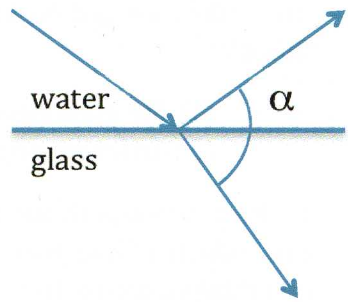
1. Unpolarized light in water (n = 1.33) is incident on a plate of glass (n = 1.5). The reflected light is completely polarized.

   a) What is the angle α shown in the figure? Justify your answer.
   b) What is the angle of incidence?
   c) What is the polarization orientation for the polarized reflection?



2. a) How does the index of refraction of transparent materials behave as a function of the wavelength of light? Explain. (*1.5 points*)

   b) How does the index of refraction of a dielectric medium find an explanation through the process of light scattering? (*1.5 points*)

   c) A nonmagnetic medium has a dielectric constant that depends upon frequency w and is given by $\varepsilon = \varepsilon_0(1 - A/\omega^2)$, where A is a positive constant and ε_0 is the permittivity of free space.

   (i) Write down the dispersion relation for an electromagnetic wave, which expresses ω as a function of wave number k. (*1 point*)

   (ii) Find the critical frequency below which a wave launched into the medium will not propagate through the medium, but rather will be evanescent or decaying. (*1 point*)

   (iii) Calculate the propagation distance over which the amplitude of the wave decays by a factor of e. (*1 point*)

3. An electromagnetic plane wave E_I traveling in medium n_1 is incident normally on medium n_2. It produces a reflected wave E_R and a transmitted wave E_T.

   a) Using the Poynting flux $\mathbf{S} = \mathbf{E}\times\mathbf{H}$, derive an expression for S in terms of ε_0, c, n and E.

   b) Using the expression derived in a), and the conservation of S ($S_I = S_R + S_T$), derive the flux relation between E_I, E_R and E_T; the incident, reflected and the transmitted fluxes.

   c) Using the result from b) and the tangential boundary conditions on E at the interface, derive expressions for $r = E_R/E_I$ and $t = E_T/E_I$ in terms of n_1 and n_2 ($n_2 > n_1$).

   d) Rewriting the relation found in b) in the form $R + T = 1$ where R and T are the reflection and transmission coefficients, show that $R = r^2$ and $T = (n_2/n_1)t^2$.

4. A circular lens in an earth satellite at 100 km height focuses images of objects on the ground onto a photographic film. The diameter of the lens is 0.5 m, its focal length 1 m, and the wavelength of the light recorded is 550 nm.

The image formed on the photographic film will be blurred. Two reasons for this are:

(1) the graininess of the photographic film, and
(2) diffraction by the lens aperture.

If the graininess of the film blurs the image of a point over a distance of 10 μm, which of the two sources of blurring will be more important? Give a quantitative reason for your answer.

5. (a) Write the rate equations for a two-level system, showing that a steady-state population inversion cannot be achieved by using direct optical pumping between the levels.

(b) Consider a three-level system which is pumped into level 3 in order to obtain an inversion between levels 2 and 1. Find the population inversion $\Delta N = N_2 - N_1$ as a function of the total number of atoms N, the pump rate Γ and the relaxation rates γ_{21}, γ_{31}, and γ_{32}. Show that if $\gamma_{32} \gg \gamma_{31}$, the inversion is achieved when $\Gamma > \gamma_{21}$.