

# Phys 2310 Wed. Sept. 20, 2017

## Today's Topics

### - **Brief History of Light & Optics**

#### **Electromagnetic Spectrum**

- **Electromagnetic Spectrum**
  - Visible, infrared & ultraviolet
- **Wave/Particle Duality (waves vs. photons)**
- **Inverse Square Law, Doppler Shift**
- **Photoelectric Effect (photon energy)**
- **Energy Density**

# Next Time: Begin Geometric Optics

- **Read SZ Ch. 32 (Electromagnetic Waves)**

# **Homework this Week**

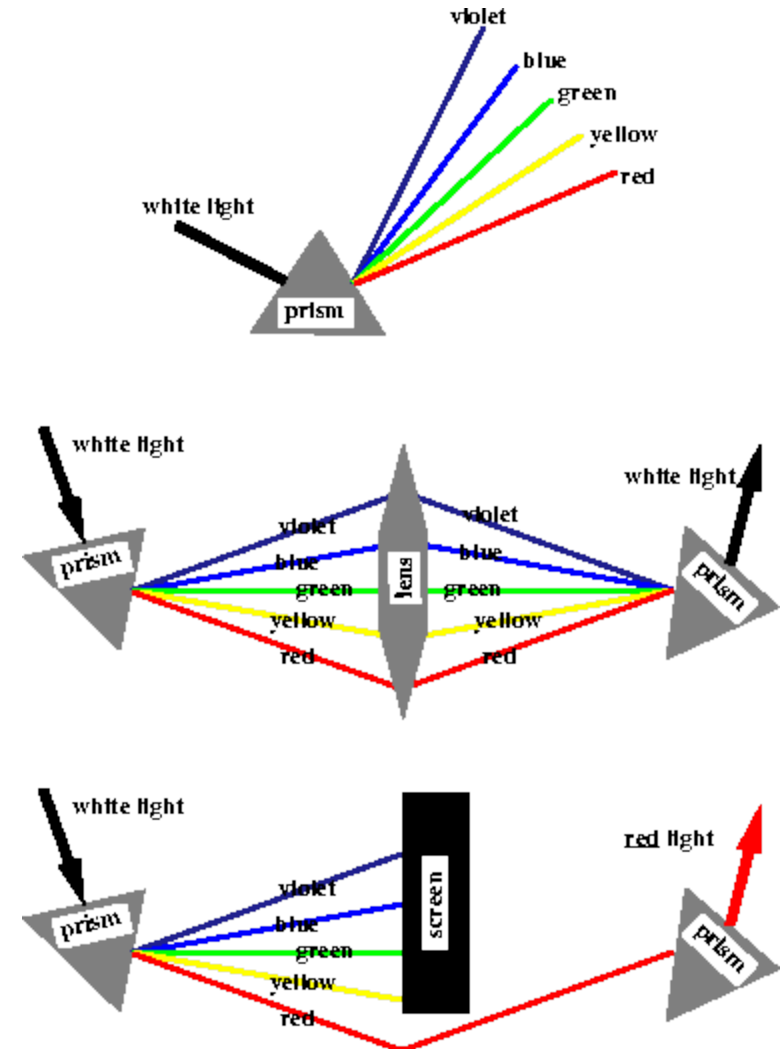
**French Chapter 3: 3-2, 3-13, 3-14, 4-3, 4-4,  
4-5**

**SZ Chapter 32: #8, 9, 10, 11, 20, 29, 46**

**Due Mon. Sept. 26**

# Introduction & Brief History of Optics

- **Summary of Newton's Experiments**
  - Prisms disperse light by changing its direction
  - White light is composed of all colors (spectrum)
  - Color of a light ray cannot be changed
  - Spectrum can be recombined to form white light



