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Optics

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Lecture (1)

For third year Students

Lecture Title: Light reflection and refraction

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Chronological Evolution of Ideas on Light's Nature and Behavior

Light

- The study of light has intrigued scientists and philosophers for centuries.
- The Four Important Theories:

Throughout history, various theories about light have been proposed, including wave theory, particle theory, electromagnetic theory, and quantum theory.

- The Sources of Light:

Light can originate from natural sources like the sun, artificial sources like light bulbs, and even bioluminescent organisms.

- Properties of Light:

Light exhibits properties like reflection, refraction, dispersion, and polarization, each revealing unique characteristics of this phenomenon.

- Optical Path:

Understanding the path of light through different media is essential in predicting its behavior.

- Dispersion:

Dispersion occurs when light splits into its constituent colors, revealing the spectrum, as in a rainbow.

- The Velocity of Light:

The speed of light, a universal constant, plays a crucial role in various scientific calculations.

- Refractive Index:

The refractive index describes how much a medium can bend light, a fundamental concept in optics.

- Speed of light:

The first laboratory measurement of the speed of light was carried out in 1849 by the French physicist H.L.Fizeau. Later, many experimenters using different methods have measured c. The most precise determination gives a value : $c = 2.997924 \times 10^8$ m/s. which is usually simplified as: $c = 3 \times 10^8$ m/s

- Visible Range:

The human eye can perceive light within a specific range of wavelengths, resulting in the vibrant spectrum of colors we see in the world.

- Photons:

Light is composed of discrete packets of energy called photons, a central concept in quantum mechanics.

- The Dual Nature:

The duality of light, behaving as both waves and particles, is one of the most fascinating aspects of this phenomenon.

The Nature of Light.

- Light is an electromagnetic wave, but in geometric optics, we treat it as a collection of rays.
- Light travels in straight lines unless it interacts with something, like an optical element or a medium with varying refractive index μ.

$$\mu = \frac{c}{\upsilon}$$

Ray and Ray Tracing:

- A ray is a directed line that represents the path of light.
- Ray tracing is the technique we use to predict how light rays behave when they interact with optical components.

Fermat's Principle of Least Time:

Fermat's principle, states that light follows the path that minimizes the time it takes to travel between two points. In other words, light rays take the quickest route between two points, which might not always be the most direct path. This principle serves as the foundation for understanding the behavior of light in various optical phenomena.

A light ray travelling from one point to another point will traverse a path fo r which, compared to all neighboring paths, the time required is a minimum or a maximum or stationary. This is known as "Fermat's principle of extreme path" or "Fermat's principle of stationary time"

Huygen's Principle: Huygen's principle gives a geometrical construction for finding the position of a wave front at a future instant if its position is known at some particular instant. The construction is based on the following two fundamental postulates.

(i) Every point on a wave front acts as a 'secondary' source of disturbance. Secondary wavelets spread in all directions from these new sources. The secondary wavelets are spherical and have the same frequency and velocity as the original wave.

(ii) The surface, which touches all the wavelets from the secondary sources, gives the new position of the wave front.

We now apply the Huygens' principle to the propagation of spherical wave fronts, of light from a point source, spreading in an isotropic medium.

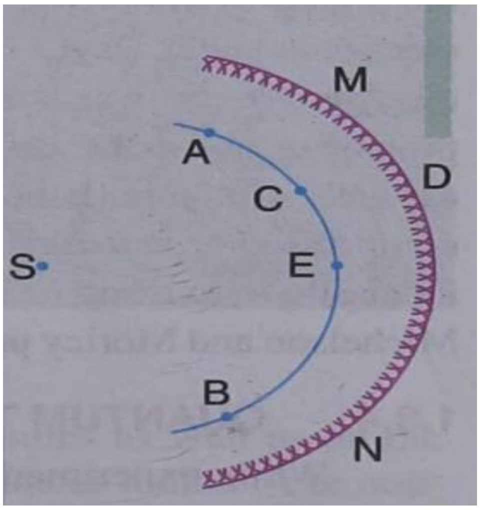


Fig: Huygens' principle

Light Reflection:

- The laws of reflection describe how light rays behave when they strike a reflecting surface. There are two fundamental laws of reflection:

- The **angle of incidence** is equal to the **angle of reflection**. In other words, the incoming and outgoing light rays make equal angles with the normal (a line perpendicular to the reflecting surface) at the point of incidence.

