# Ray Optics and Optical Instruments

CHAPTER 9

## TRY YOURSELF ANSWERS

**1.** $\theta = 45°$, $n = \frac{360°}{45} - 1 = 7$

**2.** To make the reflected ray horizontal, it must be turned further through 90° – 60° = 30°. So, the mirror must be turned through 30/2 = 15°.

**3.** Nature exhibits left right symmetry *i.e.*, physical law are the same for an object and its mirror image. Therefore, an outsider cannot distinguish between the two films.

However, the distinction can be made if there is any initial asymmetric information.

**4.** Images are formed due to multiple reflections. At each reflection, a part of light energy is absorbed. Therefore, distant images get fainter.

**5.** The origin of multiple images is the multiple reflection of light between the front and back surfaces of glass. Infact, at the front surface of glass, light is partially reflected and partially refracted. The refracted light gets reflected at the back surface and then multiple reflections follow within the thickness of glass. They are responsible for multiple images.

**6.** The spherical mirror formula is $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ ...(i)

For a plane mirror, $R = \infty$

$$f = \frac{R}{2} = \infty$$

From (i), $\frac{1}{u} + \frac{1}{v} = \frac{1}{\infty} = 0$ or $\frac{1}{v} = -\frac{1}{u}$

or $v = -u$

As $u$ is negative, $v$ becomes positive.

Hence, image is formed behind the mirror at the same distance as the object is in front to it. This is what happens in a plane mirror. Hence the desired result.

**7.** In search lights, we need an intense parallel beam of light. If a source is placed at the focus of a concave spherical mirror, only paraxial rays are rendered parallel. Due to large aperture of mirror, marginal rays give a divergent beam.

But in case of parabolic mirror, when source is at the focus, beam of light produced over the entire cross-section of the mirror is a parallel beam.

**8.** For observing traffic at our back, we prefer to use a convex mirror. This is because a convex mirror has a much larger field of view than a plane mirror or a concave mirror.

**9.** A concave mirror forms a magnified and erect image of the face when it is held close to the face. That is why a concave mirror is preferred over a plane mirror for shaving.

**10.** Let $u = -\frac{3f}{2}$

When object lies between $f$ and $2f$.

From mirror equation

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

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{-1}{f} + \frac{2}{3f} = \frac{-3+2}{3f} = -\frac{1}{3f}$$

For concave mirror, $f$ is negative

$v = -3f$

*i.e.*, distance of image from the concave mirror is $3f$, *i.e.*, image formed is beyond $2f$.

**11.** $R = 30$ cm, $m = 5$, $u = ?$

$$m = \frac{-v}{u} = 5 \quad \Rightarrow \quad v = -5u$$

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

$$\frac{1}{-5u} + \frac{1}{u} = -\frac{1}{15}$$

$$\frac{4}{5u} = -\frac{1}{15} \quad \Rightarrow \quad u = -12\text{ cm}$$

**12.** $\lambda = 6000$ Å $= 6 \times 10^{-7}$ m, $m = 1.5$, $\lambda' = ?$, $\upsilon' = ?$

$$\lambda' = \frac{\lambda}{\mu} = \frac{6000}{1.5} = 4000\text{ Å}$$

$$\upsilon' = \upsilon = \frac{c}{\lambda} = \frac{3 \times 10^8}{6 \times 10^{-7}} = 5 \times 10^{14}\text{ Hz}$$

**13.** Lateral shift will be maximum, when

$\sin(i_1 - r_1) = \text{maximum} = 1 = \sin 90°$

or $(i_1 - r_1) = 90°$ If $r_1 = 0°$, $i_1 = 90°$

Also, maximum lateral shift, $MN' = \frac{t \times 1}{1} = t$ = thickness of glass slab.

**14.** No, because, $\mu = \frac{c}{v} = \frac{\text{speed of light in vaccum}}{\text{speed of light in medium}}$

$c > v$

$\Rightarrow \mu > 1$

**15.** Frequency remains constant, but wavelength reduces

as $\lambda' = \frac{\lambda}{\mu}$.

**16.** As $\mu = \frac{\sin i}{\sin r} = \frac{c}{v}$.

$c > v$, so, $\sin r < \sin i$, thus a ray of light bend towards normal as it passes from air to glass.

**17.** (i) Bending of an immersed portion of an object.

(ii) Visibility of two images of an object floating inside water.

Still some other phenomena, which can be explained in terms of refraction of light through the atmosphere are :

(a) Twinkling of stars.

(b) Oval shape of sun at the time of sunrise and sunset.