# Introduction & Brief History of Optics Cont.

- **Herschel's Discovery of Infrared Light**
  - **Herschel attempted to quantify the energy contained in light using a thermometer**
    - **Measure the change in temperature over time (energy/time) for different wavelengths.**
- **Discovered increase in temperature beyond the red-limit of spectrum**
- **Existence of light beyond the red (Infrared)**



# Introduction & Brief History of Optics Cont.

- **Ritter's Discovery of Ultraviolet Light**
  - Johann Ritter heard of Herschel's discovery and tried to detect light shorter than violet
    - Silver Chloride was known to turn black upon exposure to light (early photographic "wet" plates)
    - Fastest reaction for "invisible" light beyond the violet



# Introduction & Brief History of Optics

## Cont.

- **Light: A Particle?**

- **Light moves in a straight line (rectilinear motion)**

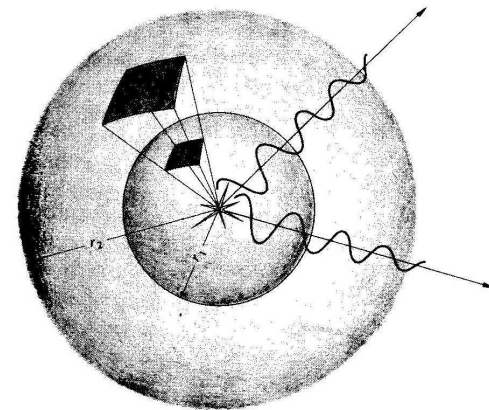
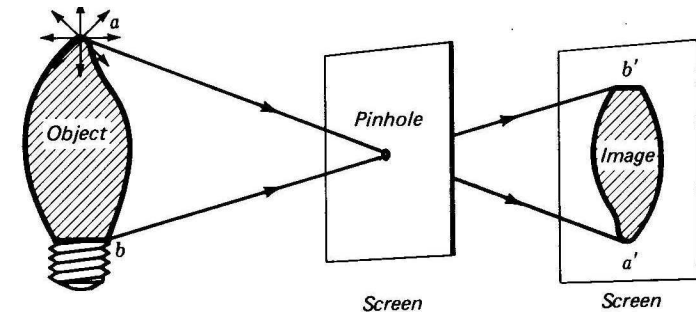
- Sharp shadows
- Pinholes can be used to form images

- **Light traverses empty space**

- No evidence of any medium
- Follows inverse-square law
  - Radiant Power distributed uniformly over enclosing sphere (area increases with square of radius Irradiance (power/area):

