$M = \frac{h'}{h}$

Real - Screen
virtual - through

$\frac{1}{f} = \frac{1}{D_o} \pm \frac{1}{D_{image}}$

Experiment 10.1
Lenses

Purpose

Determine the focal length of a thin lens and study the image characters.

Equipment

Optics bench (OS-8518), light source (OS-8517) with power supply, converging lens (f = 20cm), screen, ruler (15 cm), reading light.

Theory

A lens of the type shown in Fig. 1 has the property that when a beam of parallel rays passes through the lens (i.e., the object distance $s = \infty$), the rays converge to a point F_2 (i.e., the image distance $s' = f$), (Fig. 1a), and form a real image at that point. Such a lens is called converging lens. Similarly, rays passing through point F_1 ($s = f$) emerge from the lens as a beam of parallel rays ($s' = \infty$), (Fig. 1b). The points F_1 and F_2 are first and second focal points respectively. The value of the focal length (f) of converging lens is positive.

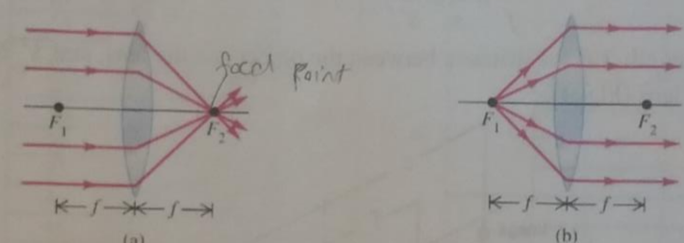

Figure 1 The first and second focal points of a converging thin lens. The numerical value of f is positive.

Fig. 2 shows a diverging lens. The beam of parallel rays ($s = \infty$) incident on this lens diverges after refraction (Fig. 2a) and appears to come from the second focal point F_2 which is to the left of the lens, while incident rays converging toward the first focal point F_1 emerge parallel ($s' = \infty$) to the axis, as shown in Fig. 2b. The value of the focal length (f) of diverging lens is negative.

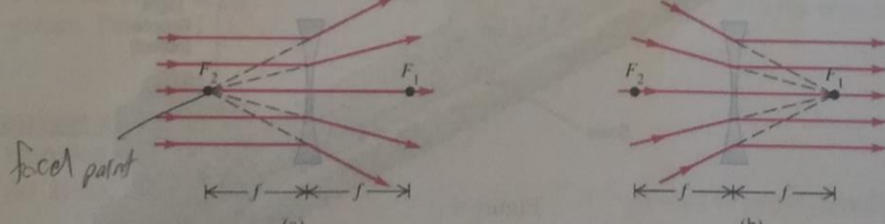

Figure 2 The first and second focal points of a diverging thin lens. The numerical value of f is negative.

The image character, size and position can also be determined by a graphical method called a principal-ray diagram. The rays used in such a diagram shown in Fig. 3 are:

(1) Parallel ray --- a ray parallel to the axis emerges from the lens in a direction that passes through the second focal point F_2 of a converging lens, or appears to come from the second focal point F_2 of a diverging lens;
(2) Central ray --- a ray through the center of the lens is not deviated;
(3) Focal ray --- a ray through first focal point F_1 emerges parallel to the axis.

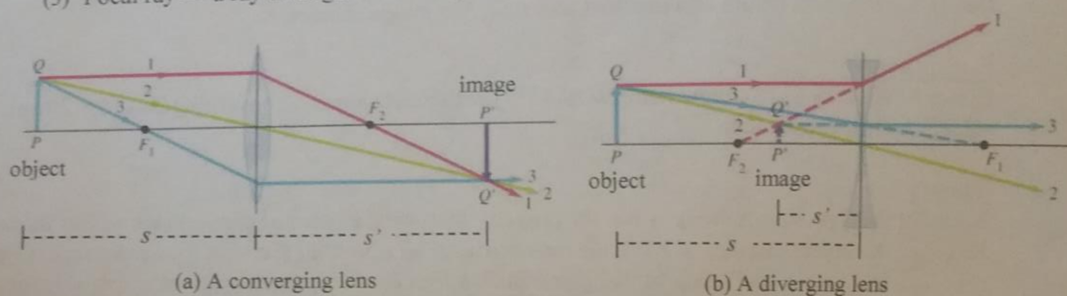

Figure 3 Principal-ray diagrams showing the graphical method of locating an image formed by a thin lens.

For a thin lens:

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}, \quad (1)$$

where f is focal length, s is the distance between the object and the lens, and s' is the distance between the image and the lens (Fig. 4).

