**Magnetism**

- Opposite poles attract and likes repel
  - Like electric force, but magnetic poles always come in pairs (North, South)
  - If you break a magnet in half, you get two magnets!
  - Does this still hold at the atomic level?

**DEMO - Lodestone**

- All magnets are surrounded by a field
  - Induces other magnetized objects to line up along it

- Which charged particles are moving in a bar magnet?
  - The electrons. They spin like tops.
  - Clusters of spins can align with one another
  - Called magnetic domains

**Magnetic Fields and Magnetic Domains**

- Creating and Destroying a Magnet
  - How can we create a magnet from unmagnetized iron?
    - Align domains => put in strong magnetic field
    - How can we weaken the field strength of a magnet?
Creating and Destroying a Magnet

- How can we create a magnet from unmagnetized iron?
  - Align domains => put in strong magnetic field

- How can we weaken the field strength of a magnet?
  - Heat it
    - Random thermal motion will cause the domains to disalign

Inducing Magnetic Fields

Can a magnet pick up a penny? an aluminum can? a piece of glass?

DEMO - Electromagnet

Inducing Magnetic Fields

- Can a magnet pick up a penny? a piece of glass?

- Strong fields can align electron spins to create a temporary magnetic field (paramagnetic materials)

- Strong fields can align electron spins to create a temporary magnetic field in opposition to the imposed magnetic field (diamagnetic materials)

DEMO - Electromagnet

Electric Currents and Magnetic Fields

- Moving charge creates a magnetic field => so will a current in a wire
  - First detected by the deflection of compasses
    - Pattern of concentric circles
  - What happens if the direction of the current is reversed?

DEMO - fields around a wire

Electric Currents and Magnetic Fields

- Moving charge creates a magnetic field => so will a current in a wire
  - First detected by the deflection of compasses
    - Pattern of concentric circles
  - What happens if the direction of the current is reversed?
    - Compass directions will also reverse
The Electromagnet

- We can make a magnet that we can turn off and on.

Clicker Question:

Most of us have magnets on our refrigerator door, why do they stick there?
A: Because refrigerators are large magnets.
B: Because the door is paramagnetic.
C: Because the door is superconducting.
D: Because the door is diamagnetic.

Clicker Question:

Which of the following materials would a strong magnet not be able to pick up?
A: An aluminum can
B: Another magnet
C: A piece of glass
D: A nail

Clicker Question:

What is a galvanometer?
A: A really strong magnet
B: A meter that measures electric current
C: A meter that measures voltage
D: A meter that measures magnetic field strength

Magnetic Forces on Charges and Currents

- A charged particle moving in a magnetic field will feel a deflecting force
  - Creates its own field
    - A stationary charge feels no such force
  - Direction is perpendicular to magnetic field lines and to velocity of the charges
  - Unlike other forces which act along a line between them

DEMO - The Electric Motor

Magnetic Forces on Charges and Currents

- A wire carrying current will deflect a magnetized needle creating a simple electric meter (galvanometer)
Metal Detectors
- The current in a loop will vary depending on what is inside it.

Earth's Magnetic Field
- Protects us from high energy cosmic rays
  - Fast moving charged particles are deflected away or towards the poles
- What produces the Earth's magnetic field?

Earth's Magnetic Field
- Protects us from high energy cosmic rays
  - Fast moving charged particles are deflected away or towards the poles
- What produces the Earth's magnetic field?
  - Rotation of the Earth!

Aurora Borealis (Northern Lights)
Magnetic Resonance Imaging

Clicker Question:

Jupiter spins more than twice as fast as the Earth, what could we predict based on this about its magnetic fields?
A: They should be stronger than Earth’s
B: They should be weaker than Earth’s
C: They should be the same as Earth’s
D: It doesn’t depend on rotation.

Clicker Question:

If we think of the Earth as a giant magnet, its north (-seeking) pole is nearest to:
A: Northern Canada within the arctic circle
B: At the edge of the antarctica south of Australia
C: Just west of Hawaii in the tropics
D: Albuquerque, NM in the southwest US

Electromagnetic Induction

- Current-carrying wire => magnetic field
- Moving magnet => current in a wire
  - The greater the number of loops, the greater the induced voltage
  - Why doesn’t this violate conservation of energy?
    - The voltage produces a current turning the coil into an electromagnet which produces a field that acts to repel the incoming magnet. Since more work has to be done to move the magnet in the coil, conservation of energy is saved!

DEMO -Solenoid and Jumping Rings

Transformers

- Used to step voltage up or down
Transformers
- Used to step voltage up or down

Faraday's Law and EM Waves
- **Change** in the magnetic field strength in coils generates a current
  - A magnet at rest in a coil will not induce a current
- More generally
  - A changing magnetic field induces an electric field
  - A changing electric field induces a magnetic field
  - In combination this produces the phenomenon of EM waves!

Clicker Question:
When a bar magnet is broken in two pieces, each half is:
A: no longer magnetic.
B: stronger than the original magnet.
C: the same strength as the original magnet.
D: half as strong as the original magnet

Clicker Question:
When a bar magnet is thrust inside a copper coil, the coil tends to:
A: repel the magnet
B: attract the magnet
C: have no effect