(For Counsellor's use only)

Grade . . . . Name . . . .

Evaluated by . . . . Enrolment Number . . . . .

EXPERIMENT 7

STUDY OF SOME PROPERTIES OF LENSES

Structure

7.1 INTRODUCTION

Most of you have handled a camera at one time or other. A most important part of a camera is its lens. It forms the image of the scene at the plane where a film is kept. The telescope, tbe microscope and reading lens are some optical instruments used in the laboratories. All of them use at least one lens. Therefore it is important that we learn the properties of lenses. A lens system is a combination of two or more lenses. We will learn about some of these combinations also.

Objectives:

After doing this experiment, you should be able to determine the focal length of a given convex lens by the following method :

* Distant object method .
* Image coincidence method
* U-V method
* Graphical method

(2) After doing this experiment you should be able to explain the relationship between lens focal length, lens diameter and brightness of an image.

(3) After doing this experiment you would be able to determine the focal length of a concave lens using another convex lens of known focal length.

(i) By contact method with a convex lens of known focal length.

(ii) By the method of "separation by a distance", using a convex lens.

7.2 APPARATUS

Two convex lenses of focal length about 15 cms
Two concave lenses of focal length 10 cms
Meter - scale
60 watts frosted incandescent bulb, holder and wires
Wire mesh
Lens holders
Plane-mirror
Screen
Stop

Note: Lens holders, if not available can be made conveniently and cheaply by cutting circular holes on 15 cm squares of "thermocole" material. The circular holes have a diameter slightly less than the diameter of the lens. A lens is kept sandwiched between two thermocole pieces and rubber bands can be used to press the two thermocoles together. To keep the lens mount sturdy, an aluminium T frame can be inserted at the bottom in between the two thermocoles, as shown in Fig.7.1.

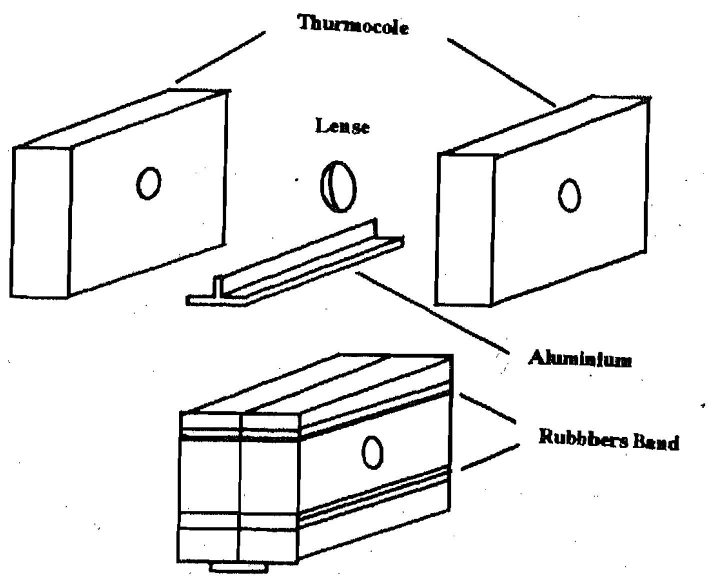

Fig 7.1

7.3 STUDY MATERIAL

7.3.1 Classification of Lenses

There are two classification of lenses :

(1) converging lens or positive lens and (2) diverging lens or negative lens.

A converging lens forms a real image on a plane in space. If a screen is placed at that plane, the image can be seen. For this reason the converging lens is also celled a positive lens.

A diverging lens cannot **form a real image.** It produces a virtual image, which cannot be **caught** on a screen. So diverging lens is also called a as negative lens.

7.3.2 Distinction between the Lenses

How to distinguish between converging lens and a diverging lens ?.

A converging lens is thick at the centre and is **thin at** the edge. **A** diverging lens is thin at the centre and thick at the edge. We can also distinguish them by their optical **properties.** When a lens is kept close to an object and viewed through the lens, if the object appears **enlarged,** it is a converging lens. If the object appears smaller, it is a **diverging lens.** If the thickness of the lens is neglected, a lens can be regarded as a thin lens. For a system **of lenses,** consisting of two or more lenses **seperated** by a distance this **approximation** is not valid.

