Problem 1

A beam from a helium-neon laser (λ=633 nm) is incident on a glass plate that is 3.5 cm thick. The angle of incidence is 20° (see figure). Part of the beam goes through the glass without any reflections, the rest of the radiation is multiply reflected before emerging from the bottom of the glass plate. The index of refraction n_g for glass at 633 nm is 1.55. Calculate the following using Snell's Law and the Law of Reflection:

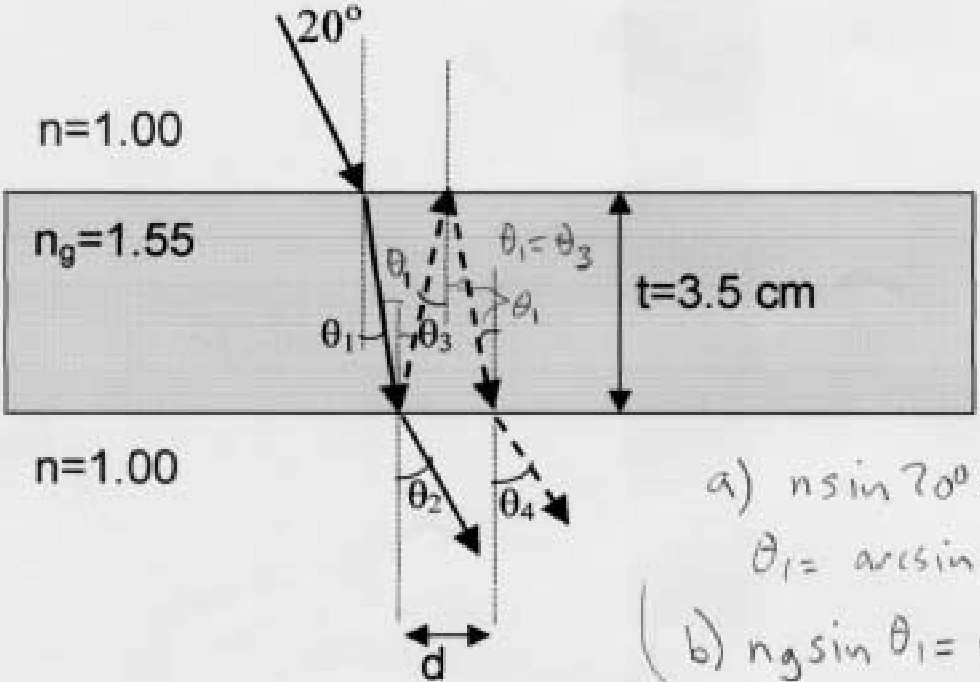
(a) The initial angle of refraction θ_1. (5 points)

(b) The exit angle θ_2 for the un-reflected beam (solid line in figure). (5 points)

(c) The angle θ_3 at the second reflection (dashed line in figure). (5 points)

(d) The exit angle θ_4 for the twice-reflected beam (dashed line in figure). (5 points)

(e) The distance d that separates the positions where the two beams (solid and dashed lines) exit the glass plate. (5 points)



a) $n \sin 20^\circ = n_g \sin\theta_1$

$\theta_1 = \arcsin\left(\frac{1.00}{1.55}\sin 20^\circ\right) = 12.7^\circ$

b) $n_g \sin\theta_1 = n\sin\theta_2 = n\sin 20^\circ$

$\theta_2 = 20.0^\circ$

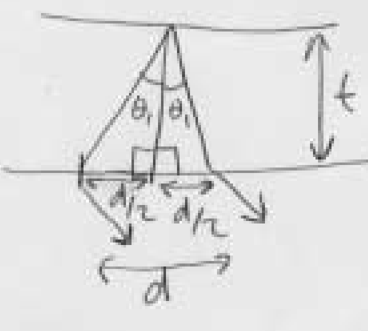
c) $\theta_{incidence} = \theta_1 = \theta_{reflection} = \theta_3$

$\theta_3 = 12.7^\circ$

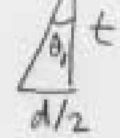
d) $n_g \sin\theta_1 = n\sin\theta_4 = n\sin 20^\circ$

$\theta_4 = 20.0^\circ$

e)



$\tan\theta_1 = \frac{d/2}{t}$



$d = 2t\tan\theta_1 = 2(3.5\,cm)\tan(12.7^\circ)$

$= 1.58\,cm = 1.58\times10^{-2}\,m$

Problem 2

A single thin **lens** is used to create an image of a 10.0 cm tall source that is located at position x=0 cm (30.0 cm to the left of the lens), as shown in the figure below. The magnitude of the radius of curvature for the front surface is $|R_f|$= 60.0 cm and the focal length f= -20.0 cm, respectively. The lens is made of synthetic diamond with an index of refraction of 2.42.

