Refraction of Light at Curved Surfaces

Improve your learning

Q. 1. A man wants to get a picture of a zebra. He photographed a white donkey after fitting a glass with black stripes on to the lens of his camera. What photo will he get? Explain. (AS1)

Answer :

• The man will get the photograph of a white donkey with less intensity. Moreover, the whole photograph will have black strips instead of only the body of the donkey.

• The black strips will block the light coming from the object. Thus, refraction will take place only where the lens is clear. Thus, providing a very hazy image.

• The photograph will look like the picture below.

Q. 2. Two converging lenses are to be placed in the path of parallel rays so that the rays remain parallel after passing through both lenses. How should the lenses be arranged? Explain with a neat ray diagram. (AS1)

Answer :

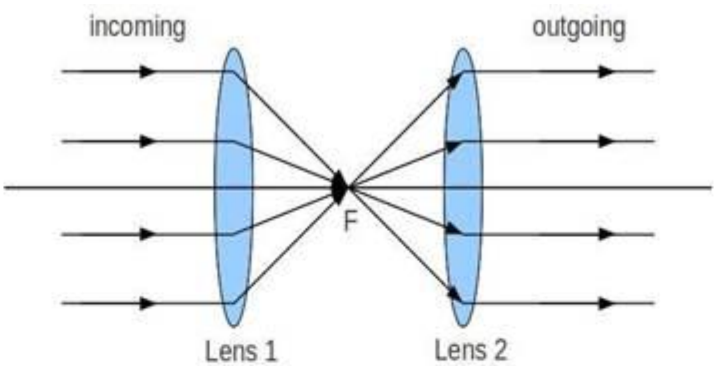
• The rays which are parallel to the principal axis , after passing from convex lens , converges to the second focal point of the lens.

• The rays coming out from the focal point of lens, after refraction through lens, will be parallel to the principal axis.

• If the two lenses are kept parallel to each other such that the second focal point of first lens coincide with the first focal point of the second lens, then the parallel rays after refraction from first lens will converge at the second focal point.

• This focal point will act as the first focal point of second lens and the rays emerging from it, after refraction from second lens will be parallel to the principal axis.

• To conclude, both the lenses should be f1 + f2 unit apart where f1 = f2 = focal length



Q. 3. The focal length of a converging lens is 20 cm. An object is 60 cm from the lens. Where will the image be formed and what kind of image is it? (AS1)

Answer : Focal length (F) = 20cm

Object distance (u) = -60cm

Image distance (v) = ?

Using Lens formula: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

$$\frac{1}{20} = \frac{1}{v} - \left(\frac{1}{-60}\right)$$

$$\frac{1}{20} = \frac{1}{v} + \frac{1}{60}$$

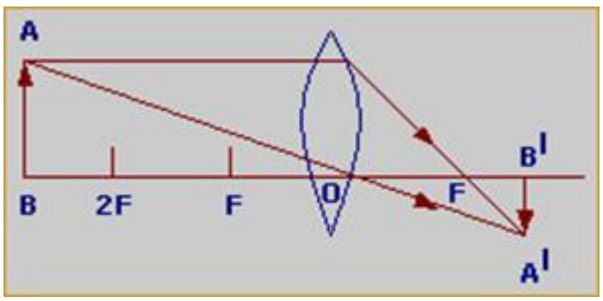
$$\frac{1}{20} - \frac{1}{60} = \frac{1}{v}$$

$$\frac{3-1}{60} = \frac{1}{v}$$

$$\frac{2}{60} = \frac{1}{v}$$

v = 60/2 = 30cm

As the object is beyond the centre of curvature (2F = 40cm), then the image will be formed between focus & centre of curvature. The image will be real, diminished, inverted and 30 cm away from the lens.



Q. 4. A double convex lens has two surfaces of equal radii 'R' and refractive index n 15. Find the focal length 'f. (AS1)

Answer :

Using Lens maker formula: $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

f = focal length

n = refractive index = 15

R_1 = R = radius of the surface = R_2 = -R

$$\frac{1}{f} = (15-1)\left(\frac{1}{R} - \frac{1}{-R}\right)$$

$$\frac{1}{f} = 14\left(\frac{1}{R} + \frac{1}{R}\right)$$

$$= 14\left(\frac{2}{R}\right) = \frac{28}{R}$$

$$f = \frac{R}{28} \text{ units}$$

Lens Maker's Formula: $\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$

f = focal length

R1 = radius of curvature of the lens surface closer to the source of light

R2 = radius of curvature of the lens surface farther to the source of light

n = refractive index of the lens material with respect to the surrounding medium

This formula is used to determine the values of R1 & R2 needed for a desired focal length of a lens of a given refractive index. The values of both the radii should be taken with their signs. For thin lens, focal length is independent of the order of surface.

Q. 6. How do you verify experimentally that the focal length of a convex lens is increased when it is kept in water? (AS1)

Answer : Aim: To verify that the focal length of a convex lens is increased when it is kept in water.

Materials required: Convex lens, tumbler, water, circular lens holder, stone

Procedure:

• Take a convex lens of focal length & a tumbler whose height is known and is four times the focal length of lens.

• Put the stone into the tumbler. Pour some water upto the level where the height of level should be greater than the focal length of lens.

• Now dip the lens horizontally using the lens holder.