A **lens** has two spherical surfaces. The straight **line joining** the centres **of curvature** of these surfaces is called the "optic axis" of the lens. The "optic **centre" of the lens** is the point of intersection of the straight line connecting the **diametrically** opposite points on the edge of the **lens** and the optic axis of the lens. For a thin lens, the optic centre is situated at the centre of the lens, as shown in **Fig.7.2.**

Focus and focal length: When a beam of parallel light rays, coming from the left, runs close to the optic axis of a converging lens, it converges to a fixed point on the other side of the lens, This point is called the "principal focus" or simply the "focus" of the lens. The **focal** length is positive for a converging lens. This focus is called the second (image side) focus. When a beam of parallel 'light rays coming from the **right** runs close to the principal axis of a converging lens, it converges to a fixed point on the other side of the lens. **This** focus is called the **first** (object side) focus of the lens.

When a beam of parallel light rays coming from the left runs close to the optic axis of a diverging lens, it appears to diverge **from a** fixed point on the same side of the lens. **This point** is called the second (image side) focus of the lens. When a beam of parallel light **rays** coming **from** the right runs close to the optic axis of a diverging lens, it **appears** to diverge from a point on **the** same side of the lens. This point is called the first (object side) focus of the lens. **The** focal length of a converging lens is assigned a **positive** sign and that of a diverging lens, negative. This is known as the. sign convention to distinguish the lenses. See **fig.7.2.** below.

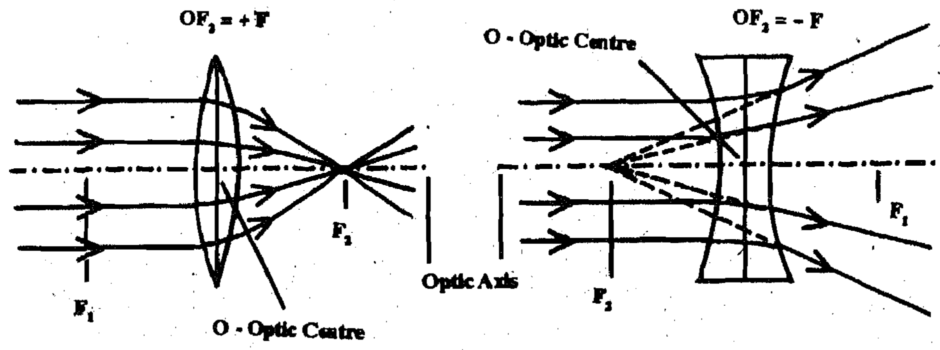

Fig.7.2

7.4 PRECAUTIONS

Lenses should not be kept on rough surfaces like the table. A lens should be handled by the edge of the lens with fingers only. When lenses are not used, they should be put in their enclosures so that dust does not gather on the surface of the lens. Lenses should be mounted vertically and at a proper height from the sources.

7.5 EXPERIMENTS

7.5.1 Image Concidence Method

Illuminate the wire mesh with the frosted bulb. Cover the bulb with a card board to stop the unwanted light. Use this illuminated wire mesh as the object 'O' in the experiments to follow. Place this object in front of the convex lens and a plane mirror at the back of the lens as shown below:

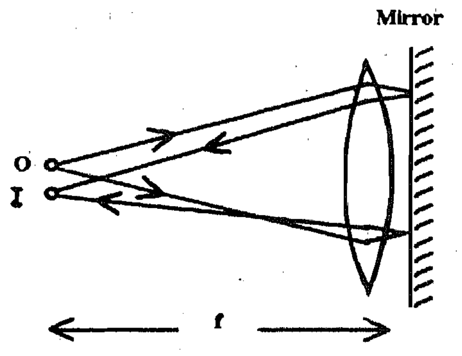

Fig 7.3

If you adjust the position of the object, the image 'I' the object is seen by the side of the object on the same plane. The light incident normally on the mirror is reflected back and rays retrace their path. When the object is at the front focal plane, the light after refraction from the lens becomes parallel and, incident normally on the plane mirror which reflects it. So the rays nearly retrace their paths and an image is formed on the same side of the object. Measure the distance between the object and the centre of the lens. This distance is the focal length of the covex lens. Repeat the experiment by removing the mirror and again replacing it. Locate the positionof a clear image by the side of the object. Repeat for a total of 5 trials.Tabulate your observations in Table 1. Do the experiment with another lens.

TABLE 1. : Focal Length

	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Calculate the average of each set of measurements. For each set of measurements estimate the measument error, by methods you know already. Enter values in the Table 1.

7.5.2 *U-V* Method

The first method-give an estimate of the focal length of the converging lens. In the *u-v* **method** you measure the object and image distances from the lens **many** times and using a **formula** you calculate the focal length. There is a control over the distances of the object and image from the lens you measure. Besides, you **can see** magnified and diminished images of the object.

Mount **the "15 cm focal length" lens. Keep the** object at a distance from the lens greater than the focal length but less then twice the focal length of lens. The screen is placed **on** the other side. Adjust the **screen** position until a well - defined clear image of the object is obtained. Measure the distance between the object and the centre of the lens. Enter this as u in Table 2. Measure the distance **of the** image and the centre of the lens. Enter it as *v* in Table ***2.*** Then use the formula

$$f = \frac{u\,v}{u+v}$$

to calculate the focal length of the lens, and enter in Table 2. Note the characteristics of the image **and enter** in the last two columns of Table 2. Repeat the experiment by changing the object distance u keeping it between *f* and 2f of the lens, where f is the focal length of the lens. **In** each case measure u and ***v.*** Calculate f and note the characteristics of the image.

Repeat the experiment by keeping the object distance beyond ***2f.*** In this case, the image is formed between f and 2f on the other side and it is diminished and inverted. Use the same formula to calculate the focal length of the lens. You can take 5 readings for magnified and 5 **readings** for diminished images. Calculate the mean focal length of the lens, and enter in Table 2. calculate an estimate of the statistical error by your usual **method, and** enter in Table 2.

TABLE 2 **:** Focal length **of** a convex lens: u-v method

u	v	$f = \frac{u\,v}{u+v}$	$\frac{u}{v}$	Image inverted? Not?	Image enlarged? Reduced**?**

f_{mean} = ___________

Error estimate = ___________

The linear magnification of the image is given by $M = v/u$. Calculate and enter **in the fourth column** In Table 2. This **corresponds** to the ratio of the size of the image and **the size of the** object.

7.5.3 Graphical Method

Graphical method makes it easy to visualise the relative magnitude of u and v. Draw each of the following graphs.

(i) u-v graph

The object distance 'u' is plotted along the x - axis and the image distance v, along the y - axis. Take a suitable 'scale' to cover the maximum distance in the observations. Take the same 'scale' on both axes. For each trial in Table 2, plot the u and v values as a point. When all are plotted, sketch a smooth curve connecting the points as near as possible.

Draw a straight line through the origin, and at an angle of 45 degrees to the x - axis. It intersects the curve at a point. Find the co-ordinates of this point. They are equal. Each co-ordinate gives 2f. Enter the value of f here.

f = ...

SAQ

Each point on the curve gives a set of u,v values. The point of intersection of the straight line with the u, v curve corresponds to the position of the object at a distance 2f from the lens. What is the distance of the image from the lens ?

u - v graph

(ii) $1/u$ vs $1/v$ GRAPH

In this method, plot $1/u$ along x - axis and $1/v$ along y - axis, by chosing proper scales. Calculate the appropriate values using the u-v pairs from the Table 2 and enter in Table 3.

