## 1. Details of Module and its structure

| Module Detail | |
|---|---|
| Subject Name | Physics |
| Course Name | Physics 04 (Physics Part-2, Class XII) |
| Module Name/Title | Unit-06, Module-07(A): Optics Experiments<br>Chapter-09: Ray Optics and Optical Instruments |
| Module Id | leph_20907_eContent |
| Pre-requisites | Reflection refraction, reflection at curved surfaces, refraction at curved surfaces, mirror and lens formula, real and virtual image |
| Objectives | After going through the module the learner will be able to:<br>• Know the optics laboratory equipment<br>• Understand the principle for the following experiments<br>• To Study the nature and size of image formed by a<br>i) convex lens<br>ii) concave mirror<br>using a candle and a screen<br>• To Determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v<br>• To Determine the focal length of concave mirror by plotting graphs between u and v, between 1/u and 1/v<br>• To determine the focal length of a convex mirror using a convex lens<br>• To find the focal length of a concave lens using a convex lens<br>• To find the refractive index of a liquid by using a convex lens and a plane mirror |
| Keywords | Focal length of concave mirror, Focal length of convex mirror, focal length of convex lens, focal length of concave lens, refractive index of a liquid using a convex lens and a plane mirror |

## 2. Development Team

| Role | Name | Affiliation |
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## 1. UNIT SYLLABUS

**UNIT 6: Optics**

**Chapter–9: Ray Optics and Optical Instruments**

**Ray optics:** Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue color of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers.

**Chapter 10 Wave Optics**

**Wave optics:** Wave front and Huygens's principle, reflection and refraction of plane wave at a plane surface using wave fronts, proof of laws of reflection and refraction using Huygens's principle, Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope, polarisation, plane-polarized light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

## 2. MODULE WISE DISTRIBUTION OF UNIT SYLLABUS 15 MODULES

| | |
|---|---|
| Module 1 | • Introduction<br>• How we will study optics - plan<br>• Light facts<br>• Ray optics, beams<br>• Light falling on surfaces of any shape and texture<br>• Peculiar observations |
| Module 2 | • Reflection of light<br>• Laws of reflection<br>• Reflection of light by plane and spherical surfaces<br>• Spherical Mirrors aperture, radius of curvature, pole principal axis<br>• Focus, Focal length, focal plane<br>• Image – real and virtual<br>• Sign convention<br>• The mirror equation, magnification<br>• To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror<br>• Application of mirror formula |
| Module 3 | • Refraction of light<br>• Optical density and mass density<br>• Incident ray, refracted ray and emergent ray<br>• Angle of incidence, angle of refraction and angle of emergence<br>• To study the effect on intensity of light emerging through different colored transparent sheets using an LDR<br>• Refractive index<br>• Oblique incidence of light, Snell's law<br>• Refraction through a parallel sided slab Lateral displacement, factors affecting lateral displacement<br>• To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab<br>• Formation of image in a glass slab |
| Module 4 | • Special effects due to refraction<br>• Real and apparent depth<br>• To determine the refractive index of a liquid using travelling microscope<br>• Total internal reflection<br>• Optical fibers and other applications |

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| **Module 5** | • **Refraction through a prism**<br>• **Deviation of light -angle of deviation**<br>• **Angle of minimum deviation**<br>• **Expression relating refractive index for material of the prism and angle of minimum deviation**<br>• **To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation**<br>• **Dispersion, spectrum** |
| **Module 6** | • **Refraction at spherical surfaces**<br>• **Radius of curvature**<br>• **Refraction by a lens**<br>• **Foci, focal plane, focal length, optical center, principal axis**<br>• **Formation of images real and virtual**<br>• **Lens maker's formula**<br>• **Lens formula and magnification**<br>• **Sign convention**<br>• **Application of lens formula**<br>• **Power of lens**<br>• **Combination of thin lenses in contact** |
| **Module 7 A and 7 B** | **After going through the module the learner will be able to:**<br>**7A**<br>• **Know the optics laboratory equipment**<br>• **Understand the principle for the following experiments**<br>• **To Study the nature and size of image formed by a**<br>**i) convex lens**<br>**ii) concave mirror**<br>**using a candle and a screen**<br>• **To Determine the focal length of convex lens by plotting graphs between u and v , between 1/u and 1/v**<br>• **To Determine the focal length of concave mirror by plotting graphs between u and v , between 1/u and 1/v**<br>**7 B**<br>• **To determine the focal length of a convex mirror using a convex lens**<br>• **To find the focal length of a concave lens using a convex lens**<br>**To find the refractive index of a liquid by using a convex lens and a plane mirror** |
| **Module 8** | • **Scattering of light**<br>• **Blue color of sky**<br>• **Reddish appearance of the sun at sunrise and sunset** |

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| | • Dust haze |
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| Module 13 | • Diffraction<br>• Diffraction at a single slit<br>• Width of the central maxima<br>• Comparison of fringes in young's experiment and those in diffraction from a single slit |
| Module 14 | • Diffraction in real life<br>• Seeing the single slit diffraction pattern<br>• Resolving power of optical instruments<br>• Validity of ray optics<br>• Fresnel distance |
| Module 15 | • Polarisation<br>• to observe polarization of light using two polaroid<br>• Plane polarised light<br>• Polariser analyser Malus law |

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| | • **Brewster/s law**<br>• **Polarisation due to scattering**<br>• **Uses of plane polarised light and polaroids** |

## MODULE 7 A

**We have divided module 7 into two parts. This has been done so that we give sufficient time to concepts.**

**Module 7 A**

- **Know the optics laboratory equipment**
- **Understand the principle for the following experiments**
- **To Study the nature and size of image formed by a**
  - **a. convex lens**
  - **b. concave mirror using a candle and a screen**
- **To Determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v**

**Module 7 B**

- **To determine the focal length of a convex mirror using a convex lens**
- **To find the focal length of a concave lens using a convex lens**
- **To find the refractive index of a liquid by using a convex lens and a plane mirror**

## 3. WORDS YOU MUST KNOW

Let us remember the words and the concepts we have been using in the study of this module:

- **Light:** Light is a form of energy which gives the sensation of vision when it falls on the retina of the eye.
- **Ray of light:** The straight line path along which light travels is called a ray of light. Light rays start from each point of a source and travel along straight line until they strike an object or a surface separating two media.
- **Beam of light:** A group of rays of light is called a beam of light.
- **Parallel beam of light**: If all the rays of light in the group are parallel to each other then the beam is said to be a parallel beam of light.

- **Converging beam of light**: If the rays of light in the group come closer to each other i.e. converge to a point, then the beam is said to be a converging beam of light.
- **Diverging beam of light**: If the rays of light in the group move away from each other i.e. diverge then the beam is said to be a diverging beam of light.
- **Transparent medium:** A medium through which light can pass freely over large distance is called a transparent medium. Glass and still water are some examples of transparent objects
- **Opaque medium:** A medium through which light cannot pass is called an opaque medium. Wood and metals are some examples of opaque objects.
- **Real image:** If the rays of light after reflection from a mirror actually meet at a point i. e. the reflected beam is a converging beam, then the image is said to be real image.
- **Virtual image:** If the rays of light after reflection from a mirror do not actually meet at a point but meet on producing backwards i.e. the reflected beam is a diverging beam then the image is said to be a virtual image.
- **Refractive index**: (n) = speed of light in vacuum/ speed of light in the medium
- **Relative refractive index:** Consider light going from medium 1 to medium 2

Then refractive index of medium 2 with respect to medium 1 is

$$n_{21} = (n_2/n_1) = v_1 / v_2$$

- **Laws of Refraction of light:**

i) The incident ray, the refracted ray and the normal at the point of incidence, all lie in the same plane.

ii) The ratio of sine of the angle of incidence to the sine of the angle of refraction *r, for two media* is constant for a given wavelength of light and is equal to the refractive index of the second medium with respect to first medium.

