SECTION 6.2 – Refraction and Snell's Law

Explore Notes

Opening

When light passes from one material into another, it changes speed. This change in speed causes the light to bend. This bending of light is called refraction.

Objectives

- I can explain why light bends when it passes between materials with different optical densities
- I can use Snell's Law ($n_1 \sin\theta_1 = n_2 \sin\theta_2$) to calculate angles of refraction
- I can predict the direction light will bend based on which material it is entering
- I can describe real-world examples of refraction such as objects appearing in water or mirages

Introduction

Refraction is the bending of light when it travels from one material into another. Unlike reflection, refraction occurs as light crosses a boundary between materials.

The refractive index of a material describes how much light slows down in that material. It is defined as: $n = \frac{c}{v}$, where c is the speed of light in vacuum and v is the speed of light in the material.

The bending of light at a boundary is described by Snell's Law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

Real-World Connection

Refraction explains why objects underwater appear closer to the surface than they really are, why lenses can focus light, and how fiber optic cables transmit information.

Historical Context

Snell's Law was discovered in the early 1600s by Willebrord Snell. It remains a fundamental equation in optics and is essential for understanding lenses, microscopes, telescopes, and modern communication systems.

Vocabulary

Refraction: The bending of light when it passes from one material to another.

Refractive Index (n): A measure of how much light slows down in a material compared to vacuum, defined as $n = \frac{c}{v}$.

Optical Density: A measure of how strongly a material slows down light; materials with higher refractive index are more optically dense.

Angle of Refraction: The angle between the refracted ray and the normal.

Snell's Law: The relationship $n_1 \sin\theta_1 = n_2 \sin\theta_2$ that describes how light bends between two materials.

Core Strategies

1. Identify the Two Materials First

Before applying Snell's Law, determine which material the light is leaving (n_1) and which material it is entering (n_2).

2. Always Measure Angles from the Normal

Both the angle of incidence (θ_1) and the angle of refraction (θ_2) are measured from the normal to the boundary, not from the surface.

3. Predict the Direction Before Calculating

If light enters a material with a higher refractive index, it bends toward the normal. If it enters a material with a lower refractive index, it bends away from the normal.

4. Isolate the Sine First

When solving Snell's Law, solve algebraically for the sine of the unknown angle first, then apply the inverse sine to determine the angle.

Formulas

Refractive Index:

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

Snell's Law:

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

Example 1

Light travels through a transparent plastic where the speed of light is 2.0×10^8 m/s. Determine the refractive index of the plastic.

Example 2

Light travels from air ($n_1 = 1.00$) into water ($n_2 = 1.33$). The angle of incidence is 50°. Determine the angle of refraction.

Example 3

Light travels from glass ($n_1 = 1.50$) into air ($n_2 = 1.00$). The angle of incidence is 25°. Predict the direction of bending and determine the angle of refraction.

Example 4

A light ray travels from water ($n_1 = 1.33$) into glass ($n_2 = 1.50$). The angle of refraction in the glass is 20°. Determine the angle of incidence in the water.

Summary of Key Concepts

- Refraction is the bending of light when it passes from one material to another.
- Light changes direction because its speed changes in different materials.
- The refractive index is defined as $n = \frac{c}{v}$.
- Snell's Law relates the angles and refractive indices: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.
- When light enters a more optically dense material, it bends toward the normal.
- When light enters a less optically dense material, it bends away from the normal.
- All angles in Snell's Law are measured from the normal.

Common Mistakes

- Measuring angles from the surface instead of from the normal.
- Switching n_1 and n_2 in Snell's Law.
- Forgetting to apply the inverse sine when solving for an angle.
- Failing to predict the direction of bending before calculating.
- Assuming light always bends toward the normal.
- Using degrees and radians inconsistently on a calculator.

Practice

Vocabulary Review

1. Define refraction.

2. What is refractive index and what does it physically represent?

3. Define optical density.

4. State Snell's Law.

5. What happens to light when it enters a material with a higher refractive index?

6. What happens to light when it enters a material with a lower refractive index?

Conceptual Understanding

7. Why does light change direction when its speed changes between materials?

8. If light travels from air into diamond, how would the bending compare to air into water? Explain.

9. Why must angles in Snell's Law be measured from the normal?

10. If $n_1 = n_2$, what happens to the direction of light? Explain.

11. Why does a submerged object appear closer to the surface than it really is?

12. Predict whether light bends more between materials with large or small differences in refractive index.

Single-Step Calculations

13. Light travels through a material where the speed of light is 2.4×10^8 m/s. Determine the refractive index of the material. (Use $c = 3.0 \times 10^8$ m/s.)