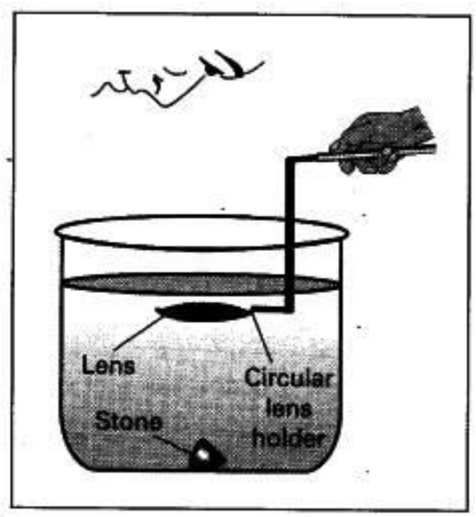
• Set the distance between the lens & the stone such that the distance is equal or less than the focal length of the lens.

• Look at the stone through the lens. The stone is visible at this stage.

• Now slowly increase the distance between the lens & stone.

• As soon as the distance gets greater than the focal length, the stone will be not visible anymore.

Conclusion: If the lens is dipped to a certain height which is greater than the focal length of lens in air, the image is clearly visible. Thus the focal length of lens is increased in water.



Q. 7. How do you find the focal length of a lens experimentally? (AS1)

Answer :

• The rays of light coming from a distant object are considered parallel to each other.

• Parallel rays after refraction from lens converges/diverges to focus of the lens.

Aim: To find the focal length of a lens

Apparatus required: convex lens, metre scale, a white screen, lens holder, a distant object

Procedure:

• Set up the apparatus near a window so to locate a distant object .

• Mount the convex lens on the lens holder.

• Now place the metre scale on the table and keep the lens at a distance of 5 cm mark on the metre scale such that the mid point of lens holder coincides with 5 cm mark.

• Place the white screen behind the lens such that the image of the object is formed on the screen.

• Now move the screen until you get a sharp, diminished & inverted image of the distant object.

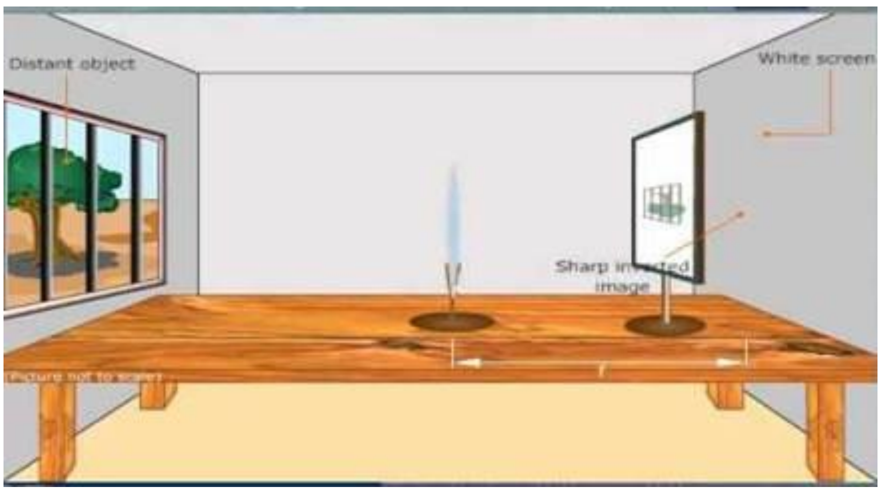
• Mark the point on the scale where you get the desired image. The difference between the lens mark & the screen mark will give the focal length.

• Now place the lens on a new position that is 10 cm and find the focal length.

• Repeat the above steps by keeping the lens at 10 cm, 15 cm & so on to get more observations.

Observation:

Position of convex lens	Position of screen	Focal length
5 cm	20 cm	15 cm
10 cm	25 cm	15 cm



Q. 8. Harsha tells Siddhu that the double convex lens behave like a convergent lens. But Siddhu knows that Harsha assertion is wrong and corrected Harsha by asking some questions. What are the questions asked by Siddhu? (AS2)

Answer : Siddhu knows that the double convex lens acts as a convergent lens but there are some exceptions when double convex lens does not behave like a converging lens. So he may ask the following questions:

• What will happen when the refractive index of the surrounding medium is greater than the refractive index of lens?

• When the object is placed between pole & focal point, then will the lens behave like a convergent lens?

• How does the lens behave when kept in water?

Q. 9. Assertion (A): A person standing on the land appears taller than his actual height to a fish inside a pond. (AS2)

Reason (R): Light bends away from the normal as it enters air from water.
Which of the following is correct? Explain.
a) Both A and R are true and R is the correct explanation of A.
b) Both A and R are true and R is not the correct explanation of A.
c) A is true but R is false.
d) Both A and R are false.
e) A is false but R is true.

Answer :

Using refraction for plane surfaces: $\frac{n_2}{v} = \frac{n_1}{u}$

n_1 = refractive index of air = 1

n_2 = refractive index of water = n

let x be the actual height of the person and y be the apparent height.

$$\frac{1}{-x} = \frac{n}{-y}$$

$$\Rightarrow y = nx$$

As the refractive index of water is greater than 1, therefore y is greater than x which implies that apparent height is greater than the actual height. Thus, assertion A is correct.

