REFRACTION THROUGH LENSES

Definition

A lens is a piece glass bounced by one or two spherical surfaces.

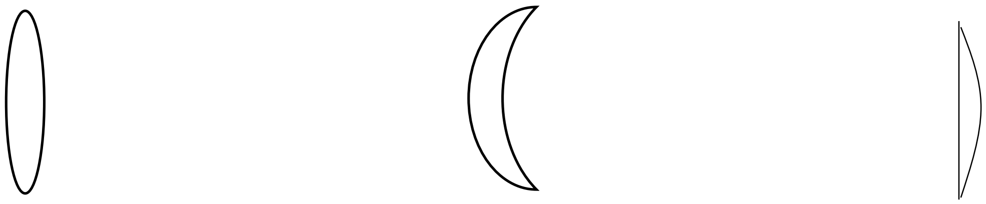
Types of lenses

1) Convex (converging) lens
2) Concave (diverging) lens

Converging (convex) lens

It is a lens which is thicker in the middle than at the edges and curves outwards.

<u>Types of convex lenses</u>

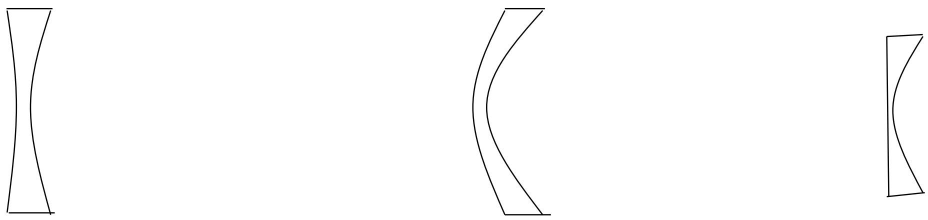


i) bi-convex ii) Converging meniscus (iii) Plano convex

Diverging (concave) lens

It is a lens which is thinner in the middle than at the edges and curves inwards.

Types of concave lenses

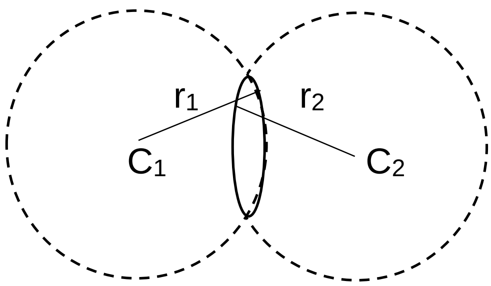


i) bi-concave ii) diverging meniscus iii) plano concave

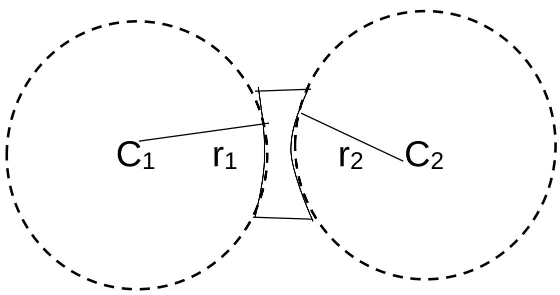
Definition of Terms Used:

1. Centres of curvature of a lens:

These are centres of the spheres to which the lens surfaces form part.



i) convex lens



ii) concave lens

Points C_1 and C_2 are the centers of curvature of the lens surfaces.

2. Radii of curvature of a lens:

These are the radii of the spheres of which the lens surfaces form part; r_1 and r_2 are the radii of curvature

3. Principal axis of a lens:

This is the line joining the centers of curvature of the two surfaces of the lens.

4. Optical centre of the lens:

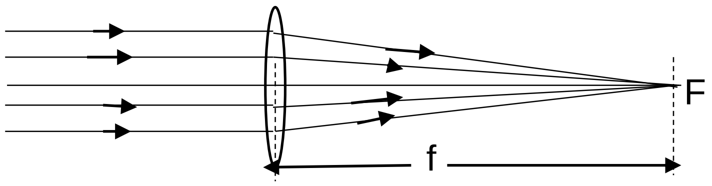
This is the mid-point of the lens surface through which rays incident on the lens pass un deviated.

5. Paraxial rays:

These are rays close to the principle axis and make small angles with the lens axis.

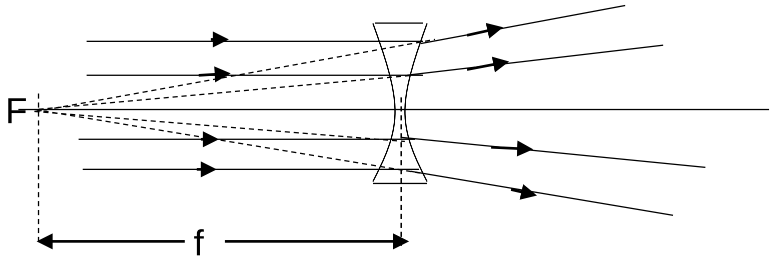
6. Principal focus (principal focus)
   (i) Principal focus (focal point) F, of a convex lens:

   It is a point on the principal axis where rays originally parallel and close to the principal axis converge after refraction by the lens.



   (ii) Principal focus (focal point) F, of a concave lens:

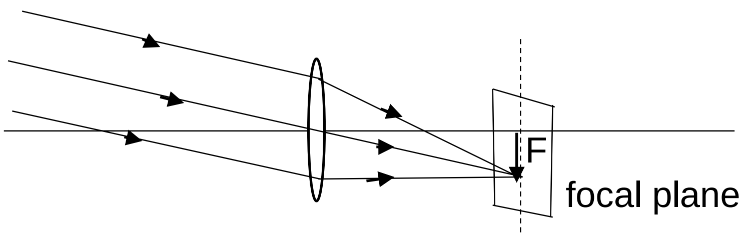
   It is a point on the principal axis where rays originally parallel and close to the principal axis appear to diverge from after refraction by the lens.



   (iii) Principal focus (focal point) F, of a lens

   This is the point on the principal axis where rays originally close and parallel to the principal axis converge to or appear to diverge from after refraction through the lens.

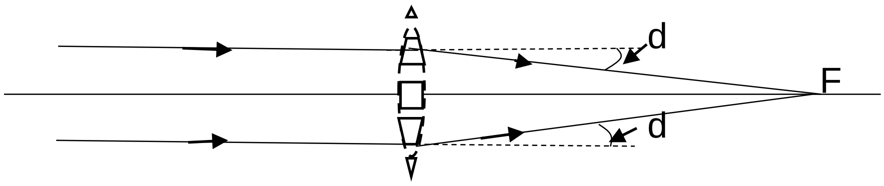
7. Focal length, f
   This is the distance between the focal point and the pole of a lens.
8. Focal plane
   This is the plane that is perpendicular to the principal axis and contains the principal focus.



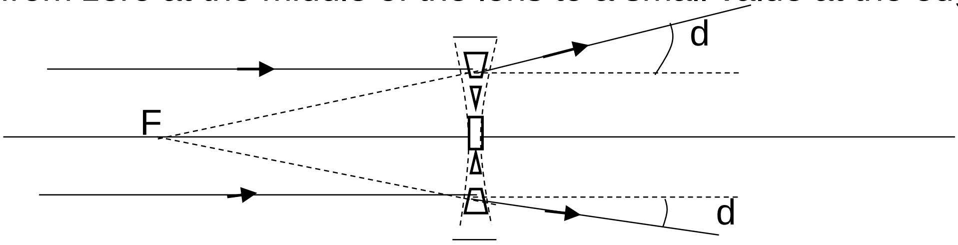
9. The power P of a lenses.
   The power of a lens, is the reciprocal of the focal length in metres.
   The S.I unit of power of a lens is Dioptres(D). A diopter is the power of a lens of focal length one metre

Action of the lens

A thin lens is regarded as made up of a large number of small angle prism whole angles.
The prism angles point outwards away from the optical center and increase from zero at the middle of the convex lens to a small value at the edge.
The deviation by a small angle prism is $d = (n - 1)$ where n is the refractive index therefore, for light incident on a path of a prism, it bends towards the base. Therefore the refracted rays converge to a common point.



For a concave lens the prism angle point towards the optical center of the lens and increase from zero at the middle of the lens to a small value at the edge.



The light incident on a path of a prism, it bends towards the base and away from the principal axis. Therefore the refracted rays appear to come from a common point.

Sign convention for radii of curvature:

For a convex lens the focal length is positive while it is negative for the concave lens. The radius of curvature is positive if the surface is convex to the less dense medium and if the surface is concave towards the less dense medium then its radius of curvature is negative.

Considering the figure above, surface A is convex to the less dense air, hence its radius of curvature is positive. Surfaces B and D are also convex to the less dense air and therefore their corresponding radii of curvature are positive. However surface C is concave to the less dense air and therefore its radius of curvature is negative.

