PHY 124 Lab 7 - Reflection, Refraction and Images

There are two parts to this lab that can be done in either order. In Part I you will study the Laws of Reflection and Refraction, measure the index of refraction of glass, and observe dispersion. In Part II you investigate images produced by lenses.

Important! You need to print out the 4 page worksheet you find by clicking on this link and bring it with you to your lab session. [http://www.ic.sunysb.edu/Class/phy122pk/labs/pdfs/phy124s13reflrefrimgslab7worksheet.pdf]

If you need the .pdf version of these instructions you can get them here [http://www.ic.sunysb.edu/Class/phy122pk/labs/pdfs/phy124s13reflrefrimgslab7.pdf].

Video

Part I

Equipment

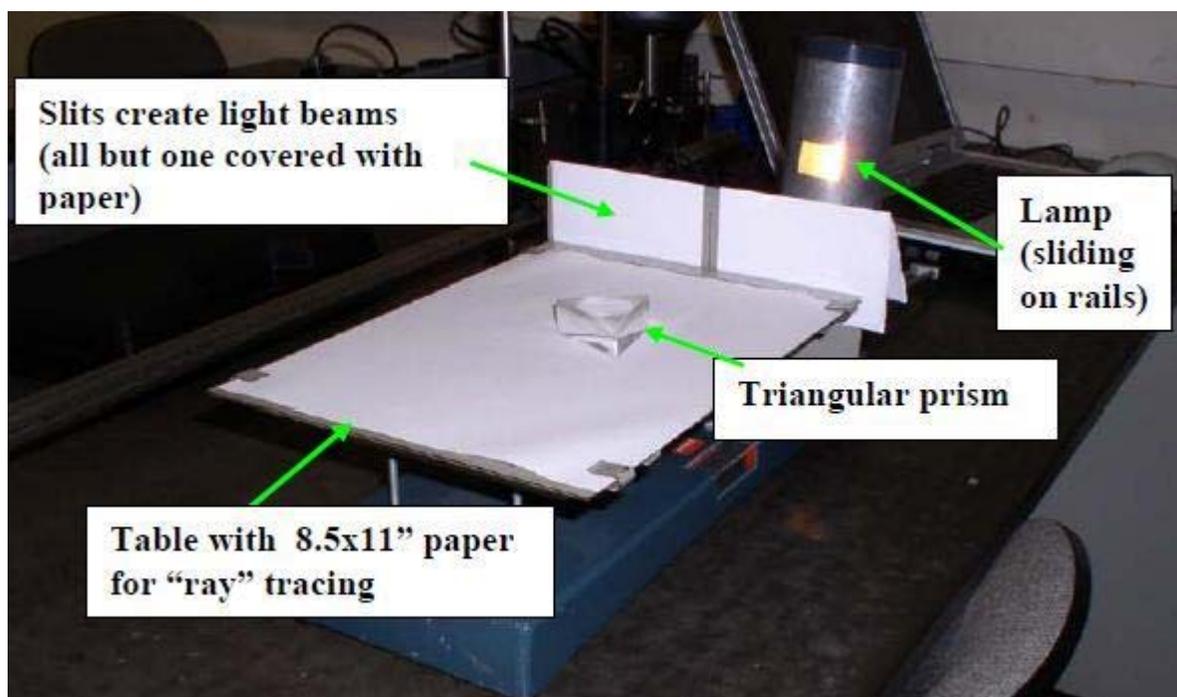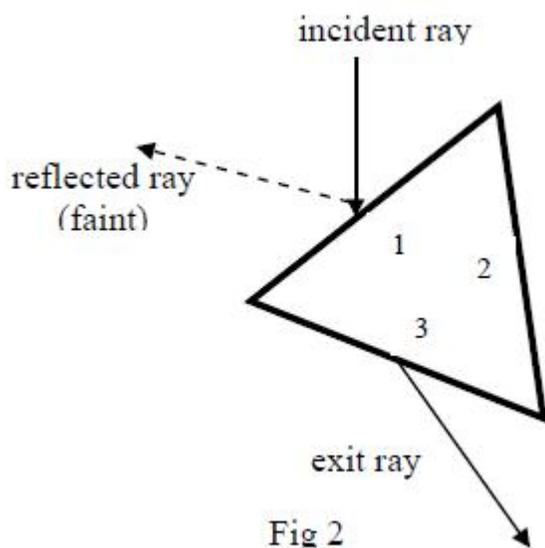- "Ray" table