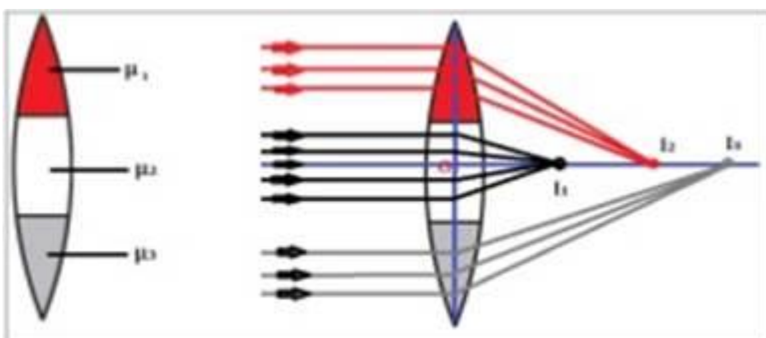
As light travels from denser to rarer medium, the light rays bends away from the normal due to refraction and the speed of light also changes in two mediums due to refraction. Thus, reason R is also correct . So, option A is the correct answer.

Q. 10. A convex lens is made up of three different materials as shown in the figure Q-10. How many of images does it form? (AS2)

fig-Q(10)

Answer :

As the lens is made up of three different materials, their respective refractive index would also differ. Let the refractive index of three materials be u1, u2, u3 respectively. If parallel beams of light are incident in the lens then due to the difference in refractive index, all the three materials would converge the light at different foci thus creating three images of the same object at different foci .



Q. 11. Can a virtual image be photographed by a camera? (AS2)

Answer : Yes, the virtual image can be photographed by a camera. The camera makes a secondary image of the image that is the virtual image acts as an object for the lens of the camera and it produces another image of the image. This secondary image acts as a real image for the camera.

• When we stand in front of mirror then our virtual image is formed by the mirror. so when we click our image through the mirror's virtual image then this image acts as a real image which can be projected on the film.

• Our eye acts on the same phenomenon. When we see ourselves on mirror, we get the real image of the virtual image on our retina.

Q. 12. You have a lens suggest an experiment to find out the focal length of the lens. (AS3)

Answer : Aim: To find the focal length of a lens

Apparatus required: double convex lens, metre scale, a white screen, lens holder ,distant object

Procedure:

• Set up the apparatus near a window so to locate a distant object .

• Mount the convex lens on the lens holder.

• Now place the metre scale on the table and keep the lens at a distance of 5 cm mark on the metre scale such that the mid point of lens holder coincides with 5 cm mark.

• Place the white screen behind the lens such that the image of the object is formed on the screen.

• Now move the screen until you get a sharp, diminished & inverted image of the distant object.

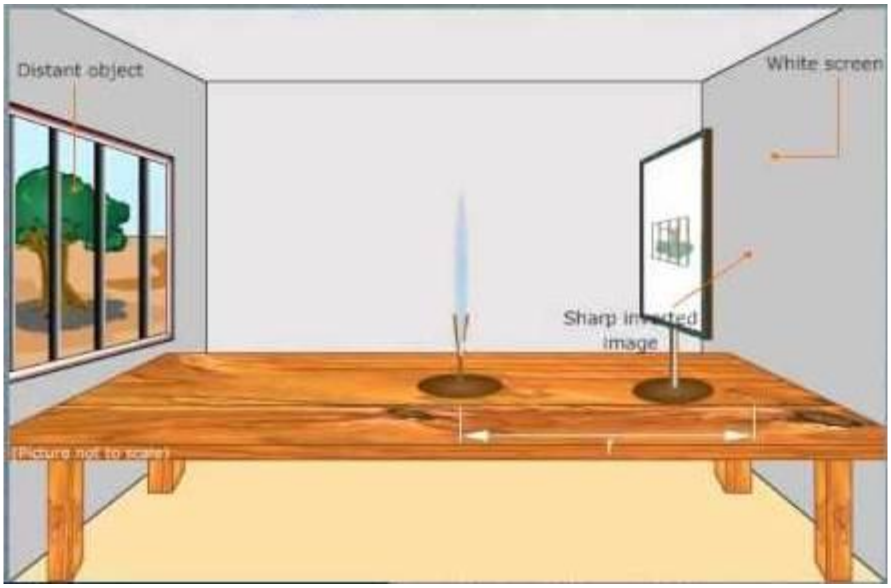
• Mark the point on the scale where you get the desired image. The difference between the lens mark & the screen mark will give the focal length.

• Now place the lens on a new position that is 10 cm and find the focal length.

• Repeat the above steps by keeping the lens at 10 cm, 15 cm & so on to get more observations

Observation:

Position of convex lens	Position of screen	Focal length
5 cm	20 cm	15 cm
10 cm	25 cm	15 cm



Q. 13. Let us assume a system consist of two lenses with focal length f_1 and $f_2$respectively. How do you find the focal length of the system experimentally? When
i) two lenses are touching each other
ii) they are separated by a distance 'd' with common principle axis. (AS3)

Answer : Let us take two convex lenses made up of the same material so that their refractive index (n) is same.

i) The first case given is two lenses are touching. So let us define the lens as lens A & lens B and their focal length be f_1 & f_2 respectively.

Now place a point object in front of the two lenses at a distance of u. Rays coming from the object after refraction from lens A forms an image I1 at a distance v1. Now this I1 will act as an object for lens B and after refraction from the lenses will form an image I at distance v.

