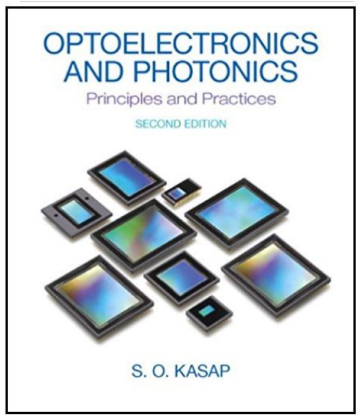
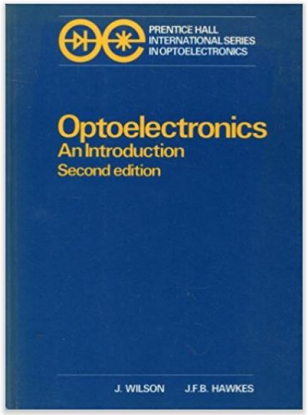
Optoelectronics-I

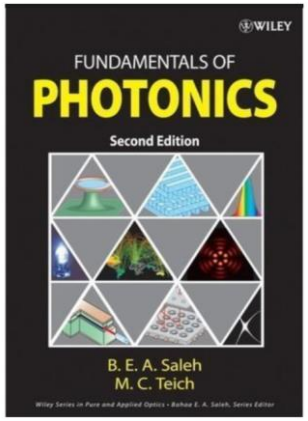
Assoc. Prof. Dr. Isa NAVRUZ

Lecture Notes - 2018

Recommended books







Department of Electrical and Electronics Enginnering, Ankara University
Golbasi, ANKARA

Fundamentals of Optics

Objectives

When you finish this lesson you will be able to:

- ✓ Define some properties of light: Speed, Frequency, Refractive index, Wavelength, Energy
- ✓ Describe the dual nature of light
- ✓ Describe the ray optics
- ✓ Describe the postulates of ray optics
  Describe the optical path length and Fermat”s Principles
- ✓ Describe Light Propagation in Homogeneous Medium
- ✓ Define the reflection and refraction
- ✓ Define the Snell”s Law

Fundamentals of Optics

What is light?

This question has been discussed for many centuries.

- ✓ The sun radiates light, and the light bulbs illuminate the darkness. Many other uses of light impact our lives daily.

- ✓ The first experiments conducted on the light showed that it propagates like a straight line. So the ***ray optics*** came out.

The speed of light in a vacuum is expressed as $c = 2.99 \times 10^8$ **m/s**.

Fundamentals of Optics

What is light?

- ✓ The light travels in a vacuum at a constant speed of about 300.000 km\s. However its speed changes in non-vacuum media. For example, its speed slower 0.03% in the air and about 30% in the glass than in the vacuum media.

- ✓ The speed of light in any medium is closely related to the refractive index of that medium.

Velocity of light in the medium

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

Velocity of light in the vacuum

Refractive index of medium

- ✓ Refractive index does not have any unit.

Fundamentals of Optics

Refractive index for various material

Media	Index of Refraction
Vacuum	1.00
Air	1.0003
Carbon dioxide gas	1.0005
Ice	1.31
Pure water	1.33
Ethyl alcohol	1.36
Quartz	1.46
Vegetable oil	1.47
Olive oil	1.48
Acrylic	1.49
Table salt	1.51
Glass	1.52
Diamond	2.42
Gallium phosphide	3.50

Fundamentals of Optics

Exercise:

1. **The speed of light a material is 2.5×10^8 m/s. Find the refractive index of materials.**

2. **The refractive index of crown glass is 1.4. Find the speed of light in crown glass.**

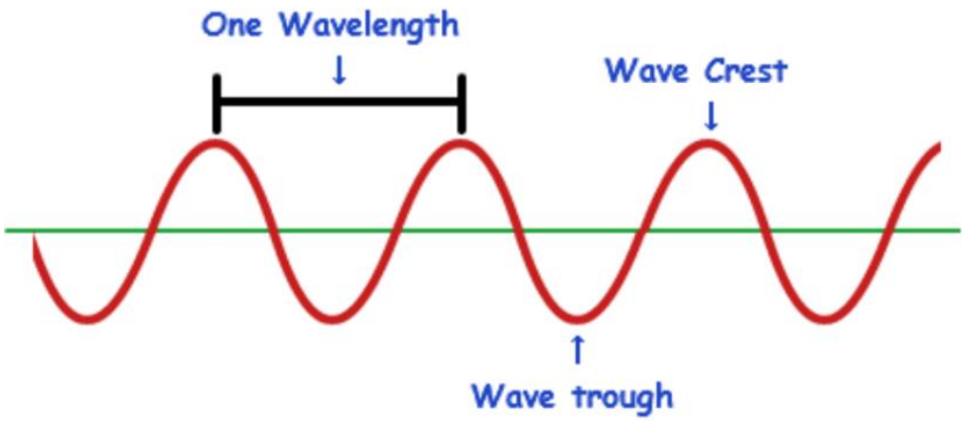
3. **Find the speed of light in a water of refractive index 4/3.**

