Chapter 5: Optics

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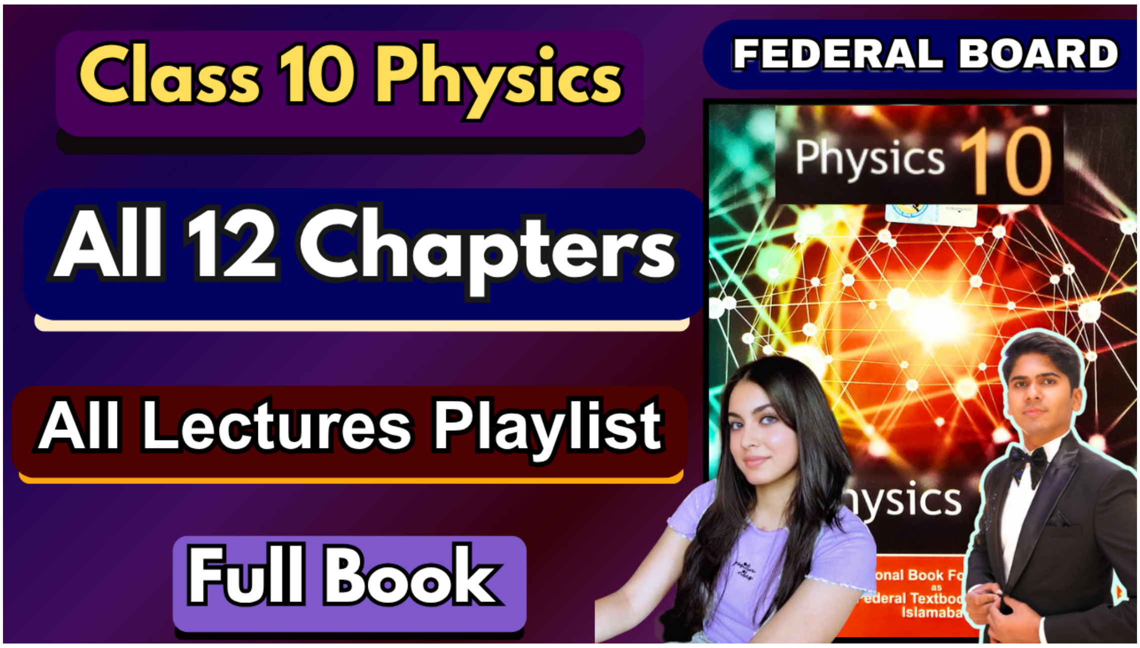

Optics is the science of light and its interaction with matter. It explores the behavior of light waves, the properties of lenses and mirrors, and the intricacies of human vision. But beyond its practical applications in fields like photography, microscopy, and astronomy, optics holds a deeper significance.

14.1 Reflection of Light

'When a ray of light approaches a smooth polished surface and bounces back is called reflection.' Reflection is the phenomenon in which light rays strike a surface and bounce back into the same medium. It occurs when light hits smooth, polished surfaces such as mirrors. Reflection is responsible for our ability to see objects. In all cases, light travels in a straight line or as a ray. The word ray comes from mathematics and it means a straight line, we would use the travelling of light in a ray diagram in this unit.

14.1.1 Laws of Reflection

1. **First Law:** The incident ray, the reflected ray, and the normal at the point of incidence all lie in the same plane.
2. **Second Law:** The angle of incidence (i), θ_i, is equal to the angle of reflection (r), θ_r.

A. Regular or Specular Reflection

Occurs on smooth and polished surfaces such as plane mirrors. Reflected rays remain parallel, producing a sharp, clear image.

B. Diffused Reflection

Occurs on rough or uneven surfaces. Reflected rays scatter in multiple directions, producing no clear image. This is why we can see objects from different angles.

14.2 Spherical Mirrors

A spherical mirror is a mirror whose reflective surface is a part of a sphere. There are two types:

A. Concave Mirror (Converging Mirror)

A mirror whose inner (concave) surface is the reflecting surface. Light rays parallel to the principal axis converge (meet) at the principal focus after reflection.

B. Convex Mirror (Diverging Mirror)

A mirror whose outer (convex) surface is the reflecting surface. Light rays parallel to the principal axis diverge (spread out) after reflection, appearing to come from the principal focus behind the mirror.

