Lecture
3/10/05

Magnetism: A New Non-Touching Force

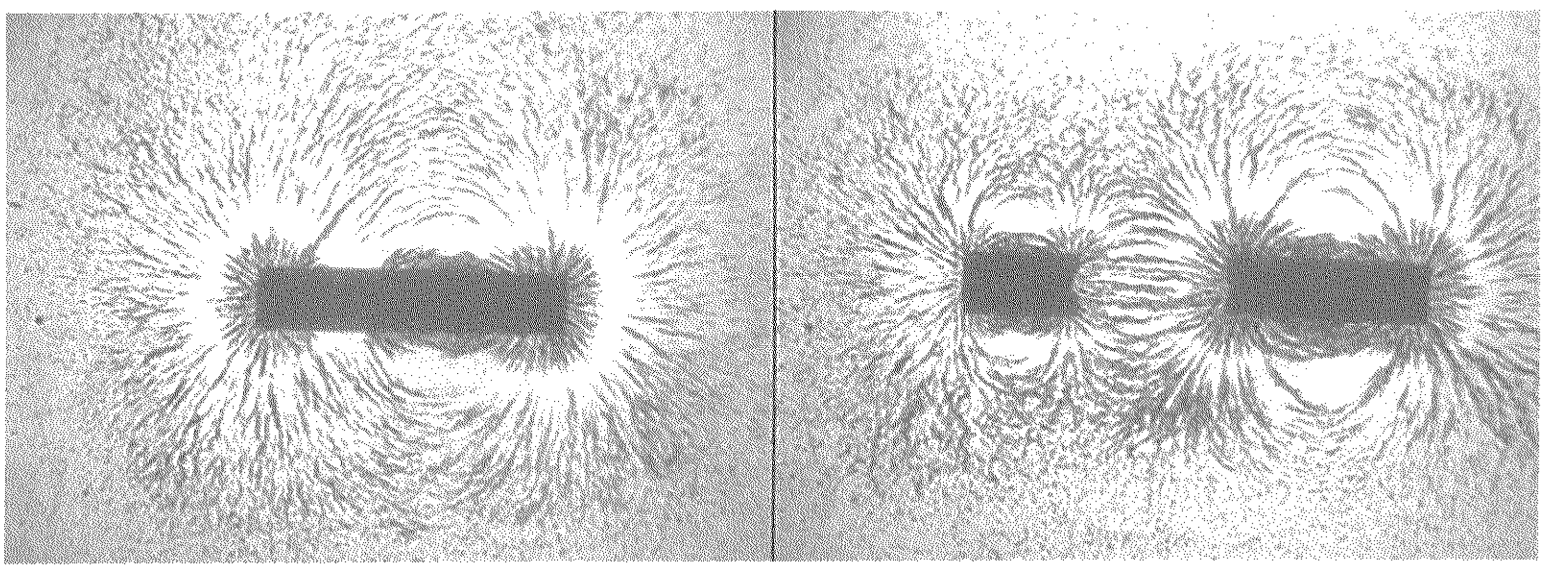
- Lodestone – materials exist that exert forces on each other and on some kinds of matter.
- Magnets both attract and repel each other, depending on orientation.
- Magnets attract some kinds of materials that are not magnets.
  (What will a refrigerator magnet stick to?)

Is Magnetism a New Force? Or is it a form of gravity or electricity?

- Not gravity:
  Gravity only attracts.
  Magnets both attract and repel.
- Not electricity:
  Freely pivoting magnets orient them with respect to N-S, charges do not.
  Magnets attract (stick to) different kinds of materials than charges do.

Is there "magnetic charge"?

- If you break a magnet in half, both parts are still full (N-S) magnets. You can do this all the way down to a single electron and it still holds true.



Describing Magnetism: The Magnetic Field

- In analogous way to how we defined the electric field, we will define a magnetic field.
- Take the direction of a magnetic field as the direction a compass needle (tiny bar magnet) will point.
- We can define the strength of the magnetic field by having a standard strength compass and making the magnet field turn the compass needle against the spring.

The Magnetic Field

- Take the direction of a magnetic field as the direction a compass needle (tiny bar magnet) will point.
- Electrons are little bar magnets. This basic magnetic property is unexplainable like charge or mass. We can only describe its properties.
- Most atoms have most electrons "paired" (matched up NS to SN) so they have no magnetic effect outside the atom.
- Magnetic materials have one unpaired electron making the atom into a little bar magnet. All the atomic magnets get aligned in the same direction to make a big bar magnet.

Fields

Field	*Source*	*Response*
gravity	mass	mass
electricity	charge	charge
magnetism	moving charge / magnetic dipoles	moving charge / magnetic dipoles

What are the basic properties of magnetism?