- **Critical angle:** That angle of incidence in denser medium for which the refracted ray just grazes the interface of two media is called the critical angle.

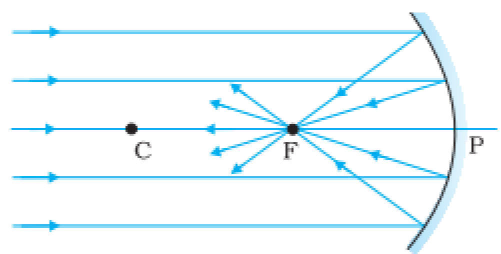
- **Total internal reflection:** The phenomenon in which a ray of light travelling from a denser medium to rarer medium at an angle of incidence greater than critical angle is totally reflected back into the same medium is called total internal reflection.

- **Conditions for total internal reflection:**
  1) Light must travel from optically denser medium to optically rarer medium.
  2) Angle of incidence must be more than critical angle

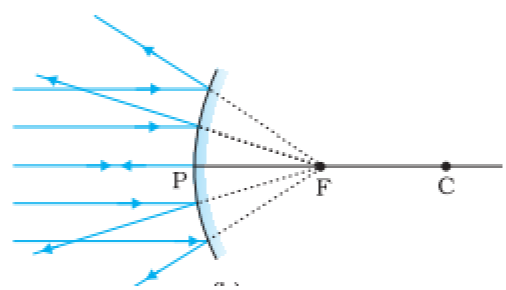
- **Relation between refractive index and critical angle:**

  $n = 1/\sin i_c$

- **Convex** mirror if the reflecting surface convex
- **Aperture** or the lateral size of **the mirror or lens**
- **Pole or vertex-** Center of the mirror
- **Optical center:** Point in a lens through which a ray of light passes through un-deviated
- **Focus:** The reflected rays converge at a point F on the principal axis of a concave mirror

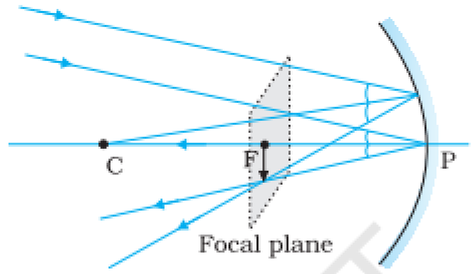



For a convex mirror, the reflected rays appear to diverge from a point F on its principal axis




The point F is called the principal focus

- **Focal length:** The distance from the pole/center of the mirror to the focus is the focal length.
- **Focal plane:** The plane perpendicular to the principal axis containing the focus is called the focal plane




- **Real image:** If rays emanating from a point actually meet at another point after reflection and/or refraction, that point is called the image of the first point. The image is real if the rays actually converge to the point;
- **Virtual image:** Virtual if the rays do not actually meet but appear to diverge from the point when produced backwards.

  An image is thus a point-to-point correspondence with the object established through reflection and/or refraction

- **Object distance-** (u)- distance of the object from the pole
- **Image distance-** (v)- distance of the image from the pole
- **Linear Magnification-** $m = \frac{\text{size of image}}{\text{size of object}} = -\frac{v}{u}$
- **Angular magnification-** $\frac{\text{angle subtented by the image}}{\text{angle subtented by the object if placed at the same position as the image}}$
- **Rectangular glass slab-** A parallel sided glass cuboid
- **Equilateral glass prism-** A glass prism with refracting surfaces at $60^0$
- **Lens-** A thin lens is a transparent optical medium bounded by two surfaces; at least one of which should be spherical,
- **Principal axis of a lens** is the line joining centre of curvature of the two surfaces.
- **Principal focus** is the point where rays parallel to the principal axis focus after passing through the lens (convex) or appear to come from after passing through the lens (concave).
- **Focal length of a lens** is the distance between optical centre of lens and focus.
- **Intercepts of a graph**: If a graph cuts x-axis and y-axis, then lengths between origin and points of interception are intercepts of the graph.

## 4. INTRODUCTION

Experiments in the laboratory are very important. They help us to understand what we learn in our theory.

In this module, we will try and understand the principle behind the optics experiments.

## 5. APPARATUS TO DO OPTICS EXPERIMENTS IN THE LABORATORY

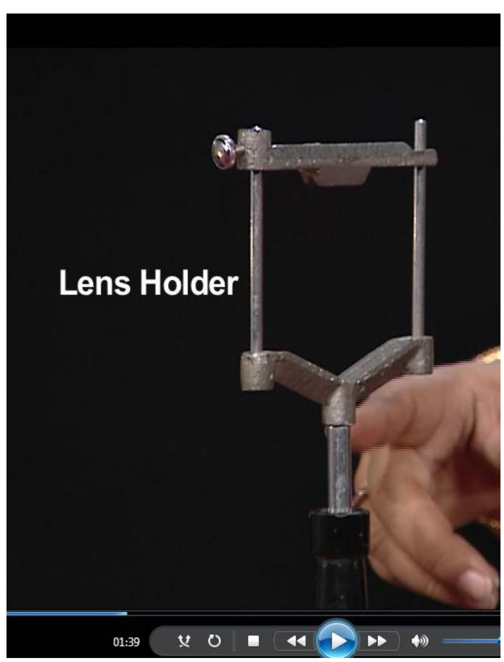
- **Optical bench**

The *optical bench* is commonly used in physics labs today, and consists of a long, rigid member with a linear scale applied to it. Holders for needles, light sources lenses and screens are placed on the apparatus so that image formation can be observed.

It is usually a metal or a wooden bench with sliders. Pins or lens/mirror holders can be placed on the sliders

A cm scale is engraved or marked on the optical bench. Usually an optical bench is 100 cm to 150 cm long


- **Lens/mirror holders**



- **Pins or needles:** A set of thick needles sharp at one end. We need at least two as one pin is made the object and the second becomes an image locater pin.

  By image locator we mean it is used in a way so that by removal of parallax it can help us find the location of the image.

**https://4.imimg.com/data4/KH/PF/MY-13492542/optical-bench-500x500.jpg**

Uprights have a pointer to read the position on the scale

Up rights may not be vertical so the distance between the object pin head and the mirror/lens may not be the same as read from the scale attached to the bench. The error is called bench error.

**Length of a knitting needle is read both by the bench scale and by placing it between the needle head and center of mirror/lens. The difference in the readings gives the error and hence correction in observed readings can be made.**

- **Screens**

  The images that are bright can be obtained on a screen, and hence we can find the image distance

- **RAY DIAGRAMS**

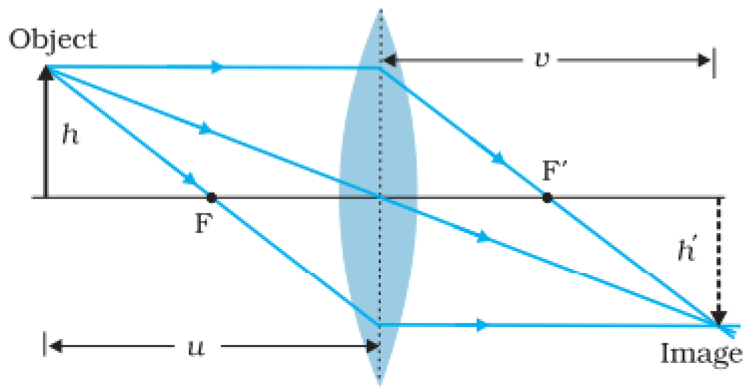
  It is convenient to choose any two of the following rays:

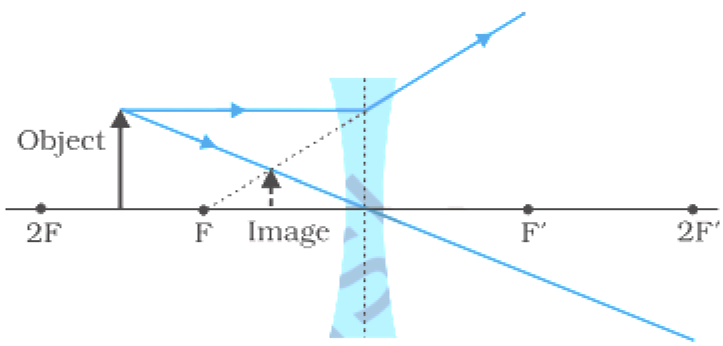
**(i)** A ray emanating from the object parallel to the principal axis of the lens after refraction passes through the second principal focus F′ (in a convex lens) or appears to diverge (in a concave lens) from the first principal focus F.