Using lens formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{F}$

Lens A: $\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1}$ ....(1)

Lens B: 1/v-1/v1 = 1/f2 …(2)

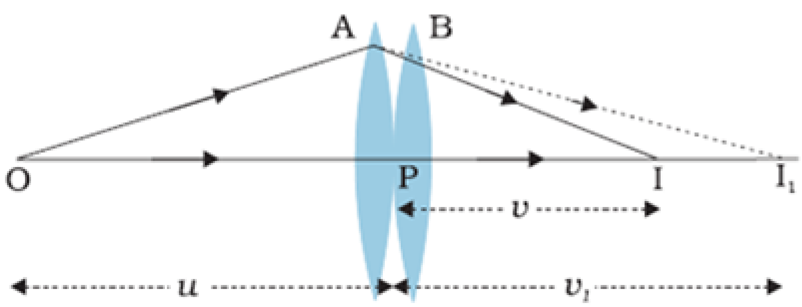
Adding equation (1) & (2) we get,

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\frac{1}{F} = 1/f_1 + \frac{1}{f_2}$$

$$F = \frac{f_1 f_2}{f_1} + f2$$

Where F = effective focal length of lens



ii) Lenses are separated by a distance 'a' with common principle axis.

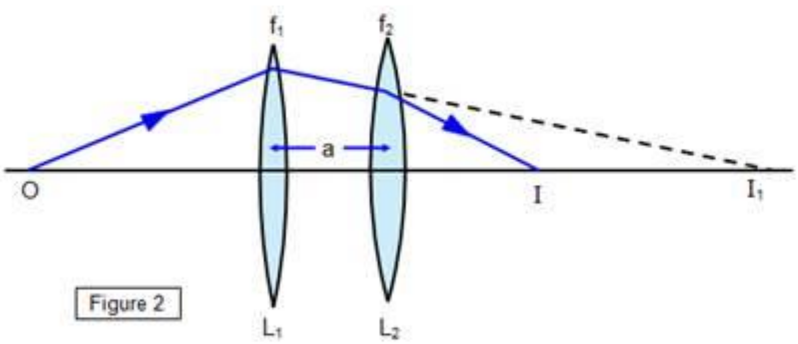


Figure 2

Let O be the point object placed at a distance u1. Rays from it after refraction from lens 1 alone will converge at I1 at a distance v1. But lens 2 will converge it before I1 creating the actual image I t distance v.

Object distance for lens 1 = u_1 = OC_1

where C_1 is center of curvature of lens 1

Image distance for lens 1 = v_1 = I_1C_1

Object distance for lens 2 = I_1C_2 = u_2

Image distance for lens 2 = $IC_2 = v_2$

where C_2 is center of curvature of lens 2

Now from the figure: $I_1C_1 = I_1C_1 + a$

using lens formula: $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Lens 1: $\frac{1}{f_1} = \frac{1}{v_1} + \frac{1}{u_1} = \frac{1}{I_1C_1} + \frac{1}{OC_1}$ ....(1)

Lens 2: $\frac{1}{f_2} = \frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{IC_2} - \frac{1}{I_1C_2}$

$\frac{1}{f_2} = \frac{1}{IC_2} - \frac{1}{I_1C_1} - a$ ....(2)

$\frac{1}{OC_1} + \frac{1}{IC_2} = \frac{1}{F}$ ...(3)

Solving [1],[2], & [3]

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{F} + \frac{a}{f_1 f_2}$$

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{a}{f_1 f_2}$$

Q. 14. Collect the information about the lenses available in an optical shop. Find out how the focal length of a lens may be determined by the given 'power of lens. (AS4)

Answer : An optical shop consists of different lenses according to the eye problem a patient has. Like a myopic patient uses a concave lens while a patient suffering from hypermetropia uses convex lens. Old aged people used bifocal lens and so on. People prescribed a sphere and a cylinder prescription have astigmatism of the eye and can be given atoric to correct it.So the following lists include all the types of lenses available in an optical shop:

• Plano convex lens

• Double convex lens

• Plano concave lens

• Double concave lens

• Cylindrical lens

• Achromatic lens

• Aspheric lens

• IR lens

• UV lens

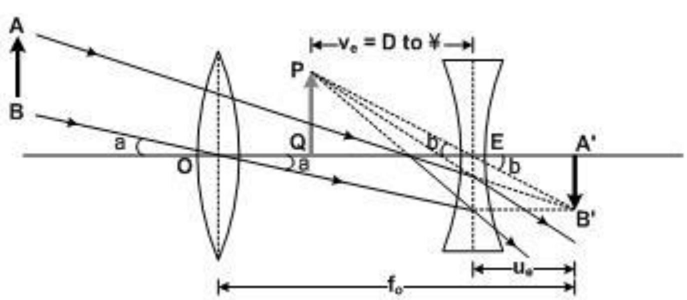
• Atoric lens

The SI unit of power is diopter (D). 1 D lens focuses rays of light at a distance of 1 metre. Thus the focal length of such lens is 1 metre (100 cm). So if power is given then focal length will be:

$$\text{Focal length } = \frac{100\text{cm}}{\text{power}}$$

Q. 15. Collect the information about lenses used by Galileo in his telescope. (AS4)

Answer : The Galilean telescope consists of two lenses- a convex & a concave. The convex lens near to the object is called the objective lens & is of higher focal length. The concave lens near to the eye is called eyepiece and its focal length is less than the objective lens. The parallel rays of light coming from the celestial objects form an image at the focal length of the objective lens. This image acts as an object for eyepiece and after refraction from eyepiece, a final erect & magnified image is formed.