- The incident ray, the reflected ray, and the normal to the surface all lie in the same plane.

Reflection: Reflection is the change in the direction of a light ray when it strikes a reflecting surface. The angle of incidence (i) is equal to the angle of reflection (r). The law of reflection is expressed as: $i = r$

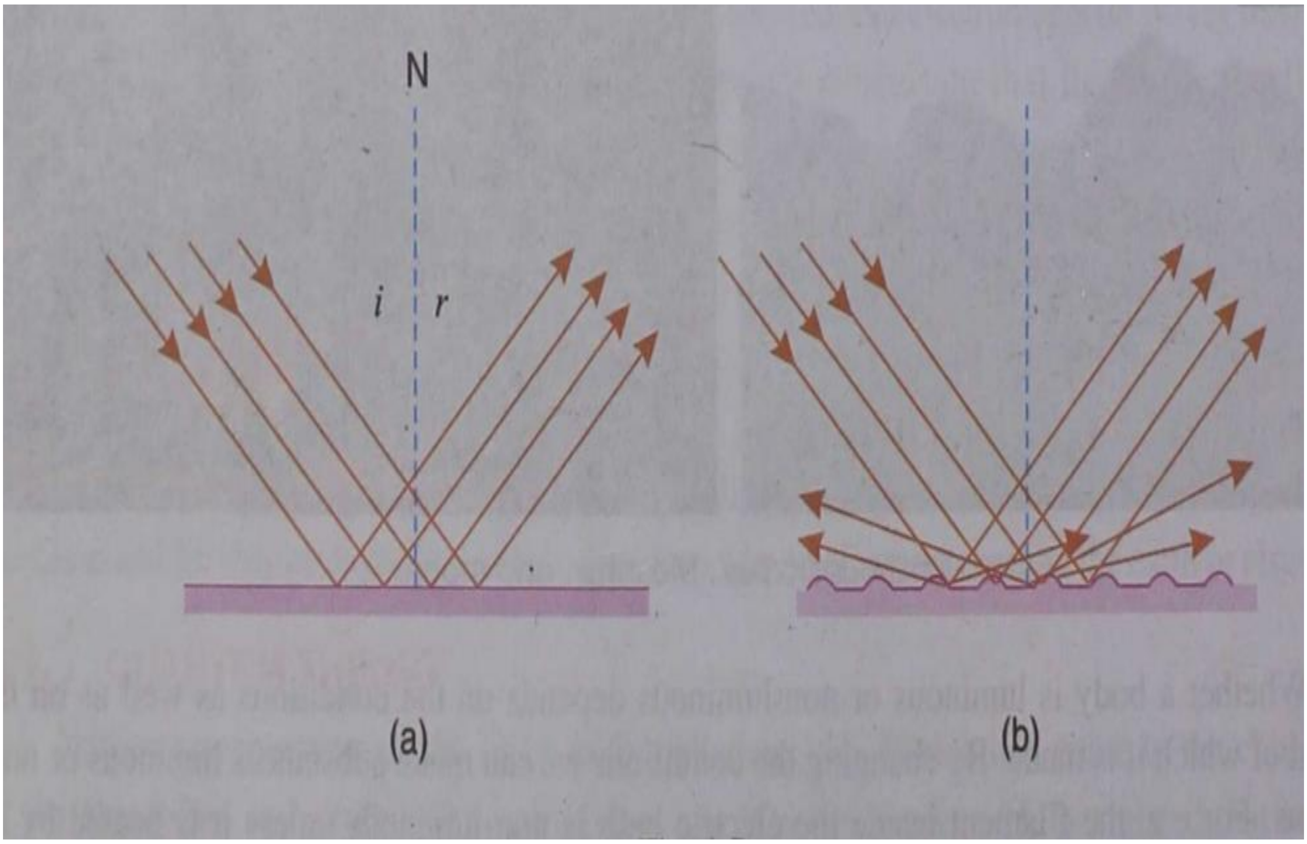
Example: Consider a light ray incident on a mirror at an angle of 30^o. What will be the angle of reflection?

Solution: Using the law of reflection, (i=r), the angle of reflection will also be 30^o .

Specular and diffuse reflections: are two fundamental processes by which light interacts with surfaces, resulting in distinct optical behaviors.

