CHAPTER

5 Optics

Optics

The branch of physics which deals with the propagation, nature and behaviour of light is known as **optics**.

Light

Light is a form of energy which enables human beings and creatures to 'see' things. When light emitted from an object or reflected from the object enters our eyes we are able to see the object. We can't see an object in dark even if we are in light because there is no light coming from the object to our eyes.

Light is an electromagnetic radiation which exhibits properties like a wave as well as a particle. It always propagates in a straight line.

Light travels with a speed nearly equal to 3×10^8 m/s. According to current theories, no material particle can travel at a speed greater than the speed of light.

Luminous and Non-luminous Objects

Luminous objects are those which emit its own light e.g., sun, glowworm, burning candle, electric lights. *Non-luminous objects do not give out its own light but are visible only when light from a luminous object falls on it. e.g*., moon, earth, table, paper, etc.

Transparent Translucent and Opaque materials

Transparent materials are those which allow most of light to pass through them. *Example* : Glass, water, air.

Translucent materials allow only a part of light to pass through it. We cannot see distinctly through them. *Example* : greased paper, paraffin wax, etc.

Opaque materials do not allow any light to pass through it. They reflect or absorb all the light that falls on them. *Example* : Books, desk, stone, rubber, trees, etc.

Reflection of Light

When light hits an opaque material, the light may be absorbed by the material and converted into heat energy. If light is not absorbed, it is bounced back or reflected at the surface of material.

The turning back of light in the same medium is called reflection of light.

Laws of reflection

1. The angle of incidence '*i*' is equal to the angle of reflection '*r*'.
2. At the point of incidence, the incident rays, the normal to the surface and the reflected ray all lie in the same plane.

Reflection by Plane Mirrors

Plane mirror is a looking glass which is highly polished on one surface and is silvered on the other surface. When a light ray strikes the polished surface, it is reflected by the silvered surface. *An 'image' is defined as the impression of an object carried over and formed by light reflected from it*.

Use of plane mirrors

(a) Plane mirrors are primarily used as looking glasses.
(b) Since, a combination of mirrors can produce multiple images, they are used to provide false dimensions in showrooms.
(c) They are also used as reflectors in solar cookers.
(d) Plane mirrors are used in the construction of a periscope.

Images and their properties

An 'image' is defined as the impression of an object carried over and formed by light reflected from it. An image is said to be a **real image** if it can be caught on a screen, and a **virtual image** if it cannot be caught on the screen. For example, the image on the screen in a theatre is a real image and the image observed in a plane mirror is a virtual image.

Real image

1. When the rays of light actually meet, the image so formed is known as real image.
2. A real image can be caught on a screen since it is formed by actual meeting of rays.
3. A real image is always inverted.
4. A real image is formed by a convergent reflected beam.
5. In ray diagrams, for real image, the rays are represented by full lines.

Virtual image

1. When the rays of light appear to meet, the image so formed is known as virtual image.
2. A virtual image cannot be caught on a screen since it is formed by meeting of imaginary rays.
3. A virtual image is always erect.
4. A virtual image is formed by a divergent reflected beam.
5. In ray diagrams, for virtual image, the rays are generally represented by dotted lines.

Characteristics of images formed by a plane mirror

The image formed by a plane mirror is

(a) virtual (the image cannot be formed on a screen)
(b) upright
(c) laterally inverted (the left side of an image is formed by the right side of an object)
(d) the same size as the object
(e) the same distance behind the mirror as the object is in front of the mirror

Concave and Convex Mirror

Concave mirror : If the reflection takes place from the inner surface of a spherical mirror, then the mirror is called concave mirror.

Convex mirror : If the outer surface of the spherical mirror acts as a reflector then the mirror is called convex mirror.

Uses of concave mirrors :

(i) In torches, search-lights and vehicles headlights to get powerful beams of light.

(ii) As a shaving mirror to see a large image of the face.

(iii) As a dentists mirror to see large images of the teeth of patients.

