

Geometrical Optics

Exercise Solutions

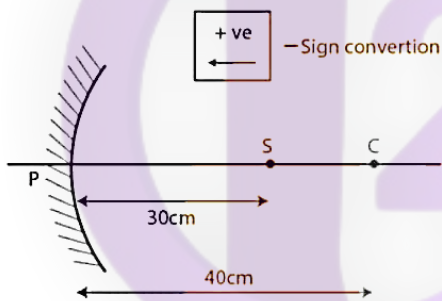
SIGN CONVENTION:

- (1) The direction of incident ray is taken as positive direction.
- (2) All measurements are taken from pole (mirror) or optical centre (lens) as the case may be.

Question 1:

Solution:

Here $u = -30\text{ cm}$ and $R = -40\text{ cm}$



From the mirror equation,

$$1/v + 1/u = 2/R$$

$$\Rightarrow 1/v = 2/-40 - 1/-30 = 1/60$$

Therefore, the image will be formed at the distance of 60 cm in front of the mirror.

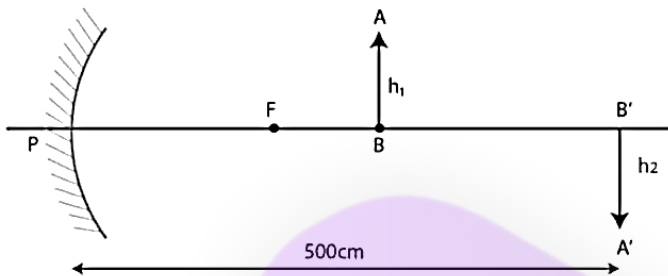
Question 2:

Solution:

Height of the image = $h_1 = 20\text{ cm}$

Height of the image = $h_2 = 50\text{ cm}$

The distance of screen from the mirror = $v = 5.0 \text{ m}$



Since, $-v/u = h_2/h_1$

$$\Rightarrow u = [-500 \times 2] / 5$$

$$= -200 \text{ cm} = 2 \text{ m}$$

From the mirror formula,

$$1/v + 1/u = 1/f$$

$$\Rightarrow 1/-5 + 1/-2 = 1/f$$

$$\Rightarrow f = -1.44 \text{ m} \rightarrow \text{[focal length]}$$

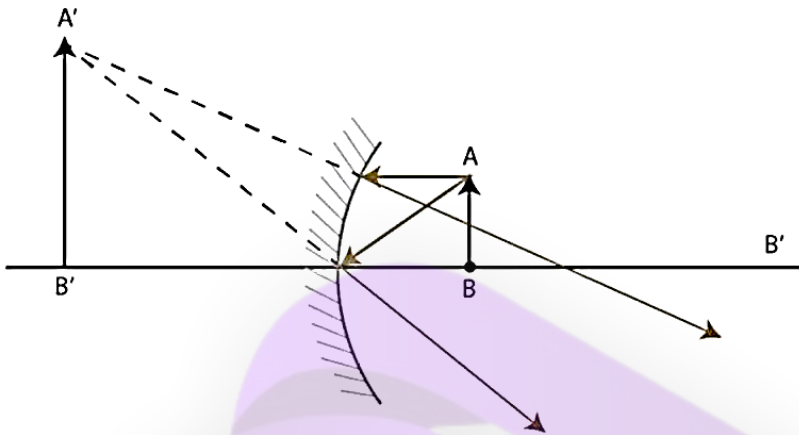
Question 3:

Solution:

Focal length of the concave mirror = $f = -20 \text{ cm}$

Magnification of the mirror = $M = v/u = 2$

$$\Rightarrow v = 2u$$



Let us consider the image formed will be virtual and beyond the mirror.
Hence, $v = -20u$

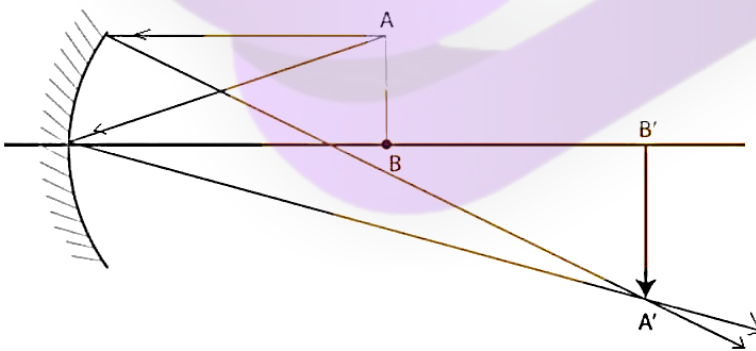
From the mirror formula,

$$1/v + 1/u = 1/f$$

$$\Rightarrow 1/-20u + 1/u = 1/-20$$

$$u = 10 \text{ cm}$$

When image formed will be real and inverted. Hence, $v = 20u$



$$\Rightarrow 1/20u + 1/u = 1/20$$

$$u = 30 \text{ cm}$$

Therefore, the positions are 10 cm and 30 cm from the concave mirror.

