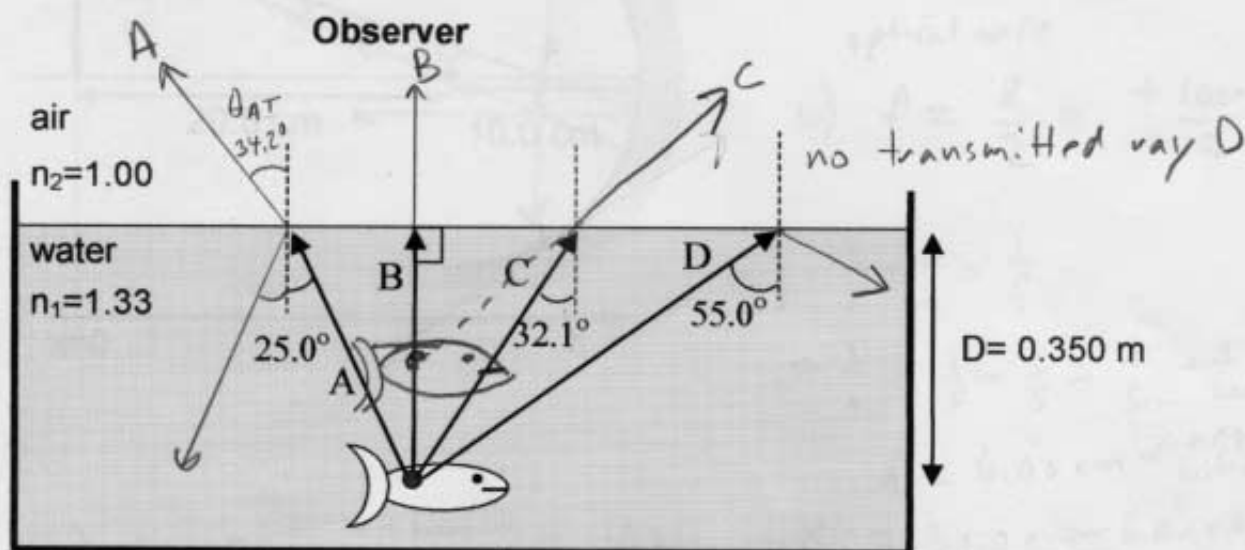


Problem 1

A dark spot on a goldfish is 0.350 m below the water surface. Consider 4 rays of light (A, B, C, and D) that leave the spot and head toward an observer who is above the water. Calculate the following using Snell's Law and the Law of Reflection:

- Calculate the speed of light in the water. (2 points)
- For Ray A, calculate the angles (with respect to the surface normal) of the light that is **transmitted** through and **reflected** from the surface. **Draw** both the **transmitted** and **reflected** rays for Ray A on the figure below. (6 points)
- For Rays B, C, and D, calculate the angles (with respect to the surface normal) of the light that is **transmitted** through the surface. **Draw** the **transmitted** rays for Rays B, C, and D on the figure below. (9 points)
- What is the apparent depth of the spot as seen by the observer? **Draw** on the figure the apparent position of the spot (and the rest of the fish) as seen by the observer. Hint: From where in the water due Rays B and C appear to originate for the observer? (8 points)



a) $v = \frac{c}{n} = 2.26 \times 10^8 \text{ m/s}$

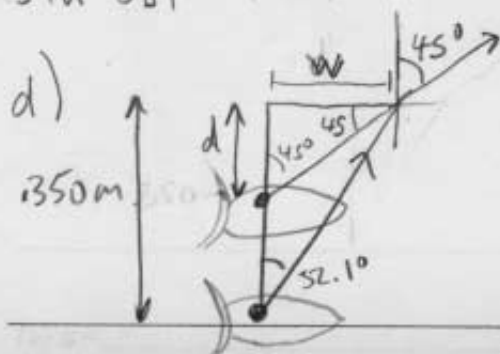
b) $n_1 \sin \theta_i = n_2 \sin \theta_{AT}$
 $1.33 \sin 25.0^\circ = 1 \sin \theta_{AT} \rightarrow \theta_{AT} = 34.2^\circ$ transmitted
 $\theta_{AR} = 25.0^\circ$ reflected

c) $n_1 \sin \theta_i = n_2 \sin \theta_{iT}$

$\theta_{BT} = 0^\circ$

$\theta_{CT} = 45.0^\circ$

$\sin \theta_{DT} = 1.09 > 1$ no θ_{DT} possible \rightarrow total internal reflection



