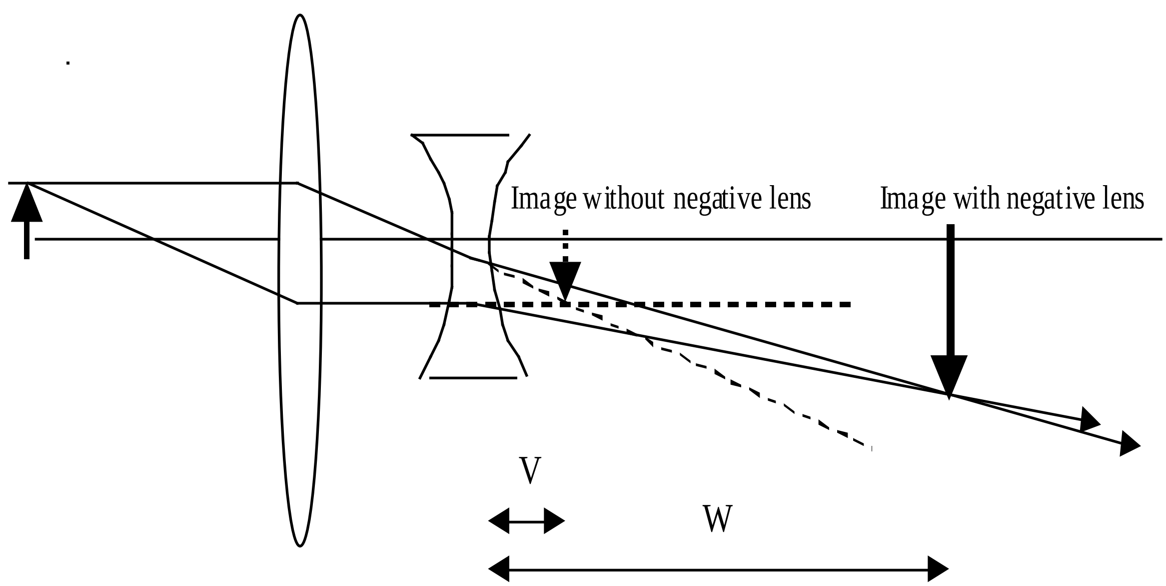
Physics 319
Lab Exercise
Optical Systems

Part 1: Preliminary

Measure the focal length of the negative lens provided using the following technique. Put the object and any positive lens of about 20 cm focal length on the optical bench. Put a screen on the bench and adjust its position for an in focus image. Now place the negative lens on the bench on the near side of the screen, and measure the distance from the negative lens to the screen. This value is labeled V in the figure below. Now move the screen to find the image location with the negative lens present. Again measure the distance from the lens to the screen. This distance is labeled W in the figure.



The focal length can then be calculated via the relation:

$$f = \frac{VW}{V - W} =$$

Part 2: Focal length and magnification

When a distant object is imaged onto a photographic emulsion with a single lens, it is easily shown that the magnificationdepends linearly on the focal length of the lens.

The magnification is defined as:

$$M_T = -\frac{S'}{S}$$

where y' is the image height, y is the object height. The thin lens equation implies that:

$$1 + PS = \frac{S}{S'}$$

For an object at large enough distance the second term on the left is much larger than unity and this implies that the magnification is simply:

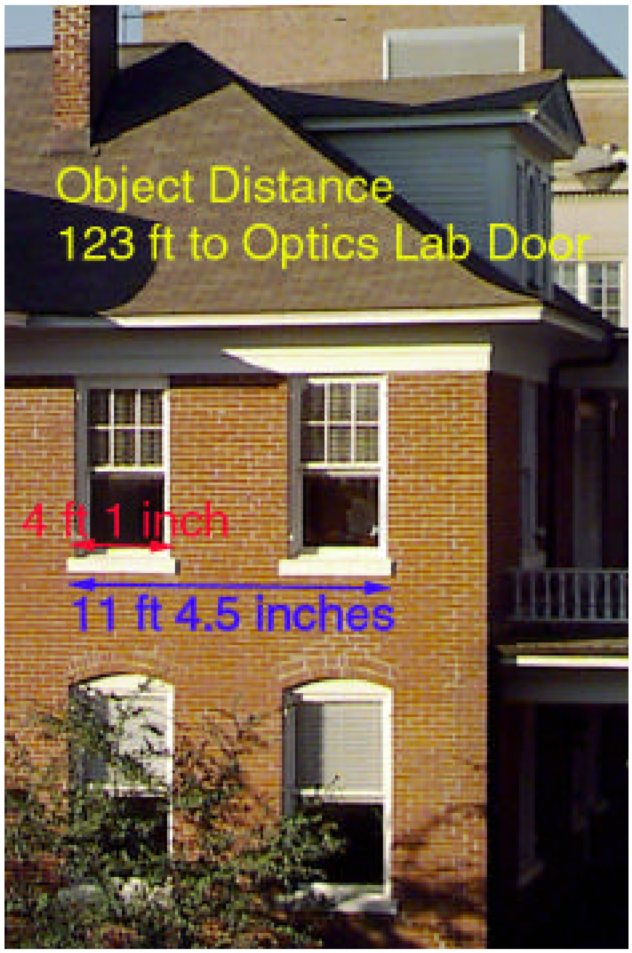
$$M_T = \frac{f}{S}$$

where:

$$f = \frac{1}{P}$$

Procedure:

Align the optical bench so that you will be able to view the Faculty House across from Lewis Hall. The picture below will identify some dimensions that you may use in calculating magnification for images in this exercise.



Put lens #1 on the optical bench and place the screen at about one focal length behind the lens. Adjust its position until you bring the image of Faculty House into focus. Measure y', the height of the image, and the distance, l' from the lens to the screen.

Repeat this for lens #4, then verify that:

$$\frac{M_1}{M_4} = \frac{f_1}{f_4} = \frac{k_1'}{k_4'}$$

For a single lens, it is obvious that a large magnification requires an elongated camera.

Part 3: Telephoto lens system

A telephoto lens system is intended solve the problem of obtaining large magnification in a compact package, it reduces the required distance from the front lens to the film for a given magnification.

A simple telephoto system can be contrived out of two lenses, one positive and one negative. As we have seen the system matrix for a system of two thin lenses of power P_1 and P_2 separated by a distance d_{12} is given by:

$$= \begin{bmatrix} 1 - P_1 d_{12} & d_{12} \\ -(P_1 + P_2 - P_1 P_2 d_{12}) & 1 - P_2 d_{12} \end{bmatrix}$$

The equivalent power of the system is:

$$P_{eq} = -M(2,1)$$

We know for this system of thin lenses in air the nodal points coincide with the principal planes H_1 and H_2.. If a ray is directed toward plane H_1 at a point along the optical axis, that ray will emerge from the axis at plane H_2 going in the same direction as the incoming ray. The situation is pictured in the figure below.

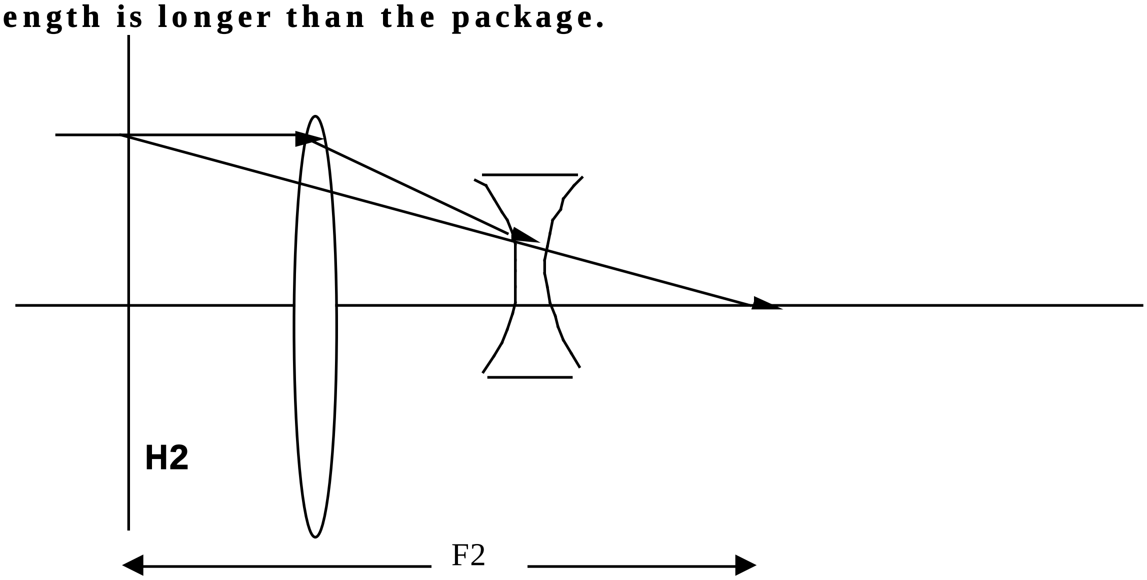
Consequently the magnification is given by:

$$\frac{1}{M_T} = 1 + P_{eq} S$$

as in the preceding section, but S is measured from H1. For an object at infinity:

$$M_T \approx \frac{f_{eq}}{S}$$

The telephoto system achieves its magnification in a compact package by pushing H_2 far to the left of the first lens. The focal length is longer than the package.



Procedure:

Put lens #1 on the optical bench. Put lens #2 on the bench behind lens #1 and the screen behind lens #2. Using the equation above calculate the distance d_{12} needed between the two lenses in order to achieve a value of P_{eq} which is the same as the power of lens #4. Move lens #2 to a position a distance d_{12} behind lens #1. Move the screen to find a focused image of the distant object and measure the image height. Verify that the telephoto system obtains the same magnification as lens #4. Compare the distance k' for the telephoto case and for lens #4.

Now try to verify the thin lens equation for the telephoto system and predict the magnification of the system. To do this put lens # 1 on the optical bench. Put lens #2 on the bench about 20 cm behind lens #1 and the screen behind lens #2.

Align and adjust the optical bench and components so that a virtual image of the object at infinity is in focus on the screen.

Now find the principal planes, they can be determined from the matrix elements. The distance r is the distance from the first lens to the principle plane H_1. It is positive if H_1 is to the right of the first lens. It can be found from the relation:

$$r = \frac{D-1}{C},$$

Find the location of H_1

r= **H_1=**

The distance s gives the distance from the back lens to H_2. It is negative if the plane H_2 is to the left of the last lens.

The distance s can be gotten from the relation:

$$s = \frac{1 - A}{C}$$

Find the location of H_2.

s = **H_2 =**

Use the thin lens equation:

$$\frac{1}{S} + P_{eq} = \frac{1}{S'}$$

to predict the location of the image and see if it agrees with the position of the screen. The object distance can be set to infinity if you like. Remember that the image distance is measured relative to H_2.