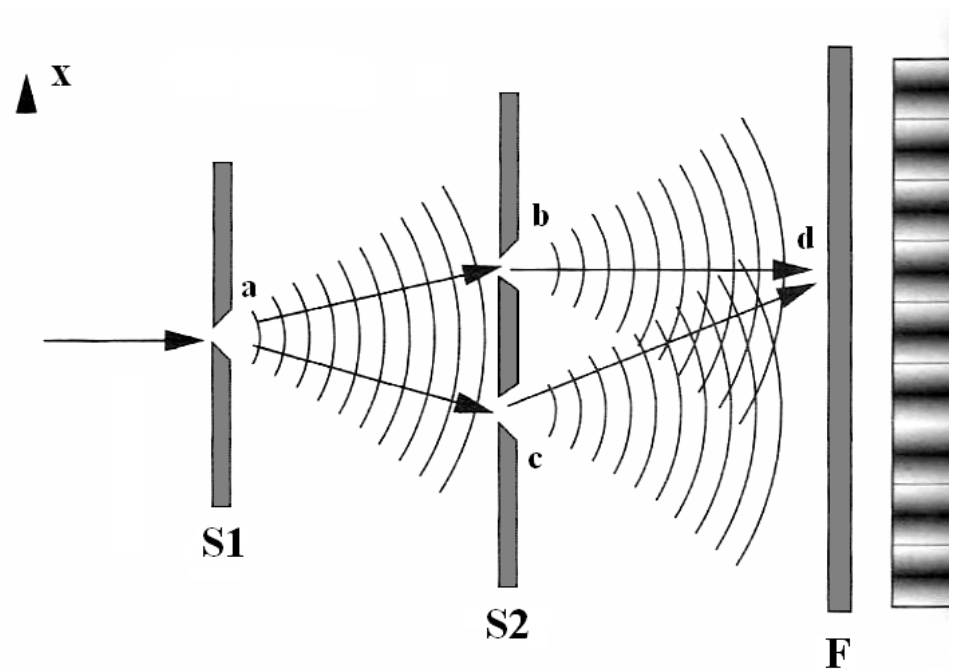
$$I = P/4\pi r^2$$

- Newton's mechanical formalism requires light moves faster in denser media (like sound)
  - Foucault found the reverse!



# Introduction & Brief History of Optics Cont.

- **Light: A wave?**
  - Young's Experiments in Interference (~ 1800)
- **Existence of interference fringes implies light is a wave**
  - like seen in ripple tank of water
  - fringe spacing depends on wavelength of light
- **If light is a wave what does it travel in (what medium)??**
  - **The Aether**
    - Low viscosity (no friction in space)
    - Rigid (high velocity)
  - Led to reluctance to accept wave nature

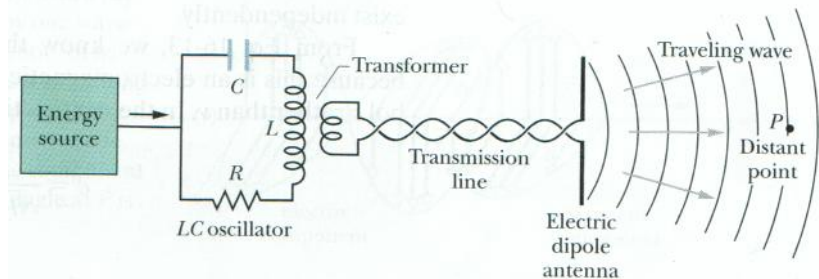
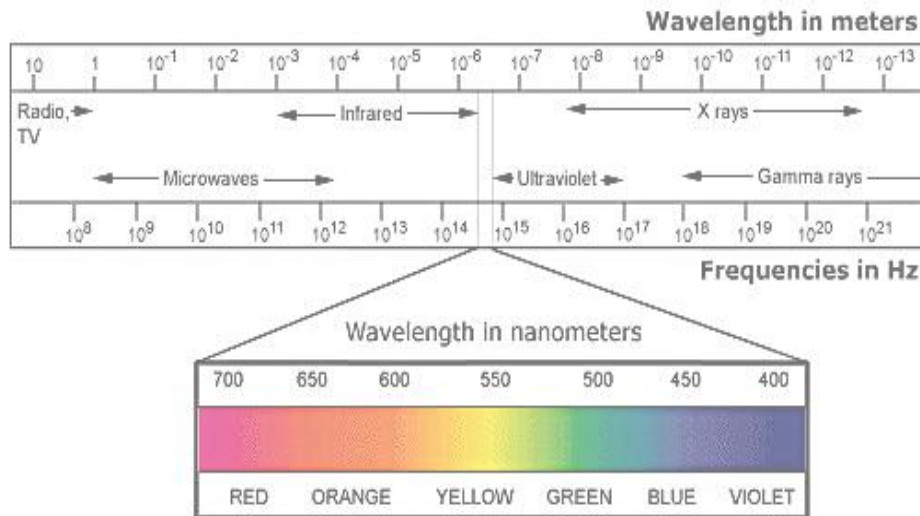


# Introduction & Brief History of Optics

## Cont.

- **Visible spectrum is just a portion of electromagnetic spectrum**
  - **Discovery of Radio Waves (Hertz 1888)**
    - **Light is a transverse wave (disturbance in the electromagnetic field)**
  - **Frequency and wavelength are related to speed of wave**
    - **Electrical (oscillators) circuits tuned to detect/produce radio waves**

$$\nu \text{ (cycles/sec)} = c \text{ (speed)} / \lambda \text{ (wavelength)}, \text{ where } c = 299,792,458 \text{ m/sec}$$

