James Clerk Maxwell

Michael Faraday

Electromagnetism

Electromagnetic Induction

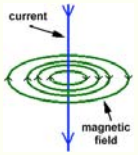
Electromagnetic Waves

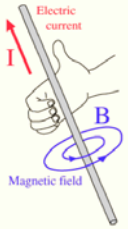
Electromagnetism

- 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, Maxwell
- Einstein saw electricity and magnetism as frame-dependent facets of *unified* electromagnetic force

Magnetic fields from electricity

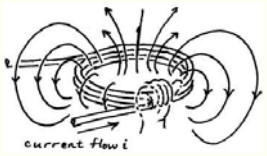
- A static distribution of charges produces an electric field
- Charges in *motion* (an electrical current) produce a magnetic field
  - electric current is an example of charges (electrons) in motion

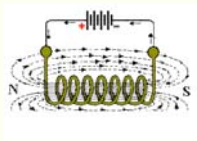


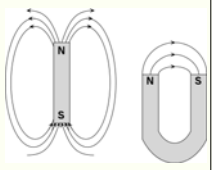


Electromagnets

- Arranging wire in a coil and running a current through produces a magnetic field that looks a lot like a bar magnet
  - called an electromagnet
  - putting a real magnet inside, can shove the magnet back and forth depending on current direction: called a solenoid

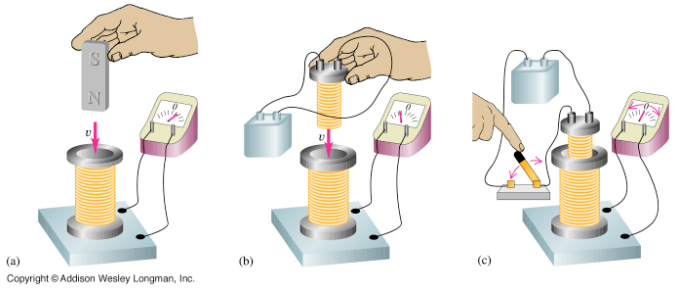






Induced Current

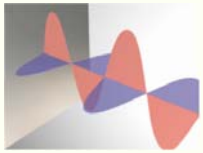
- The next part of the story is that a *changing* magnetic field produces an electric current in a loop surrounding the field
  - called electromagnetic induction, or Faraday's Law



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 $c = 3\times10^8$ 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

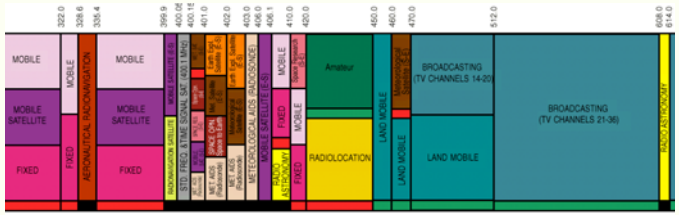
$$f \cdot \lambda = c$$

f is frequency, λ 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

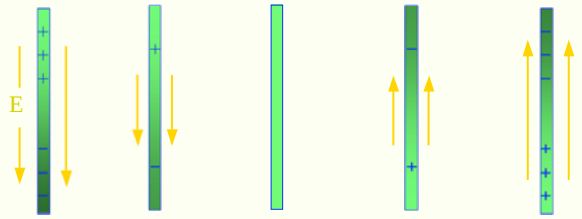


(300 MHz has a wavelength of 1 meter)

International allocation gets tricky

Generation of Radio Waves

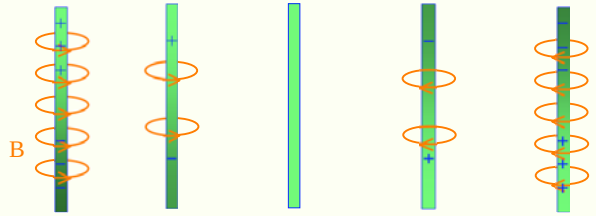
- Accelerating charges radiate EM energy
- If charges oscillate back and forth, get time-varying fields



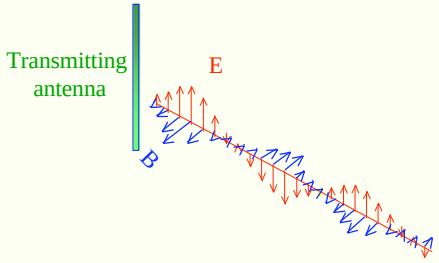
Generation of Radio Waves

If charges oscillate back and forth, get time-varying magnetic fields too

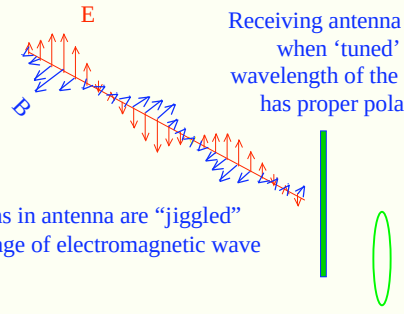
Note that the magnetic fields are perpendicular to the electric field vectors



Polarization of Radio Waves



Reception of Radio Waves



Receiving 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

Optimal antenna length is one quarter-wavelength (λ/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
- HW 6 due 5/23: 22.E.1, 22.E.5, 22.E.11, 22.E.16, 22.E.20, 22.E.30, 22.E.33, 22.P.1, 23.E.3, 26.E.7, 26.E.9, 26.E.11