National Exams May 2019

17-Phys-A7, OPTICS

3 hours duration

Notes:

- If doubt exists as to the interpretation of any question, the candidate should include in the answer clear statements of the interpretation and any assumptions made.
- This is a CLOSED BOOK EXAM.
- Candidate may use one of the approved Casio or Sharp calculators.
- Place all final answer in the examination booklet(s) provided. Only the answers in the booklets are graded.
- Each question value is as indicated. Exam is out of 67.
- Questions 1 through 6 are mandatory.
- Answer either question 7 or 8. Indicate which is to be graded.
- Answer either question 9 or 10. Indicate which is to be graded.
- This exam has 10 pages.
- Poor handwriting is graded as incorrect.

Question 1 mandatory (13 points total):

A phrase or a diagram and a phrase is all that is required in most cases. Answer should be clear and to the point.

a) In layman terms define geometrical optics. (1 point)

b) Describe the optical processes that are responsible for removing reflected rays when a glass surface is anti-reflection coated. (1 point)

c) Describe what is understood when a beam of light is characterized as having elliptical polarization. (2 points)

d) Write out Ampère's and Faraday's laws. These are two of Maxwell's equations. You may choose to write them in either derivative or integral form. (2 points)

e) Often observed shortly after a rain fall is a rain-bow in the sky. Describe the optical processes that take place such that a rain is produced and observed. (2 point)

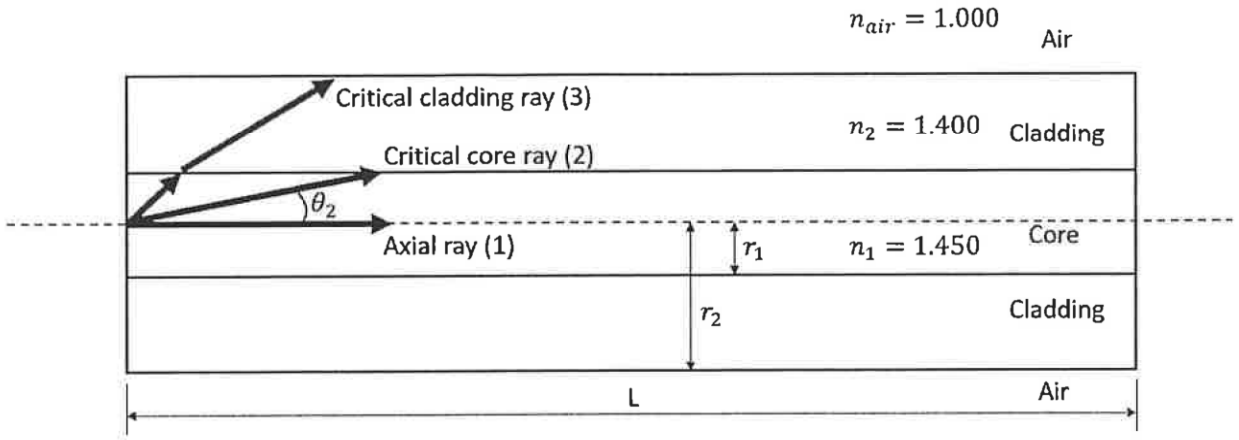
f) An optical beam composed of monochromatic plane waves is measured on a calibrated photodetector to have a power of 5 W. If the active area of the detector is 2 mm^2 what is the intensity (irradiance) for the beam detected? (1 points)

g) Why is the sky blue and why are sunsets red? (2 points)

h) There are 5 basic aberrations involved in a lens imaging system (third order theory). Describe, with the help of a diagram and with words, what constitutes spherical aberrations in an image. (2 points)

Question 2 mandatory (9 points total):

A simplified diagram of a step index multimode fiber is shown in the figure below. The core region has a refractive index, $n_1 = 1.450$ and radius, $r_1 = 1\ mm$. The outer cladding layer has a refractive index, $n_2 = 1.400$, and radius, $r_2 = 3\ mm$. The segment of fiber is straight with total length, L = 100 m. Three of the many propagated rays are shown, axial ray propagating along the central axis (1), critical angle core ray (2) propagating in a zig-zag path at an angle, $\theta_2 = 15.1^o$, and critical angle cladding ray (3) also propagating in a zig-zag path within the core / cladding. The medium external to the fiber is air with index of refraction $n_{air} = 1.000$.



