SUPERNOVA PHYSICS

for

JEE ADVANCED & OLYMPIADS

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1000+ SELECTED PROBLEMS FOR SUPERCHARGING YOUR PHYSICS

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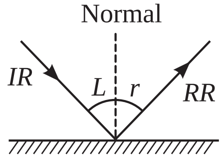
15 Geometric Optics

1. When a ray of light is incident on a surface, there are three phenomenon which occurs
   (*a*) Reflection (*b*) Refraction
   (*c*) Absorption

2. **Laws of Reflection:**



- Angle of incidence = Angle of Reflection
- Incident ray, reflected ray and normal all lies in same plane.

3. Let two plane mirror are inclined to each other at angle θ.

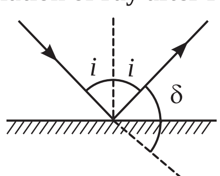
   Method to find number of images

   $\frac{360}{\theta} = n$

   - n = even → No of images = n–1
   - n = odd
     - object lying symmetrically → No of images = n –1
     - object lying unsymmetrically → no of images = n

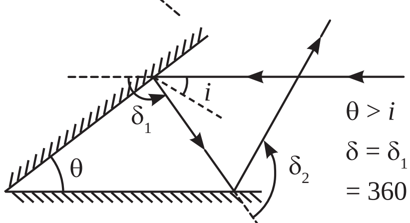
4. **Deviation of ray after reflection:**

(*a*)



$\delta = 180 - 2i$

(*b*)



$\theta > i$

$\delta = \delta_1 + \delta_2$

$= 360 - 2\theta$

5. When Incident ray is rotated by angle θ, keeping mirror stationary. The image rotates by same angle θ in opposite sense

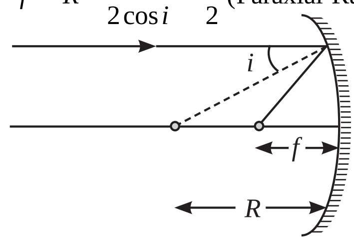
   Whereas,

   If the mirror is rotated by angle θ keeping object stationary, image rotates by 2θ in same direction of rotation.

6. For a plane mirror, image is of opposite nature as of object, it is of same size as of object, at same distance as of object from mirror. These properties can be utilised to determine the velocity of image, when object or mirror is moving.

7. The relationships between angle of incidence and focal length.

$$f = R - \frac{R}{2\cos i} \approx \frac{R}{2} \text{ (Paraxial Rays)}$$



8. For reflection through spherical surface certain sign convention rules are used which can be considered same for all future case.

   Sign Convention

   - Direction of incident ray will be same as direction to be considered to be positive.
   - All distance are measured from pole/optical centre.
   - Distances measured in direction of IR will be measured positive anti-parallel to direction of IR, will be considered negative.

- Distances measured vertically upward from principal axis will be positive whereas measurement vertically downward will be taken as nagative.

9. For spherical surface Reflection:

(*a*) Mirror formula is $\frac{1}{f} = \frac{1}{v} + \frac{1}{u}$

f = focal length from pole

v = Image distance from pole

u = object distance from pole

(*b*) To Relate height of object & Image we use lateral magnification.

$$m_{\text{Lateral}} = \frac{h_i}{h_o} = \frac{-v}{u}$$

(*c*) To Relate thickness along PA for object and Image we have Longitudinal magnification valid for small thickness only.

$$m_{\text{Long}} = \frac{t_I}{t_o} = \frac{-v^2}{u^2} \quad \text{(Only valid for small thickness)}$$

(*d*) If object moves parallel or perpendicular or at any angle to principle axis of mirror. We can relate velocities of image & object using magnifications.

Velocity of image parallel to PA = $m_{\text{Long}} \times$ velocity of object parallel to PA.

Velocity of image perpendicular to PA. = m_{Lateral} × velocity of object perpendicular to PA.

10. Laws of Refraction:

(*a*) Incident Ray, Normal Ray, Refracted Ray all lies in same plane.

(*b*) **Snell's Law:** product of Refractive Index and sine of angle made with normal is always const

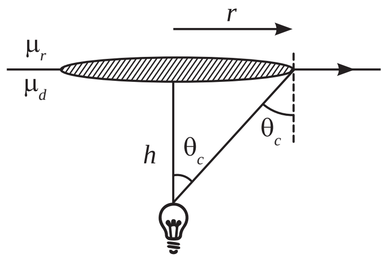
$$\mu \sin\theta = \text{constant}$$

11. When light moves from denser medium to rarer medium, it shifts away from normal. At a certain angle from denser medium emergent ray grazes out from surface called critical angle.

$$\theta_c = \sin^{-1}\left(\frac{\mu_r}{\mu_d}\right)$$

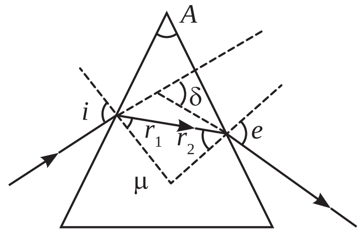
If angle of incidence is greater than critical angle, light is reflected back in denser medium. This phenomenon is called TIR (Total Internal Reflection).

12. Area of visible region from under water



$$\text{radius} = \frac{h \times 1}{\sqrt{\left(\frac{\mu_d}{\mu_r}\right)^2 - 1}}$$

13. For refraction through prism, we need to mention some important points

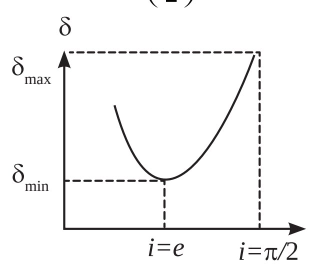


- $A = r_1 + r_2$
- $\delta = i + e - (r_1 + r_2)$
- $\delta = i + e - A$
- $\sin i = \mu \sin r_1$
- $\mu \sin r_2 = \sin e$.
- For minimum deviation $i = e$

$A/2 = r$

$\delta_{\min} = 2i - A$

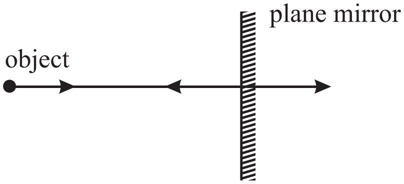
$$\mu = \frac{\sin\left(\frac{A + \delta_{\min}}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

- 

EXERCISE QUESTIONS

Multiple Choice Questions

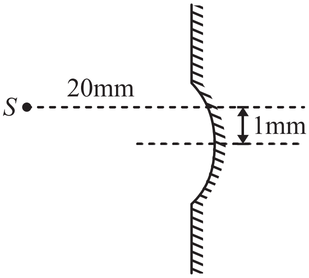
1. In the diagram shown, the object is performing SHM according to the equation $y = 2A\sin(\omega t)$ and the plane mirror is performing SHM according to the equation $Y = -A\sin\left(\omega t - \frac{\pi}{3}\right)$. The diagram shows the state of the object and the mirror at time $t = 0$ sec. The minimum time from $t = 0$ sec after which the velocity of the image becomes equal to zero?



(*a*) $\frac{\pi}{3\omega}$ (*b*) $\frac{3\pi}{\omega}$

(*c*) $\frac{\pi}{6\omega}$ (*d*) $\frac{2\pi}{3\omega}$

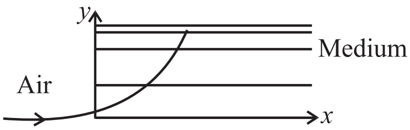
2. A practically very small source (*S*) of light is kept in front of a plane mirror. But due to imperfect manufacturing, there is a small spherical bulge (radius of curvature 80 mm). The situation is as shown in the figure. You can assume that principal axis of bulge is perpendicular to the plane mirror. Find the separation between the images formed.



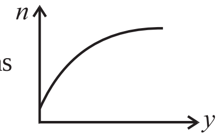
(*a*) 10.025 mm (*b*) 20.025 mm

(*c*) 40.025 mm (*d*) 80.025 mm

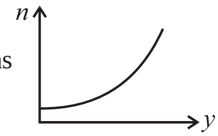
3. The refractive index of the medium within a certain region $x > 0$, $y > 0$, changes continuously with y. A thin light ray travelling in air in the *x*-direction strikes the medium at right angles and moves through the medium along a circular arc of radius *R*.



(*a*) Refractive index of medium varies with *y* as



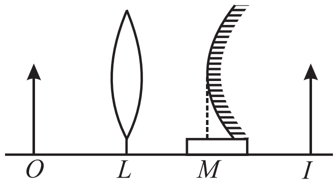
(*b*) Refractive index of medium varies with *y* as



(*c*) If refractive index of medium can increase up to a value $n = 2.5$, the maximum value of y is $\frac{3R}{5}$

(*d*) If refractive index of medium can increase up to a value $n = 2.5$, the maximum value of y is $5R$

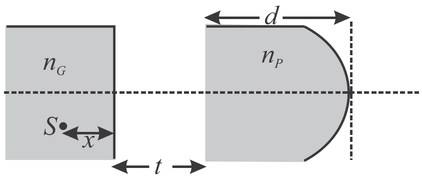
8. An optical bench is used to estimate the focal length of a convex mirror. First an object needle (O), convex lens L and image needle I are placed and parallax is removed. Now convex mirror is introduced between L and I and the mirror is moved so that image as seen from left of O has no parallax with O. Which of the following readings is/are required to estimate the focal length of mirror and random error in it?



(*a*) O (*b*) L

(*c*) M (*d*) I

9. As shown below, a point light source (S) is inside a glass block of refractive index $n_G = \frac{3}{2}$, at a distance 2 mm from the optical axis and distance x = 3 cm from the flat surface. A thick plano-convex lens made of transparent plastic material of refractive index n_P = 2, is placed near the source as shown. The thickness of the lens is d, and the radius of convex surface is R = 15 cm. The width of air gap between the glass block and the lens is 't'. The width of air gap t and thickness of lens d is adjusted so that light (paraxial rays) from point source forms always a parallel beam after passing through the lens. Select correct option(s).



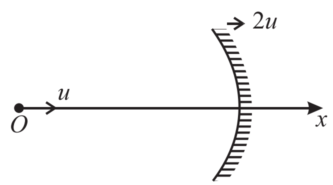
(*a*) For d = 16cm, width of air gap t = 5 cm.

(*b*) For thickness d = 10 cm, width of air gap t = 8 cm.

(*c*) The maximum adjustable value of d = 26 cm.

(*d*) The maximum adjustable value of d = 16 cm.

10. An object and a concave mirror is moving with velocities $u\hat{i}$ and $2u\hat{i}$ respectively as shown in figure. The image formed by the concave mirror:



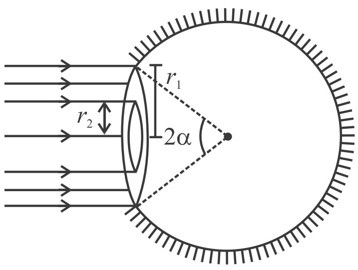
(*a*) will have speed greater than the speed of the object

(*b*) may have speed greater than the speed of the object

(*c*) will have speed greater than the speed of the mirror

(*d*) must move away from the mirror.

11. A silvered, hollow glass sphere (mirror), having radius R, has a round hole as shown in the figure. Radius of round hole makes α (acute) angle at the centre. Into this round hole a parallel beam of ray falls, perpendicular to the plane of the hole. Part of rays having undergone one reflection, (portion crossing the smaller circle of radius r_2) exits the sphere back through the hole. (Assume 100 % reflection). Choose the correct option.



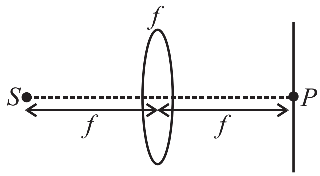
(*a*) $r_2 = R\sin\left(\frac{\alpha}{2}\right)$

(*b*) $r_1 = 3r_2 - \frac{4r_2^3}{R^2}$

(*c*) $r_1 = \frac{R^2}{r_2}\sin(\alpha)$

(*d*) Fraction of the power of the incoming beam, which exit through the hole after one reflection is $\left[\frac{\sin(\alpha/3)}{\sin\alpha}\right]^2$

Geometric Optics



12. A monochromatic point light source S is placed at a distance $2f$ from a screen as shown. A convex lens of focal length f is placed in between source and screen as shown. Assume complete transmission of light through lens.

(*a*) Intensity at point P on the screen before and after placing lens will be same

(*b*) Intensity at point P on the screen after placing lens will become two times that of before placing lens

(*c*) Intensity at point P on the screen after placing lens will become four times that of before placing lens

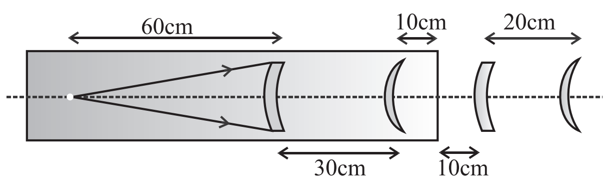
(*d*) Intensity at point P on the screen before and after placing lens is not comparable

13. Light passes from air into flint glass with index of refraction n. The angle of incidence must the light have for the component of its velocity perpendicular to the interface to remain same in both mediums is

(*a*) $\sin^{-1} n$ (*b*) $\sin^{-1}\left(\frac{1}{n}\right)$

(*c*) $\cos^{-1} n$ (*d*) $\tan^{-1} n$

14. Parallel to each other there are four thin lenses along the same optical axis, as shown in the figure. The radii of the curvatures of each lens are 5 cm, and 10 cm. Two of the lenses are air lenses which are in glass of refractive index of $n = 1.5$ and the other two lenses are made of glass of the same refractive index. In the glass there is a point-like light source on the optical axis at a distance of 60 cm from the fist air lens which is thinner in the middle. The boundary of the glass is at a distance of 10 cm from the other air lens as shown. From the boundary of glass at a distance of 10 cm there is the concave glass lens and the fourth glass lens is at a distance of 20 cm from the third one.



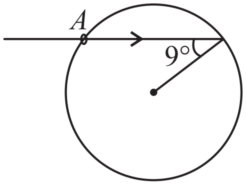
(*a*) The image of the light source created by the four lenses is virtual

(*b*) The image of the light source created by the four lenses is inverted w.r.t. object

(*c*) The image of the light source created by the four lenses is real

(*d*) The image of the light source created by the four lenses is at a distance of 40 cm from the last lens

15. A ray of light, travelling parallel to diameter of a sphere enters the sphere through a hole at point A as shown in the figure. The inner surface of the sphere is made perfectly reflecting. Find the number of reflections suffered by the ray before coming out of the sphere.



(*a*) 180 (*b*) 20

(*c*) 179 (*d*) 19

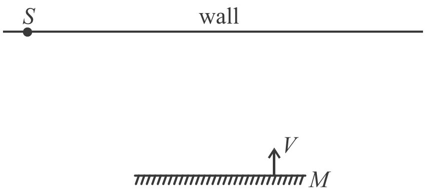
16. An equi-concave lens of radii of curvature of the two surfaces numerically equal to 7 cm and refractive index $\mu = 1.5$ has a small silver dot on the rear surface. As a result of this, a ray of light incident parallel to the principal axis gets reflected from its rear surface and then reflected also from the inner front surface. The ray after the second reflection emerges out of the thin lens and appears to focus at a point P on the principal axis. The point P lies

(*a*) 1 cm before the lens (*b*) 2 cm before the lens

(*c*) 1 cm beyond the lens (*d*) at none of these

Paragraph Type Questions

Passage for (Q. 1 - 2): A point source of light is as shown in the figure reflected light form the mirror M forms a patch on the wall. As mirror approaches the wall from a distance:



1. Mark the correct statement

(*a*) The patch will increase in size

(*b*) The patch will remain the same size

(*c*) The size of the patch will increase then decreases

(*d*) The size of the patch will decrease then increase

2. Mark the correct statement

(*a*) Patch will become brighter

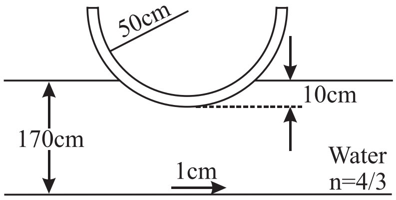
(*b*) Patch will become dimmer

(*c*) Brightness of the patch will remain the same.

(*d*) Patch will first become brighter then dimmer

Numericals & Subjective Questions

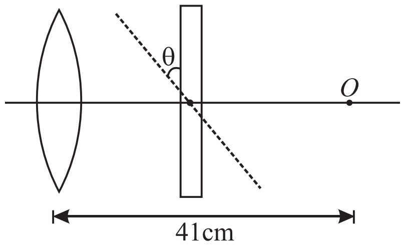
1. A thin hemispherical bowl of transparent plastic floats on water in a tank. The radius of the bowl is 50 cm and the depth of the bowl in water is 10 cm. The depth of the water ($\mu = 1.33$) in the tank is 170 cm. An object 1 cm long is on the bottom of the tank directly below the bowl. The object is viewed from directly above the bowl. Ignore the refractive effects of the plastic.



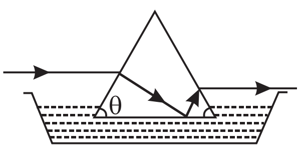
What is the size (in cm) of the image?

Geometric Optics

2. Parallel beam of light falls normally on a wall of a dark room and illuminates on it a round spot of radius $r = 4$ cm. when a ball (radius = 5cm) whose surface is mirrored is placed so that its center is on the axis of the beam and at a distance of $d = 11$ cm from the wall, a large part of the wall is illuminated but at the center is formed a circular shadow of radius R cm. Find R in cm.

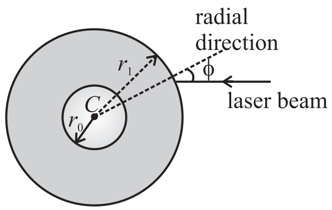


3. A point object O is placed at a distance of 41 cm from a convex lens of focal length $f = 20$ cm on its principal axis. A glass slab of thickness 3 cm and refractive index $\mu = 1.5$ is placed between the lens and the object with its faces perpendicular to the principal axis of the lens. Image of the object is formed at point I_1. Now the glass slab is tilted by an angle of $\theta = 1°$ (as shown in the figure) and the final image is formed at I_2. Calculate the distance (in mm) between points I_1 and I_2. (Take $\frac{\pi}{180} = 0.017$). Consider only paraxial rays for the lens and near normal incidence for the glass slab.



4. An isosceles triangular glass prism stands with its base in water as shown. The angles that its two equal sides make with the base are θ each. An incident ray of light parallel to the water surface internally reflects at the glass-water interface and subsequently re-emerges into the air. Taking the refractive indices of glass and water to be $\frac{3}{2}$ and $\frac{4}{3}$ respectively, find maximum possible value of $\cos^2\theta$ for this to happen?

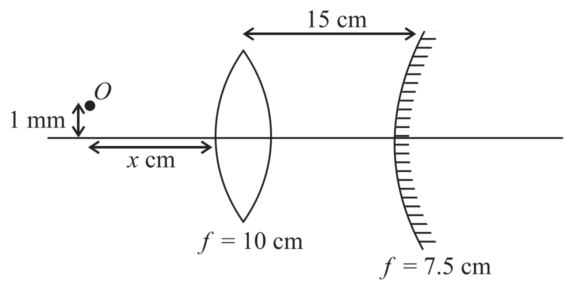
5. Travelers in the desert sometimes observe what appears to be a sea or lake. At what distance (in m) from the observer does such a mirage appear? Assume that the speed of light near the ground in the desert varies according to the formula $c(z) = c_0(1 - az)$, where c_0 is the speed of light at the ground and z is the altitude above the ground. Assume rays were travelling parallel to ground near the ground. [$h = 2$ m, $a = \frac{1}{2500}$ m^{-1}, (where h is height of man eye from ground)]



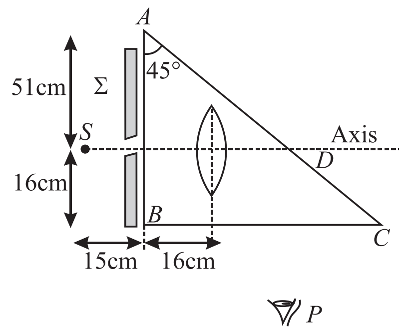
6. A laser beam propagates through a spherically symmetric medium, as shown in the figure. The refractive index varies with the distance to the symmetric centre C by the law $\mu(r) = \mu_0\left(\frac{r}{r_0}\right)$ where $\mu_0 = 1$, $r_0 = 3$ cm, $r_0 \le r < \infty$. The beam's trajectory lies in the plane that includes C. At distance $r_1 = 8\sqrt{2}$ cm the beam makes an angle $\phi = 30°$ with radial direction as shown in figure. Find the minimum distance (in cm) the beam reaches relative to the symmetry centre C.

7. A ray of light is incident on a glass sphere of refractive index $\mu = \sqrt{3}$ such that the directions of the incident ray and emergent ray when produced meet the surface at the same one point. The value of angle of incident is θ. Calculate the value of $\frac{\theta}{30°}$.

8. Point object O is as shown in diagram. At distance x the object should be placed such that its final image coincides with it. If the value of x is 5n then find the value of n?



9. An isosceles right angled triangular glass (μ = 1.6) prism has a cavity inside it in the shape of a thin convex lens whose both surfaces have radius of curvature equal to 20 cm. The cavity has been filled with a transparent liquid of refractive index 2.4. S is a point object and there is an opaque sheet having a small hole such that the source and the hole both lie on the principal axis of the lens. The small hole in the opaque sheet is there to ensure that only paraxial rays are incident on the original system. However, the size of hole is large enough to neglect diffraction effects. At what perpendicular distance (in cm) from line BC, the observer P will see the image?



10. Consider an equilateral prism ABC as shown in the figure. A ray of light is incident on the face AB and gets transmitted into the prism. Then total internal reflection takes place at the face BC and the ray comes out of prism through the face AC. The total angle of deviation is 120°. Find the angle of incidence of light on the prism (in degree). **(Refer Fig.: 15.10)**

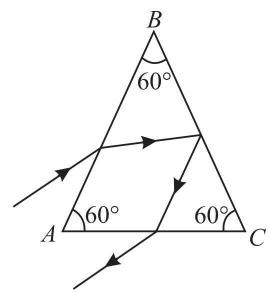
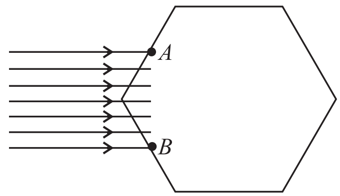


Fig.: 15.10

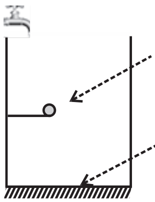
11. A capillary tube is made of glass with the index of refraction n'. The outer radius of the tube is R. The tube is filled with a liquid with the index of refraction $n < n'$. What should be the minimum internal radius of the tube r so that any ray that hits the tube would enter the liquid?

12. A parallel beam of monochromatic light strikes a transparent prism. The cross section of the prism is a regular hexagon. The beam is parallel to the "top" and "bottom" faces of the prism, and points A and B in the diagram are the midpoints of the corresponding edges. After the refraction, two separate parallel beams of light emerge from the prism. What is the minimum index of refraction of the material of the prism that allows such an effect?



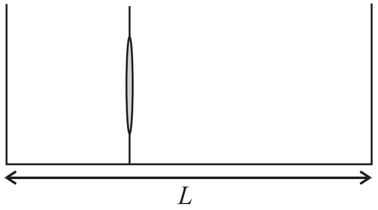
13. Two converging lenses have focal lengths f and f_0. The optical axes of the lenses coincide. This lens system is used to form an image of an object. It turns out that the size of the image does not depend on the distance between the lens system and the object. Find the distance x between the lenses.

14. A thin glass lens is formed by two convex surfaces that have equal radii of curvature. When the lens is in the air, the distance between its foci is $2f_1$. When the same lens is immersed in water, that distance changes to $2f_2$. What is the distance d between the foci of the lens when the lens is placed on the boundary between the water and the air? The index of refraction of air is 1.00; that of water is 1.33.

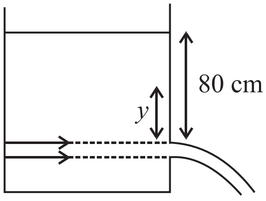


15. A small source of light is mounted inside a cylindrical container of height h. The bottom of the container is covered with a mirror. Initially, the container is empty. Then a clear liquid with the index of refraction n is slowly poured into the container. The level of liquid rises steadily, reaching the top of the container in time T. Find the speed of the image of the source during this process. Consider all cases.

16. On a distant plane, the index of refraction of the atmosphere depends on the altitude as $n(h) = n_0 - bh$, where b is a constant coefficient ($b << n_0/h$). An alien scientist shines a laser beam horizontally from the top of the highest mountain on the planet. The scientist is surprised to discover that the laser beam orbits the planet and hits the back of his head. How high is the mountain? The radius of the planet is R.

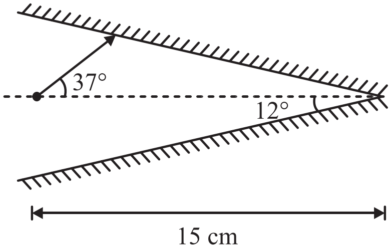


17. A fish tank of length L contains a vertical partition with an embedded lens. An arrow is taped to the left wall of the tank. When only the left section of the tank is filled with water, a sharp image of the arrow appears on the right wall of the tank. The length of that image is l_1. If instead only the right section of the tank is filled with water, another sharp image of the arrow appears on the right wall. Find (a) the distance between the lens and the left wall, (b) the length of the second image, and (c) the length of the arrow. The index of refraction of water is n.



18. A tank of water is filled up to 80 cm above the hole. The radius of tank is 1 m and radius of hole is 1 mm. A circular light beam of radius 1 mm which covers the hole completely is incident on the hole from inside water. It is seen that the beam is travelling along the water stream like in an optical fibre. At what level of water y (in mm) will the light beam begin to emerge from the curved surface of water stream? $n_{water} = \frac{4}{3}$

19. A ray strikes a system of two mirrors inclined at 24° starting from position as shown in the figure.



(*a*) Find total number of reflections before ray exits the system.

(*b*) Find minimum distance between the ray and apex point.

ANSWER KEYS

MULTIPLE CHOICE QUESTIONS

1. (*d*) **2.** (*b*) **3.** (*b*, *c*) **4.** (*a*, *c*) **5.** (*a*, *b*, *d* **6.** (*a*, *b*, *c*, *d*) **7.** (*a*, *b*, *d*) **8.** (*c*, *d*)
9. (*a*, *b*, *c*) **10.** (*a*, *c*) **11.** (*b*, *d*) **12.** (*c*) **13.** (*d*) **14.**(*b*, *c*, *d*) **15.** (*d*) **16.** (*a*)

PARAGRAPH TYPE QUESTIONS

1. (*b*) **2.** (*d*)

NUMERICALS & SUBJECTIVE QUESTIONS

1. 0.55 to 0.56 **2.** 52.00 **3.** 0.17 **4.** 0.81 **5.** 49.96 to 50.00 **6.** 8.00 **7.** 2.00

8. 6.00 **9.** 6.80 to 6.95 **10.** 30.00 **11.** $r = \frac{R}{n}$ **12.** $n = \frac{\sqrt{13}}{2}$ **13.** $L = f_1 + f_2$

14. $d = \frac{4.66 f_1 f_2}{f_2 + 1.33 f_1}$

15. Water level below the source

$$V = 2\left|\frac{h}{T}\left(\frac{1}{n} - 1\right)\right|$$

Water level above the source

$$V = \left|\frac{h}{T}\left(\frac{1}{n} - 1\right)\right|$$

16. $h = \frac{n_0 - bR}{2b}$ **17.** (*a*) $d = \frac{L}{2}$ (*b*) $l_2 = \frac{l_1}{n^2}$ (*c*) $h = \frac{l_1}{n}$ **18.** 2.57 **19.** reflections = 6, d_{min} = 9cm

20. x = 30 cm (inverted), x = 28.57 cm (erect) **21.** $r = \frac{r_1 r_2 (\beta_A - \beta_B)}{r_1 \beta_B - r_2 \beta_A}$

About The Author

Rajwant Singh

Rajwant Singh Sir, affectionately known to many as RJ Sir, is a distinguished alumnus of IIT Dhanbad, where he achieved both his bachelor's and master's degrees in Physics. Following his academia, he served as a meteorologist at the Indian Meteorological Department (IMD), enriching his expertise with practical experience. With over nine years dedicated to teaching JEE Main, Advanced, and Olympiad aspirants, RJ Sir's pedagogical journey is marked by a profound commitment to enriching students' understanding of physics.Drawing inspiration from the venerable HC Verma Sir, RJ Sir aspires to create a pedagogical masterpiece that transcends conventional learning. His forthcoming book is a testament to this vision, meticulously designed to challenge and cultivate critical thinking and analytical prowess among students. Through his work, RJ Sir aims to not merely educate but to inspire a perpetual passion for physics, equipping learners with the intellectual toolkit necessary for navigating the intricacies of the subject.RJ Sir's philosophy is grounded in the empowerment of students, believing firmly in unlocking their potential and kindling an enduring love for learning. His approach is emblematic of a teacher who does not just instruct but transforms, leaving a lasting impact on the minds and hearts of those he guides.

Heimant Singhal

Heimant Singhal Sir, an illustrious IIT Kanpur alumnus with a degree in Computer Science and Engineering, achieved an impressive AIR 62 in JEE 2002. Turning away from a promising corporate path, he embraced his passion for Physics and education. Singhal Sir regards himself more as a perpetual student of Physics than merely a teacher, a philosophy that deeply influences his approach to teaching.His mentorship has led numerous students to excel in the JEE, underscoring his exceptional ability to motivate and guide. Despite his successes, he dedicates daily time to advancing his own understanding of Physics, epitomizing lifelong learning.Singhal Sir's impact on his students is profound, fostering not just academic achievement but a lasting love for learning. This book represents his effort to challenge and refine the talents of advanced students, aiming to deepen their mastery of Physics and inspire continued academic exploration.

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