RAY DIAGRAMS

In drawing of ray diagrams;

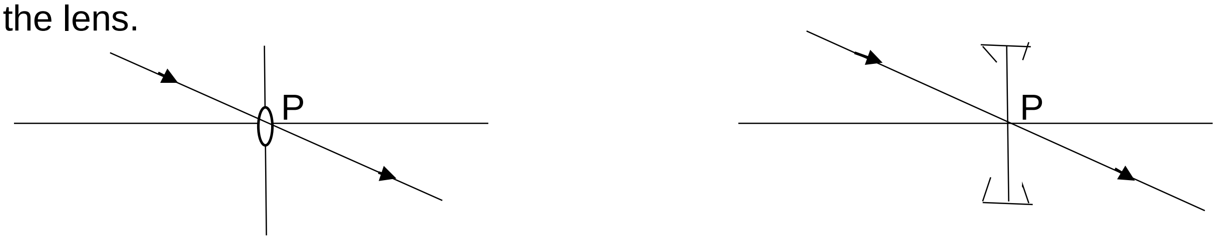
- The object is placed perpendicular to the principal axis
- All the principal rays are drawn from the same point usually the tip of the object
- The image formed is drawn perpendicular to the principal axis

Principal rays

1) A ray parallel to the principal axis is refracted to pass through the principal focus F or appear to becoming from the principal focus F, after refraction through the lens.

2) A ray passing through the principal focus F is refracted to parallel to the principal axis or a ray converging to the principal focus is refracted parallel to the principal axis

3) A ray passing through the optical center, P is not deviated after refraction through the lens.



<u>Images formed in a convex lens.</u>

(i) Object between F and P (Magnifying glass)

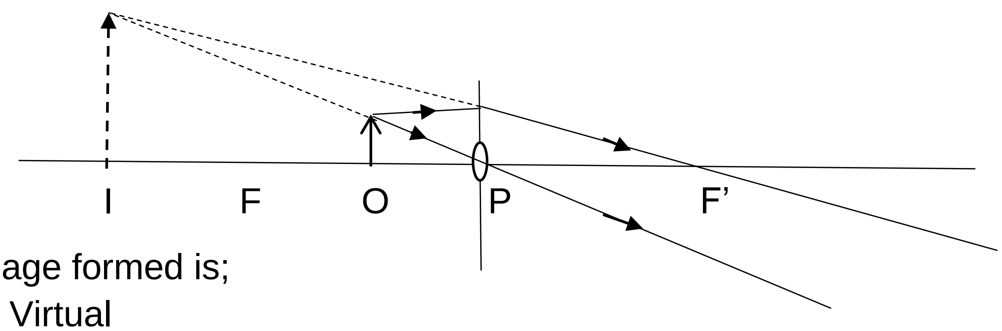
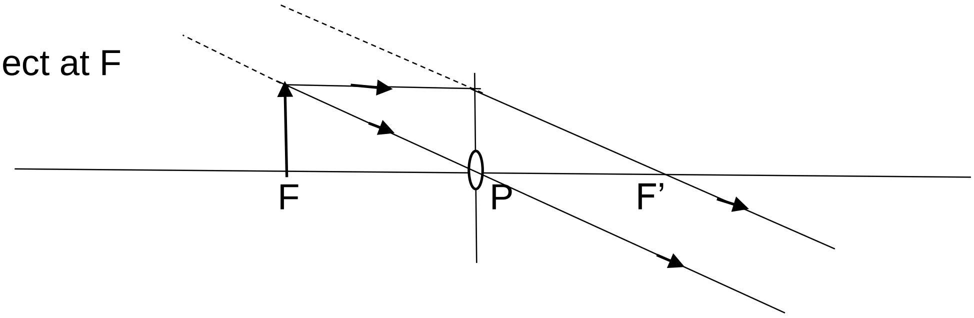


Image formed is;

- Virtual
- Upright (erect)
- Magnified
- Formed on same side as object

(ii) Object at F



- Image is formed at infinity

(iii) Object between F and 2F

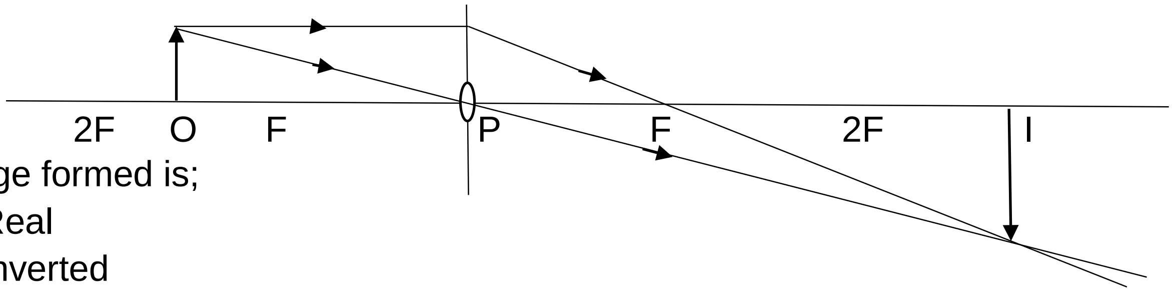


Image formed is;
- Real
- Inverted
- Magnified
- Formed beyond 2F

(iv) Object at 2F

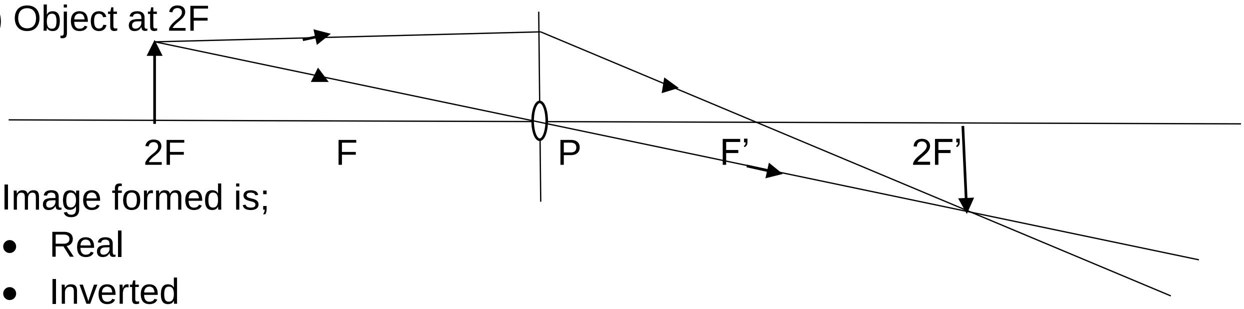


Image formed is;
- Real
- Inverted
- Same size as the object
- Formed at 2F

(v) Object beyond 2F

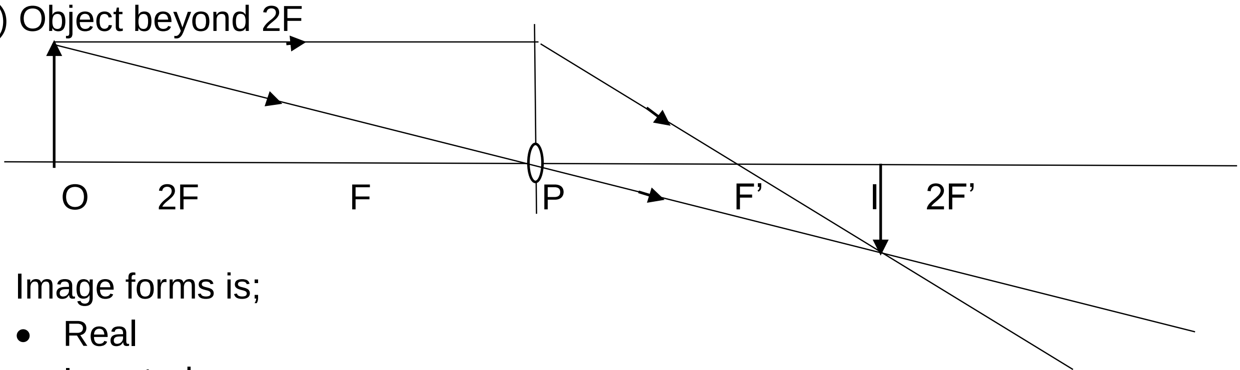


Image forms is;
- Real
- Inverted
- Diminished
- Formed between F and 2F

(vi) Object at infinity

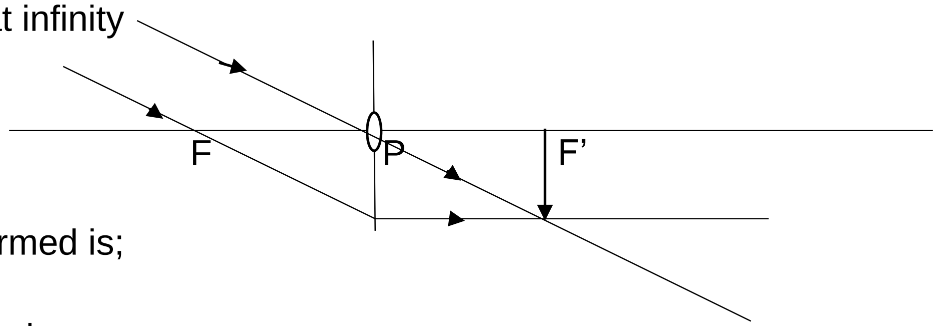
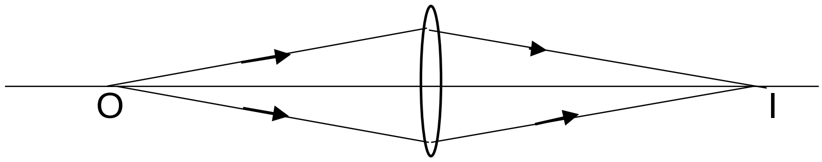


