Electricity and magnetism are different facets of electromagnetism.
- A moving electric charge produces magnetic fields.
- Changing magnetic fields move electric charges.

This connection first elucidated by Faraday and Maxwell.

Einstein saw electricity and magnetism as frame-dependent facets of unified electromagnetic force.
The next part of the story is that a changing magnetic field produces an electric current in a loop surrounding the field—called electromagnetic induction, or Faraday’s Law.

The Electromagnetic Connection

- A changing magnetic field produces an electric field, and a changing electric field produces a magnetic field.
- Electric and Magnetic fields can produce forces on charges.
- An accelerating charge produces electromagnetic waves (radiation).
- Both electric and magnetic fields can transport energy:
  - Electric field energy used in electrical circuits, e.g., released in lightning.
  - Magnetic field carries energy through transformer, for example.

Electromagnetic Radiation

- Interrelated electric and magnetic fields traveling through space.
- All electromagnetic radiation travels at \( c = 3 \times 10^8 \text{ m/s} \) in vacuum—*the cosmic speed limit!*
  - Real number is 299792458.0 m/s *exactly*.

What’s “Waving” in EM waves?

- What medium transports sound waves?
  - Can there be sound waves in the vacuum of outer space?
- What medium transports water waves?
- What medium transports radio waves?
- A topic of considerable debate in the late 1800’s and early 1900’s.
- Led to the concept of the “luminiferous ether” — an invisible “jello” that was thought to vibrate electromagnetically.
- Experiments that sought this ether didn’t find it.
- This was quite a surprise.

Electromagnetic waves travel through *empty* space!
Examples of Electromagnetic Radiation

- AM and FM radio waves (including TV signals)
- Cell phone communication links
- Microwaves
- Infrared radiation
- Light
- X-rays
- Gamma rays
- What distinguishes these from one another?

Uses of Electromagnetic Waves

- Communication systems
  - One-way and two-way
- Radar
- Cooking (with microwaves)
- Medical Imaging (X rays)
- “Night Vision” (infrared)
- Astronomy (radio, μwave, IR, visible, UV, gamma)

All that we experience through our eyes is conveyed by electromagnetic radiation…

The Electromagnetic Spectrum

- Relationship between frequency, speed and wavelength
  \[ f \cdot \lambda = c \]
  
  \( f \) is frequency, \( \lambda \) is wavelength, \( c \) is speed of light
- Different frequencies of electromagnetic radiation are better suited to different purposes
- The frequency of a radio wave determines its propagation characteristics through various media

US Frequency Allocation – the FCC

“Radio” frequency-space is allocated to the hilt!
Here’s a sample region from 300–600 MHz

(300 MHz has a wavelength of 1 meter)

International allocation gets tricky
Generation of Radio Waves

- Accelerating charges radiate EM energy
- If charges oscillate back and forth, get time-varying fields

If charges oscillate back and forth, get time-varying magnetic fields too. Note that the magnetic fields are perpendicular to the electric field vectors.

Polarization of Radio Waves

Transmitting antenna works best when 'tuned' to the wavelength of the signal, and has proper polarization.

Electrons in antenna are “jiggled” by passage of electromagnetic wave.

Reception of Radio Waves

Receiving antenna works best when 'tuned' to the wavelength of the signal, and has proper polarization.

Optimal antenna length is one quarter-wavelength ($\lambda/4$).
Questions

Why are car radio antennas vertical?

Why are cell phone antennas so short?

How do polarizing sunglasses work?

Assignments

• Read Chapter 31 for Friday

• Q/O #4 due 5/23 by midnight