■ Triangular prism

Fig1

The laws of reflection and refraction

Fig 2

When the light beam hits the air–glass boundary, side 1 of the prism in Fig. 2 above, reflection and refraction occurs; see Figs. 18.8 and 18.15 of Chap. 18 of Knight, Jones and Field, *College Physics: A Strategic Approach* (KJF2), 2nd ed., the optional textbook for our course. [If you don't have a copy, one is bolted to a table in the Help Room, A-131 physics building. A few copies are also on closed reserve in the Math/Physics Library, "C" level, physics building.] A small fraction of the intensity of the incident beam is reflected, leaving a faint reflected ray outside the prism, and the remainder of the intensity is refracted into the prism. The refracted ray hits the glass-air boundary on side 3 of the prism and the ray is again refracted into the air as the "exit" ray in Fig. 2 above. The ray reflected inside the prism on boundary 3 is barely visible.

The law of reflection states that the incident angle θ_i equals the angle of reflection θ_r (Ch. 21.1, Sh 8 of the online notes; KJF2, Ch. 18.2)

$$\theta_i = \theta_r$$
(7.1)

For refraction, Snell's Law holds. Snell's Law is given in Ch. 21 Sh 9 of the online notes and in Eq. (18.2) of KJF2 and in Eq. (7.2) here:

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
(7.2)

In our case for boundary 1 n_1 is the index of refraction of air (which we assume to be 1 as for vacuum) and n_2 is the index of refraction of glass. In this lab n_2 is considered to be unknown and you will be measuring it by applying Snell's Law on boundaries 1 and 3.

Procedure

Make sure the lamp is as close as possible to the slits. Using a piece of paper, block all beams except the central beam, then place a sheet of paper onto the trace table (secure it with the clamps on each corner). Position the triangular prism so that side 1 is ~45° with respect to the incident ray direction as shown in Fig. 2 above. Trace the incident, reflected and exit rays (shown in Fig. 2) and trace the outline of the prism.

Closely inspect the exit ray. You should notice that it has a blue side and a red side. On your sketch, record which side of the exit ray shows which color. You will use this information during Section 3 of Part I, which deals with dispersion.

Make sure your paper stays fixed in place while you are tracing.

1. The Law of Reflection

First, take your sketch and add "normal" lines (lines perpendicular to where the rays hit the boundaries) to the sides 1 and 3. Since light will travel in a straight line, connect the incident from where it hits side 1 and the exit ray from where it hits side 3. This will be the path of the light ray inside the prism. Find the angles of incidence and reflection for the incident ray. Make sure you take these angles with respect to the normal line you drew! Measure the angles of incidence and reflection and include an estimate of the error with your values. Check them against the Law of Reflection, ie. Are the two angles equal within error?

2. Snell's Law

Measure the angles of incidence and refraction on boundaries 1 and 3 (again with respect to the normal lines you drew). Use Snell's Law to calculate the index of refraction of the prism glass for both boundaries

Be Careful! Make sure you pay attention to which index of refraction you use for glass and air for the two separate cases. For the side 1 boundary n_1 should be for air and n_2 should be for glass. For the side 3 boundary n_1 should be for glass and n_2 should be for air.

3. Dispersion: qualitative only

The index of refraction depends slightly on the wavelength of light. Thus light with different wavelengths (and hence different color) is bent by different angles. When you looked at the exit ray and saw different colors being refracted at slightly different angles you were observing dispersion (see Ch. 21.1 Sh 9' of the online notes and KJF2, Ch. 19.6).

Which color is bent more, red or blue? Which light has the larger index of refraction, red or blue light (hint: Look at Snell's Law)?

4. Total Internal Reflection: qualitative only

For a critical angle of incidence θ_c on the glass-air boundary 3 no refracted intensity is visible, the full intensity of the incident beam is reflected back into the glass. At the angle with this happens, total internal reflection occurs. See Ch. 21.1 Sh 10 of the online notes and pp. 583-585 of KJF2.

Place a new sheet on the ray table and slowly rotate the prism slowly clockwise from the position it had for the measurements above (~45°) with respect to the incident beam from the slit). As you rotate the prism you should notice that the exit ray makes smaller and smaller angles with boundary 3. You should also observe a beam exiting boundary 2. Observe the intensity of the beam coming from side 2 as you continue to turn the prism. Rotate the prism until the exit ray disappears completely, while observing the intensity of the new ray from boundary 2. Rotate back and observe a couple of times.