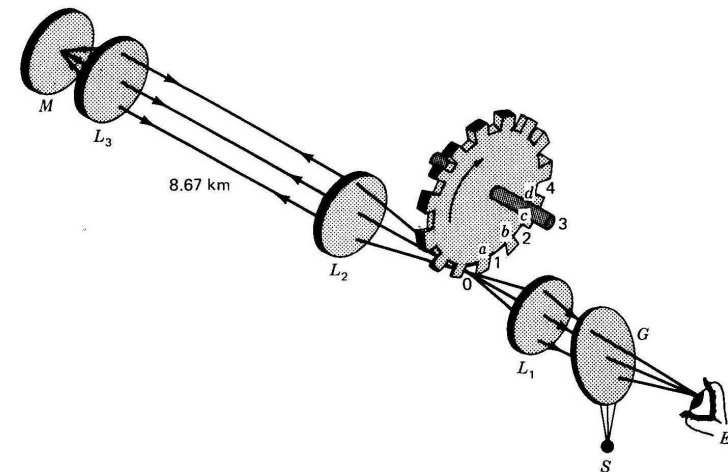


# Introduction & Brief History of Optics Cont.

- **Speed of Light**
  - Galileo concluded light was essentially instantaneous
  - Romer measured speed of light from timing of orbits of Jupiter's moons (no color so all wavelengths travel at same speed)
  - Fizeau first measured speed of light on Earth
    - Time of flight relative to angular velocity of cogged wheel.

$$c = 299,792,458 \text{ m/sec}$$

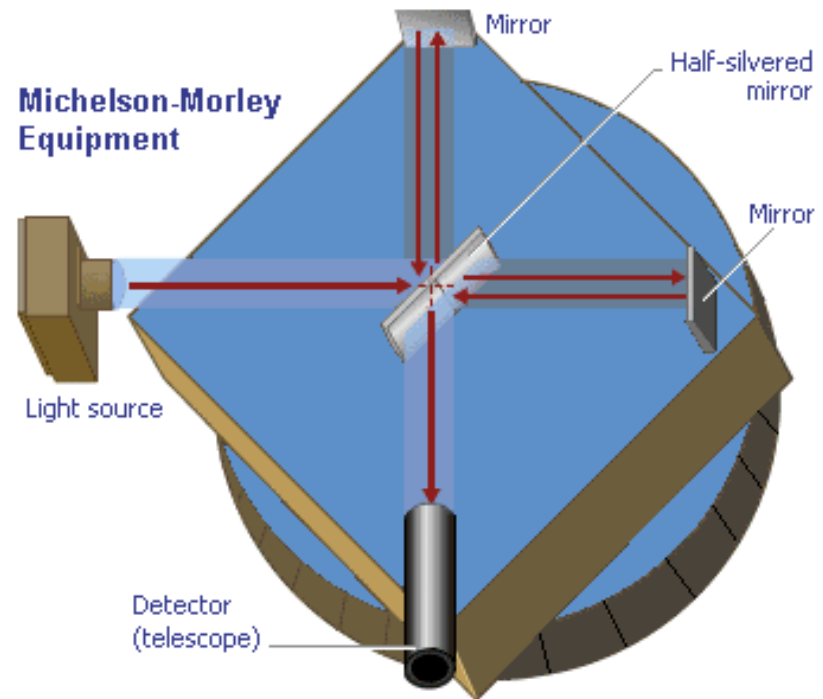
- Foucault measured speed of light to be lower within transparent media.
  - sound waves travel faster in denser material
  - used similar technique but with path within water.



