To Find the Focal Length Of a Convex Lens By Plotting Graphs Between U & V Or Between 1/u & 1/v

Aim
To find, the focal length of a convex lens by plotting graphs between u and v or between 1/u and 1/v.

Apparatus
An optical bench with three uprights (central upright fixed, two outer uprights with lateral movement), a convex lens with lens holder, two optical needles, (one thin, one thick) a knitting needle and a half metre scale.

Theory
The relation between u, v and f for a convex lens is

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \quad \Rightarrow \quad \frac{1}{f} = \frac{u-v}{uv} \quad \Rightarrow \quad f = \frac{uv}{u-v}$$

where,
f = focal length of convex lens
u = distance of object needle from optical centre of the lens
v = distance of image needle from optical centre of the lens.
Note. According to sign-convention, u has negative value and v has positive value. Hence, f comes positive.

Ray diagram

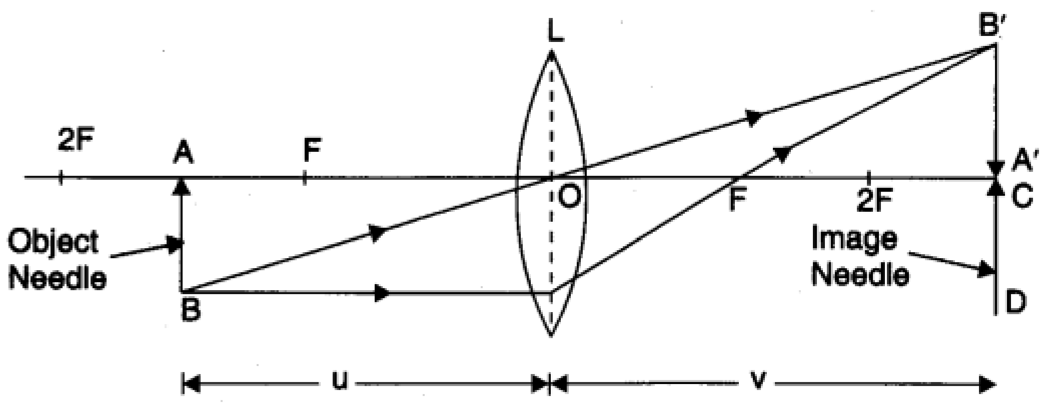

Fig. Focal length of convex lens.

Procedure

To determine rough focal length

1. Mount the concave mirror in mirror holder.
2. Go out in the open and face the mirror towards distant tree or building.
3. Obtain the image of the tree or the building on a white painted wall (screen) and move the mirror forward and backward to get a sharp image on the wall.
4. Measure the distance between the mirror and the wall (screen). This will be equal to the rough focal length of the mirror.
   To set the lens
5. Clamp the holder with lens in a fixed upright and keep the upright at 50 cm mark.
6. Adjust the lens such that its surface is vertical and perpendicular to the length of the optical bench.
7. Keep the upright fixed in this position throughout.
   To set the object needle
8. Take the thin optical needle as object needle (O). Mount it in outer laterally moveable upright near zero end.
9. Move the object needle upright and clamp it at a distance (in full cms) nearly 1.5 times the obtained rough focal length of the lens.
10. Adjust height of the object needle to make its tip lie on horizontal line through the optical centre of the lens.
11. Note the position of the index mark on the base of the object needle upright.
    To set the image needle
12. With left eye closed, see with the right open eye from the other end of the optical bench. An inverted and enlarged image of the object needle will be seen. Tip of the image must lie in the middle of the lens.
13. Mount the thick optical needle (image needle) in the fourth upright near the other end of the optical bench.
14. Adjust the height of the image needle so that its tip is seen in line with the tip of the image when seen with right open eye.
15. Move the eye towards right. The tips will get separated. The image tip and the image needle tip have parallax.
16. Remove the parallax tip to tip.
17. Note the position of the index mark on base of the image needle upright.
18. Record the position of the index marks on the base of upright of the lens, the object needle and the image needle in the table against observation 2.
    To determine index correction
19. Find the index correction for distance between optical centre of lens and tip of the object needle and also for distance between optical centre of lens and tip of the image needle as described.
    To get more observations
20. Move object needle upright towards mirror in steps of 1 cm to get observation 2 and 1. Repeat the experiment.
21. Move object needle upright away from mirror (from position of observation 2) in steps of 1 cm to get observations 4, 5 and 6. Repeat the experiment.