1. **Specular Reflection:**

- Regular and Predictable: Specular reflection occurs when light rays bounce off a smooth and polished surface, like a mirror or a still body of water.
- Angle of Incidence Equals Angle of Reflection (i=r): The angle at which light approaches the surface (angle of incidence) is equal to the angle at which it leaves the surface (angle of reflection).
- Intact Image: In specular reflection, the reflection preserves the original image's sharpness and clarity. You can see a clear and well-defined reflection.
- High Intensity: Specular reflection often results in high-intensity reflections because most of the incoming light rays follow the same direction.
- Examples: Mirror reflection, reflection on a **calm lake** or a shiny car.



a) Specular reflections and b)diffuse reflections

First Law: The incident ray, the reflected ray and the normal at the point of incidence are in the same plane. This plane is called the plane of incidence.

Second Law: The angle of reflection is equal to the angle of incidence. Thus, in Fig. below:

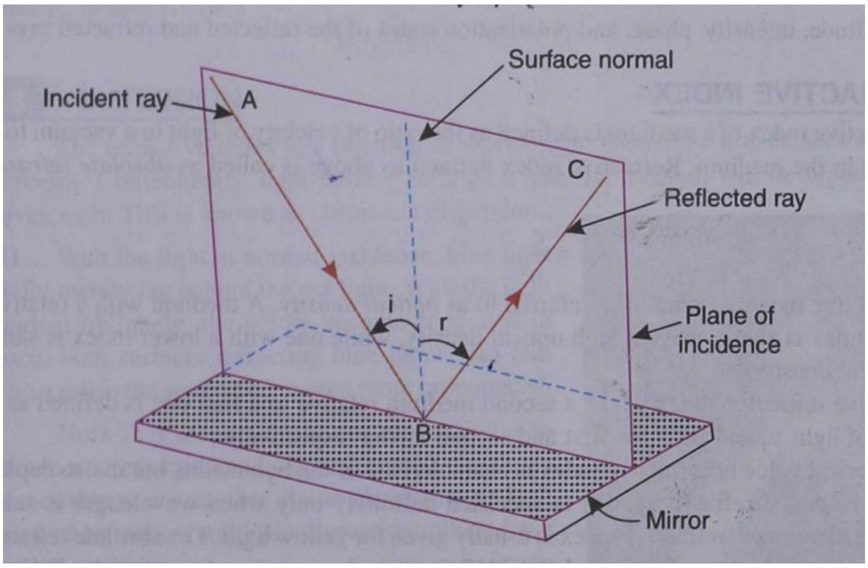


Fig: Reflection of light

Note — The laws of reflection are obeyed in specular reflection. They do not hold in case of irregular or diffuse reflection.

Laws of Refraction:

The laws of refraction govern the behavior of light as it passes from one medium to another with a different refractive index (optical density). There are two primary laws of refraction:

- Snell's Law: This law states that the ratio of the sines of the angles of incidence and refraction is equal to the ratio of the speeds of light in the two media. Mathematically, it is expressed as:

  $$\mu 1 Sin(i) = \mu 2 Sin(r) \quad \text{Or} \quad \frac{Sin(i)}{Sin(r)} = \frac{\mu 2}{\mu 1}$$

  where **μ1**and **μ2** are the refractive indices of the two media.

- The incident ray, the refracted ray, and the normal to the interface all lie in the same plane.