**(ii)** A ray of light, passing through the optical centre of the lens, emerges without any deviation after refraction.

**(iii)** A ray of light passing through the first principal focus (for a convex lens) or appearing to meet at it (for a concave lens) emerges parallel to the principal axis after refraction.

Illustration of these rules for a convex and a concave lens are respectively.




You should practice drawing similar ray diagrams for different positions of the object with respect to the lens and also verify that the lens formula.

**Ray diagrams are necessary as they help us in imagining the rays which we cannot see.**

**Always draw ray diagrams, with rays from the left side of the pole or optical center, remember to draw the principle axis**

- **PARALLAX**

**Parallax is the lateral displacement between two objects in the same line of sight but not in the same location. It can be observed by using one eye and closing the other.**

**Moving our head sideways will show parallax between two objects initially seen in the same line of sight.**

**Removal of parallax- If two objects are in the same position, there will be no parallax.**

**The term is used in laboratory optics experiments. The image position is obtained by removal of parallax between the image and the image locator pin.**

- **Practice this by closing one eye**
- **Holding index finger of your hands one behind the other in front and away from your body**
- **See them along a straight line**
- **Move your head sideways, the two fingers will seem to move away from each other. this is parallax**
- **Now bring the fingers closer, repeat still with one eye closed**
- **There will be reduction in parallax and finally when the two fingers are in the same place touching each other there is no parallax**

- **FORMULA**

**The mirror equation-**

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

The size of the image relative to the size of the object is another important quantity to consider. We define linear magnification (m)

$$m = \frac{\text{the height of the image (h}')}{\text{height of the object (h):}} = -\frac{v}{u}$$

This holds good for all cases concave and convex mirrors

Here again it must be remembered that each point on an object gives out infinite number of rays. All these rays will pass through the same image point after refraction at the lens.

**The lens formula**

$$\frac{\mathbf{1}}{\mathbf{f}} = \frac{\mathbf{1}}{\mathbf{v}} - \frac{\mathbf{1}}{\mathbf{u}}$$

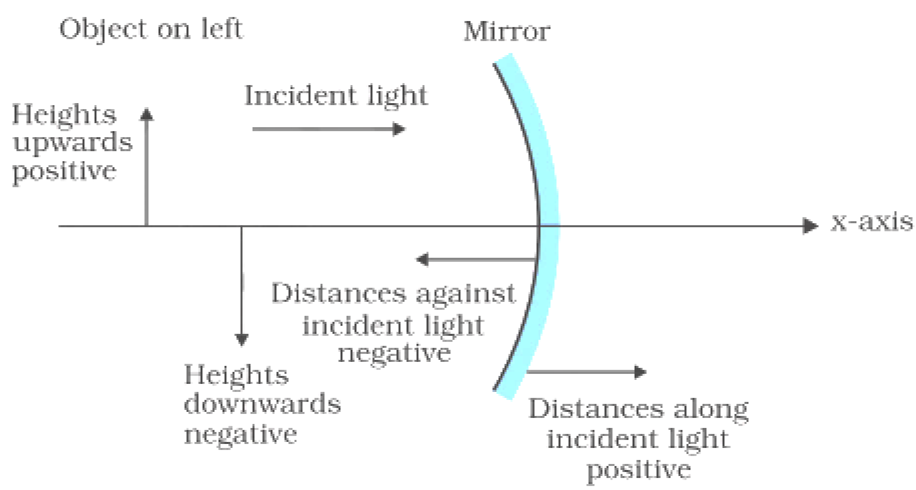
Notice the **negative sign** between the two terms of the equation on the right hand side.

Magnification (m) produced by a lens is defined, like that for a mirror, as the ratio of the size of the image to that of the object. Proceeding in the same way as for spherical mirrors, it is easily seen that for a lens

$$m = \frac{\text{the height of the image (h}')}{\text{height of the object (h)}} = \frac{v}{u}$$

- **SIGN CONVENTION**

We follow the **Cartesian sign convention**. According to this convention,




- All distances are measured from the pole of the mirror or the optical centre of the lens.
- The distances measured in the same direction as the incident light are taken as positive and those measured in the direction opposite to the direction of incident light are taken as negative
- The heights measured upwards with respect to x-axis and normal to the principal axis (x-axis) of the mirror/ lens are taken as positive
- The heights measured downwards are taken as negative.

**With a common accepted convention, it turns out that a single formula for spherical mirrors and a single formula for spherical lenses can handle all different cases.**

- **GRAPHS**

**Graphs can be plotted between v-u showing the dependence of image distance v on object distance u, or 1/u-1/v with suitable choice of quadrant. According to the sign convention, we can find the value of focal length of mirrors and lenses.**

