

# EXPERIMENT 8

## AIM

To determine the frequency of alternating current using a sonometer and an electromagnet.

## APPARATUS AND MATERIAL REQUIRED

A sonometer with a soft iron wire stretched over it, an electromagnet, a step-down transformer, slotted 1/2 kg weights hanger, a physical balance, two sharp edge wedges and a weight box.

## PRINCIPLE

The frequency  $n$  of the fundamental mode of vibration of a stretched string, fixed at two ends, is given by

$$n = \frac{1}{2l} \sqrt{\frac{T}{m}} \quad \text{(E 8.1)}$$

Here  $l$  is the length of the vibrating string,  $T$  is the tension in the wire and  $m$  is its mass per unit length.

If an alternating current is passed in the coil of the electromagnet, the magnetisation produced in the core is proportional to instantaneous value of the current. If the electromagnet is held close to the middle of the sonometer wire, the wire will be attracted twice during each cycle towards the electromagnet. The attractive force experienced by the wire will be proportional to the magnetisation produced in the core of the electromagnet. Since in each cycle, the wire will be pulled twice and hence at resonance, it will vibrate with a frequency which is twice the frequency of alternating current. Hence, if  $f$  is the frequency of the alternating current, then

$$f = \frac{n}{2} = \frac{1}{4l} \sqrt{\frac{T}{m}} \quad \text{(E 8.2)}$$

$$4n^2 l^2 m = T$$

$$\text{or } l^2 = \frac{1}{4n^2 m} \times T$$

A graph between  $T$  (taken on x-axis), and  $l^2$  (taken on y-axis), would be a straight line. The slope of this straight line would be

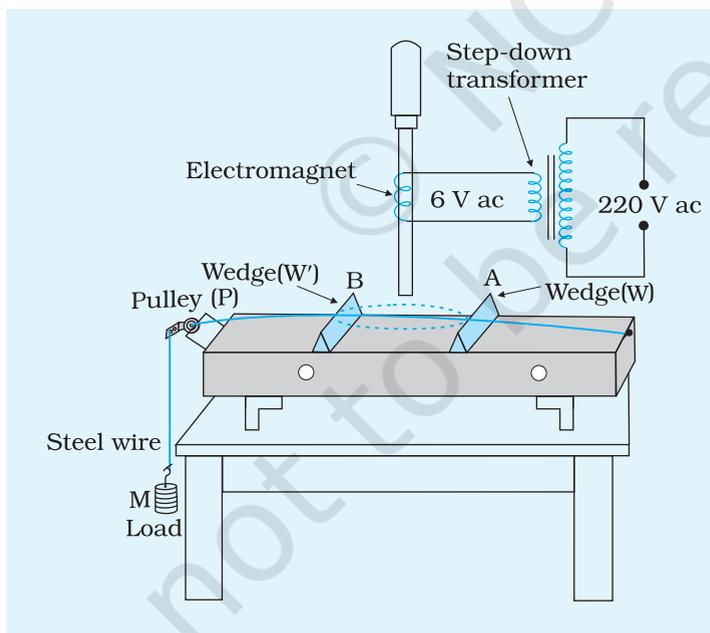
$$\frac{1}{4n^2 m}, \text{ so that}$$

$$\text{[E 8.3]} \quad n^2 = \frac{1}{4m \times \text{slope}}$$

$$n = \frac{1}{2} \frac{1}{\sqrt{m \times \text{slope}}}$$

The frequency of alternating current,  $f = \frac{n}{2} = \frac{1}{4} \frac{1}{\sqrt{m \times \text{slope}}}$  can be determined using the value of the slope.

## PROCEDURE



**Fig. E 8.1** Set up for finding frequency of ac mains using a sonometer

1. Set up the sonometer and stretch the wire AB by placing a load of  $\frac{1}{2}$  kg on the hanger (Fig. E 8.1).
2. Support the electromagnet in a stand and connect it to the secondary of a stepdown transformer. Adjust its position, such that its one pole lies close to the middle of the sonometer wire.
3. Switch on the alternating current supply and adjust the length of vibrating portion of AB by sliding the wedge W or W'. Make this adjustment until the amplitude of the vibrating string is maximum.
4. Measure the vibrating length and note the tension in the string.
5. Increase the load in steps of  $\frac{1}{2}$  kg and each time find the vibrating length.
6. Switch off the ac supply. Untie the wire of the sonometer from its peg and find its mass in a physical balance. Calculate mass of 100 cm sonometer wire. Hence find the mass per unit length,  $m$  for the wire.

## OBSERVATIONS

1. Length of the wire = ...cm = ... m
2. Mass of the wire = ...g = ...kg
3. Mass per unit length,  $m = \dots \text{g/cm} = \dots \text{kg/m}$
4. Acceleration due to gravity,  $g = \dots \text{ms}^{-2}$

Table E 8.1: Resonant length

Sl. No.	Load ( $M$ ) including mass of hanger (kg)	Tension $T = mg$ (N)	Resonant length $l$			Mean $l$ in (m)	$n = \frac{1}{2l} \sqrt{\frac{T}{m}}$ (Hz)
			First trial (cm)	Second trial (cm)	Mean (cm)		
1							
2							
3							
4							
Mean							

## CALCULATIONS

1. For each set, calculate the value of  $n$  using the formula given above. Find the mean of these values.
2. Plot a graph of  $l^2$  against  $T$  with  $l^2$  on y-axis and  $T$  on x-axis. Determine the slope of the graph. Using the value of the slope determine the frequency of alternating current.

## RESULT

1. The graph between  $T$  and  $l^2$  is a straight line.

2. Slope of the graph =  $\frac{1}{4mn^2} = \dots$

3. Frequency of ac supply  $f = \frac{n}{2}$

- (i) from calculation ...Hz
- (ii) from graph ...Hz

## PRECAUTIONS

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1. Pulley should be as frictionless as possible.
2. Edges of the wedge should be sharp.
3. Tip of the electromagnetic pole should be close to the middle of the sonometer wire.
4. After taking each of the observations, circuit should be switched off for a few minutes.

## SOURCES OF ERROR

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1. Friction of the pulley is the main source of error in the experiment. Due to this, the value of tension acting on the wire is less than that actually applied.
2. AC frequency may not be stable.

## DISCUSSION

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1. The frequency of alternating current is half that of the frequency of the vibrating string.
2. Sonometer wire is made of soft iron for better results.

## SELF ASSESSMENT

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1. How is ac different from dc?
2. What is the meaning of frequency of ac?
3. How does the wire vibrate? Identify and explain the rule with the help of which you can determine the direction of force acting on the wire.
4. What should be the property of the iron for making it a good electromagnet?
5. Is there any relation between frequency and magnetism of the electromagnet, and frequency of the alternating current?

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

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Perform the above experiment using a permanent horse shoe magnet and passing the alternating current in the sonometer wire. In this case the resonant frequency is equal to the frequency of the alternating current. Sonometer wire need not be made of soft iron. You can use constantan or manganin wire for this purpose.

# EXPERIMENT 9

## AIM

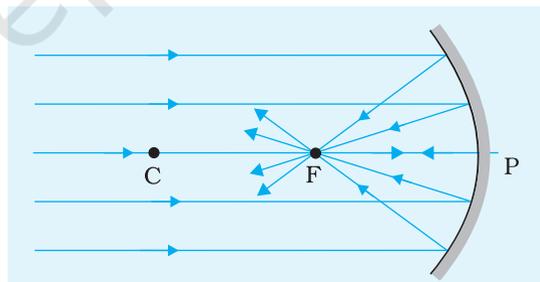
To find the value of ' $v$ ' for different values of ' $u$ ' in case of concave mirror and to find the focal length.

## APPARATUS AND MATERIAL REQUIRED

An optical bench, two sharp-edged needles (pins), concave mirror of less than 20 cm focal length, three uprights (with clamps), index needle (may be a knitting needle), metre scale and spirit level.

## TERMS AND DEFINITIONS

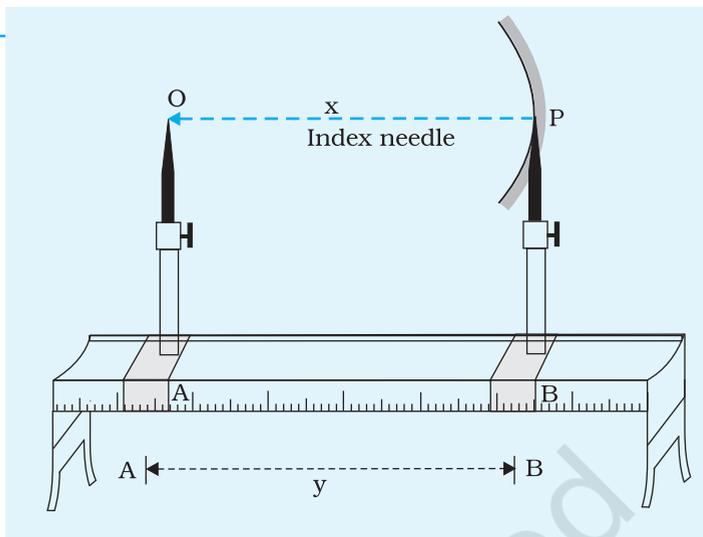
1. *Principal axis* of a mirror is the line passing through the centre of curvature and pole of the mirror.
2. *Principal focus* is the point where rays parallel to principal axis, focus after reflection from the surface of the mirror (Fig. E 9.1).
3. *Geometrical centre* of the mirror is called pole, P.
4. *Focal length* is the distance between the pole, P and the focus, F.