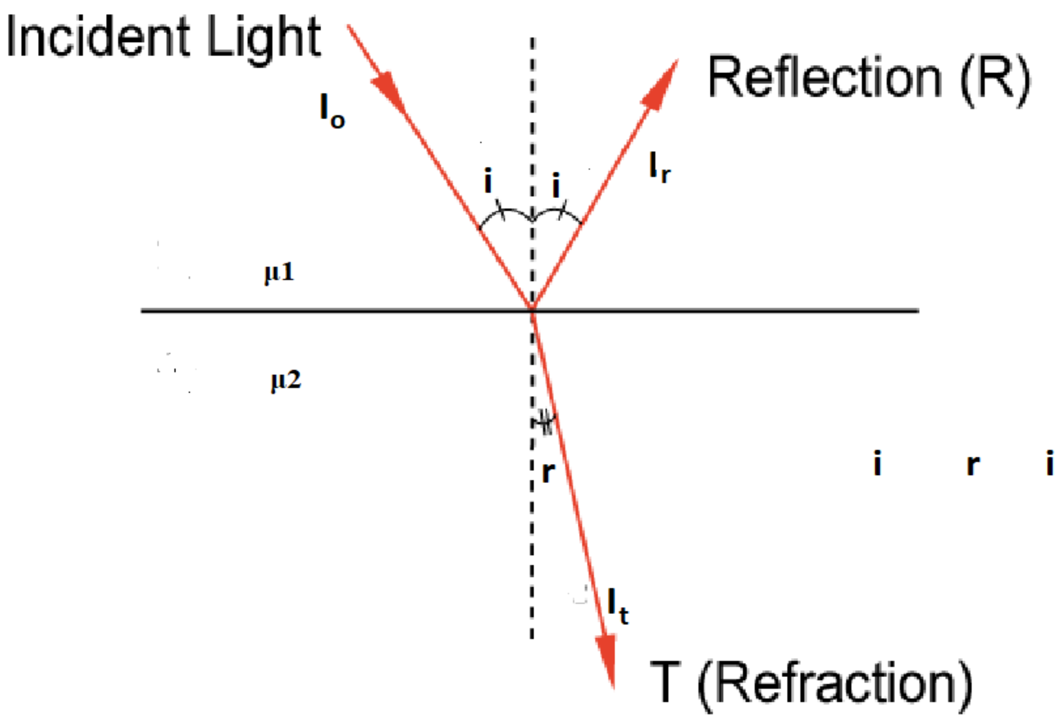


Fig: Phenomenon of refraction—A ray obliquely incident on air-glass nterface bends toward the normal in glass.

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

Second Law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction for any two given media is constant.

$$\frac{Sin(i)}{Sin(r)} = \frac{\mu 2}{\mu 1} = \frac{\mu 2}{1} = \mu 2 = \mu$$

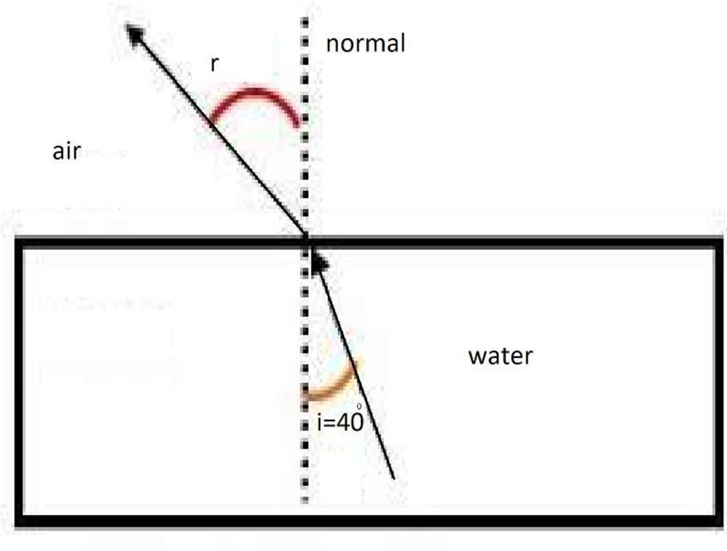
Where **μ** is called the refractive index of the medium

The refractive index of a medium is defined as the ratio of velocity of light in a vacuum to the velocity of light in the medium. Refractive index defined as above is called as absolute refractive index. Thus refractive index of medium given by:

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

Problem: A ray of light is incident on the surface of a water-air interface. The angle of incidence is 40^o, and the refractive indices of water and air are 1.33 and 1.00, respectively. Calculate the angle of refraction.

Solution: Use Snell's Law,: $\mu 1 Sin(i) = \mu 2 Sin(r)$



Where: Angle of incidence ($i = 40^o$), angle of refraction (r) is what we want to find, refractive index of water(**μ1=1.33), and r**efractive index of air **(μ2=1):** 1.33Sin(40) = 1 Sin(r),