(iv) Large sized concave mirror is used to concentrate sunlight to produce heat in solar furnaces.

Uses of convex mirrors :

(i) As a rear -view mirrors in vehicles.

(ii) For security purposes.

Mirror Formula

If an object is placed at a distance *u* from the pole of a mirror and its image is formed at a distance *v* (from the pole) then,

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

Magnification

If a thin object linear size *O* situated vertically on the axis of a mirror at a distance *u* from the pole and its image of size *I* is formed at a distance *v* (from the pole), magnification (transverse) is defined as

$$m=\left[\frac{I}{O}\right]=\left[\frac{v}{u}\right]$$

- → (+ve means erect image)
- → (–ve means inverted image)
- → (|m| >1 means large image)
- → (|m| < 1 means small image)

Refraction of Light

When a ray of light passes from one medium to another medium it bends – towards the normal when goes from rarer to denser and away from the normal when goes from denser to rarer medium. This phenomenon is called refraction of light.

Twinkling of stars, sun is visible to us about 2 minutes before the actual sunrise, and about 2 minutes after actual sunset etc. due to atmospheric refraction.

Refractive index

Refractive index of medium II with respect to medium I

$$\mu_{21}=\frac{Speed\ of\ light\ in\ medium\ I}{Speed\ of\ light\ in\ medium\ II}$$

Laws of Refraction

(i) **Snell's law :** For any two media and for light of a given wavelength, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant.

i.e., $\frac{\sin i}{\sin r}$ =constant, where i = incidence angle, r = refraction angle.

(ii) The incident ray, the refracted ray and the normal at the incident point all lie in the same plane.

When object is in denser medium and observer is in rarer medium:

$$Refractive\ index\ \mu=\frac{Real\ depth}{Virtual\ depth}$$

Lens

A lens is a piece of transparent material with two refracting surfaces such that atleast one is curved and refractive index of used material is different from that of the surroundings.

Refraction through a thin lens (lens formula)

If an object is placed at a distance *u* from the optical centre of a lens and its images is formed at a distance *v* (from the optical centre) and focal length of this length is *f* then

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

This is called lens formula.

Power of a lens

The power of a lens is defined as $P=\frac{1}{f(\text{in } m)}$. The unit of power is diopter.

Focal length of a lens (lens maker's formula)

$$\frac{1}{f}=({}_{m}\mu_{\ell}-1)\left[\frac{1}{R_1}-\frac{1}{R_2}\right]$$

where ${}_{m}\mu_{\ell}$ refractive index of lens with respect to medium.

R_1 = radius of curvature of first surface of lens, R_2 = radius of curvature of second surface of lens.

Total Internal Reflection

When the object is placed in an optically denser medium and if the incident angle is greater than the critical angle then the ray of light gets reflected back to the originating medium. This phenomenon is called total internal reflection.

Critical angle (i_c) : When a ray passes from an optically denser medium to an optically rarer medium, the angle of refraction r is greater than the corresponding angle of incidence i. From Snell's law.

Let $\mu_1=\mu$ and $\mu_2=1$ and let for $i=i_c$, $r=90^o$ then $\sin i_c=1/\mu$

$\therefore\ i_c=\sin^{-1}\frac{1}{\mu}$; i_c is called the critical angle.

This phenomenon takes place in shining of air bubble, sparkling of diamond, mirage, looming, in optical communication, endoscopy using optical fibre.

Dispersion of Light

When a white ray of light or sunlight passes through a prism it breakes into its seven constituents colours violet, indigo, blue, green, yellow, orange and red (VIBGYOR). This phenomenon is called ***dispersion of light***. The band of seven constituents colours is called **spectrum.** The deviation is maximum for violet colour and least for red colour.

The Rainbow

A rainbow is a spectrum of white light from the sun. This is a phenomenon due to combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of rain.

(i) **Primary rainbow:** It is formed due to two refractions and one total internal reflection of the light incident on the droplet. Sunlight is first refracted as it enters a raindrop which cause different colours of light to separate. The observer sees a rainbow with red colour on the top and violet on the bottom.

