Physics 319 Laboratory: Optics

Thin Lens Geometric Optics

Objective: To determine the focal lengths and powers of various lenses using thin lens techniques and to determine the uncertainty of a focal length.

Apparatus: You will need the spherometer, a piece of flat glass, the large lens, a caliper, a meter stick, the optics bench with accessories

Theory: See **Thin Lens Experiment** from PHYS222 for theory.

There is no formal write up necessary for this lab, just fill in the blanks as you go and answer the questions at the end of the write-up.

Procedure:

I. **The Lens-Makers Formula**

In this section you will estimate the power of a lens using the thin lens version of the lens-makers formula

You will begin by measuring the radius of curvature of each surface of the lens with a spherometer, as pictured below

First put the spherometer on a flat glass surface and adjust the screw so the central point is just touching the glass. Measure the distance from the central point to one of the legs with a caliper.

Now put the spherometer on the lens surface and find the sagitta (labeled 'a' in the figure below).

Apply the formula $R = \left(\frac{a^2 + b^2}{2a}\right)$

Where a is the measured sagitta, and b is the distance from the center point to one leg

Using formula above and the radius of curvature for each surface (where applicable)

a=________

b=________

R1 = _____________ R2 = (for your lens =infinity. Why?)

Now apply the lens-makers formula in the form

$$P = (n_{lens} - n_{air})\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Remember to assign the correct sign to each radius, positive if it is convex as viewed from the direction that the light is incident. For n_{lens} you will need to estimate. The index for glass runs from 1.5 to 1.7 depending on the glass. Take 1.6 as a crude estimate.

Give a value for the power of the lens and estimate how uncertain this value is due to the uncertainty in the index of refraction of the glass. See question 3 below.

P = ______________ +/- ______________

II. Finding the Focal Length

Take the lens for which you found the power in part I. Take it to a window along with a meter stick and a white sheet of paper. Using the lens, project an image of a distant object on the white paper and adjust the distance between the lens and the paper until the image is in focus. Make a crude measurement of the distance from the lens to the paper. That is your focal length f.

f = _________________

The power of the lens ought to be related to the focal length by

$$P = 1/f$$

Does this result fall within you range calculated in part I?

P = 1/f = ________________ . Within uncertainty?

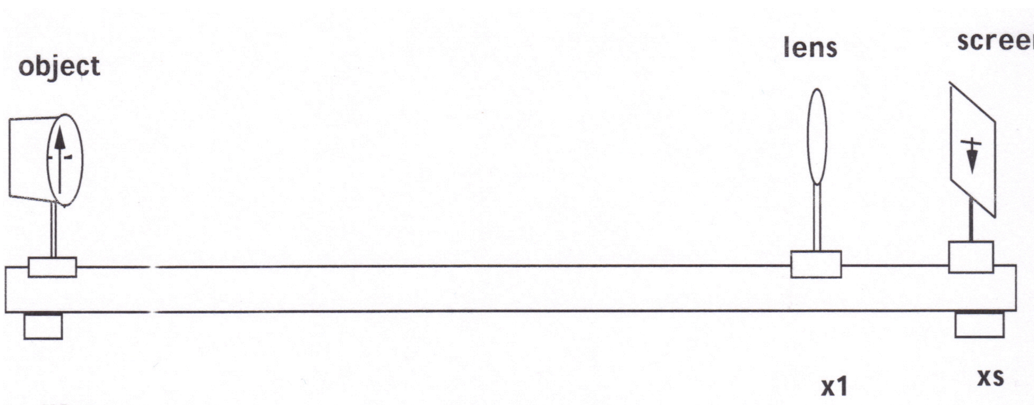
III. Finding f via thin lens equation

In this section you will determine the focal length of a lens by a method using an equivalent to the thin lens equation:

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

IV Conjugate Foci Method

Place the object lamp on the optical bench along with lens #1 provided and the screen in relative positions about as shown in the figure. The object lamp should be at one extreme end and the screen at the other.



Adjust the position of the lens until there is a small in-focus image visible on the screen. The optical bench has rulings on the side from which you can determine the positions x_0, x_1, x_s of the object, the lens and the screen. Estimate the uncertainty in x_1 by finding the smallest range of values that you feel sure contains the location of the lens for the best focus. “fuzzy-clear-fuzzy”.

X_0 = ____________

X_1 = ____________ +/- __________

X_s = ____________

Without moving the object or the screen, move the lens to a position as indicated in the figure below. Find the location x_2 at which the lens must be placed in order to see a larger in-focus image at the screen. Find an estimate for the uncertainty on x_2 as well.

X_2 = ___________ +/- ____________

The value of the focal length is to be found via the equation :

$$f = \frac{L^2 - d^2}{4L}$$

Where L is the distance from the object plane to the screen and d is the distance that the lens was moved. i.e.

$$L = |x_s - x_0|$$
$$\delta d = |x_2 - x_1|$$

We will also find the uncertainty on the focal length due to the uncertainty in the measurements using:

$$\delta f = \left|\frac{\delta f}{\delta d}\right| \delta d$$

$$\delta d = \sqrt{\delta x_1{}^2 + \delta x_2{}^2}$$

Where δx_1 and δx_2 are the uncertainties you put for the values of x1 and x2 respectively.

V Determination of 'f' for a Diverging Lens

In this part of the experiment a real image will be used as a virtual object. *Before starting steps below explore the behavior of a negative lens by looking at an object from various distances. Note what you observe. Does image ever go out of focus. Is it is always upright?*

Place the light box at some position O. Form an image of the light box on the screen with the converging lens. **Record this image position as I.** *This image will serve as a virtual object for the next part of the experiment.* See figure below.

Next, place the diverging lens in the system at **some point between convex lens and the location where image I was formed on screen.** (See figure 27-3.) While keeping the diverging lens stationary, form a clear image on the screen by moving it **away** from the lenses to **a new position** I' **.**

Ray diagram

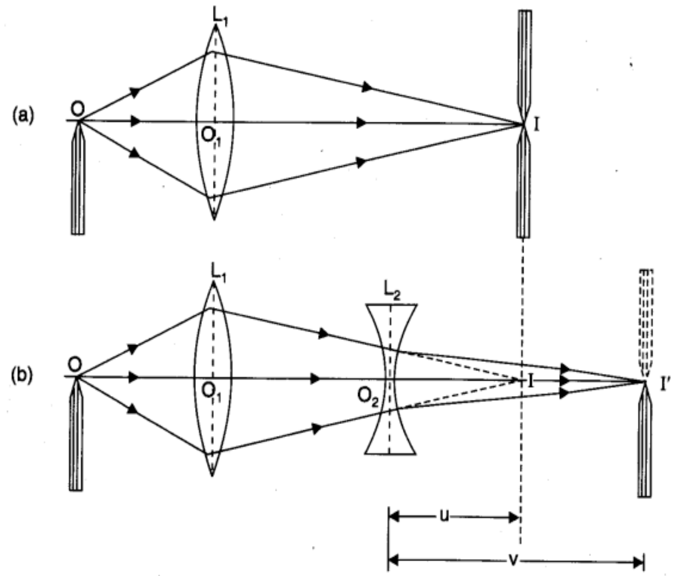


Fig. Focal length of a concave lens.

The distance from the **concave lens** to the new screen position **(**at I') is the ***image distance*** s' **.**

The distance from the **concave lens** to position of the **first image formed** (at position I) is the (virtual) **object distance** s . See figure 27-3.

Calculate the focal length of the diverging lens. **Please note that s is a negative value.**

Move the lens arrangement, repeat three times and calculate the average

Questions: (SHOW ALL CACULATIONS)

1) Considering uncertainty, both the Lens Equation and Conjugate foci methods should yield the same focal length. Was this the case for your results? Explain.

2) The conjugate foci method should yield a more precise result than the lens equation (i.e., the uncertainty of Conjugate Foci method should be smaller). See next page.

Examining the uncertainty relationships from the 222 website explain why this is the case. Did your results confirm this supposition?

3) Show the calculations for the uncertainty of the power of the lens in part two of procedure. (Use handout from lab- **Uncertainty Of Lens Makers Equation**).

4) Complete the table below taken from PHYS222 Thin Lenses experiment

PHYS222
Uncertainty Notes for The Thin Lenses Experiment

The uncertainty for the **Lens Equation** (i.e., $\frac{1}{f}=\frac{1}{p}+\frac{1}{q}$) is given by the relationship

$$\delta f = f\sqrt{\left(\frac{q}{p(p+q)}\delta p\right)^2+\left(\frac{p}{q(p+q)}\delta q\right)^2}$$

where δp and δq are the uncertainties in object and image distances respectively.

We can assume that the uncertainty in object distance δp (i.e., the distance from the lens to the object or light source) is small compared to the uncertainty of the image distance δq (i.e., the distance from the lens to the image). This is a good approximation if we fix both the light source (i.e., the object) and lens and **vary only the image while focusing.**

This yields an object uncertainty δq of approximately $\sqrt{\left(\frac{1}{2}mm\right)^2+\left(\frac{1}{2}mm\right)^2}=\sqrt{2}\frac{1}{2}mm$ which we can ignore.

Thus we can use the following approximation for the uncertainty of the lens equation

$$\boxed{\delta f \approx f\left(\frac{p}{q(p+q)}\delta q\right)} \qquad \text{Eq-1)}$$

where $\delta q = \frac{fuzzy_1 - fuzzy_2}{2} = \frac{\Delta fuzzy}{2}$.

Since we make 5 measurements we will use the average of the 5 uncertainties in our final result to go along with the average of the 5 focal lengths. See table below for δq.

The **uncertainty for the conjugate foci equation** (i.e., $f=\frac{L^2-d^2}{4L}$) is given by

$$\delta f = f\sqrt{\left[\left(\frac{L^2+d^2}{(L^2-d^2)L}\delta L\right)^2+\left(\frac{2d}{L^2-d^2}\delta d\right)^2\right]}$$

For the same reasons given above we can ignore the uncertainty between light and screen (i.e., $\delta L \approx 0$) and use

$$\boxed{\delta f = f\left(\frac{2d}{L^2-d^2}\delta d\right)} \qquad \text{Eq-2)}$$

where $\delta d = \sqrt{\left[\frac{\Delta Fuzzy_{left}}{2}\right]^2+\left[\frac{\Delta Fuzzy_{right}}{2}\right]^2}$

DATA TABLE for LENS EQUATION ONLY

Note that focal length from part one (i.e., the distance object method) is denoted by f_{dist_obj}

Trial	Lens location *on optics bench* *[This column is simply to tell you where to place lens in next column]*	**object distance p** [Lens distance from light source] **(cm)**	Screen (**image**) location *on optical bench* **[fuzzy$_1$/clear/fuzzy$_2$** measurements] **(cm)**	**Image distance q** *[distance of image from lens]* **(cm)**	focal length (cm)	δq [$^{\Delta fuzzy}/_2$] (cm)	δf (cm)
1	7 x f_{dist_obj} =						
2	6 x f_{dist_obj} =						
3	4 x f_{dist_obj} =						
4	2 x f_{dist_obj} =						
5	1.75 x f_{dist_obj} =						
Example f_{dist_obj} = **19.6 cm**)	8 x 19.6cm = 156.7cm **Use 160cm**	160 cm	182.6cm/183.4/183.9 183.9cm-182.6cm = 1.1cm	183.4cm – 160 cm= **23.4** cm	(using lens eq) **20.4 cm**	(2.3cm-1.1cm)/2= 0.65cm **use 0.7**	Using Equation 2 from above $\delta f = \pm 0.5$