Image formed is;

- Real
- Inverted
- Diminished
- Formed at F

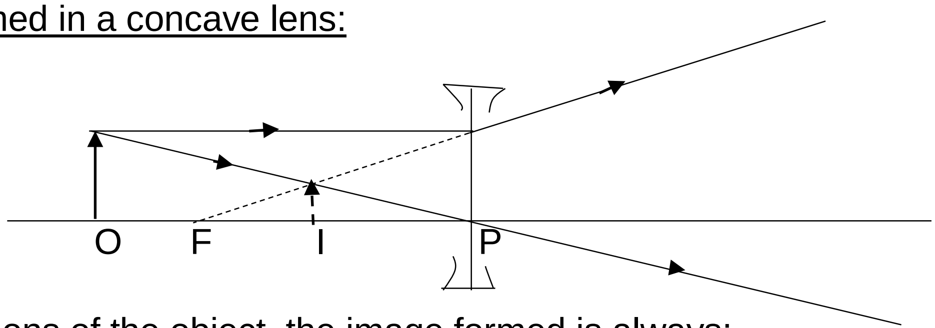
Conjugate points:

These are points on the principle axis such that when the object is placed at any one of them, a real image is formed at the other.



Suppose a convex lens forms an image of an object O at I; if the object was placed at I, the lens would form the image of the object at O, then O and I are called conjugate points

Images formed in a concave lens:



For all positions of the object, the image formed is always;

- Virtual
- Upright (erect)
- Diminished
- Formed between F and P

SIGN CONVENTION

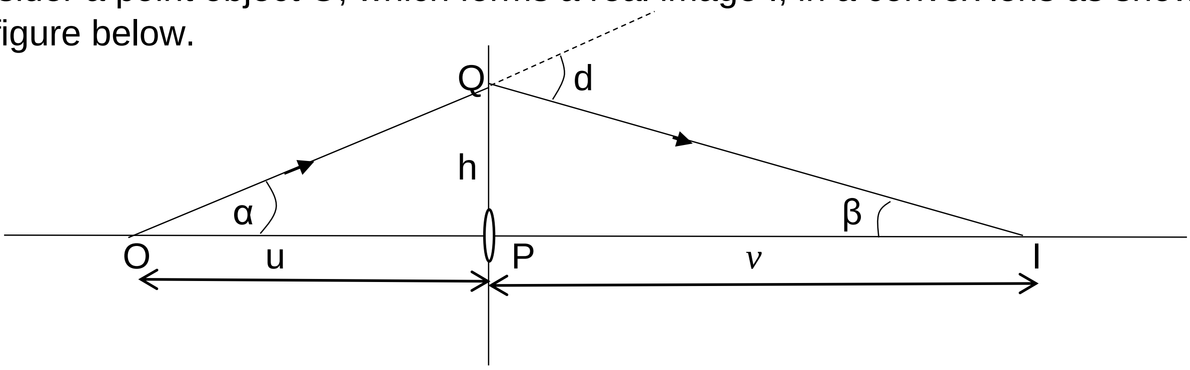
The real is positive and virtual is negative sign convention is used; in which

- real object and image distances are taken to be positive
- focal length of a convex lens is positive since it has a real focal point
- virtual object and image distances are taken to be negative

- the focal length of a concave lens is taken to be negative since it has a virtual focal point

THE GENERAL LENS FORMULAE

1) Using a point object to form a real image in a convex lens
   Consider a point object O, which forms a real image I, in a convex lens as shown in the figure below.



From the geometry

$\alpha + \beta = d$ ……………………………………. (1)

$\tan \alpha = \frac{h}{u}$ and $\tan \beta = \frac{h}{v}$

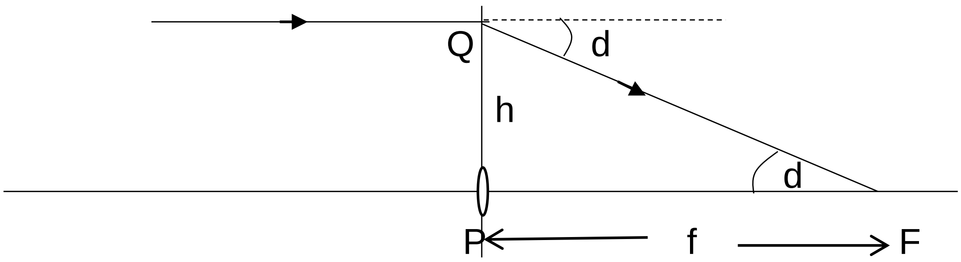
For small angles measured in radians;

$\alpha \approx \tan \alpha = \frac{h}{u}$ and $\beta \approx \tan \beta = \frac{h}{v}$

Substituting for α and β in (1)

$\frac{h}{u} + \frac{h}{v} = d$ …………………………………….. (2)

Considering a ray parallel to the principal axis at same height h, at point Q as shown in the ray diagram below;



For small angles measured in radians

$d \approx \tan d = \frac{h}{f}$ …………………………… (3)

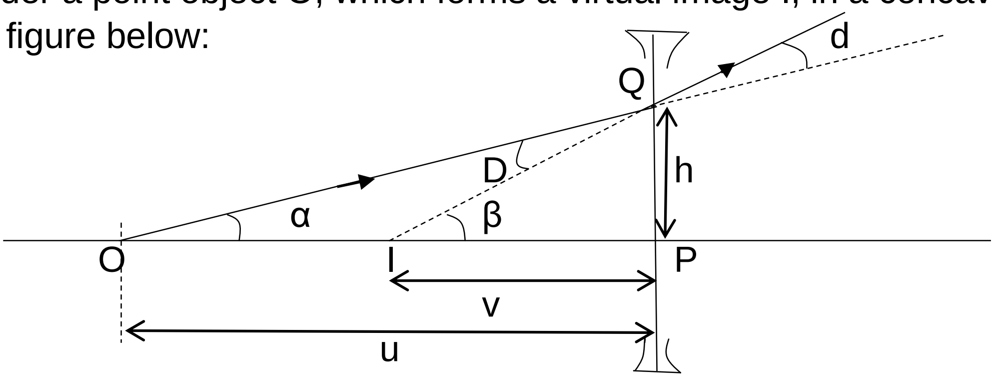
using eqn (2) and (3)

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

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

2) Using a point object to form a virtual image in a concave lens

Consider a point object O, which forms a virtual image I, in a concave lens as shown in the figure below:



$\alpha + d = \beta$ ………………………………………….. (1)

using the real –is – positive and virtual – is – negative sign convention;

$\tan \alpha = \frac{h}{u}$ and $\tan \beta = \frac{h}{-v}$

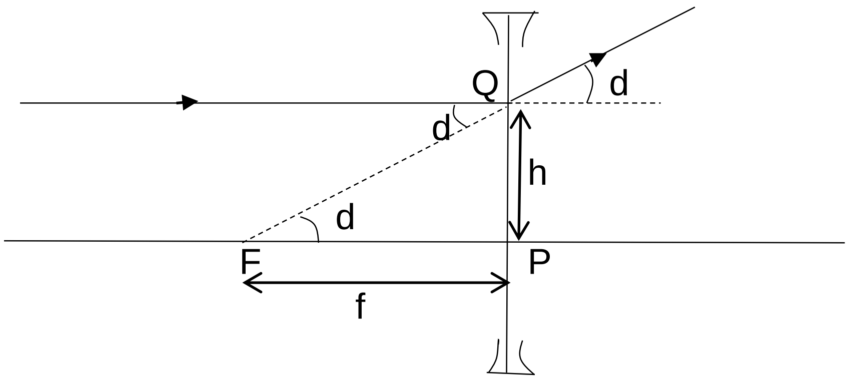
For small angles measured in radians;

$\alpha \approx \tan \alpha = \frac{h}{u}$ and $\beta \approx \tan \beta = \frac{h}{-v}$

Substituting for α and β in (1)

$\frac{h}{u} + d = \frac{h}{-v}$ …………………………………… (2)

Considering a ray parallel to the principal axis at same height h, at point Q as shown in the ray diagram below;



using the real –is – positive and virtual – is – negative sign convention; for small angles measured in radians

$d \approx \tan d = \frac{h}{-f}$ …………………………… (3)

using eqn (2) and (3)

$$\frac{h}{u} + \frac{h}{-f} = \frac{h}{-v}$$

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

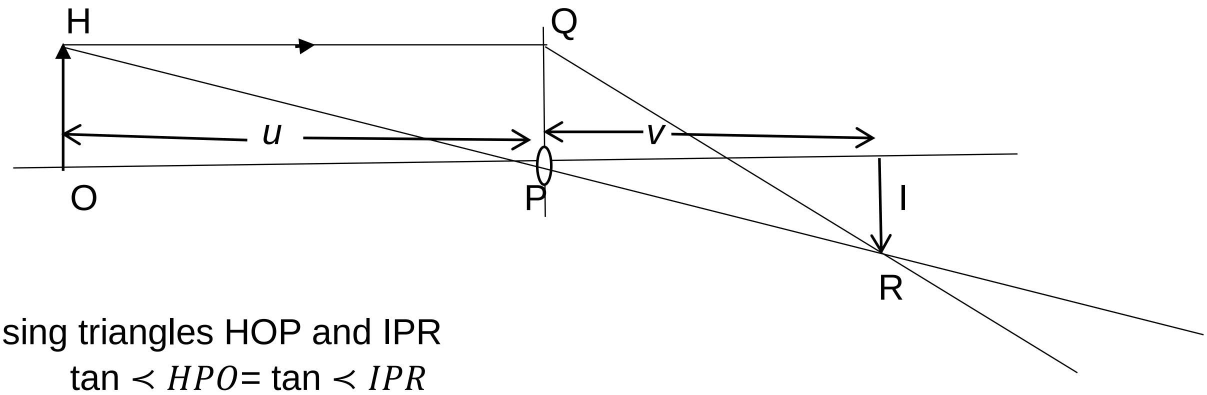
Hence $\quad \frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

Linear or lateral magnification, m:

It is defined as the ratio of the image height to object height.

$$m = \frac{height\ of\ image}{height\ of\ object}$$

Consider formation of real image by a convex lens.