14.2.1 Characteristics of the Image Formed by a Plane Mirror

- The image is **virtual** (cannot be formed on a screen).
- The image is **erect** (upright).
- The image is the **same size** as the object.
- The image distance is **equal** to the object distance.
- The image is **laterally inverted** (left and right are flipped).

14.2.2 Uses of Spherical Mirrors

- **Concave Mirrors:** Used as shaving mirrors, dentist mirrors, headlights, and solar furnaces (to focus heat).
- **Convex Mirrors:** Used as side-view (wing) mirrors in vehicles and as security mirrors in shops (due to their wide field of view).

14.3 Refraction of Light

Refraction is the phenomenon in which light rays **bend** as they pass from one transparent medium to another (e.g., from air to water). This bending is caused by the change in the **speed of light** as it moves between media of different densities.

14.3.1 Laws of Refraction (Snell's Law)

1. **First Law:** The incident ray, the refracted ray, and the normal at the point of incidence all lie in the same plane.

2. **Second Law (Snell's Law):** For any two specific media, the ratio of the sine of the angle of incidence (θ_i) to the sine of the angle of refraction (θ_r) is constant.

$$\frac{\sin\theta_i}{\sin\theta_r} = \text{constant} = \text{n}$$

   where n is the refractive index between the two media.

14.4 Refractive Index

The refractive index (n) is a measure of how much a medium slows down light. It is defined as the ratio of the speed of light in a vacuum (c) to the speed of light in the medium (v).

$$\text{n} = \frac{\text{Speed of light in vacuum (c)}}{\text{Speed of light in medium (v)}}$$

A. Absolute Refractive Index

This is the refractive index of a medium when the first medium is a vacuum (or air, since the difference is negligible). $\text{n} = \text{c}/\text{v}$.

B. Relative Refractive Index

This is the refractive index between two non-vacuum media. $\text{n}_{21} = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}}$.

14.5 Total Internal Reflection (TIR)

When light travels from a **denser** medium to a **rarer** medium (e.g., water to air), the refracted ray bends **away** from the normal.

A. Critical Angle (θ_c)

The angle of incidence in the denser medium for which the angle of refraction in the rarer medium is $90°$.

B. Total Internal Reflection

If the angle of incidence is **greater** than the critical angle ($\theta_i > \theta_c$), the light ray is completely reflected back into the denser medium. This phenomenon is called Total Internal Reflection (TIR).

C. Applications of TIR

- **Optical Fibers:** Used to transmit data (light signals) over long distances with minimal loss. Light enters one end and undergoes repeated TIR inside the fiber.
- **Periscopes:** Modern periscopes use prisms to achieve TIR, offering a clearer image than mirrors.
- **Binoculars:** Use reflecting prisms to invert the image and shorten the overall length of the optical device.
- **Sparkling of Diamonds:** Diamonds are cut such that light entering them undergoes multiple total internal reflections before exiting, making them sparkle brilliantly.

14.6 Lenses

A lens is a piece of transparent material (like glass) that has at least one curved surface. Lenses work by **refraction**.

A. Convex Lens (Converging Lens)

Thicker at the center and thinner at the edges. It causes light rays parallel to the principal axis to **converge** at a single point (the principal focus).

B. Concave Lens (Diverging Lens)

Thinner at the center and thicker at the edges. It causes light rays parallel to the principal axis to **diverge** (spread out), appearing to come from the principal focus.

14.7 Power of a Lens

The power (P) of a lens is its ability to converge or diverge light rays. It is the **reciprocal of the focal length** (f) in meters.

$$P = \frac{1}{f}$$

- **Unit:** The unit of power is the **diopter** (D), where 1 D $=$ 1 m^{-1}.
- **Sign Convention:** Power is **positive** for a convex lens (real focus) and **negative** for a concave lens (virtual focus).

14.8 Applications of Lenses

- **Corrective Eyeglasses:** Lenses are used to correct vision defects like myopia (short-sightedness, corrected by concave lens) and hyperopia (long-sightedness, corrected by convex lens).
- **Microscopes:** Use a combination of two convex lenses to produce a highly magnified image of tiny objects.
- **Telescopes:** Use lenses and/or mirrors to magnify distant objects.
- **Cameras:** Use a lens system to focus an image onto a sensor or film.