22. Record all the observations as given ahead.
(**Note.** Same as in Experiment 1).

Observations

Rough focal length of the given convex lens = …….cm
Actual length of the knitting needle x=…….cm
Observed distance between the object needle and the lens when knitting needle is placed between them y =…….cm
Observed distance between the image needle and the lens when knitting needle is placed between them z =…….cm
Index correction for the object distance u, x -y =…….cm
Index correction for the image distance v, x-z =…….cm

Table for u, v; $\frac{1}{u}$ and $\frac{1}{v}$

Serial No. of Obs.	Position of			Observed distance		Corrected distance			
	Object needle A (cm)	Lens O (cm)	Image needle C (cm)	OA = u (cm)	OC = v (cm)	u (cm)	v (cm)	$\frac{1}{u}$ (cm^{-1})	$\frac{1}{v}$ (cm^{-1})
(1)	(2a)	(2b)	(2c)	(3a)	(3b)	(4a)	(4b)	(5)	(6)
1.									
2.									
3.									
4.									
5.									
6.									

Calculations

Calculations of focal length by graphical methods:
(i) u-v Graph. Select a suitable but the same scale to represent u along X'-axis and v along Y-axis. According to sign conventions, in this case, u is negative and v is positive. Plot the various points for different sets of values of u and v from observation table second quadrant. The graph comes out to be a rectangular hyperbola as shown in graph between u and v.
Draw a line OA making an angle of 45° with either axis (i.e., bisecting ∠YOX') and meeting the curve at point A. Draw AB and AC perpendicular on X'- and Y-axes, respectively.
The values of u and v will be same for point A. So the coordinates of point A must

be $(2f, 2f)$, because for a convex lens, when $u = 2f$, $v = 2f$.