a) For the ray propagating in the cladding, determine the angle of incidence for this ray when if it is incident at the critical angle of the cladding-air interface. (2 points)

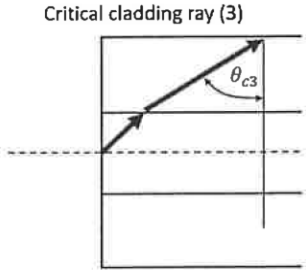


Figure provided with only ray (3) included for answering part (a)

b) Using Snell's law determine the cladding ray's propagation angle in the core region (θ_3). The calculation is to be performed for the cladding ray which intersects the cladding-air interface at the critical angle as computed in part (a) of this question. (2 point)

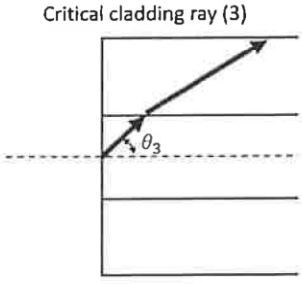
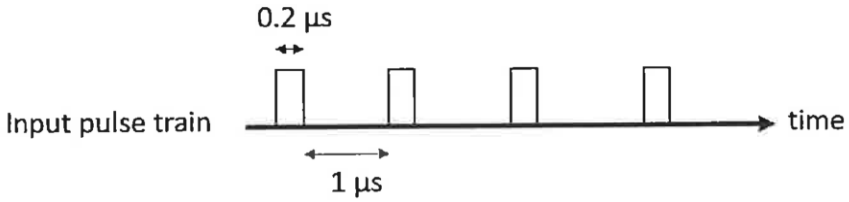


Figure provided with only ray (3) included for answering part (b)

c) Suppose that the three rays depicted in the figure are launched at the same time and from a single pulse of light of very short duration. Comment on the time and time difference it takes for each ray to traverse the 100 m length of fiber. (3 points) Detailed computations are not required but should you wish to compute transit times use the speed of light in vacuum as $c = 3E8\ {}^{m}/_{s}$.

d) A sequence of short duration identical light pulses are launched at the input end of the fiber and excite, with equal power, all modes of ray propagation in the core and cladding regions. Sketch the

expected output pulse train that would be recorded by a very fast detector. The input pulse train and shape are provided in the figure below (Input pulse train). Use a fiber length of 100 m to sketch the expected output pulse train. No detailed computations are required. You should add a few phrases to justify the output pulse train you have sketched. (2 points)



Question 3 mandatory (8 points total):

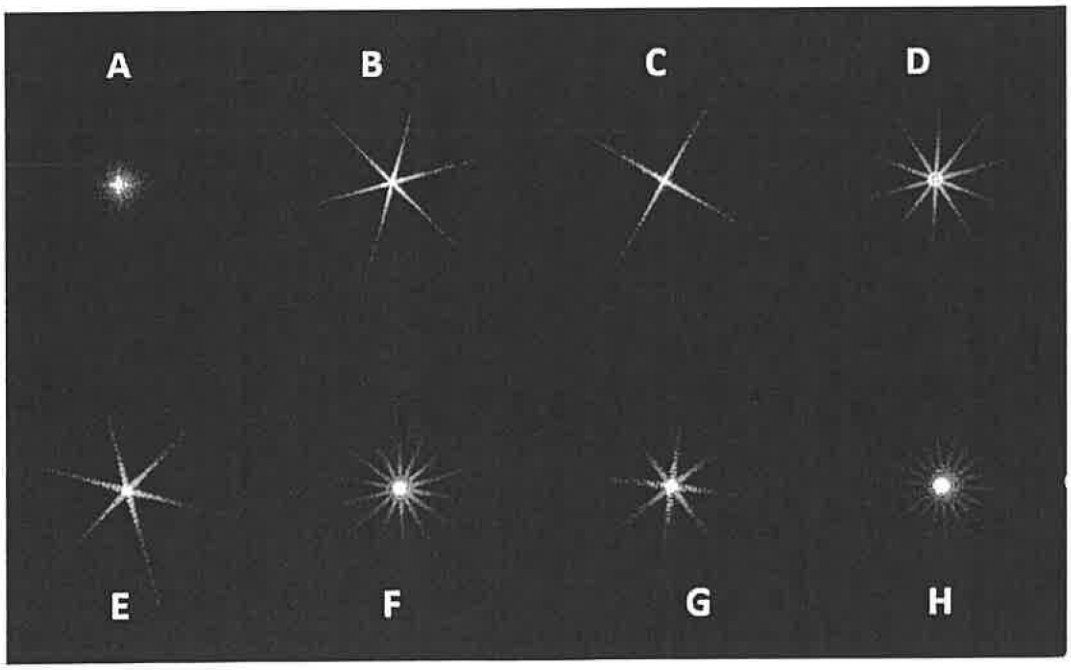
A rectangular opening (10 μm by 200 μm) is illuminated from the left side by plane waves at normal incidence and wavelength of 1 μm.

