NATIONAL EXAMS - DECEMBER 2018

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 Sharp or Casio 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 78.
- Questions 1 through 6 are mandatory.
- Answer either of 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.

Question	Maximum grade this question	Candidate grade this question
1	12	
2	12	
3	8	
4	8	
5	9	
6	9	
7	10	
8	10	
9	10	
10	10	

Question 1 mandatory (12 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 optics. (1 point)

b) What is the relationship between the incident and refracted "ray" at the Brewster condition? (1 point)

c) Make a sketch an optical wave train and identify its amplitude, wavelength, and two points in the wave that differ in phase by 4π. (2 points)

d) Electromagnetic optics is founded on Maxwell's equations. Write the equations. You may choose to write them in either derivative or integral form. (2 points)

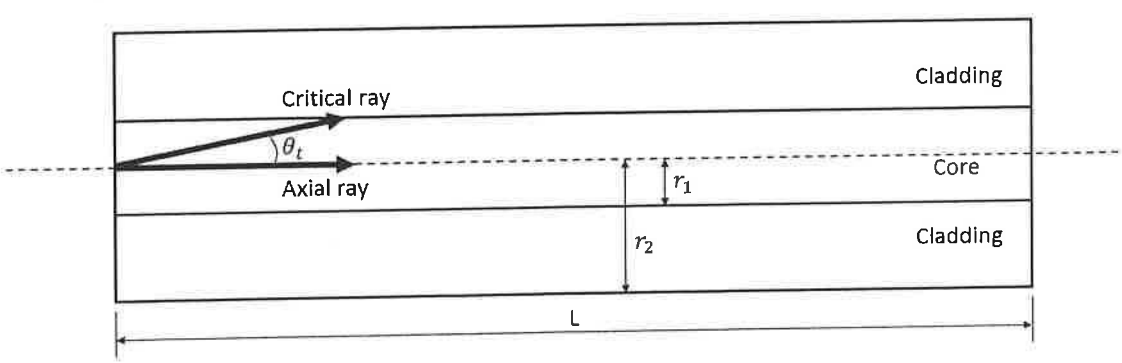
e) An optical beam may be characterized by its state of polarization. What is understood when the state of polarization is circular. (1 point)

f) Based on third order theory there are 5 primary aberrations that are associated with optical systems. Define three of the 5 and provide a representative sketch showing the presence of the aberration in a lens imaging system. (3 points)

g) What are the relationships between the amplitude, irradiance (intensity) and power for a light beam approximated as a series of plane waves. (2 points)

Question 2 mandatory (12 points total):

A simplified diagram of a step index multimode fiber is shown in the figure below. The core region has a refractive index, $n_1 = 1.45$ and radius, $r_1 = 1\ mm$. The outer cladding layer has a refractive index, n_2, and radius, $r_2 = 3\ mm$. The segment of fiber is straight with total length, L. Two of the many propagated rays are shown, axial ray propagating along the central axis and the critical ray propagating in a zig-zag path at an angle, $\theta_t = 30^o$, (with respect to the central axis).

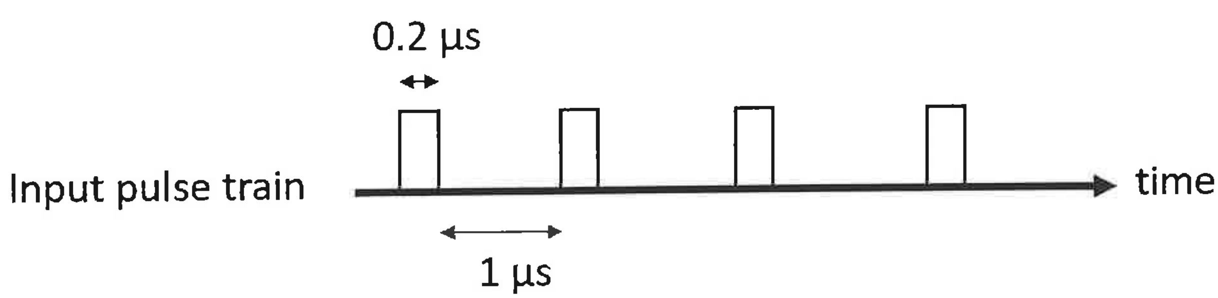


a) Given that ray two corresponds to the ray that intersects the core cladding interface at the critical angle, determine the refractive index value of the cladding material. (2 points)