Using triangles HOP and IPR

$\tan \prec HPO = \tan \prec IPR$

$$\frac{OH}{OP} = \frac{IR}{IP}$$

Re-arranging

$$\frac{image\ height,\ IR}{object\ height,\ OH} = \frac{image\ \ distance,IP}{Object\ distance,OP}$$

Hence linear magnification

$$m = \frac{Image\ distance}{Object\ distance}$$

Magnification can also be defined as the ratio of distance of the image from the lens to the distance of the object from the lens.

$$m = \frac{image\ distance,\ v}{object\ distance,\ u}$$

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

Relation between Linear magnification and focal length

From the lens formula

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

Multiplying both sides by *v*

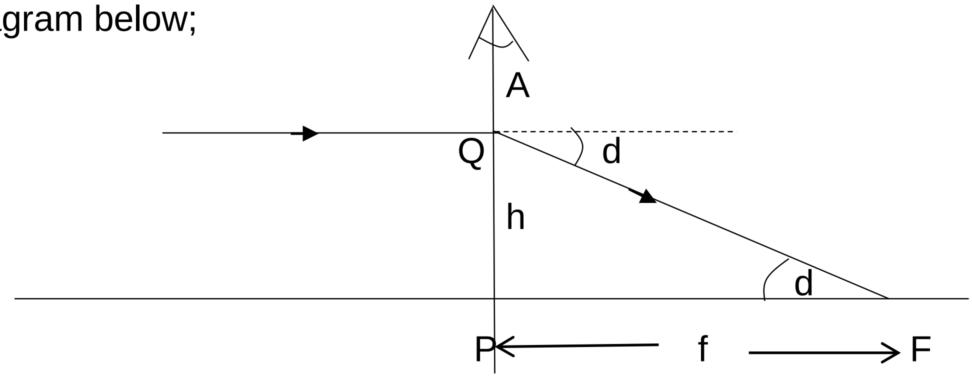
$$\frac{v}{f} = \frac{v}{u} + \frac{v}{v}$$

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

Hence $\frac{v}{f} = m + 1$

The thin lens formula:

Considering a ray parallel to the principal axis at same height h, at point Q as shown in the ray diagram below;



For small angles measured in radians

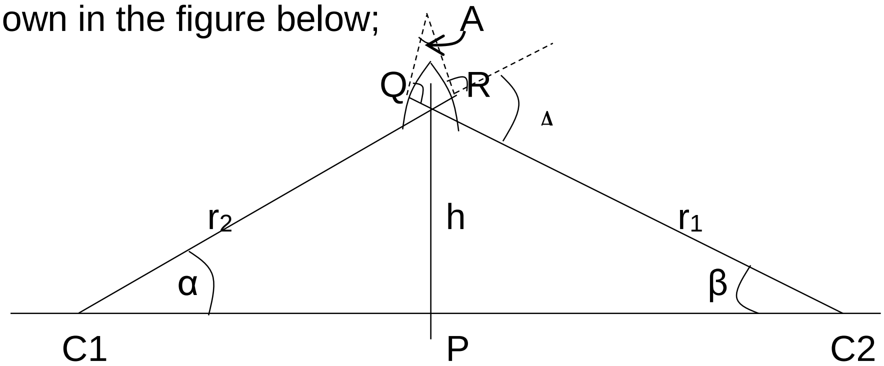
$d \approx \tan d = \frac{h}{f}$ …………………………… (1)

For a small prism angle;

d= (n-1)A

thus $\frac{h}{f}$ = (n-1)A …………………………………….. (2)

Considering the normals Q and R to the surfaces of the prism at the same height h above P as shown in the figure below;



From the geometry

$\alpha + \beta = A$ …………………………………… (3)

$\sin \alpha = \frac{h}{r_1}$ and $\sin \beta = \frac{h}{r_2}$

For small angles measured in radians;

$\alpha \approx \sin \alpha = \frac{h}{r_1}$ and $\beta \approx \sin \beta = \frac{h}{r_2}$

Substituting for α and β in (3)

$$\frac{h}{r_1} + \frac{h}{r_2} = A \qquad \text{.. (4)}$$

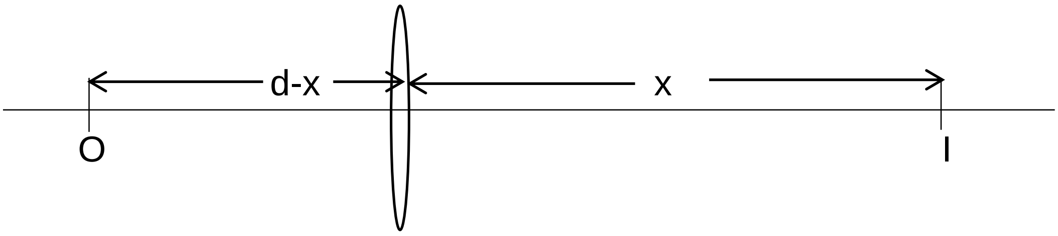
Using (2) and (4)

$$\frac{h}{f} = (n-1)\left(\frac{h}{r_1} + \frac{h}{r_2}\right)$$

Hence $$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Least distance between object and screen for formation of a real image:

Suppose the object and the screen area distance d, apart with the image at a distance x from the lens as shown in the figure below:



Object distance u = d – x

Image distance v = x

Using the lens formula

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

$$\frac{1}{f} = \frac{1}{d-x} + \frac{1}{x}$$

$$\frac{1}{f} = \frac{x+d-x}{x(d-x)}$$

$$\frac{1}{f} = \frac{d}{dx-x^2}$$

$$fd = dx - x^2$$

$$x^2 - dx + fd = 0$$

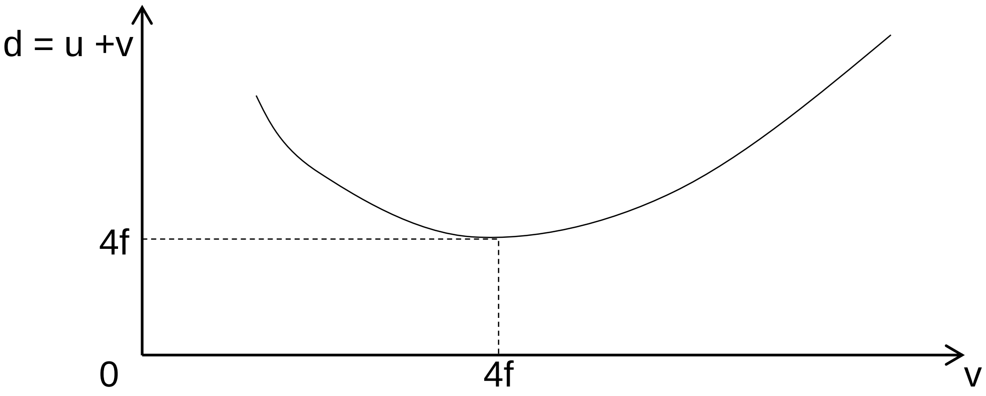
For a real image to be formed the quadratic equation above should have real roots; that is $x = \frac{-b \pm \sqrt{b^2-4ac}}{2a}$

Hence $$(-d)^2 \geq 4fd$$

$$d^2 \geq 4fd$$

$$\therefore d \geq 4f$$

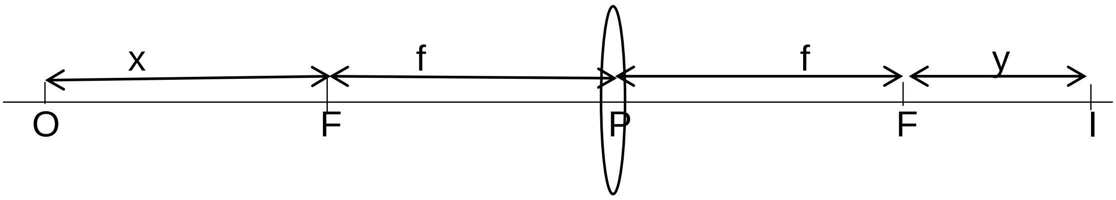
If a graph of d = u +v is plotted against v a curve is obtained as shown in the figure below;



The minimum value of d corresponds to 4f, that is, the minimum distance between the object and screen for a real image to be formed is four times the focal length of the lens.