Describe your observations of the intensity of the beam emanating from boundary 2 as you rotate the prism. When the "exit ray" in Fig 2 disappears, is the intensity of the beam emanating from boundary 2 maximal or minimal? On which boundary do you observe total internal reflection?

Part II

Equipment

- 1 "Optical Bench: a rail to mount the holders of lenses/screen on
- 1 Box with lenses (Use #3 and # 4 only – marked at bottom of shaft)
- 2 Holders for lenses/screen
- 1 Screen
- 1 Lamp with arrow (our object to be imaged)

Verify that you have the correct lens mounted before you start measuring! The lenses are marked at the bottom of the shaft of the lens holder: #3: 10 cm diverging lens #4: 5 cm converging lens
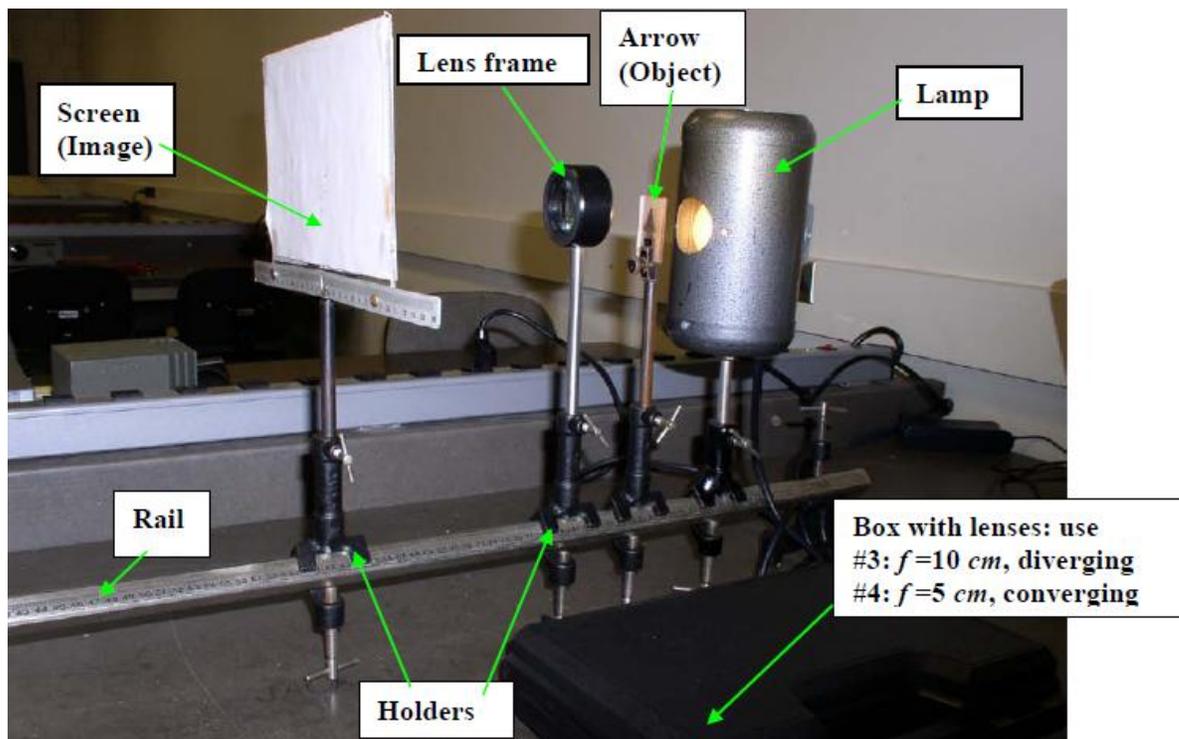
Fig3

The imaging law for lenses

The purpose of this part is to study images made by lenses and to verify the imaging laws for lenses.

The imaging law for the lenses relates the distance *o* from the object to the lens, the distance *i* from the image to the lens, and the focal length *f* of the lens. This relationship is given in Ch22 sheet 20' of the online lecture notes for PHY 122. [NOTE: Ch. 18.7, pp. 597-601, of Knight, Jones, and Field, *College Physics: A Strategic Approach*, 2nd ed. (KJF2) calls the object distance *s*, the image distance *s'* and the focal length *f*.]

$$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$$
(7.3)

The equation for the magnification m of lenses is given in Ch22 sheet 20 of the online lecture notes for PHY 122. [The equation for the magnification *m* of lenses is given in Eq. (18.8) of KJF2; see also Integrated Example 18.15 on p. 601 of KJF2.]

$$m = -\frac{i}{o}$$
(7.4)

You will use Eqs. (7.3) and (7.4) to measure the focal length and the magnification of a lens with an expected focal length of 5 cm.