a) Define Fresnel diffraction and roughly sketch the expected Fresnel diffraction pattern observed for the rectangular opening. Make certain to include all important features in the diffraction pattern sketch you make. (3 points)

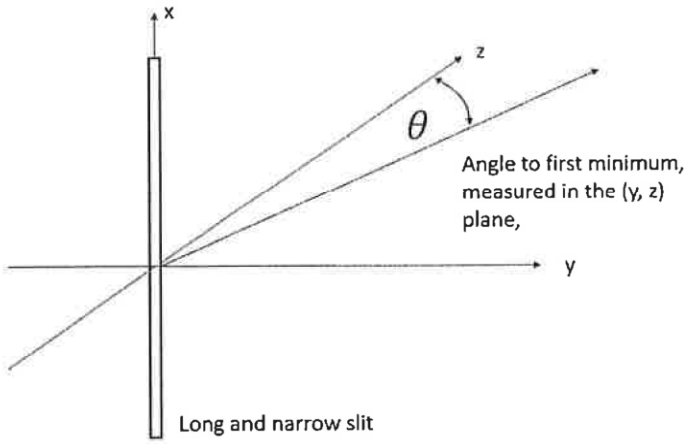
b) Define Fraunhofer diffration and roughly sketch the expected Fraunhofer diffraction pattern observed for the rectangular opening. Make certain to include all important features in the diffraction pattern sketch you make. (3 points)

Answer either part (c) or (d)

c) If the rectangle is replaced with an equilateral triangular opening, which of the following diffraction patterns images best represents what would be observed on a screen for Fraunhofer diffraction pattern. Briefly explain your selection. (2 points)



d) If the width of the slit is reduced to 1 mm and the length of the slit is made very large (1 cm), compute the angular deviation to the first off central axis minimum in the Fraunhofer diffraction pattern if the illumination wavelength is 1 mm. Helpful figure below. (2 points)



Question 4 mandatory (7 points total):

a) Describe how a pair of high quality sun-glasses can remove reflected glare. (1 point)

b) A light beam propagating along the z axis is linearly polarized in the (x, y) plane and characterized by the Jones column matrix $S_{in} = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$. An optical component is placed in the beam path and the polarization state of the beam after passage through the component is measured as $S_{out} = \begin{bmatrix} 1 \\ i \end{bmatrix}$. The optical component that changed the polarization state may be represented by a 2 by 2 matrix in the general form as M= $\begin{bmatrix} E & F \\ G & H \end{bmatrix}$. Determine the matrix elements for this polarization altering component. (3 points) Of the many possible answers select the answer that results in two of the matrix elements being 0.

c) What is the general name associated with the polarization converting component described in part (b). (1 point)

d) If the input polarization state of the beam is now $S_{in} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}$. What would be the output polarization state after this beam has traversed the component described in part (b). (2 point)

Question 5 mandatory (9 total points):

Select one of the following optical detectors; photomultiplier, PIN or solar cell.

a) Describe in detail the physical characteristics of the device you have selected. Include a figure showing its structure labelling its key optical components. (3 points)

b) Indicate the optical processes that must take place such that the device you selected detects light when in operation. (3 points)

c) Indicate and describe a few applications of the light detector you selected. (3 points)

Question 6 mandatory (7 points total):

A beam of white light is passed through a column of unknown gas. It is observed the wavelength at 0.5 μm is missing when the exit light visible spectrum is examined. In relation to the process(es) taking place answer the following. Plank's constant is $h = 6.626E - 31Js$.

a) Define and discuss the properties of a photon. (1 points)

b) What is the energy of a single photon if its wavelength is 0.5 μm. (2 point)