Newton's relation:

Suppose a convex lens forms a real image of an object O at a point I, as shown in the figure below.



If the object is placed at a distance x from the focal point and form a real image at a distance y away from the focal point on the other side of the lens.

Object distance u = x + f

Image distance v = y + f

Using the lens formula

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

$$\frac{1}{f} = \frac{1}{f+x} + \frac{1}{f+y}$$

$$\frac{1}{f} = \frac{f+y+f+x}{(f+x)(f+y)}$$

$$\frac{1}{f} = \frac{2f+x+y}{f^2+fy+fx+xz}$$

$$f^2 + fy + fx + xy = 2f^2 + fx + fy$$

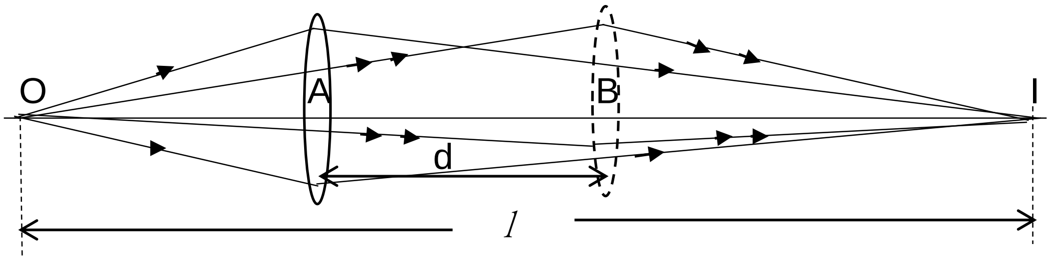
$$xy = f^2$$

Hence $x = \frac{f^2}{y}$ this is Newton's relation

and $x \propto \frac{1}{y}$ since f is constant, as x increases y reduces and vice versa.

Displacement of the lens for fixed positions of object and screen

Let an object O, be placed at a distance u, away from the lens in position A; to form a real image I, and let the screen be at a fixed distance l, from the object.



Keeping the object O, and screen I fixed in their positions the lens is moved through a distance d to some other position B, where a diminished and clear image is again formed on the screen.

If the object is placed at I, it forms a real magnified image at O when the lens is in position B and a diminished (smaller) image when the lens is in position A. therefore O and I are conjugate points.

With the lens in position A;

Object distance u = OA= IB = $\frac{l-d}{2}$

Image distance v= AI = OB = $\frac{l+d}{2}$

Using the lens formula

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

$$\frac{1}{f} = \frac{2}{l-d} + \frac{2}{l+d}$$

$$\frac{1}{f} = \frac{2(l+d)+2(l-d)}{(l-d)(l+d)}$$

$$\frac{1}{f} = \frac{2l+2d+2l-2d}{l^2 - d^2}$$

$$\frac{1}{f} = \frac{4l}{l^2 - d^2}$$

$$\therefore f = \frac{l^2-d^2}{4l}$$

<u>Magnification produced with displaced lens</u>

When in position A the magnification produced

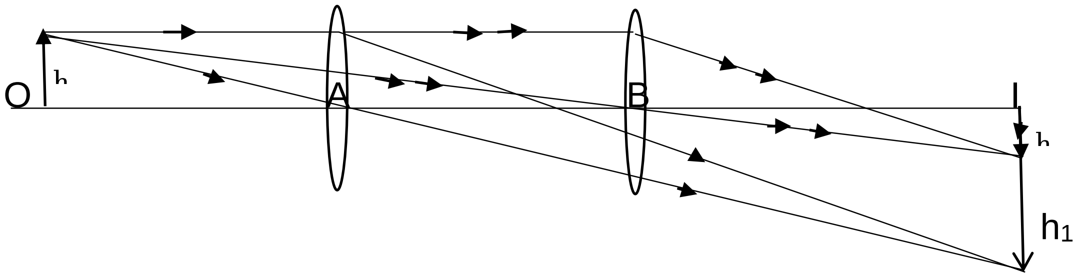
$$m_1 = \frac{A\,I}{OA} = \frac{l+d}{2} \, x \, \frac{2}{l-d} = \frac{l+d}{l-d}$$

In position B, the magnification produced by the lens is given by

$$m_2 = \frac{BI}{OB} = \frac{l-d}{2} x \ \frac{2}{l+d} = \frac{l-d}{l+d}$$

The product $m_1 m_2 = \frac{l+d}{l-d} \text{ x } \frac{l-d}{l+d} = 1$

For a **finite object**; the images are formed as shown in the figure below;



The magnification produced with the lens in position A

$m_1 = \frac{h_1}{h_0}$

With the lens in position B, the magnification produced

$m_2 = \frac{h_2}{h_0}$

Where h_o, h_1 and h_2 are the height of object, height of image when lens is in position A and height of image for lens in position B respectively

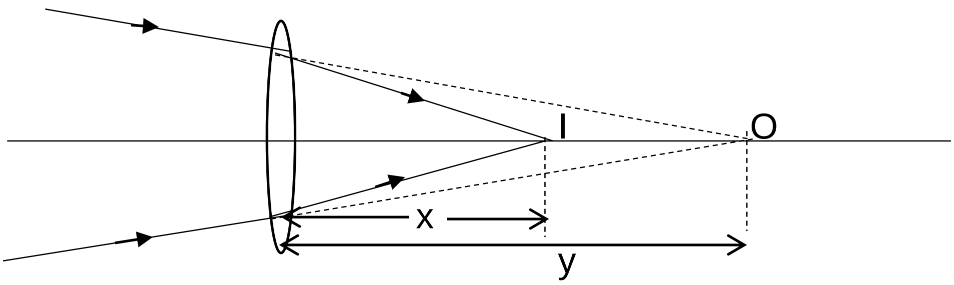
Thus $m_1 \text{ x } m_2 = \frac{h_1}{h_0} \text{ x } \frac{h_2}{h_0} = 1$

$h_o^2 = h_1 h_2$

$h_o = \sqrt{h_1 h_2}$

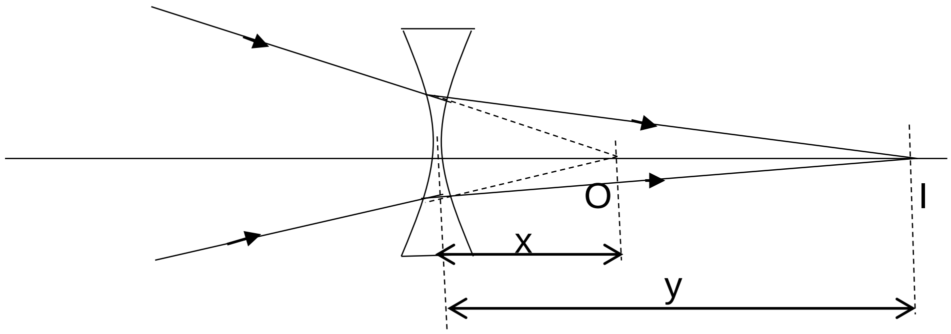
Conversion of rays through lenses:

1) Convex (converging) lens
When a convergent beam of light is refracted through a convex lens a virtual object O, is produced beyond the position of the final image I as shown in the figure below:-



Object distance u = - y cm
Image distance v = x cm

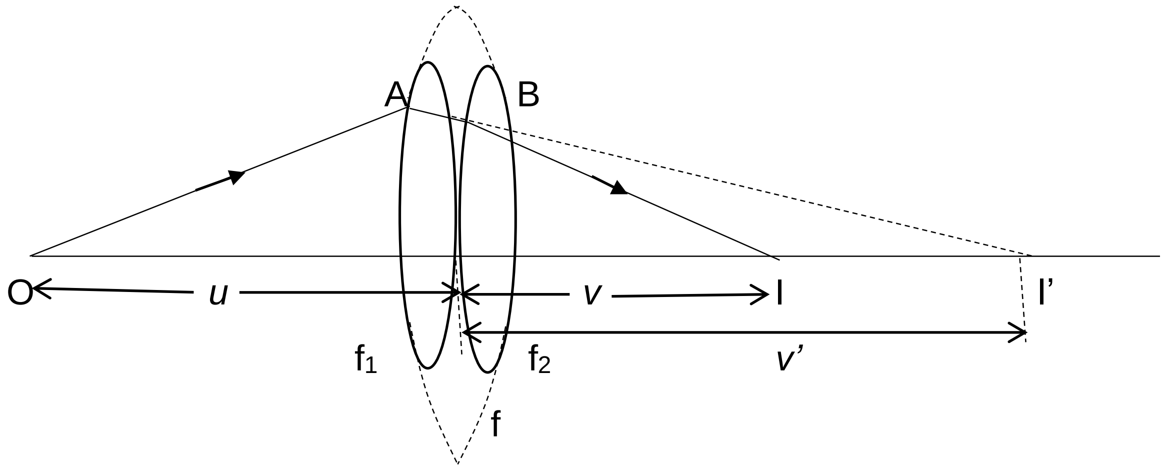
2) Concave (diverging) lens
When a convergent beam of light is refracted through a concave lens a virtual object, O is produced at the position closer to the lens and may form a real image I beyond the position of the virtual object as shown in the figure below:-



