Physics Comprehensive Exam 2009
Special Topic: Optics

Instructions: Do 3 and only 3 of the following. They have equal value.

1. Define Lambertian source. Derive the relationship between radiance and irradiance for a Lambertian point source. If the point source emits 2.5×10^{12} photons per second at a wavelength of 555 nm and has a radiance of 7.5 W/m^2sr, find the irradiance. How many photons per second will be detected by a detector of 3.2 cm^2 area placed directly above the source at a distance of 1 m?

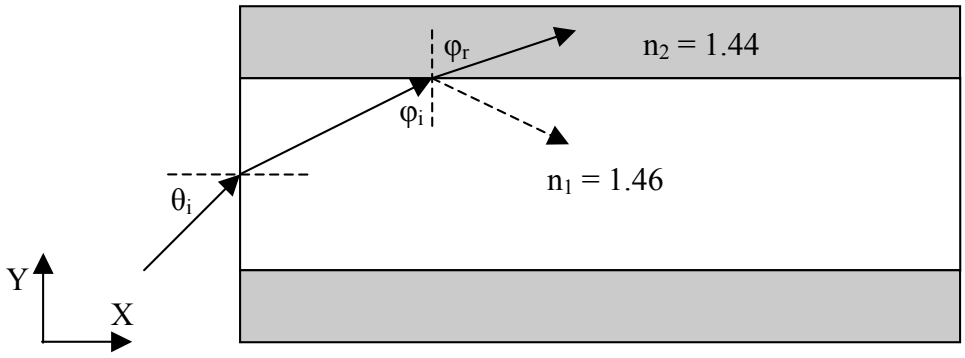
2. Given a single visible laser source, sketch the experimental arrangements that would produce an easily viewable demonstration of the following:

   a. Plane wave – Plane wave interference
   b. Spherical wave – Spherical wave interference
   c. Plane wave – Spherical wave interference

Now sketch the interference patterns expected for each case.

3. The total field acting on a single molecule in a material can be modeled as the sum of the _____field and the field in the material produced by the _____. Write down the expression for this. Now each molecule has an electric dipole moment given by _____, where _____ is the mean polarizability. If N is the number of molecules per volume, then the total electric moment per volume (which is the electric polarization) is _____. The electric polarization can also be written in terms of the electric susceptibility ($\mathbf{P} = \eta\, \mathbf{E}$). Using all this good information, and the equation relating the dielectric constant to the susceptibility, derive the very famous Lorentz-Lorenz equation and relate the mean polarizability to the index of refraction.

4. **Optical waveguide.** An optical waveguide consists of a glass slab sandwiched by a cladding material as shown in the cross-sectional diagram below. The glass has a refractive index $n_1 = 1.46$ and the cladding has a slightly smaller refractive index $n_2 = 1.44$.
a) A ray of light in X-Y plane is incident on the glass-cladding interface (from the glass) with an angle of incidence $\varphi_i = 45^\circ$. Calculate the angle φ_r of the refracted ray in the cladding.
b) What is the critical angle for the rays inside the glass slab so that total reflection occurs at the glass-cladding interface?
c) Suppose rays from an external source are coupled from air ($n_0 = 1$) into this waveguide through the end of the waveguide at an incident angle θ_i , as shown in the figure. What is the maximum value of θ_i that ensures that the rays are "guided" inside the glass slab (i.e. totally-reflected)?



5. **Camera.** A camera can be simplified to a single-lens imaging system as shown in the figure below. Assume you are a photographer and you want to choose the right settings of your camera to shoot the best pictures. Please use your knowledge of optics to make selections in the following scenarios.

a) You want to photograph natural scenery containing a large Depth of Field (DOF). Should you choose a lens with a long focal length or a short focal length? Explain your answer using elementary imaging formulae. The DOF is the distance range of the object within which the image produced appears to be "in focus" on the film.

b) You want to "zoom in" to make a distant object appear bigger on the film. Should you increase the focal length of your lens or decrease it? Why? To make sure your camera stays focused, which direction should the lens move when you zoom in?

c) In order to create photographs having high resolution, should you choose a lens with a large f-number or a small f-number? Why? Hint: Ignore aberration and consider only the Fraunhofer diffraction of a circular aperture.