Q. 16. Use the data obtained by activity-2 in table-1 of this lesson and draws the graphs of u vs v and 1/u vs 1/v. (AS5)

Answer : Let the focal length f be 20 cm. for convex lens object distance, u is negative.

using lens formula:

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

Object Distance(u)	Image Distance(v)	Focal length(f)
50 cm	33.33 cm	20 cm
60 cm	30.00 cm	20 cm
70 cm	28.00 cm	20 cm
80 cm	26.67 cm	20 cm

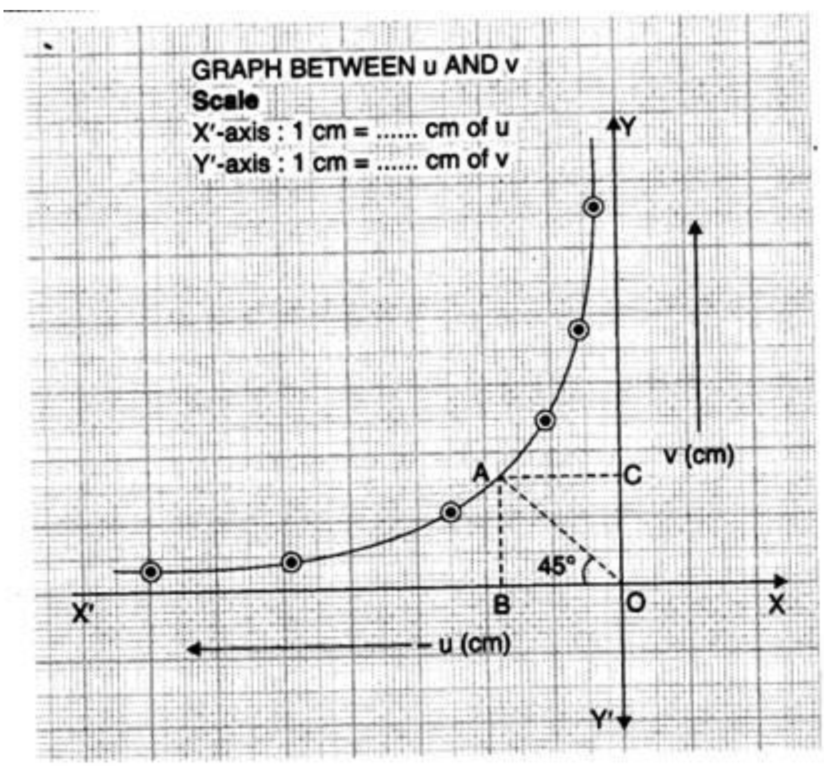


Fig. Graph between u and v. It is a rectangular hyperbola.

Object Distance(u)	Image Distance(v)	1/u (1/cm)	1/v(1/cm)
50 cm	33.33 cm	0.0200	0.0300
60 cm	30.00 cm	0.0167	0.0333
70 cm	28.00 cm	0.0143	0.0357
80 cm	26.67 cm	0.0125	0.0375

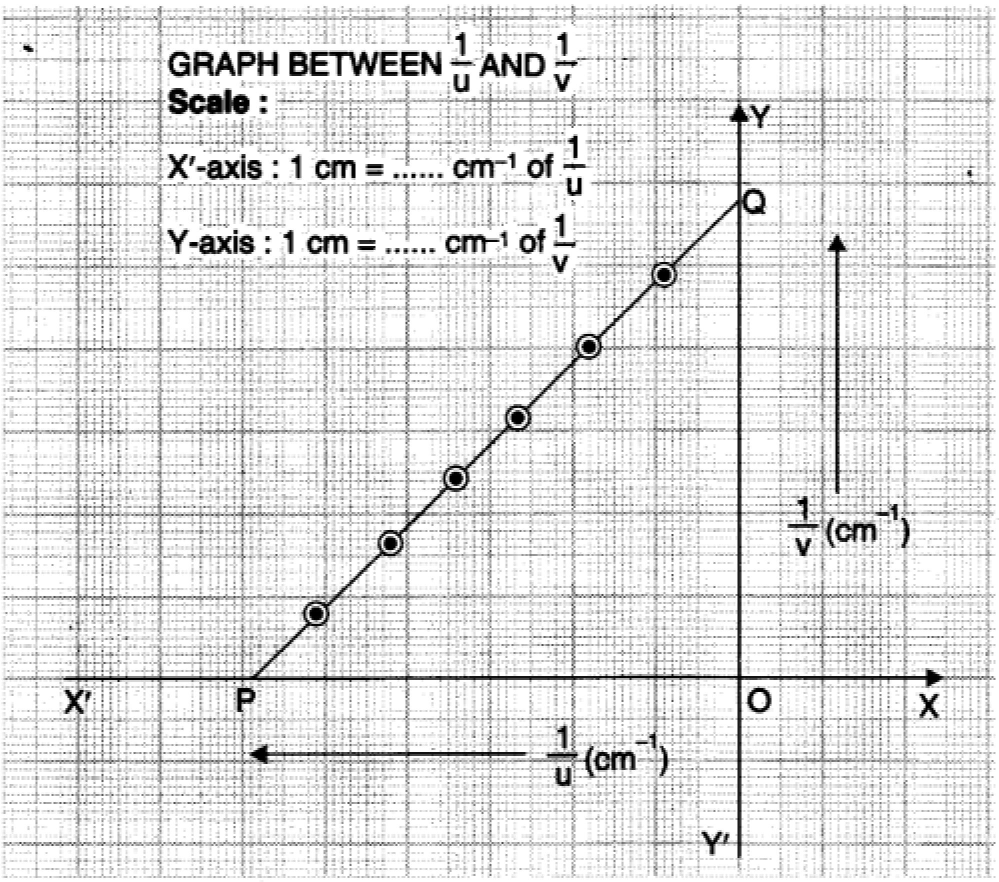


Fig. Graph between $\frac{1}{u}$ and $\frac{1}{v}$. It is a straight line.

