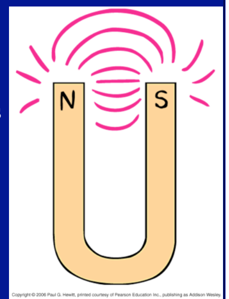
Magnetism

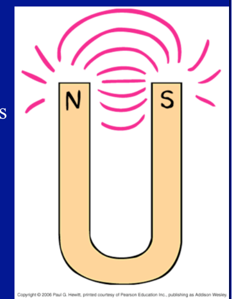
- Opposite poles attract and likes repel
  - Like electric force, but magnetic poles always come in pairs (North, South)
    - If you break a magnet in half, you get two magnets!
  - Does this still hold at the atomic level?



DEMO - Lodestone

Magnetism

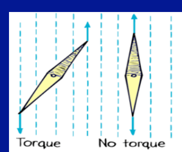
- Opposite poles attract and likes repel
  - Like electric force, but magnetic poles always come in pairs (North, South)
    - If you break a magnet in half, you get two magnets!
  - Does this still hold at the atomic level?
    - Yes. Individual atoms act like little bar magnets.
    - All magnetic phenomena due to motions of charged particles (usually electrons)
      - Electricity and magnetism different aspects of same phenomenon - electromagnetism



You can never have a North magnetic pole without a South pole!

Magnetic Fields and Magnetic Domains

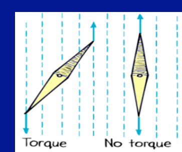
- All magnets are surrounded by a field
  - Induces other magnetized objects to line up along it
- Which charged particles are moving in a bar magnet?



A compass is a magnet that is free to pivot in a field.

Magnetic Fields and Magnetic Domains

- 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

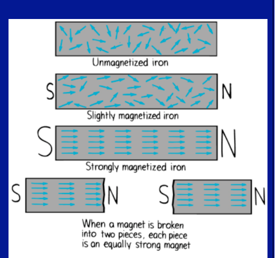


A compass is a magnet that is free to pivot in a field.

Domains in unmagnetized iron cancel one another

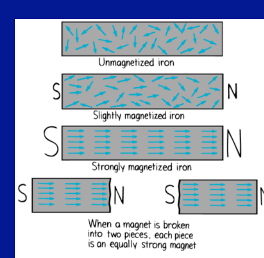
Creating and Destroying a Magnet

- How can we create a magnet from unmagnetized iron?



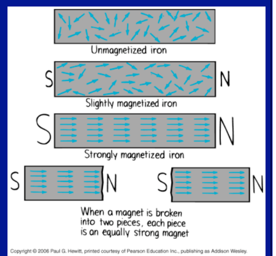
Creating and Destroying a Magnet

- 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



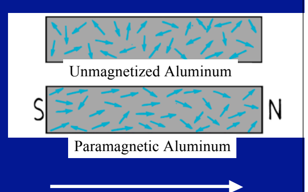
Inducing Magnetic Fields

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

DEMO - Electromagnet

Inducing Magnetic Fields

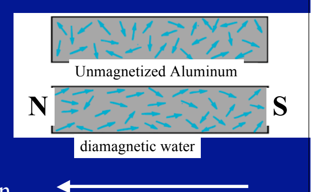
- Can a magnet pick up a penny? a piece of glass?
- Strong fields can align electron spins to create a temporary magnetic field (paramagnetic materials)



DEMO - Electromagnet

Inducing Magnetic Fields

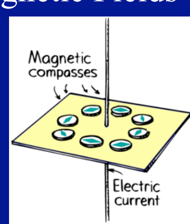
- Can a magnet pick up a penny? a piece of glass?
- Strong fields can align electron spins to create a temporary magnetic field in opposition to the imposed magnetic field (diamagnetic materials)

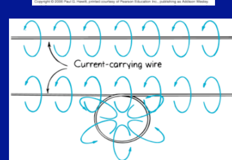


DEMO - Electromagnet

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?

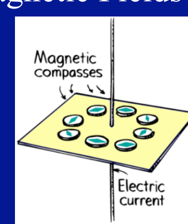


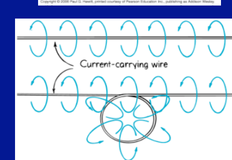


DEMO - fields around a wire

Electric Currents and Magnetic Fields

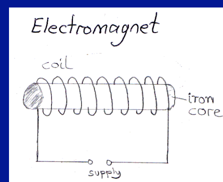
- Moving charge creates a magnetic field => so will a current in a wire
  - First detected by the deflection of compasses
    - Pattern of concentric circles
  - What happens if the direction of the current is reversed?
    - Compass directions will also reverse

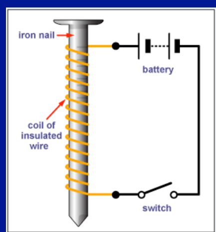




The Electromagnet

- 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

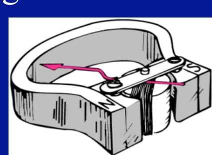
B: A meter that measures electric current

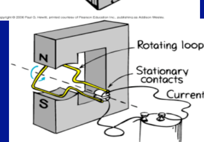
C: A meter that measures voltage

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



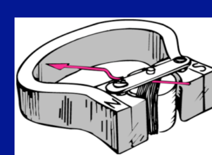


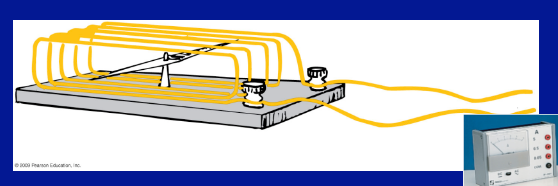
Basic principle behind electric meters and motors