TABLE 3

$\frac{1}{u}$	$\frac{1}{v}$

Choose a proper scale for the x - axis ($1/u$) and the y -axis ($1/v$) so that all points can be plotted. Plot the points, and draw a smooth curve connecting the points as near as possible. This graph is a nearly a straight line. You extrapolate the straight line to intersect the axes at points P and Q, respectively. Calculate f = 1/ OP and f = 1/OQ. Enter here, and calculate the mean value.

1/OP = ...

1/OQ = ...

Average f = ...

The formula of 7.5.2 is written here again.

$$f = \frac{uv}{u + v}$$

It can be rewritten as $1/u + 1/v = 1/f$. Along an axis, $1/u = 1/f$ or $1/v = 1/f$. $1/f$ is called the "power" of the lens.

1/u -1/v graph

7.5.4 Distant Object Method

Keep a 15 cm focal length convex lens in the mount and place it on a laboratory bench in front of an open window. Place a sheet of thin white paper in one of the thermocole holders, in place of a lens. This will act as a screen. If you are not using thermocole holders, gum a white paper to a 5cm x 10 cm stiff cardboard and mount vertically in a clamp, as a screen. Place the screen on the otherside of the lens. Adjust the distance between the lens and the screen so that the distant object is clearly imaged on the screen. Measure the distance between the centre of the lens and the plane of the screen with the meter scale, and enter in Table 4. Remove the screen, again replace it and locate the position of the sharp image. Measure the lens-to screen distance and enter in Table 4. Repeat for a total of 5 trials. Repeat for a lens of different focal length. Calculate the average value for the trials of each lens, and calculate the estimated error by your usual method. Enter in the Table 4.

Table 4 : Focal Length

	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

7.5.5. Focal Length and Brightness

Mount two or three converging lenses of the same diameter and of different focal lengths. Place them side by side to face a distant object such a tree. Place a screen on the opposite side of the lenses and adjust the distance between each of the lenses and the fixed wider screen such that the images formed on the screen are clear. You will now see these images side by side. Now compare the brightness of the images formed by the lenses, and their sizes. Enter your visual observation in the Table 5.

Table 5

	Focal length	relative brightness	size of the image
lens 1			
lens 2			

Write in the space below any relationship you find in the Table 5 between relative brightness, size of the image and the focal length of each lens.

....

....

....

Take a cardboard with a round hole, called the 'aperture', in it. Such a cardboard is called a 'stop'. The diameter of the aperture should be about 70 % of the diameter of lens. Take one of the lenses and keep the stop just in front of the lens. The stop reduces the amount of light falling on the lens.

Measure the focal length of this lens with the stop by the distant object method of Sec 7.5.4. Enter the data in Table 6.

Table 6 : Focal Length

stop	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Are you able to locate the position of the focus precisely? Why? Repeat the experiment with the stops of smaller apertures: 50 % and 30 % of the diameter of the lens. Enter the data in Tables 7 and 8 respectively.

Table 7 : Focal Length

---% slop	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

Table 8 : Focal Length

---% stop	trial 1	trial 2	trial 3	trial 4	trial 5	average	error estimate
lens 1							
lens 2							

As you use stops of lesser diameter in conjunction with 'a lens, the 'error' of your measurement may change. The 'error' represents the range of distance of acceptable focus. However the amount of light passing through the lens decreases when you'use' use a stop of smaller diameter. The compensation you get is that there is a greater range of object distance of acceptable focus on the image plane.

SAQ'S

In your high-school, you have studied about 'pin-hole' camera. What is the focal length of a pin-hole camera?

You know that some cameras are expensive and these cameras have lenses of large diameter. There is a provision to adjust the distance of the lens from the film plane. With a range finder you first measure the distance of the scene you want to photograph and adjust the lens accordingly.

The 'Aim and shoot' cameras are not very expensive and the lenses of these cameras have a small aperture. There is no provision, for the adjustments of the lens. Why? Correlate these cameras with the results' of the experiment you have done with stops and lenses.

7.5.6 Focal Length of a Concave Lens.

Since a concave lens cannot form a real image on a screen, we have to combine it with a convex lens of suitable known focal length. This lens-combination is called a lens-system. There are two methods by which you can find the focal length of a concave lens:

(1) Contact method.

