Chapter 2 Summary

Index of Refraction
Dispersion
Reflection at a Plane Surface
Law of Reflection
Snell's Law
Law of Refraction
Critical Angle & Total Internal Reflection
Fermat's Principle
Refraction through Parallel Sided Surfaces
Apparent Position
Multiple Parallel Sided Surfaces

Index of Refraction

The index of refraction for a given medium is determined by the velocity of light in air divided by the velocity of light in the medium.

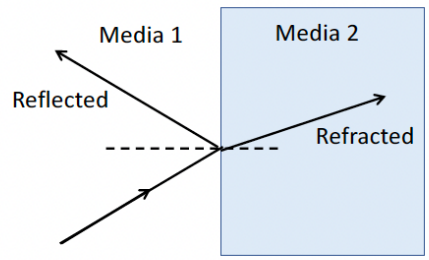
$$n = \frac{3x10^8\ {}^{m}/_{s}}{V_{media}}$$

n is always greater than or equal to 1
There are no units for n
As the index increases, the velocity of light through the medium decreases
The index of refraction for spectacle lenses ranges from 1.49 to about 1.70

Dispersion

Dispersion is an indicator of the optical quality of a material.
Dispersion is related to chromatic aberration.
Dispersion occurs because the index of refraction varies with wavelength.

The Interface between 2 media



(from Dr Loshin's course notes)

Reflection at a Plane Surface

The Law of Reflection

The angle of reflection is equal to the angle of incidence.

Factors that determine the amount of light reflected

Color
Nature of Surface
Refractive Index
Angle of Incidence (for diffuse reflection)

Fresnel's Law of Reflection

Used to determine the percent of incident light that is reflected by a material:

$$\%Reflected = \left(\frac{\{n' - n\}}{\{n' + n\}}\right)^2 x100$$

n is index of air
n' is index of material

Note that the higher the index of the material, the greater the percentage of light that is reflected.
High index spectacle lenses require anti-reflected coatings.

Snell's Law

Snell's Law quantifies the refraction that occurs at a surface.

$$n sin\theta = n' sin\theta'$$

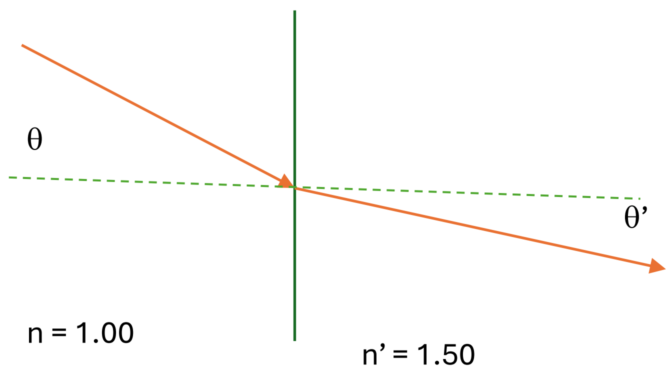
Where:

n = index of the primary (first) medium

n' = index of the secondary (second medium)

θ = angle of incidence (with respect to the normal)

θ' = angle of refraction (with respect to the normal)



Note that the ray of light is refracted toward the normal when traveling from a rarer medium (lower index) to a denser medium (higher index).

When light travels from a denser medium to a rarer medium (higher index to lower index) the opposite occurs – the ray is refracted away from the normal (angle of refraction is greater than angle of incidence).

If the angle of incidence is 30° then the angle of refraction is 19.5°

$$n sin(30) = n' \sin(\theta')$$

$$\theta = 19.5°$$

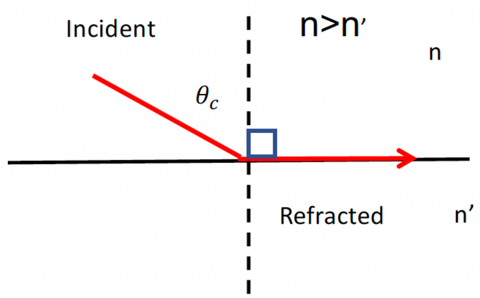
Critical Angle

There is an angle of incidence where incident light is refracted parallel to the normal (angle of refraction is 90 degrees).

This angle of incidence is easily determined because sin(90) = 1.

$$nsin(\theta) = n' \sin(\theta')$$

$$sin\theta c = \frac{\mathrm{n}'}{\mathrm{n}}$$



(from Dr Loshin's course notes)

Total Internal Reflection

When light travels from a higher index medium to a lower index medium and the angle of incidence is increased, and angle of incidence (known as the Critical Angle) is reached where all light is reflected internally. This is known as Total Internal Reflection.

This is the principle used in the design of fiber optic cables.

Fermat's Principle

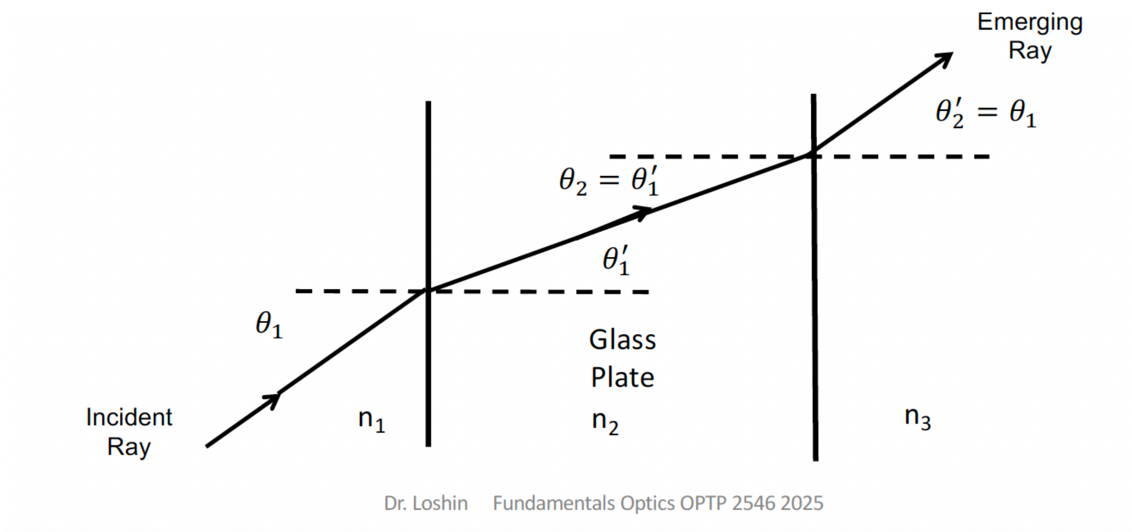
Fermat's Principle of Least Time states that the actual path travelled by light going from one point to another is that which, under the given conditions, requires the least time.

Sometimes, when the optical surface is curved, the time may be a maximum rather than a minimum, but it is always one or the other.

The time to travel in a medium can be calculated using the index of refraction:

$$t = \frac{nd}{c} = \frac{(c/v)d}{c} = \frac{cd}{cv} = \frac{d}{v}$$

Refraction Through Parallel Sided Surfaces

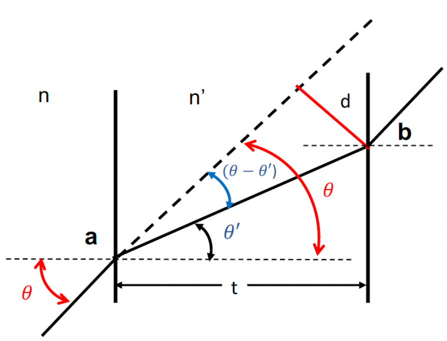


$\theta_2 = \theta_1{}'$

$\theta_1 = \theta_2{}'$

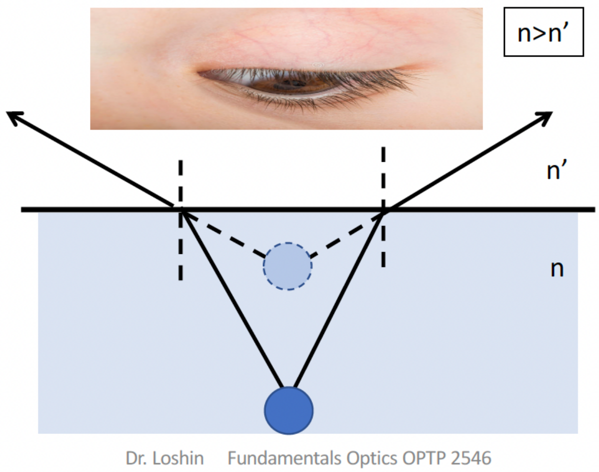
Apparent Position

Lateral Displacement: the perpendicular distance between an incident and emerging ray after traveling through a parallel sided interface.



(from Dr Loshin's course notes)

$$d = \left\{\frac{t}{cos\theta_1'}\right\} \sin(\theta_1 - \theta_1')$$



$$\frac{n}{l} = \frac{n'}{l'}$$

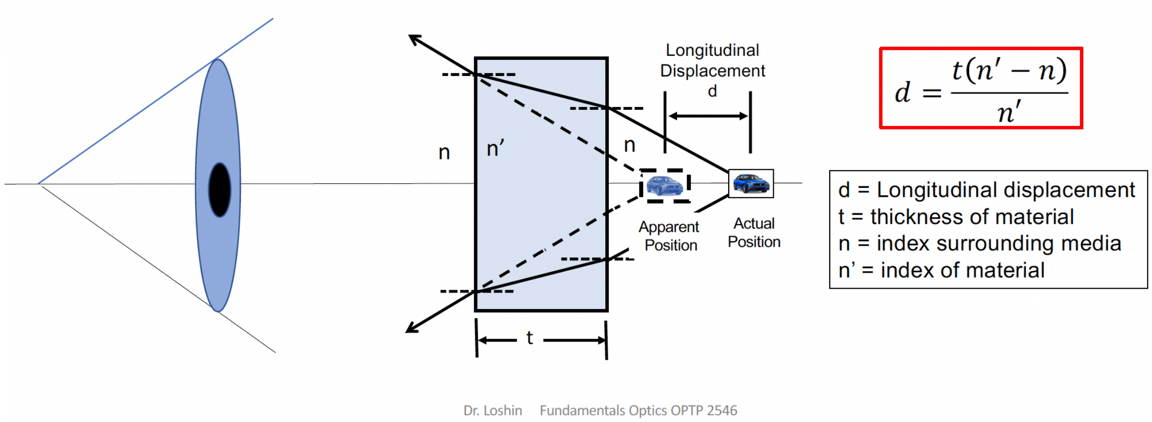
Where:

n = index of object space
n’ = index of image space
l = object distance (distance from surface)
l’ = image distance (apparent distance from surface)

When objects in a higher index medium are viewed from a lower index medium, they appear closer to the surface than they really are.

Apparent Longitudinal Displacement

The apparent position of an object viewed normally through parallel-sided surfaces



Apparent Position: Multiple Parallel Sided Surfaces

Reduced Distance (rd) – thickness of a parallel sided plate or the path a ray travels divided by the index.

$$rd = \frac{t}{n} = \frac{\ell}{n}$$

The apparent position of an object viewed through multiple parallel sided interfaces may be calculated by adding the reduce distances for each interface.

The relative position is relative to the last surface interface.

$$\frac{\ell'}{n'} = \sum_{i=1}^{m} \left\{\frac{\ell_i}{n_i}\right\} = \frac{\ell_1}{n_1} + \frac{\ell_2}{n_2} + \frac{\ell_3}{n_3} + \cdots \frac{\ell_m}{n_m}$$

$\ell' = apparent\ position\ relative\ to\ the\ last\ surface$

$n' = index\ from\ which\ object\ is\ viewed$

(from Dr Loshin's course notes)

Chapter 2 Additional Problems

Problem Types

Percent of incident light reflected at a surface
Refraction at a plane surface
Critical Angle
Apparent Position

Percent of incident light reflected at a surface

Remember

$$\%Reflected = \left(\frac{\{n' - n\}}{\{n' + n\}}\right)^2 x100$$

1. What percentage of light incident normally on a lens surface with an index of 1.49 is reflected back into the air?

2. Which lens material will reflect the most incident light (incident normal to surface)?

   A. CR39 (n=1.49)
   B. Trivex (n=1.53)
   C. Polycarbonate (n=1.586)

Refraction at a plane surface

Remember

Snell's Law :

$$nsin\theta = n'sin\theta'$$

1. What is the angle of refraction of a light ray with an angle incidence of 40 degrees incident on a plane surface with an index of 1.53?

2. After refraction at a plane surface a light ray has an angle of 20 degrees. If the angle of incidence is 30.6 degrees, what is the index of the lens material?

Critical Angle

Remember

$$\sin\theta c = \frac{\mathrm{n}'}{\mathrm{n}}$$

The critical angle is the angle of incidence where the angle of refraction is 90 degrees. Total internal reflection requires light to travel from a denser material (higher index of refraction) to a less dense material (lower index of refraction).

1. What is the critical angle of crown glass (n = 1.523) in air?

2. The critical angle at the interface between two optical media is 35 degrees. If light travels in the second medium at a velocity of 2.75 x 10^8 m/s. What is the index of the first medium?

Apparent Position

Remember

$$\frac{n}{l} = \frac{n'}{l'}$$

n = index of object space
n' = index of image space
l = object distance (distance from surface)
l' = image distance (apparent distance from surface)

When objects in a higher index medium are viewed from a lower index medium, they appear closer to the surface than they really are.

1. A coin placed on the bottom of a pool that is 4m deep appears from above the surface to be 3m below the surface. What is the index of the liquid in the pool?

2. A postage stamp is covered by a plate of glass that is 3cm thick. If viewed from above what is the apparent position of the stamp if the index of the glass is 1.60?