Fundamentals of Optics

What is light?

wavelength

- ✓ Another important parameter of light is its wavelength.
- ✓ The wavelength behaviour of light will be examined in the next section. For now, it is enough to know that the wavelength is a characteristic feature of light.
- ✓ The wavelength in the visible spectrum allows us to see the colors of the light.



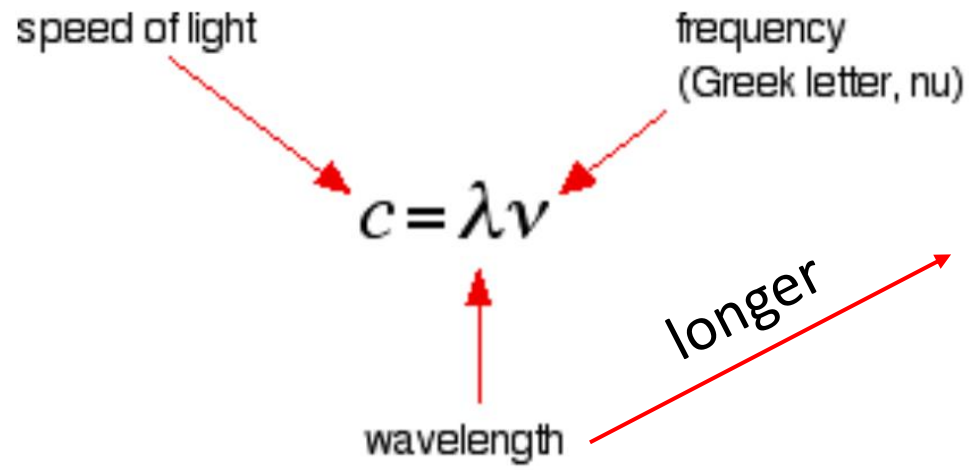
This is spatial domain, not time domain!!!

Color	Wavelength
violet	380–450 nm
blue	450–495 nm
green	495–570 nm
yellow	570–590 nm
orange	590–620 nm
red	620–750 nm

Fundamentals of Optics

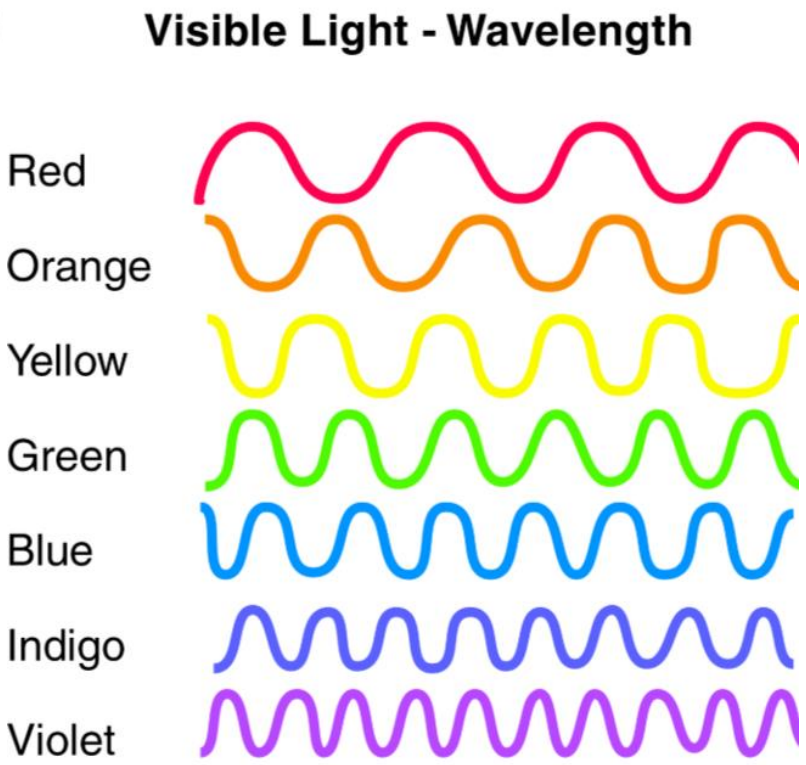
What is light?

Wavelength & frequency



C: constant

$\lambda \uparrow \quad \nu \downarrow$



If the wavelength of light increases in a homogeneous medium, its frequency decreases.

Fundamentals of Optics

Dual nature of light

Energy

- ✓ The light carries energy while traveling and this energy is an measurable optical characteristic.

- ✓ Scientists have observed that light energy can behave like a wave as it moves through space, or it can behave like a discrete particle with a discrete amount of energy (quantum) that can be absorbed and emitted.

Concept of a photon

- ✓ The particle-like nature of light is modeled with photons.
- ✓ A photon has no mass and no charge.
- ✓ Photons can interact with other discrete particles (e.g., electrons, atoms, and molecules).

Fundamentals of Optics

Dual nature of light

Energy

$$\text{Photon energy } (E) = hc/\lambda = h\nu$$

where E is in joules

h = Planck's constant = $6.625\ 10^{-34}$ J•s

c = Speed of light = 2.998×10^{8} m/s for free space or vacuum

λ = Wavelength of the light in meters

Exercise:

Blue light have a wavelength of 500 nm. What is the energy of photons in this light.

Fundamentals of Optics

Ray Optics

- ✓ When light waves propagate through and around objects whose dimensions are much greater than the wavelength, the behaviour of light can be adequately described by rays obeying a set of geometrical rules. This model of light is called ray optics.

- ✓ Ray optics is the simplest theory of light. Light is described by rays that travel in different optical media in accordance with a set of geometrical rules.

- ✓ Ray optics is therefore also called geometrical optics.

- ✓ The ray optics cannot fully explain the behaviour of optical light, but it can adequately describe many phenomena such as reflection, refraction, focusing of light.

Fundamentals of Optics

Postulates of Ray Optics

There is a set of postulates related to the simple rules of light rays that traveling through optical media.

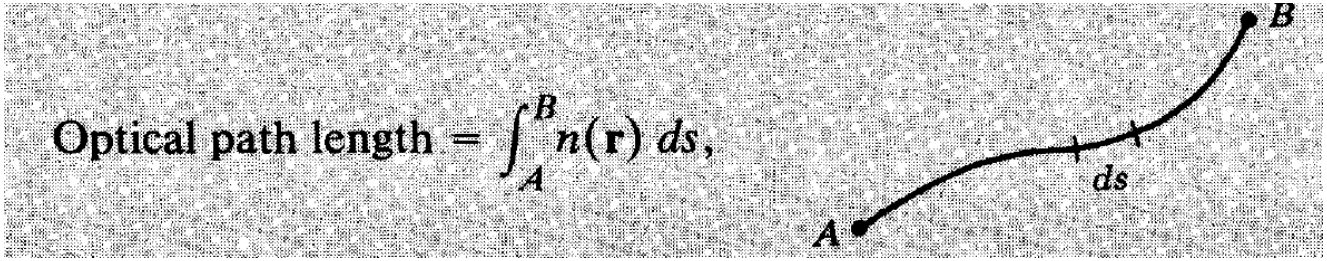
✓ The light travels in the form of rays. The rays are emitted by the light sources and they reach an optical detector.

✓ The time taken by light to travel a distance d equals to $d/c=nd/c_0$.

The term of ***nd*** is known as ***optical path length***.

Here, $\mathbf{c}$ and $\mathbf{c_0}$ are the speeds of the light in the medium and free space, respectively.

✓ In an inhomogenous medium, if the refractive index ***n(r)*** is a function of the position r(x,y,z)

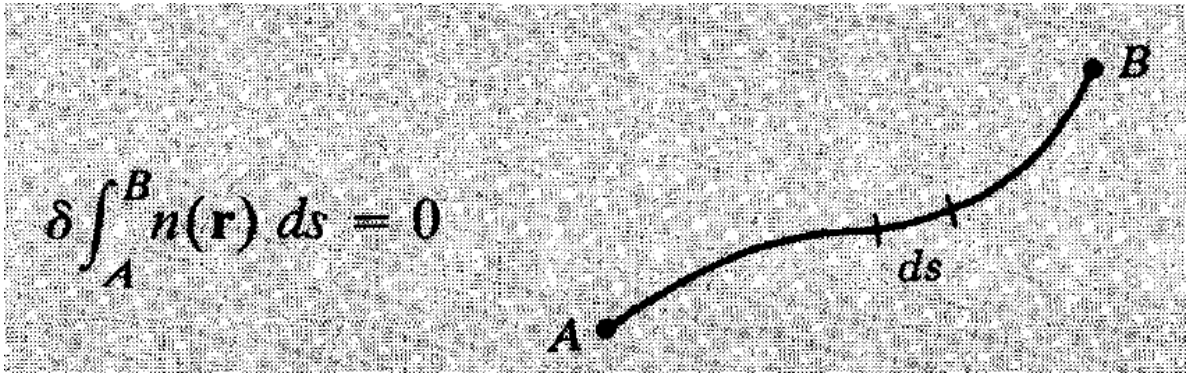


Fundamentals of Optics

Postulates of Ray Optics

✓ Fermat's principles:

Optical rays traveling between two points, A and B, follow path such that the time of travel between the two points is an extremum relative to neighbor paths.

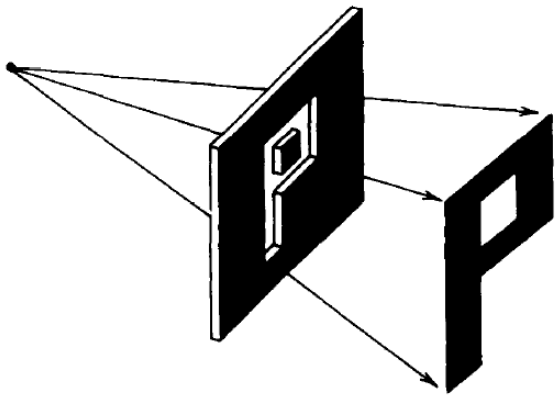


light rays travel along the path of least time

Fundamentals of Optics

Light Propagation in Homogeneous Medium

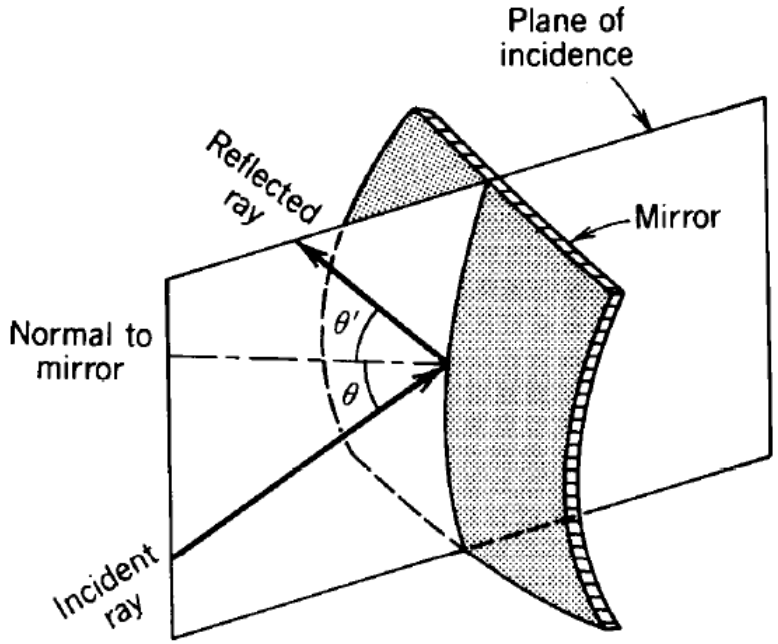
- ✓ In a homogeneous medium the refractive index is the same everywhere
- ✓ The path of minimum distance between two points is a straight line so that in a homogeneous medium light travel in straight lines



Shadows are evidence of the light travelling in the straight lines.