Question 4 :**Solution:**

Here $f = 7.5$ cm and $M(\text{Magnification}) = 0.6 \text{ cm} = v/u$

$$\Rightarrow v = 0.6u$$

From the mirror formula,

$$1/v + 1/u = 1/f$$

$$\Rightarrow 1/0.6u - 1/u = 1/7.5$$

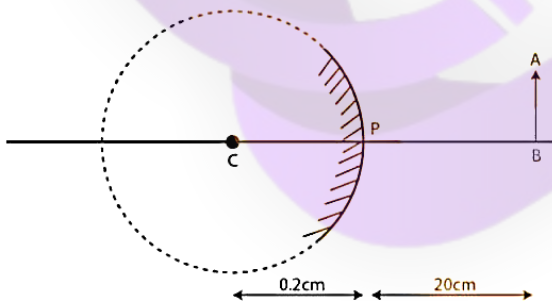
$$u = 5 \text{ cm}$$

Question 5:**Solution:**

The distance of object from the ball $= u = 20$ cm

Diameter of ball bearing $= d = 0.4$ cm

Height of the object $= h = 1.6$ cm



Consider distance of the object from the ball = $u = -20\text{cm}$

From the mirror formula,

$$1/v + 1/-20 = 2/0.2$$

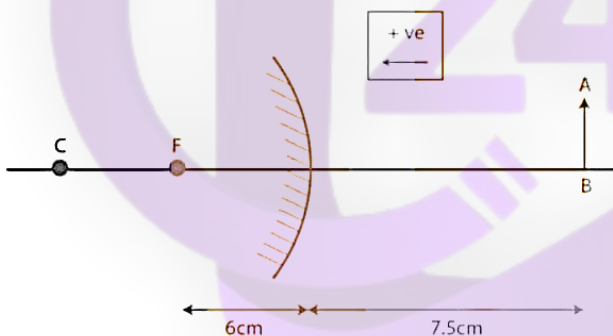
$$\Rightarrow v = 0.1 \text{ cm}$$

$$\text{Now, Magnification} = M = -v/u = 0.1/-20 = 1/200$$

$$\text{So, height of the image} = 16/200 = 0.8 \text{ m} = 0.8 \text{ mm}$$

Question 6:**Solution:**

$AB = 3 \text{ cm}$, $u = -7.5 \text{ cm}$ and $f = 6 \text{ cm}$



From the mirror formula,

$$1/v + 1/u = 1/f$$

$$1/v + 1/-7.5 = 1/6$$

$$\Rightarrow v = 10/3 \text{ cm}$$

$$\text{Now, Magnification} = M = -v/u = 10/[7.5 \times 3]$$

$$\Rightarrow A'B'/AB = 10/[7.5 \times 3]$$

$$\Rightarrow A'B' = 100/72 = 1.33 \text{ cm}$$

Image will form at a distance of $10/3$ cm. From the pole and image is 1.33 cm.

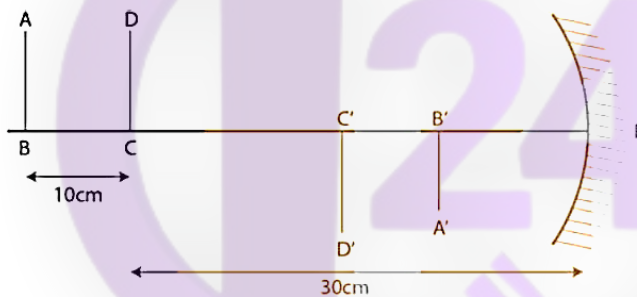
Question 7:

Solution:

$$R = 20 \text{ cm}, f = R/2 = -10 \text{ cm}$$

For part AB, $PB = 30 + 10 = 40 \text{ cm}$

Here $u = -40 \text{ cm}$



From the mirror equation,

$$1/v + 1/u = 1/f$$

$$1/v + 1/-40 = 1/-10$$

$$\Rightarrow v = -13.3 \text{ cm}$$

$$\text{So, } PB' = 13.3 \text{ cm}$$

$$\text{Now, Magnification} = M = -v/u = -13.3/-40 = -1/3$$

$$\Rightarrow A'B' = -10/3 \text{ cm}$$

$$\text{For part CD, } PC = 30 \text{ cm}$$

$$\text{Here } u = -30 \text{ cm}$$

From the mirror equation,

$$1/v + 1/u = 1/f$$

$$1/v + 1/-30 = 1/-10$$

$$\Rightarrow v = -15 \text{ cm}$$

$$\text{So, } PC' = -15 \text{ cm}$$

$$\text{Now, Magnification} = M = -v/u = -15/-30 = -1/2$$

$$\Rightarrow C'D' = 5 \text{ cm}$$

$$\text{Now, } B'C' = PC' - PB' = 15 - 13.3 = 1.7 \text{ cm}$$

$$\text{Therefore, total length} = A'B' + B'C' + C'D' = 3.3 + 1.7 + 5 = 10 \text{ cm}$$

Question 8:**Solution:**

$$\text{Here } u = 25 \text{ cm}$$

$$\text{Magnification in the image} = 1.4$$

$$\Rightarrow A'B'/AB = -v/u$$

$$\Rightarrow 1.4 = -v/-25$$

$$\Rightarrow v = 35 \text{ cm}$$

Using mirror formula,

$$1/v + 1/u = 1/f$$

$$\Rightarrow 1/f = 1/35 + 1/25 = -2/175$$

$$f = -87.5 \text{ cm}$$

Which is focal length of the concave mirror.

