Experiment No. 13
Lenses

Objective:

(a) To determine the focal length of a convex lens by plane mirror method.

(b) To determine the focal length of a convex lens and the focal length of a concave lens by conjugate foci method.

Apparatus:

An optical bench, 2 convex lenses, a concave lens, a plane mirror, object and image pins, light source and ground glass screen.

Theory:

A lens (Figs. 13-1 and 13-2) consists of a refracting medium bounded by two spherical surfaces. A lens has two principal foci (F_1 and F_2). The line passing through F_1 and F_2 is known as the principal axis of the lens. Point O is called the optical center of the lens. The following rules define the optical center O, and, the two principal foci F_1 and F_2:

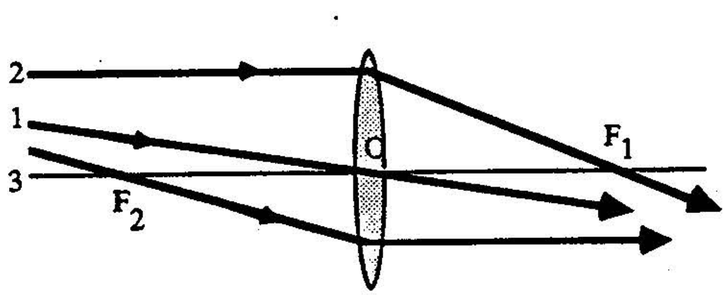

Fig. 13-1

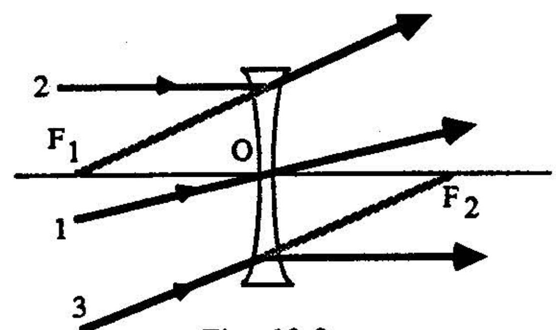

Fig. 13-2

(1) An incident ray of light passing through the optical center is not deviated. (See rays marked 1 in the above figures.)

(2) If an incident ray is parallel to the principal axis (rays marked 2 in the above figures), then the refracted ray passes through the first principal focus F_1 (as in Fig. 13-1) or appears to come from the first principal focus F_1 (as in Fig. 13-2).

(3) If an incident ray passes through the second principal focus F_2 (as in Fig. 13-1) or is directed towards the second principal focus F_2 (as in Fig. 13-2), the refracted is parallel to the principal axis. (See rays marked 3 in Figs. 13-1 and 13-2.)

The above rules are used to draw ray diagrams and to locate the positions of images as shown in Figs. 13-3 and 13-4.

Focal length: The distance of the first principal focus from the optical center (which is also numerically equal to the distance of the second principal focus from the optical center) is defined as the focal length (f) of the lens. The focal length f is positive for a convex (converging) lens and it is negative for a concave (diverging) lens.