Fundamentals of Optics

Light Propagation in Homogeneous Medium

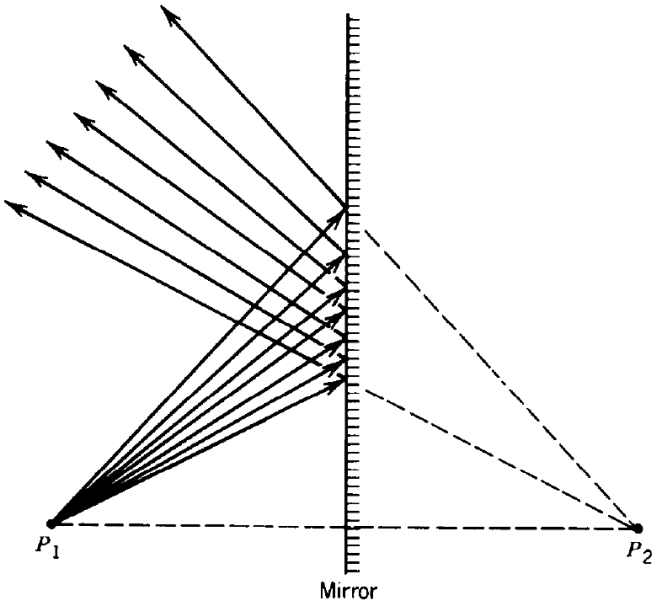


Reflection from the surface of a curved mirror.

Reflection from the mirror

- ✓ The reflected ray lies in the plane of incidence.
- ✓ The angle of reflection equals the angle of incidence.

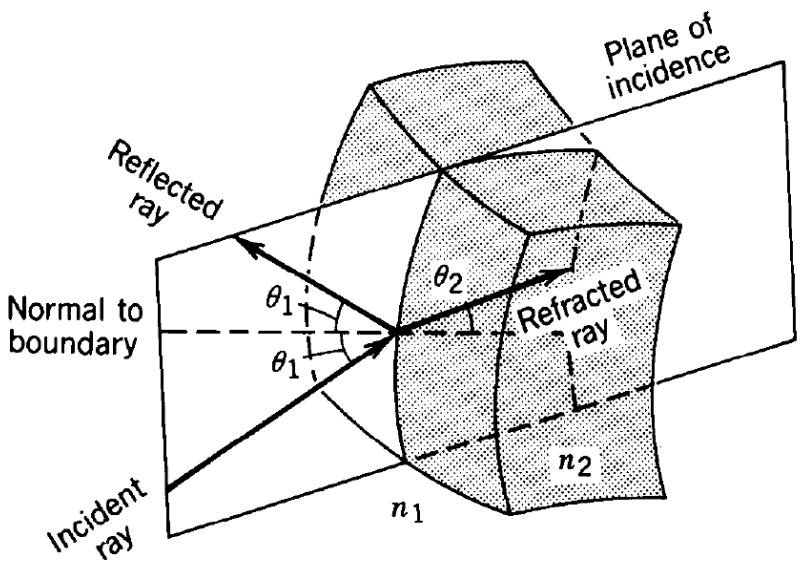
The plane of incidence is the plane formed by the incident ray and the normal to the mirror at the point of incidence.



Reflection from a planar mirror.

Fundamentals of Optics

Light Propagation in Homogeneous Medium



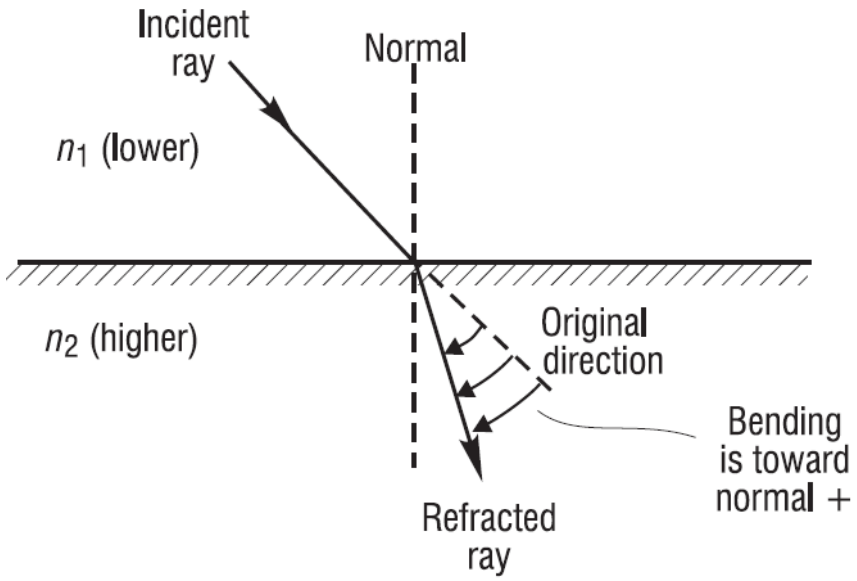
Reflection and refraction at the boundary between two media