Object distance u = - x cm
Image distance v = y cm

Combined focal length of two thin lenses in air:

Consider two thin lenses A and B of focal length f_1 and f_2 respectively placed in contact with each other as shown in the figure below:-



For the combined lens, the focal length f, is given by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

With the first lens A, of focal length f_1

Object distance = *u*

Image distance = *v'*

then $$\frac{1}{f_1} = \frac{1}{u} + \frac{1}{v'} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The image I' acts as a virtual object for the second lens B, of focal length f_2;

Object distance = -*v'*

Image distance = *v*

then $\frac{1}{f_2} = \frac{1}{-v'} + \frac{1}{v}$ …………………………. (3)

(2) + (3) gives $\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{u} + \frac{1}{v}$ ……………………… (4)

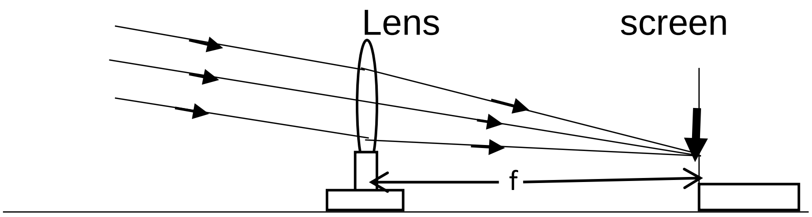
Using (1) and (4) then

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

EXPERIMENT TO DETERMINE THE FOCAL LENGTH OF A LENS

a) Convex (Converging) lens
Expt 1: Focusing a distant object

- A white screen is placed behind the lens and the lens placed facing a distant object such a window or a tree outside.

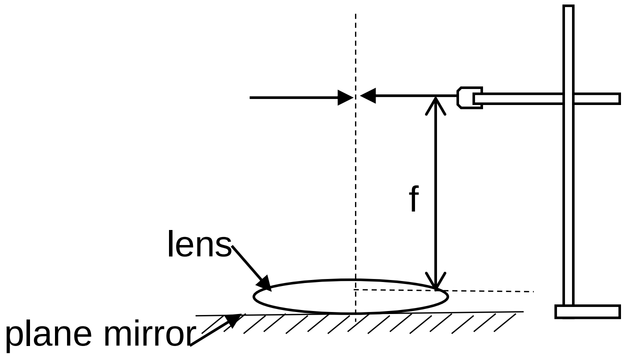


- The position of the lens is adjusted until a clear inverted image of the object is formed on the screen.
- The distance f, of the screen from the lens is measured using a meter rule and then recorded.
- The procedure is repeated by focusing different objects outside the window
- The average value of the distance is calculated and this gives the focal length f of the lens.

Expt 2. Using a plane mirror

i) Using a plane mirror and an object pin at no parallax

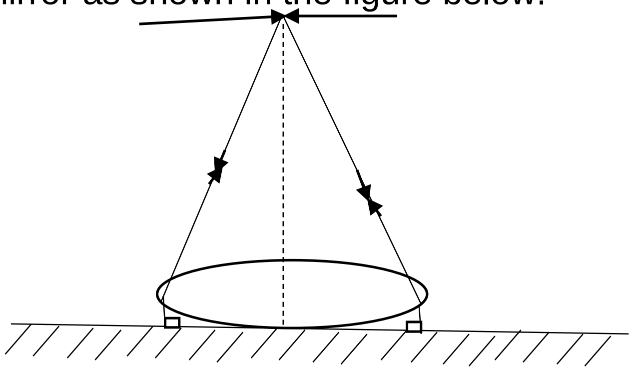
- A plane mirror M is placed on a table with its reflecting surface facing upwards and the a biconvex lens is placed on top of the mirror.



- An object pin is clamped horizontally on a retort stand with the apex along the principal axis of the lens.
- The pin up or down to locate the position where the pin coincides with its image using the method of no parallax.
- The distance f, from the pin O to the lens is measured using a meter rule.
- The lens is turned over and the experiment repeated.
- The average value of the distance f, is determined and this gives the focal length f, of the lens.

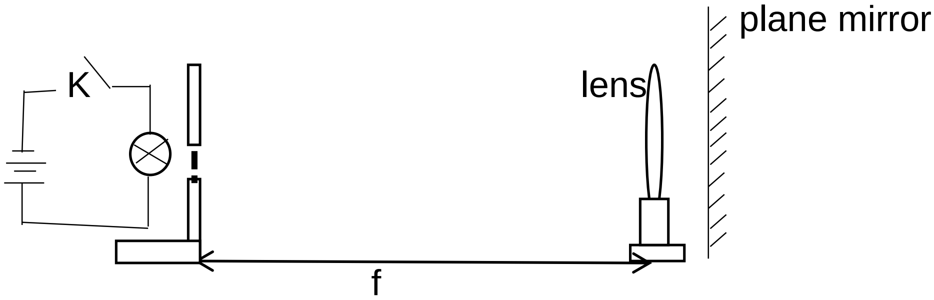
Theory of the experiment:

When the image coincides with its own object, the rays are reflected from the mirror along the same path. Therefore the rays are all normal (perpendicular) to the reflecting surface of the plane mirror as shown in the figure below.



The rays reflected from the mirror are parallel to each other and are then focused by the lens to converge at the focal point of the lens. The distance from the focal point to the lens thus gives the focal length, f.

ii) Using a plane mirror and an illuminated object

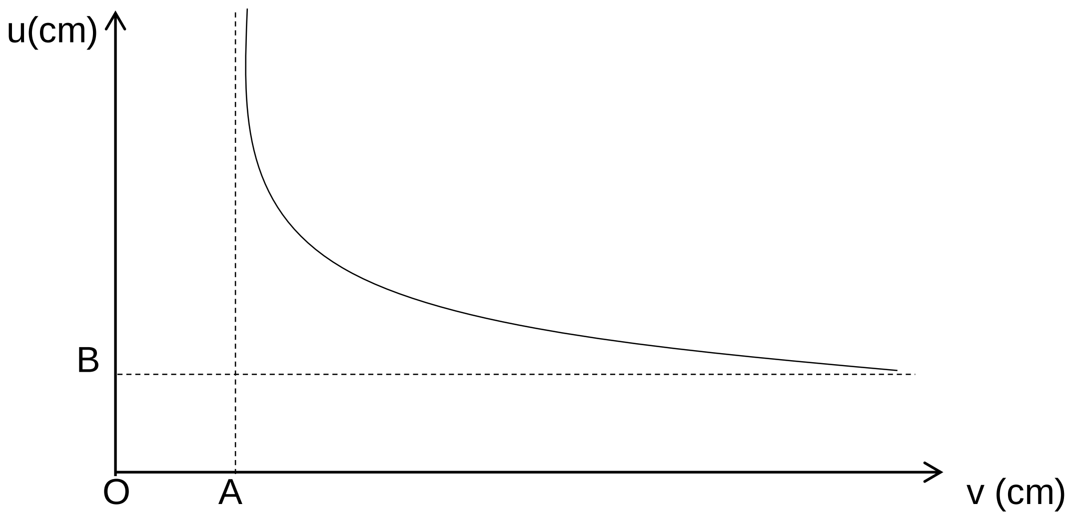


- A lens is mounted in a holder and placed between a screen (with cross wires over a hole at its center) and a plane mirror as shown in the figure above.
- The position of the lens is adjusted until a sharp image of the cross-wire is formed on the same screen besides the illuminated object.
- The distance f of the lens from the screen is measured using a meter rule and recorded.
- The lens is turned over and the experiment is repeated.
- The average value of the distance f is determined and this gives the focal length of the lens.

Expt 3: using the simple lens formula (using object and image distances)

i) With an Illuminated object and screen method

- An illuminated object O is placed, in front of a mounted convex lens at a distance u greater than the focal length of the convex lens.
- The position of the screen is adjusted until a sharp image of O is formed on it.
- The distance v of the screen from the lens is measured and recorded.
- The procedure is repeated for different values of object distances u and the results are entered in a table.
- A graph of $\boldsymbol{u}$ against $\boldsymbol{v}$ is plotted as shown in the figure below.