Q. 17. Figure Q-17 shows ray AB that has passed through a divergent lens. Construct the path of the ray up to the lens if the position of its foci is known. (AS5)

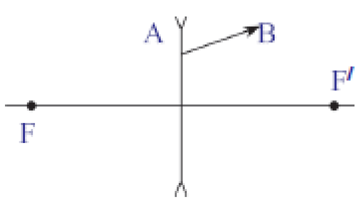
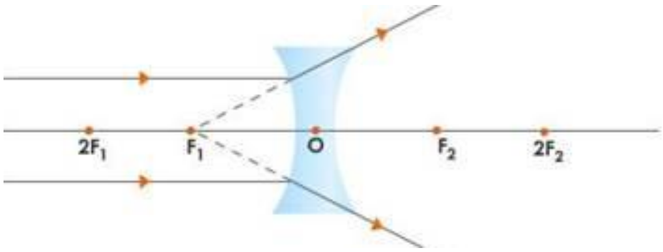


fig-Q(17)

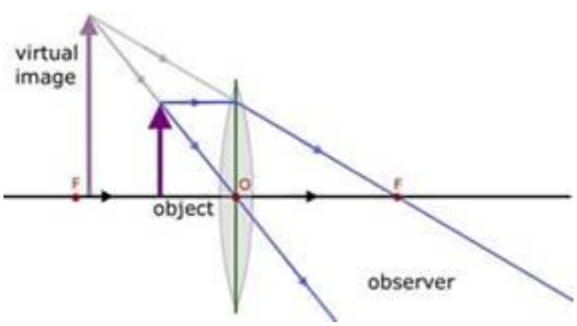
Answer : As it is given that the lens is diverging and ray AB is the ray after refraction. This implies that the Incident rays must be parallel to the principal axis making it appear to diverge from the focus after refraction.



Q. 18. Figure Q- 18 shows a point light source and its image produced by a lens with an optical axis N_1N_2. Find the position of the lens and is foci using a ray diagram. (AS5)

fig- Q(18)

Answer : From the given points we can infer that the image formed will be magnified according to the heights of the dots. Moreover, the image should be erect. So now we have to select the lens. For concave lens only, diminished image will be formed of the object. Thus, we cannot take the concave lens and hence convex lens is the only option. In convex lens, there is only one position of the object where the image is erect & magnified that is the image should be between focus & O. This figure represents the opposite of the given figure.



Q. 19. Find the focus by drawing a ray diagram using the position of source S and the image S' given in the figure Q-I9. (AS5)
Answer :

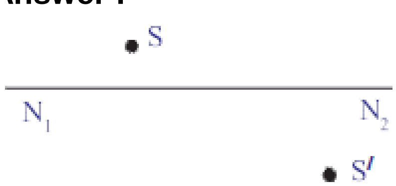
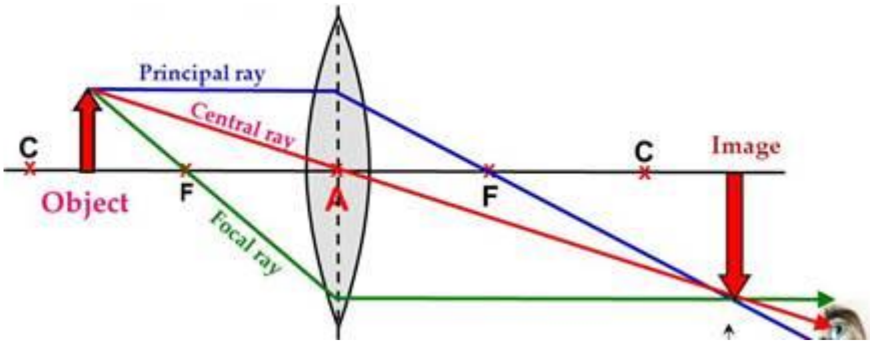


fig-Q(19)

From the figure we can infer that the image is magnified & inverted. Moreover, it is on the opposite side of the lens. We cannot use concave lens as it will produce diminished image of the object. In convex lens ,if the object is placed between F & C, then only the required condition can be achieved.



Q. 20. A parallel beam of rays is incident on a convergent lens with a local length of 40cm. Where should a divergent lens with a focal length of 15 cm be placed for the beam of rays to remain parallel after passing through the two lenses? Draw a ray diagram. (AS5)

Answer : When parallel beams of light are incident on the convex lens then after refraction the beams will converge at the focal point of the lens. We have to find the position of diverging lens so the beams after refracting from lens emerge as a parallel beam. The effective focal length of the lens must be infinity as the rays are parallel.

