Equations and Constants

Week 1:
The electron volt: change in electric potential energy = charge x change in voltage = \( qV \)
When charge = 1 * charge on electron, energy = 1 eV
\[ e = 1.60 \times 10^{-19} \text{Coulombs} \]
\[ 1 \text{ eV} = 1.60 \times 10^{-19} \text{J} \]

Photon energy:
\[ E = hf \]
\[ h = \text{Planck’s const} = 6.63 \times 10^{-34} \text{J} \cdot \text{s} \]
\[ h = 4.14 \times 10^{-15} \text{eV} \cdot \text{s} \]
\[ c = \lambda f \]
\[ c = "\text{speed of light"} = 3 \times 10^8 \text{m/s} \]
so \[ E = \frac{hc}{\lambda} \]
\[ hc = 1240 \text{ eV} \cdot \text{nm} \]

Traveling wave equation:
\[ y(x,t) = A \sin \left( k(x - vt) \right) \]
\[ = A \sin \left( kx - \omega t \right) \]
\[ = A \sin \left( \left( \frac{2\pi}{\lambda} \right) x - \left( \frac{2\pi}{T} \right) t \right) \]
where \[ k = \frac{2\pi}{\lambda} \]
\[ \omega = \frac{2\pi}{f} = \frac{2\pi}{T} \]
\[ c = \frac{\omega}{k} \]

Week 2:
Photoelectric effect equations:
energy of photon = energy to release electron from surface + KE of electron
symbols from class handout:
\[ \text{energy of photon} = h \nu \] (Greek lower-case nu) \[ = hf \] (frequency)
\[ \text{energy to release electron from surface} \] = “work function” = \( \phi \)
KE of electron = \( \frac{1}{2} m v^2 = e V_0 = e \text{ * stopping potential} \)
\( \lambda_c \) = critical wavelength = longest wavelength for which any electrons are released
\( f_c \) = critical frequency = lowest frequency for which any electrons are released
Note: when incoming photon has the critical energy, the electron KE = 0
\[ hf = \phi + E_k \quad \text{or} \quad \frac{hc}{\lambda} = \phi + eV_0 \quad \text{or} \quad \frac{hc}{\lambda} = \frac{hc}{\lambda_c} + eV_0 \]

Blackbody Radiation:

Wien displacement law \[ \lambda_{\text{max}} T = 0.29 \text{ cm} \cdot \text{K} \]
Stefan-Boltzmann law \[ \sigma = 5.67 \times 10^{-8} \text{ W} / (\text{m}^2 \text{ K}^4) \]
energy / (time * area) = \( \sigma T^4 \)

Bohr Model of Atom

Allowed energy levels: \( E_n = -13.6 \text{ eV} / n^2 \)
Energies of photons that can be emitted or absorbed = \( \text{[exactly]} | E_{n1} - E_{n2} | \)
LED model: in solids, energy levels become bands (Pauli Exclusion Principle)

![Energy Level Diagram]

Electrons can move from various places in one band to various places in the other, thus, there is a range of allowed energies = a range of allowed wavelengths that can be absorbed or emitted. The minimum energy = energy of band gap.

**Week 3:**

Energy and momentum is carried by waves and particles:

For photons: \( E = h f \) and \( \text{momentum, } p = h / \lambda \)

The EM wave consists of a transverse wave, with perpendicular electric and magnetic field waves that are in phase with each other and whose magnitudes are related by: \( E_0 = c B_0 \) and whose speed in vacuum is given by \( c = 1 / \sqrt{\varepsilon_0 \mu_0} \)

For waves, the Poynting vector gives us the average energy per time per unit area [also called intensity or irradiance] carried by an electromagnetic wave:

\[
<S> = \frac{1}{2} \varepsilon_0 c E_0^2 = \frac{c}{2 \mu_0} B_0^2 = \frac{1}{2 \mu_0} E_0 B_0
\]

and momentum transferred per time per unit area = Irradiance / c

Wave packets: a way to visualize something that is both/neither a wave and/nor a particle

Huygens -- a way to visualize qualitative effects by seeing each point on a wave front as the source on a new spherical wave

**Reflection/refraction**

- Define index of refraction: \( n = c / v \)
- And since \( f \) is constant \( \lambda n = \lambda / n \)
- Snell’s Law: \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)

**Dispersion:** index of refraction varies with wavelength/frequency, causing different colors to bend different amounts at boundaries between materials.

The graph to the right, showing the index of refraction as a function of frequency, shows “normal dispersion” where the index increases as the frequency increases.
Total Internal Reflection [TIR] occurs when the light in the more (optically) dense medium bends away from the normal to the surface. If the incident angle is large enough, $\geq \theta_c$, the critical angle, then no light is transmitted, all is reflected, and we have TIR. We derive the equation for the critical angle by saying that the refracted (transmitted angle) = 90°:

$$n_1 \sin \theta_c = n_2 \sin 90°$$

$$\sin \theta_c = n_2 / n_1$$

**Week 4:**

Reflections from curved surfaces = mirrors:

- **Mirror Equations**
  
  \[
  \frac{1}{u} + \frac{1}{v} = \frac{2}{r} = \frac{1}{f}
  \]

  \[
  \text{magnification} \quad m = \frac{h_i}{h_o} = -\frac{v}{u}
  \]

- **Mirror Sign conventions:** all based on incoming light coming from the left
  
  - $u$, $v$, and $r$ (and hence $f$) are negative when the object, image, center of curvature is left of the vertex (point where the mirror intersects the axis) and positive otherwise
  
  - $h$ is positive when the object/image is above the (horizontal) axis

**Week 5:**

Fiber Optics: