PhyzExamples: Unfinished Refractions

Physical Quantities • Symbols • Units • Brief Definitions

Wavelength • λ • meter: m • Light wavelength is the distance between successive electric field maxima or minima or magnetic field maxima or minima.
Frequency • *f* or ν *(nu)* • hertz: Hz • The rate at which a source emits light waves or an observer receives light waves.
Speed • *v* • meters per second: m/s • The rate at which a light wave propagates through a transparent material.
Speed of Light in a Vacuum • $c = 3.0\text{x}10^8$m/s
Index of Refraction • *n* • unitless • The ratio of the speed of light in a vacuum to the speed of light in a transparent material.
Angle of Incidence • θ_i • degrees: ° • The angle between an incident ray of light and the normal line from the point of incidence.
Angle of Refraction • θ_r • degrees: ° • The angle between a normal line from the point of incidence and a refracted ray of light.
Critical Angle • θ_c • degrees: ° • The angle of incidence for a beam of light passing from a denser material to a lighter material such that the angle of refraction is 90°.

Equations

$c = f\lambda$ • *speed of light = frequency · wavelength*
$n = c/v$ • *index of refraction of a material = speed of light in vacuum / speed of light in the material*
$n_2/n_1 = v_1/v_2$ • *index of refraction of a second material / index of refraction of a first material = speed of light in first material / speed of light in second material* • $n = v_1/v_2$ (if first medium is air)
$n_2/n_1 = \sin\theta_i/\sin\theta_r$ • *index of refraction of a second material / index of refraction of a first material = sine of the angle of incidence / sine of the angle of refraction* • $n = \sin\theta_i/\sin\theta_r$ (if first medium is air)
$n_2/n_1 = \lambda_1/\lambda_2$ • *index of refraction of a second material / index of refraction of a first material = wavelength of light in first material / wavelength of light in second material* • $n = \lambda_1/\lambda_2$ (if first medium is air)
$\theta_c = \text{Sin}^{-1}(n_2/n_1)$ • *critical angle for light passing from a denser to a lighter material = arcsine of (index of refraction of second, optically less dense material / index of refraction offirst, optically dense material)* • $\theta_c = \text{Sin}^{-1}(1/n)$ (if *second* medium is air)

Smooth Operations Examples

1. A beam of light enters a transparent medium at an angle of incidence of 45° and continues in the medium with an angle of refraction of 30°. What is the index of refraction of the medium?

1. $\theta_i = 45°$ $\theta_r = 30°$ $n = ?$
$n = \sin\theta_i/\sin\theta_r$
$n = \sin 45° / \sin 30°$
$n = 1.41$

2. What is the index of refraction of a material whose critical angle (in air) is 60°?

5. $\theta_c = 60°$ $n_1 = ?$
$\theta_c = \sin^{-1}(1/n)$ => $\sin\theta_c = 1/n_1$
$n_1 = 1 / \sin\theta_c$
$n_1 = 1 / \sin 60°$
$n_1 = 1.15$

3. What is the critical angle for glass (n = 1.52) immersed in water (n = 1.33)?

6. $n_1 = 1.52$ $n_2 = 1.33$ $\theta_c = ?$
$\theta_c = \sin^{-1}(n_2/n_1)$
$\theta_c = \sin^{-1}(1.33 / 1.52)$
$\theta_c = 61°$

Welcome to the Real World Example

4. A beam of light from a tunable laser has a frequency of 625 THz. It approaches a two-layer transparent composite at an angle of incidence of 60°. In the top layer, the light propagates with a speed of 1.15×10^8 m/s. In the bottom layer, the wavelength of the light is 267 nm.

a. What is the wavelength of the light in air?

$c = f\lambda$ $\lambda = c/f$
$\lambda = 3 \times 10^8 \text{ m/s} / 625 \times 10^{12} \text{ Hz} = 4.8 \times 10^{-7} \text{ m} = 480 \text{ nm} = \lambda$

b. What is the index of refraction of the top layer?

$n = c/v$
$n = 3 \times 10^8 \text{ m/s} / 1.15 \times 10^8 \text{ m/s} = 2.61 = n$

c. What is the angle of refraction as the beam passes from the air to the top layer?

$n = \sin\theta_i/\sin\theta_r$ $\sin\theta_r = \sin\theta_i/n$ $\theta_r = \sin^{-1}(\sin\theta_i/n)$
$\theta_r = \sin^{-1}(\sin 60° / 2.61) = 19° = \theta_r$

d. What is the index of refraction of the material in the bottom layer?

$n = \lambda_1/\lambda_2$
$n = 480 \times 10^{-9} \text{ m} / 267 \times 10^{-9} \text{ m} = 1.79 = n$

e. What is the angle of refraction in the bottom layer?

$n_2/n_1 = \sin\theta_i/\sin\theta_r$ $\sin\theta_r = n_1\sin\theta_i/n_2$ $\theta_r = \sin^{-1}(n_1\sin\theta_i/n_2)$
$\theta_r = \sin^{-1}(2.61 \cdot \sin 19° / 1.79) = 29° = \theta_r$

f. Sketch the path that light takes through the two layers of transparent material.