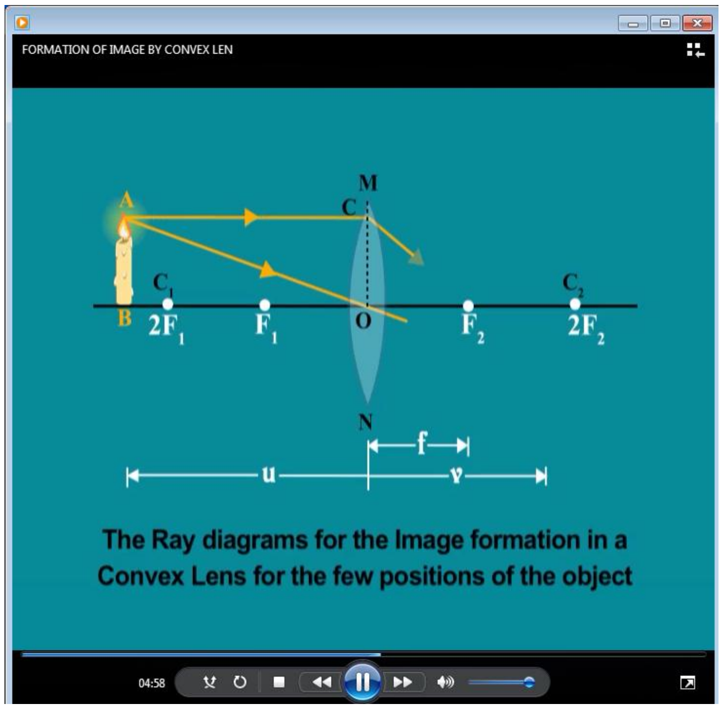
## 6. THE EXPERIMENTS

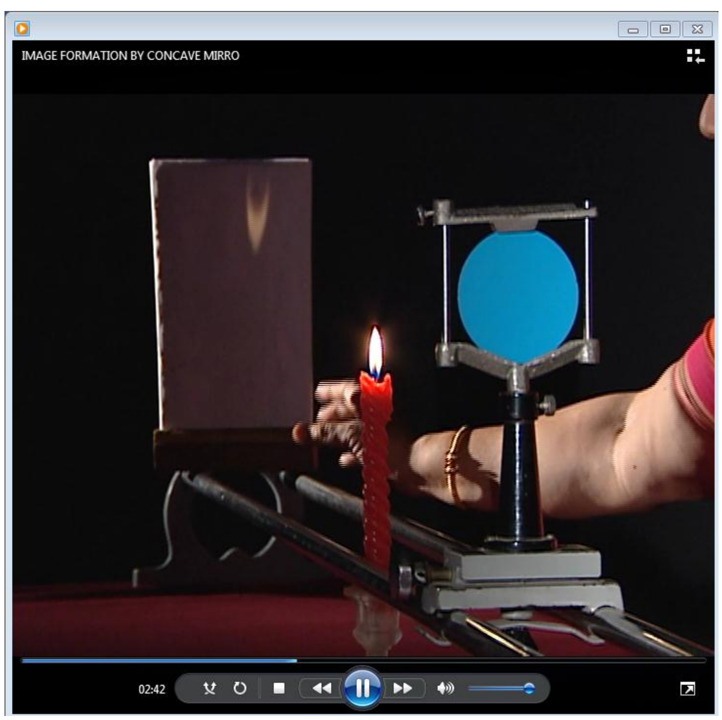
### a) To Study the nature and size of image formed by a convex lens and concave mirror using a candle and a screen

This is very easy to do (Here we have only given reference to the videos explaining the experiment)

**APPARATUS REQUIRED:** **Optical bench, convex lens, concave mirror, Candle, screen**

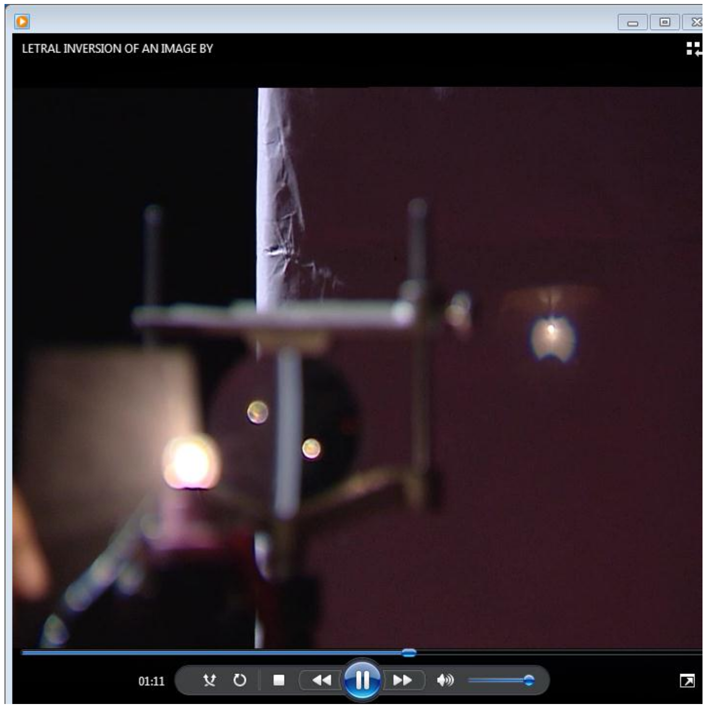
**Watch the video and study the variation of image with change in distance of candle from the lens and the mirror**



**Formation of image by a convex lens and concave mirror see video**

**Lateral inversion of the image**




**The image not only inverted that is object becomes upside down. There is lateral inversion as well.**

## DISCUSSION

- **Why does the image size change with distance from the object to the lens or mirror?**
- **What is lateral inversion as seen in the video?**
- **Would lateral inversion be there for the virtual image formed by convex lens and concave mirror?**
- **What about the formation of image by concave lens and convex mirror?**
- **Can we use the above apparatus to study image formed in convex mirror? Concave lens? give a reason for your answer**

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

**Apparatus required**

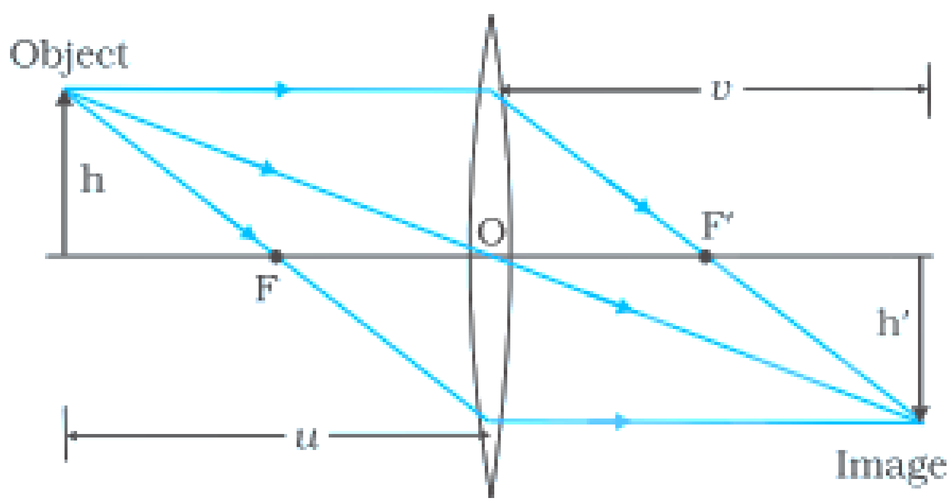
- An optical bench,

- Two sharp-edged needle (pins),
- Convex lens of less than 20 cm focal length,
- Three uprights (with clamps),
- A lens holder
- Index needle (may be a knitting needle),
- Metre scale
- Spirit level.

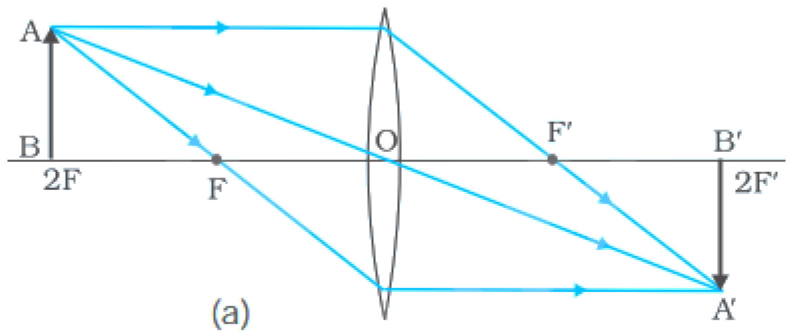
**Principle**

**A real inverted image is formed by a convex lens. The image locator pin can find the position of the image by method of removal of parallax.**

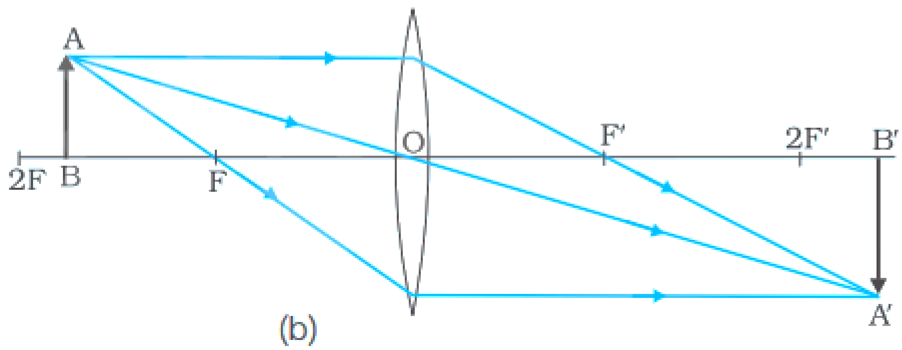
**Ray diagram**




**Most books in general show the rays ending at the image, actually there is no way they would stop there the image is just an intersection of reflected or refracted rays.**




(a)




(b)

For an object placed at a distance u from the optical centre of a thin convex lens of focal length f, a real and inverted image is formed on the other side of the lens at a distance v from the optical centre.

