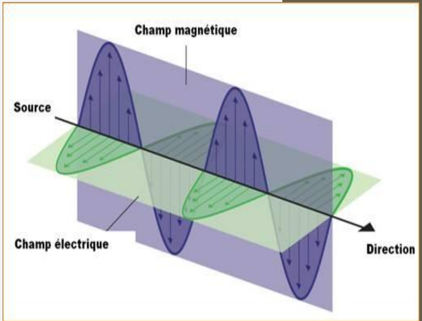
I.S.T.A

# Optics

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# Background

## Wave

Derived from the Latin word "unda," the term "wave" originally referred to moving water, particularly the movements on the surface of the sea. From the 18th century onwards, the term "wave" came to signify propagation on the surface of a liquid. It was later generalized to any phenomenon of propagation, whether supported by a material medium (mechanical waves) or without material support (electromagnetic waves).

# Background

## Optics

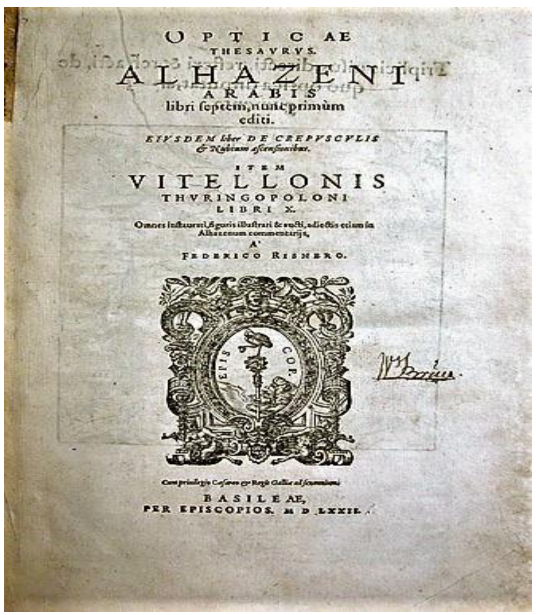
There were several competing theories :

- ✓ The Pythagoreans believed that the **eye** emitted straight rays from the **inner fire** of each individual, allowing them to see objects. Thus, cats had a more intense inner fire than humans since they could see at night. **Euclid** (-300 BC) was one of these scientists; he also described in a work the obtaining of shadows, reflection on mirrors, and refraction. His optics is geometric.

- ✓ **Aristotle** opposed the idea that the eye emits light, for the simplest of reasons: if the eye emitted light, we could see as well at night as during the day. Instead, he believed that the sensation of vision was caused by the propagation of the object to the eye. Unfortunately for him, he would not be listened to in this field.

## Optics

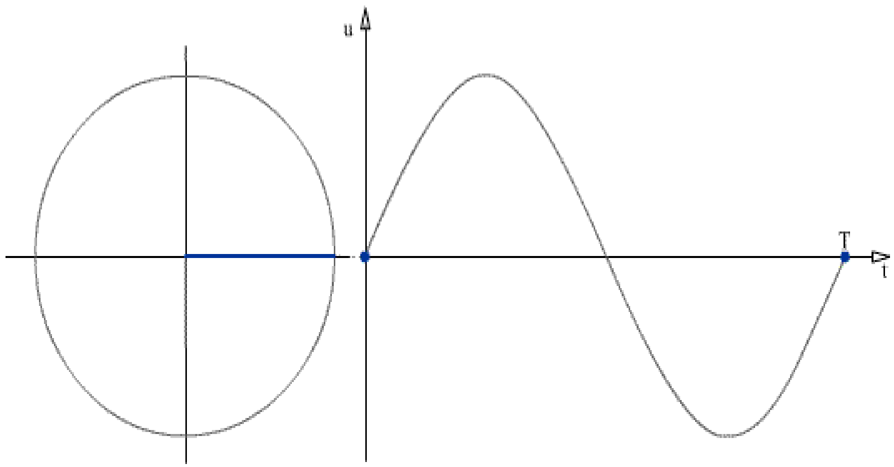
**Ibn al-Haytham** (965-1039), a Muslim scientist from the **Golden Age of Islam**, known to Westerners as Alhazen, is considered the **father** of modern optics and experimental physics. A Latin translation of a portion of his works, the "Book of Optics," had a significant influence on Western science.

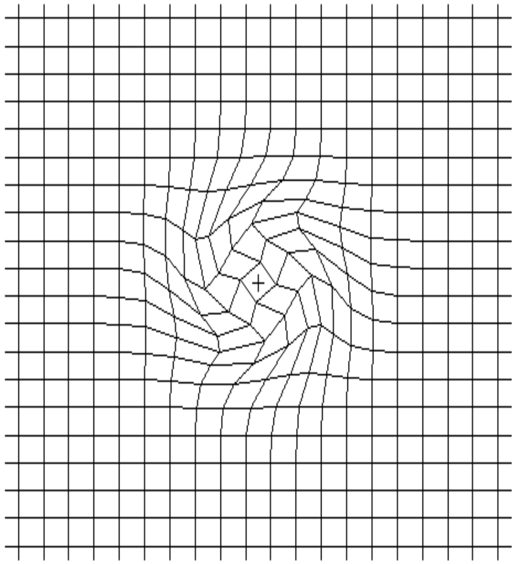

OPTICAE
THESAVRVS.
ALHAZENI
ARABIS
libri ſeptem, nunc primùm
editi.
EIVSDEM liber DE CREPVSCVLIS
ITEM
VITELLONIS
THVRINGOPOLONI
LIBRI X.
A'
FEDERICO RISNERO.
BASILEAE,
PER EPISCOPIOS. M D LXXII.

Kitāb al-Manāẓir

# What is a wave?

Propagation of a **disturbance** causing, in its passage, a reversible variation of the local physical properties of the medium. It moves with a determined velocity that depends on the characteristics of the propagation medium.



**A wave is a phenomenon of ordered propagation of energy, without the transport of matter.**

# What is a wave?

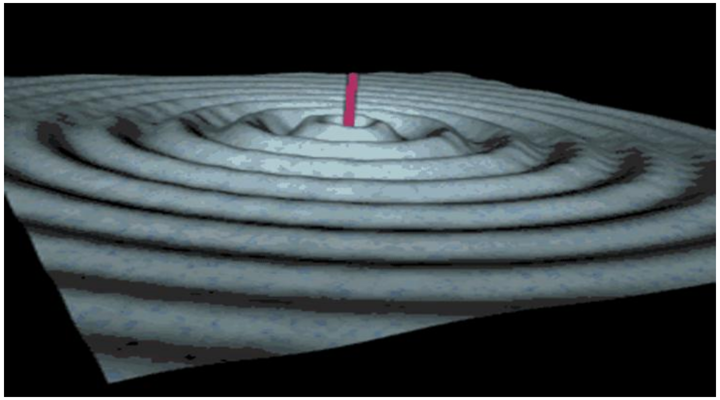
There are three main types of waves:

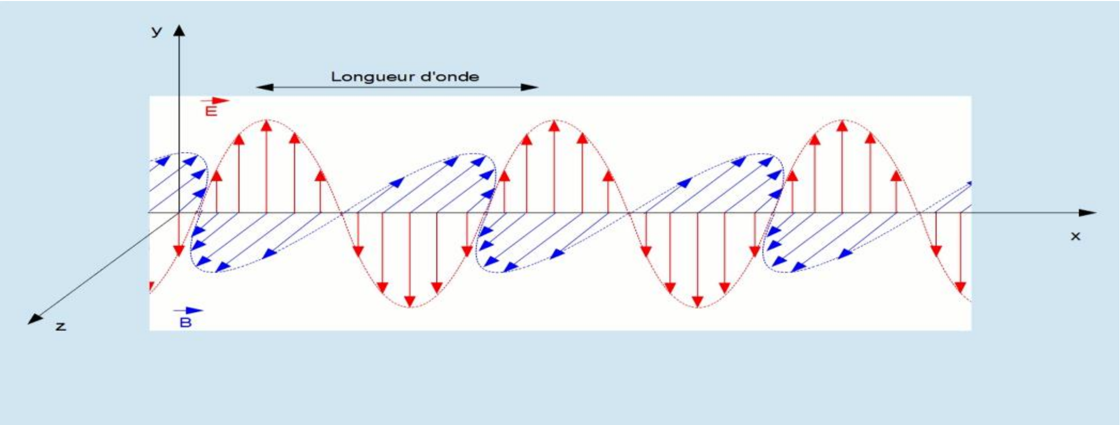
1. **Mechanical waves** propagate through a physical medium whose substance deforms. Restorative forces then reverse the deformation. For example, sound waves propagate through air molecules that collide with their neighbors. When molecules collide, they also bounce off each other. This prevents the molecules from continuing to move in the direction of the wave.

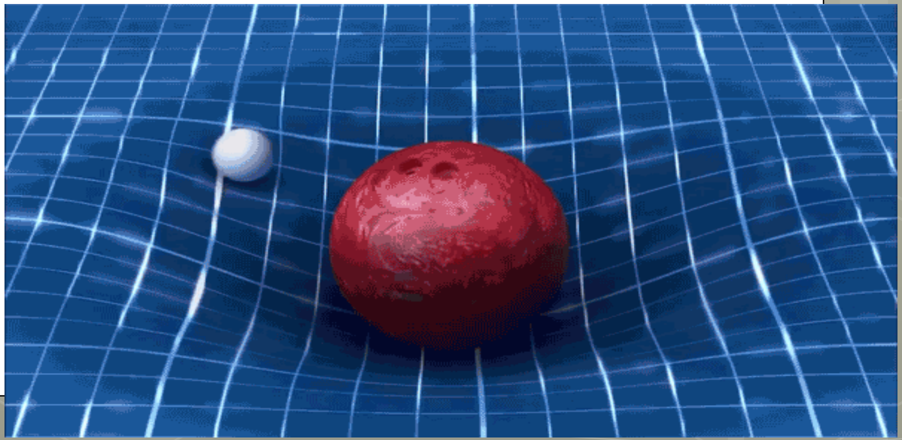
2. **Electromagnetic waves** do not require a physical medium. Instead, they consist of periodic oscillations of electric and magnetic fields generated originally by charged particles, and can thus travel through vacuum.

3. **Gravitational waves** also do not require a medium. These are deformations of the geometry of spacetime that propagate.

# What is a wave?





## Properties of light, propagation in a medium

**Light** is a physical phenomenon that can produce a visual sensation. The discipline that studies light is optics.

### ❑ Frequency, Period, Wavelength

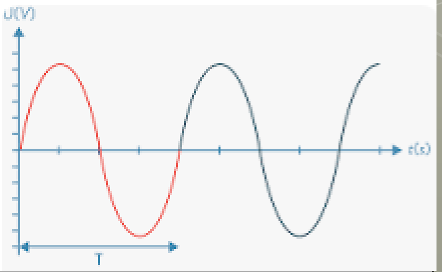
A light is characterized by its:

Frequency 'f', expressed in Hertz (Hz), is the number of times a periodic phenomenon repeats per unit of time measurement.