- The asymptotes to the u- and v- axes are drawn.
- The distances OA and OB, of the points where the asymptotes cross the axes is determined
- The average value of OA and OB is determined and this gives the focal length f, of the lens, that is, $f = \frac{OA+OB}{2}$

<u>Analysis of the results</u>:

At point A, the object distance u → ∞ and v= OA

Using the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

When u → ∞ then $\frac{1}{u}$ →0 and $\frac{1}{f} = \frac{1}{u}$ $= \frac{1}{OA}$

Hence f_1= OA

At point B, the image distance v → ∞ and u= OB

Using the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

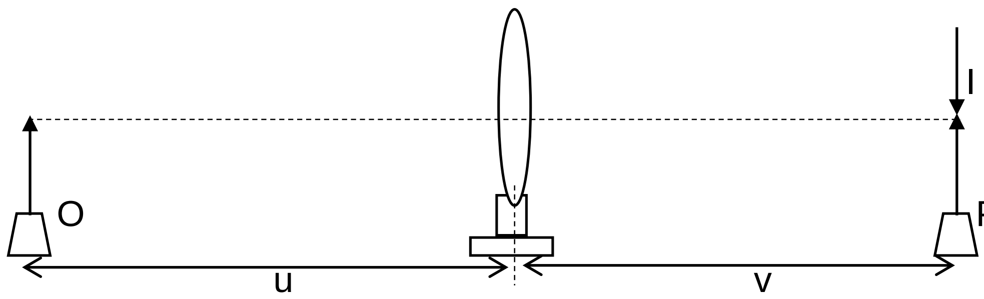
When v → ∞ then $\frac{1}{v}$ →0 and $\frac{1}{f} = \frac{1}{v}$ $= \frac{1}{OB}$

Hence f_2= OB

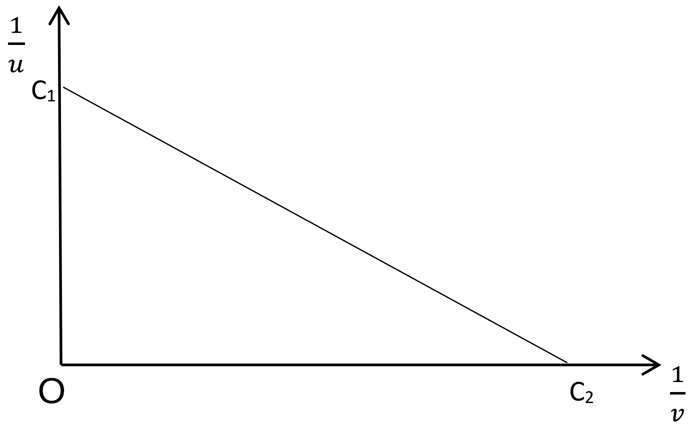
The focal length f is the average value of f_1 and f_2, that is, $f = \frac{f_1+f_2}{2} = \frac{OA+OB}{2}$

ii) With an object pin and search pin method (for no parallax)

- An object pin O, is placed, in front of a mounted convex lens at a distance u greater than the focal length of the convex lens.



- While viewing from the opposite side of the lens the position of the search pin P, is adjusted until coincides with the image I of the object pin.
- The distance v between the search pin and the lens is measured and recorded.
- The procedure is repeated for different values of object distances u.
- The results are entered in a table including values of $\frac{1}{u}$ and $\frac{1}{v}$.
- A graph of $\frac{1}{u}$ against $\frac{1}{v}$ is plotted as shown in the figure below.



- The intercepts C_1 and C_2 on the $\frac{1}{u}$ - and $\frac{1}{v}$ – axes respectively are determined.
- The focal length f, is calculated from $f = \frac{C_1+C_2}{2(C_1C_2)}$

<u>Analysis of the results</u>:

For the intercept C_1 on the $\frac{1}{u}$ – axis, $\frac{1}{v} = 0$

Using the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

When $\frac{1}{v} = 0$ then $\frac{1}{f} = \frac{1}{u} + 0$

$$\frac{1}{f} = \frac{1}{u} = C_1$$

Hence $f_1 = \frac{1}{C_1}$

For the intercept C_2 on the $\frac{1}{v}$ – axis, $\frac{1}{u} = 0$

Using the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

When $\frac{1}{u} = 0$ then $\frac{1}{f} = 0 + \frac{1}{v}$

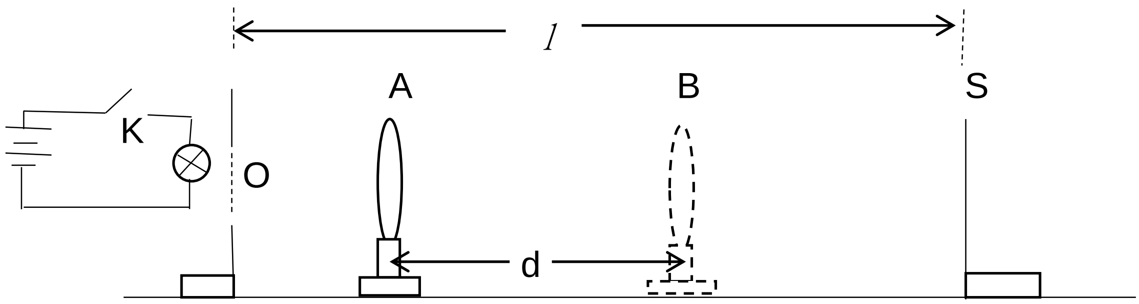
$$\frac{1}{f} = \frac{1}{v} = C_2$$

Hence $f_2 = \frac{1}{C_2}$

The focal length f is the average value of f_1 and f_2, that is, $f = \frac{f_1+f_2}{2} = \frac{1}{2}(\frac{1}{C_1} + \frac{1}{C_2})$

$$\therefore f = \frac{C_1+C_2}{2(C_1C_2)}$$

Expt 4: Displacement of the lens method



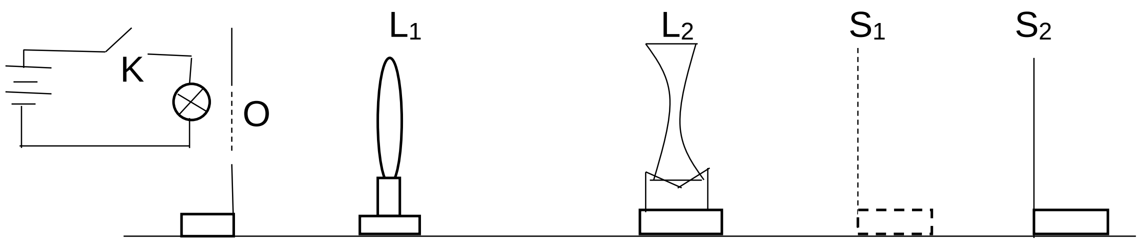
- The convex lens is placed in front of the illuminated object O, at certain position A so that a real image is formed on the screen S.
- A screen S is adjusted so that a real magnified image of the object O is formed on it.
- The distance l between O and S is measured and recorded.
- Keeping the screen and the object fixed, the lens is then moved to position B such that a sharp diminished image is formed on the screen S.
- The distance d between the positions A and B of the lens is measured and recorded.
- The experiment is repeated for different values of the distance, l
- The results are entered in a table including values of l^2, d^2, and l^2-d^2
- A graph of l^2 - d^2 against l is plotted.
- The slope S, of the graph is determined.
- The focal length f, of the graph is determined from the expression f = $\frac{S}{4}$

Advantages of the displacement method

1) The method can be used to determine the focal length of an inaccessible lens such as a lens contained inside a short tube
2) It is also suitable in determining the focal length of thick glass lenses

b) Concave (Diverging) lens

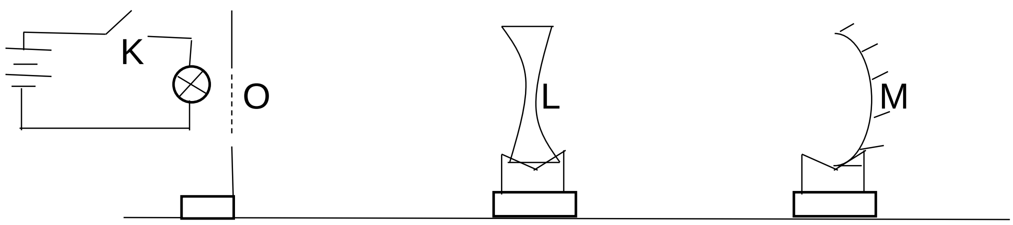
Expt 1: using a converging lens



- An object O is placed in front of a converging lens L_1 so as to obtain a real image on the screen at S_1
- The distance L_1S_1 is measured and recorded.
- A diverging lens L_2 whose focal length is required is placed between the screen and the converging lens.
- The screen is adjusted to obtain a new real image on to it at position S_2.
- The distance L_1L_2 and L_2S_2 is measured and recorded.
- The object distance u, from this lens is got from $u = -(L_1S_1 - L_1L_2)$ while the image distance $v = L_2S_2$
- The focal length f of the diverging lens is calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

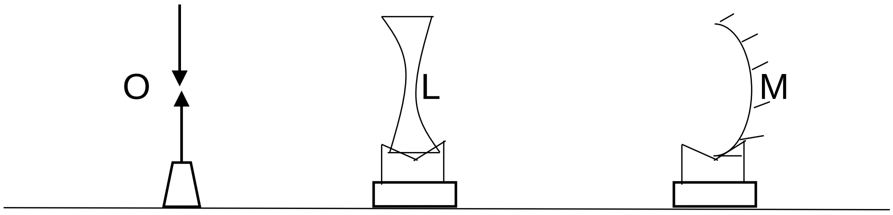
Expt 2: Using a concave mirror

Method 1: With an illuminated object



- An illuminate object O is placed in front of a diverging lens, L arranged coaxially with a concave mirror, M of known radius of curvature r.
- The position of object O is adjusted until it coincides with its image.
- The distance OL and LM is measured and recorded.
- For the concave lens; object distance $\boldsymbol{u} = \mathrm{OL}$ and image distance $\boldsymbol{v} = -(\boldsymbol{r} - \mathrm{LM})$
- The focal length f, of the concave lens can be calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Method 2: With an object pin