Acoustic Lenses

Acoustic lenses are devices designed to **focus or shape sound waves**, similar to how optical lenses focus light waves. They use materials and geometric shapes to control the direction and intensity of sound.

1. Materials Used for Acoustic Lenses

- **A. Acrylic:** Used in acoustic lenses because it can easily be fabricated and have good acoustic properties.
- **B. Epoxy:** Epoxy is also commonly used material for making acoustic lenses; it offers good sound permeability and can be molded into specific shapes.

- **C. Rubber:** Rubber is used in acoustic lenses for their flexibility and the ability to deform the lenses.

- **D. Liquid:** Some acoustic lenses use liquid-filled chambers to converge or diverge sound waves.

Similarly, acoustic lenses come in different shapes; each shape serves a specific purpose. They can be shaped in spherical, ellipsoidal, parabolic, and gradual geometric curves as explained here:

E. Spherical Acoustic Lenses

These acoustic lenses have curved surfaces like a sphere. They focus or diverge the sound waves according to their curvature.

F. Ellipsoidal Acoustic Lenses

These are similar to spheres but a little elongated in one direction (somehow like an egg). They can focus sound waves in a specific direction.

G. Parabolic Acoustic Lenses

These acoustic lenses have a parabolic shape and are excellent at focusing sound waves to a single point.

H. Gradual Geometric Acoustic Lenses

Lenses with gradual geometric curves achieve gradient refractive index distribution, allowing precise acoustic focusing.

Characteristics

- Must have minimal energy loss.

- Should withstand operational environments (e.g., underwater pressure for sonar lenses).

- Designed based on the wavelength of sound to achieve proper focusing.


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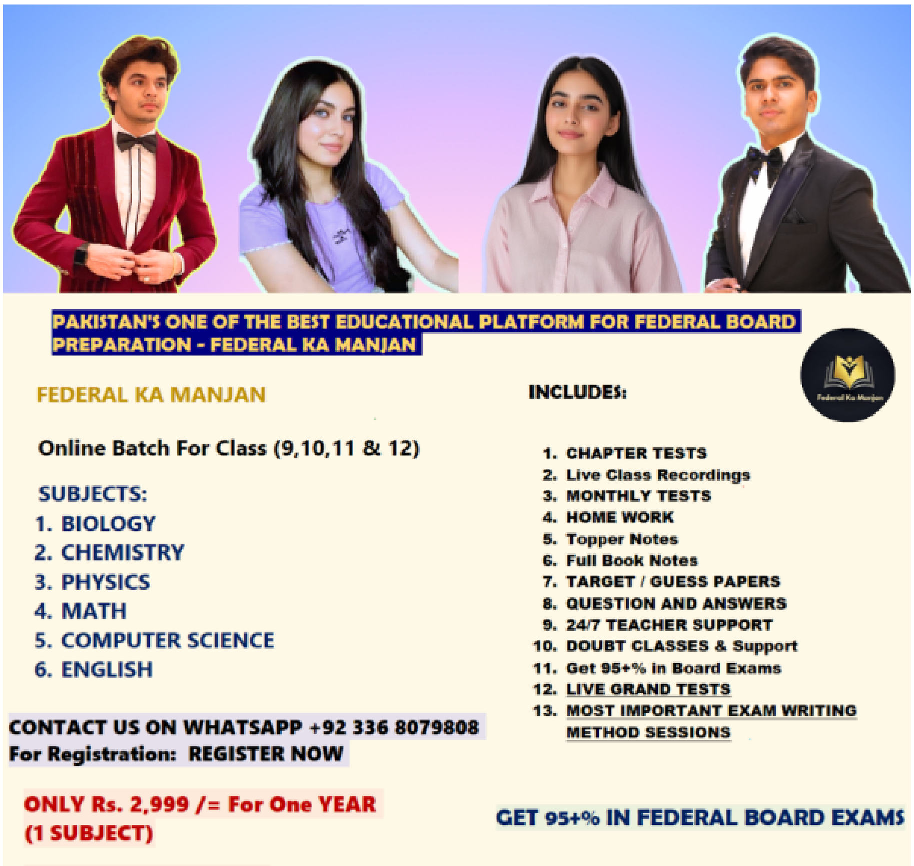
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