Using the formula: $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{a}{f_1 f_2}$

F = effective focal length = ∞

f_1 = focal length of converging lens = 40 cm

f_2 = focal length of diverging lens = -15 cm

a = distance between two lenses = ?

$$\frac{1}{\infty} = \frac{1}{40} + \frac{1}{-15} - \frac{a}{40} \times -15$$

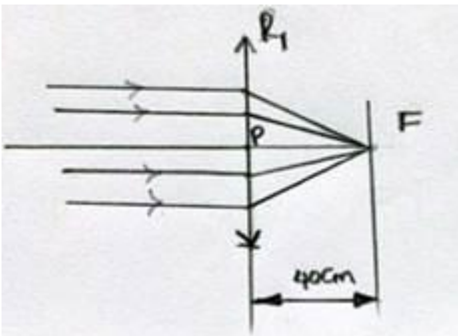
$$0 = \frac{1}{40} - \frac{1}{15} + \frac{a}{600}$$

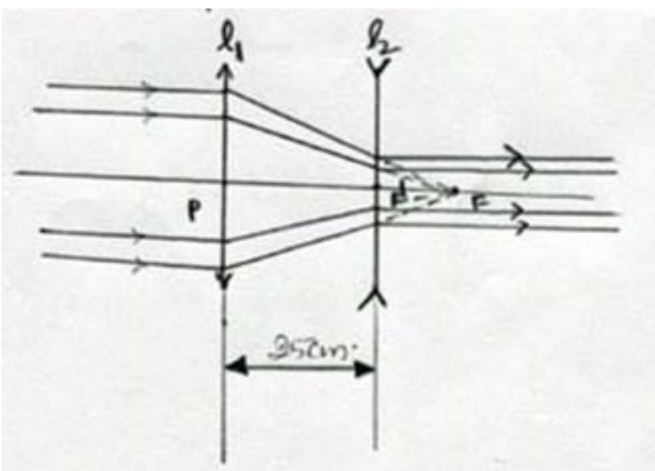
$$0 = -\frac{1}{24} + \frac{a}{600}$$

$$\frac{1}{24} = \frac{a}{600}$$

$$a = \frac{600}{24} = 25 \text{ cm}$$

So the distance between two lens should be 25 cm so as to get parallel beams of light after refraction.

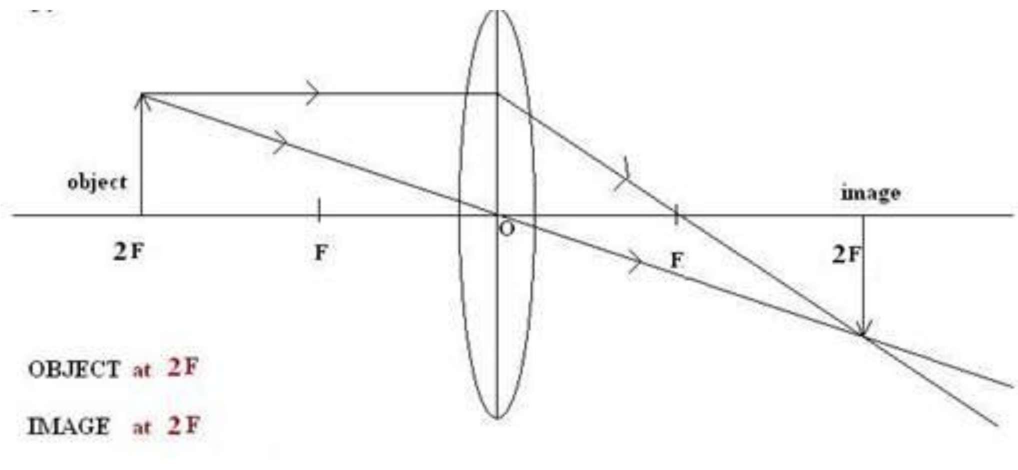




Q. 21 A. Draw a ray diagram for the following positions and explain the nature and position image.

Object is placed at C_2

Answer :

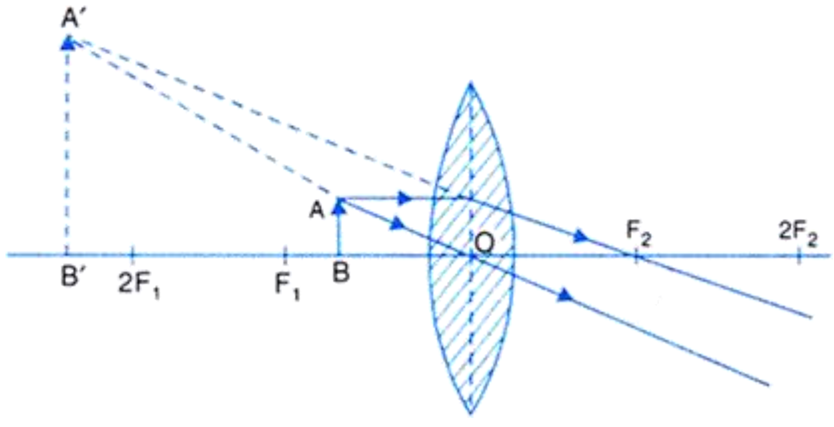


When the object is placed at C2 (2F) , then the rays coming from the object parallel to the principal axis after refraction will pass through focus. The ray passing through optic centre O will pass without deviation. The point where two rays meet will give the point of image formation. The image formed will be real, inverted & of the same size of as that of the object.

Q. 21 B. Draw a ray diagram for the following positions and explain the nature and position image.

Object is placed between F$_2$ and optic centre P. (AS5)

Answer :



When the object is placed between F2 (in fig marked as F1) and optic centrethen the rays coming from the object parallel to the principal axis after refraction will pass through focus. The ray passing through optic centre O will pass without deviation. The two refracted rays will never meet in real so the rays are extended backwards to get a virtual image. The image is formed beyond 2F behind the object and is virtual, magnified & erect.

