PHYSICS 534

ANSWERS

EX SE-50 Law of Refraction Part-1 /2

Edward Appleton received the Nobel prize for physics in 1947 for his work on the ionosphere (known today as the Appleton layer).

APPLETON

- **INDEX OF REFRACTION**

The optical density of a transparent medium (material) is an ***inverse*** measure of the speed of light through the medium. The more optically dense a transparent medium is, the slower the speed of light travels in that medium.

↳ ***Reminder***: The speed of light in a vacuum is 3×10^8 m/s. The speed of light in air is very close to the speed of light in a vacuum. In this course, we assume the speed of light in air is "c" or 3×10^8 m/s.

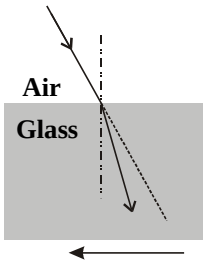
Refraction is the bending of light rays as they pass from one medium into another medium of different optical density. The ***index of refraction*** of a transparent medium is a **ratio** of the speed of light in a vacuum (air) to the speed of light in the medium:

$$n = c/v$$

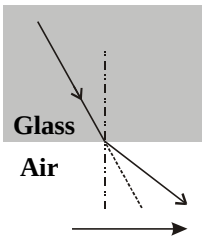
where n = is the index of refraction (no units)
$c = 3 \times 10^8$ m/s
v = speed of light in the medium (in m/s)

↳ ***Note***: The greater the index of refraction of a medium, the slower light travels in that medium. The index of refraction for a vacuum is one (1), for water it is 1.33, for diamond it is 2.42, etc.

When refraction occurs, light bends ***away*** from the normal when the optical density (index of refraction) is ***less*** dense (and vice versa). The following illustration demonstrates this fact:



Refracted ray bends towards normal.



Refracted ray bends away from normal.

- **SNELL'S LAW**

Snell's Law describes the relationship between the angle of incidence and the angle of refraction when refraction occurs. Mathematically, Snells's Law is written as:

$$n_1 \sin i^o = n_2 \sin r^o$$

where n_1 = index of refraction of medium-one (medium of incident ray)

n_2 = index of refraction of medium-two (medium of refracted ray)

i^o = angle of incidence

r^o = angle of refraction

1. Define ***refraction*** and explain how it differs from reflection.

Reflection is the bending of light with the incident ray and the reflected ray being in the same medium (there is only one medium). Refraction is the bending of light as it passes from one medium into another medium (there are two mediums).

2. Define what is meant by the ***optical density*** of a medium.

The optical density of a medium refers to the speed of light in that medium. The greater the index of reaction of a medium, the slower light travels in that medium.

3. Does the speed of light ***increase*** or ***decrease*** as the optical density of a medium ***increases***?

Decrease

4. Explain what is meant by the ***index of refraction*** of a medium.

The index of refraction (n) of a medium is the ratio of the speed of light in that medium to the speed of light in a vacuum (3×10^8 m/s). The greater the index of refraction of a medium, the slower light travels in that medium. Note that the index of refraction has no units.

5. State Snell's Law.

$$n_1 \sin i = n_2 \sin r$$

6. What is the purpose of Snell's Law?

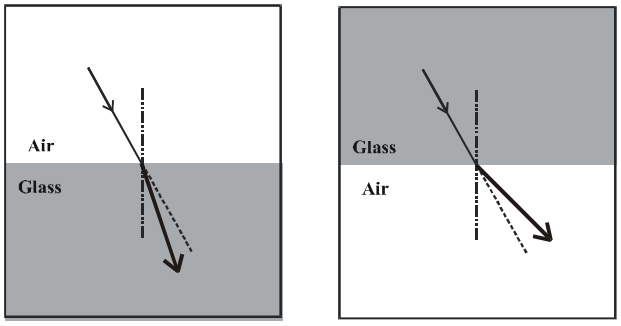
The purpose of Snell's Law is to calculate the angle of refraction given the angle of incidence. Or, conversely, to calculate the angle of incidence given the angle of refraction.

7. The speed of light in a plexiglas is 2.1 x 10^8 m/s. Calculate the index of refraction for this plexiglas. [1.43]

$$n = \frac{c}{v_n} = \frac{3\times10^8\ m/s}{2.1\times10^8\ m/s} = 1.428 = 1.43$$

8. The diagrams below illustrate a ray of light traveling from one medium to another. In the first case, light travels from a lesser to a greater density medium (air to glass). In the second case, light travels from a denser to a less dense medium (glass to air).

