320 Final Formulae and Constants:

\[ e = 1.60 \times 10^{-19} \text{ Coulombs} \]
\[ 1 \text{ eV} = 1.60 \times 10^{-19} \text{ J} \]
\[ E = h \frac{f}{\lambda} \quad \text{where } h = \text{Planck’s const} = 6.63 \times 10^{-34} \text{ J} \cdot \text{s} \]
\[ \text{momentum, } p = h / \lambda \]
\[ h c = 1240 \text{ eV} \cdot \text{nm} \]
\[ c = \text{“speed of light”} = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} = 3 \times 10^8 \text{ m/s} \]
\[ c = \lambda f \]
\[ \varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/(\text{N} \cdot \text{m}^2) \]

Waves and Intensities:

\[ I = \frac{1}{2} \varepsilon_0 c E_0^2 \]
\[ I_{\text{tot}} = I_1 + I_2 + 2 \sqrt{I_1 I_2} \cos \delta \]
where \( \delta = k^* \text{path difference} + \text{intrinsic phase difference} \)

We get \( I_{\text{max}} \) when \( \cos \delta = 1 \) and get \( I_{\text{min}} \) when \( \cos \delta = -1 \).

fringe contrast (or visibility) = \( \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}} \)

Thin Films: film index required for equal amplitudes: \( n_{\text{film}} = \sqrt{n_0 n_s} \)

Optical path difference = index of refraction * actual distance = nd

Traveling wave equation:

\[ y(x,t) = A \sin [k(x - vt)] = A \sin (kx - \omega t) = A \sin \left[ \frac{2\pi}{\lambda} x - \left( \frac{2\pi}{T} \right) t \right] \]
where \( k = \frac{2\pi}{\lambda} \quad \omega = \frac{2\pi}{T} f = \frac{2\pi}{T} \quad \nu = \omega / k \)

Polarization

- intensity of polarized light transmitted proportional to the amplitude squared:
  Malus’ Law \( I = I_0 \cos^2 \theta \)

- by reflection -- Brewster’s angle = polarizing angle -- \( \tan \theta_p = n_2/n_1 \)

- by scattering

For a crystal with thickness \( d \), the phase difference between the 2 rays (ordinary and extraordinary) is \( \Phi = \left[ 2\pi / \lambda_0 \right] * |n_\perp - n_i| * d \)

Inverse Square Law:

\[ I = P / (4\pi r^2) \quad P = I_1 r_1^2 = I_2 r_2^2 \]
Note: \( 4\pi r^2 \) is the surface area of a sphere

Photoelectric Effect

\[ h f = \phi + E_k \quad \text{or} \quad h c / \lambda = \phi + eV_0 \quad \text{or} \quad h c / \lambda = h c / \lambda_c + eV_0 \]

Bohr Model of Atom

Allowed energy levels: \( E_n = -13.6 \text{ eV} / n^2 \)
Energies of photons that can be emitted or absorbed = \( |E_{n_1} - E_{n_2}| \)
Blackbody Radiation:

Wien displacement law
\[ \lambda_{\text{max}} T = 2.880 \times 10^6 \text{ nm•K} \]
Stefan-Boltzmann law
energy / (time•area) = \( \sigma T^4 \)
\[ \sigma = 5.67 \times 10^{-8} \text{ W / (m}^2 \text{ K}^4) \]

Reflection/refraction
\[ n = c / v \]
\[ \lambda_n = \lambda / n \]
Snell’s Law: \( n_1 \sin \theta_1 = n_2 \sin \theta_2 \)

For step-index fibers
Numerical Aperture = N.A. = \( n_0 \sin \theta_m = \sqrt{n_1^2 - n_2^2} \)
Skip distance = \( L_\alpha = n_2 d / \sqrt{n_1^2 - n_2^2} \)

\# of modes = \( (1/2) \left[ \pi d (\text{N.A.}) / \lambda \right]^2 \)
in order to be single-mode, a fiber diameter \( d \) must be:
\[ d < 2.4 \lambda / \pi (\text{N.A.}) \]

For fibers in general:
Loss of power in dB = \( \alpha L = 10 \text{ dB} \log_{10} (P_1 / P_2) \)
where \( \alpha \) is the attenuation coefficient

Lenses/Mirrors
Textbook sign conventions: [these assume light is coming from the left !]
• if the object/image is to the left of the vertex (where lens/mirror crosses axis), its distance \( u/v \) is negative
• radii of curvature follow the same rule as above, so diverging mirrors have positive \( f = \) focal lengths, but diverging lenses have negative focal lengths

<table>
<thead>
<tr>
<th>Object/image location</th>
<th>Mirror Equations</th>
<th>Lens Equations</th>
</tr>
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<tbody>
<tr>
<td>1/u + 1/v = 2/r = 1/f</td>
<td>- 1/u + 1/v = 1/f</td>
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For Mirrors: \( f = \) radius of curvature / 2
Lens Maker’s Equation: \( 1/f = [(n_2 - n_1) / n_1] [1/r_1 - 1/r_2] \)

3 standard rays for ray diagrams:
• in thru focus, out parallel to axis
• in parallel, out thru focus
• in thru center, undeviated