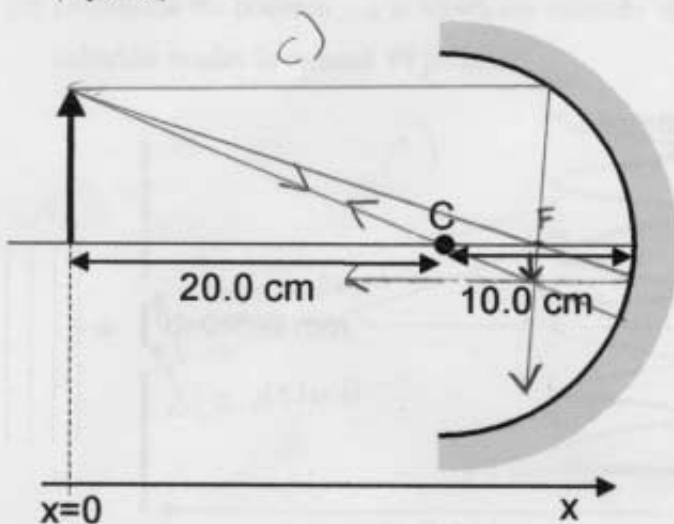
$w = 0.350 \text{ m} \tan 32.1 = 0.220 \text{ m}$
 $w = d$ ($45^\circ - 45^\circ - 90^\circ$ triangle)
 depth = $d = 0.220 \text{ m}$

Place your answers here:

Problem 2

A single concave spherical mirror is used to create an image of a 5.00 cm tall source that is located at position $x=0$ cm which is 20.0 cm to the left Point C, the center of the mirror, as shown in the figure below. The magnitude of the radius of curvature for the mirror is ~~20.0~~ ^{10.0} cm.

- What is the source distance s from the mirror? Be careful! (2 points)
- What is the magnitude and sign of the mirror's focal length? (5 points)
- Using three principal rays, show the resulting image. (6 points)
- Calculate the position x_i where the image is formed (4 points)
- What is the height h_i of the image? (4 points)
- Is the image upright or inverted (upright=pointing up, inverted=pointing down)? Is it real or virtual? (4 points)



a) $s = 20 + 10 = \boxed{30.0 \text{ cm}}$
 distance from where surface of lens/mirror intersects optical axis

b) $f = \frac{R}{2} = +\frac{10 \text{ cm}}{2} = \boxed{5.00 \text{ cm}}$

d) $\frac{1}{s} + \frac{1}{i} = \frac{1}{f}$

$$\frac{1}{i} = \frac{1}{f} - \frac{1}{s} = \frac{1}{5 \text{ cm}} - \frac{1}{30 \text{ cm}}$$

$$i = 6.00 \text{ cm} \checkmark \text{ agrees with c)!}$$

e) $m = -\frac{i}{s} = -\frac{6 \text{ cm}}{30 \text{ cm}} = -0.200$ $x_i = 30.0 \text{ cm} - 6.00 \text{ cm} = \boxed{24.0 \text{ cm}}$
 $h_i = m h_s = (-0.20)(5 \text{ cm}) = \boxed{-1.00 \text{ cm}}$ or just $\boxed{1.00 \text{ cm}}$

f) inverted ($h < 0$, and drawn in part c)

real

Place your answers here:

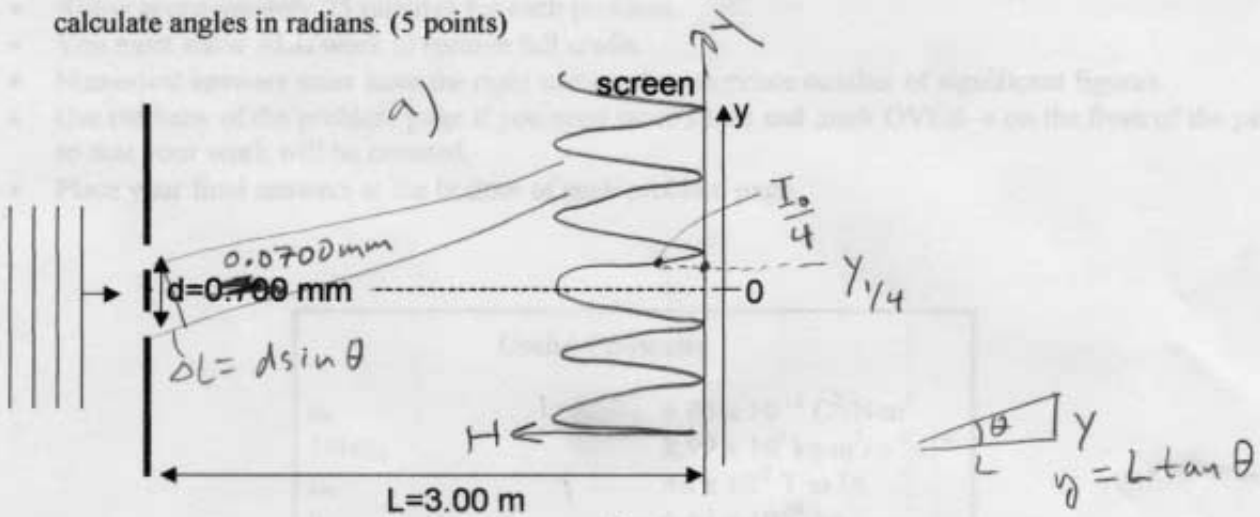
(a) $s =$

(2)

Problem 3

Monochromatic ($\lambda=633 \text{ nm}$), coherent plane waves of light from a laser are incident on two slits that are separated by a distance $d = 0.070 \text{ mm}$. Independently (without interference effects), each slit illuminates the screen 3.00 m away with an intensity of 200 W/cm^2 at the screen.

- Sketch the intensity pattern from the two slits that appears on the screen on the right in the figure. (4 points)
- Determine the positions $y_{\min}(m)$ (for $y_{\min} \geq 0$) on the screen of the first three intensity minima, where m is the order of each minimum? What is the intensity I_{\min} at these positions? (8 points)
- Determine the positions $y_{\max}(m)$ (for $y_{\max} \geq 0$) on the screen of the first three intensity maxima, where m is the order of each maximum? What is the intensity I_{\max} at these positions? (8 points)
- Determine the position $y_{1/4}$ at which the intensity of the central peak (at $y=0$) drops to $I_{\max}/4$. Hint: calculate angles in radians. (5 points)



b) minima \Rightarrow destructive interference
 $\Delta L = d \sin \theta_{\min} = (n + \frac{1}{2}) \lambda \quad n = 0, 1, 2, \dots$
 $\sin \theta_{\min} = (n + \frac{1}{2}) \frac{633 \times 10^{-9} \text{ m}}{0.070 \times 10^{-3} \text{ m}}$
 $\theta_{\min, n=0} = 0.259^\circ \quad y_{\min 1} = 13.6 \text{ mm}$
 $\theta_{\min, n=1} = 0.777^\circ \quad y_{\min 2} = 40.7 \text{ mm}$
 $\theta_{\min, n=2} = 1.30^\circ \quad y_{\min 3} = 68.1 \text{ mm}$
 $I_{\min} = 0$ completely destructive

c) maxima \Rightarrow constructive interference
 $\Delta L = d \sin \theta_{\max} = n \lambda \quad n = 0, 1, 2, \dots$
 $\sin \theta_{\max} = n \frac{\lambda}{d}$
 $\theta_{\max, n=0} = 0^\circ, \theta_{\max, n=1} = 0.518^\circ, \theta_{\max, n=2} = 1.04^\circ$
 $y_{\max, 0} = 0, y_{\max, 1} = 27.1 \text{ mm}, y_{\max, 2} = 54.5 \text{ mm}$
 $I_{\max} = \frac{1}{2} \epsilon_0 (E_0 + E_0)^2 \Rightarrow (4) (\frac{1}{2} \epsilon_0 E_0^2) = 4 I_0 = 4 (200 \frac{\text{W}}{\text{cm}^2}) = 800 \frac{\text{W}}{\text{cm}^2}$

d) $I_{\text{net}} = (4) I_0 \cos^2 \left(\frac{\pi d}{\lambda} \sin \theta_{1/4} \right) = \frac{I_{\max}}{4} = \frac{(4 I_0)}{4}$
 $4 \cos^2 \left(\frac{\pi d}{\lambda} \sin \theta_{1/4} \right) = 1 \rightarrow \theta_{1/4} = \arcsin \left(\frac{\lambda}{\pi d} \arccos \left(\sqrt{\frac{1}{4}} \right) \right) = 3.01 \times 10^{-3} \text{ rad}$

Place your answers here: $y_{1/4} = 9.04 \text{ mm}$

(a) Sketch on figure

3
(4)