Q. 22. How do you appreciate the coincidence of experimental facts with the results obtained by a ray diagram in terms of the behavior of images formed by lenses? (AS6)

Answer : Convex & concave lens form images when objects are placed at different positions from the lens. The concave lens always forms a virtual & diminished image of the object irrespective the position of the object. But convex lens form real or virtual, enlarged or diminished, inverted or erect depends on the position of the object. On the other hand ray diagrams are inspired by Fermat's Principle which states that the light travels in a straight path and takes the shortest path to travel.

Experimental observations coincide with the ray diagrams proving the Fermat's Principle.

Q. 23. Find the refractive index of the glass which a symmetrical convergent lens of its focal lengths is is equal to the radius of curvature of its surface. (A57)

Answer : Using formula: Lens Maker's Formula:

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

f = focal length

R_1 = radius of curvature of the lens surface closer to the source of light

R_2 = radius of curvature of the lens surface farther to the source of light

n = Refractive index

Given: The lens is symmetrical. Therefore $R_1 = R_2$

According to sign convention: $R_1 = R$ & $R_2 = -R$

focal length (f) = Radius of curvature(R)

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{R} = (n-1)\left[\frac{1}{R} - \frac{1}{-R}\right]$$

$$\frac{1}{R} = (n-1)\left[\frac{1}{R} + \frac{1}{R}\right]$$

$$\frac{1}{R} = (n-1)\left[\frac{2}{R}\right]$$

$$R = \frac{R}{2}(n-1)$$

$$1 = \frac{1}{2n} - 2$$

2n-2 = 1

2n = 3

n = 3/2 = 1.5

n = Refractive index = 1.5

Q. 24. Find the radii of curvature of a convexo- concave convergent lens made of glass with refractive index n-1.5 having focal length of 24cm. One of the radii of curvature is double the other.

Answer : Using formula: Lens Maker's Formula:

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

f = focal length

R_1 = radius of curvature of the lens surface closer to the source of light

R_2 = radius of curvature of the lens surface farther to the source of light

n = Refractive index

Given: focal length (f) = 24 cm

One of the radii of curvature is double the other that is if R_1 = R then R_2 = 2R

n = Refractive index = 1.5

For convexo-concave lens both the radii are positive.

$$\frac{1}{f} = (n-1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

$$\frac{1}{24} = (1.5 - 1)\left[\frac{1}{R} - \frac{1}{2R}\right]$$

$$\frac{1}{24} = 0.5\left[\frac{1}{2R}\right]$$

$$\frac{1}{24} = \frac{0.5}{2R}$$

2R = 0.5 × 24

R = 12/2 = 6cm

R1 = R = 6 cm

R2 = 2R = 12 cm

Q. 25. The distance between two point sources of light is 24cm .Where should a convergent lens with a focal length of f = 9cm be placed between them to obtain the images of both sources at the same Point? (AS7)

Answer : Let the first point source be located at the distance u1 & its image is formed at the distance v1. Similarly, the second point source be located at the distance u2 & its image located at v2.

Given: focal length f = 9 cm

Distance between two sources = 24 cm

For first point source:

$$\frac{1}{f} = \frac{1}{v_1} - \frac{1}{-u_1} = \frac{1}{v_1} + \frac{1}{u_1}$$

As both the images are at the same point therefore $v_1 = v_2 = v$

$\frac{1}{9} = \frac{1}{v} + \frac{1}{u_1}$ ..(1)

For second point source: $v_2 = -v$

$$\frac{1}{9} = -\frac{1}{v} + \frac{1}{u_2}$$

$\frac{1}{9} = \frac{1}{24} - u_1 - \frac{1}{v}$ ...(2)

[$u_1 + u_2 = 24$ cm]

Adding (1) & (2)

$$\frac{1}{9} + \frac{1}{9} = \frac{1}{v} + \frac{1}{u_1} - \frac{1}{v_1} + \frac{1}{24} - u_1$$

$$\frac{2}{9} = \frac{1}{u_1} + \frac{1}{24} - u_1$$

$$\frac{2}{9} = 24 - u_1 + \frac{u_1}{24u_1} - u_1^2$$

$24 u_1 – u_1^2 = 108$

$U_1^2 - 24u_1 + 108 = 0$

$U_1^2 - 18u_1 - 6u_1 + 108 = 0$

$(u_1 - 6)(u_1 - 18) = 0$

$u_1 = 6$ cm or $u_1 = 18$ cm

So the lens is kept at the distance of 6 cm or 18 cm from the first point source.

Q. 26. Suppose you are inside the water in a swimming pool near an edge. A friend is standing on the edge. Do you find your friend taller or shorter than his usual height? Why? (A S7)

Answer : Using refraction for plane surfaces: n2/v = n1/u

n1 = refractive index of air = 1

n2 = refractive index of water = n

let x be the actual height of my friend and y be the apparent height.

$$\frac{1}{-x} = \frac{n}{-y} \Rightarrow y = nx$$

As the refractive index of water is greater than 1, therefore y is greater than

x which implies that apparent height is greater than the actual height.

As light travels from denser to rarer medium, the light rays bend away from the normal due to refraction and the speed of light also changes in two mediums due to refraction.

So my friend will appear taller if I see him while inside the water.