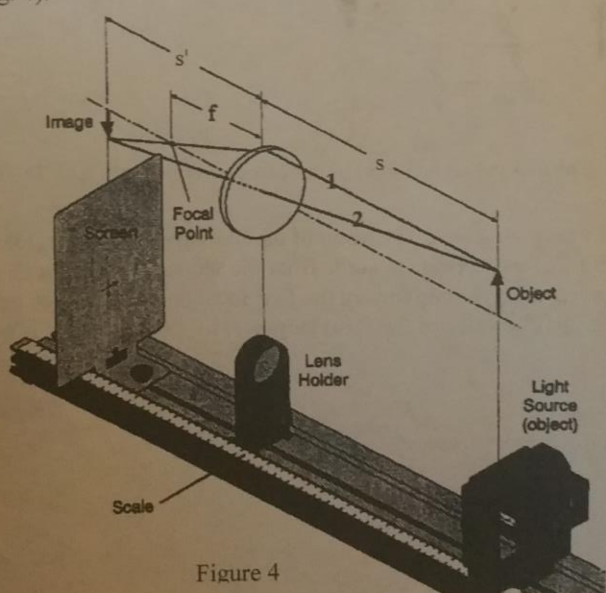

Figure 4

The magnification of a thin lens:

$$m = \frac{h'}{h} = -\frac{s'}{s}, \quad (2)$$

where h' and h are the sizes of the image and the object respectively.

GE

Measurement: measure the focal length by plotting $1/s$ vs $1/s'$ (both s and s' vary)

Place the light source at -1 cm on the optics bench. The cross attached to the light source is used as an object. Turn on the light source and turn off the room light.

The unit of length is cm for all measured quantities: s, s', h, h' and f.

1. Measure and record the size of the object (h) using a ruler.
2. Place the lens to the position as indicated in the Data Table, move the screen until a clear image is on the screen. Measure and record the image position on the optics bench.
3. Measure and record the size of the image (h'). Calculate the magnification $m = h'/h$.
4. Calculate s, s', $1/s$ and $1/s'$.
5. Move the lens to the next position as indicated in the Data Table, repeat the steps 2, 3 and 4.
6. Plot $1/s$ vs $1/s'$ using the data in Table 1 and fit it with a straight line, the intercept gives $1/f$.

Table 1

Object (light source)		Lens	Image					Calculation				f value	
Size (h)	Position on the bench	Position on the bench	Position on the bench	Size (h')	Erect or invert	Real or virtual	$m = h'/h$	s	$1/s$	s'	$1/s'$	fitting result	from manu-facturer
4cm	-1	24	111 cm	14.5 cm	invert	real							20 cm
		25	100 cm	12 cm									
		26	94 cm	10.5 cm									
		28	86 cm	8.4 cm									
		30	81 cm	6.8 cm									
		32	78.5 cm	5.9 cm									
		35	77 cm	4.9 cm									
		40	76.5 cm	3.6 cm									
		45	78.3 cm	3 cm									
		50	80.9 cm	2.5 cm									
		55	84.2 cm	2.1 cm									
		60	88.1 cm	1.8 cm									
		65	92.2 cm	1.7 cm									

Observation:

Place the object at -1 cm and the screen at 112 cm, move the lens until the clear image is on the screen. Position 1: 23.8. Position 2: 87.5

Questions and exercises

1. Question on the measurement

(a) Is the image enlarged or reduced when $s > 2f$? Is the image enlarged or reduced when $s < 2f$?

(b) Is the image erect or inverted? Is the image real or virtual? Why?

2. Question on the observation:
Explain why, for a fixed separation between the object and the screen (i.e., $s + s'$ is fixed), there are two positions of the lens at which the images formed on the screen are in focus (clear images).

3. Exercise
A lens forms an image of an object. The object is 16 cm from the lens. The image is 12 cm from the lens on the same side as the object. (a) What is the focal length of the lens? Is the lens converging or diverging? (b) If the object is 8.5 mm tall, how tall is the image? Is it erect or inverted? (c) Draw a principle-ray diagram.

Experiment 10.2
Telescope

Purpose
Construct a telescope and determine the magnification.

Equipment
Optics bench (OS-8518), two converging lenses (f =10 cm, f =20 cm), screen (graphic paper), ruler (2 m),

Theory
Telescope is used to view large objects at large distances. An astronomical telescope is constructed with two converging lenses: an objective and an eyepiece. The objective lens forms a real reduced image of the object. This image is the object for the eyepiece lens. Objects that are viewed with a telescope are usually so far away from the instrument that the first image is formed very nearly at the second focal point of the objective lens. If the final image formed by the eyepiece is at infinity, the first image must also be at the first focal point of the eyepiece. The distance between objective and eyepiece is therefore the sum of the focal lengths of objective and eyepiece, i.e. $L = f_1 + f_2$ as shown in Fig. 1.