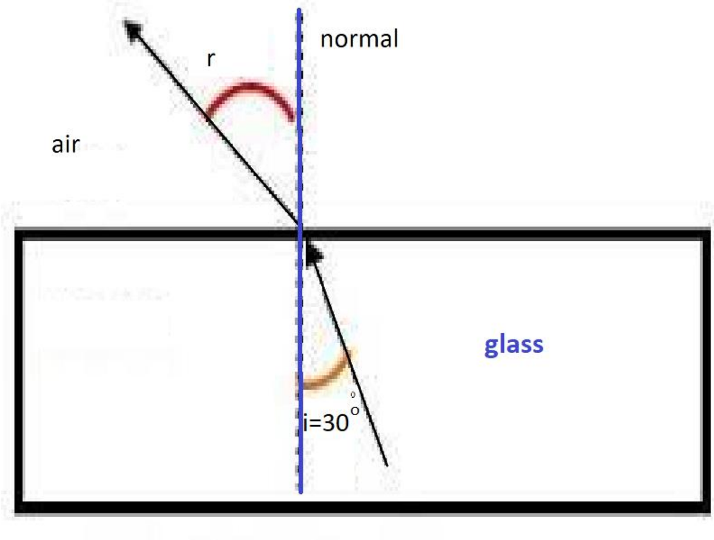
$$Sin(r) = 1.33 \times 0.6428 = 0.8549$$
$$r = Sin^{-1}(0.8549) = 59.38^o$$

So, the angle of refraction is approximately $\mathbf{59.38^o}$ when light passes from water to air with an angle of incidence of $\mathbf{40^o}$.

H.w: A ray of light is incident on a air-to-water interface. The refractive index of glass is 1.33. If the angle of incidence is $\boldsymbol{i = 40^o}$, calculate the angle of refraction (r) as the light from air enters to the water.

Problem: A ray of light is incident on a glass-to-air interface. The refractive index of glass is 1.5. If the angle of incidence is $\boldsymbol{i = 30^o}$, calculate the angle of refraction (r) as the light enters the air.

Solution: Use Snell's Law,: **µ1Sin(i) = µ2 Sin(r):**



Where: Angle of incidence (i = 30°), angle of refraction (r) is what we want to find, refractive index of water(**µ1=1.5), and r**efractive index of air **(µ2=1):**
1.5Sin(30) = 1 Sin(r),

$$\mathbf{Sin(r)=1.5\times 0.5 = 0.75}$$
$$\boldsymbol{r = Sin^{-1}(0.75) = 48.59^{\,o}}$$

So, the angle of refraction is approximately $\mathbf{48.59^{\,o}}$ when light passes from glass to air with an angle of incidence of $\mathbf{30^o}$.

H.w: A ray of light is incident on a air-to-glass interface. The refractive index of glass is 1.5. If the angle of incidence is $\boldsymbol{i = 30^o}$, calculate the angle of refraction (r) as the light from air enters to the glass.

The refractive index is sometimes referred to as optical density. A medium with a relatively high refractive index is said to have a high optical density, while one with a lower index is said to have a low optical density.

The relative refractive index **µ21** of a second medium relative to a first one is defined as the ratio of speeds of light **v1** and **v2** , in the first and second media respectively. The numerical value of refractive index is characteristic of the two medium and depend on light frequency.

$$\mu 21 = \frac{\mu 2}{\mu 1} = \frac{v1}{v2}$$

Note:The refractive index depends not only on the substance but also on the wavelength of the light. The dependence on wavelength is called dispersion.

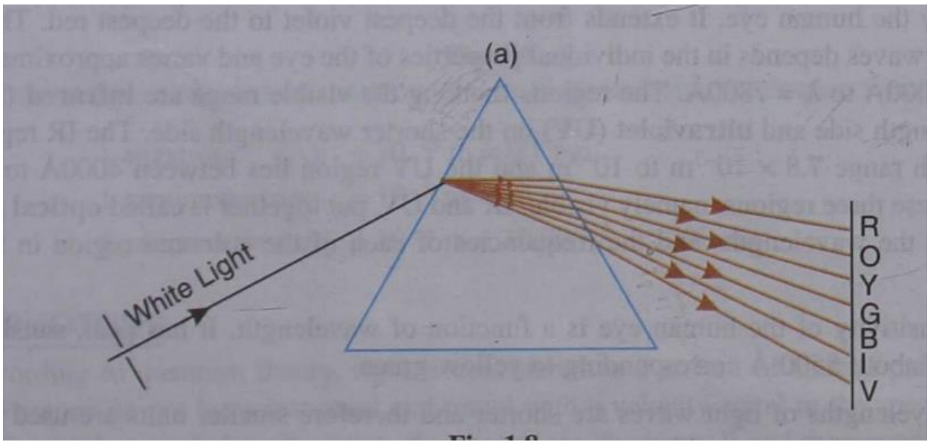


Fig: light dispersion by prism.

References

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