Unit 13: EM Radiation and Waves

The Wave Nature of Light

White

[Diagram showing the wave nature of light with measurements: 2.0 mm and 3.5 mm]
Unit 13 Outline

• Waves Versus Particles
• EM Waves and EM Spectrum
• Scattering of Light by the Atmosphere
• The Visible Spectrum and Dispersion, Rainbows
• Interference by Thin Films
• Polarization
Particle Behavior of Light

• Isaac Newton – particle concept of light.
• Geometric optics - describes refraction, reflection, and the operation of a pinhole lens via rays of light traveling from the point of emission to the eye.
• These rays are composed of particles of light.
• The fact is that light exhibits behaviors that are characteristic of both waves and particles.
Waves

• Mechanical waves – slinky, strings, and air (sound waves).
• Mechanical waves need a medium in order to support the wave propagation.
• Sound waves can not propagate through vacuum.
• The spaceship movies have sound effects but outer space is QUIET
Is Light a Wave?

• If light is a wave, how can it get through the vacuum of space to earth without a medium?

• At one point, scientists thought that there was an ether – an invisible, undetectable medium, that supported electromagnetic radiation.

• Our understanding - EM radiation can propagate through a vacuum.
Electromagnetic Waves

We will learn about electricity and magnetism later in this year.

- EM Waves are Transverse
Source of all waves is an object moving

- Slinky – Hand moves end
- Sound – A mechanical vibration
- Electromagnetic – A moving charge
  - The frequency that the charge moves is the same as the frequency of the electromagnetic wave
  - In an antenna charges are made to move forward and backward along the wire with the frequency of the radio waves.
Production of Electromagnetic Waves

Since a changing electric field produces a magnetic field, and a changing magnetic field produces an electric field, once sinusoidal fields are created they can propagate on their own.

These propagating fields are called electromagnetic waves.

• Propagation of electromagnetic waves is analogous to the propagation of mechanical waves. However no medium is required!
Light as an Electromagnetic Wave and the Electromagnetic Spectrum

Electromagnetic waves can have any wavelength; we have given different names to different parts of the wavelength spectrum.

\[ \nu = c = \lambda f \]

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The Visible Spectrum and Dispersion

Wavelengths of visible light: 400 nm to 750 nm

Shorter wavelengths are ultraviolet; longer are infrared

The index of refraction of a material varies somewhat with the wavelength of the light.
Scattering of Visible Light

• Visible light is scattered as the light from the sun moves through the atmosphere.

• The scattering is dominated by a process called Rayleigh scattering.

• This process preferentially scatters the shorter wavelengths:

\[ \text{Scattering} \propto \frac{1}{\lambda^4} \]

• Blue light scatters more than red light.
Why is the sky blue?

- We can only see something if light scatters off of it and eventually gets into our eyes.
- When we see the blue sky, what we are seeing is the light that scatters off of the Nitrogen molecules and Oxygen molecules.
- Because blue light scatters much more strongly than the other colors, the sky looks blue to us.
Why are sunsets red?

- As the Sun gets lower in the sky, its light is passing through more of the atmosphere to reach you.
- Even more of the blue light is scattered, allowing the reds and yellows to pass straight through to your eyes.
Why Clouds are Wight?

- Clouds are white because their water droplets or ice crystals are large enough to scatter the light of the seven wavelengths which combine to produce white light.
- Clouds will appear dark or gray when either they are in another clouds shadow or the top of a cloud casts a shadow upon its own base.
Electromagnetic Waves

- All types of EM waves follow same basic principles in a vacuum
- However, because of size effects, when EM radiation interacts with matter, you can get very different physical effects
  - Geometric optics
    - When the wavelength of the EM radiation is much smaller than the size of the object - shadow effects only
  - Wave optics
    - When the wavelength of the EM radiation is ~comparable to the size of the object
    - In wave optics – interference effects play a very important role
Do Now
Calculate wavelength (a) of a 60-Hz electromagnetic wave; (b) 93.3 × 10^6 -Hz radio wave; (c) of a beam of visible red light from a laser at frequency 4.74 × 10^{14} Hz.

a) \[ \lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{60 \text{ s}^{-1}} = 5 \times 10^6 \text{ m} = 5,000 \text{ km} \]

b) \[ \lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{93.3 \times 10^6 \text{ s}^{-1}} = 3.22 \text{ m} \]

c) \[ \lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{4.74 \times 10^{14} \text{ s}^{-1}} = 6.33 \times 10^{-7} \text{ m} = 633 \text{ nm} \]