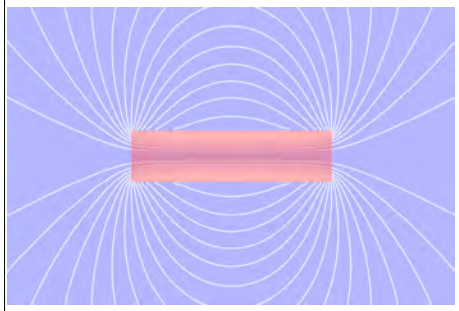
- Unlike electric charge that exists as positive (proton) and negative (electron) separately, there are no separate magnetic monopoles (an isolated north pole or an isolated south pole)
- Scientists have carried out extensive searches for magnetic monopoles and none have been found

Magnetic Field Lines

- The permanent magnets just discussed interact with each other at a distance without visibly touching
- In analogy with the electric field, we define the abstract concept of a magnetic field to describe the magnetic force
- As we did for the electric field, we can represent the magnetic field using magnetic field lines
- The magnetic field is always tangent to the magnetic field lines

Magnetic Field Lines (2)

- The magnetic field line from a permanent bar magnet are shown below



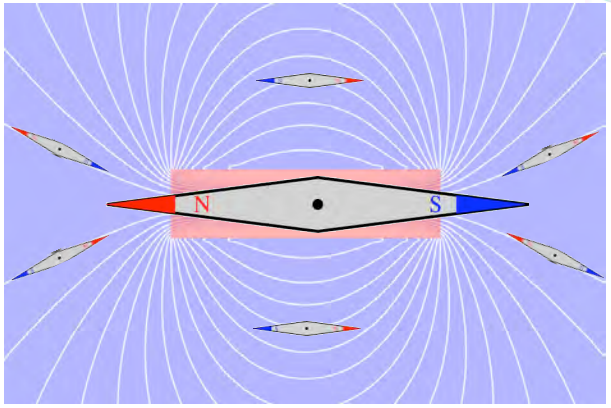
Two dimensional computer calculation

Three dimensional real-life

Magnetic Field Lines

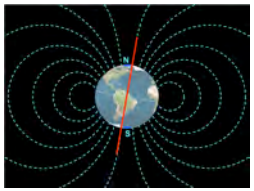
- For the electric field, the electric force pointed in the same direction as the electric field and the electric force was defined in terms of a positive test charge
- However, because there is no magnetic monopole, we must employ other means to define the magnetic force
- We can define the direction of the magnetic field in terms of the direction a compass needle would point
- A compass needle, with a north pole and a south pole, will orient itself such that its north pole points in the direction of the magnetic field
- Thus the direction of the field can be measured at any point by moving a compass needle around in a magnetic field and noting the direction that the compass needle points

Magnetic Field Lines (2)



The Earth's Magnetic Field

- The Earth itself is a magnet
- It has a magnetic field like a bar magnet
- The poles of the Earth's magnetic field are not aligned with the Earth's geographic poles defined as the endpoints of the axis of the Earth's rotation



- The Earth's magnetic field is not a simple as drawn here because it is distorted by the solar wind
  - Protons from the Sun moving at 400 km/s

Earth's Magnetic Poles

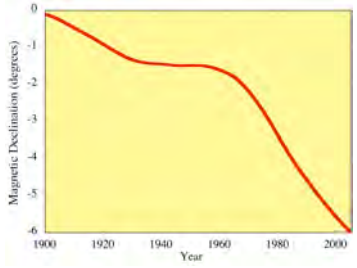
- The north and south magnetic poles are not located at the north and south geographic poles
  - The magnetic north pole is located in Canada
  - The magnetic south pole is located on the edge of Antarctica
- The magnetic poles move at a rate of 40 km per year
  - By the year 2500 the magnetic north pole will be located in Siberia
  - There are indications that the Earth's magnetic field flips on the time scale of 1 million years

Magnetic Declination

- A compass needle points toward the magnetic north pole rather than the geographic or true north pole
- The difference between the direction a compass needle points and true north is called the magnetic declination
- The magnetic declination is defined to be
  - positive when magnetic north is east of true north
  - negative when magnetic north is west of true north
- The magnetic north pole currently resides on a line that passes through central Missouri, Eastern Illinois, Western Iowa, and Eastern Wisconsin
- Along this line the magnetic declination is zero
- West of this line the magnetic declination is positive and reaches 18° in Seattle
- East of this line the declination is negative, up to -18° in Maine.

Magnetic Declination (2)

- Because the positions of the Earth's magnetic poles move with time, they change the magnetic declination for locations on the Earth's surface
- For example, here is the estimated magnetic declination for Lansing, Michigan for the period 1900 – 2004



Magnetic Force

- We define the magnetic field in terms of its effect on a moving charged particle
- Remember that an electric field exerts a force on a particle with charge q given by

$$\vec{F}_E = q\vec{E}$$

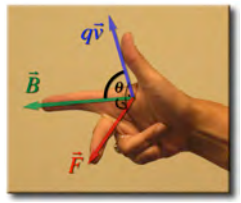
- A magnetic field exerts no force on a stationary charge
- The force that a magnetic field exerts on a charge moving with velocity v is given by

$$\vec{F}_B = q\vec{v} \times \vec{B}$$

- The direction of the force is perpendicular to both the velocity of the moving charged particle and the magnetic field

Right Hand Rule

- The direction of the magnetic force on a moving charged particle is given by the right hand rule
- To apply the right hand rule
  - Use your right hand!
  - Align thumb in the direction of v
  - Align your index finger with the magnetic field
  - Your middle finger will point in the direction of the magnetic force



Magnitude of Magnetic Force

- The magnitude of the magnetic force on a moving charge is

$$F_B = qvB\sin\theta$$

- where θ is the angle between the velocity of the charged particle and the magnetic field.
- One can see that there is no magnetic force on a charged particle moving parallel to the magnetic field because θ is zero
- If a charged particle is moving perpendicular to the magnetic field, the magnetic force assumes its maximum value

$$F = qvB$$

Units of Magnetic Field Strength

- The magnetic field strength has received its own named unit, the tesla (T), named in honor of Croatian-born American physicist and inventor Nikola Tesla (1856-1943)

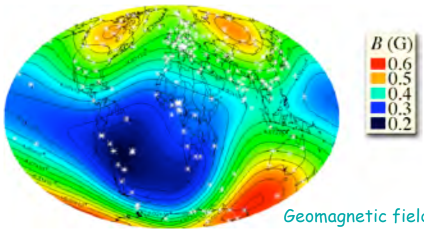
$$1\ \mathrm{T} = 1\ \frac{\mathrm{Ns}}{\mathrm{Cm}} = 1\frac{\mathrm{N}}{\mathrm{Am}}$$

- A tesla is a rather large unit of the magnetic field strength
- Sometimes you will find magnetic field strength state in units of gauss (G), 1 gauss, which is not officially recognized as an SI unit

$$1\ \mathrm{G} = 10^{-4}\ \mathrm{T} \qquad 10\ \mathrm{kG} = 1\ \mathrm{T}$$

Earth's Magnetic Field Strength

- The strength of the Earth's magnetic field at the surface of Earth is on the order of 1 G
- The strength varies between 0.25 G and 0.65 G



Geomagnetic field strength
(National Geophysical Data Center)

The Geodynamo

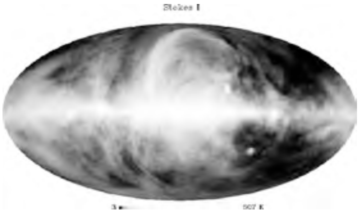
- Photo of Napali coast, Kauai, Hawaii (from paleomagnetic group at UCSC)
- Record of magnetic field at time lava cooled and was magnetized
- Indications that magnetic field reverses direction

http://www.es.ucsc.edu/grad/research/groups/paleomag/geodyn.html

Simulations of the Geodynamo

- Simulations of fluid motions in the earth's core find such a field reversal (Glatzmeier & Roberts 1995, *Nature*)
- simulated 80,000 yrs of core evolution on a Cray C-90 at the Pittsburgh Supercomputing Center
- http://www.psc.edu/research/graphics/gallery/gallery.html
- gold lines: field points outward
- blue lines: field inward

Magnetic fields exist throughout the universe



Towards a model of full-sky Galactic synchrotron intensity and linear polarisation: A re-analysis of the Parkes data, G.Giardino et al., Astron. & Astrophys. **387**: 82 (2002)

Map of radio emission from electrons spiraling around magnetic field lines in our galaxy

Magnetic field strengths range from ~10^{-6} G (galaxy) to 10^{14} G (neutron stars)