The relation between these distances is:

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

According to the new **Cartesian sign convention**

u is negative but

v is positive

Therefore the

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

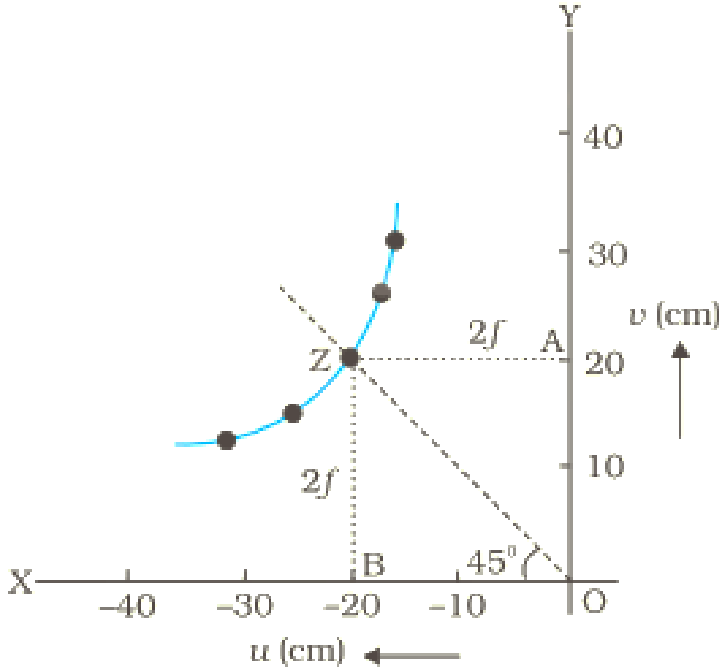
takes the following form for magnitudes of u and v.

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

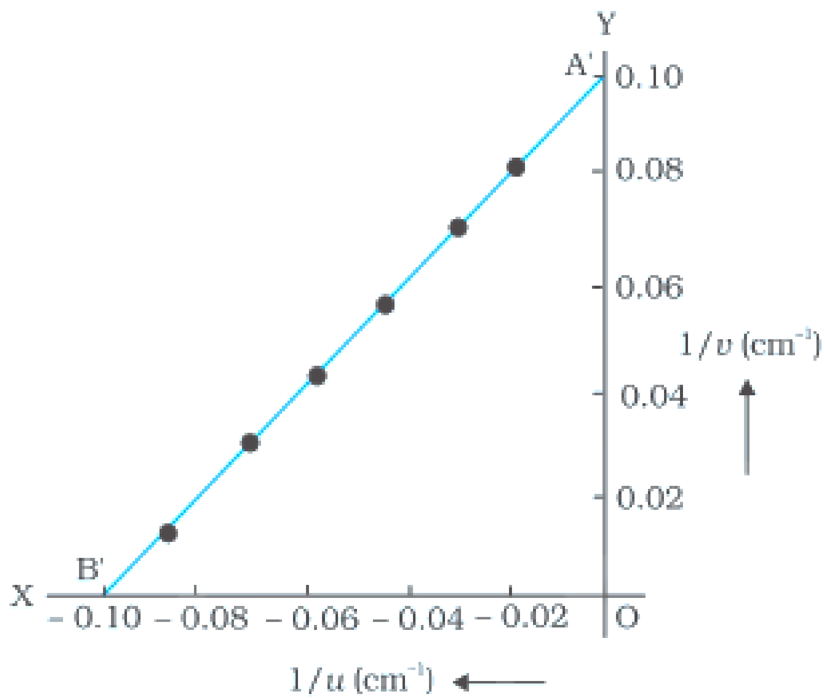
**Or**

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

In this result the positive values of u and v are substituted.




**U versus v graph for convex lens**




$1/v$ versus $1/(u)$ graph not to scale shows that $\frac{1}{v}$ versus $\frac{1}{u}$ graph is a straight line of negative slope.

If $\frac{1}{v}$ **or** $\frac{1}{u}$ equals zero the other equals zero,

Then the intercepts of the graph on both axes are $\frac{1}{f}$

Graph of u versus v is a hyperbola. When u = v, then each equals 2f.

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

shows that **values of u and v are interchangeable**.

When an object (say, a pin) is placed in front of a thin convex lens at a distance equal to 2f, a real and inverted image of same size as that of the object is formed at a distance equal to 2f on the other side of the lens

If the object's position lies in between distance 2f and distance f from the optical centre of the lens then a real, inverted and magnified image is formed at a point beyond 2f from the optical centre on the other side of the lens

Thus, by measuring the distances u and v, the focal length of the convex lens can be determined using the connecting relation

The focal length of the lens may also be determined by plotting graphs between u and v or between 1/u and 1/v.

**Procedure**

1. Obtain approximate value of the focal length of the thin convex lens by focusing the image of a distant object. It can be found by obtaining a sharp image of a distant tree on a screen, say a plane wall, or a sheet of paper placed on the other side of the lens and measuring the distance between the lens and the image with a scale.

   This distance is a rough estimate of the focal length, f of the convex lens.

   **This will help in organizing a suitable optical bench and object distances.**

2. Place the optical bench on a rigid table or on a platform, and using the spirit level, make it horizontal with the help of leveling screws provided at the base of the bench.

   **This will keep the imaginary symmetrical line the principal axis parallel to the table top**

3. Clamp the convex lens on an upright and mount it vertically almost near to the middle of the optical bench such that its principal axis is parallel to the optical bench.

   **In this position, the lens would lie in a plane perpendicular to the optical bench.**

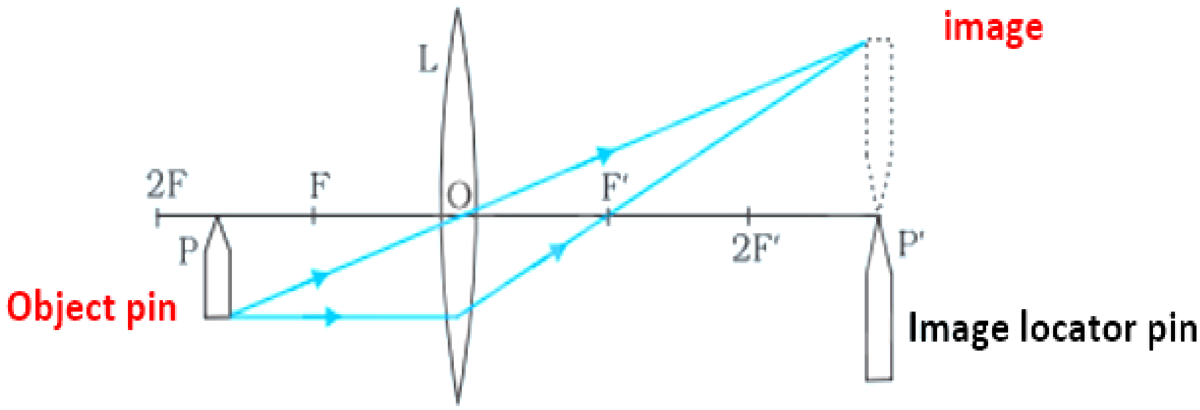
4. For the determination of the bench error, bring a mounted pin close to the lens. Adjust a sharp-edged knitting needle would also serve the purpose) horizontally such that its one end touches one of the curved surfaces of the lens and the other end touches the tip of the pin.

   **Note the positions of the two uprights on the scale provided on the optical bench.**

   **The difference of the two would give the observed length of the index needle.**

   Find index correction for both the pins.

5. Place the vertically mounted sharp pins P and P’ on left and right hand sides of the lens respectively. Adjust the pins P and P′ so that the heights of the tips of these pins become equal to the height of the optical centre O of the lens from the base of the optical bench.




Schematic arrangement of pins for finding the focal length of a convex lens

6. Displace the object pin P (on left side of the lens) to a distance slightly less than 2f from the optical centre O of the lens. Locate the position of the real and inverted image on the other side of the lens above the image pin P′.
7. **Using the method of parallax, adjust the position of the image pin P′ such that the image of the object pin P coincides with the image pin P′.**

Note: **As the value of u changes from 2f to f, v changes from 2f to infinity. Since the values of u and v are interchangeable, i.e., the object and image are two conjugate points, this means interchangeable.**

**Therefore it is clear that complete range of values for both u and v between f and infinity are obtained for a movement of the object pin over the range 2f to f.**

8. Note the upright position of the object pin, convex lens and image pin on the optical bench and record the readings in an observation table.
9. Move the object pin P closer to the optical centre O of the lens (say by 2 cm or 3 cm). Repeat the experiment and record at **least six sets of readings** for various distances of object pin between f and 2f from the lens.

## OBSERVATIONS

1. Approximate focal length of the convex lens = ... cm
2. Length of the index needle as measured by the metre scale, L0 =... cm
3. Thickness of the thin convex lens (given), t = ... cm
4. Actual length between the optical centre O of the lens and tip of the pin, l 0 = L0 + t/2 = ... cm
5. Observed length of the index needle, l′ 0 = Distance between the centre of convex lens and tip of the object pin = Position of lens upright – position of object pin upright on the scale. = ... cm – ... cm =...cm

6. Index correction for object distance, eo = l 0 – l′ 0 = cm; similarly for image pin, ei = l i – l′ i = ...cm

| Sl. No. | Lens upright a (cm) | Object pin upright b (cm) | Image pin upright c (cm) | Observed u = a – b (cm) | Observed v = a – c (cm) | Corrected u = Observed u + $e_o$ (cm) | Corrected v = Observed v + $e_i$ (cm) | $\frac{1}{u}$ cm$^{-1}$ | $\frac{1}{v}$ cm$^{-1}$ | $f \quad \frac{uv}{u \quad v}$ cm | Δ f (cm) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | |
| 2 | | | | | | | | | | | |
| -- | | | | | | | | | | | |
| 6 | | | | | | | | | | | |
| | | | | | | | | | Mean | | |

## CALCULATIONS

**A. Calculate f using the formula with corrected values of u and v.**

**B. Plot u – v Graph**:

**Take u along x-axis and v along y-axis. Scales of x- and y-axis should be same. Draw a hyperbola curve for various values of u and v**

**Note**

**That six sets of readings for u between f and 2f, give you 12 points on the graph by interchanging values of u and v**.

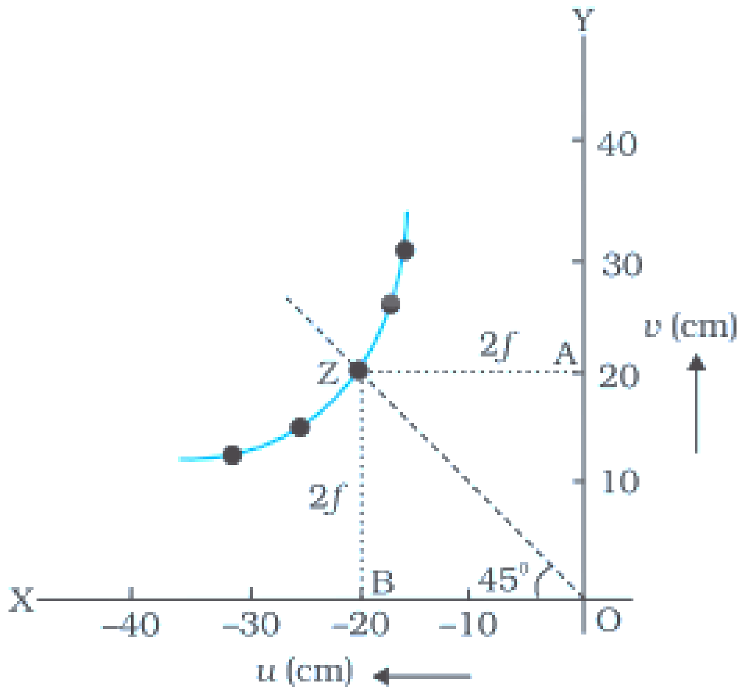
The point u = 2f; v = 2f is shown as point Z on u – v graph

The point Z is the point of intersection of a line OZ bisecting the angle ∠XOY with hyperbola.

Draw two lines AZ and BZ perpendicular to Y- and X-axis, respectively.

The lengths AZ and BZ are both equal to distance 2f.

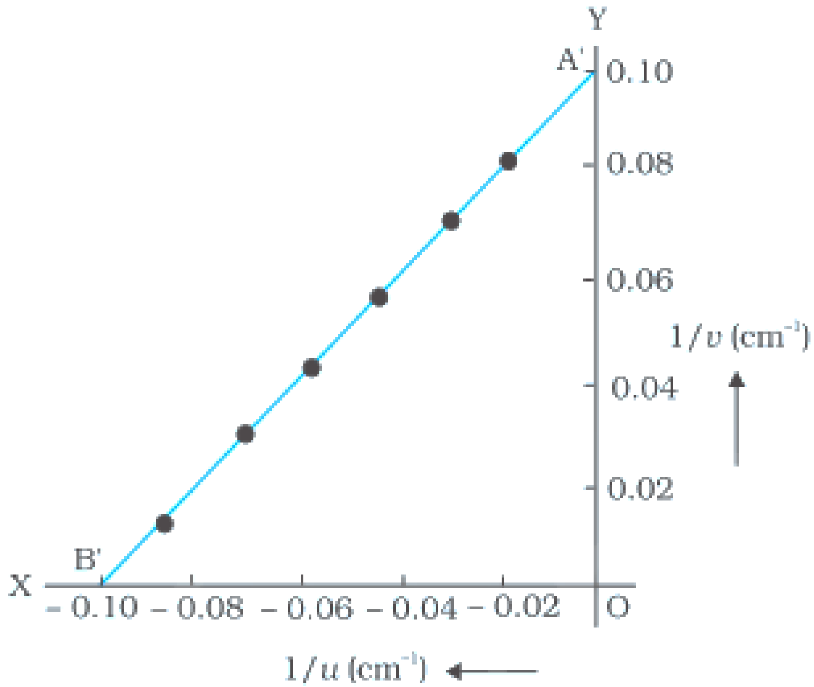
Thus by plotting the u – v graph, the focal length of the lens can be obtained.




**C. 1/u – 1/v graph**:

Draw a straight line graph by plotting 1/u along the X-axis and 1/v along the Y-axis
Both the intercepts OA′ (on y-axis) and OB′ (on X-axis) will be equal to distance 1/f.