# Introduction & Brief History of Optics

## Cont.

- **Michelson & Morley and the Aether**
  - If light is a wave and traverses some sort of medium filling all space (aether) its speed should reflect the motion of the Earth through space.
    - No difference in speed of light!
    - Earth's orbital motion is  $\sim 30$  km/sec. (aberration of starlight)
    - Speed of light beam in direction of Earth's motion should be slightly faster and vice versa,
  - Michelson & Morley spent several years making high precision measurements
    - No difference in speed of light
      - Aether dragged by Earth? (no)
      - Medium is the vacuum (cool!)

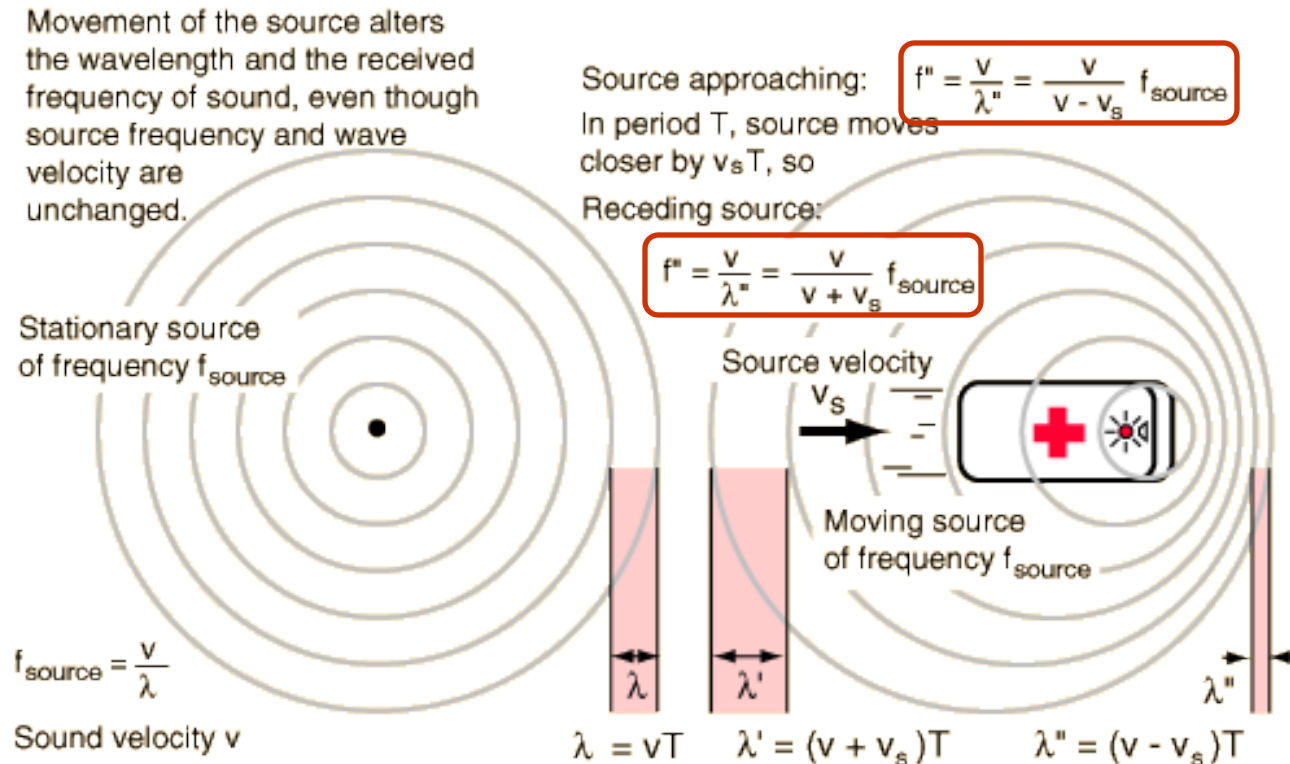


# Comments on Doppler Effect and Relativity

- Although speed of light is constant there is a shift of frequency/wavelength if the source or detector is in motion.

