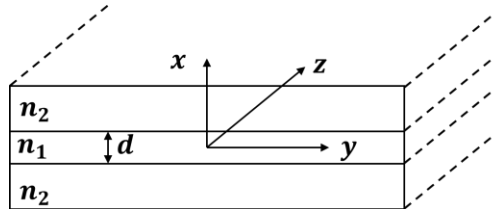
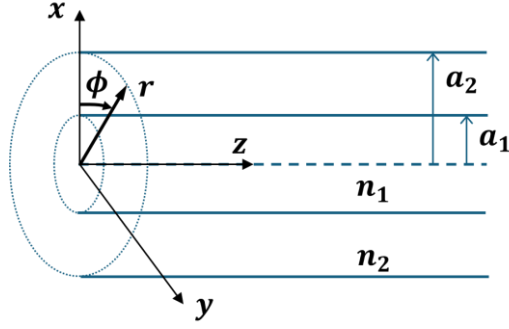


1. An optical cavity/resonator has one of its two end reflectors as a flat mirror with 90% reflectivity and another spherical mirror with diameter $D = 2\text{cm}$, focal length $f = 50\text{cm}$ and 100% reflectivity.
 - 1.1. What should be the length of the cavity/resonator for most stable operation?
 - 1.2. Name at least three reasons which contribute to the net radiation loss in the cavity.
 - 1.3. A gain medium comprising 3-level atoms is placed inside the cavity and suitably pumped to generate radiation (centered at 800nm) by stimulated emission. At room temperature, the absorption coefficient (α_l) of the medium at 800nm is 0.005cm^{-1} . Derive a relation between the gain coefficient (α_g) and α_l for achieving lasing. What is the numerical value of α_g that is just enough to satisfy the threshold condition.
 - 1.4. For the 3-level systems, show that population inversion is necessary but not a sufficient condition for achieving lasing.
 - 1.5. Upon lasing, a narrow bandwidth of FWHM 1nm is measured irrespective of the pumping strength. If the pumping strength is increased such that the new gain coefficient becomes 10 times its value at threshold, calculate the numerical value of N_2/N_1 , i.e., ratio between the lasing and the ground state populations. If required, the values of spontaneous lifetime of the lasing level and the refractive index of the gain medium can be taken as 3ms and 1.7, respectively.
2. A beam of plane wave light at wavelength $1.6\mu\text{m}$ is coupled into a planar waveguide as shown below. The waveguide parameters are, $d = 14.5\mu\text{m}$, $n_1 = 1.3$, $n_2 = 1.26$.



- 2.1 Find the total number of TE modes excited by the light used.
 - 2.2 Find the value of the propagation constant and hence the complete expression (core + cladding) for the electric field of each of the above propagating modes.
 - 2.3 Draw the modal profiles in the entire transverse region for the highest and the second highest order modes from the above.
 - 2.4 Find the angles of the propagation vectors of these modes from the symmetric axis of the waveguide along z – *direction* (see figure above).
 - 2.5 Explain how this modal analysis of the waveguide in the above is different from the ray analysis.
3. Step index cylindrical waveguides as shown below have modal solutions, represented by $E(r, \phi)$ while the complete wave functions representing guided em waves propagating along the length can be written as $E(r, \phi, z, t)$.



For a given V -number, the allowed modes are determined by finding the solutions of the transcendental equation as follows

$$V(1-b)^{1/2} \frac{J_{l-1}[V(1-b)^{1/2}]}{J_l[V(1-b)^{1/2}]} = -Vb^{1/2} \frac{K_{l-1}[Vb^{1/2}]}{K_l[Vb^{1/2}]}; \quad (l \geq 1)$$

$$V(1-b)^{1/2} \frac{J_1[V(1-b)^{1/2}]}{J_0[V(1-b)^{1/2}]} = Vb^{1/2} \frac{K_1[Vb^{1/2}]}{K_0[Vb^{1/2}]}; \quad (l = 0)$$

Different symbols and functions have their usual meaning and other definitions are: $U = a_1(k_0^2 n_1^2 - \beta^2)^{1/2}$, $W = a_1(\beta^2 - k_0^2 n_2^2)^{1/2}$, and the normalized propagation constant b . For the solutions indicated in the graphs shown below for a waveguide with $n_1 = 1.5$ and $n_2 = 1.48$, write the exact normalized wave functions representing the electric field of all the propagating modes in the entire core and cladding regions. Also, by stating the physical meaning of degeneracy here, write the value of the mode degeneracy in each case.