Intercept OA′ (= 1/f) on y-axis =...$cm^{-1}$` Intercept OB′ (= 1/f) on x-axis =...$cm^{-1}$
Mean focal length (f) of the convex lens = cm




## RESULT

The focal length of the given converging thin convex lens:

(i) from calculations as shown in Observation Table E10.1 f ± f = ...cm (here f is mean value of the focal length)

(ii) from u – v graph =...cm, and

(iii) from 1/u – 1/v graph =...cm.

## THINK ABOUT THESE WHY?

- **The uprights supporting the optical elements should be rigid and mounted vertically.**
- The aperture of the lens should be small otherwise the image formed will not be distinct.
- Eye should be placed at a distance more than 25 cm from the image needle.
- 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 optical centre of the lens are not at the same horizontal level.
- The image and object needles should not be interchanged during the performance of the experiment, as this may cause change in index corrections for object distance and image distance.
- The tip of the inverted image of the object needle must touch the tip of the image needle and must not overlap. This should be ensured while removing the parallax.

- The general instructions to be followed in all optical bench experiments (as given in the description of optical bench) must be taken care of.
- The corrected values of the distances u and v must be put in the formula for calculating f and then a mean of 'f' should be taken. Calculations for f must not be made using the mean values of u and v.
- Parallax should be removed carefully
- In plotting 1/v versus 1/u graph, if scales for the two axes are not same, then the straight line graph may (rather will) not be at 45° to x-axis. This may result in confusions and error in drawing the graph. Keeping the scale same and drawing the best fit graph at 45° to x-axis is the best method. Then, due to inherent errors in measurement 1/f on both axes may be a bit too large or a bit too small.

## TRY THESE

**i.) Draw the ray diagram for image formation in case of a convex lens for position of object varying from infinity to optical centre.**
**ii.) What are the differences between the image formed by a convex lens and a concave lens?**
**iii.) How does the focal length of a thick convex lens differ from that of a thin lens?**
**iv.) How can you recognise a convex lens, a circular glass slab and a concave lens, without touching them?**
**v.) Where does the centre of curvature of the plane surface of a plano-convex lens lie?**
**vi.) Define the principal axis of a plano-convex lens?**
**vii.) How does the focal length of a convex lens change if it is dipped in water?**
**viii.) What is the relation between focal length and radius of curvature of a plano-convex lens?**
**ix.) Can a virtual image produced by a lens be inverted?**
**x.) Can we have two convex lenses of same focal length but different size?**
**xi.) Draw a graph by plotting u v along y-axis and u + v along x-axis. Determine focal length f of the convex lens from the slope.**

## TRY AND EXPLAIN

**You have a glass vase**

**an open window at some distance from it, and a magnifying glass of 50 mm diameter. (A hand magnifying glass)**

**With your 30 cm scale find the rough focal length of the magnifying**

**glass in air.**

**Then dip it in water by left hand and a white plastic bag (folded with a 5 cm 5 cm card in it to make a white screen) by right hand.**

**Focus image of a distant object on the screen by adjusting the position of the screen.**

**Is the rough focal length in water bigger or smaller than that in air?**

**Let a friend measure the focal length in water and find the ratio of the two**.

**c) To find the focal length of a concave mirror by plotting graphs between u and v or between 1/u and 1/v.**

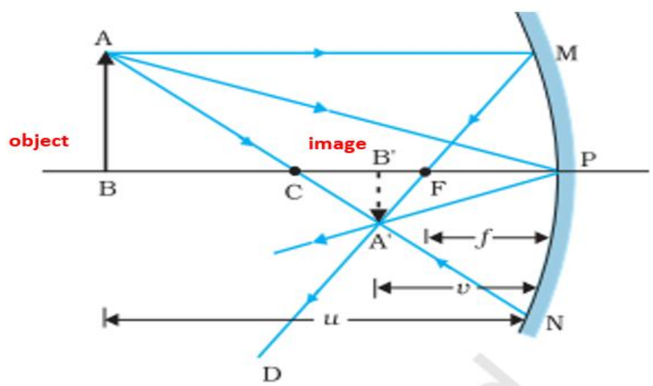
**Apparatus required**

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

**Principle**

**A real inverted image is formed by a concave mirror. The image locator pin can find the position of the image by method of removal of parallax. The image is formed on the same side of the mirror.**

**Ray diagram**

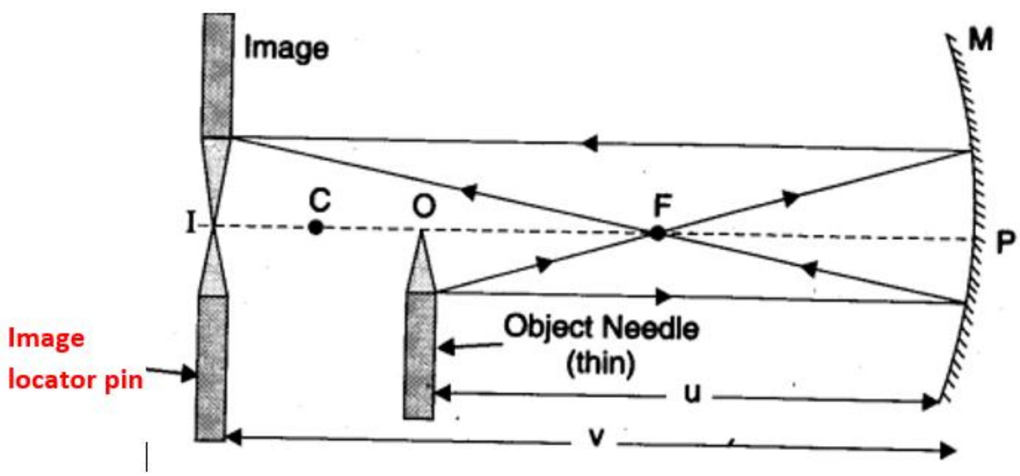



**Ray diagram showing image formation by a concave mirror**

**Notice the image is formed on the same side as the object it is real and will change in magnification depending upon the distance of the object pin from the mirror.**

**Important**

- **Rough focal length of the mirror should be taken by focusing rays from a distant object on a wall or on a screen.**
- **Out of the two pins one is to be treated as object pin and the other as image locator pin**
- **Both the pins will give images.**
- **So in order to proceed with the experiment we must distinguish between the object pin and the image locator pin. So we put a small piece of paper on one pin, we could also put paint on one.**




**Formula used**

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

**Procedure**

1. **Find the rough focal length of the concave mirror, this means estimates the focal length of the mirror my getting a clear image of a far off object on a wall and measuring the distance of the wall from the center of the mirror.**

2. Place the concave mirror on the zero mark on the optical bench
3. **Find the index error and record the same**
4. Select a pin to be the object, place it at a distance about 2 f from the mirror. Remember to adjust the height of the pin. **Place a small piece of paper on the pin to identify it as the object.**

5. **Remove parallax between the pin and its image. This position will be 2f and half the distance from zero mark will be the focal length.**
6. Now choose three value of u less than 2 f and three values more than 2 f, this will help you organize your work.
7. **Find the image position corresponding to object position using the image locator pin.**

## OBSERVATIONS

1. Approximate focal length of the concave mirror = ... cm
2. Length of the index needle as measured by the metre scale, L0 =... cm
3. Thickness of the thin concave mirror (given), t = ... cm
4. Actual length between the pole O of the mirror and tip of the pin, l 0 = L0 + t/2 = ... cm
5. Observed length of the index needle, l′ 0 = Distance between the pole and tip of the object pin = Position of lens upright – position of object pin upright on the scale. = ... cm – ... cm =...cm
6. Index correction for object distance, eo = l 0 – l′ 0 = cm; similarly, for image pin, ei = l i – l′