Question 9:**Solution:**

Here $f = 7.6 \text{ m}$ and diameter of the moon is 3450 km

Using mirror formula,

$$1/v + 1/u = 1/f$$

$$\text{using } u = -3.8 \times 10^5 \text{ km and } f = -7.6 \text{ m}$$

$$\Rightarrow v = -7.6 \text{ cm}$$

Since distance of moon from the earth is very large as compared to focal length it can be taken as infinity.

Now, Magnification, $m = -v/u = [\text{distance of the image}]/[\text{distance of the object}]$

$$\Rightarrow -(-76)/[-3.8 \times 10^5] = [\text{distance of the image}]/[3450 \times 10^3]$$

$$\Rightarrow \text{Distance of the image} = 0.069 \text{ m} = 6.9 \text{ cm}$$

Question 10:**Solution:**

Here $u = -30$ cm and $f = -20$ cm

Using mirror formula,

$$1/v + 1/u = 1/f$$

$$\Rightarrow v = -60 \text{ cm}$$

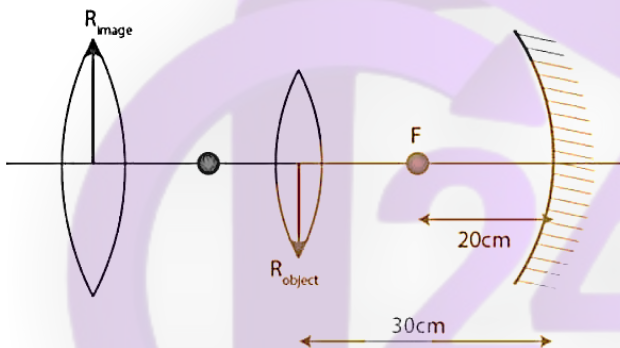


Image of the circle formed at distance 60 cm in front of the mirror.

$$\Rightarrow m = -v/u = [\text{Radius of the image}]/[\text{Radius of the object}]$$

$$\Rightarrow -(-60)/(-30) = [\text{Radius of the image}]/2$$

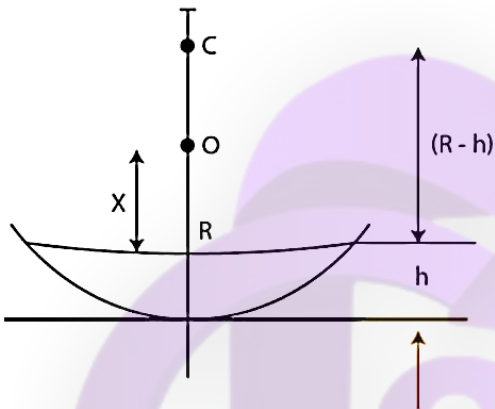
$$\Rightarrow \text{Radius of the image} = 4 \text{ cm}$$

Hence, radius of the image formed = 4cm

Question 11:

Solution:

Let the object placed at a height x above the surface of water.



If the image has to be formed at the same position, then the apparent position of the object with respect to mirror should be at the center of curvature.

$$\Rightarrow [\text{Real depth}]/[\text{apparent depth}] = 1/\mu$$

$$\text{Now, } x/(R-h) = 1/\mu$$

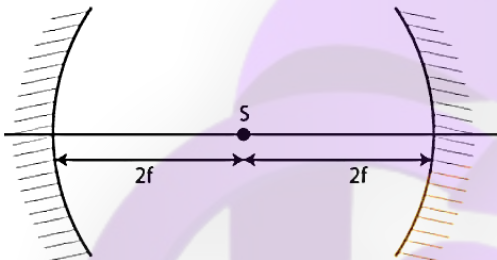
$$\Rightarrow x = [R-h]/\mu$$

Question 12:**Solution:**

Both the mirrors have equal focal length f . (Given)

Case 1:

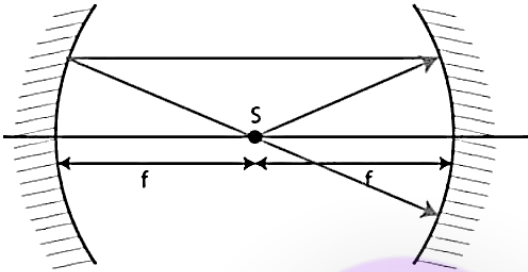
The source is at distance ' $2f$ ' from each mirror, that is the object is at center of curvature of the mirrors. Then the image will be produced at the same point S .



$$\Rightarrow d = 2f + 2f = 4f$$

Case 2:

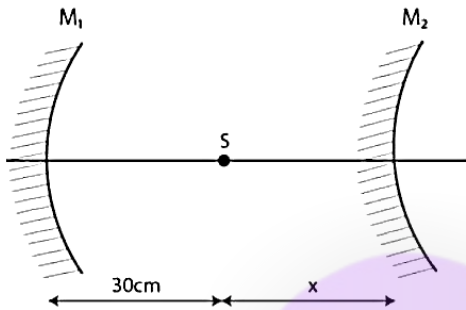
When the source s is at a distance f from each mirror, the rays from the source after reflecting from one mirror will become parallel and so these parallel rays after the reflection from the other mirror the object itself. In this case only one image is formed.



$$\Rightarrow d = f + f = 2f$$

Question 13:**Solution:**

The focal length of both the mirrors is same, i.e. 20 cm, and the image is also formed at the focus after the reflection from both the mirror surfaces.



For mirror M_1 :

The distance of object from the mirror, $u = -30\text{cm}$ (converging mirror)

Focal length, $f = -20\text{cm}$

Using mirror formula,

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

Here $u = 30$ and $f = -20$

$$\Rightarrow v = -60 \text{ cm}$$

For mirror M_2 :

Object distance from the mirror will be the difference of the image formed by first mirror and the distance between the two mirrors.

$$\Rightarrow u = 60 - (30 + x) \text{ cm} = 30 - x \text{ cm}$$

Distance of image from the mirror, $v = -x \text{ cm}$

Focal length of the mirror, $f = 20\text{cm}$

$$\text{mirror formula} \Rightarrow -\frac{1}{x} + \frac{1}{(30-x)} = \frac{1}{20}$$

$$\Rightarrow x = 20 \text{ cm or } -30 \text{ cm}$$

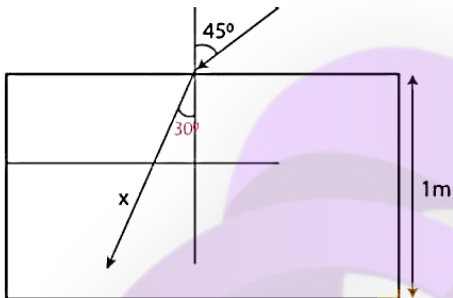
Therefore, total distance between the two lines is $20+30 = 50 \text{ cm}$.

Question 14:

Solution:

Angle of incidence $i = 45^\circ$

Angle of refraction $r = 30^\circ$



Using the Snell's law:

$$[\sin i]/[\sin r] = c/v$$

Where c = velocity of light in air and v = velocity of light in medium

$$\Rightarrow [\sin i]/[\sin r] = [3 \times 10^8]/v$$

$$\Rightarrow \sin 45^\circ/\sin 30^\circ = [3 \times 10^8]/v$$

$$\Rightarrow v = [3 \times 10^8]/\sqrt{2} \text{ m/s}$$

Now, Distance travelled by light in the slab is x

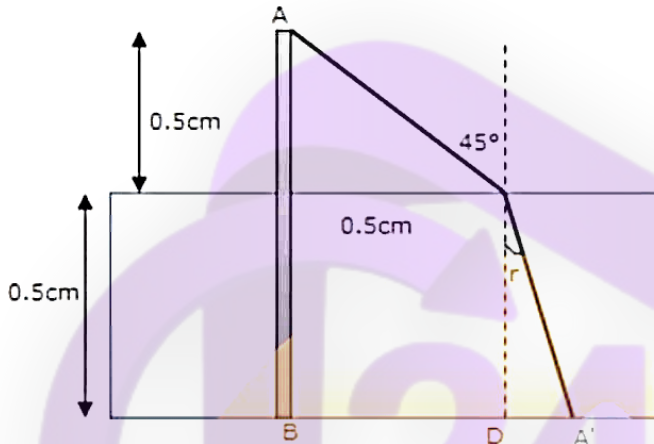
$$x = 1/\cos 30^\circ = 2/\sqrt{3}$$

$$\text{Hence, time taken by light} = 2\sqrt{2}/[\sqrt{3} \times 3 \times 10^8]$$

$$= 5.4 \times 10^{-9} \text{ sec}$$

Question 15:**Solution:**

Shadow length = $BA' = BD + A'D = 0.5 + 0.5 \tan r$



Now, $1.33 = \sin 45^\circ / \sin r$

$$\Rightarrow \sin r = 0.53$$

$$\Rightarrow \cos r = \sqrt{1 - \sin^2 r} = \sqrt{1 - (0.53)^2} = 0.85$$

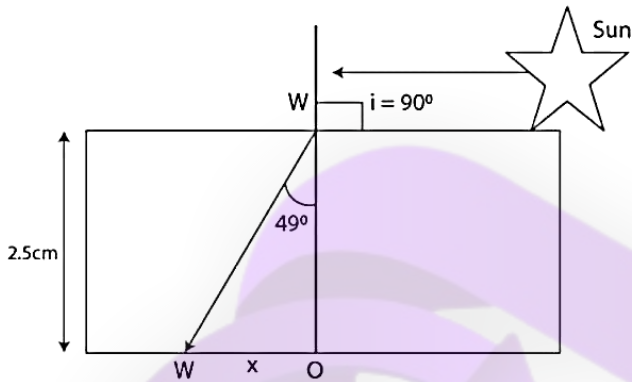
$$\Rightarrow \tan r = 0.6235$$

Therefore, shadow length = $0.5(1 + 0.6235) = 0.812$ cm

Question 16:

Solution:

Height of the lake = 2.5m



Using the Snell's law:

$$[\sin i]/[\sin r] = \mu_2/\mu_1 = (4/3)/1$$

$$\Rightarrow \sin r = 3/4$$

$$\Rightarrow r = 49^\circ$$

From diagram,

$$\tan r = x/2.5$$

$$\Rightarrow \tan 49^\circ = x/2.5$$

$$\Rightarrow x = 2.8 \text{ m}$$

Question 17:

Solution:

The thickness of the glass slab, $d = 2 \text{ cm}$
and refractive index of the slab $\mu = 1.5$

shift due to the glass slab: $\Delta T = (1 - 1/\mu) d = (1 - 1/1.5)2.1 = 0.7 \text{ cm}$

Microscope should be shifted 0.70cm to focus the object again.

Question 18:**Solution:**

Let Δt_o is shift due to oil and Δt_w = shift due to water

$$\Delta t_w = \left(1 - \frac{1}{\mu}\right) d = \left(1 - \frac{1}{1.33}\right) 20 = 5 \text{ cm}$$

and,

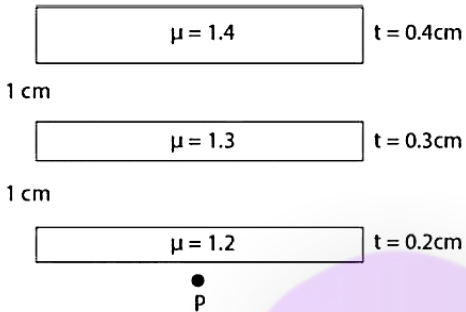
$$\Delta t_o = \left(1 - \frac{1}{\mu}\right) d = \left(1 - \frac{1}{1.3}\right) 20 = 4.6 \text{ cm}$$

Total shift $\Delta t = 5 + 4.6 = 9.6 \text{ cm}$

Apparent depth = $40 - (9.6) = 30.4 \text{ cm}$ below the surface.

Question 19:**Solution:**

The presence of air medium in between the sheets does not affect the shift.



Hence, the shift will be due to 3 sheets of different refractive index other than air
 $= (1 - 1/1.2)0.2 + (1 - 1/1.3)(0.3) + (1 - 1/1.4)(0.4)$
 $= 0.2 \text{ cm above point P}$

Question 20:

Solution:

Total number of transparent slabs = k

Refractive index = $\mu_1, \mu_2, \mu_3, \dots, \mu_k$

Thickness of the slabs = $t_1, t_2, t_3, \dots, t_k$

Let refractive index, μ , of combination of slabs and image is formed at same place.

Then the shift:

$$\Delta t = \left(1 - \frac{1}{\mu_1}\right)t_1 + \left(1 - \frac{1}{\mu_2}\right)t_2 + \left(1 - \frac{1}{\mu_3}\right)t_3 + \dots + \left(1 - \frac{1}{\mu_k}\right)t_k \dots(1)$$

and,

$$\Delta t = \left(1 - \frac{1}{\mu_1}\right)(t_1 + t_2 + t_3 + \dots + t_k) \dots(2)$$

From (1) and (2)

$$\left(1 - \frac{1}{\mu_1}\right)t_1 + \left(1 - \frac{1}{\mu_2}\right)t_2 + \left(1 - \frac{1}{\mu_3}\right)t_3 + \dots + \left(1 - \frac{1}{\mu_k}\right)t_k =$$

$$\left(1 - \frac{1}{\mu_1}\right)(t_1 + t_2 + t_3 + \dots + t_k)$$

$$= (t_1 + t_2 + t_3 + \dots + t_k) - \left(\frac{t_1}{\mu_1}\right) + \left(\frac{t_2}{\mu_2}\right) + \dots + \left(\frac{t_k}{\mu_k}\right)$$

$$\Rightarrow -\frac{1}{\mu} \sum_{i=1}^k t_i = -\sum_{i=1}^k \left(\frac{t_i}{\mu_i}\right)$$

$$\Rightarrow \mu = \frac{\sum_{i=1}^k t_i}{\sum_{i=1}^k \left(\frac{t_i}{\mu_i}\right)}$$

Question 21:

Solution: Volume of water in cylindrical vessel = $800 \pi \text{ cm}^3$

Volume of cylindrical water column after putting the glass piece inside it:

$$\pi r^2 h = 800\pi + \pi r_g^2 h_1$$

r_g = Radius of glass piece = 4 cm

h_1 = Height of glass piece = 8cm

and $r = 6$ cm

$$\Rightarrow h = 25.7 \text{ cm}$$

There will two shifts due to the presence of glass and water:

1st shift for glass and 2nd shift for water are as

$$\Delta t_1 = \left(1 - \frac{1}{\mu_g}\right) t_g = \left(1 - \frac{1}{3/2}\right) \times 8 = 2.26 \text{ cm}$$

$$\Delta t_2 = \left(1 - \frac{1}{\mu_w}\right) t_{h_w} = \left(1 - \frac{1}{4/3}\right) \times (25.7 - 8) = 4.44 \text{ cm}$$

Total shift = $\Delta t_1 + \Delta t_2 = (2.26 + 4.44) \text{ cm} = 7.1 \text{ cm}$ above the bottom.

Question 22:

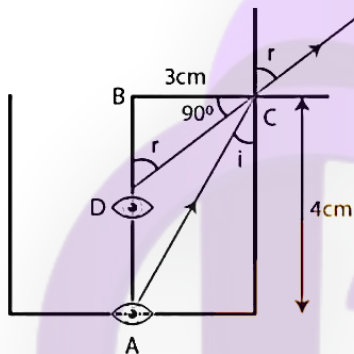
image of fish becomes $3H/2$.

Apparent depth for the surface of water = $3H/2\mu$

Therefore, the distance of image from the eye is $H + 3H/2\mu = H(1 + 3/2\mu)$

Question 23:

Solution:



By using Snell's law;

$$\sin i / \sin r = 1/\mu_w = 1/1.33 = 3/4$$

Where μ_w = Refractive Index of water = 1.33

$$\Rightarrow \sin r = (4/3) \sin i \dots (A)$$

From the diagram, $\cos r = x/3 \dots (1)$

and $\sin i = 3/5$

$$(A) \Rightarrow \sin r = 4/5$$

Therefore, $\cot r = 3/4 \dots (2)$

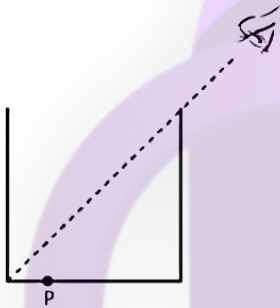
Equating (1) and (2)

$$x/3 = 3/4$$

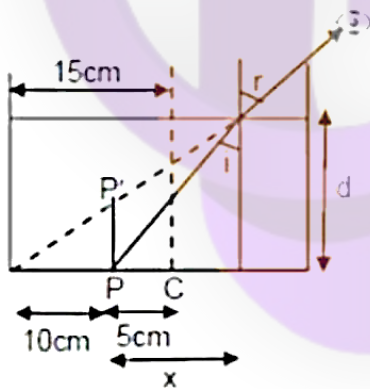
$$\Rightarrow x = 9/4 = 2.25 \text{ cm; apparent depth}$$

Hence, The ratio of real depth to apparent depth = $4 : (2.25) = 1.78$.

Question 24:



Solution:



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For the given cylindrical vessel;

Diameter (d) = 30cm, Radius (r) = 15 cm, Height (h) = 30 cm and d = height of water

By using Snell's law;

$$\sin i / \sin r = 1 / \mu_w = 1 / 1.33 = 3/4$$

Where μ_w = Refractive Index of water = 1.33

here Angle of refraction = 45°

$$\Rightarrow \sin i = 3/(4\sqrt{2})$$

The Point "P" will be visible when the refracted ray makes angle of 45 degree at the point of refraction.

Let x cm distance from P to X.

$$\tan 45^\circ = (x+10)/d$$

$$\Rightarrow d = x + 10 \dots(1)$$

Now, $\tan i = x/d$

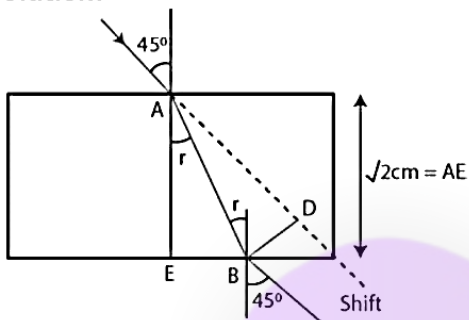
Using value of $\sin i$, we have the value of $\tan i = 3/\sqrt{23}$

$$\Rightarrow 3/\sqrt{23} = (d-10)/d$$

$$\Rightarrow d = 26.7 \text{ cm}$$

Question 25:

Solution:



From the diagram,

$$(\sin 45^\circ)/\sin r = 2/1$$

$$\Rightarrow \sin r = 1/(2\sqrt{2})$$

$$\text{or } r = 21^\circ$$

$$\text{Here } \theta = (45^\circ - 21^\circ) = 24^\circ$$

$$\text{and } BD = \text{shift in path} = AB \sin 24^\circ$$

$$= 0.406 \times AB$$

$$= AE/\cos 21^\circ \times 0.406$$

$$= 0.62 \text{ cm}$$

Question 26:

Solution:

By Snell's law;

$$\sin i/\sin r = \sin \theta_c/\sin 90^\circ = \mu_g/\mu_o$$

Where μ_o = Refractive index of optical fibre = 1.72

and μ_g = Refractive index of glass coating = 1.50

Also, $\theta_c = \text{critical angle} = \sin^{-1}(1/\mu)$

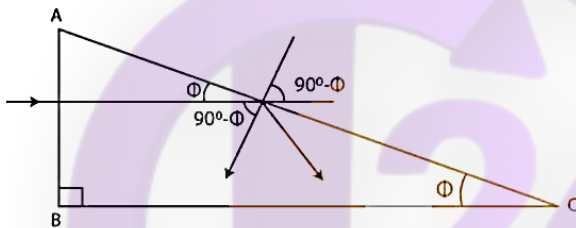
$$\Rightarrow \sin \theta_c / \sin 90^\circ = 1.50/1.72 = 75/86$$

$$\Rightarrow \theta_c = 75/86$$

Therefore, critical angle is $\sin^{-1}(75/86)$

Question 27:

Solution:



By Snell's law;

$$\sin i / \sin r = 1/\mu$$

Also, $\theta_c = \text{critical angle} = \sin^{-1}(1/\mu)$

$$\Rightarrow \sin \theta_c / \sin 90^\circ = 1/\mu = 1/1.50 = 2/3$$

$$\Rightarrow \theta_c = \sin^{-1}(2/3)$$

Now, for total internal reflection, $90^\circ - \phi > \theta_c$ (from diagram)

$$\Rightarrow \phi < 90^\circ - \theta_c = \cos^{-1}(2/3)$$

Thus, largest angle ϕ for which the light ray is totally reflected at the surface,
 $\phi = \cos^{-1}(2/3)$

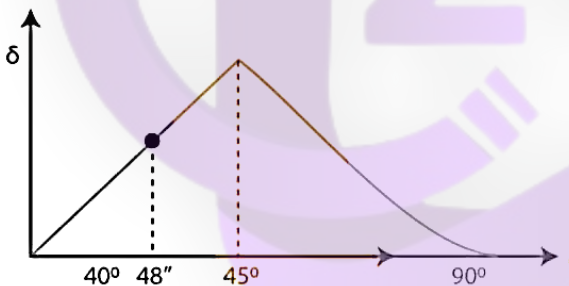
Question 28:

Solution:

From the definition of critical angle, if a refracted ray makes an angle more than 90 degrees, then total internal reflection will occur. So, the maximum angle of refraction is 90 degrees.

Question 29:

Solution:



$$\theta_c = \text{critical angle} = \sin^{-1}(1/\mu)$$

$$\text{and } \sin \theta_c / \sin r = \mu_a / \mu_g$$

Here $\mu_a = 1.0$ and $\mu_g = 1.5$ and $r = 90^\circ$

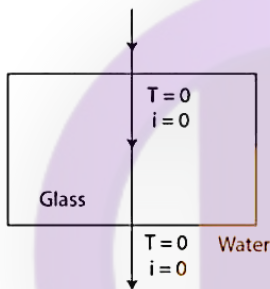
$$\Rightarrow \sin \theta_c / \sin 90^\circ = 2/3$$

$$\Rightarrow \theta_c = 40^\circ 48''$$

The angle of deviation due to refraction from glass to air increases as the angle of incidence increases from 0° to $40^\circ 48''$. The angle of deviation due to total internal reflection further increases for $40^\circ 48''$ to 45° and then it decreases.

Question 30:

Solution:



For two angles of incidence,

1) When light passes through the normal:

Angle of incidence = 0° , Angle of refraction = 0° and Angle of deviation = 0°

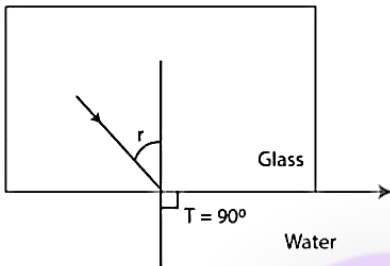
(2) When light incident at critical angle :

$$\sin \theta_c / \sin r = \mu_w / \mu_g$$

here $\mu_w = 1.33 = 4/3$ and $\mu_g = 1.5 = 3/2$

Therefore, $\sin \theta_c = 8/9$

and $\theta_c = \sin^{-1}(8/9)$



Also, the Angle of deviation = $90^\circ - \theta_c$

$$= 90^\circ - \sin^{-1}(8/9)$$

$$= \cos^{-1}(8/9)$$

So, If angle of incidence increases beyond critical angle, total internal reflection will occur.

Thus, the range of angle of deviation is from 0° to $\cos^{-1}(8/9)$.

Question 31:

Solution:

$$\sin \theta_c = 8/9$$

We know, critical angle = $\theta_c = \sin^{-1}(1/\mu) = 41.8^\circ$

Here $\mu = 1.5$

Maximum angle of deviation in refraction = $90^\circ - 41.8^\circ = 47.2^\circ$

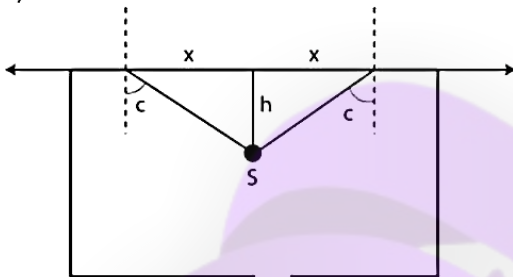
In this case, total internal reflection must have taken place. In reflection, deviation = $180^\circ - 2i = 90^\circ$

$$\Rightarrow i = 45^\circ$$

Question 32:

Solution:

(a)



Here S be the source point and x be the radius of circular area.

We know, critical angle = θ_c

So, $\tan \theta_c = x/h$

\Rightarrow

$$\frac{x}{h} = \frac{\sin \theta_c}{\sqrt{1 - \sin^2 \theta_c}} = \frac{\frac{1}{\mu}}{\sqrt{1 - \frac{1}{\mu^2}}}$$

[we know, $\sin \theta_c = (1/\mu)$]

$$\Rightarrow x = h/\sqrt{\mu^2 - 1}$$

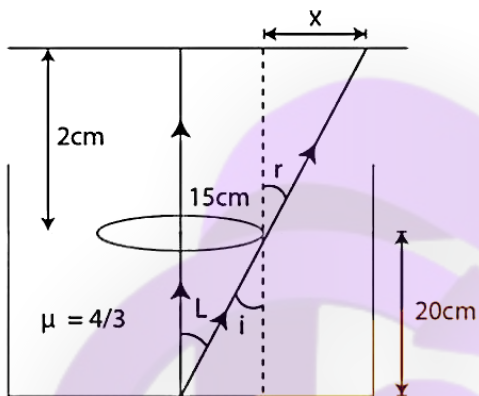
Light escapes from the circular area at a fixed desistance r on the water surface, directly above the point source S.

(b) As, $\sin \theta_c = (1/\mu)$

$$\Rightarrow \theta_c = \sin^{-1}(1/\mu)$$

Question 33:

Solution:



(a) Height of water container = $h = 20 \text{ cm}$..(given)
 Ceiling of the room is 2.0 m above the water surface. ..(given)

From diagram, $\sin i = 15/25$

By Snell's law,

$$\sin i / \sin r = 1/\mu = 3/4$$

[Refractive index of water = $4/3$ (given)]

$$\Rightarrow \sin i = 4/5$$

Again $\tan r = x/2$ (from diagram)

Therefore,

$$\sin r = \frac{\tan r}{\sqrt{1 + \tan^2 r}} = \frac{\frac{x}{2}}{\sqrt{1 + \frac{x^2}{4}}}$$

$$\Rightarrow \frac{x}{\sqrt{4+x^2}} = \frac{4}{5}$$

$$\Rightarrow x = 8/3 \text{ cm}$$

Total radius of the shadow = $8/3 + 0.15 = 2.81 \text{ m}$

(b) For Maximum angle of refraction: $i = \theta_c$
 Let R is the maximum radius.

$$\sin \theta_c = \sin i / \sin r$$

$$\Rightarrow \sin \theta_c = \sin \theta_c / \sin r$$

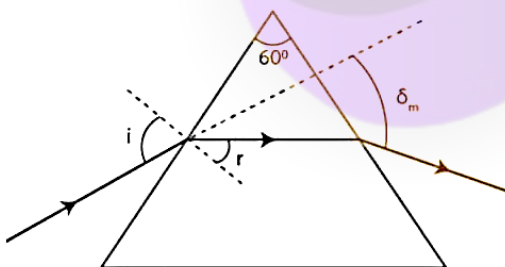
$$\Rightarrow R / \sqrt{R^2 + 20} = \frac{3}{4}$$

$$\Rightarrow 16R^2 = 9R^2 + 9 \times 400$$

$$\Rightarrow R = 22.67 \text{ cm}$$

Question 34:

Solution:



Let Angle of prism = A and δ_m is the minimum deviation.

$$\Rightarrow 1.732 \times \sin 30^\circ = \sin[(\text{Angle of minimum deviation} + 60^\circ)/2]$$

$$\Rightarrow 1.732 \times (1/2) = \sin[\delta_m + 60^\circ)/2]$$

[Here $1.732 \times \sin 30^\circ = \sqrt{3}/2$ which is equal to $\sin 60^\circ$]

$$\text{So, } \sin 60^\circ = \sin[(\delta_m + 60^\circ)/2]$$

$$\text{or } \delta_m + 60^\circ = 2 \times 60^\circ$$

$$\Rightarrow \delta_m = 60^\circ$$

$$\text{Also, } \delta_m = 2i - A$$

$$\Rightarrow 2i = 120^\circ$$

$$\text{or } i = 60^\circ$$

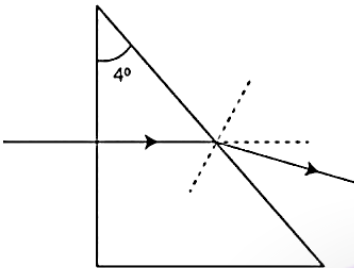
Therefore, the minimum angle of deviation, $\delta_m = 60^\circ$.

Required angle of incidence = $i = 60^\circ$

Question 35:

Solution:

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We know, Angle of minimum deviation,

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

Find angle of deviation, δ_m

For small angle, $\sin \theta = \theta$ (approx.)]

$$\Rightarrow \mu = \frac{A + \delta_m}{2} / \frac{A}{2}$$

Here $A = 4^\circ$

$$\Rightarrow 1.5 = \frac{4^\circ + \delta_m}{2^\circ}$$

Given $\mu = 1.5$

$$\Rightarrow \delta_m = 2^\circ$$