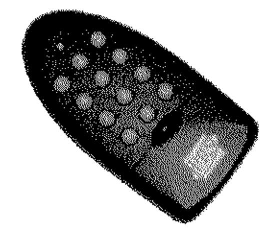
- There are multiple kinds of materials

	Magnets	*Paramagnetic*	*Diamagnetic*	*Nonmagnetic*
Magnets	Attraction & repulsion	Attraction	Repulsion	No force
Paramagnetic		No force	No force	No force
Diamagnetic			No force	No force
Nonmagnetic				No force

Basic Particles

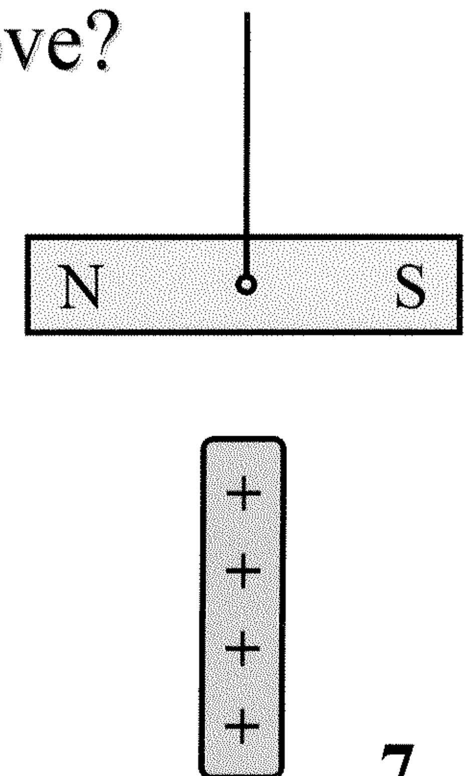
- The fundamental particles making up matter (electrons and protons and neutrons) can be classified by how they behave in response to (and as sources of) gravity, electricity, and magnetism.
- Ordinary matter turns is made up of 3 constituents:

	Mass	*Charge*	*Magnetic Moment*
proton	1.67 x 10^{-27} kg	1.6 x 10^{-19} C	0.0015 Bohr magnetons
neutron	1.67 x 10^{-27} kg	0	0.0010 Bohr magnetons
electron	9.1 x 10^{-31} kg	-1.6 x 10^{-19} C	9.28 Bohr magnetons



Puzzle

- A bar magnet is hung so it can pivot freely about its center. A charged rod is slowly brought up along the midline as shown. How will the magnet tend to move?
  - – 1. rotate clockwise
  - – 2. rotate counterclockwise
  - – 3. be pulled down
  - – 4. be pushed up
  - – 5. there will be no additional force on the magnet at all



Current Carrying Wires Also Create Magnetic Fields

- For a small bit of wire, the magnetic field created by a current, *I*, in that wire a distance *r* away is

$$\vec{B} = k_{BS} \frac{(I\,\Delta\vec{L}) \times \hat{r}}{r^2} \qquad \vec{E} = k_C \frac{q\hat{r}}{r^2}$$

$$k_{BS} = 10^{-7}\,\frac{\text{N}}{\text{A}^2} \qquad k_C = 9 \times 10^{9}\,\frac{\text{N - m}^2}{\text{C}^2}$$

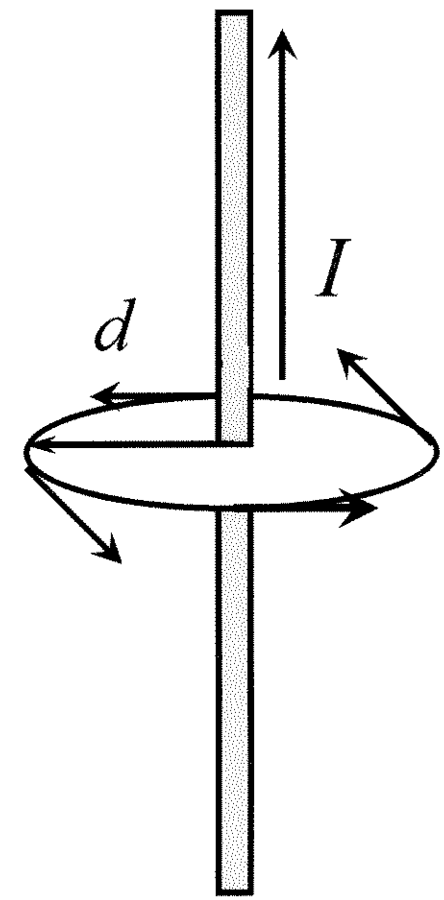
Magnetic Field Near a Long Wire

- Magnitude

$$B = \frac{\mu_0}{2\pi} \frac{I}{d}$$

- Direction

  In circles about the wire
  Orientation by RH Rule



Not only bar magnets respond to magnetic fields!

- There is a surprising and interesting connection between electricity and magnetism.
- Moving electric charges feel a magnetic force
  - proportional to their speed,
  - proportional to their charge
  - perpendicular to the direction of their velocity
  - perpendicular to the direction that a compass needle would point if placed in the charge's position.

Magnetic Force on a Moving Charge

- The direction of a magnetic field at a particular location in space is given by the direction a small compass needle would point if placed at that location.
- A charge q moving with a velocity v at a point where there is a magnetic field B feels a force

$$\vec{F}_{B\rightarrow q} = q\vec{v}\times\vec{B}$$

Units of the Magnetic Field

- We can infer the units of a magnetic field from the defining force law. $\vec{F}_{B\to q} = q\vec{v} \times \vec{B}$

$$[B] = \left[\frac{F}{qv}\right] = \frac{\text{N}}{\text{C - m/s}} = \frac{\text{N - s}}{\text{C - m}}$$

$$1\,\frac{\text{N - s}}{\text{C - m}} \equiv 1\,\text{T} \quad \text{(Tesla)}$$

$$1\,\text{G (Gauss)} = 10^{-4}\ \text{T}$$