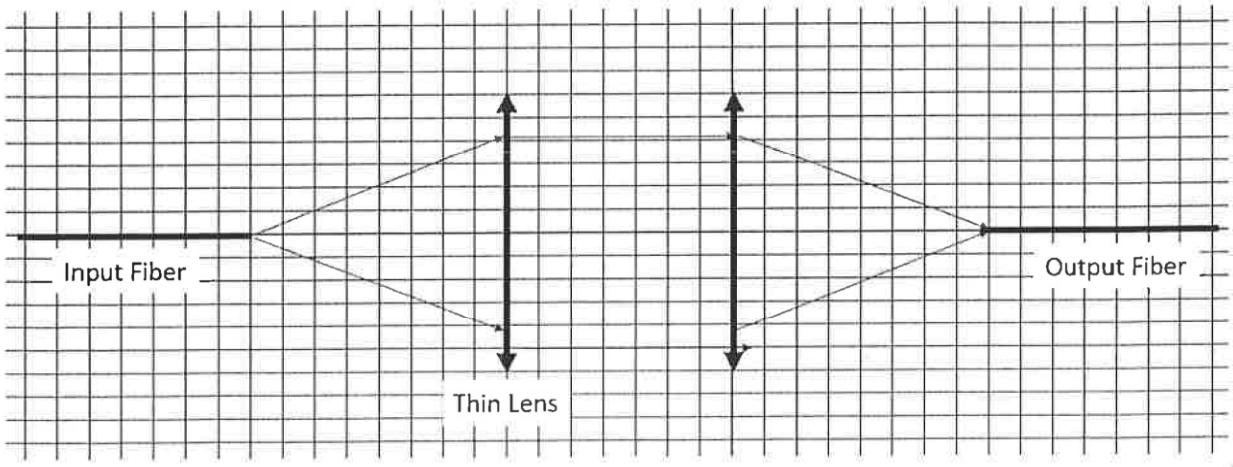
c) What optical processes are taking place in the gas such that the photons of wavelength 0.5 μm are removed? (2 points)

d) Suppose now that the white light source is turned off and the gas is heated until it starts to glow. Draw a sketch of the expected emission spectrum for the gas over the visible spectrum and label any characteristic wavelengths. (2 points)

Answer either question 7 or question 8

Question 7 (10 points total):

a) An expanded beam approach is often utilized when connecting two optical fibers. This makes the interconnection less sensitive to alignment inaccuracies. The approach examined here will utilize two thin lenses of 6.0 mm diameter and 4 mm focal length. The input (launch) optical fiber is located at the "object side" focal point of the left side thin lens and the receive (output) optical fiber is located at the "image side" focal point of the right side lens. The figure below shows the optical arrangement and extremum rays. One grid space equals 0.5 mm.



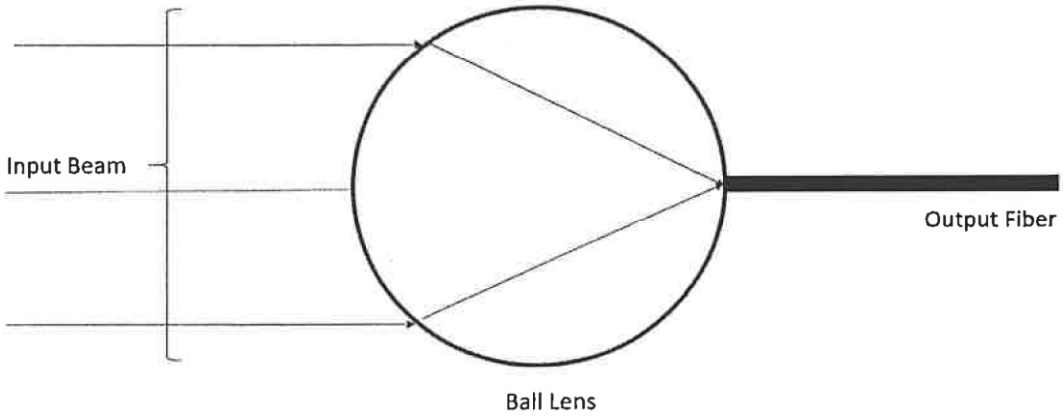
b) Using a matrix optics approach obtain the system matrix which will relates the input and output optical fiber end-faces. For this step, do not substitute any numerical values for focal length, object

positions and lens separation. Points are provided on the accuracy of the approach used to obtain the system matrix. The matrix T_D represents the translation of a ray by a distance "D" towards the right: $T_D = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix}$. The matrix L_f represents a thin lens of focal length "f": $L_f = \begin{bmatrix} 1 & 0 \\ \frac{-1}{f} & 1 \end{bmatrix}$ in air. The matrix $R_T = \begin{bmatrix} 1 & 0 \\ \frac{-(n_{out}-n_{in})}{R} & 1 \end{bmatrix}$ represents a refraction at a curved interface of curvature radius R. A ray in a medium of refractive index, n, is characterized by its off central axis position, x, and propagation angle, α, through the following column vector: $R = \begin{bmatrix} x \\ n\alpha \end{bmatrix}$. (8 points)

Answer either question 7 or question 8

Question 8 (8 points total):

Several early versions of optical fiber coupling approaches utilized a ball lens to increase the amount of light launched into the fiber. The ball lens is designed such that the focal length is exactly twice the ball lens radius. Consider a beam of parallel rays (such as from a laser) incident from the left side onto the lens and the optical fiber directly in contact with the back side of the ball lens. The diagram below shows the optical arrangement. The ambient medium is air with refractive index 1.000.

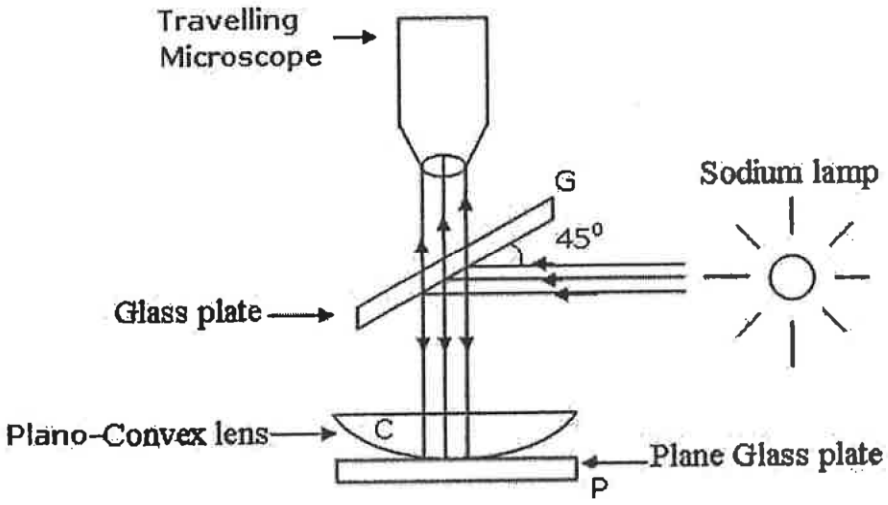


a) Using a matrix optics approach obtain the refractive index of the ball lens. If required, take the diameter of the ball lens to be 1 mm. The matrix T_D represents the translation of a ray by a distance "D" towards the right: $T_D = \begin{bmatrix} 1 & D \\ 0 & 1 \end{bmatrix}$. The matrix L_f represents a thin lens of focal length "f": $L_f = \begin{bmatrix} 1 & 0 \\ \frac{-1}{f} & 1 \end{bmatrix}$ in air. The matrix $R_T = \begin{bmatrix} 1 & 0 \\ \frac{-(n_{out}-n_{in})}{R} & 1 \end{bmatrix}$ represents a refraction at a curved interface of curvature radius R. A ray in a medium of refractive index, n, is characterized by its off central axis position, x, and propagation angle, α, through the following column vector: $R = \begin{bmatrix} x \\ n\alpha \end{bmatrix}$. (8 points)

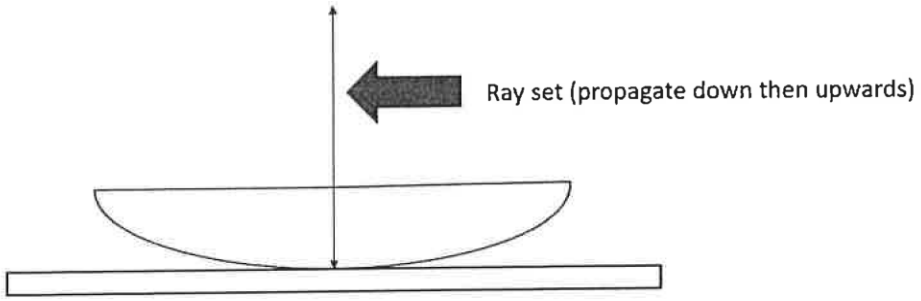
Answer either question 9 or question 10

Question 9 (6 points total):

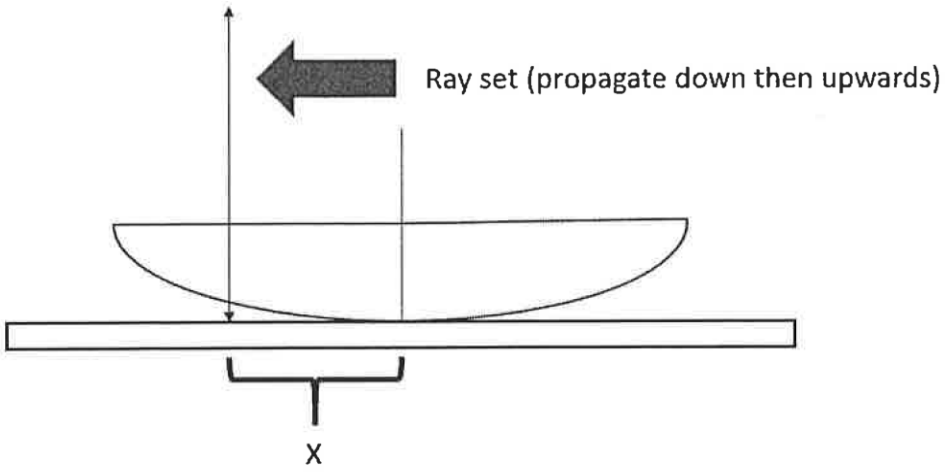
The following geometrical arrangement is utilized to view an interference effect known as Newton Rings. A plano-convex lens of very large radius of curvature is placed curved side in contact with a flat glass plate. The structure is illuminated from the side and the returned light is examined from the top. To simplify the processes involved, all reflected rays originating from the flat surface of the plano-convex lens and bottom surface of the glass plate are ignored. Although this is a wave effect, it is simpler to discuss using the notion of rays to represent the waves.



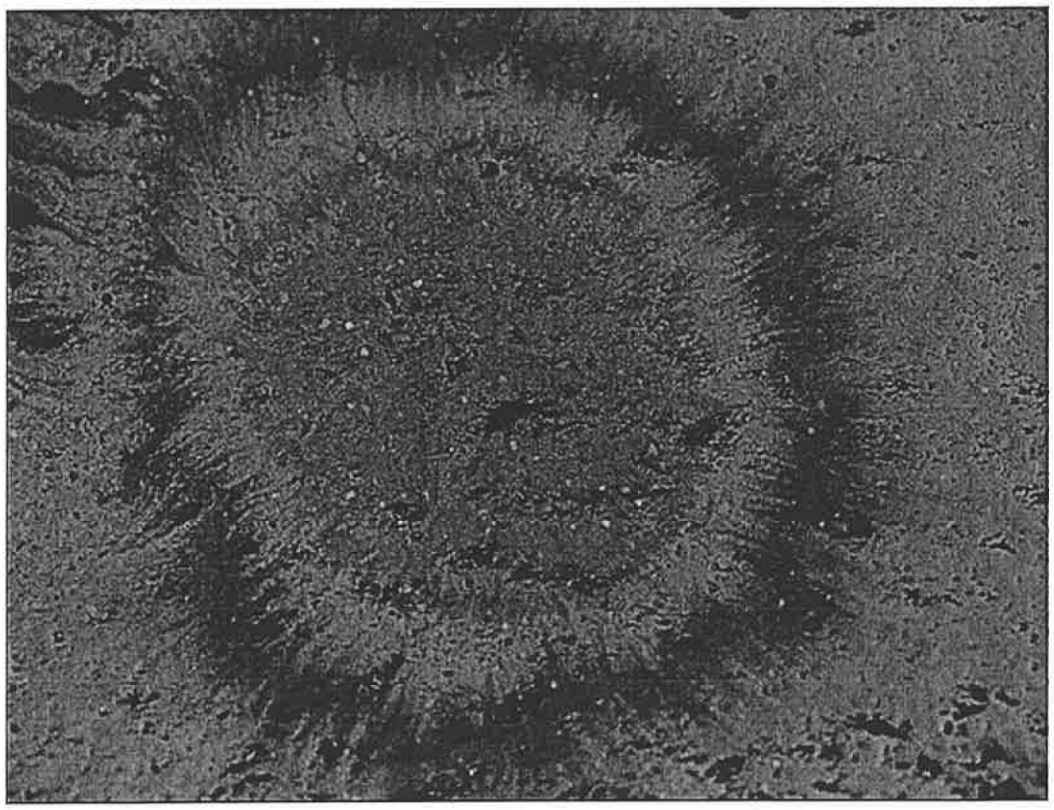
a) For the ray set that propagate as shown in the accompanying figure below, will the observer see rays that interfere constructively or destructively? We are considering rays that propagate where the lens and glass plate are in contact. You must justify your answer by indicating the optical processes that are taking place. Indicate from which surface each reflected ray is produced as a minimum of two rays must be combined to obtain interference. (1 points)



b) Suppose that the lens has a radius of curvature of 1 m. If the incident light has a wavelength of 0.5 μm, what is the distance X to the first dark ring. The distance, X, is measured from the contact point between lens and glass plate. (3 points)



c) A thin film of oil on water when examined in ambient light displays a light pattern similar to a rainbow. (Such an observation can be made in a parking lot after a light rainfall. See image below.) Explain this observation using wave arguments. (2 points)

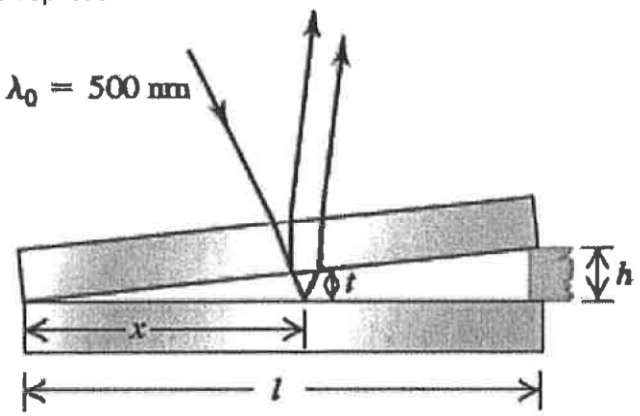


Answer either question 9 or question 10

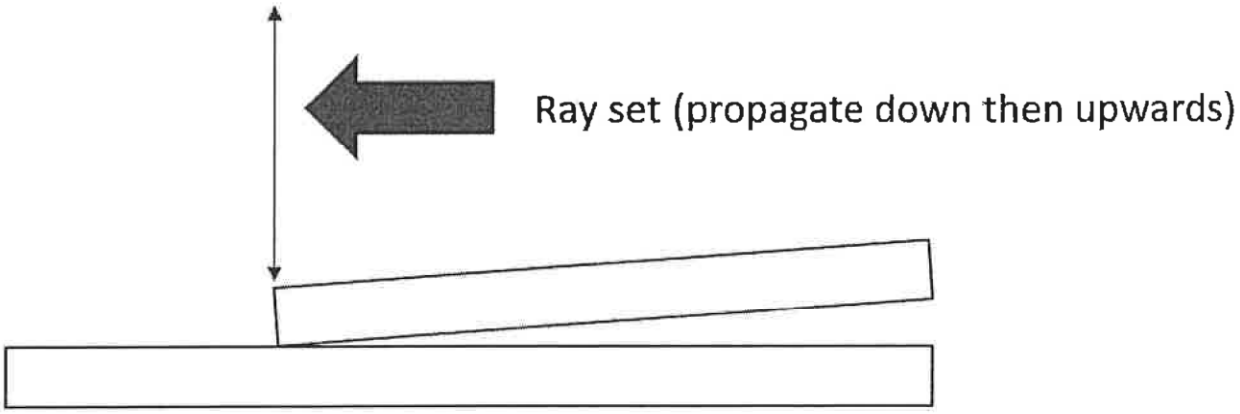
Question 10 (6 points total):

The following geometrical arrangement is utilized to view an interference effect known as thin film fringes. A glass plate is placed with one edge in contact with a flat horizontal reflective plate. A small air gap of increasing width is created by inserting a thin wedge at the other end between the glass plates. The structure is illuminated from the top and the returned light is examined. To simplify the processes

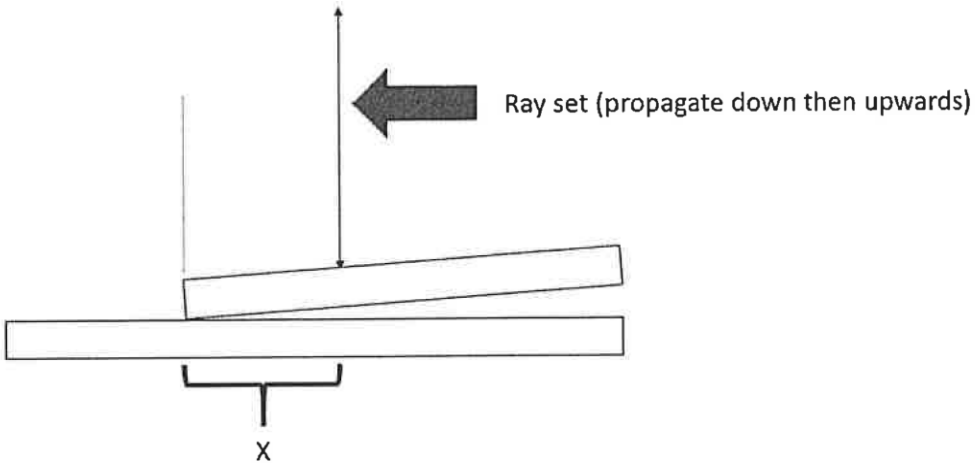
involved, all reflected rays originating from the top surface of the inclined glass plate are and bottom surface of the horizontal glass plate are ignored. Although this is a wave effect, it is simpler to discuss using the notion of rays to represent the waves.



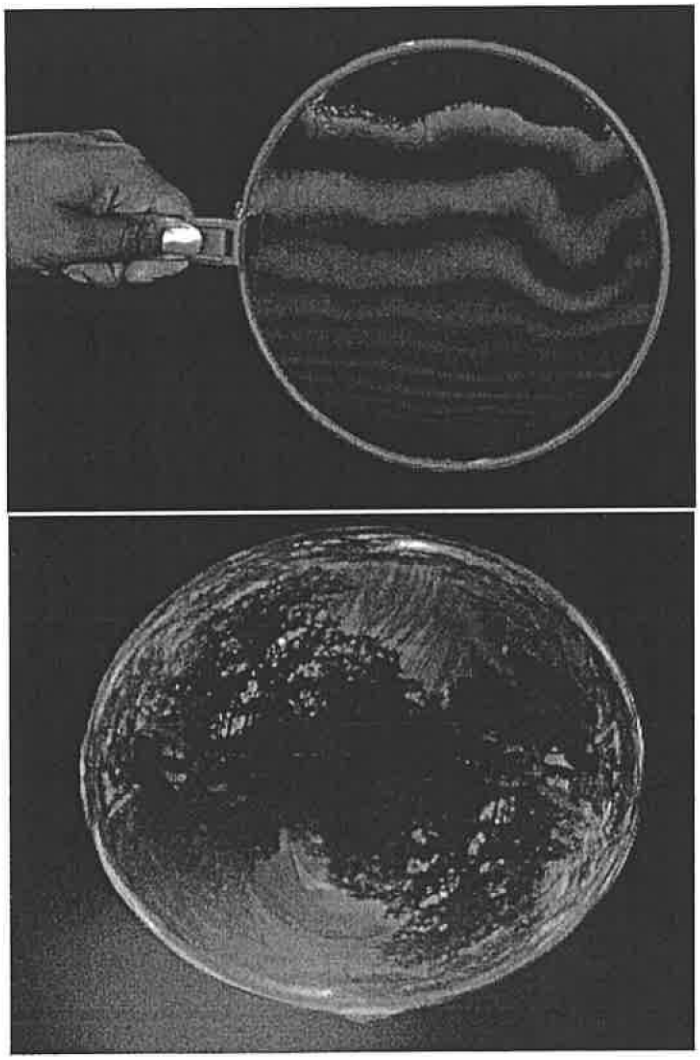
a) For the ray set that propagate as shown in the accompanying figure below, will the observer see rays that interfere constructively or destructively? We are considering rays that propagate where the two glass plates are in contact. You must justify your answer by indicating the optical processes that are taking place. Indicate from which surface each reflected ray is produced as a minimum of two rays must be combined to obtain interference. (1 points)



b) Suppose that the wedge has a thickness of 0.5 mm and the plate has total length of 2 cm. If the incident light has a wavelength of 500 nm, what is the distance, X, to the first dark fringe. The distance, X, is measured from the contact point between the two glass plates. (3 points)



c) A soap film, or soap bubble, when examined in ambient light displays a light pattern similar to a rain-bow. See images below. Explain the observed effect using wave arguments. (2 points)



End of exam