14. Light travels from air ($n_1 = 1.00$) into glass ($n_2 = 1.50$). If the angle of incidence is 35°, determine the angle of refraction.

15. Light travels from water ($n_1 = 1.33$) into air ($n_2 = 1.00$). If the angle of incidence is 40°, determine the angle of refraction.

16. A light ray travels from glass ($n_1 = 1.50$) into water ($n_2 = 1.33$). The angle of refraction is 28°. Determine the angle of incidence.

17. Light enters a material with refractive index 1.80 at an angle of incidence of 25°. If the angle of refraction is 13°, determine the refractive index of the first material.

Multi-Step Problems

18. Light travels from air into water at an angle of incidence of 55°. a) Determine the angle of refraction in the water. b) Compare the size of the two angles and explain why this result makes sense.

19. A light ray travels from water into glass at an angle of incidence of 38°. a) Determine the angle of refraction in the glass. b) Does the ray bend toward or away from the normal? Explain using refractive index values.

20. A beam of light travels from air into glass at 45°, then exits from glass back into air at a different boundary. a) Determine the angle inside the glass. b) Determine the angle after exiting back into air. c) Compare the original and final angles and explain why this occurs.

Solutions

1–6 Vocabulary

1. Refraction is the bending of light when it passes from one material to another.

2. Refractive index measures how much light slows down in a material compared to vacuum. It is defined as $n = \frac{c}{v}$.

3. Optical density describes how strongly a material slows down light. A higher refractive index means greater optical density.

4. Snell's Law states: $n_1 \sin\theta_1 = n_2 \sin\theta_2$.

5. Light bends toward the normal when entering a material with a higher refractive index.

6. Light bends away from the normal when entering a material with a lower refractive index.

7–12 Conceptual

7. Light changes direction because its speed changes when entering a new material. The change in speed alters the direction of wave propagation.

8. Light bends more when the difference in refractive indices is larger. Air to diamond produces more bending than air to water because the change in optical density is greater.

9. Angles must be measured from the normal because Snell's Law relates the sine of the angle relative to the perpendicular boundary.

10. If $n_1 = n_2$, then $\sin\theta_1 = \sin\theta_2$. The direction does not change; no refraction occurs.

11. The refracted rays bend away from the normal as they leave water. Our brain traces the rays backward in straight lines, making the object appear shallower.

12. Light bends more when the difference between refractive indices is large because the speed change is greater.

13–17 Single-Step Calculations

13. $n = \frac{c}{v} = \frac{3.0\times10^8}{2.4\times10^8} = 1.25$

14. $(1.00)\sin(35^\circ) = (1.50)\sin(\theta_2)$ $\sin(\theta_2) = \frac{\sin(35^\circ)}{1.50}$ $\sin(\theta_2) = \frac{0.574}{1.50} = 0.383$ $\theta_2 = 22.5^\circ$

15. $(1.33)\sin(40^\circ) = (1.00)\sin(\theta_2)$ $\sin(\theta_2) = (1.33)(0.643) = 0.855$ $\theta_2 = 58.7^\circ$

16. $(1.50)\sin(\theta_1) = (1.33)\sin(28^\circ)$ $\sin(\theta_1) = \frac{(1.33)(0.469)}{1.50} = 0.416$ $\theta_1 = 24.6^\circ$

17. $n_1\sin(25^\circ) = (1.80)\sin(13^\circ)$ $n_1(0.423) = (1.80)(0.225)$ $n_1(0.423) = 0.405$ $n_1 = 0.958 \approx 0.96$

18–20 Multi-Step Problems

18. a) $(1.00)\sin(55^\circ) = (1.33)\sin(\theta_2)$ $\sin(\theta_2) = \frac{0.819}{1.33} = 0.616$ $\theta_2 = 38.0^\circ$ b) The angle decreases because light enters a more optically dense material.

19. a) $(1.33)\sin(38^\circ) = (1.50)\sin(\theta_2)$ $\sin(\theta_2) = \frac{(1.33)(0.616)}{1.50} = 0.546$ $\theta_2 = 33.1^\circ$ b) The ray bends toward the normal because it enters a material with higher refractive index.

20. a) $(1.00)\sin(45^\circ) = (1.50)\sin(\theta_g)$ $\sin(\theta_g) = \frac{0.707}{1.50} = 0.471$ $\theta_g = 28.1^\circ$ b) Exiting glass: $(1.50)\sin(28.1^\circ) = (1.00)\sin(\theta_{air})$ $\sin(\theta_{air}) = 0.707$ $\theta_{air} = 45^\circ$ c) The final angle equals the original angle because the ray exits into the same medium it started in.