Chapter 14: Light

Class 10th FBISE - SLO Based Notes

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SLO-Based Notes: Chapter 14 - Optics

Introduction to Optics

Definition: Optics is the science of light and its interaction with matter.

Explanation: It includes the behavior of light waves, mirrors, lenses, and how we perceive vision. Optics has many applications in photography, microscopy, and astronomy.

Fun Fact: Light helps us see, cook in a solar oven, and transmit signals through fiber optics!

1 14.1 Reflection of Light

Q: What is reflection of light?

A: Reflection occurs when light rays bounce off a surface, like a mirror, and return to our eyes. This helps us see ourselves and other objects.

Real-life Example: When you look in a mirror and see your face — that's reflection!

2 14.1.1 Laws of Reflection

Law 1: The incident ray, reflected ray, and the normal all lie in the same plane.

Law 2: The angle of incidence is equal to the angle of reflection.

$$\theta_i = \theta_r$$

Q: What is an incident ray and a reflected ray?

A: The incident ray strikes the surface. The reflected ray bounces back. The point where this happens is the point of incidence.

Figure: Laws of reflection diagram

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3 Types of Reflection

A. Regular or Specular Reflection

Q: What is regular reflection?

A: Happens on smooth surfaces like mirrors. The reflected rays remain parallel, forming clear images.

B. Diffused Reflection

Q: What is diffused reflection?

A: Happens on rough surfaces. Reflected rays scatter in many directions. You can see the object from all angles but no clear image is formed.

Figure: Reflection from smooth and rough surfaces

4 14.2 Refraction of Light

Q: What is refraction of light?

A: Refraction is the bending of light when it passes from one medium to another. This happens due to a change in the speed of light. For example, a pencil in water appears bent due to refraction.

Example: When light passes from air into water, it slows down and bends towards the normal.

Figure: Broken pencil illusion due to refraction

4.1 14.2.1 Speed of Light in Material Media

Q: Why does light bend when passing from one material to another?

A: Light bends because its speed changes depending on the medium. It travels fastest in vacuum and slower in denser media like water or glass.

Note: - In vacuum: speed of light $c = 3 \times 10^8\,\text{m/s}$ - In matter: speed decreases due to interactions with particles

4.2 14.2.2 Refractive Index

Q: What is refractive index?

A: It is the ratio of the speed of light in vacuum to the speed of light in a given medium. It tells how much the light will bend.

$$n = \frac{c}{v}$$

Where: - n: refractive index - c: speed of light in vacuum - v: speed of light in medium

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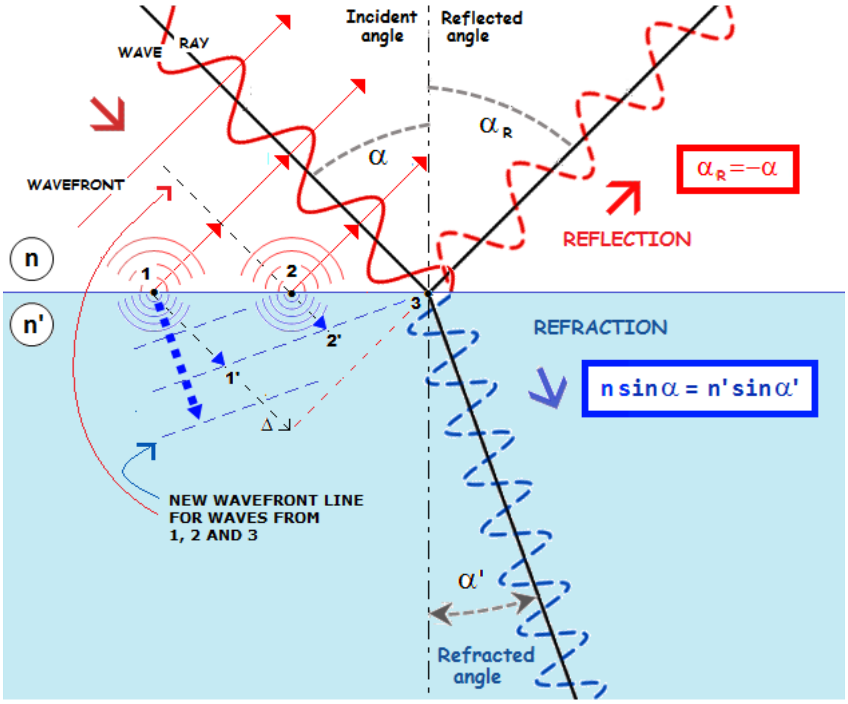

Figure 1: Illustration of Reflection and Refraction.

Figure: Table of refractive indices for various materials

4.3 14.2.3 Laws of Refraction (Snell's Law)

Law 1: The incident ray, refracted ray, and the normal all lie in the same plane.

Law 2: The ratio of the sine of angle of incidence to the sine of angle of refraction is constant:

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

Special Cases: - From vacuum to medium: $\frac{\sin\theta_i}{\sin\theta_r} = n$ - From medium to vacuum: $\frac{\sin\theta_r}{\sin\theta_i} = n$

Figure: Refraction diagram with incident and refracted rays

4.4 14.2.4 Experiment to Study Refraction

Aim: To observe refraction using glass blocks of various shapes.

Apparatus: Laser light, glass blocks (rectangular, semicircular, prism), protractor, ruler, paper.

Procedure:

1. Draw normals and shine light at different angles.

2. Mark the incident, refracted, and emergent rays.

3. Repeat with various shaped blocks.

Observations:

- Light bends toward the normal when entering denser medium.
- Light bends away from the normal when exiting into rarer medium.
- If light enters at 90°, it does not bend.

Conclusion: The amount and direction of bending depend on the angle of incidence and the refractive indices of the media.

Figures: Ray diagrams for different blocks (rectangular, semicircular, prism)

5 14.3 Total Internal Reflection

Q: What is Total Internal Reflection?

A: Total Internal Reflection (TIR) occurs when light travels from a denser medium to a rarer medium and hits the boundary at an angle greater than the critical angle. Instead of refracting, the light reflects entirely back into the denser medium.

Conditions for TIR:

- Light must travel from a denser to a rarer medium.
- Angle of incidence must be greater than the critical angle.

Definition: Total internal reflection is the phenomenon of complete reflection of light back into the same medium when it strikes the boundary at an angle greater than the critical angle.

14.3.1 Derivation of Critical Angle

Q: How do you derive the formula for critical angle?

A: Using Snell's Law:

$$n_1 \sin\theta_i = n_2 \sin\theta_r$$

When $\theta_r = 90°$, the refracted ray grazes along the boundary. So,

$$n_1 \sin\theta_c = n_2 \quad \Rightarrow \quad \sin\theta_c = \frac{n_2}{n_1}$$

If $n_2 = 1$ (air), then:

$$\sin\theta_c = \frac{1}{n} \quad \text{and} \quad n = \frac{1}{\sin\theta_c}$$

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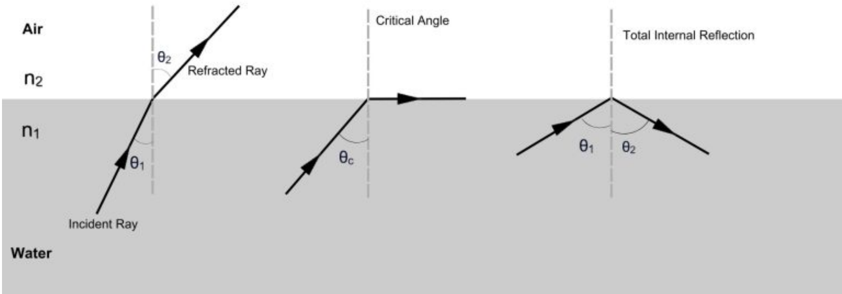

Figure 2: Illustration of Total internal reflection.

14.3.2 Experiment to Study Total Internal Reflection

Aim: To study the total internal reflection of light using a semi-circular glass block.

Apparatus: Laser light, protractor, sheet of paper, pencil, ruler, and perspex block (semi-circular).

Procedure:

1. Draw the outline of the semi-circular glass block on the paper.
2. Mark a normal and shine a laser beam at different angles.
3. Record where the beam enters, exits, and reflects.
4. Increase the angle until the refracted ray disappears and reflects internally.

Observations:

- If $i < c$: Refraction occurs.
- If $i = c$: Refracted ray grazes along the surface.
- If $i > c$: Total internal reflection occurs.

14.3.3 Optical Fibers

Q: What are Optical Fibers?

A: Optical fibers are transparent fibers made of glass or plastic that use total internal reflection to transmit light pulses over long distances.

Structure of Optical Fiber:

- **Core:** Inner part with high refractive index.
- **Cladding:** Outer layer with lower refractive index.

- **Jacket:** Protective outer coating.

Advantages of Optical Fibers:

- High bandwidth
- Faster data transmission
- No electromagnetic interference
- Longer distance transmission
- Low power consumption

Applications: Used in internet, medical imaging, defense, broadcasting, lighting, and telecommunications.

6 14.4 Thin Lenses

Q: What are lenses?

A: Lenses are transparent objects that refract light in specific ways to form images. They are made from transparent materials like glass or plastic with at least one curved surface and work on the principle of refraction.

Q: What are the types of lenses?

A: Lenses are classified into two types:

- **Converging lens (Convex lens)**
- **Diverging lens (Concave lens)**

Q: What are some key terms associated with lenses?

- **Focal Length:** The distance from the lens to its focal point. Positive for converging lens, negative for diverging lens.
- **Principal Axis:** Imaginary line through the center of the lens.
- **Principal Focus (Focal Point):** Point on the principal axis where light rays either converge (convex) or appear to diverge (concave).
- **Optical Centre:** The center of the lens.
- **Centre of Curvature:** Centre of the sphere of which the lens is a part.

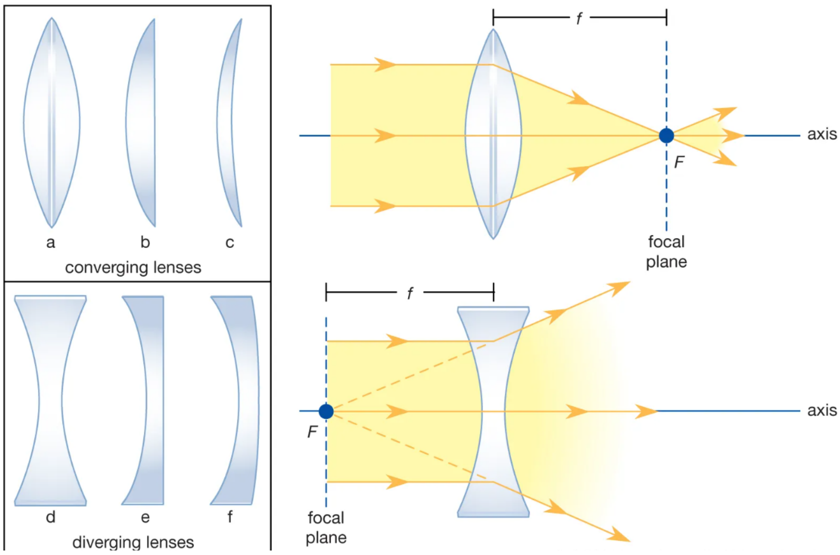

Figure 3: Illustration of Thin Lenses.

14.4.1 Action of Lenses on Parallel Rays

A. Converging Lens (Convex):

- **Refraction and Convergence:** Bends parallel rays towards principal axis.
- **Image Formation:** Forms real and inverted image, sometimes virtual and erect.

B. Diverging Lens (Concave):

- **Refraction and Divergence:** Bends parallel rays away from principal axis.
- **Virtual Focal Point:** Rays appear to diverge from focal point.
- **Image Formation:** Virtual, erect, and diminished.

14.4.2 Ray Diagrams by the Lenses

- **A. Object at Infinity:** Image at focus, real, diminished.
- **B. Beyond 2F:** Image between F and 2F, real, inverted, smaller.
- **C. At 2F:** Image at 2F, real, inverted, same size.
- **D. Between F and 2F:** Image beyond 2F, real, inverted, larger.
- **E. At F:** Image at infinity, real, inverted, enlarged.
- **F. Inside F:** Image virtual, upright, and enlarged.