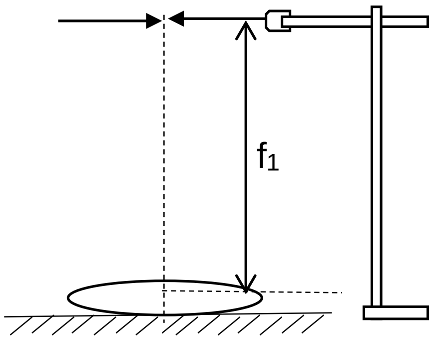


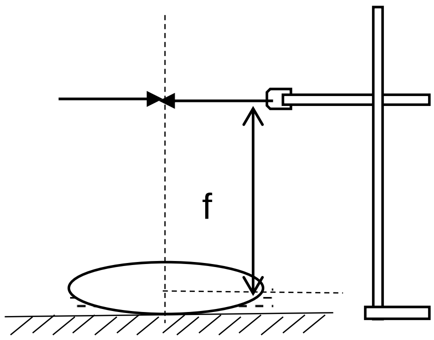
- An object pin O is placed in front with its tip along the principal axis of a diverging lens, L arranged coaxially with a concave mirror, M of known radius of curvature r.
- The position of the pin O is adjusted until it coincides with its image.
- The distance OL and LM is measured and recorded down.

For the concave lens; object distance = OL and image distance $\boldsymbol{v} = -(\boldsymbol{r} - \mathrm{LM})$

- The focal length f, of the concave lens is then calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

AN EXPERIMENT TO DETERMINE THE REFRACTIVE INDEX OF A LIQUID USING A CONVEX LENS AND A PLANE MIRROR

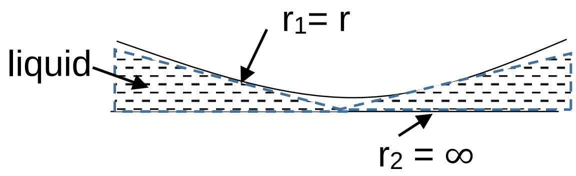




- An object pin is clamped horizontally on a retort stand with the apex along the principal axis of the lens.
- The pin up or down to locate the position where the pin coincides with its image using the method of no parallax.
- The distance f_1, from the pin O to the lens is measured using a meter rule.
- The lens is removed and a little quantity of the specimen liquid is placed on the plane mirror.
- The convex lens is placed on top of the liquid and then the new position is located where the pin coincides with its image.
- The distance f of the pin from the lens is measured and recorded.
- The focal length f_2 of the liquid lens is calculated from the formula $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$
- The refractive index of the liquid is got from $n_l = 1 - \frac{r}{f_2}$; where r is the radius of curvature of the surfaces of the convex lens

Theory of the experiment:

For the liquid lens



using the lens formula $\frac{1}{f} = (\frac{1}{r_1} + \frac{1}{r_2})(n - 1)$

$$\frac{1}{f_2} = (n_l - 1)\left(\frac{1}{-r} + \frac{1}{\infty}\right)$$

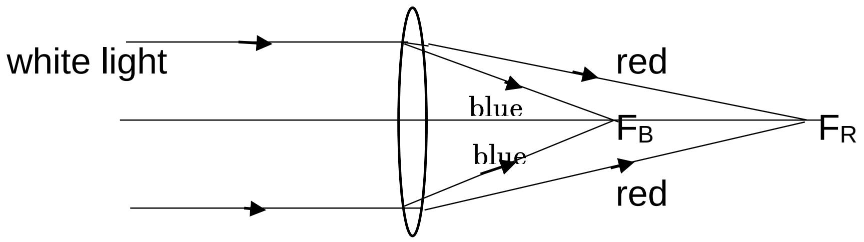
$$\therefore n_l = 1 - \frac{r}{f_2}$$

DEFFECTS OF LENSES

(i) Chromatic aberration.
(ii) Spherical aberration.

CHROMATIC ABERRATION

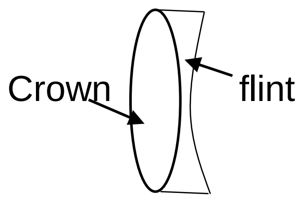
This is the colouring of the image produced by a lens when white light is incident onto the lens.



- When white light is incident on a lens, the different colour components are refracted by different amounts. Images corresponding to the different colours are formed in different positions F_B and F_R along the principal axis of the lens. The image viewed has colored edges.

Minimizing chromatic aberration

- Chromatic aberration can be reduced by using an achromatic doublet. This consists of a convex lens combined with a concave lens made from different glass materials.

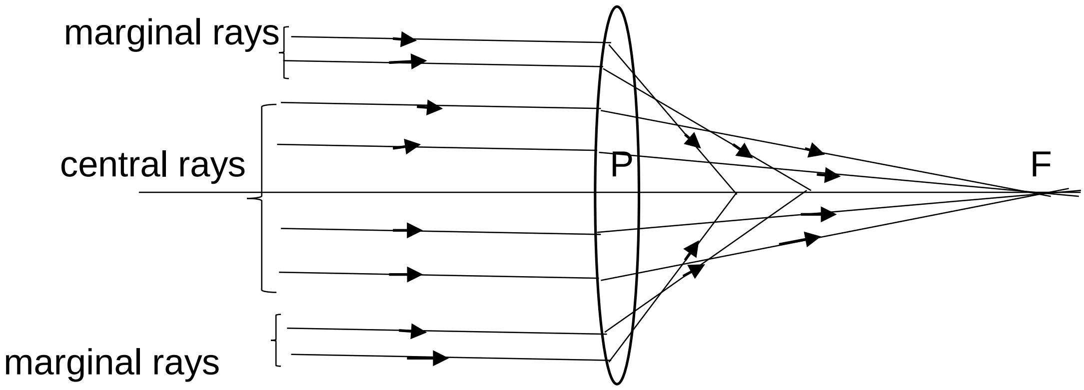


<u>Conditions for chromatic doublet to work</u>

- Lenses should be of different glasses e.g crown and flint glasses
- Ratio of their focal length should be equal to the ratio of their dispersive power
- If lenses are of same glass then should not be in contact with each other The separation between them should be equal to mean of their focal lengths

SPHERICAL ABERRATION

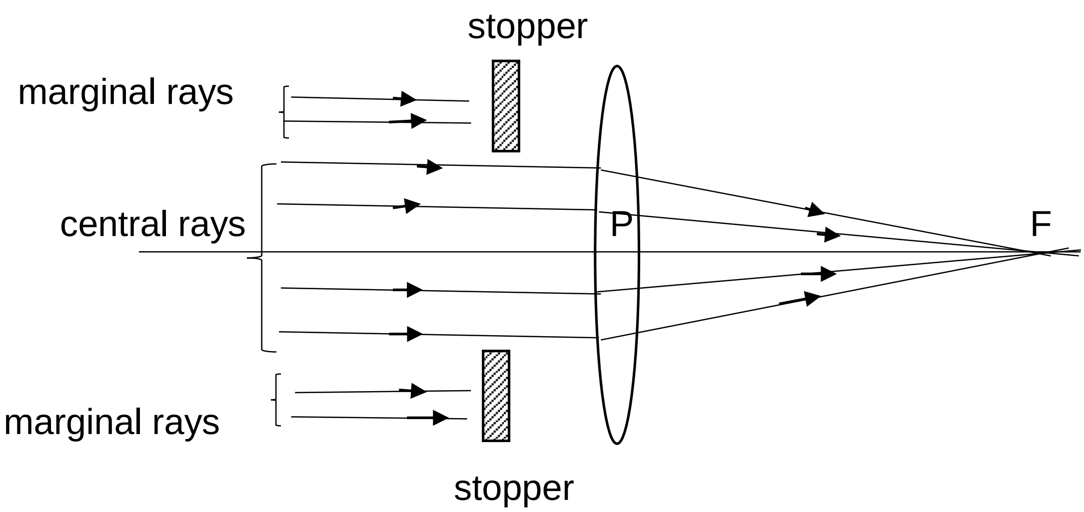
This is distortion of the image by either a lens or a mirror of wide aperture.



- When a wide beam of white light is incident on either a lens or a mirror of wide aperture, central rays are brought to converge at the same point F, far away from the lens. The marginal rays which are far from the principal axis are brought to converge near the pole P of the lens.
- The image formed is circular blurred due to a series of images of the same object

Minimizing spherical aberration

- In lenses, Spherical aberration can be minimized using a stopper i.e. using an opaque disc with a central hole to cut off marginal rays.



A circular stop is an opaque disc having a hole in the middle for allowing in only paraxial rays incident on the lens. The disadvantage with this method is light intensity is cut down and so the brightness of the image is reduced

- Spherical aberration can also be minimized by use of a plano-convex lens with curved side facing the incident rays

- In mirrors, spherical aberration can be minimized by using a parabolic mirror. This because a parabolic mirror converges a wide parallel beam of light incident onto its surface to a single focus as shown.

NUMERICAL EXAMPLES: