1. Miscellaneous Optics Trivia
(please circle the correct statements within the following sentences – only one each is correct)

(a) In Rayleigh scattering, IR light is scattered less strongly than UV light.

(b) In an optical fiber, the cladding has a lower index than the fiber core.

(c) If you reflect an unpolarized beam from a glass plate at the polarization angle, the reflected light is linearly polarized.

(d) In an optically dense material, interference between an incoming beam and the secondary wave it creates is constructive in the forward direction.

(e) In specular reflection, the reflected intensity in the direction where $\theta_{in} = \theta_{out}$ is larger than in diffuse reflection.

(f) Light rays follow orthogonal trajectories to their associated wavefronts in all isotropic media.

(g) A group of rays forms a *Normal Congruence* if all these rays intersect a continuous surface in space orthogonally.

(h) The minimum angular deviation between a ray incident on one side of a triangular prism and the exiting ray at another side occurs if the ray runs inside the prism parallel to the base.

(i) An evanescent wave of visible light penetrates the optically less dense medium across an interface with a depth approximately equivalent to the light wavelength.

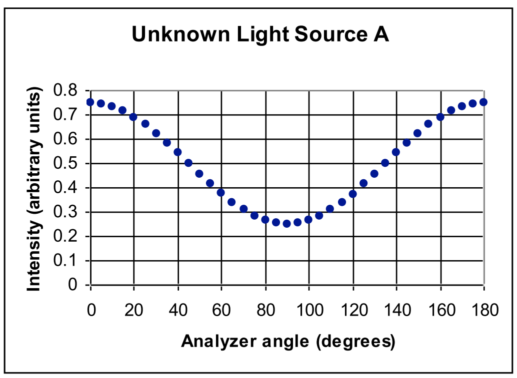
(k) In a medium with *continuously varying* index of refraction, a light ray is deflected toward the region of higher index.

2. Measurements of Polarized Light

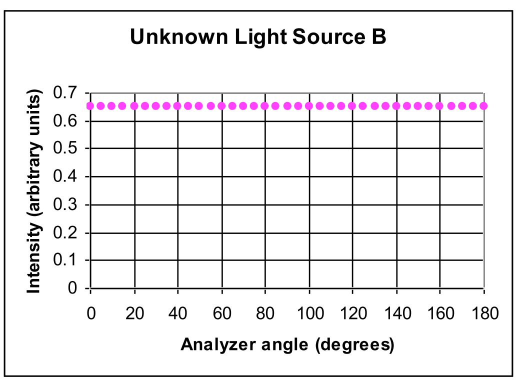
(a) A plane-polarized laser has a power output of 2.8 mW, as measured by a laser power meter. A linear polarizer is placed between the laser and the power meter, with its polarization axis oriented at 60° with respect to the plane of the laser polarization. Calculate the expected reading on the power meter.

$$I = I_0 \cos^2 \alpha = 2.8\ \text{mW} \cdot \cos^2(60°) = 0.7\ \text{mW}$$

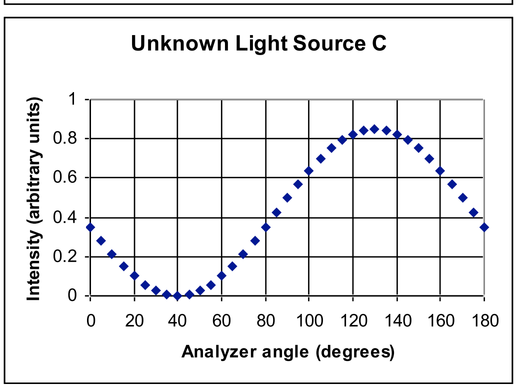
(b) You wish to determine the polarization state of three different light sources by rotating an analyzer (*i.e.* a linear polarizer) between the source and a detector and measuring the light intensity as a function of the analyzer angle. The results are shown in the plots below. For each plot, identify the polarization state of the source and give a plausible argument as to why you have identified it as such.



Elliptical polarization: The irradiance changes between two extrema at angles that correspond to the directions of the principal axes of the ellipse. Because the length of the smaller principal axis isn't zero, the minimum doesn't reach zero.



Unpolarized or circular polarization: The irradiance is constant because the projection of $\vec{E}$ on the analyzer direction is independent of the analyzer angle. This can be true for natural or for circularly polarized light.



Linear polarization: Unlike case (a), the minimum irradiance is zero. Therefore the minor axis of the ellipse is zero, *i.e.*, the polarization state is linear. Here, the polarization direction of the source and the analyzer differ by 135°.

3. Eyesight Correction

In a myopic (near-sighted) eye, the image focal length f_i is shorter than the distance of the retina from the optical center of the refracting system of the eye.

(a) What type of lens would you recommend to correct for the near-sightedness? Explain the motivation for your suggestion in one sentence.

Need diverging lens, because the focal length of the eye is too short to view objects at infinite distance and the diverging lens will increase the focal length of the compound system.

(b) Assume that the affected person can focus comfortably only on objects at d = 50 cm or closer with unaided eyes (*i.e.*, the *far point* of the eyes is at that distance d). If the focal point of a normal eye is $f_{i,\,norm}$ = 24 mm behind the optical center, by how much is the retina displaced in the myopic eye with respect to the normal eye?

An object at the far point is focused on an image length that should correspond to the image point of an infinitely distant object, *i.e.*, the focal length:

$$\frac{1}{s_i}=\frac{1}{f}-\frac{1}{s_o} \quad\rightarrow\quad s_i=\frac{fs_o}{s_o-f};\quad \Delta d=s_i-f=\frac{24\cdot 500}{500-24}\text{ mm}-24\text{ mm}\approx 1.2\text{ mm}$$

[Account for the different indices outside and within the eye, $n \approx 1$ and 1.37, respectively, this result doesn't change much:

$$\frac{n}{s_i}=\frac{n}{f}-\frac{1}{s_o} \quad\rightarrow\quad s_i=\frac{nfs_o}{ns_o-f};\quad \Delta d=s_i-f=\frac{1.37\cdot 24\cdot 500}{1.37\cdot 500-24}\text{ mm}-24\text{ mm}\approx 0.9\text{ mm}\ ]$$

(c) Neglecting the distance between a corrective glass and the eye lens, determine the focal length needed of a lens that corrects the vision of the myopic eye specified in (b). (Mind the sign of your result!)

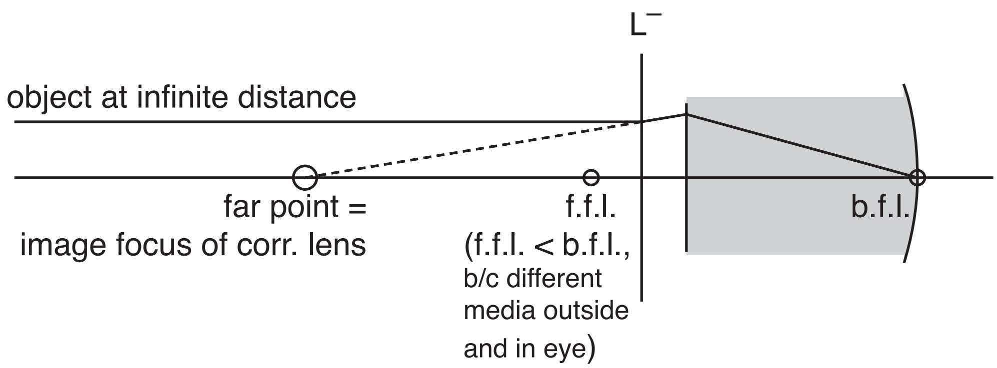
The object at d = 50 cm should be seen by the aided eye as if it comes from an object distance $s_o = \infty$. Therefore, a negative lens is required that produces a virtual image at d of an object at $s_o = \infty$. Without any calculation, the result is therefore f = – 500 mm.

(d) Design a lens for eyesight correction. The index of the glass you use is n_l = 1.48. If the curvature radius of the front interface of the final lens is to be R_1 = + 1,000 mm, which radius would the back interface have to obtain the correct focal length? [If you were unable to solve part (c), please design a lens with a focal length, f = – 600 mm. This is *not* the correct answer for part (c).]

$$\frac{1}{f}=(n_l-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \quad\rightarrow\quad \frac{1}{R_2}=\frac{1}{R_1}-\frac{1}{f(n_l)-1},\ \text{or}\ R_2=\frac{R_1 f(n_l-1)}{f(n_l-1)-R_1}\approx +193.5\text{ mm}$$

The resulting lens is <u>meniscus concave</u>, as both radii are positive.