**18.** Here ${}^a\mu_w = \frac{4}{3}$, ${}^a\mu_g = \frac{3}{2}$; ${}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{3/2}{4/3} = \frac{9}{8}$

Angle of incidence in water, $i = 30°$, $r = ?$

$\frac{\sin i}{\sin r} = {}^w\mu_g = \frac{9}{8}$; $\sin r = \frac{8}{9}\sin i = \frac{8}{9}\sin 30° = \frac{8}{9} \times \frac{1}{2}$

$\sin r = 0.4444$

$r = \sin^{-1}(0.4444) = 26.38°$

**19.** Here, real depth of glass, $x_1 = 6$ cm,

real depth of water, $x_2 = 4$ cm.

${}^a\mu_g = \frac{3}{2}$, ${}^a\mu_w = \frac{4}{3}$

if $y_1$, $y_2$ are the corresponding apparent depths,

Then, $\frac{x_1}{y_1} = {}^a\mu_g = \frac{3}{2}$

$\therefore \quad y_1 = \frac{2}{3}x_1 = \frac{2}{3} \times 6 = 4\text{ cm}$ ; $\frac{x_2}{y_2} = {}^a\mu_w = \frac{4}{3}$

$\therefore \quad y_2 = \frac{3}{4}x_2 = \frac{3}{4} \times 4 = 3\text{ cm}$

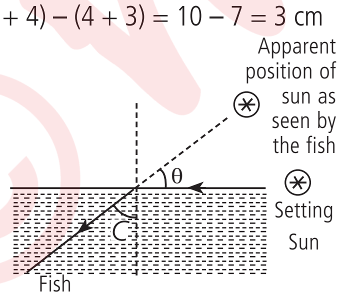
Apparent position of the object

$= (y_1 + y_2) = (4 + 3)$ cm $= 7$ cm

$\therefore$ Rise in position of the object

$= (x_1 + x_2) - (y_1 + y_2) = (6 + 4) - (4 + 3) = 10 - 7 = 3$ cm

**20.** In figure the setting sun is in the direction of water surface. A ray of light from setting sun enters the eye of the fish when apparent position of the sun makes critical angle $C$ with the vertical.




$\therefore \sin C = \frac{1}{\mu} = \frac{1}{1.33} = 0.7518$

$C = \sin^{-1}(0.7518) = 48.7°$

**21.** A crack in a window pane appears silvery on account of total internal reflection of light in the crack.

**22.** $\sin C = \frac{1}{{}^a\mu_g} = \frac{1}{3/2} = \frac{2}{3}$ and $\sin C' = \frac{1}{{}^w\mu_g} = \frac{1}{9/8} = \frac{8}{9}$

$\sin C' > \sin C \Rightarrow C' > C$.

**23.** For medium $R$, angle of refraction ($r$) is minimum.

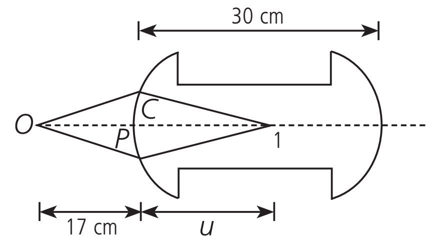
Thus, $\mu = \frac{\sin i}{\sin r}$ is maximum. As $\mu = \frac{c}{v}$, so $v$ is minimum, *i.e.*, velocity of light is minimum in $R$.

**24.** Here, $l = 30$ cm, $\mu_2 = 1.5$ u, $\mu_1 = 1$.

$R = 3$ cm, $u = -12$ cm.

Image formed is at $I$, as shown in figure.

$PI = v = ?$




As refraction occurs from air to glass.

$\therefore \quad -\frac{\mu_1}{u} + \frac{\mu_2}{v} = \frac{\mu_2 - \mu_1}{R}$

$-\frac{1}{-12} + \frac{1.5}{v} = \frac{1.5-1}{3} = \frac{1}{6}$ ; $\frac{3}{2v} = \frac{1}{6} - \frac{1}{12} = \frac{1}{12}$

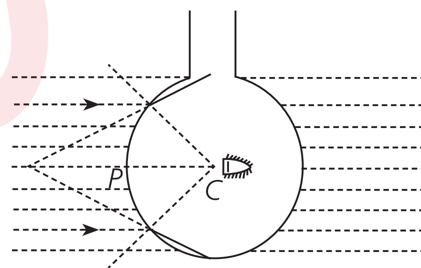
$v = 18$ cm

As $v$ is positive, the image is real.

**25.** Here, $R = PC = +15/2$ cm

$\mu_2 = 4/3$, $\mu_1 = 1$

For a parallel beam of light, $u = \infty$,




The beam diverges on refraction and appears to come from $I$.

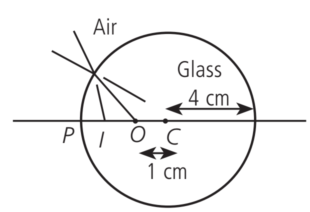
$PI = v = ?$

As refraction occurs from denser to rarer medium, therefore,

$-\frac{\mu_2}{u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$ $\quad -\frac{4}{3 \times \infty} + \frac{1}{v} = \frac{1 - 4/3}{15/2} = -\frac{2}{45}$

$v = -\frac{45}{2} = -22.5\text{ cm}$

**26.** (a) Let $C$ be the centre of sphere and $O$ is the position of bubble. When seen through the nearest surface, the image formed is $I$ which is virtual




For denser to rarer medium

$\frac{-\mu_2}{u} + \frac{\mu_1}{v} = \frac{\mu_1 - \mu_2}{R}$

$u = PO = PC - OC = 4 - 1 = 3$ cm, $R = +4$ cm, $v = ?$

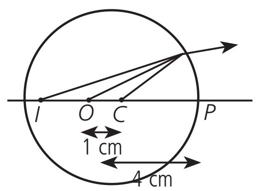
$$\frac{-1.5}{3}+\frac{1}{v}=\frac{-0.5}{4}$$

$$\frac{1}{v}=\frac{-0.5}{4}+\frac{1.5}{3}=\frac{-1.5+6}{12}=\frac{+4.5}{12}$$

$$u=\frac{12}{4.5}=2.7\text{ cm}$$

The bubble will appear at 2.7 cm from the glass surface nearest the bubble.

(b) When seen through the farthest surface, the rays from $O$ appear to come at $I$,




$$\frac{-\mu_2}{u}+\frac{\mu_1}{v}=\frac{\mu_1-\mu_2}{R}$$

u = – (4 + 1) = –5 cm

R = – 4 cm

$$\frac{-1.5}{-5}+\frac{1}{v}=\frac{-0.5}{-4}$$

$$\frac{1}{v}=\frac{0.5}{4}-\frac{1.5}{5}=\frac{2.5-6}{20}=\frac{-3.5}{20}$$

$$v=\frac{-20}{3.5}=-5.7\text{ cm}$$

**27.** Since surfaces of the sunglasses have same radii. Therefore power is given by, Here, $R_1 = R_2$

$$P=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)=(\mu-1)\left(\frac{1}{R}-\frac{1}{R}\right)=0 \qquad (\because\ R_1=R_2)$$

**28.** When the convex lens is held in a transparent medium of refractive index greater than the refractive index of lens material, it would behave as a concave lens.

**29.** Yes, the various rays from a point on the candle, after refraction through different parts of the lens, will still converge at the same point, only their number will now be less. Hence still the full image of the candle will be obtained, but the intensity will be less.

**30.** $$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

For convex lens, $R_1$ = '+ve', $R_2$ = '–ve'

$R_1 = R$, $R_2 = -R$, $\mu = 1.5$

$$\frac{1}{f}=(1.5-1)\left(\frac{1}{R}+\frac{1}{R}\right)=0.5\times\frac{2}{R}$$

$f = R$

**31.** $R_1 = R_2 = R$

$$\frac{1}{f}=(\mu-1)\left(\frac{1}{R}+\frac{1}{R}\right)=\frac{2(\mu-1)}{R}$$

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

On cutting in thickness, each half becomes a plane convex lens ($R_1 = \infty$, $R_2 = R$) whose focal length $f'$

$$\frac{1}{f'}=(\mu-1)\left(\frac{1}{\infty}+\frac{1}{R}\right)=\frac{\mu-1}{R}$$

$f'=\dfrac{R}{\mu-1}=2f$, power becomes half.

**32.** $$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$$

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

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

$v = f(1 - m)$

since image is real so, $m$ is negative.

$v = f(1 + m)$

**33.** $$\frac{1}{f}=(\mu-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Now, the refractive index of lens material is smaller for red light than violet light ($\mu_R < \mu_v$). So the focal length of lens is larger for red light than for violet light ($f_r > f_v$), whether the lens is converging or diverging. Hence the focal length will increase in each case.

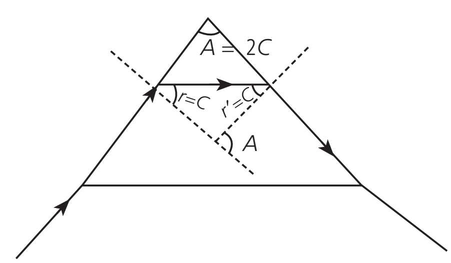
**34.** Yes, if the prism be immersed in a transparent liquid of refractive index greater than that of the material of the prism, the ray would deviate away from the base.

**35.** The refractive indices of glass prism in air and water, in terms of angle of minium deviation are given by

$$^{a}\mu_g=\frac{\sin\left[\frac{A+\delta_m}{2}\right]}{\sin\frac{A}{2}},\qquad {}^{w}\mu_g=\frac{\sin\left(\frac{A+\delta'_m}{2}\right)}{\sin\frac{A}{2}}$$

since, ${}^{w}\mu_g < {}^{a}\mu_g$, it follows that $\delta_m < \delta'_m$ that is minimum deviation decreases on immerging the prism in water

**36.** Let $i$ and $r$ be the angles of incidence and refraction at the first surface of the prism and $r'$ the angle of incidence at the second surface. If $A$ be the angle of prism $r + r' = A$




Now, greater the angle of incidence, the more likely is the ray to energy from the prism. Let us consider the extreme case for $i = 90°$. If $\mu$ be the refractive index of prism material with respect to air,

$$\mu=\frac{\sin i}{\sin r}=\frac{\sin 90°}{\sin r}=\frac{1}{\sin r}$$

But $\mu=\dfrac{1}{\sin C}$, where $C$ is critical angle, so, $r = C$

and $r' = A - r = A - C$

if $A = 2C$, then

$r' = 2C - C = C$

The ray refracted through the first surface of the prism will be incident at the second surface at the critical angle. Hence the emergent ray will be tangential to the second surface.

If $A > 2C$, then $r' > C$. In this condition, the ray incident at the second surface will be totally reflected that is, there will be no emergent ray.

**37.** $\delta = (\mu - 1) A$

$$\mu = {}^a\mu_g = \frac{3}{2}$$

$$\delta_{air} = \left(\frac{3}{2} - 1\right) A = \frac{A}{2}$$

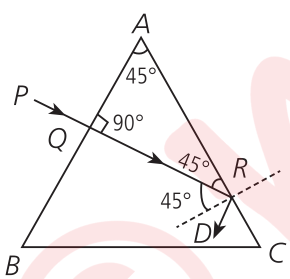
when the prism in water.

$$ {}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{3 \times 3}{2 \times 4} = \frac{9}{8}$$

$$\delta_{water} = \left(\frac{9}{8} - 1\right) A = \frac{A}{8}$$

$$\frac{\delta_{water}}{\delta_{air}} = \frac{A \times 2}{8 \times A} = \frac{1}{4}.$$

**38.** The incident ray $PQ$ falling normally on face $AB$ of prism, goes straight striking face $AC$ at 45° as shown. As $C = 45°$, so the refracted ray $QR$ suffers total internal reflection and goes along $RD$.




$$\mu = \frac{1}{\sin 45°} = \sqrt{2}$$

**39.** As refractive index μ for glass for different colours is different, so images of different coloured letters will not raised equally and hence they will not lie in the same plane.

**40.** (a) Speed of light in glass increases on increasing the wavelength.

(b) There is no effect of changing intensity on speed of light in glass.

**41.** On washing, clothes get a yellowish colour. Blue and yellow are complimentary colours giving us a sensation of white.

**42.** An impure spectrum is that in which different colours overlap one another.

**43.** A pure spectrum is that in which there is no overlapping of colours.

**44.** Speed of light in vacuum is constant. It is not affected by change in wavelength or intensity of light.

**45.** This is because light rays from the nearly tiny objects spread over small aperture and final image formed is very bright.

**46.** Magnifying power, $|m| = \frac{v_0}{u_0} \times \frac{d}{u_e}$, $L = v_0 + u_e$

when $L$ is increased, $u_e$ increased and $v_0$ is fixed and $|m|$ will decrease.

**47.** $m = 1 + \frac{d}{f}$, As $f_r > f_v$, so magnifying power increases when violet light is used.

**48.** Yes, because the objective with large diameter will collect more light and even the distant objects can be seen.

**49.** Range of a telescope tells us how far away a star of some standard brightness can be spotted by the telescope.

**50.** $M = -\frac{f_0}{f_e}\left(1 + \frac{f_e}{d}\right)$

The two conditions for large magnification are

(i) Focal length of objective lens ($f_0$) should be large.

(ii) focal length of eye lens ($f_e$) should be small.