**Fig. E 9.1** Focal length of a concave mirror.

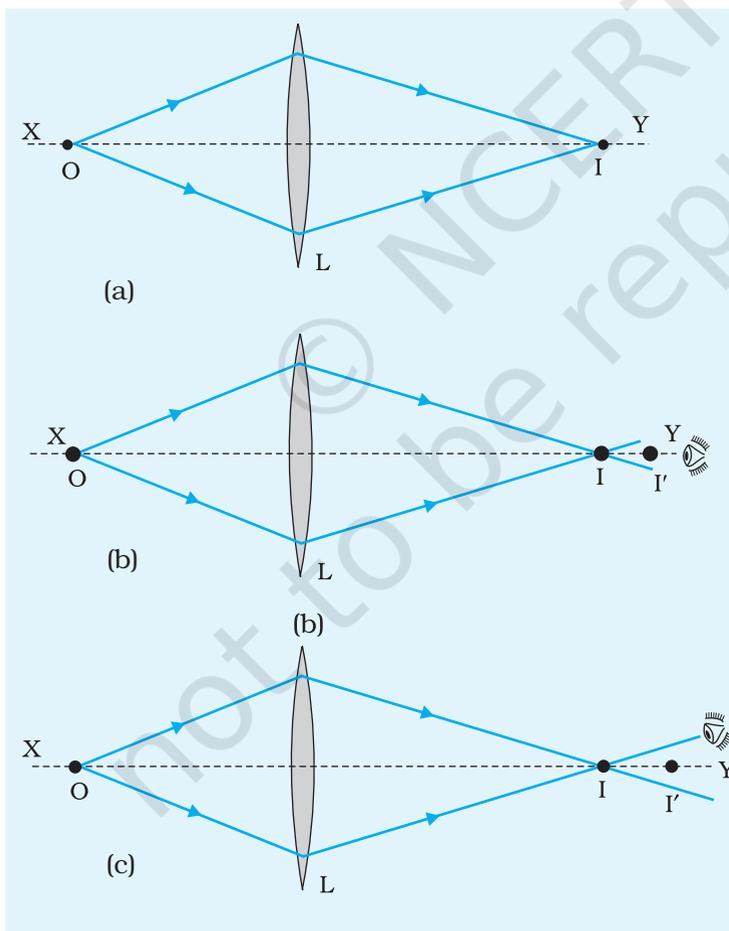
## INDEX CORRECTION

Usually the distance between concerned points of two elements is not the same as the distance between their uprights as read on the scale. For example, in Fig. E 9.2 the reading of two uprights do not give the actual distance between the tip of the pin and the pole of the mirror. A correction must, therefore, be applied. It is called the index correction.



**Fig. E 9.2** Determination of Index correction

## PARALLAX



**Fig. E 9.3 (a),(b),(c)** Locating the position of an image on the optical bench by a pin

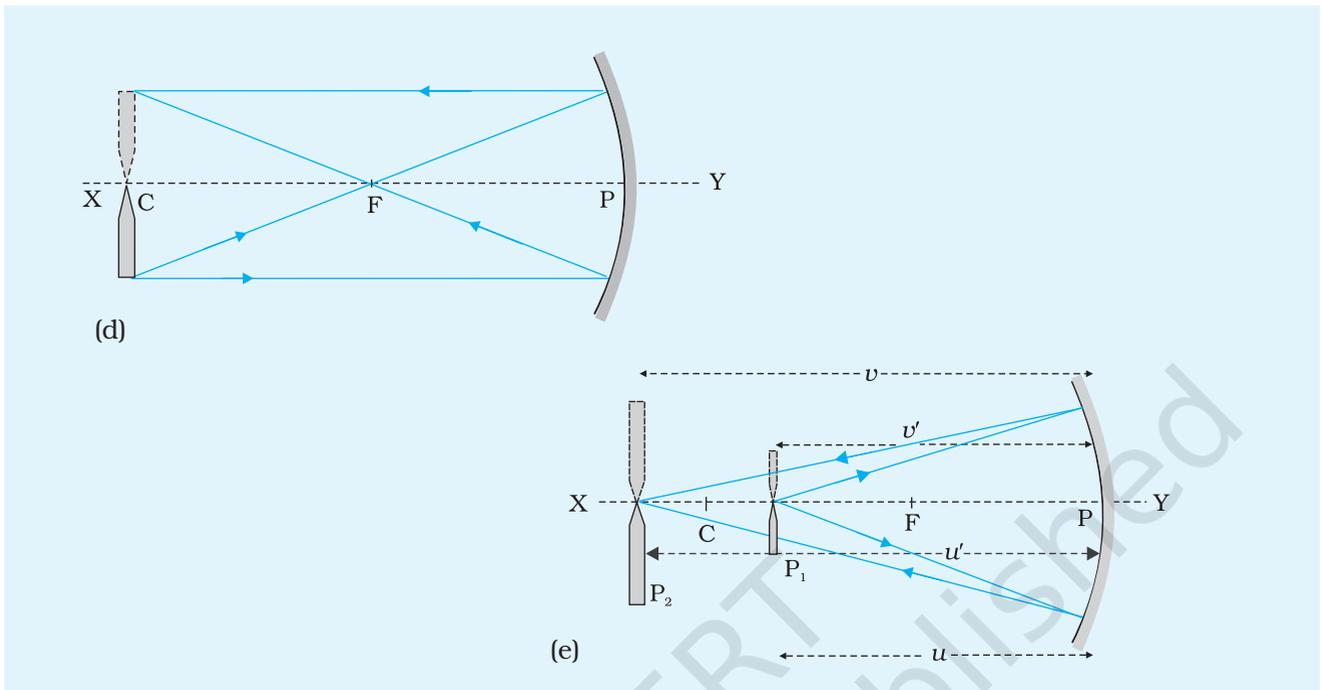
This is employed in the location of image of an object.

For example, as shown in the Fig. E 9.3 (a) O and I are the object and image points for a mirror/lens.