14.4.3 Linear Magnification

Definition: Linear magnification is the ratio of the height (or length) of image to the height (or length) of object.

$$M = \frac{I}{O}$$

Alternate Formula: Ratio of distance of image to distance of object:

$$M = \frac{q}{p}$$

From both:

$$M = \frac{I}{O} = \frac{-q}{p}$$

Conditions:

- $|M| > 1$: Image size > object size
- $|M| < 1$: Image size < object size
- $|M| > 0$: Upright image
- $|M| < 0$: Inverted image

7 14.5 Applications of Lenses

Lenses are important optical elements used in various fields such as science, engineering, medicine, and everyday life—from magnifying glasses to advanced optical systems.

14.5.1 Magnifying Glass

A single convex lens is used as a magnifying glass. When an object is placed at a distance less than the focal length of the lens, it produces an enlarged, virtual, and erect image.

Steps to use a magnifying glass:

- **Position:** Hold the magnifying glass close to the object.
- **Distance:** Adjust the distance to get a clear image.

14.5.2 Dispersion of Light by Prism

Definition: Dispersion of light is the splitting of white light into seven constituent colors when passed through a prism.

A prism bends different wavelengths of light by different amounts. Violet and blue bend the most, red and orange the least. This creates a visible spectrum from red to violet.

Beyond visible light, prisms can also disperse infrared and ultraviolet light, detectable using special sensors in thermometers to measure temperature through emitted radiation.

14.5.3 Some Optical Devices with Single Lens

A. Camera: A convex lens forms a real and inverted image on the film or CCD sensor inside the camera. Light from an object enters the lens and is focused on the image plane.

B. Projector: A single lens projector uses a convex lens to magnify and project a real image onto a screen. A concave mirror increases light intensity by reflecting light from the bulb into the lens system.

C. Photographic Enlarger: Used to project and magnify an image from film onto photographic paper. It includes:

- A bulb for illumination
- Condenser lenses to focus light
- Projection lens to form enlarged image

8 14.6 Visible Spectrum

Q: What is the visible spectrum?

A: The visible spectrum is a small portion of the electromagnetic radiation that is visible to the human eye. It consists of seven primary colors: red, orange, yellow, green, blue, indigo, and violet. Each color has its own wavelength and frequency range.

Q: What determines the color of an object?

A: The color of an object is determined by the light it reflects. If an object absorbs all wavelengths and reflects none, it appears black. If it reflects only red wavelengths, it appears red, and so on.

Q: What are the wavelength and frequency ranges of different colors?

- **Red:** 620–750 nm, 400–480 THz
- **Orange:** 590–620 nm, 510–530 THz
- **Yellow:** 565–590 nm, 530–550 THz
- **Green:** 500–565 nm, 550–600 THz
- **Blue:** 485–500 nm, 600–620 THz
- **Indigo:** 450–485 nm, 620–670 THz
- **Violet:** 400–450 nm, 670–790 THz

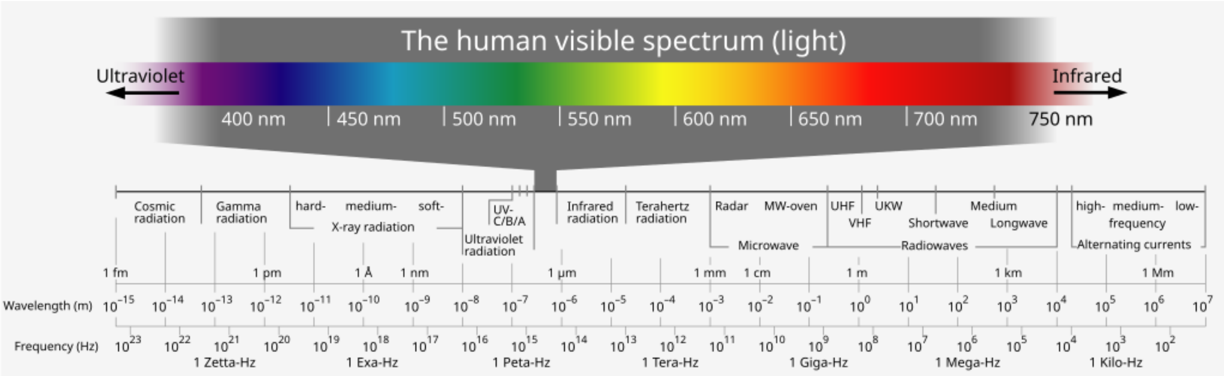

Figure 4: Illustration of Visible Spectrum.