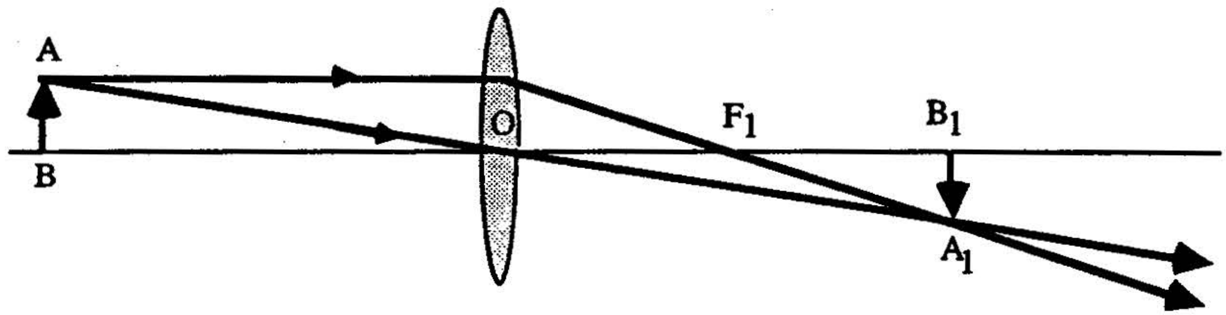

Fig. 13-3

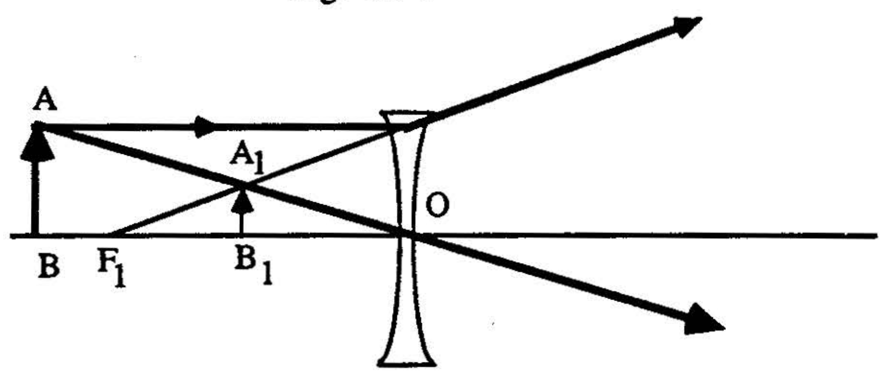

Fig. 13-4

In Fig. 13-3, the rays starting from the point A (of the object AB) pass through the point A_1 after refraction through the lens. Thus the image A_1 which is formed by the actual intersection of the refracted rays, is the real image of the point A. Similarly, B_1 is the real image of point B.

In Fig. 13-4, the rays starting from the point A (of the object AB) appear to come from the point A_1 after refraction through the lens. Thus the image A_1 which is not formed by the actual intersection of the refracted rays, is the virtual image of the point A. Similarly, B_1 is the virtual image of point B.

The path of a ray is reversible. Thus if a real object is placed at B_1 (Fig. 13-3) a real image is obtained at B. Thus B and B_1 are known as conjugate foci. Similarly, if in Fig. 13-4, a virtual object is placed at B_1, a real image will be formed at B. Thus B and B_1 are conjugate foci.

The distance BO is known as the object distance (p) and the distance O B_1 is known as the image distance (q).

Convention of signs:

The distances which are actually traversed by the rays are taken to be positive and those which are not actually traversed by the rays are taken to be negative. Thus the focal length of a convex lens (in Fig. 13-1) and the object distances in Figs. 13-3 and 13-4 which are actually traversed by light rays are positive. The image distance (q) in Fig. 13-3 is also positive because the rays actually travel from the lens to the image A_1B_1. The focal length of the concave lens (Fig. 13-2) is negative and the image distance (q) in Fig. 13-4 is negative because the rays appear to come from the virtual image A_1B_1.

The relationship between the object distance (p), the image distance (q) and the focal length (f) is

$$1/p + 1/q = 1/f. \qquad (1)$$

This formula is used to find the focal length (f) by the conjugate foci method.

The magnification (m) is defined by

$$m = (\text{size of image})/(\text{size of object}) = -q/p. \qquad (2)$$

If two lenses of focal lengths f_1 and f_2 are placed in contact, the focal length of the combination (f) is given by

$$1/f = 1/f_1 + 1/f_2. \qquad (3)$$

Plane mirror method of determining the focal length of a convex lens:

This method is especially suitable for determining the focal length of a convex lens of large focal length. If an object AB (Fig. 13-5) is placed in the focal plane of the convex lens such that the point A is at the principal focus, then all the rays starting from A will become parallel to the principal focus after refraction through the convex lens.

This beam of parallel rays is incident normally on the plane mirror M and thus it is reflected back along its own path. The reflected beam is parallel to the principal axis of the lens and thus it is brought to a focus at the principal focus of the lens (point A). Thus the image of AB is formed at A'B' such that the point A' of the image coincides with the point A of the object.

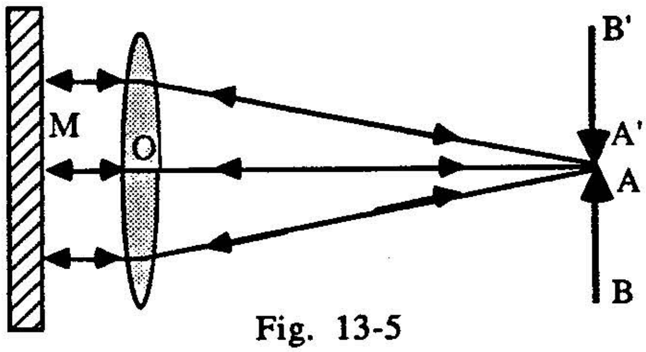

Fig. 13-5

The method of no parallax is adopted to locate the position of images. Parallax is the relative motion observed between two objects (or between an object and an image) which are not situated at the same point, due to the motion of the observer. For example, consider the image A_1 (Fig. 13-6). If the image pin is placed at A_2' (or A_3'), points A_1 and A_2' (or A_1 and A_3') will appear to move relative to each other when the observer moves sideways. Thus parallax will be observed between A_1 and A_2' (and, A_1 and A_3'). However, if the tip of the image pin is at A_1' (coinciding with A_1), there no parallax will be observed between A_1 and A_1'.