Procedure

Make sure that the lamp and the painted arrow (the "object") are placed at one end of the optical bench, with the arrow a few cm in front of the lamp and pointing upward. The arrow and lamp will remain in that position for this part of the experiment. The screen and the lenses will be moved. You will observe two images, one magnified, the other demagnified, depending on the position of your lens.

Focal length and Magnification for the 5 cm Converging Lens: Quantitative

Mount the 5 cm (#4) lens in the lens holder. Mount the screen into a holder and place it at ~ 30 cm from the object. Place the lens between the screen ("image") and the object as close to the object as possible. Move the lens towards the screen until you can see a sharp image on the screen. First, observe the size and orientation of the object and of the image. Record them into your Execution Sheet. Next, locate the positions of the image, lens and object and record them in your Execution Sheet. Your dominant error in the locations will be the error of the lens position.

Note that the lens is not centered on the lens holder but offset by 0.6 cm. Make sure you note the orientation of the lens. If it is oriented as shown in Fig. 4, so that the lens is closer to the screen, you must increase the lens position by 0.6 cm. If the lens is further from the screen you must decrease the lens position by 0.6 cm. Assume an error in the lens position of 0.2 cm. Estimate the errors of the image and object size (h_i and h_o) as well.

The important quantities you obtain from these positions are the distance from the lens to the image and the lens to the object and the errors associated with these distances.

On the graph paper on your worksheet make a drawing – to scale (1 square = 1cm in the horizontal direction, but 1 square = 0.25 cm in the vertical direction) – containing object and image arrows and the lens with object and image distance and the nominal focal length of 5 cm. Reconstruct the image with the principal rays (see Ch22 sheet 20 of the online lecture notes; see also KJF2, Ch. 18.5, especially Figs. 18.28, 18.29, 18.30, 18.34 18.37, and Example 18.7 on p. 590.)

Use equation (7.3) to calculate the focal length f of the lens and its error from your measured o and i values.

To calculate the uncertainty in f simply assume that the object (o) and image (i) distance have the same absolute uncertainty, which is given by the dominant absolute uncertainty of the lens position (discussed above). Use the fact that the reciprocals 1/i, 1/o and 1/f have the same relative uncertainties as i, o and f, and propagate the absolute uncertainties of the reciprocals according to expression (E.6) in *Uncertainty, Errors and Graphs*. (Also, remember Question 3 on your Lab 7 pretest!)

Compare your obtained value of f with the nominal value of 5 cm: Are they consistent?

Find the magnification from the measured object and image heights using $m = h_i/h_o$.

Calculate the uncertainty in the measured magnification from the errors in h_i and h_o using Eq. (E.7) in *Uncertainty, Errors and Graphs*.

Calculate the magnification from the measured image and object distances using equation (7.4).

Calculate the error in this calculated value for the magnification from the errors in i and o using equation (E.7) in Error and Uncertainty.

Are the two values obtained for the magnification consistent with each other?

Move the lens to another position, closer to the screen, where you get a sharp image of a different size. Record the same data for that position. No uncertainties are needed here.

On the graph paper on your worksheet make a drawing – to scale as before – containing object and image arrows and the lens with object and image distance and the nominal focal length of 5 cm. Reconstruct in your drawing the image with the two principal rays (see Ch22 sheet 20 and KJF2, Chap. 18.5). Get the measured

magnification $m = h_i / h_o$ [NOTE: KJF2 uses slightly different notation] and compare it to the value obtained for your 1st lens position.

Image and Magnification for the 10 cm Diverging Lens: Qualitative only

Mount the 10 cm (#3) diverging lens in the lens holder. Place the lens at as close as possible to the object. Try to make an image on the screen by moving the lens and screen around (verify that you don't in fact produce an image on the screen). Remove the screen and place your eye close to the lens so that you can observe the image the lens produces from the object. Describe on your worksheet whether the image (what you see) appears upright/inverted, magnified/demagnified with respect to the original object

Slide the lens away from the object and, keeping your eye close to the lens, state on your worksheet whether the properties of the image, apart from the size, change as you increase the distance of the lens from the object., i.e., is the image for any object distance upright/inverted, magnified/demagnified. Is the image real or virtual?