(e) Sketch a ray diagram of the corrected optical system in which the person looks at an object at a distance $D \approx \infty$. Indicate where the front and back focal points of the eye's optical system are approximately located. [Don't waste your time drawing a detailed picture of the eye or the lens! Sketch just the refracting planes for both the eye and the corrective lens and a back screen.]



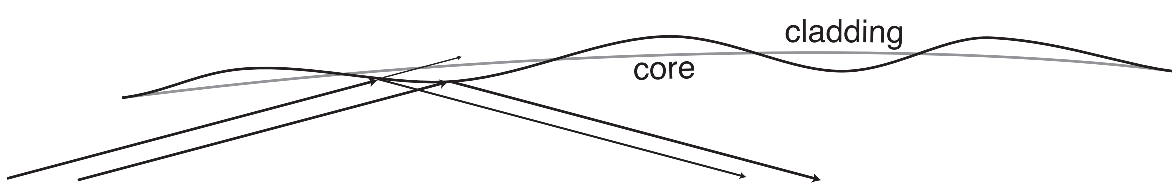
4. Modal Transmission in an Optical Fiber

(a) Determine the numerical aperture (N.A.) for an optical fiber with a core index of $n_f = 1.52$ in air (no cladding).

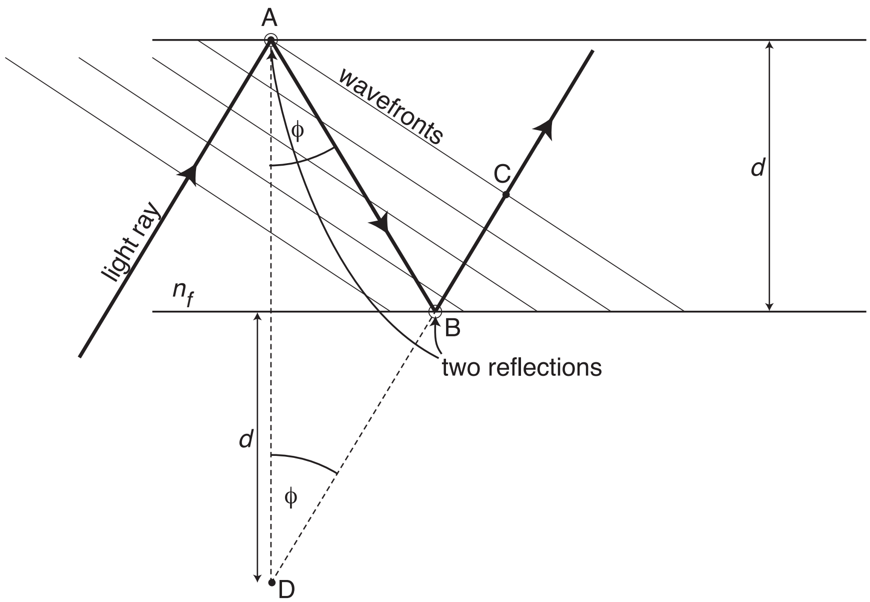
$\text{N.A.} = n_i \sin\theta_{\max} = \sqrt{n_f^2 - n_i^2}$ with $n_i = 1$. → N.A. ≈ 1.14

(b) In a stepped-index fiber, the interface between the core and the cladding is of optical quality (*i.e.*, its surface roughness is below λ/10). Explain why that is essential to reduce transmission losses.

If the core/cladding interface is rough, the critical angle is locally reduced, which will lead to the leaking of energy into the cladding, *i.e.* loss of transmitted energy.



(c) Explain qualitatively, by sketching the geometry of a planar light guide, why there is a selection of transmitted modes in the angular directions of rays within the light guide.



Phase of wave at point **A** must match phase after two reflections at point **C**.

[Was not required:
Optical path {ABC} equals {DC},
$\overline{\mathrm{DC}} = 2d\cos\phi$
→ resonance condition:
$m\lambda = 2dn_f\cos\phi + 2\phi_r$ where θ_r is phase jump upon reflection.]

Bonus question (can bring your result above 100%) – Attempt only after completing other problems.

When a light ray is totally reflected at the cladding within a fiber, a discontinuous phase change occurs upon reflection. Discuss qualitatively, by sketching the phase change that a light beam experiences upon reflection at an optically less dense medium, what the magnitudes of these phase changes are for modes close to grazing reflection and for modes reflected at angles near the critical angle for total internal reflection, θ_c.