Light and Electromagnetism

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Force Fields

- A force field describes the direction and magnitude of a force that that an object would feel at different points in space around the source of a force.

- A field can exist even in empty space.

- Examples of fields include gravitational, electric, magnetic, and *electromagnetic* fields.

Electric Field

- Particles and objects can have a positive charge, a negative charge, or be neutral.
- Like charges repel.
- Unlike charges attract.
- The attracting or repelling force (the electric force) is greater the larger the strength of the charges and the smaller the separation between charges.

Magnetic Field

- Magnets have a north and a south pole. Magnetic poles always come in pairs.
- Like poles repel, unlike poles attract.
- All magnetic forces are a result of the motion of charged objects.
- A changing electric field generates a magnetic field, and a changing magnetic field generates an electric field.

Waves

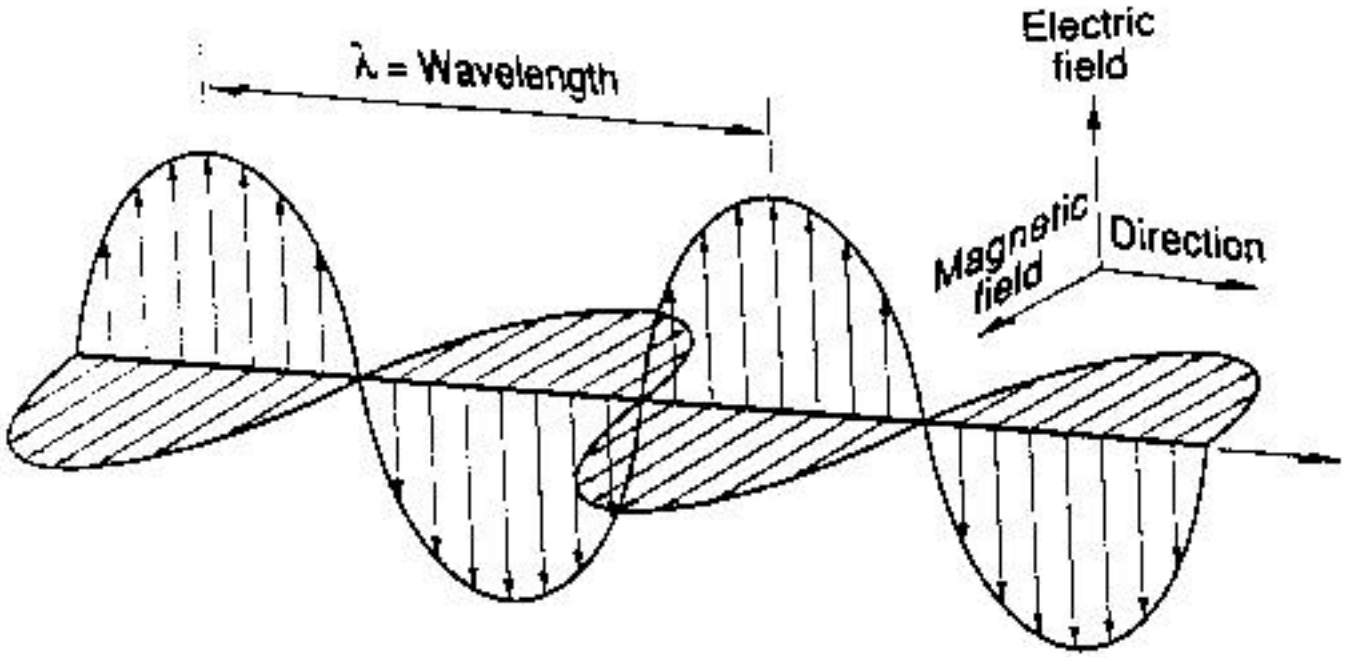
- A wave is a disturbance that transfers energy without a net transfer of matter.
- Examples: water waves, waves in a spring or rope
- A wave can be characterized by its frequency, amplitude, and wavelength.
- wavespeed = wavelength * frequency
- Waves can interfere with each other, constructively or destructively.