$\Delta\lambda/\lambda \sim v/c$  (see Modern Physics for exact, relativistic derivation)

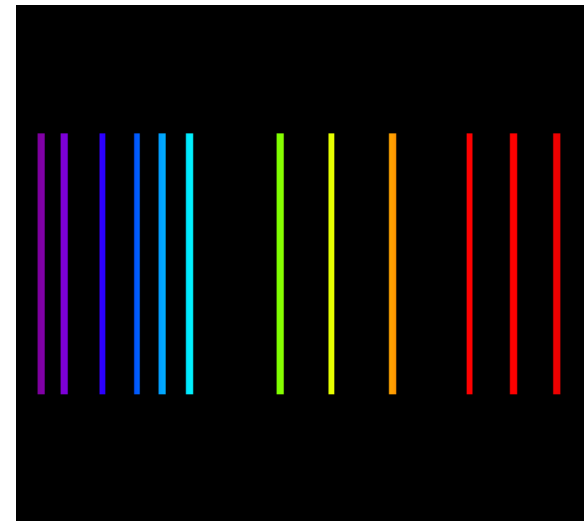
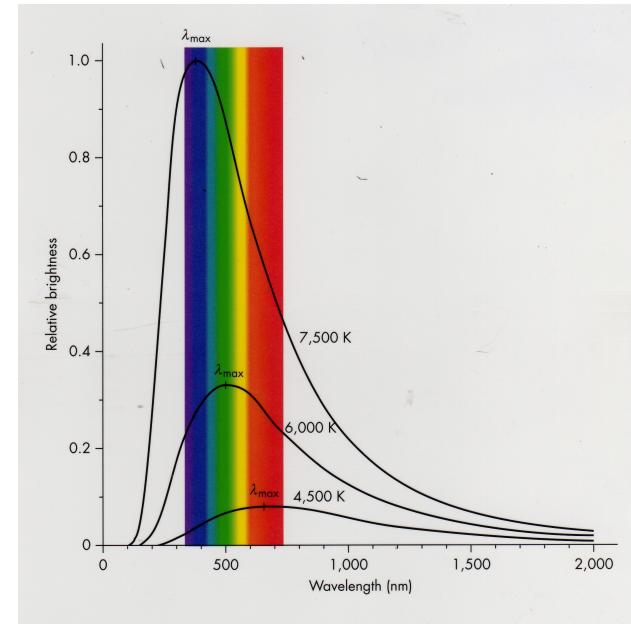
- No way to measure absolute motion only relative motion (Relativity). If speed of light is constant then time and space must distort with motion!



# Introduction & Brief History of Optics

## Cont.

- **Plank, Einstein, and the Photon**
  - A hot solid radiates light over a broad range of wavelengths. Hotter objects emit bluer light (blackbody spectrum)
  - Hot, low-density gasses emit at discrete wavelengths.
  - Hot, high-density gas (like the sun) emits more like a solid
  - Each element has unique spectrum
    - Atomic Structure
  - Solids composed of atoms vibrating according to temperature but simple theory of oscillators doesn't work.
  - Plank suggests light might be quantized into discrete energy packets (photons) in order to explain the thermal blackbody spectrum.
    - $E = h\nu = hc/\lambda$
    - where  $h$  is a constant ( $6.626 \times 10^{-34} \text{ J}\cdot\text{s}$ )
    - Quantum theory works perfectly!



