LECTURE 22

- EM wave Intensity $I$, pressure $P$, energy density $u_{av}$ from chapter 30
- Light wave or particle

White Light: A Mixture of Colors (DEMO)

1. Add together magenta, cyan, and yellow. Play with intensities of each to get white light.
2. Try to make white light out of blue, red, green light.
3. Take look at shadows that result from putting an object in the light path.
Spectral Lines

Energy states of an atom are discrete and so are the energy transitions that cause the emission of a photon.

Emission spectra are produced by thin gases (few collisions). The emission lines correspond to photons emitted when excited atomic states in the gas make transitions back to lower-lying levels.

Continuum spectrum: Solids, liquids, or dense gases emit light at all wavelengths when heated.

Absorption spectrum occurs when light passes through a cold, dilute gas. Atoms in the gas absorb at characteristic frequencies. Re-emitted light is unlikely to be emitted in the same direction ⇒ dark lines in the spectrum.

Dependence of Intensity on Distance

Consider spheres at different radius from the source emitting the EM radiation.

Intensity I, power $P_{av}$, pressure $P_r$, energy density $u_{av}$ etc. of EM waves.

- Notation problem: too many “P”s. $I$ is not current.
- Let us try to reduce the number of formula that you have to remember.
Transfer of Momentum

Total Absorption
\[ \Delta p = p(\text{momentum}) \]
\[ \Delta p = I \Delta \frac{A}{c} = \frac{U}{c} \]
\[ F = \frac{IA}{c} \]
Pressure \( P = \frac{F}{A} \), so
\[ P_r = \frac{I}{c} \]
\[ F = \frac{\Delta p}{\Delta t} = \frac{\text{momentum}}{\text{time}} \]
\[ \Delta U = IA\Delta t \]

Total Reflection
\[ \Delta p = 2p(\text{momentum}) \]
\[ \Delta p = 2I \Delta \frac{A}{c} = \frac{2U}{c} \]
\[ F = \frac{2IA}{c} \]
\[ P_r = \frac{2I}{c} \]

Radiation Pressure on a Surface

- Reality is somewhat more complicated: radiometer
  - Invented by Sir William Crookes in 1873.
  - It consists of four vanes, black on one side and silvered on the other, mounted on the arms of a spinning rotor.
  - When illuminated, the rotor spins as if the black sides of the vanes are being pushed

- Light falling on the black side should be absorbed
- Light falling on the silver side of the vanes should be reflected.
- The net result is that there should be twice as much radiation pressure on the metal side as on the black. The rotor is turning the wrong way??

Tail of a Comet

A spherical dust particle of density \( \rho \) is released from a comet. What radius \( R \) must it have in order for the gravitational force \( F_g \) from the sun to balance the sun’s radiation force \( F_r \)?

Assume:
1. The Sun is far away & acts as an isotropic light source.
2. \( P_r \) is radially outward and \( F_R \) is radially outward.
3. \( F_G \) is directed radially inward.
4. The particle is totally absorbing.

\[ P_r = 3.9 \times 10^{26} \text{ W} \]
\[ G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2 \]
\[ M_{s} = 1.99 \times 10^{30} \text{ kg} \]
\[ \rho = 3,500 \text{ kg/m}^3 \]
Wave-Particle Duality

1. Isaac Newton (1642–1727): Light is a stream of particles.
2. Christian Huygen (1629–1695): Light is a wave.
3. Thomas Young (1801): experimental proof that light is a wave by showing that light exhibits interference phenomena
4. Augustin Fresnel (1819): submitted a paper on the wave theory of light to explain diffraction to the French Academy of Sciences. If correct, there should be a “Fresnel bright spot”. An Academy test of this showed its existence.
5. James Clerk Maxwell (1860): wave theory of light
6. Albert Einstein (1905): particle nature of light to explain the photoelectric effect

Photo-Electric Effect

- Observation:
  - Current does not depend on light intensity
  - Depend on the wavelength of light
- Einstein’s hypothesis:
  - Photon has energy \( E = h \nu = h \frac{c}{\lambda} \) where \( h \) is the Planck’s constant (wave-particle duality)
  - To release an electron from a metal plate \( E(\text{photon}) > \text{threshold energy} \)

\[ c = 2.99792458 \times 10^8 \text{ m/s} \]

\[ h = 6.62606876(52) \times 10^{-34} \text{ J} \cdot \text{s} = 4.1356673 \times 10^{-15} \text{ eV} \cdot \text{s} \]

Since energies are often given in eV and wavelengths in nm, it is convenient to express \( hc \) in eV \cdot nm: \( hc = 1240 \text{ eV} \cdot \text{nm} \)
Wave-Particle Duality

Light & Matter can exhibit properties of both waves and particles.

Emission, Absorption, Scattering

(a) $hf$  
(b) $hf$  
(c) $hf$  
(d) $hf$

Ruby is an aluminum oxide crystal in which some Al atoms have been replaced with chromium. Chromium atoms absorb green and blue light and emit or reflect only red light.

Laser (Light Amplification by stimulated emission)

Ruby Laser Energy Levels