PHYS302 Fall 2023

Homework 5

1. Two thin lenses, both with f = + 30 cm are 20 cm apart. An object is 50 cm from the first lens. Find the final image.

   (Hint, if you want it) Solve the problem in steps:
   1. Solve the problem in the absence of lens 2. Find the (intermediate) image distance (s_{i1}). Find the (intermediate) transverse magnification (M_{T1}).
   2. Calculate the s_{02} from figuring out how far s_{i1} is from the second lens. Pay attention to the sign.
   3. Solve for s_{i2} as if lens 1 wasn't there. Find the (final) image distance (s_{i2}). Find the transverse magnification from the second lens (M_{T2}).
   4. Find the total transverse magnification of the final image compared to the original object.
   5. Draw a ray tracing diagram in which you include both steps.

   Note: If you are comfortable with another method (for example, the use of principle planes and eqn. 6.8 in the text, or matrix ray tracing) feel free to use this. However, please include an accurate ray tracing diagram.

(1) $\frac{1}{30cm} = \frac{1}{50cm} + \frac{1}{s_{i,1}} \Rightarrow s_{i,1} = +75cm$

(2) $s_{o,2} = d - s_{i,1} = -55$ cm

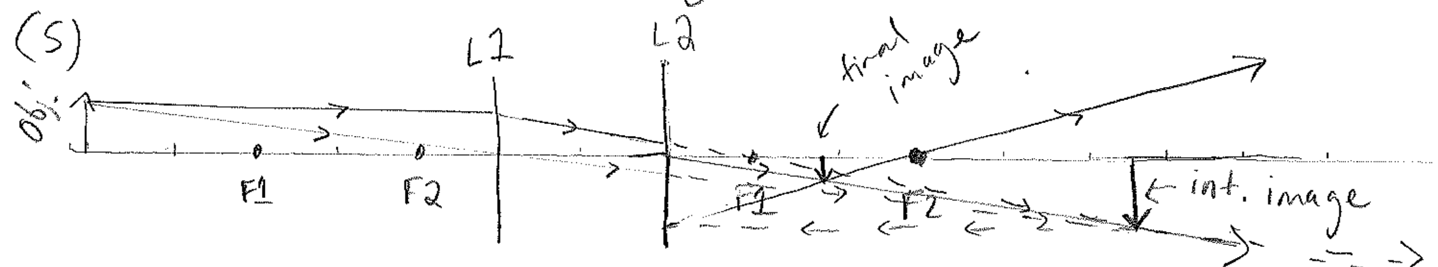
(3) $\frac{1}{f_2} = \frac{1}{s_{o,2}} + \frac{1}{s_{i,2}}$

$\frac{1}{30cm} = \frac{1}{-55cm} + \frac{1}{s_{i,2}} \Rightarrow \boxed{s_{i,2} \approx +19 \text{ cm}}$

(4) $M_T = M_{T1} \cdot M_{T2} = \left(-\frac{75}{50}\right)\left(\frac{-19}{-55}\right) = \boxed{-0.52}$

→ real, inverted from original object.

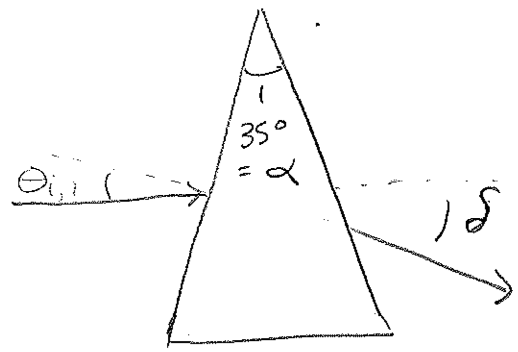
(5)