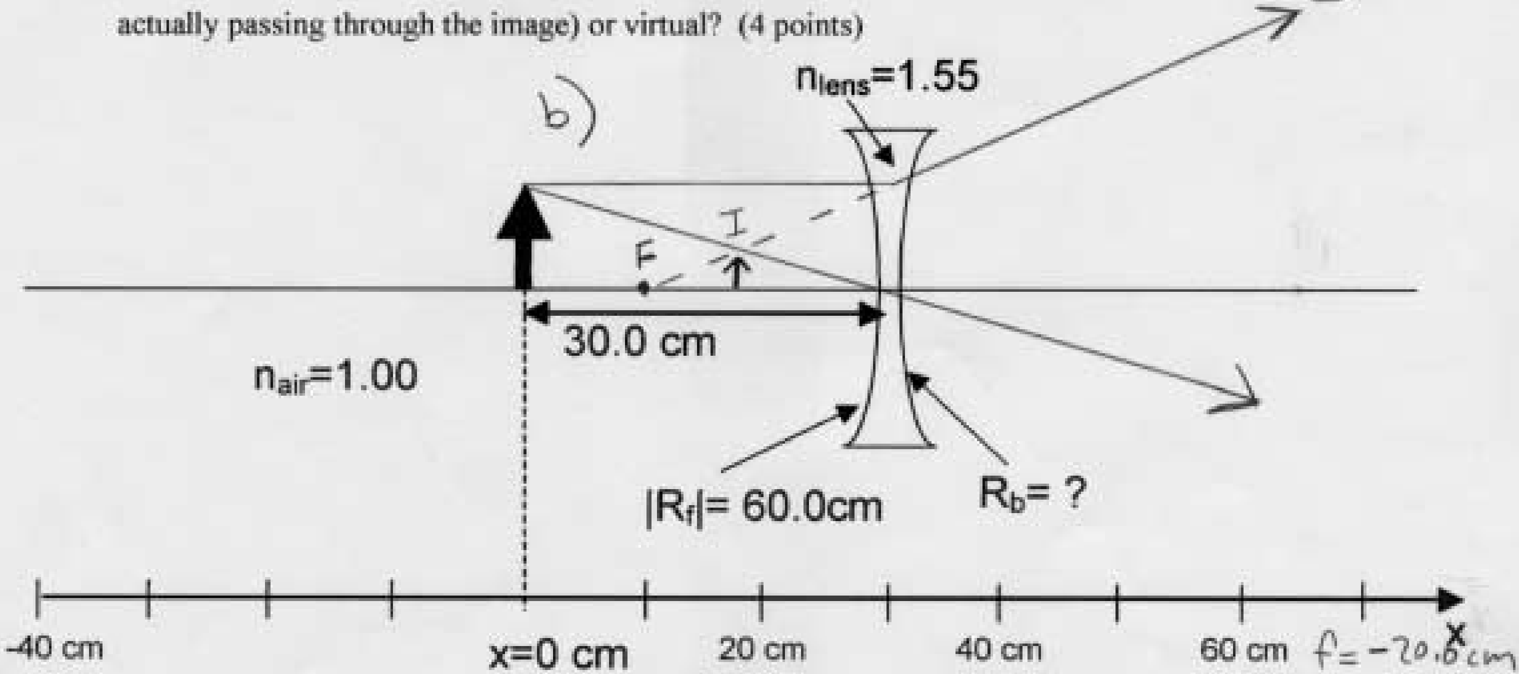
(a) What is the **magnitude** and **sign** of radius of curvature for the back surface R_b? (5 points

(b) Using two principal rays, show the resulting image. (6 points)

(c) At what position x_i does the image get formed? Please use the coordinate system that is provided in the figure below. (5 points)

(d) What is the height h_i of the image? (5 points)

(e) Is the image upright or inverted (upright=pointing up, inverted=pointing down)? Is it real (all rays are actually passing through the image) or virtual? (4 points)



$f = -20.0$ cm

a) thin lens formula in air $\quad \frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad R_1 = R_f = -60.0$ cm

expect $R_2 = R_b > 0$

$$-\left(\frac{1}{f(n-1)} - \frac{1}{R_1}\right) = \frac{1}{R_2} \rightarrow R_2 = \frac{-1}{\frac{1}{(-20)(2.42-1)} - \frac{1}{-60}} = +53.9\text{cm}$$

c) $\frac{1}{s} + \frac{1}{i} = \frac{1}{f} \rightarrow i = \frac{1}{\frac{1}{f} - \frac{1}{s}} = \frac{1}{\frac{1}{-20} - \frac{1}{30}} = -12.0\text{ cm}$

$x_i = 30\text{cm} - 12.0\text{cm} = 18.0\text{ cm}$

d) $m = -\frac{i}{s} = \frac{-(-12\text{cm})}{30\text{cm}} = +.400\text{ cm} \rightarrow h_i = m h_s = (.4)(10\text{cm})$