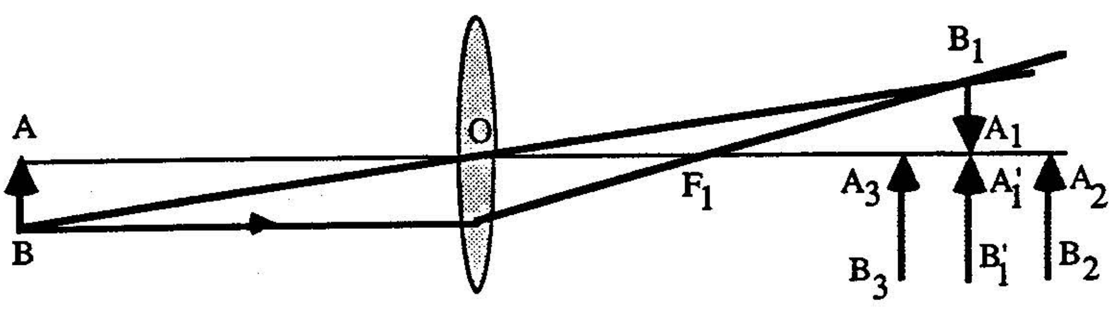

Fig. 13-6

Conjugate foci method of determining the focal length of a convex lens:

In Fig. 13-6, AB is an object whose image is A_1B_1. Thus points A and A_1 are the conjugate foci. Further, in Fig. 13-6, the image A_1B_1 is real. Thus the method of no parallax can be employed for determining the object distance (p) and the image distance (q). Then the focal length f can be calculated from Eq. (1). Alternatively, a well-defined image of a source of light (placed at AB) can be obtained on a ground glass screen (placed at $A_1'B_1'$). Thus the object and image distances can be measured.

Conjugate foci method of determining the focal length of a concave lens:

The image of a real object in a concave (diverging) lens is always virtual. Thus its focal length can not be determined by the methods adopted for determining the focal length of convex lenses described above. However, the image of a virtual object formed by a concave lens is real. Therefore, the focal length of a concave lens can be determined by the method described below (Fig. 13-7)

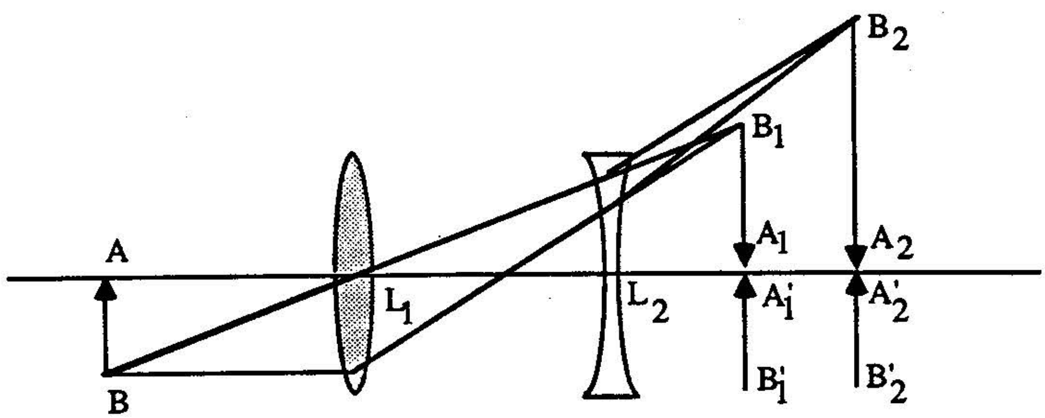

Fig. 13-7

The real image of the object AB is formed by the convex lens L_1 at A_1B_1. This image is located by the image pin $A_1'B_1'$. Alternatively, a light source can be placed at AB and its real image can be obtained by placing a screen at A_1. Now let a concave lens L_2 be placed between the convex lens L_1 and the image A_1B_1. In such a case, the real image A_1B_1 (of the object AB formed by the convex lens L_1) serves as a virtual object for refraction through the concave lens L_2. This is because the rays refracted by lens L_1 pass through lens L_2 before they actually meet at the real image A_1B_1. The concave lens forms a real image A_2B_2 of the virtual object A_1B_1. This real image can be located by the method of no parallax by using the image pin $A_2'B_2'$ or the image can be located by using a light source (placed at AB) and a screen (placed at A_2B_2). Obviously, for the concave lens L_2, the object distance (p) is the distance from O_2 to A_1, and the image distance (q) is the distance from O_2 to A_2. Thus the focal length of the concave lens can be calculated from Eq. (1).