2. A prism made of silicon nitride ($n \approx 2.0$) has an apex angle of 35 degrees.

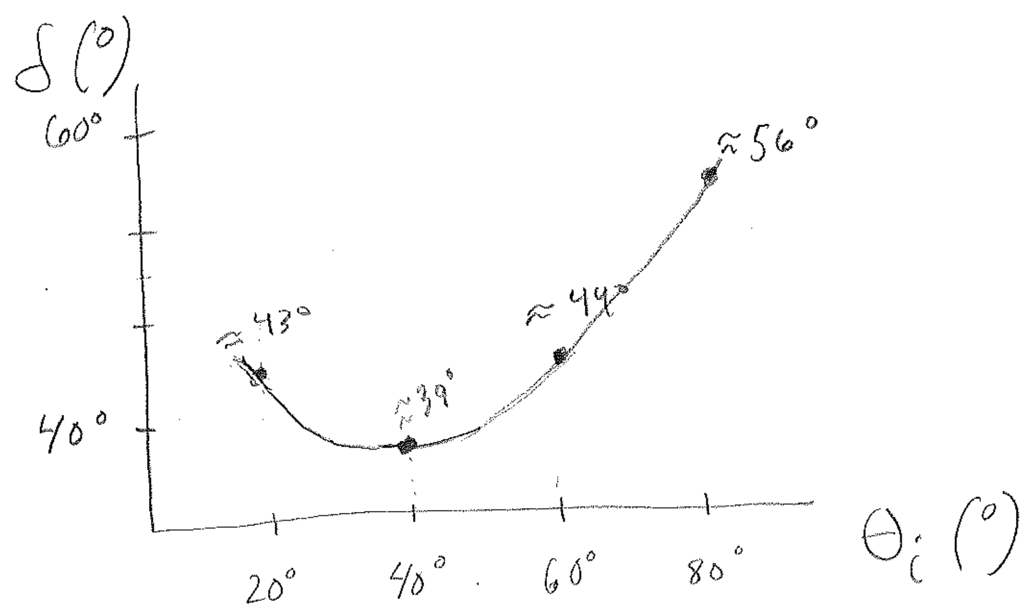
(a) Find the angle of deviation for angles of incidence from 20 to 80 degrees in steps of 20 degrees. Plot these (angle of deviation vs. angles of incidence). (Creating a table and plot in Wolfram Cloud or another plotting software is fine! Just show your work/equations.)

(b) Calculate the minimum angle of deviation and show that it agrees with your plot.

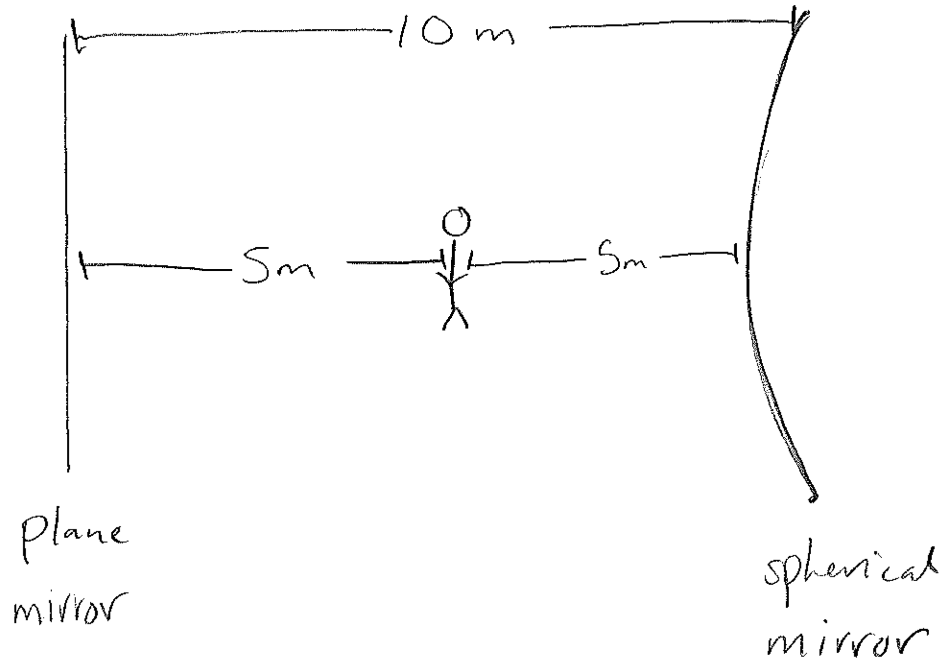


$$\delta = \theta_{i1} + \arcsin\left((\sin\alpha)(n^2 - \sin^2\theta_{i1})^{1/2} - \sin\theta_{i1}\cos\alpha\right) - \alpha$$

$$\delta_{min} = 2\arcsin\left[n \cdot \sin\left(\frac{\alpha}{2}\right)\right] - \alpha \approx \boxed{39^\circ}$$