$= 4.00\text{ cm}$

e) Upright, virtual (most of the rays do not actually pass through the image)

Problem 3

A single beam of coherent light (λ=633x10^{-9} m) is split into two beams by a beam splitter (partially silvered mirror), as shown in the figure depicting a Michelson interferometer below. Beam 1 goes through the beam splitter along Path 1, reflects off fixed Mirror 1, and returns to the beam splitter, where it reflects downward. Beam 2 reflects off the beam splitter going upward along Path 2, reflects off a moveable Mirror 2, and returns to go straight through the beam splitter to recombine with Beam 1 at Point P. The position of Mirror 2 is given by y; note that when y=0, Mirror 1 and Mirror 2 are the same distance L=0.25 m away from the beam splitter. As y increases, Mirror 2 to moves way from the beam splitter.

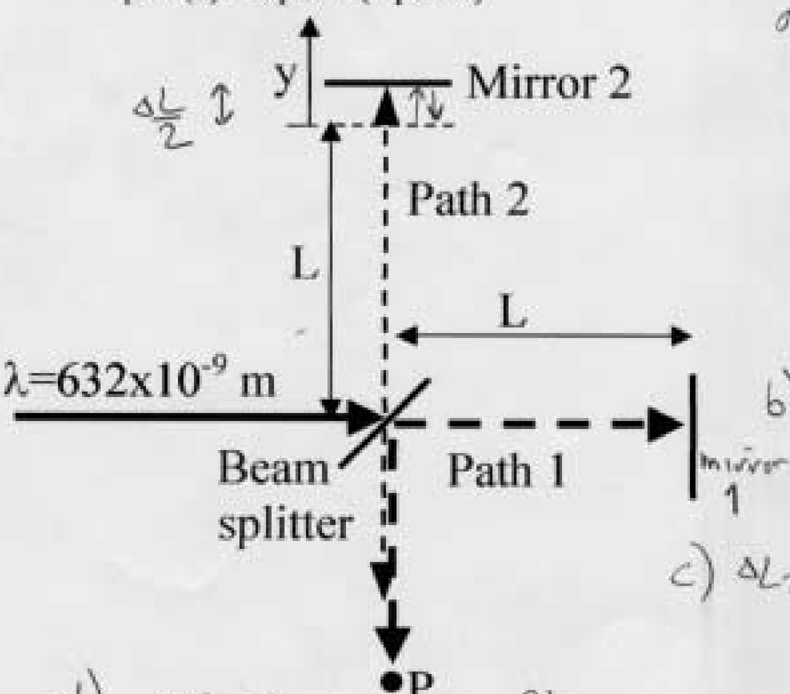
(a) Is there any phase **difference between** the two beams when they recombine due to **differences in reflection**? Explain. (2 points)

(b) When Mirror 2 is at y=158x10^{-9} m, what is the path difference ΔL_1 between the two beams at Point P? What kind of interference (constructive, destructive, neither, etc) results at Point P? (6 points)

(c) When Mirror 2 is at y=316x10^{-9} m, what is the path difference ΔL_2 between the two beams at Point P? What kind of interference (constructive, destructive, neither, etc) results at Point P? (6 points)

(d) Make a rough plot showing the intensity at point P as a function of y, starting at y=0 and extending to y=632x10^{-9} m. (6 points)

(e) If the coherence length of the light is 0.10 m (the phase relationship between parts of the beam that are separated by more than 0.10 m is random), will one still get the interference effects that you plotted in part (d)? Explain. (5 points)

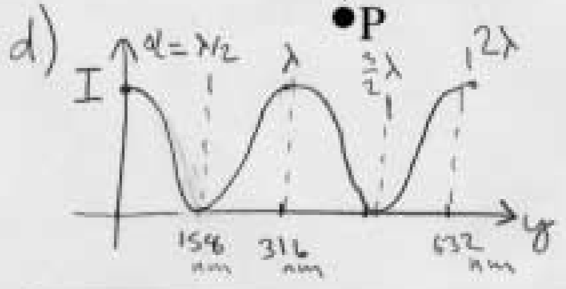


a) Path 1: 2 reflections
Path 2: 2 reflection
so both beams experience a phase shift of $2\times(\pi) = 2\pi$
$\Delta\phi_{refl} = 2\pi - 2\pi = 0$
no phase difference due to reflection differences

b) $\Delta L_1 = 2y_1 = 2(158nm) = 316nm$
$= \frac{632nm}{2} = \frac{\lambda}{2} \rightarrow$ destructive interference

c) $\Delta L_2 = 2y_2 = 2(316nm) = 632nm$
$= \lambda \rightarrow$ constructive interference

d)



e) max ΔL is only 632×10^{-9}m so we're never looking at parts of the beam separated by more than 632×10^{-9}m, which is much shorter than the coherence length of 0.10m,