The refracted ray lies in the plane of incidence; the angle of refraction θ_2 is related to the angle of incidence θ_1 by Snell's law,

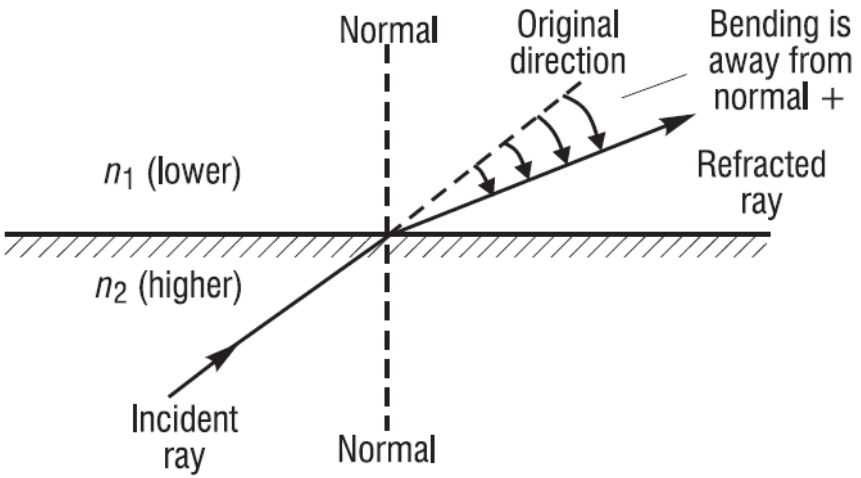
$$n_1 \sin \theta_1 = n_2 \sin \theta_2.$$

At the boundary between two media of refractive indices n1 and n2, an incident ray is split into two-a reflected ray and a refracted (or transmitted) ray.

Fundamentals of Optics



(a) Lower to higher: bending toward normal



(b) Higher to lower: bending away from normal

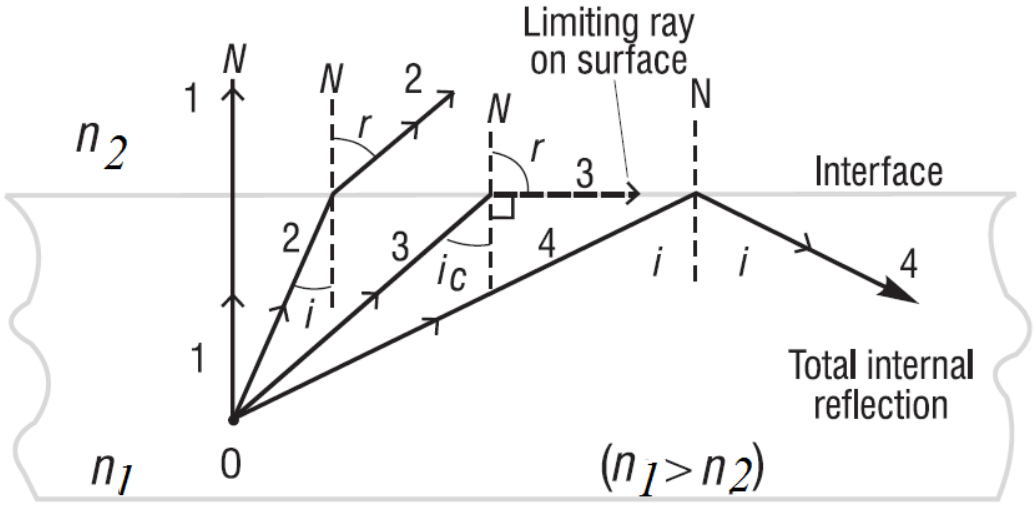
Exercise:

In a handheld optical instrument used under water, light is incident from water onto the plane surface of flint glass at an angle of incidence of 45°.
(the index of refraction is 1.33 for water and 1.63 for flint glass)

(a) What is the angle of reflection of light off the flint glass?
(b) Does the refracted ray bend toward or away from the normal?
(c) What is the angle of refraction in the flint glass?

Fundamentals of Optics

Critical angle and total internal reflection



Critical angle and total internal reflection

For internal refraction (n1>n2), the angle of refraction is greater than the angle of Incidence (θ2>θ1), so that as θ1 increases, θ2 reaches 90º. This occurs when θ1= θc (the critical angle)

$$n_1 \sin \theta_c = n_2$$

$$\theta_c = \sin^{-1} \frac{n_2}{n_1}.$$