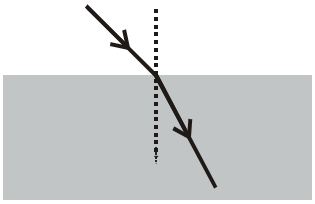
Draw the refracted ray for each case.



9. A ray of light enters a transparent material at an angle of incidence of 45°. If the angle of refraction is 28°, what is the index of refraction of the substance? [1.5]
Draw the refracted ray.

$$n_1 \text{Sin } i = n_2 \text{Sin } r$$

$$\therefore \quad n_2 = \frac{n_1 \text{Sin } i}{\text{Sin } r} = \frac{(1)(\text{Sin } 45^o)}{\text{Sin } 28^o} = 1.5$$



10. Knowing that the index of refraction for diamond is 2.42, calculate the speed of light in diamond. [1.2 x 10^8 m/s]

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

$$\therefore \quad v_n = \frac{c}{n} = \frac{3\times10^8\ m/s}{2.42} = 1.2\times10^8\ m/s$$

11. A ray of light enters water at an angle of incidence of 30^o. The angle of refraction is found to be 22^o. Calculate the index of refraction for water. [1.33]

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \; n_2 = \frac{n_1 \text{ Sin } i}{\text{Sin}_r} = \frac{(1)(\text{Sin } 30^o)}{\text{Sin } 22^o} = 1.33$$

12. In traveling from air into water, a ray of light makes an angle of incidence of 52^o. Calculate the angle of refraction. [36^o]

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \; \text{Sin } r = \frac{n_1 \text{ Sin } i}{n_2} = \frac{(1)(\text{Sin } 52^o)}{1.33} = 0.5924 \qquad \therefore \; r = 36.3^o = 36^o$$

From previous problem

13. In traveling from water into air, a ray of light makes an angle of refraction of 59^o. Calculate the angle of incidence. [40^o]

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \; \text{Sin } i = \frac{n_2 \text{ Sin } r}{n_1} = \frac{(1)(\text{Sin } 59^o)}{1.33} = 0.6444 \qquad \therefore \; i = 40.1^o = 40^o$$

14. A ray of light emerges from water into air with an angle of incidence of 22^o. What is the angle of refraction? [30^o]

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \; \text{Sin } r = \frac{n_1 \text{ Sin } i}{n_2} = \frac{(1.33)(\text{Sin } 22^o)}{1} = 0.4982 \qquad \therefore \; r = 29.8^o = 30^o$$

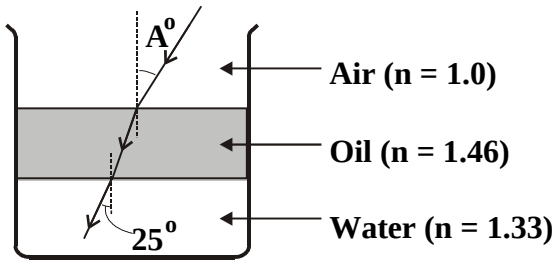
15. The index of refraction of flint glass is 1.63. Find the angle of incidence for a ray of light entering flint glass from air such that the angle of refraction is 35^o. $[69^o]$

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \text{ Sin } i = \frac{n_2 \text{ Sin } r}{n_1} = \frac{(1.63)(\text{Sin } 53^o)}{1} = 0.9349 \qquad \therefore \ i = 69.2^o = 69^o$$

16. A light ray passes through two liquids, one floating on top of the other, in a beaker. The angle of refraction in the water is 25^o.

Determine the angle of incidence (A^o). $[34^o]$



Oil – Water

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \text{ Sin } i = \frac{n_2 \text{ Sin } r}{n_1} = \frac{(1.33)(\text{Sin } 25^o)}{1.46} = 0.3849 \qquad \therefore \ i = 22.6^o$$

Water – Oil

$$n_1 \text{ Sin } i = n_2 \text{ Sin } r$$

$$\therefore \text{ Sin } i = \frac{n_2 \text{ Sin } r}{n_1} = \frac{(1.46)(\text{Sin } 22.6^o)}{1} = 0.5610 \qquad \therefore \ i = 34.1^o = 34^o$$

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