(29 "Separated by a distance" method.

(1)Contact method : Keep the given concave lens and a single convex lens together

in-contact. This combination is treated as though **it** were a single lens. Adopt the'u-v method to find the effective focal **length *F*.** If f_1 and f_2 **are the focal** lengths of the convex lens and concave lens respectively, then

$$1/f_1 + 1/f_2 = 1/F$$

or $$f_2 = \frac{F f_1}{f_1 - F}$$

You will find that $F > f_1$ and therefore the focal length of the concave lens is negative as expected. The experimental procedure is identical to the one **you** did earlier, namely **the determination of** focal **length of a** convex lens. U and V are the distances of the object and image distances from the centre of the lens system.

Enter the readings in the Table 9 shown below:

TABLE 9 : **Focal length of a** mauve **lens - Contact method**

Focal length of convex lens = f_1 = ______________

U	V	$F = \frac{UV}{V+U}$

F_{mean} = ______________

estimated **error** = ______________

$$f_2 = -\frac{Ff_1}{F - f_1} = \text{______}$$

(2) "Separated by a distance" **method** :

With the convex lens, an image I' of the screen source is formed on the screen. Note the position of the screen. The **concave** lens is introduced in between the convex lens and the screen at a distance *U* **from** the image ***I'***. **You** observe that the image ***I'*** after the introduction of the **concave** lens becomes blurred. Move the screen away **from the** concave lens to a **new position where the** new image ***I*** **formed on** it **is clear. The distance** of this new image ***I*** from the concave lens is measured as V. **Enter** the distances *U* and *V* in the 'Table 10. **Calculate** f_2. **For** the concave lens, the **virtual object *I'*** produces a **real** image ***I'***. **See** Fig.7.4.

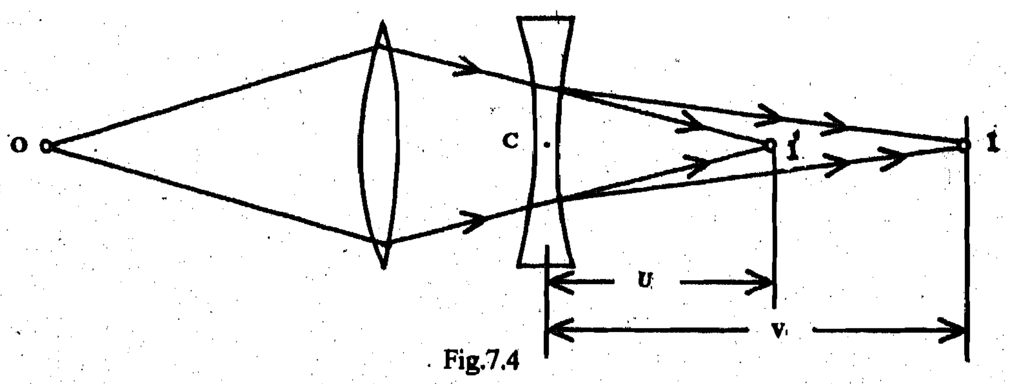

Fig.7.4

We have

$$\frac{1}{f_2} = \frac{1}{U} + \frac{1}{V}$$

$$f_2 = - \frac{U V}{V - U} \quad \text{as } V > U.$$

Repeat the experiment by changing the distance between the concave lens and the convex lens. Make measurements for two such lenses.

TABLE 10 : Focal length of a concave lens - "Separated by a distance" method

Focal length of convex lens = f_1 = ____________

U	V	$F = \frac{U V}{V - U}$

$F_{2\,mean}$ = ____________
estimated error = ____________

7.6 Conclusions

You have determined the focal length of a convex lens by a number of methods. The focal length of a concave lens was determined using another convex lens of known focal length. You have observed the way in which focal length and diameter affect the brightness and size of an image formed by a lens.

You now know quite a lot about lenses and bow they behave!