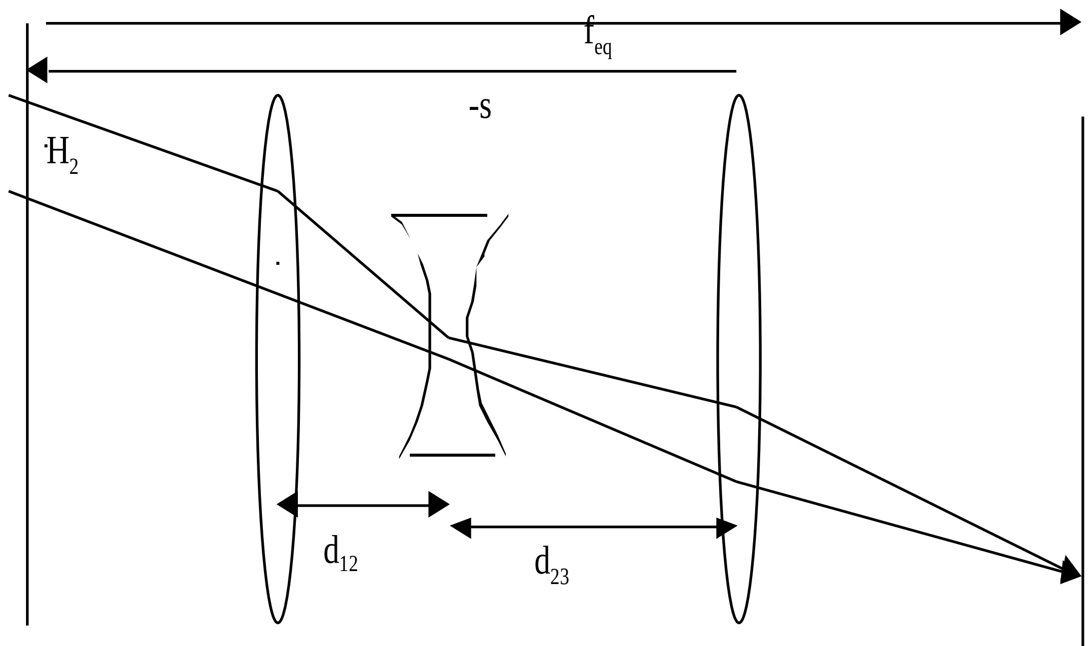
S' predicted: **S' measured:**

See whether the magnification of the telephoto system is in proportion to its focal length by checking whether:

$$\frac{h_i}{h_{i4}} = \frac{M_{tel}}{M_4} = \frac{f_{eq}}{f_4}$$

Part 4: Zoom Lens

A zoom lens keeps a constant package size while varying the focal length and consequently the magnification. We will mock up such a system using three thin lenses. We need to keep the front vertex of the first lens at a constant distance from the back focal plane where an in focus virtual image of a distant object will be cast on the screen.



The condition required can be imposed by keeping the distance from the front vertex to H2 plus the equivalent focal length constant, i.e.

$$d_1 + d_2 + s + f_{eq} = D_s$$

where D_s is the constant distance from the front vertex to the screen. Since

$$s + f_{eq} = \frac{1 - A}{C} - \frac{1}{C}$$

it follows that

$$D_s = d_1 + d_2 - \frac{A}{C}$$

In this section you will make a prediction of the magnification of the zoom lens as a function of the positions of the intermediate lenses and check it against results on the optical bench.

Procedure:

Put Lenses #1 and 4 on the optical bench with the negative lens you have previously used between them. Put a screen on the bench a distance D_s = 80 c.m. from the first lens, and adjust #4 and the negative lens until you get an in focus image on the screen.

Record the distances d_{12} (the distances between the first two lens) and d_{23} (between the second and third lenses) as well as the image size. Repeat this for at least six total locations of the lenses.

d_{12}	d_{23}	hi
______________	______________	______________
______________	______________	______________
______________	______________	______________
______________	______________	______________
______________	______________	______________
______________	______________	______________

To make your prediction of the magnification, follow these steps. (If you get stuck there is an example in the lab manual, but try it on your own first.)

1) **Set up a system matrix for the three lens system in Maple V. Leave the values d_{12} (the distances between the first two lens) and d_{23} (between the second and third lenses) variable. Don't forget to start the worksheet with :**

   with(linalg);

2) **Solve the D_s equation above for d_{23} as a function of d_{12}.**

Remember:

$$D_s = .8$$
$$A = M(1,1)$$
$$C = M(2,1)$$

   and use the solve function. It is well documented in the help files.

3) **Substitute the resulting expression for d_{23} into an appropriate expression for M_T to obtain an expression for M_T as a function of d_{12} only.**

4) **Plot d_{23} and M_T as functions of d_{12} using the plot function (as documented in the help files). You will need to put the line**

with(plots);

into your worksheet.

Plot your measured values for d_{23} as a function of d_{12} on top of the plot in the worksheet. Do they match reasonably well? Then plot the actual magnification as a function of d_{12} on top of the worksheet plot. Do they match?