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)

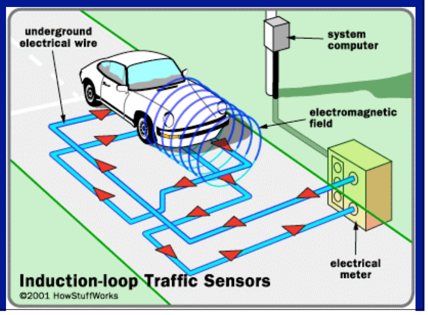




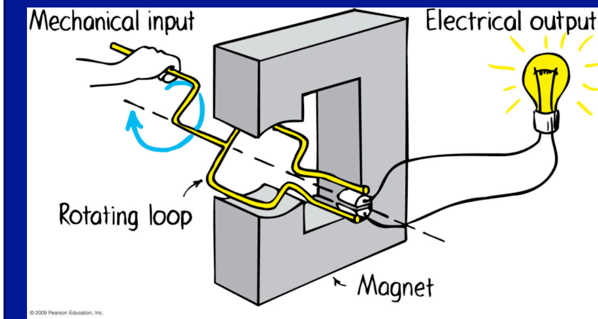
Metal Detectors

- The current in a loop will vary depending on what is inside it

DEMO
Induced currents

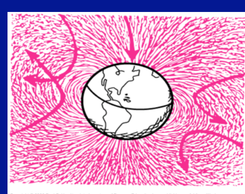


The Electric Generator



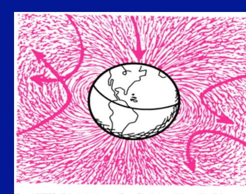
Earth's Magnetic Field

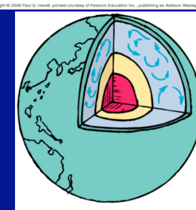
- Protects us from high energy cosmic rays
  - Fast moving charged particles are deflected away or towards the poles
- What produces the Earth's magnetic field?



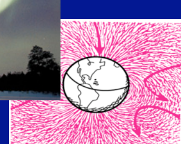
Earth's Magnetic Field

- 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)



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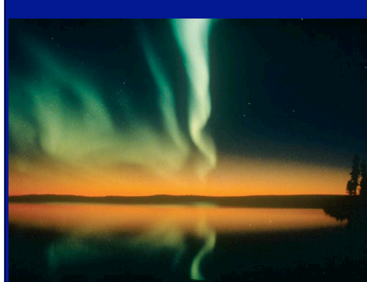
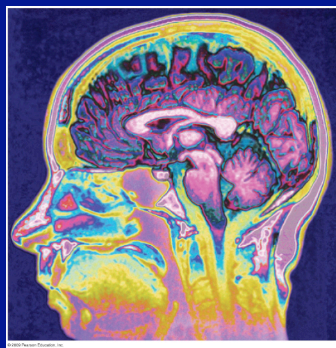


Magnetic Resonance Imaging



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

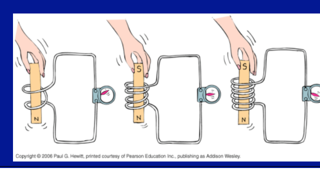
B: At the edge of the antartica south of Australia

C: Just west of Hawaii in the tropics

D: Albuquerque, NM in the southwest US

Electromagnetic Induction

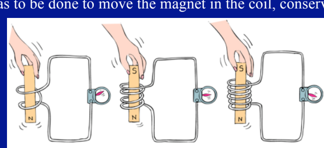
- Current-carrying wire => magnetic field
- <u>Moving magnet => current in a wire</u>
  - The greater the number of loops, the greater the induced voltage
    - Why doesn't this violate conservation of energy?



Electromagnetic Induction

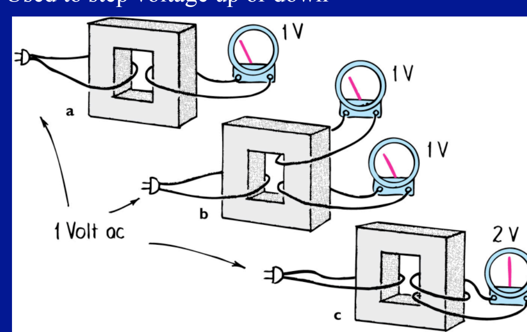
- Current-carrying wire => magnetic field
- <u>Moving magnet => current in a wire</u>
  - The greater the number of loops, the greater the induced voltage
    - Why doesn't this violate conservation of energy?
      - The voltage produces a current turning the coil into an electromagnet which produces 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



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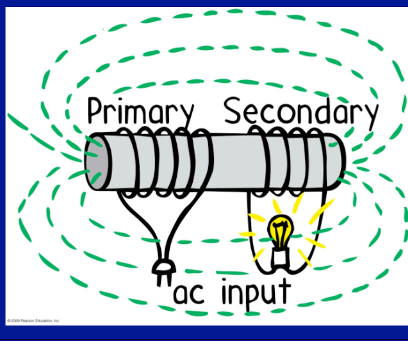
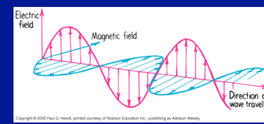


Faraday's Law and EM Waves

- 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!



Electromagnetic waves – oscillating electric and magnetic fields that continually regenerate one another via EM induction.

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 at 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