b) Compute the numerical aperture for this fiber. If you were unable to obtain the refractive index of the cladding in part a) you may still solve this problem by considering Snell's law at the core-air interface. (1 point)

c) If the two rays shown in the figure were launched at exactly the same time and using a very short optical pulse, what would be the time difference in their arrival at the exit end of the fiber if L = 1 m. Use speed of light in vacuum as $c = 3E8\ ^{m}/_{s}$. (5 points)

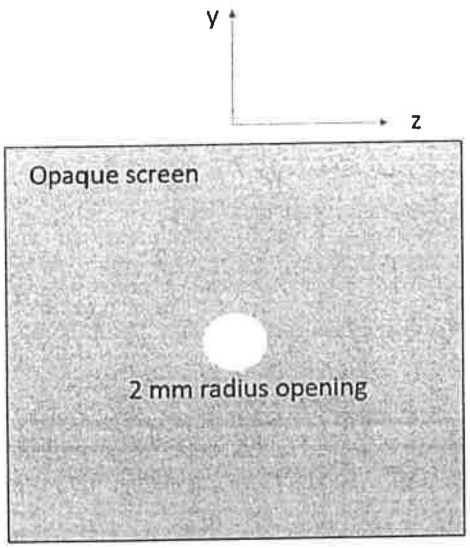
d) A sequence of short duration identical light pulses is launched at the input end of the fiber and excite equally all modes of ray propagation in the core region. Sketch the expected output pulse train that would be recorded by a very fast detector. The input pulse train and shape are provided in the figure below (Input pulse train). Use a fiber length of 1 km (1000 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. (4 points)

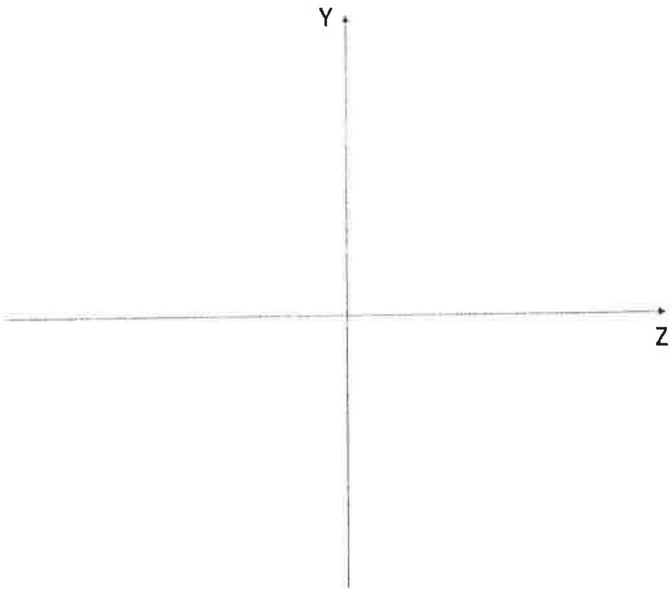


Question 3 mandatory (8 points total):

a) Define diffraction and clearly state the similarities and differences associated between Fresnel and Fraunhofer diffraction. (3 points)

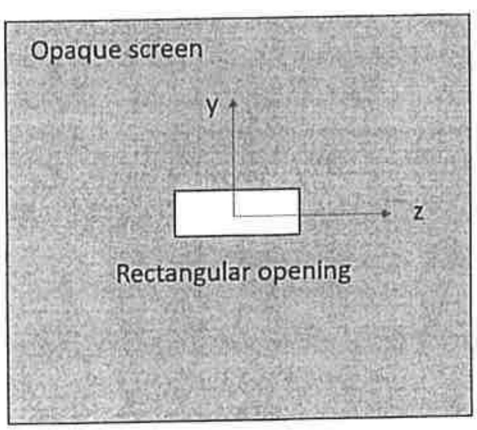
b) A circular opening of radius (2 mm) is illuminated from the left side by plane waves at normal incidence and wavelength of 2 µm. A lens of focal length 1 m is place directly on the right side of the opening. See diagram below for screen with opening and orientation of the (y, z) axis. Sketch the expected diffraction pattern observed on an observation screen placed 1 m on the right side of the opening. Sketch should be a 2-D plot (Y, Z) using coordinate axis orientation provided, intensity should be plotted in grey scale. y-Y axis are in the same orientation. (2 points)

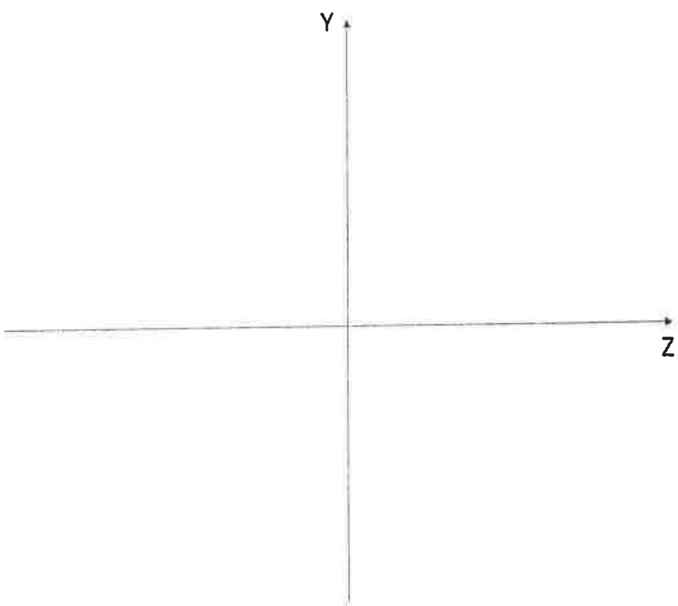




Place sketch in answer booklet using axis in this orientation

c) A rectangular opening with aspect ratio (2 : 1), (4 μm : 2 μm), oriented as shown in the figure below, is illuminated from the left side by plane waves at normal incidence and wavelength of 1 μm. A lens of focal length 1 m is place directly on the right side of the opening. See diagram below for screen with opening and orientation of the (y, z) axis. Sketch the expected diffraction pattern observed on an observation screen placed 1 m on the right side of the opening. Sketch should be a 2-D plot (Y, Z) using coordinate axis orientation provided, intensity should be plotted in grey scale. y-Y axis are in the same orientation. (3 points)



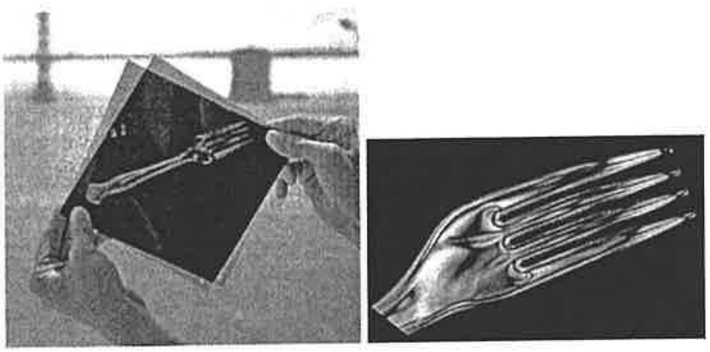


Place sketch in answer booklet using axis in this orientation

Question 4 mandatory (8 points total):

a) A light source emits a random polarized beam, which is incident onto an input linear polarizer with its transmission axis oriented along the y-axis. A exit linear polarizer has its transmission axis oriented at an angle, θ, with respect to the y-axis and intersects the light that passed through the input polarizer. If the incident unpolarized beam has an irradiance of 1 unit, make a plot of the expected output irradiance transmitted through the exit polarizer as a function of the exit polarizer's orientation angle. Assume that absorption and reflection losses are negligible for each polarizer. (4 points)

b) A plastic object (fork) is inserted and solidly clamped in place between the input and exit polarizers The polarizing axis of the two polarizers are set at 90 degrees to each other. A series a bright and dark regions (fringes) are observed when the object is viewed through the exit polarizer. Describe the optical effect taking place in the object such that the fringe pattern is observed. (3 points)



Enlargement

c) Is it possible to convert a linear polarized beam into a circularly polarized beam? Justify your answer. (1 point)

Question 5 mandatory (9 total points):

Select one of the following light sources; gas laser, semiconductor laser or light emitting diode.

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 emits light when in operation. (3 points)

c) Indicate and describe several (at least 3) applications of the light source you selected in the practice of engineering. (3 points)

Question 6 mandatory (9 points total):

A hydrogen gas is heated such that it glows and emits visible light at the following wavelengths.
(in μm; 0.410, 0.434, 0.486, 0.656).

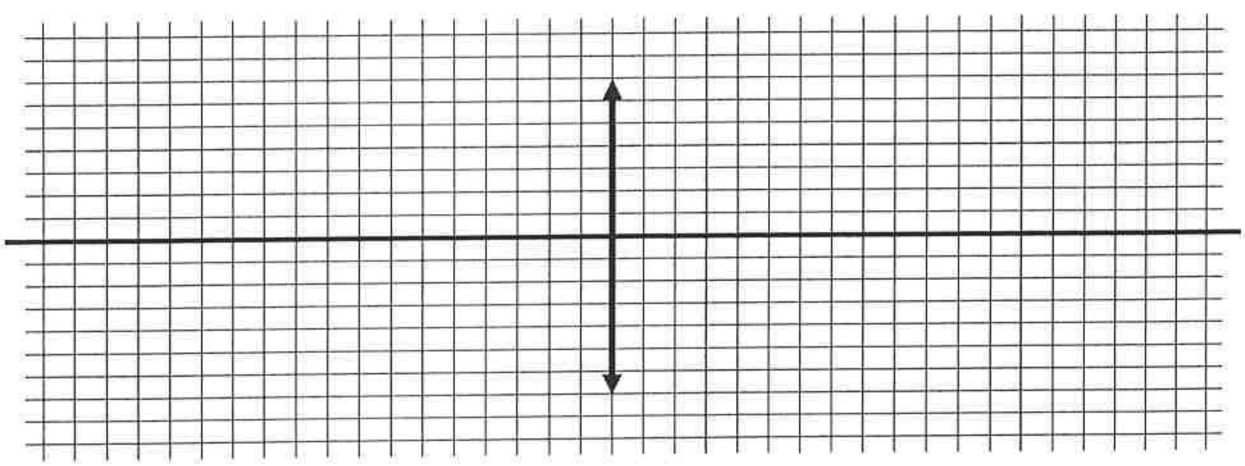
a) A beam of this light is linearly polarized and sent at normal incidence onto a reflection grating containing 1000 lines per cm. Determine the first order diffraction angle for the red line of the visible spectrum of hydrogen. (3 points)

b) Design an optical instrument that utilizes a reflection grating as its key optical component such that the emission wavelengths from an unknown source can be accurately determined. Show the optical arrangement of components, light path and mechanical components. You must indicate the procedure that would be used to measure a wavelength. You must also indicate how the instrument would be calibrated such that accurate measurements can be made. Based on geometrical considerations of the apparatus you propose comment on the accuracy and uncertainty of a wavelength measurement. (6 points)

Answer either question 7 or question 8

Question 7 (10 points total):

a) The imaging properties of a thin lens are explored through a ray diagram approach. The thin lens, placed in air, has a focal length of 7 cm, diameter 14 cm and has been placed in the diagram provided. One grid space equals 1 cm. An object is located 14 cm to the left of the thin lens and has a height of 4.5 cm directed upwards with the base of the object on the central axis. Place the lens and object in the graph paper provided and using a ray diagram approach determine the position and transverse magnification of the object. Show the rays utilized in your approach. (6 points)



b) Using a matrix optics approach obtain the system matrix which will relate the object to its image. For this step do not substitute any values for focal length and object position. 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. 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: $R = \begin{bmatrix} x \\ n\alpha \end{bmatrix}$. (4 points)

Answer either question 7 or question 8

Question 8 (10 points total):

a) An astronomical telescope optical system is constructed from two thin lenses. One lens has a focal length $f_1 = +12\ cm$ and diameter $\phi_1 = 14\ cm$, the other lens has a focal length $f_2 = +6\ cm$ and diameter $\phi_1 = 10\ cm$. The larger focal length lens is placed on the left side and constitutes the objective optics. Using the graph paper provided place the two lenses in the telescope arrangement. By considering an object "distant star" located at infinity on the left side of the objective, accurately dray the trajectory of the extremum rays through the telescope. Which of the lenses serves as the aperture stop. (4 points)

Symbol to use for a thin lens

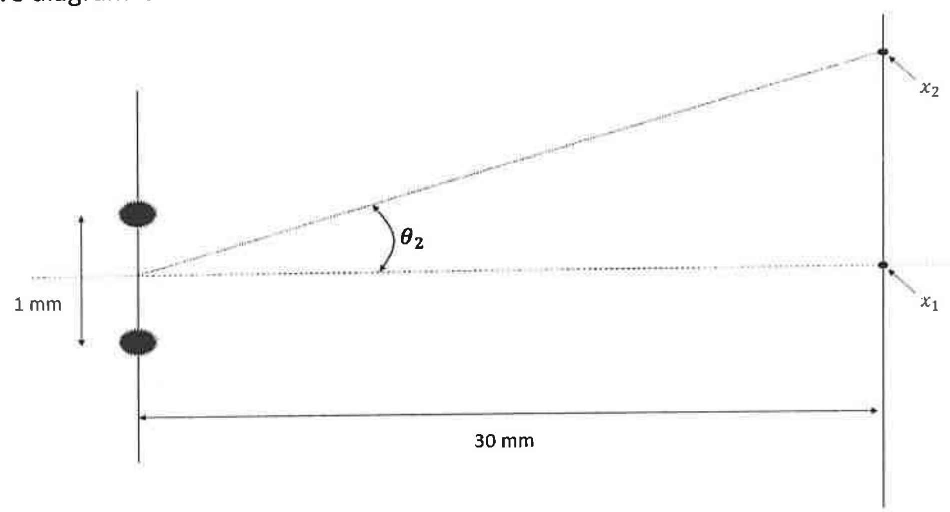
b) Using a matrix optics approach obtain the system matrix for the telescope. That is the matrix that relates a ray incident on the objective lens (from the left side) to a ray exiting the ocular lens (on the right side). For this step do not substitute any values for focal lengths and propagation distances. 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. 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: $R = \begin{bmatrix} x \\ n\alpha \end{bmatrix}$. (4 points)

c) Two very distant and close stars are to be observed with this telescope. Comment on the resolving power of the instrument. If the stars strongly emit light at a wavelength of 0.5 μm, what is the angular resolving power of this astronomical telescope? (2 points)

Answer either question 9 or question 10

Question 9 (10 points total):

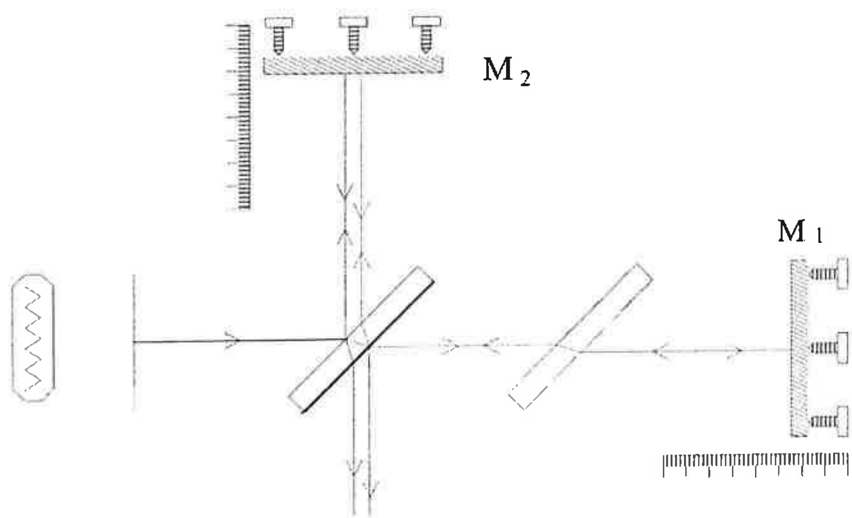
Two monochromatic point sources of equal amplitude and equidistant to the central axis, emit spherical waves. The lower source's emission is 180 degrees out of phase with respect to the upper source. A representative diagram is shown below.