An object point O and its real image 'I' are conjugate points i.e. any of the two may be considered as object and the other as its image. Thus it helps in accurate adjustment to check for no parallax at both the points.

If we say there is no parallax between an object O (pin) and its image I, then by moving the eye through which we are observing, to the left and then to the right, object and its image both appear to move together relative to the lens/mirror. It implies that the position of both are same on the optical bench [Figs. E 9.3 (d) and (e)]. If their positions are not same then in one position they may appear to coincide and in another they will appear separate [Figs. E 9.3 (b) and (c)].

This method of locating the position of an image on the optical bench by a pin is called the method of parallax.

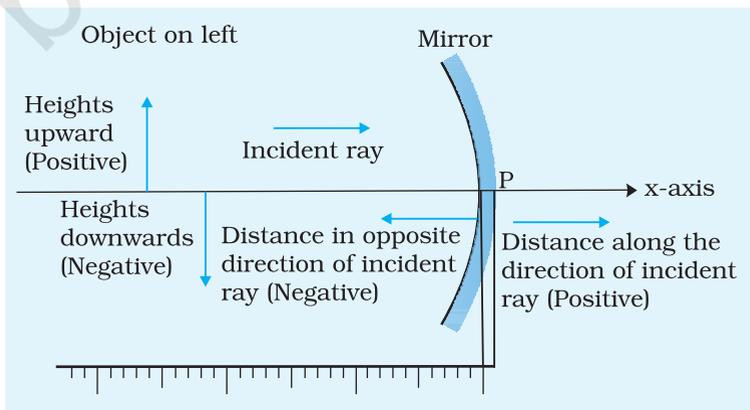


**Fig. E 9.3 (d), (e)** Ray diagram for finding focal length of a concave mirror

## SIGN CONVENTION

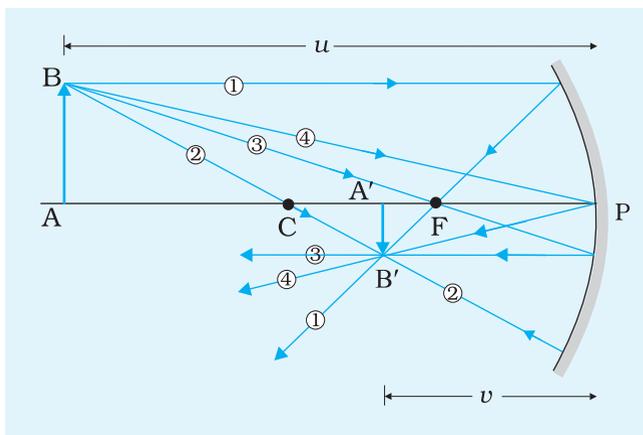
1. All the distances are measured from the pole P of the mirror (or the optical centre of a lens).
2. The distance measured in the direction of propagation of incident rays are taken as positive and those measured in the opposite direction are taken as negative.
3. The heights measured upwards (above the principal axis of the mirror/lens) are taken as positive and the heights measured downwards are taken as negative (Fig. E 9.4).

**Note:** In the cartesian sign convention, the object is always placed to the left of the mirror (or the lens).



**Fig. E 9.4** The cartesian sign convention

## RAY TRACING IN SPHERICAL MIRRORS



**Fig. E 9.5** Ray tracing for image formation by a concave mirror

To locate the image, we need to trace only a few specific paths or rays (a minimum of two) as shown in Fig. E 9.5.

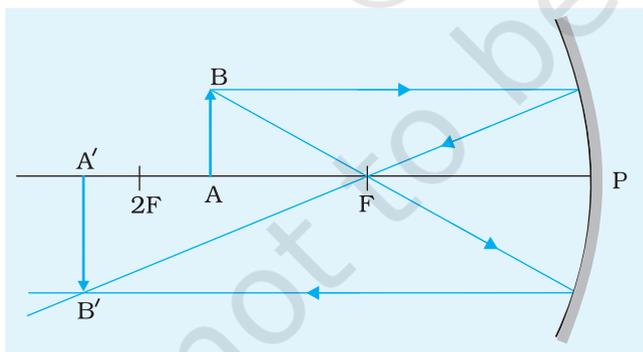
Conveniently, any two rays can be taken to locate the image.

1. An incident ray parallel to the principal axis of the mirror either passes through the principal focus F (concave mirror) or appears to be diverging from it (convex mirror).
2. An incident ray passing through the centre of curvature C (concave mirror) or appearing to pass through it (convex mirror), retraces its path i.e. reflected

back along its original path. You must note that this ray is incident normal to the mirror.

3. An incident ray passing through the principal focus F (concave mirror) or appearing to pass through it (convex mirror) will be reflected from the mirror parallel to the principal axis.
4. An incident ray striking the pole P of the mirror is reflected at an angle equal to the angle of incidence with the principal axis.

## PRINCIPLE



**Fig. E 9.6** Formation of image by a concave mirror. Object is between the centre of curvature and principal focus F; real, inverted and magnified image is between the centre of curvature and infinity

For an object placed at a distance  $u$  from the pole of a concave mirror of focal length  $f$ , the image is formed at a distance  $v$  from the pole. The relation between these distances (for a concave mirror) is

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

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

If an object (say, a pin) is placed in front of the reflecting surface of the concave mirror such that the object's position lies in between the principal focus of the mirror, F and the centre of curvature C, then a real, inverted and

magnified image is formed in between the centre of curvature C of the mirror and infinity (Fig. E 9.6).

Thus, the image formed in such a case would be clearer and easier to be seen. The focal length of the mirror, using the above relation, can be determined by placing the object in between the point  $2F$  and focus  $F$ .

## PROCEDURE

1. Obtain approximate value of the focal length of concave mirror by focusing the image of a distant object. Obtain bright and clear image of a distant building or tree on a plane wall or a sheet of paper and measure the distance between the mirror and the image which gives the approximate focal length of the concave mirror.
2. Place the optical bench on a rigid table. Make it horizontal using a spirit level and levelling screws.
3. Clamp the concave mirror on an upright and mount it vertically near one end of the optical bench. Move an object pin  $P_1$  on the optical bench back and forth so that its image is formed at the same height. Make slight adjustments of the height of the pin or the mirror inclination. This procedure ensures that the principal axis of the mirror is parallel to the optical bench.
4. Place another vertically mounted sharp and bright pin  $P_2$  in front of the reflecting surface of the concave mirror. Adjust the pins  $P_1$  and  $P_2$  so that the height of the tips of these pins become equal to the height of the pole  $P$  of the mirror from the base of the optical bench [Fig. E 9.3(e)].
5. To determine index correction, a thin straight index needle is placed so that its one end  $A_1$  touches the tip of the pin and the other end  $B_1$  touches the pole  $P$  of the mirror. The positions of the uprights are read on the scale. Their difference gives the observed distance between tip of the pin and the pole of the mirror. Length of the needle  $A_1B_1$  is measured by placing it on the scale which is the actual distance between the points in question. The difference between the two gives the correction to be applied to the observed distance. Find the index correction for both the pins  $P_1$  and  $P_2$  for all measurements.
6. Move the pin  $P_1$  away from the mirror and place it almost at  $2F$ . An inverted image of same size as the pin should be visible.
7. Now place another pin  $P_2$  on the bench, adjust its height to be almost the same as the earlier pin. Place a piece of paper on the tip of one pin, take this as the object pin.
8. Place the pin with paper at a distance lying between  $F$  and  $2F$ .
9. Locate the image of the pin using the other pin. Remember that parallax has to be removed between the image and the pin.

10. Note the values of  $u$  and  $v$  i.e., the distances of the object and image pins from the mirror respectively.
11. Repeat the experiment for at least five different positions of the object and determine the corresponding values of  $v$ . Record your observations in tabular form.
12. After doing index correction record the corrected values of  $u$  and  $v$ . Find the value of focal length,  $f$ .

## OBSERVATIONS

1. Rough focal length of the concave mirror = ... cm
2. Actual distance of the object from the mirror using index needle,  $l_0 = \dots$  cm
3. Observed distance of the object from the mirror  
= position of mirror upright – position of object pin upright on the scale,  $l'_0 \dots$  cm
4. Index correction for object distance,  $e = \text{actual distance} - \text{observed distance}$ .

$$= l_0 - l'_0 = \dots \text{cm}$$

Similarly for image pin

$$e_i = l_i - l'_i = \dots \text{cm}$$

**Table E 9.1: Determination of  $u$ ,  $v$  and  $f$**

Sl. No.	Position of			Observed $u'$ (cm)	Observed $v'$ (cm)	Corrected $u = u' + e$ (cm)	Corrected $v = v' + e_i$ (cm)	$f = \frac{uv}{u+v}$ (cm)	$\Delta f$ (cm)
	Mirror M (cm)	Object pin $P_1$ (cm)	Image pin $P_2$ (cm)						
1									
2									
...									
6									
Mean									

## CALCULATIONS

Calculate the corrected values of  $u$  and  $v$  and compute the value of  $f$ . Tabulate them and find the mean value of the focal length of the given concave mirror.

**Error**

$$\therefore \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

$$\frac{\Delta f}{f^2} = \frac{\Delta u}{u^2} + \frac{\Delta v}{v^2}$$

$$\text{or } \Delta f = f^2 \left[ \frac{\Delta u}{u^2} + \frac{\Delta v}{v^2} \right]$$

**R**ESULT

The focal length of the given concave (converging) mirror is  $(f \pm \Delta f) = \dots \pm \dots \text{cm}$

Here  $f$  denotes mean value of the focal length and  $\Delta f$  is maximum of the six values of the error.

**P**RECAUTIONS

1. The uprights supporting the optical elements should be rigid and mounted vertically.
2. The object pin should be kept in between the centre of curvature and the focus of the mirror.
3. The aperture of mirror should be small otherwise the image formed will not be distinct.
4. Eye should be placed at a distance of distinct vision (25 cm) from the image needle.
5. The tip of the inverted image of the object pin must touch the tip of the image pin and must not overlap. It should be ensured while removing the parallax.
6. The image and the object pins should not be interchanged during the course of the experiment.
7. The corrected values of the distances  $u$  and  $v$  must be put in the formula for calculating  $f$  and then a mean value of  $f$  should be taken. Calculations for  $f$  must not be made using the mean values of  $u$  and  $v$ .
8. A white screen or plane background may be used for seeing the clear image of the pin.
9. Image of the Sun should not be seen directly as it may hurt your eyes.

## SOURCES OF ERROR

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1. An error may arise in the observations if the top of the optical bench is not horizontal and similarly if the tips of pins and pole of the mirror are not at the same horizontal level.
2. The concave mirror should be front-coated, otherwise multiple reflections will come from the reflecting surface of the mirror.

## DISCUSSION

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The image B' of the point B (Fig. E 9.6) will be at the point where two such rays either intersect or appear to be intersecting. The image of the bottom of the object A (lying on the principal axis) will lie on the principal axis itself such that the final image is perpendicular to the axis as the object.

## SELF ASSESSMENT

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1. A dentist uses concave mirror to see the tooth. In what way does it help the dentist?
2. Can you determine the focal length of the concave mirror if  $u < f$ ?

### SUGGESTED ADDITIONAL EXPERIMENTS/ACTIVITIES

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1. Plot a graph of  $uv$  against  $u + v$  with  $uv$  on y-axis and  $u+v$  on x-axis. Determine  $f$  from the slope of the graph.
2. Using spherometer, determine the radius of curvature of the concave mirror and calculate its focal length ( $f = R/2$ ).