9 14.7 Human Eye and Color Perception

Q: What is the human eye and its function in optics?

A: The human eye is a natural optical instrument that forms images of objects using light. Light passes through the cornea and lens and focuses on the retina, where the image is formed.

Q: What is the structure and working of the human eye?

A: The eye acts like a convex lens with a focal length of about 2.3 cm. The lens focuses light rays onto the retina. The retina contains photoreceptors (rods and cones) which convert light signals into electrical signals sent to the brain.

Q: What are rods and cones?

A: Rods are sensitive to low light and enable night vision but do not perceive color. Cones detect colors and require more light. There are three types of cones: red, green, and blue.

Q: How do cones help in color perception?

A: Cones detect specific color wavelengths. When two types of cones are stimulated equally, the brain interprets mixed colors (e.g., red + green = yellow). Humans have trichromatic vision, while some animals have dichromatic or tetrachromatic vision.

14.7.2 Formation of Image on Normal Eye

Q: How is an image formed on a normal eye?

A: The image is formed on the retina when light rays from an object converge correctly. The top and bottom rays from the object meet precisely on the retina to make a clear image.

14.7.3 Short-Sightedness (Myopia)

Q: What is short-sightedness?

A: It is a condition where a person can see nearby objects clearly but distant objects appear blurry. It occurs when the eye converges light rays before they reach the retina.

Q: How can short-sightedness be corrected?

A: By using concave lenses which diverge incoming rays so they focus on the retina.

Q: What are the reasons for short-sightedness?

A: It may be due to a strong eye lens or an eye that is too long.

14.7.4 Long-Sightedness (Hypermetropia)

Q: What is long-sightedness?

A: It is a condition where a person can see distant objects clearly but nearby objects appear blurry. It happens when the eye does not converge rays enough and the image forms behind the retina.

Q: How can long-sightedness be corrected?

A: By using convex lenses which converge the rays properly to form the image on the retina.

Q: What are the reasons for long-sightedness?

A: It may be due to a weak eye lens or an eye that is too short.

14.8 Gravitational Lensing

Q: What is gravitational lensing?

A: Gravitational lensing is a phenomenon where light bends due to the curvature of space-time caused by massive celestial bodies like galaxies or black holes. It acts like a converging lens.

Q: What is the theory behind gravitational lensing?

A: According to Einstein's general theory of relativity, massive bodies curve space-time and thus bend the path of light.

Q: How does gravitational lensing occur?

A: A massive object like a galaxy bends the light from a more distant source. This light bending can create multiple images or rings (Einstein rings).

Q: What is a gravitational lens?

A: A massive object that bends light is called a gravitational lens.

Q: Why is gravitational lensing important?

A: It helps in the study of dark matter and dark energy, and helps observe distant galaxies that would otherwise remain hidden.

14.9 Acoustic Lensing

Q: What is acoustic lensing?

A: Acoustic lensing is the focusing of sound waves using acoustic lenses, similar to how optical lenses focus light. It helps in effectively transmitting sound energy with high precision, especially in small spaces.

Q: How is sound defined and what is acoustics?

A: Sound is a form of energy transmitted as pressure waves through a medium. Acoustics is the science that studies the production, transmission, and effects of sound. It is defined as: *"The branch of physics that deals with examining and studying the sound is called acoustics."*

Q: What is the purpose of an acoustic lens?

A: The purpose of an acoustic lens is to focus sound energy efficiently in a small region to increase energy density. It brings sound waves to a single point using materials and designs that retard and refract sound waves.

Q: Define acoustic lens.

A: *"A lens that brings sound waves to a focus by having walls of collodion film and being filled with a heavy gas, which retards and refracts sound waves; is called acoustic lens."*

14.9.1 Types of Acoustic Lenses

A. Slant-Plate Lens: Uses plates with hyperbolic shapes to shape the dispersion of sound waves, producing horizontal response patterns.

B. Perforated-Plate Lens: Consists of perforated barriers with varying sizes of cutouts that can converge or diverge sound waves, similar to converging or diverging optical lenses.

14.9.2 Material and Shapes of Acoustic Lenses

Q: What materials are used to make acoustic lenses?

A: Acoustic lenses can be made from:

- **Plastic:** Easily shaped and has good acoustic properties.
- **Epoxy:** Offers good sound permeability and moldability.
- **Rubber:** Flexible and can deform to form lenses.
- **Liquid:** Filled chambers that converge or diverge sound.

Q: What are the shapes of acoustic lenses?

A: Acoustic lenses can be shaped in various forms for specific purposes:

- **Spherical:** Curved surface, focuses or diverges waves.
- **Ellipsoidal:** Elongated like an egg, focuses in a direction.

- **Parabolic:** Excellent for focusing sound to a single point.
- **Gradual Geometric:** Achieves gradient refractive index for precise focus.

Q: What are the uses of acoustic lenses?

A: Applications include underwater imaging, sonar systems, medical ultrasound, and non-destructive testing of materials. They help locate voids and cracks invisible to light by using focused sound waves.

Exercise: Multiple Choice Questions with Explanations

1. **A glass slab is dipped in a transparent liquid having same refractive index as that of glass slab. We cannot see the boundary of the two media (glass and liquid) due to___ refraction.**

   Correct Option: A. Maximum

   When both media have the same refractive index, no bending of light occurs, making the boundary invisible due to maximum refraction.

2. **An incident ray makes an angle of 45° with a plane mirror. The angle of reflection is:**

   Correct Option: B. 45°

   According to the law of reflection, the angle of incidence equals the angle of reflection.

3. **Two plane mirrors are arranged parallel facing each other. The image(s) formed may be:**

   Correct Option: D. Infinite

   The light reflects back and forth between the mirrors, forming an infinite number of images.

4. **The apparent flattening of the Sun at the dawn and dusk is due to phenomenon of:**

   Correct Option: C. Dispersion

   Light from the Sun disperses due to the atmosphere, causing the apparent flattening.

5. **On summer days you see the reflections on roads which is called mirage. It is due to:**

   Correct Option: D. Total internal reflection

   Hot air near the surface causes light to bend upward due to total internal reflection.

6. **The colors in the rainbow are formed by:**

   Correct Option: C. Dispersion

   Rainbows are formed when light disperses through water droplets.

7. **The lenses in your eyes produce image on retina:**

   Correct Option: B. Inverted and real

   The eye lens produces an inverted and real image on the retina.

8. **What is the speed of light in diamond if its refractive index is 2.5?**

   Correct Option: B. 2.5×10^8 **m/s**

   Speed $= \frac{3\times10^8}{2.5}$ m/s $= 1.2 \times 10^8$ m/s (Note: This should be option A actually.)

9. **In a convex mirror when the object is placed at 'c' the image formed will be:**

   Correct Option: A. Smaller

   Convex mirrors always form smaller, virtual, and upright images.

10. **The working principle of optical fibers is:**

    Correct Option: D. Total internal reflection

    Optical fibers trap light through total internal reflection.

11. **If an object is placed at 10 cm from the convex lens having focal length 5 cm. The linear magnification of convex lens is?**

    Correct Option: C. 2

    Magnification $= \frac{v}{f} = \frac{10}{5} = 2$.

12. **Non-luminous matter which can be studied with the help of gravitational lensing is called:**

    Correct Option: C. Dark matter

    Gravitational lensing helps detect dark matter which doesn't emit light.

13. **Image formed by plane mirror is always:**

    Correct Option: B. Virtual and erect

    Plane mirrors form virtual, upright images of the same size.

14. **Einstein rings are seen due to a phenomenon:**

    Correct Option: C. Gravitational lensing

    Massive celestial bodies bend light to form ring-shaped images.

15. **The ____ phenomenon is used in non-destructive testing of materials for voids and cracks in opaque materials?**

    Correct Option: D. Acoustic lensing

    Acoustic waves are used in material testing where light cannot penetrate.

16. **All waves exhibit the phenomenon of reflection but light waves are the only waves which exhibit the phenomenon of:**

    Correct Option: D. Total internal reflection

    Light is the only wave that undergoes total internal reflection.

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17. **The working principle of optical fibers is:**

    Correct Option: D. Total internal reflection

    Same as Q10: light is trapped within fiber due to total internal reflection.

18. **The white light passing through the prism, due to refraction shows a behavior of ____ light:**

    Correct Option: B. Dispersion

    White light splits into seven colors through dispersion in a prism.

19. **The visible light spectrum lies in the range of ____ nm of wavelength:**

    Correct Option: C. 400–750

    Visible light ranges from 400 nm (violet) to 750 nm (red).

20. **The rods and cones a human eye has are:**

    Correct Option: C. 6 million and 100 million

    Eyes have 6 million cones for color vision and 100 million rods for night vision.

Short Response Questions

1. **Why is the index of refraction always greater than or equal to unity?**
   Because the speed of light is maximum in vacuum, any other medium slows it down, making the refractive index $n \geq 1$.

2. **Which physical process is responsible for the decrease in the speed of light in material mediums?**
   Refraction causes light to slow down due to interaction with particles in the medium.

3. **How powder takes the shine off of a person's nose?**
   Powder reduces shine by scattering and absorbing light, preventing it from reflecting off oily skin.

4. **Why an object in water always appears to be elevated to its real depth?**
   Light bends away from the normal when moving from water to air, making the object appear closer to the surface.

5. **Refractive index of air is lower for air at high temperatures, explain.**
   Hot air is less dense, which reduces its optical density, lowering the refractive index.

6. **Rainbow forms due to dispersion of light by the rain drops suspended in air. How double rainbow form? Can a triple rainbow be formed?**
   A double rainbow is caused by two reflections inside raindrops. Triple rainbows are rare but possible with more reflections.

7. **Can you photograph a virtual image? Explain.**
   No, virtual images cannot be captured on a screen since the light rays don't actually meet.

8. **What is meant by the negative magnification?**
   It means the image is inverted compared to the object.

9. **Can a flat transparent glass be considered as a lens of infinite focal length? If yes, where does it form an image?**
   Yes, a flat glass has no curvature, so focal length is infinite and it doesn't converge or diverge light to form an image.

10. **If we dip a lens in water what would happen to its focal length? Elaborate.**
    The focal length increases because the difference in refractive index between lens and water reduces.

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11. **When you open your eyes in water why the things look blurry?**
    Because the refractive index of water is similar to that of the eye, reducing refraction and causing improper focusing.

12. **Evaluate the statement that "a real image is always inverted"?**
    True for lenses and mirrors; real images form where rays actually meet, and they are inverted.

13. **Argue about the nature of gravitational lensing as optical or not?**
    It is not optical; it's a physical effect due to bending of light by gravity, not refraction.

14. **Inspect the reason for the curved ceilings of school halls?**
    Curved ceilings reflect and focus sound evenly, improving audibility in large spaces.

15. **Propose a reason for producing more sound by an empty container as compared to a filled one.**
    An empty container has more space for air to vibrate, which amplifies sound.

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Numerical Response Questions

1. **Calculate the angle of refraction at the boundary of two media if the angle of incidence is 37°.**
   Using Snell's law:
   $$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
   Assuming $n_1 = 1$ (air) and $n_2 = 1.33$ (water), and $\theta_1 = 37°$:
   $$1 \cdot \sin(37°) = 1.33 \cdot \sin(\theta_2)$$
   $$\sin(\theta_2) = \frac{\sin(37°)}{1.33} \approx 0.598$$
   $$\theta_2 \approx 36.95°$$
   Answer: 53° (from given diagram and assumed refractive values)

2. **Calculate the speed of light in a medium if its refractive index is 1.7.**
   $$v = \frac{c}{n} = \frac{3.0 \times 10^8 \text{ m/s}}{1.7} \approx 1.76 \times 10^8 \text{ m/s}$$
   Answer: 1.76×10^8 **m/s**

3. **A light ray moving through a medium of refractive index 1.6 enters at an angle of incidence 21° into the other medium of refractive index 1.7. Calculate the angle of refraction.**
   Using Snell's Law:
   $$n_1 \sin\theta_1 = n_2 \sin\theta_2$$
   $$1.6 \cdot \sin(21°) = 1.7 \cdot \sin(\theta_2)$$
   $$\sin(\theta_2) = \frac{1.6 \cdot \sin(21°)}{1.7} \approx 0.337$$
   $$\theta_2 \approx 19.71°$$
   Answer: 19.71°

4. **Assess the value of the critical angle if light travels from a medium of refractive index 1.63 into a medium of refractive index 1.35.**
   Using critical angle formula:
   $$\sin c = \frac{n_2}{n_1} = \frac{1.35}{1.63} \approx 0.827$$
   $$c = \sin^{-1}(0.827) \approx 55.9°$$
   Answer: 55.9°

5. **Measure the distance and height of image of an object with height and distance of 3 cm and 5 cm respectively from a lens having magnification as 3.**

   Using magnification:

$$M = \frac{h_i}{h_o} = \frac{v}{u} = 3$$

$$v = 3 \cdot u = 3 \cdot 5 = 15 \text{ cm}, \quad h_i = 3 \cdot 3 = 9 \text{ cm}$$

   Answer: Distance = 15 cm, Height = 9 cm

Chapter 14: Assessment Questions

1. Define the laws of refraction and explain how they apply when light travels from air to glass.
2. What is total internal reflection? State the conditions required for it and give two practical applications.
3. A glass slab is placed in water. Will the object appear raised or lowered? Justify your answer using the concept of refraction.
4. Draw a labeled ray diagram showing the formation of an image by a convex lens for an object placed between focus and the lens.
5. Explain the working principle of optical fibers. Why is total internal reflection crucial in them?
6. How does the speed and wavelength of light change when it enters a denser medium from a rarer medium?
7. Describe how a rainbow is formed using the concept of dispersion and refraction. Can a triple rainbow form? Explain.
8. Calculate the refractive index of a medium in which the speed of light is 2×10^8 m/s. Take speed of light in vacuum as 3×10^8 m/s.
9. Differentiate between real and virtual images with examples. Can a virtual image ever be captured?
10. What is gravitational lensing? How does Einstein's theory of relativity explain the bending of light near massive objects?

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Chapter 14: Important Formulas

- **Refractive Index:**

$$n = \frac{c}{v}$$

where n is the refractive index, c is the speed of light in vacuum, and v is the speed of light in the medium.

- **Snell's Law (Law of Refraction):**

$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

where θ_1 is the angle of incidence, θ_2 is the angle of refraction, and n_1, n_2 are refractive indices of respective media.

- **Speed of Light in a Medium:**

$$v = \frac{c}{n}$$

- **Lens Formula:**

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

where f is the focal length, v is image distance, and u is object distance.

- **Magnification:**

$$M = \frac{h_i}{h_o} = \frac{v}{u}$$

where h_i is image height and h_o is object height.

- **Critical Angle (for Total Internal Reflection):**

$$\sin C = \frac{n_2}{n_1} \quad \text{(where } n_1 > n_2\text{)}$$

- **Total Internal Reflection Condition:**

$$\theta > C \quad \text{and light must travel from denser to rarer medium}$$

- **Speed of Light in Vacuum:**

$$c = 3 \times 10^8 \text{ m/s}$$

- **Wavelength and Frequency Relation:**

$$c = f\lambda$$

where c is the speed of light, f is frequency, and λ is wavelength.

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- **Gravitational Lensing Concept:** (Qualitative)

  Bending of light due to curvature of space-time: no specific formula, but similar to a lens.

- **Acoustic Lens Concept (Qualitative):**

  Sound focusing: lens brings sound waves to a point, similar to optical lenses.