Light as an Electromagnetic Wave

An electromagnetic wave (i.e., light) is created by oscillating electric charges.

An electromagnetic wave can travel through a vacuum. When it does so, it travels at 186,000 miles per second.

Picture credit: www.geo.mtu.edu/rs/back/spectrum



Optics Fun Facts

- When light hits an object, it can be reflected, absorbed, and/or transmitted.
- When light is reflected from a surface, the incident angle equals the reflected angle.
- When light travels through a boundary, its change in direction is determined by the *index of refraction* of the two materials.
- The index of refraction depends slightly on wavelength. This leads to dispersion.
- The speed of light in a medium is equal to the speed of light in a vacuum divided by the medium's index of refraction.

Let there be light!

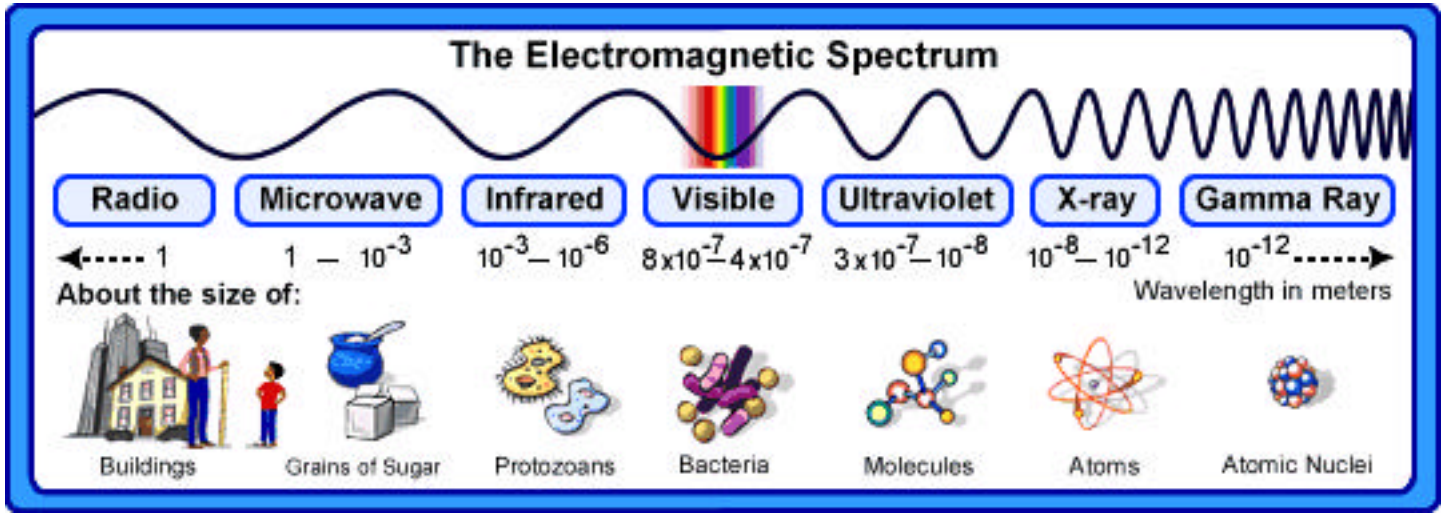
EM radiation is generated by moving charges. We generally generate light by exciting electrons, which emit light as they return to their normal state.

Examples:

- incandescent light bulb: Pass current through tungsten filament which heats up and glows.
- fluorescent light bulb: Electrons emitted by electrodes at both ends of a glass tube filled with a gas. Electrons hit atoms of gas which emit ultraviolet light. This light hits atoms in a coating on the inside of the tube. The atoms on the inside of the tube emit visible light.
- lasers: energize (or “pump”) atoms in a lasing medium and trigger them to release their energy at the same wavelength and phase
- light-emitting diodes: electrons drop from conduction band to a lower orbital
- chemical reactions: chemical light stick, fireflies

Electromagnetic Spectrum

Picture credit: http://amazing-space.stsci.edu/



Example of Radio Waves: Radio (duh!)

In a radio broadcast,

- A sound signal is converted to an electronic signal.
- The carrier wave is modulated (with amplitude modulation or frequency modulation) with the electronic signal.
- The modulated signal is fed to the antenna of a transmitter which emits radio waves.
- The antenna on a receiver picks up the radio waves, and the electronic signal is extracted.
- The electronic signal is sent to a speaker, which converts the signal into a sound signal.

Example of Radio Waves: Cell Phone

- A cell phone uses two frequencies per call, one to transmit and one to receive.
- A city is divided into *cells* about 10 square miles big, each with its own base station. Frequencies may be reused in different cells.
- The phone communicates with the base station on a control channel.
- When a phone call comes in or a request for a call goes out, the base station informs the phone over the control channel of the frequency pair selected for the call.
- If you are moving out of a cell, the base station in the first cell detects the decreasing signal strength from your phone, and the base station in the new cell detects an increasing signal strength from your phone. The two base stations coordinate with each other, and eventually your phone receives a message to switch to a new pair of frequencies for the new cell.

Example of Radio Waves: Radar

- Uses high frequency radio waves.
- Used in air traffic control, the military, space programs, storm tracking, etc.
- Uses echoes and Doppler shifts to detect the presence and speed of an object at a distance:
  - Transmit a signal and see how long it takes for the reflected signal to come back.
  - Transmit a signal and see how the frequency of the reflected signal changes. A lower frequency means the object is moving away and a higher frequency means the object is moving closer.

More Uses of Radio Waves

- cordless phones
- garage door openers/car remote entry
- TV
- baby monitors
- wildlife tracking collars
- radio controlled airplanes and cars
- etc.

Microwaves

- Microwaves are readily absorbed by water, fats, and sugars, but not by most ceramics, plastics, or glass.
- When the waves are absorbed they are converted into heat, which can cook material.
- Microwaves are reflected by metal.

Infrared Radiation

- Typically created by thermal motion of molecules.
- All objects produce infrared radiation, with hotter objects producing more than cooler objects.
- Examples of technology based on infrared radiation: infrared cameras and remote controls

Visible Light

- Visible light is the narrow section of the EM spectrum that our eyes can detect.
- Radiation from the sun peaks in this region.

Fun with visible light:

- What creates a rainbow?
- Why is the sky blue and a sunset red?
- How do eye glasses work?
    - converging and diverging lenses
    - polarization
    - anti-reflective coating

Ultraviolet Radiation

- Readily absorbed strongly by many solids, including biological material.
- Has enough energy to disrupt living cells.
- Can cause sunburns, suntans, and skin cancer.
- Eyes particularly susceptible to damage from UV light.

X-Rays

- Caused by the highest-energy electrons within atoms.
- Artificially made by boiling electrons off a thin wire filament that is heated, then accelerating the electrons toward a metal plate at the other end of a vacuum tube. The plate's atoms create X rays when the electrons smash into it.
- X-rays have so much energy that they pass through most biological material, but larger atoms (such as calcium or lead) are more likely to absorb X-rays.
- Cameras record the pattern of X-ray light that passes all the way through a patient's body in an X-ray machine.
- X-rays are an example of ionizing radiation, radiation with enough energy to ionize molecules. Ionizing radiation can damage biological matter, but it can also be put to use to destroy cancer cells.

Gamma Rays

- Created by nuclear processes within atomic nuclei.
- Wavelengths<< atom size, so they can travel deeply through matter.
- Used in nuclear medicine for imaging.
- For example, in Positon Emission Tomography (PET), a radioactive substance with a short decay time is injected into the body. Gamma rays are given off where a positron emitted from the radioactive substance hits an electron in the tissue.

Summary

Electromagnetic waves are all around you, all the time.

Your body is equipped to detect only a small fraction of them.

By building appropriate transmitters and detectors, we can use electromagnetic waves to gather information about the world around us, to communicate, to cook, to treat diseases, and much more.