SECTION 6.3 – Total Internal Reflection and the Critical Angle

Explore Notes

Opening

When light travels from a material with higher refractive index into a material with lower refractive index, it bends away from the normal. If the angle becomes large enough, the light will not leave the material at all.

Objectives

- I can describe the conditions required for total internal reflection.
- I can define the critical angle.
- I can calculate the critical angle using Snell's Law.
- I can determine whether total internal reflection will occur.

Introduction

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

At the critical angle, the refracted angle equals 90. Substituting into Snell's Law gives: $\sin\theta_c = \frac{n_2}{n_1}$.

If the angle of incidence is greater than the critical angle, light reflects completely inside the material. This is called total internal reflection.

Vocabulary

Critical Angle: The angle of incidence that produces a refracted angle of 90.

Total Internal Reflection: The complete reflection of light inside a material when the angle of incidence exceeds the critical angle.

Core Strategies

1. Check the Direction of Travel

Total internal reflection only occurs when light travels from a higher refractive index to a lower refractive index.

2. Identify the Critical Angle Condition

The critical angle occurs when the refracted angle equals 90. This means the refracted ray travels along the boundary.

3. Compare the Incident Angle to the Critical Angle

If the angle of incidence is less than the critical angle, refraction occurs. If it equals the critical angle, the refracted ray travels along the boundary. If it is greater than the critical angle, total internal reflection occurs.

4. Use Snell's Law Carefully

Begin with $n_1 \sin\theta_1 = n_2 \sin\theta_2$, then substitute 90 for the refracted angle when solving for the critical angle.

Formulas

Snell's Law:

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

Critical Angle Equation:

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

Example 1

Light travels from glass ($n_1 = 1.50$) into air ($n_2 = 1.00$). Determine the critical angle.

Example 2

Light travels from water ($n_1 = 1.33$) into air ($n_2 = 1.00$). The angle of incidence is 60. Determine whether total internal reflection occurs.

Example 3

A light ray travels from a material with refractive index 1.80 into air. Determine the smallest angle of incidence that will produce total internal reflection.

Example 4

A beam of light travels from glass into air at an angle of 50. If the critical angle for this interface is 42, describe what happens to the ray.

Summary of Key Concepts

- Total internal reflection occurs when light travels from a higher refractive index to a lower refractive index.
- The critical angle is the angle of incidence that produces a refracted angle of 90.
- The critical angle equation is $\sin\theta_c = \frac{n_2}{n_1}$.
- If the angle of incidence is greater than the critical angle, no refraction occurs.
- Snell's Law must be used to calculate the critical angle.
- All angles are measured from the normal.

Common Mistakes

- Attempting to calculate a critical angle when light travels from lower index to higher index.
- Switching n_1 and n_2 in the critical angle equation.
- Forgetting that total internal reflection only occurs when $n_1 > n_2$.
- Using degrees and radians inconsistently on a calculator.
- Measuring angles from the surface instead of the normal.
- Assuming light always refracts instead of checking for total internal reflection.

Practice

Vocabulary Review

1. Define the critical angle.

2. Define total internal reflection.

3. Under what condition can total internal reflection occur?

4. State the equation used to calculate the critical angle.

5. What happens when the angle of incidence equals the critical angle?

6. Why does total internal reflection not occur when light travels from air into glass?

Conceptual Understanding

7. Explain why total internal reflection only occurs when light travels from a higher refractive index to a lower refractive index.

8. If the critical angle for a material is 40, what happens when the angle of incidence is 30? Explain.

9. What happens when the angle of incidence is exactly equal to the critical angle?

10. Why does increasing refractive index difference affect the size of the critical angle?

11. Why do diamonds sparkle strongly compared to glass?

12. Describe how fiber optic cables use total internal reflection.

Single-Step Calculations

13. Light travels from glass ($n_1 = 1.50$) into air ($n_2 = 1.00$). Determine the critical angle.

14. A material has a refractive index of 1.70. Light exits into air. Determine the critical angle.

15. The critical angle for a certain material in air is 42. Determine the refractive index of the material.

16. Light travels from water ($n_1 = 1.33$) into air. If the angle of incidence is 48, determine whether total internal reflection occurs.

17. A material has a refractive index of 2.00. Light exits into a medium with refractive index 1.20. Determine the critical angle.

Multi-Step Problems

18. Light travels from glass ($n_1 = 1.50$) into air. a) Calculate the critical angle. b) If the angle of incidence is 50, determine what happens to the ray.

19. A beam of light travels from a material with refractive index 1.80 into water ($n_2 = 1.33$). a) Calculate the critical angle. b) If the angle of incidence is 40, determine whether total internal reflection occurs.

20. A fiber optic cable has a core with refractive index 1.60 and cladding with refractive index 1.40. a) Calculate the critical angle at the core boundary. b) Explain how this allows light to remain trapped inside the fiber.

Solutions

1–6 Vocabulary

1. The critical angle is the angle of incidence that produces a refracted angle of 90.

2. Total internal reflection is the complete reflection of light inside a material when the angle of incidence exceeds the critical angle.

3. Total internal reflection occurs only when light travels from a higher refractive index to a lower refractive index and the angle of incidence exceeds the critical angle.

4. The equation for the critical angle is $\sin\theta_c = \frac{n_2}{n_1}$.

5. When the angle equals the critical angle, the refracted ray travels along the boundary.

6. Total internal reflection does not occur from air into glass because light is entering a material with higher refractive index.

7–12 Conceptual

7. Total internal reflection only occurs when light travels from a higher refractive index to a lower refractive index because only then can the refracted angle reach 90.

8. If the angle of incidence is less than the critical angle, refraction occurs and the ray exits the material.

9. If the angle equals the critical angle, the refracted ray travels along the boundary at 90.

10. A larger difference in refractive indices changes the value of the critical angle. A higher refractive index in the first material produces a smaller critical angle.

11. Diamonds have a very high refractive index, producing a small critical angle. Light undergoes many internal reflections, creating strong sparkle.

12. Fiber optic cables trap light inside the core because the angle of incidence remains greater than the critical angle at the boundary.

13–17 Single-Step Calculations

13. $\sin\theta_c = \frac{1.00}{1.50} = 0.667\ \theta_c = 41.8$

14. $\sin\theta_c = \frac{1.00}{1.70} = 0.588\ \theta_c = 36.0$

15. $\sin 42 = \frac{1.00}{n_1}\ 0.669 = \frac{1.00}{n_1}\ n_1 = 1.49$

16. $\sin\theta_c = \frac{1.00}{1.33} = 0.752\ \theta_c = 48.8$ Since 48 is slightly less than 48.8, total internal reflection does not occur.

17. $\sin\theta_c = \frac{1.20}{2.00} = 0.600\ \theta_c = 36.9$

18–20 Multi-Step Problems

18. a) $\sin\theta_c = \frac{1.00}{1.50} = 0.667\ \theta_c = 41.8$ b) Since 50 is greater than 41.8, total internal reflection occurs.

19. a) $\sin\theta_c = \frac{1.33}{1.80} = 0.739\ \theta_c = 47.6$ b) Since 40 is less than 47.6, total internal reflection does not occur.

20. a) $\sin\theta_c = \frac{1.40}{1.60} = 0.875\ \theta_c = 61.0$ b) Light remains trapped because rays inside the core strike the boundary at angles greater than 61, producing total internal reflection.