There is another way of looking at the situation depicted in Fig. 13-7. Let an object pin be placed at $A_2'B_2'$. The concave lens L_2 produces a virtual image $A_1'B_1'$ of this object $A_2'B_2'$. This virtual image serves as a real object for refraction through the convex lens L_1 and thus a real image is formed by the convex lens at A'B'.

Procedure:

Unit 1. Determination of the focal length of a convex lens by plane mirror method:

(a) Mount the plane mirror, a convex lens and a pin on the optical bench as shown in Fig. 13-5. Rotate the plane of the mirror so as to have the tip of the pin, the tip of the image and the optical center of the lens in a straight line.

(b) Adjust the position of the pin along the optical bench and remove the parallax between the tip of the pin and the tip of the image.

(c) Record the position of the lens and the position of the pin.

(d) Repeat steps (a), (b) and (c) twice.

Units 2 & 3. Determination of the focal length of a convex lens and the focal length of a concave lens by the conjugate foci method:

(e) Mount the light source S (Fig. 13-8) near one end of the optical bench. Mount the convex lens L_1 such that the object distance SL_1 lies between f_1 and $2f_1$, where f_1 is the approximate focal length of the convex lens. Mount the screen G_1 as shown in Fig. 13-8. Adjust the position of the screen (and of the lens, if necessary) to obtain a sharp image of the light source on the screen.

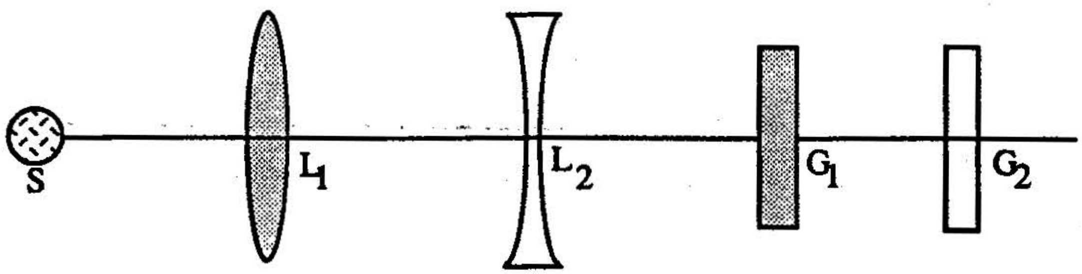

Fig. 13-8

(f) Record the positions of the lens L_1, of the light source S and of the screen G_1. The distance between S and L_1 is the object distance (p_1) and the distance between L_1 and G_1 is the image distance (q_1) for the convex lens.

(g) Keep the positions of the source and convex lens L_1 fixed in the following steps.

(h) Now mount the concave lens L_2 between the convex lens L_1 and the screen G_1. Move the screen to position G_2 so as to obtain a sharp image of the light source S on the screen. Thus the image of the light source is formed at G_2 by the two lenses L_1 and L_2.

(i) Note that for the concave lens L_2, the image formed by the convex lens L_1 is the virtual object whose image is formed by the concave lens L_2 at the new position of the screen G_2. Thus for the concave lens, the distance between L_2 and G_1 is the object distance (p_2) and the distance between L_2 and G_2 is the image distance (q_2).

(j) Record the positions of L_2 and G_2.

(k) Change the object distance for the convex lens by about 1.5 cm and repeat steps (e) through (j) twice.

York College of The City University of New York

Physics II   Name:

Experiment No. 13: Pre-Lab Questionnaire

1. In a converging lens, if an incident ray is parallel to the principal axis, the refracted ray ____

2. In a diverging lens, if an incident ray is parallel to the principal axis, the refracted ray ____

3. Can a real image be obtained by means of a diverging lens? If yes, how?

4. Draw a clearly labeled diagram showing the objects and images formed by a combination of a converging and diverging lenses.

Experiment No. 13

Name: Marks:

Partner: Remarks:

Section:

Date Submitted:

Title:

Objective:

Theory/Formulas:

DATA SHEET

Unit 1:

A. Focal length of a convex lens by plane mirror method:

No.	Position of		focal length f
	convex lens	pin	
1.			
2.			
3.			

Units 2 & 3:

B. Focal lengths of a convex lens and a concave lens by conjugate foci method:

No.	Position of				
	Light source S	Lens L_1	Screen G_1	Lens L_2	Screen G_2
1.					
2.					
3.					

No.	Convex lens			Concave lens		
	p_1	q_1	f_1	p_2	q_2	f_2
1.						
2.						
3.						

Questions:

1. Define focal length, object distance and image distance.

2. Distinguish between a real and a virtual image.

3. What is meant by parallax?

4. What is the convention of signs for f, p and q?

5. Is the object distance for L_2 in Fig. 7 positive or negative? Explain.