(ii) **Secondary rainbow:** It is formed due to two refractions and two total internal reflection of light incident on the water droplet. It is due to four - step process. The intensity of light is reduced at the second reflection and hence the secondary rainbow is fainter than the primary rainbow.

Scattering of Light

As sunlight travels through the earth's atmosphere it gets scattered by the small particles present in the atmosphere.
According to Rayleigh law, the amount of scattering is inversely proportional to the fourth power of the wavelength $\left(\frac{1}{\lambda^4}\right)$.

Phenomenon based on scattering of light

(i) **Blue colour of sky:** Blue colour has a shorter wavelength than red colour therefore blue colour is scattered strongly. Hence the bluish colour predominates in a clear sky.

(ii) **White colour of clouds:** Clouds contain large dust particles, water droplets or ice particles. These large sized Particles do not obey Rayleigh law of scattering. All wavelengths are scattered nearly equally. Hence clouds are generally white.

(iii) **Sun looks reddish at the Sunset or Sunrise:** At sunset or sunrise, the sun's rays have to pass through a larger distance in the atmosphere. Most of the blue and other shorter wavelengths are scattered. The least scattered light reaching our eyes, therefore the sun looks reddish.

Power of Accomodation of Eye

The ability of the lens to change its shape to focus near and distant objects is called accommodation.

A normal human eye can see objects clearly that are between 25 cm and infinity.

Defects of Vision and Their Correction

Nearsightedness: If the eyeball is too long or the lens too spherical, the image of distant objects is brought to a focus in front of the retina and is out of focus again before the light strikes the retina. Nearby objects can be seen more easily. Eyeglasses with concave lenses correct this problem by diverging the light rays before they enter the eye. Nearsightedness is called myopia.

Farsightedness: If the eyeball is too short or the lens too flat or inflexible, the light rays entering the eye — particularly those from nearby objects— will not be brought to a focus by the time they strike the retina. Eyeglasses with convex lenses can correct the problem. Farsightedness is called hypermetropia.

Astigmatism : Astigmatism is the most common refractive problem responsible for blurry vision. Most of the eyeball's focusing power occurs along the front surface of the eye, involving the tear film and cornea (the clear 'window' along the front of the eyeball).

The ideal cornea has a perfectly round surface. Anything other than perfectly round contributes to abnormal corneal curvature– this is astigmatism. Cylindrical lens is use to correct astigmatism.

Microscope

It is an optical instrument used to see magnified image of a tiny objects.

Resolving power (R.P.) of a microscope

Resolving power of a microscope is defined as the reciprocal of the least separation between two close objects, so that they appear just separated, when seen through the microscope.

$$\textit{Resolving power of a microscope} = \frac{1}{d} = \frac{2\mu \sin\theta}{\lambda}$$

θ = half angle of the cone of light from the point object

$\mu \sin\theta$ = numerical aperture

Telescope (Astronomical)

It is an optical instrument used to increase the visual angle of distant large objects.

It is used to see far off objects clearly.

Resolving power (R.P.) of a telescope

Resolving power of telescope is defined as the reciprocal of the smallest angular separation between two distant objects, so that they appear just separated, when seen through the telescope.

$$\textit{Resolving power of telescope} = \frac{D}{1.22\lambda}$$

Interference of Light Waves

The phenomenon of redistribution of light energy in a medium due to superposition of light waves from two coherent sources is called interference of light.

Conditions for sustained interference:

(i) Two sources must be coherent.

(ii) Amplitudes of waves should be either equal or approximately equal.

(iii) Light should be monochromatic.

Polarisation

It is the phenomenon of restricting the vibration of light in a particular plane.
Light waves are transverse in nature i.e., the electric field vector associated with light wave is always at right angles to the direction of propagation of the wave. When unpolarised light is incident on a polaroid (Nicol Prism), the light wave gets linearly polarised i.e., the vibration of electric field vector are along a single direction.

EXERCISE

1. When the distance between the object and the plane mirror increases
   (a) the image remains same
   (b) the size of the image will become less than the size of the object
   (c) the distance between the image and the plane mirror increases
   (d) the distance between the image and the plane mirror decreases
2. In lateral inversion
   (a) right side of the object will be right side of the image.
   (b) left side of the object will be left side of the image.
   (c) upside of the object will be down side of the object.
   (d) right side of the object will be left side of the image.
3. The sun is seen before the actual sunrise because of
   (a) reflection
   (b) refraction
   (c) scattering of light
   (d) rectilinear propagation of light
4. Butter paper is an example for ..... object.
   (a) a transparent (b) a translucent
   (c) an opaque (d) a luminous
5. Power of accommodation of eye implies
   (a) control intensity
   (b) prevent internal reflection of light
   (c) change of focal length of eye lens
   (d) All of the above
6. Which of the following parts of eye protects the eye and gives it shape?
   (a) Choroid (b) Sclera
   (c) Yellow spot (d) Ciliary muscles
7. The human eye forms the image of an object at its
   (a) cornea (b) iris
   (c) pupil (d) retina
8. Rainbow is caused due to
   (a) reflection of sun light from air particles
   (b) dispersion of sun light from water drops
   (c) interference of light
   (d) diffraction of sun rays from water drops
9. In the visible spectrum the colour having the shortest wavelength is
   (a) green (b) red
   (c) violet (d) blue
10. The splitting of white light into seven colours on passing through a glass prism is due to
   (a) refraction (b) reflection
   (c) interference (d) diffraction
11. At sunrise or at sunset the sun appears to be reddish while at mid-day it looks white. This is because
   (a) scattering due to dust particles and air molecules causes this phenomenon
   (b) the sun is cooler at sunrise or at sunset
   (c) refraction causes this phenomenon
   (d) diffraction sends red rays to the earth at these times
12. A person cannot see objects clearly which are nearer than 75 cm from his eyes, the disease he is suffering from is
   (a) astigmatism (b) myopia
   (c) hypermetropia (d) presbyopia
13. For seeing a cricket match, we prefer binoculars to the terrestrial telescope, because
   (a) binoculars give three-dimensional view
   (b) terrestrial telescope gives inverted image
   (c) to avoid chromatic aberration
   (d) to have larger magnification
14. Dispersion is the term used to describe
   (a) the propagation of light in straight lines
   (b) the splitting of a beam of light into component colours
   (c) the bending of a beam of light when it strikes a mirror
   (d) the change that takes place in white light after passage through red glass
15. Consider telecommunication through optical fibres. Which of the following statement is not true?
   (a) Optical fibres can be of graded refractive index
   (b) Optical fibres have extremely low transmission loss
   (c) Optical fibres are subject to electromagnetic interference from outside
   (d) Optical fibres may have homogeneous core with a suitable cladding
16. An optician while testing the eyes finds the vision of a patient to be 6/12. By this he means that
   (a) the person can read the letters of 6 inches from a distance of 12 m
   (b) the person can read the letters of 12 inches from 6 m
   (c) the person can read the letters of 6 m which the normal eye can read from 12 m
   (d) the focal length of eye lens had become half that of the normal eye
17. A mirage occurs because
   (a) the refractive index of atmosphere increases with height
   (b) the refractive index of atmosphere decreases with height
   (c) the hot ground acts like a mirror
   (d) refractive index remains constant with height
18. A well cut diamond appears bright because
   (a) of reflection of light
   (b) of dispersion of light
   (c) of the total internal reflection
   (d) of refraction of light

19. Twinkling of stars is on account of
(a) large distance of stars and storms in air
(b) small size of stars
(c) large size of stars
(d) large distance of stars and fluctuations in the density of air

20. A coin in a beaker filled with water appears raised. This phenomenon occurs because of the property of
(a) reflection of light
(b) refraction of light
(c) total internal reflection of light
(d) interference of light

21. A spherical air bubble is embedded in a piece of glass. For a ray of light passing through the bubble, it behaves like a
(a) converging lens (b) diverging lens
(c) plano-converging lens (d) plano-diverging lens

22. 'The stars seem to be higher on the sky than they actually are'. This can be explained by
(a) atmospheric refraction (b) dispersion of light
(c) total internal reflection (d) diffraction of light

23. Yellow colour light is used as fog light because yellow colour
(a) light is most scattered by fog
(b) has the longest wavelength among all colours
(c) has the longest wavelength among all colours except red and orange but the red colour is already used for brake light and stop light whereas orange colour is avoided due to its similarity with red
(d) has the shortest wavelength among all colours

24. The mirror used for the head light of a car is
(a) spherical concave (b) plane
(c) cylindrical (d) parabolic concave

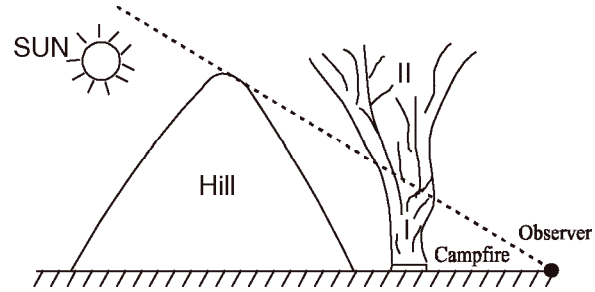
25. Soap bubble looks coloured due to
(a) dispersion (b) reflection
(c) interference (d) Any one of these

26. A star is emitting yellow light. If it is accelerated towards earth then to an observer on earth, it will appear
(a) shinning yellow
(b) gradually changing to violet
(c) gradually changing to red
(d) unchanged

27. What should be refractive index of a transparent medium to be invisible in vacuum?
(a) 1 (b) < 1
(c) > 1 (d) None of these

28. When a drop of oil is spread on a water surface, it displays beautiful colours in daylight because of
(a) dispersion of light (b) reflection of light
(c) polarization of light (d) interference of light

29. Smoke emerging from a campfire at the bottom of a hill is being observed by a person at some distance, as shown in the figure. It is evening and the sun has just set behind the hill. Consider regions I and II of the smoke going up the sky



(a) region I will be slightly brighter than the hill and region II will be slightly brighter than the sky
(b) region I will be slightly darker than the hill and region II will be slightly brighter than the sky
(c) region I will be slightly brighter than the hill and region II will be slightly darker than the sky
(d) region I will be slightly darker than the hill and region II will be slightly darker than the sky

30. The ability of an optical instrument to show the images of two adjacent point objects as separate is called
(a) dispersive power (b) magnifying power
(c) resolving power (d) None of these

31. Total internal reflection can take place only if
(a) light goes from optically rarer medium to optically denser medium
(b) light goes from optically denser medium to rarer medium
(c) the refractive indices of the two media are close to different
(d) the refractive indices of the two media are widely different

32. The least distance of distinct vision of a normal eye of an adult is
(a) 25 m (b) 25 cm
(c) 25 mm (d) None of these

33. Rear-view mirror used in a vehicle is a
(a) concave mirror (b) convex mirror
(c) plane mirror (d) None of these

34. Magnification produced by a rear view mirror fitted in vehicles
(a) is less than one
(b) is more than one
(c) is equal to one
(d) can be more than or less than one depending upon the position of the object in front of it

35. A child is standing in front of a magic mirror. She finds the image of her head bigger, the middle portion of her body of the same size and that of the legs smaller. The following is the order of combinations for the magic mirror from the top.
(a) Plane, convex and concave
(b) Convex, concave and plane
(c) Concave, plane and convex
(d) Convex, plane and concave

36. When a CD (compact disc used in audio and video systems) is seen in sunlight, rainbow like colours are seen. This can be explained on the basis of the phenomenon of
(a) reflection and diffraction
(b) reflection and transmission
(c) diffraction and transmission
(d) refraction, diffraction and transmission

37. A watch shows times as 3 : 25 when seen through a mirror, time appeared will be
(a) 8 : 35 (b) 9 : 35
(c) 7 : 35 (d) 8 : 25

38. The fine powder of a coloured glass is seen as
(a) coloured (b) white
(c) black (d) that of the glass colour

39. For which wavelength of light is our eye most sensitives
(a) 3.00 nm (b) 555 nm
(c) 200 nm (d) 800 nm

40. The acronym for LASER is
(a) Light Amplification by Stimulated Emission of Radiation
(b) Low Amplitude Stimulated Emission of Radiation
(c) Low Amplitude Short Energy Radiation
(d) Light Amplification by Short Energy Radiation

ANSWER KEY											
1	(c)	**8**	(b)	**15**	(c)	**22**	(a)	**29**	(c)	**36**	(d)
2	(d)	**9**	(c)	**16**	(c)	**23**	(c)	**30**	(c)	**37**	(a)
3	(b)	**10**	(a)	**17**	(a)	**24**	(d)	**31**	(b)	**38**	(b)
4	(b)	**11**	(a)	**18**	(c)	**25**	(c)	**32**	(b)	**39**	(b)
5	(c)	**12**	(c)	**19**	(d)	**26**	(b)	**33**	(b)	**40**	(a)
6	(b)	**13**	(a)	**20**	(b)	**27**	(a)	**34**	(a)		
7	(d)	**14**	(b)	**21**	(b)	**28**	(d)	**35**	(c)		

HINTS AND SOLUTIONS

10. (a) Disperssion arises because of basic phenomenon refraction.

20. (b) We know that, the apparent depth is μ times less than the actual depth. i.e.,

$$d_{apparent} = \frac{d_{actual}}{\mu}$$

21. (b) Bubble will behave as diverging lens because refrective index of air is less than that of a glass.

22. (a) Due to atmospheric refraction the twinkling of star, and their position appear higher than the normal.

23. (c) Yellow colour is used as fog light because of its longest wavelength it 63.33 penetrates well through dense fog.

24. (d) Parabolic reflectors are used to collect energy from a distant source (for example sound waves or incoming star light) and bring it to a common focal point, thus correcting spherical aberration found in simpler spherical reflectors. Since the principles of reflection are reversible, parabolic reflectors can also be used to project energy of a source at its focus outward in a parallel beam, used in devices such as spotlights and car headlights.

25. (c) Interference at thin films causes colouring of soap bubble.

26. (b) As the star is accelerated towards earth, its apparent frequency increases, apparent wavelength decreases. Therefore, colour of light changes gradually to violet.

27. (a) To be invisible in vacuum, μ of medium must be equal to μ of vacuum, which is 1.

28. (d) The colours are seen due to interference of light. The colours seen in reflected light are complementary with the colours seen in transmitted light.

30. (c) This ability refers to resolving power of the instrument.

31. (b) According to Snell's Law

$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$

where $r = 90^o$ for particular incidence angle called critical angle. When the incidence angle is equal to or greater then i_c, then total internal reflection occurs. It take place when ray of light travels from optically denser medium ($\mu_1 > \mu_2$)to optically rarer medium.

36. (d) The reason CDs reflect rainbow colors is because they have a clear plastic coating on top of a mirrorized surface. Light refracts (bends) when it moves from one medium (such as air) to another with a different optical density (such as the clear plastic surface of a CD). Different wavelengths of light (every color has a different wavelength) travel at different speeds, so that full spectrum appears when white light passes from the air through the plastic surface of a CD, separated light rays which are then reflected back to us by the mirrorized center surface of a CD. Here the diffraction and transmission also takes place because diffraction of light rays occur when it strikes the surface of CD and transmission is obvious when light enters from one medium to another. The thickness of the different optical media, angle of source light, and brightness of source light all affect which rainbow patterns are visible on a CD.

37. (a) Subtract the given time from 11: 60.

38. (b) All colours are reflected.

39. (b) Our eye can see wavelength of light range 4000Å to 7800Å