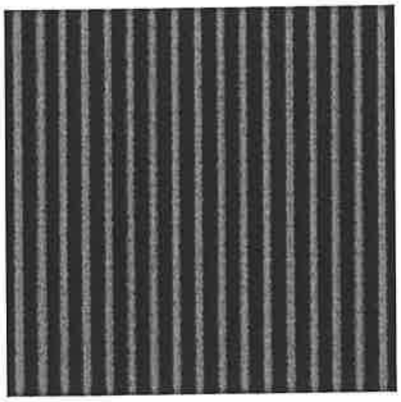
a) On the screen at position $x_1 = 0$, center of the screen, does it constitute a region of constructive or destructive interference? Justify your answer using wave addition arguments. (2 points)

b) At what distance x_2 and angle, θ_2 does maximum intensity of the first "off axis" bright fringe occur. The source spacing and screen distance are as indicated in the figure. Take the source wavelength to be 0.5 mm. (3 points)

c) A Michelson interferometer is shown in the sketch below. Describe the operation of the device based on the optical processes that are relevant to its design. (3 points)



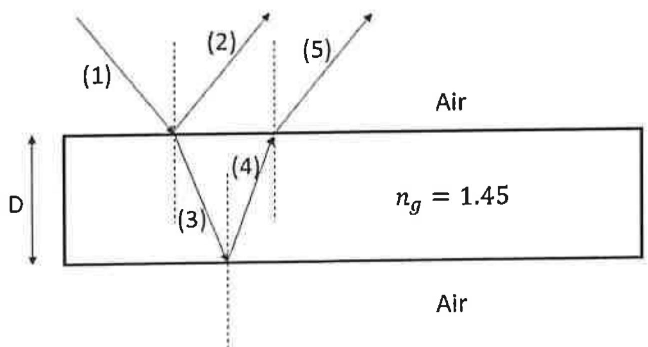
d) If the mirror M_1 is replaced with a device under test mirror and the following fringe pattern is observed. What can be determined about the surface finish of the test mirror. (2 points)



Answer either question 9 or question 10

Question 10 (10 points total):

An incident plane wave characterized by ray (1) is incident from air onto a thin glass film of uniform thickness D and refractive index $n_g = 1.45$, parallel top and bottom surfaces. This input ray is partially reflected (2) and refracted (3) at the top surface. The internal ray (3) is further reflected (4) from the lower glass-air interface and in part refracted at the top surface (5). Rays (2) and (5) are then recombined and interfere together. See figure below.



a) Rays (1) and (3) generate reflected rays. Will any of the reflected rays display a 180 degree phase change upon reflection? (1 point)

b) If ray (1) has angle of incidence of 30 degrees, compute the angle of reflection for ray (2) and the angle of refraction of ray (3). (1 point)

c) If the electric field of the incident plane wave is polarized in the plane of incidence, determine the amplitude reflection and transmission coefficients for the rays at the air-glass and at the glass-air interfaces. The following expressions may be useful. Subscripts are: *i* - incident, *t* - transmitted. (4 points)

$$r_{\parallel} = \frac{n_t cos(\theta_i) - n_i cos(\theta_t)}{n_t cos(\theta_i) + n_i cos(\theta_t)} \qquad t_{\parallel} = \frac{2n_i cos(\theta_t)}{n_t cos(\theta_i) + n_i cos(\theta_t)}$$

$$r_{\perp} = \frac{n_i cos(\theta_i) - n_t cos(\theta_t)}{n_i cos(\theta_i) + n_t cos(\theta_t)} \qquad t_{\perp} = \frac{2n_i cos(\theta_t)}{n_i cos(\theta_i) + n_t cos(\theta_t)}$$

d) Suppose the angle of incidence of ray (1) is change to normal incidence (0 degrees). What is the minimum non-zero thickness of the glass plate required for destructive interference to occur between rays (2) and (5) if the incident wavelength is 1 μm? Does this property have any practical applications in engineering? If yes give a few examples. If no, explain why it has no use. (4 points)

End of exam

Graph paper for question 7 OR 8

Graph paper for question 7 OR 8