**Make your observation table**

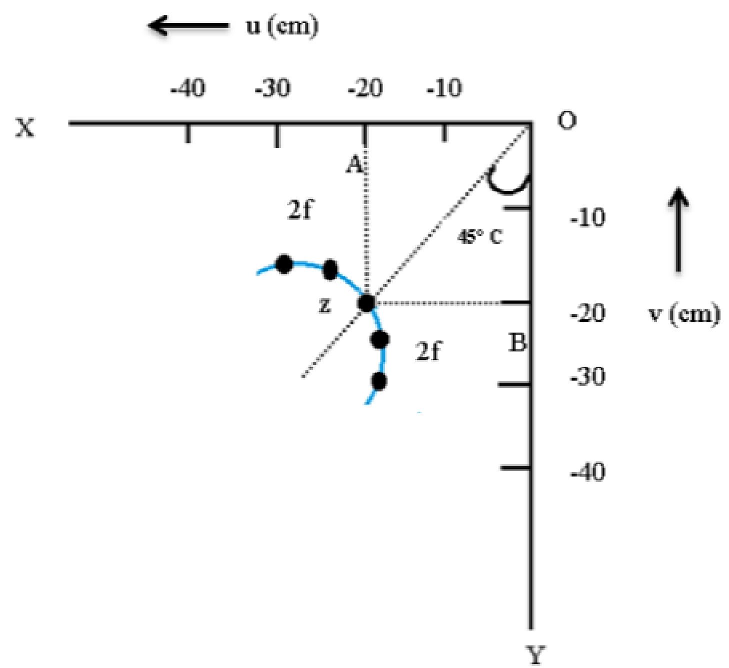
## Calculation

D. **Calculate the focal length 'f' using corrected values of u and v.**
**Use the formula**
E. **Plot u – v Graph**:

**Take u along x-axis and v along y-axis. Scales of x- and y-axis should be same. Draw a hyperbola curve for various values of u and v**

**Note:**
**That six sets of readings for u between f and 2f, give you 12 points on the graph by interchanging values of u and v.**

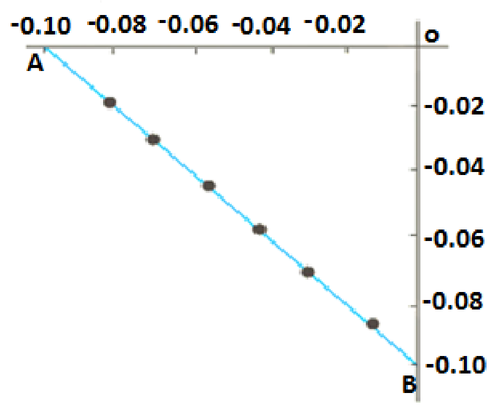
The point u = 2f; v = 2f is shown as point Z on u – v graph
The point Z is the point of intersection of a line OZ bisecting the angle ∠XOY with hyperbola.
Draw two lines AZ and BZ perpendicular to Y- and X-axis, respectively.
The lengths AZ and BZ are both equal to distance 2f.
Thus by plotting the u – v graph, the focal length of the lens can be obtained.
**Using sign convention, the graph will be in the third quadrant**




**C 1/u – 1/v graph**:
Draw a straight line graph by plotting 1/u along the X-axis and 1/v along the Y-axis
Both the intercepts OA′ (on y-axis) and OB′ (on X-axis) will be equal to distance 1/f.

Intercept OA′ (= 1/f) on y-axis =...$cm^{-1}$` Intercept OB′ (= 1/f) on x-axis =...$cm^{-1}$
Mean focal length (f) of the convex lens = cm

This can be drawn in **the third quadrant to account for object and image distances being negative, by sign convention.**



## RESULT

**The focal length of the given converging thin convex lens:**

i.) **from calculations f is mean value of the focal length) =… cm**

ii.) **from u – v graph =...cm, and**

iii.) **from 1/u – 1/v graph =...cm.**

## THINK ABOUT THESE WHY?

- **The uprights supporting the optical elements should be rigid and mounted vertically.**
- **The aperture of the mirror should be large otherwise the image formed will not be distinct.**
- **Eye should be placed at a distance more than 25 cm from the image locator needle.**
- **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 optical centre of the lens are not at the same horizontal level.**
- **The image and object needles should not be interchanged during the performance of the experiment, as this may cause change in index corrections for object distance and image distance.**
- **The tip of the inverted image of the object needle must touch the tip of the image needle and must not overlap. This should be ensured while removing the parallax.**
- **The general instructions to be followed in all optical bench experiments (as given in the description of optical bench) must be taken care of.**
- **The corrected values of the distances u and v must be put in the formula for calculating f and then a mean of focal should be taken. Calculations for f must not be made using the mean values of u and v.**
- **Parallax should be removed carefully**
- **In plotting 1/v versus 1/u graph, if scales for the two axes are not same, then the straight line graph may (rather will) not be at 45° to x-axis. This may result in confusions and error in drawing the graph. Keeping the scale same and drawing the best fit graph at 45° to x-axis is the best method. Then, due to inherent errors in measurement 1/f on both axes may be a bit too large or a bit too small.**

## EXAMPLE:

**A coin, 0.4 m below the surface of water, is viewed through a simple converging lens of focal length 3 m. The lens is kept at 0.2 m above the water surface such that**

**the coin lies on the optical axis of the lens. Find the image of the coin seen by the observer. The refractive index of water is 4/3**

**SOLUTION:**

The apparent depth of the coin from the water surface is =

$$\frac{real\ depth}{refractive\ index\ of\ water}$$

$$= \frac{0.4}{4/3}$$

= 0.3 m

Lens is 0.3 m high from the water surface. Hence the distance of the apparent position of the coin from the lens is $u = 0.2 + 0.3 = 0.5\ m$

Now, from the lens formula

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

$$\frac{1}{v} - \frac{1}{-0.5} = \frac{1}{3}$$

$$\frac{1}{v} = -\frac{5}{3}$$

$$v = -0.6\ m$$

The lens forms the image of the coin at **0.6m** below the lens, that is, at the actual position of the coin.

**EXAMPLE:**

**Two objects A and B, when placed in turn infront of a concave mirror of focal length 7.5 cm, give image of same size. If the size of A is two times the size of B, and A is placed at a distance of 15 cm from the mirror, find the distance of B from the mirror.**

**SOLUTION:**

For a mirror (concave or convex), we have

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

and magnification

$$m = -\frac{v}{u}$$

for object A: $u = -15\ cm, f = -7.5\ cm$

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = -\frac{1}{7.5} + \frac{1}{15} = -\frac{1}{15}$$

$$v = -15\ cm$$

If x is the size of object and y is the size of the image, then the magnification is

$$m = \frac{y}{x} = -\frac{v}{u} = -\frac{(-15)}{(-15)} = -1$$

For object B: size of the object = x/2, size of the image of B = -x (inverted) magnification,

$$m = \frac{-x}{x/2} = -\frac{v}{u}$$

$$v = 2u$$

by the mirror formula

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

we have

$$\frac{1}{2u} + \frac{1}{u} = \frac{1}{f}$$

$$\frac{3}{2u} = \frac{1}{f}$$

$$u = \frac{3}{2}f = \frac{3}{2} \times (-7.5) = -11.25\ cm$$

The object B is at a distance of **11.25** cm in front the mirror

## 7. SUMMARY

**In this module you have learnt**

- Apparatus used in the laboratory for optics experiments
- Parallax and removal of parallax
- Study of image formation by mirrors and lenses using a candle and screen
- Use of the optical bench and two pins to determine the focal length of a bi convex lens and a concave mirror
- Plotting graphs keeping sign convention in mind and calculating focal length