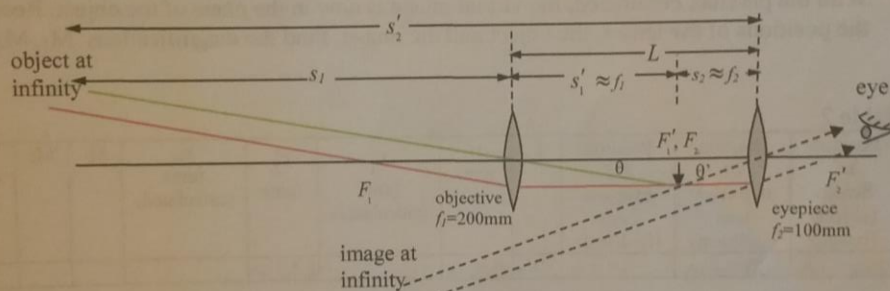

Figure 1

The magnification (M) of a two-lens system is equal to the multiplication of the magnifications of the individual lenses. For $s_1 \to \infty$ (or $s_1 >> L$), $s_1 \approx s_2'$,

$$M = M_1 M_2 = \left(\frac{-s_1'}{s_1}\right)\left(\frac{s_2'}{s_2}\right) \approx -\frac{f_1}{f_2} \qquad (1)$$

Procedure
1. Tape the graphic paper (screen) on the wall, the crosshatching on the screen acts as an object.
2. Place the two lenses on the optics bench as shown in Fig. 2.

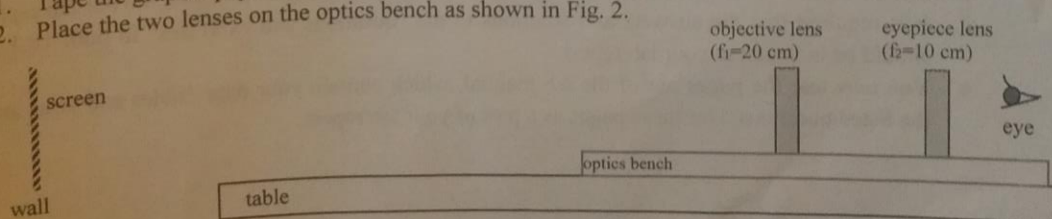

Figure 2

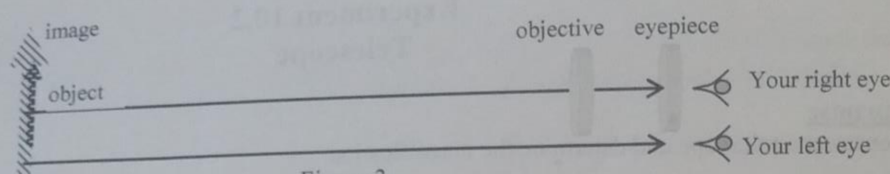

Figure 3

3. Look through the lens with one eye, adjust the position of eyepiece lens until the clear image of the object is on the wall.
4. Open both eyes and look through the lenses at the image with one eye while looking around the edge of the lenses directly at the object with the other eye. Move your head back-and-forth or up-and-down. As you move your head, the image will move relative to the object due to the parallax. To eliminate the parallax, move the eyepiece lens until the image does not move relative to the object when you move your head. Once there is no parallax, the image appears to be stuck to the object (Fig. 3).
   Note: Even there is no parallax, the image may appear to move near the edges of the lens because of lens aberrations.
5. With the parallax eliminated, the virtual image is now in the plane of the object. Record and calculate the positions of the lenses, the object and the image. Find the magnifications M_1, M_2 and M.

$$\frac{1}{F} = \frac{1}{D_o} + \frac{1}{D_i}$$

Table 2

Position of Screen (object) (image)	Position of objective lens (f_1=20cm)	Position Of eyepiece Lens (f_2=10cm)	L	s_1 (cm)	s_1' (cm) (calculated)	s_2' (cm)	s_2 (cm) (calculated)	M_1	M_2	M (M_1M_2)	Invert or erect?
596 cm	37 cm	10 cm	27cm	596 cm		623cm					

Work to be done:

1. Check that all light sources used in this lab are off. All items used in this lab are placed properly.
2. Let your TA check your data Tables. If they are OK, your TA will sign them.
3. Clean up your bench.

Lab report on Experiments 10.1 and 10.2

1. Your lab report should be in the required format described in the "Introduction" of the lab manual.
2. Tables 1 and 2 as well as the plot and fitting curve in 10.1 should be included in your lab report.
3. It is required that the answers and solutions to the "questions and exercises" in both 10.1 and 10.2 should be included in your lab report.
4. You may tear the pages out of the lab manual, which contain your data Tables and your answers to the listed questions. Use these pages as a part of your lab report.

Questions and Exercises

1. Hold the optics bench by your hand, look at the tree outside window using your telescope. Is the image of the tree erect or inverted? Is the image of the tree enlarged or reduced?

2. The world's largest refracting telescope is at the Yerkes Observatory of the University of Chicago at Williams Bay, Wisconsin. The objective has a diameter of 102 cm and a focal length of 19.5 m. The focal length of the eyepiece is 10 cm. What is its magnification (or magnifying power)?