3. (5.85 in Hecht) In an amusement park a large upright convex spherical mirror is facing a plane mirror 10.0 m away. A girl 1.0 m tall standing midway between the two sees herself twice as tall in the plane mirror as in the spherical one. In other words, the angle subtended at the observer by the image in the plane mirror is twice the angle subtended by the image in the spherical mirror. What is the focal length of the latter?



$$M_{T\_plane} \equiv 1 = 2M_{T\_spherical}$$

$$M_{T\_sph} = \frac{1}{2} = \frac{-s_i}{s_o}$$

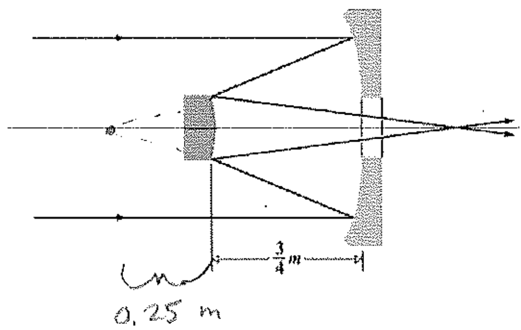
$$\rightarrow s_o = 5.0 \text{ m}$$

$$s_i = -\frac{1}{2} \cdot 5.0 \text{ m} = -2.5 \text{ m}$$

$$\frac{1}{f} = \frac{1}{s_i} + \frac{1}{s_o} = \frac{-1}{2.5\text{ m}} + \frac{1}{5.0\text{ m}}$$

$$\boxed{f = -5.0 \text{ m}}$$

4. (5.86 in Hecht) A homemade telephoto "lens" (**Fig. P.5.86**, below) consists of two spherical mirrors. The radius of curvature is 2.0 m for the primary (the big mirror) and 60 cm for the secondary (the small mirror). How far from the smaller mirror should the film plane be located if the object is a star? What is the effective focal length of the system?



For a star: $S_o \to \infty$

(1) Big mirror:

- $f_1 = \frac{-R}{2} = 1.0\ m$
- $\frac{1}{f_1} = \frac{1}{S_{o,1}} + \frac{1}{S_{i,1}}$

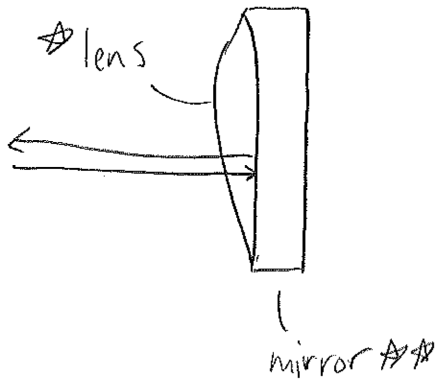
$S_{i,1} = f = 1.0\ m$

(2) Small mirror:

- $f_2 = \frac{-R}{2} = -30\ cm$
- $S_{o,2} = d - S_{i,1} = -0.25\ m$
- $\frac{1}{-30cm} = \frac{1}{-25\ cm} + \frac{1}{S_{i,2}}$
- $S_{i,2} = \underline{-150\ cm}$ or $150 - 75 =$ **film goes 75 cm behind big mirror**

$f_{eff} \approx +75\ cm$

5. (5.90 in Hecht) A thin positive lens of focal length f_L is positioned very close to and in front of a front-silvered concave spherical mirror of radius R_M. Write an expression approximating the effective focal length of the combination in terms of f_L and R_M.



✩ Light travels through the lens twice.

✩✩ $$\frac{1}{f_{mirror}} = \frac{+2}{R_M}$$ ← Note: $R_M < 0$, so $f_{mirror} > 0$

Equation for close optics:

$$\frac{1}{f_{eff}} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3}$$

$$\frac{1}{f_{eff}} = \frac{1}{f_L} + \frac{2}{R_M} + \frac{1}{f_L}$$

$$\boxed{\frac{1}{f_{eff}} = \frac{2}{f_L} + \frac{2}{R_M}}$$