Hence, $AB = AC = 2f$ or $OC = OB = 2f$

$\therefore$ $f = \frac{OB}{2}$ and also $f = \frac{OC}{2}$

$\therefore$ Mean value of f = ... cm

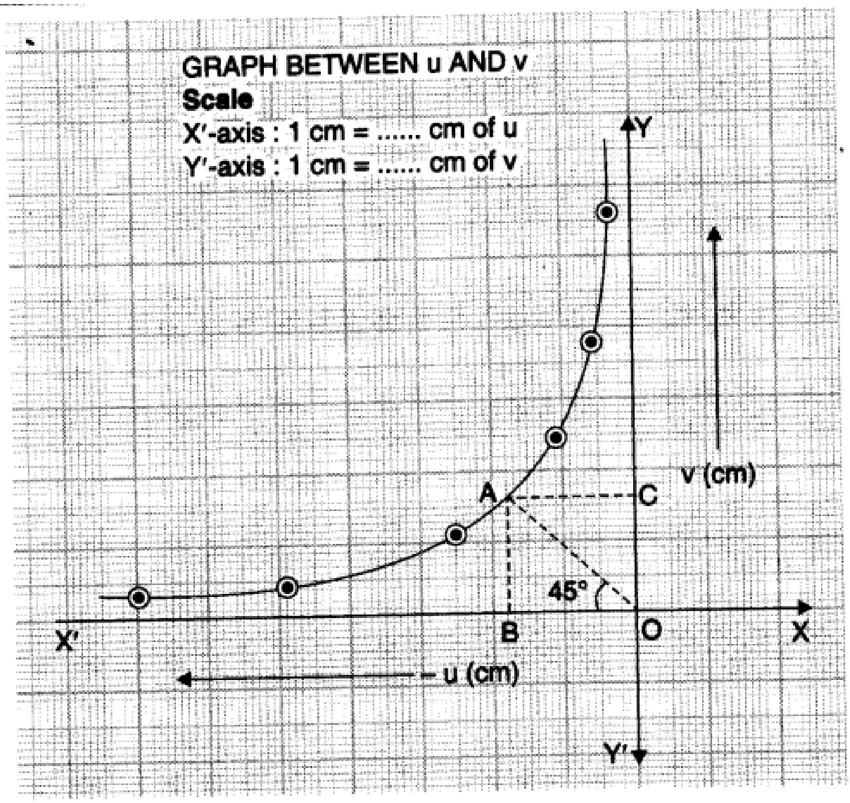

Fig. Graph between u and v. It is a rectangular hyperbola.

(*ii*) $\frac{1}{u}$ **and** $\frac{1}{v}$ **Graph.** Select a suitable but the same scale to represent $\frac{1}{u}$ along X′-axis and $\frac{1}{v}$ along Y-axis. By sign conventions $\frac{1}{u}$ is negative and $\frac{1}{v}$ is positive. Plot the various points for different sets of values of $\frac{1}{u}$ and $\frac{1}{v}$ from the observation table. The graph comes out to be a straight line as shown in graph between $\frac{1}{v}$ and $\frac{1}{u}$.

The straight line cuts the two axes OX′ and OY at an angle of 45° at points P and Q, respectively and making equal intercepts on the axes. Measure the distance OP and OQ.

Then focal length, $f = \frac{1}{OP} = \frac{1}{OQ}$

= ....

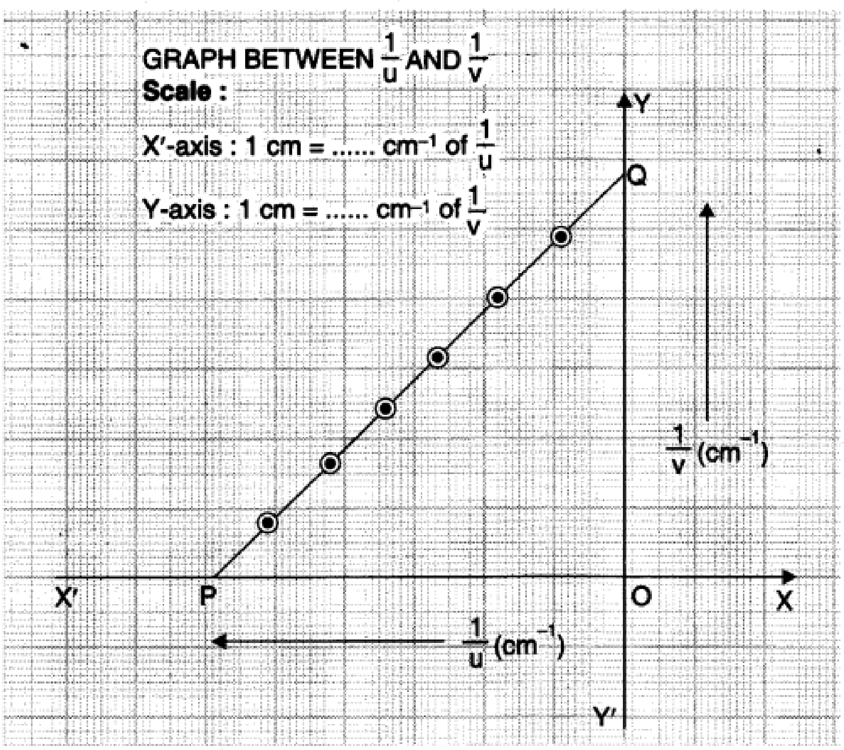

Fig. Graph between $\frac{1}{u}$ and $\frac{1}{v}$. It is a straight line.

Explanation

Same as for concave mirror:

(iii) Another u-v Graph. Select a suitable but the same scale to represent u along X'-axis and v along Y-axis. Mark the points at distances u_1, u_2, u_3,…… etc. along the OX'-axis
and the corresponding points at distances v_1, v_2, v_3,…… etc. along OY- axis for different

sets of observations from the table.

Draw straight lines joining u_1 with v_1; u_2 with v_2; u_3 with v_3;……. etc. These lines will intersect at point K as shown in the following graph.

Draw KL and KM perpendiculars on X'- and Y-axes, respectively

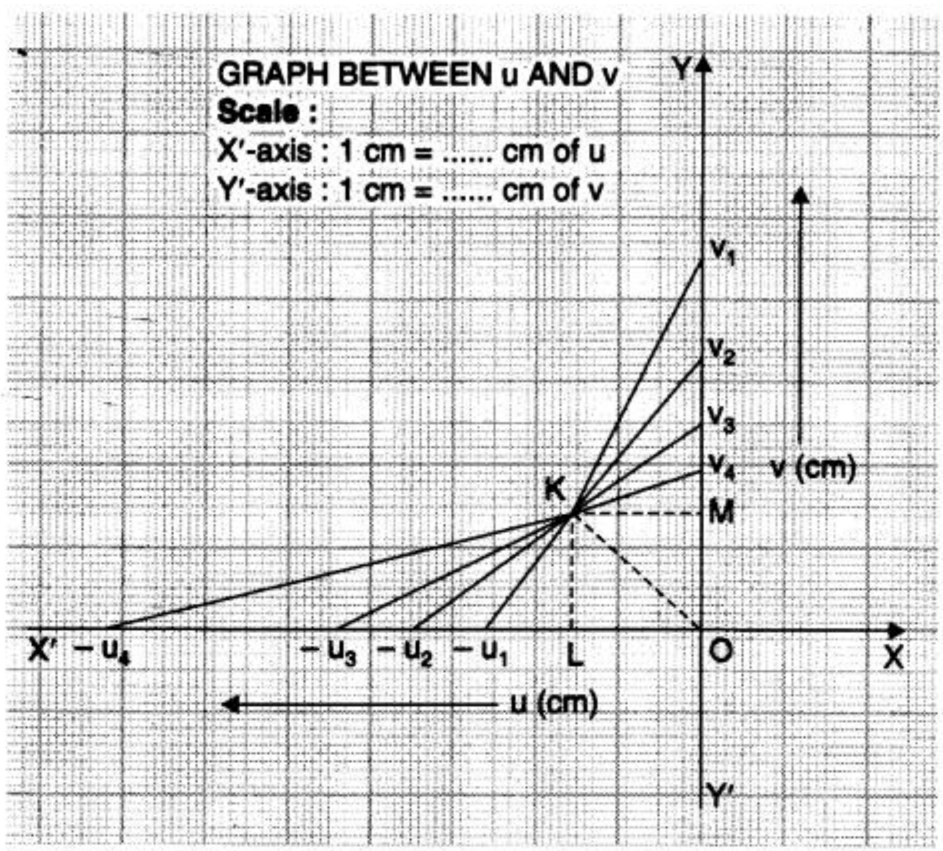

Fig. Graph between *u* and *v*.

Then $$f = OL = OM$$
$$= \ldots\ldots \text{ cm.}$$

Explanation

Same as for concave mirror:

Note. It will be better to choose any four suitable sets of (a, v) from the observation table. All the six sets of observations may complicate the graph.

Result

The focal length of the given convex lens as determined from

1. focal length from $f = \frac{vu}{u-v}$
2. $(u-v)$ graph = ... cm
3. $\left(\frac{1}{u} - \frac{1}{v}\right)$ graph = ... cm

and 4. $(u-v)$ graph = ... cm.

Precautions

1. Tips of the object and image needles should lie at the same height as the centre of the lens.
2. Parallax should be removed from tip to tip by keeping eye at a distance at least 30 cm away from the needle.
3. The object needle should be placed at such a distance that only real, inverted image of it is formed.
4. Index correction for u and v should be applied.

Sources of error

1. The uprights may not be the vertical.
2. Parallax removal may not be perfect.