# Introduction & Brief History fo Optics

## Cont.

- **Plank, Einstein, and the Photon**

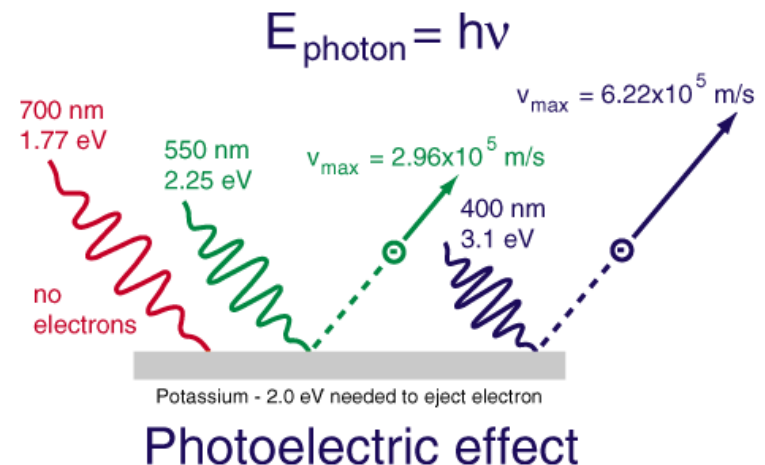
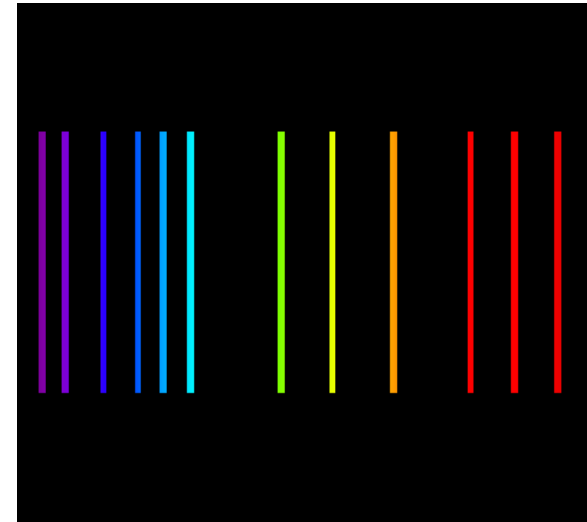
How does quantization arise?

–Einstein uses Plank's idea to explain the photoelectric effect.

- When light shines on certain solids in a vacuum electrons are ejected.
- Threshold energy ( $\nu$ ) of light needed to eject electron, higher energy with shorter wavelength (energy  $\sim$  freq.)
- Brighter light ejects more electrons but of same energy (light is quantized)
- Experimental proof of Plank's concept.
- Quantization result of atomic structure

–Light appears to have both wave and particle properties

- Birth of quantum mechanics



# Example Problems

- **Doppler Shift:**
  - What is the expected wavelength shift in the Michaelson-Morley Experiment if Earth is moving at 30 km/sec?
- **Inverse Square Law:**
  - A high-efficiency (50%) LED uses 1 watt of power to produce light from 500 – 550 nm. What is the surface brightness on a screen 2 meters away from the LED?
- **Photon Nature of Light:**
  - In the above example How many photons land on a 1-cm<sup>2</sup> detector in place of the screen? (Hint: recall that the energy of each photon  $E_\gamma = h\nu$ )

# Energy Density Example

- **We can also compute the energy density within a beam of light**
  - **Compute its volume using**
    - **Laser: cylindrical volume ( $l = ct$ )**
      - Laser produces given amount of radiant power in one sec. and consider cylinder 1 light-sec. long
    - **Point Source: spherical volume ( $r = ct$ )**
      - Point Source produces given amount of radiant power in one sec. and consider a sphere 1 light-sec. in radius.

# Summary and Key Concepts

- **Electromagnetic Spectrum:**
  - Wavelength, Frequency, Speed of Light
- **Inverse Square Law:**
  - Point Sources & spherical distribution of light
  - Intensity falls off with the inverse-square of the distance
- **Blackbody emission of solids and dens gas vs. discrete emission from low density gas.**
- **Photon Nature of Light:**
  - In the above example How many photons land on a 1-cm<sup>2</sup> detector in place of the screen? (Hint: recall that the energy of each photon  $E_\gamma = h\nu$ )
- **Energy Density in Light**
  - Beam vs. Spherical Emission

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