Period 'T', expressed in seconds (s), is given by: **T = 1/f**

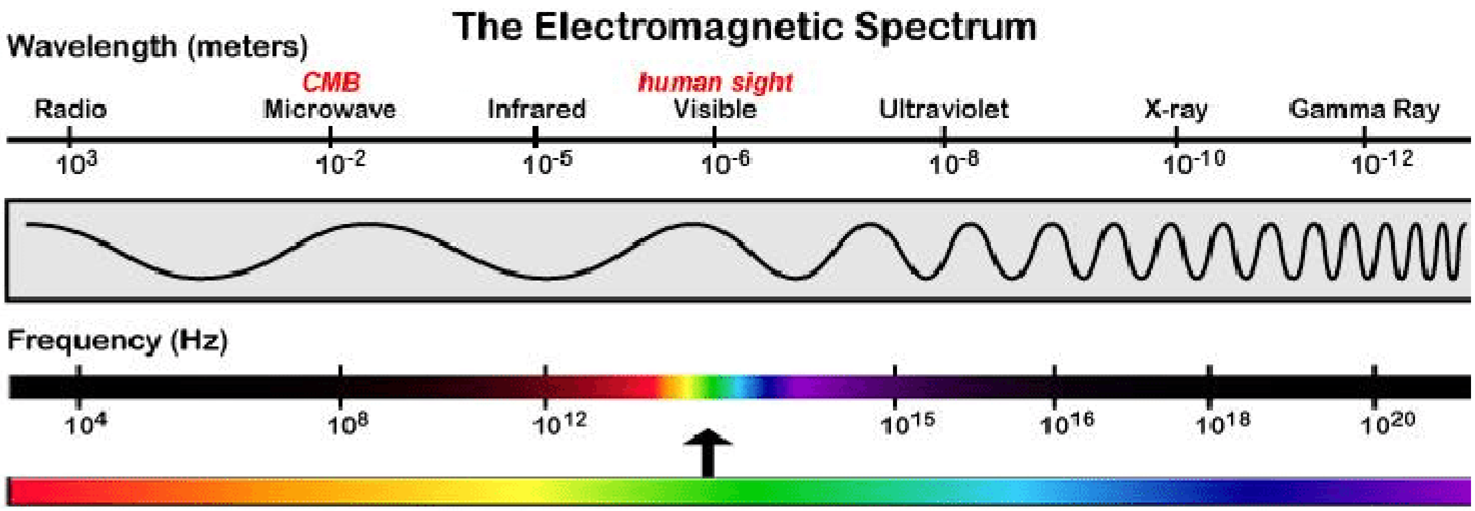
Wavelength 'λ', expressed in meters (m), is given by: λ = c * T, where c is the speed of light in a vacuum (3 * 10^8 m/s).

The **period** refers to the time interval after which the phenomenon repeats. So this is the time that passes for the curve to make a pattern. The **frequency** is the number of times the signal is reproduced per second.

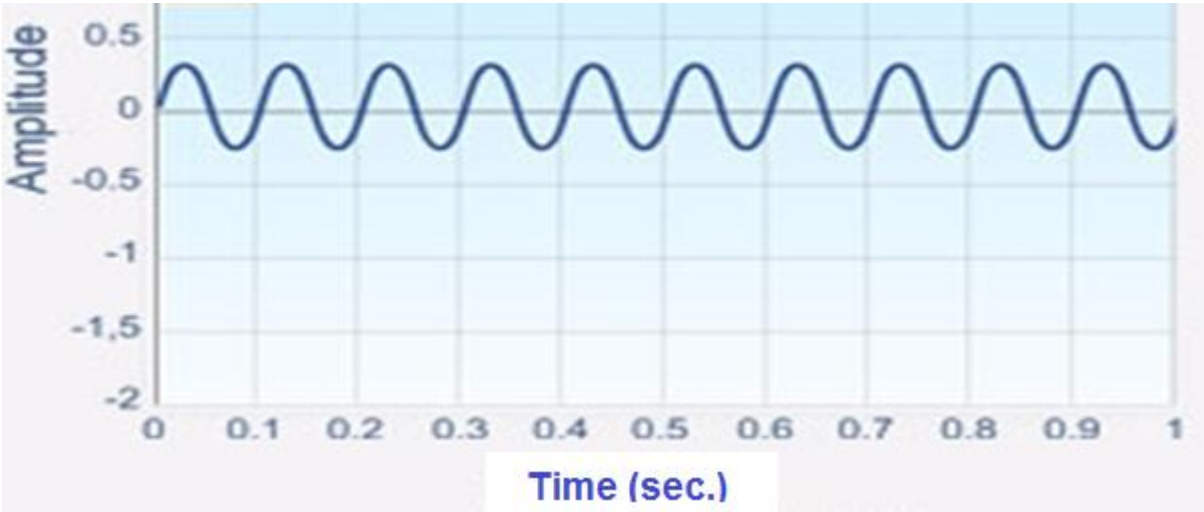


**Visible** light, as we perceive it, extends over wavelengths ranging from approximately **380 nanometers (violet)** to **780 nanometers (red).**

In the **electromagnetic spectrum**, it represents only a very small range of frequencies:



# Application 1

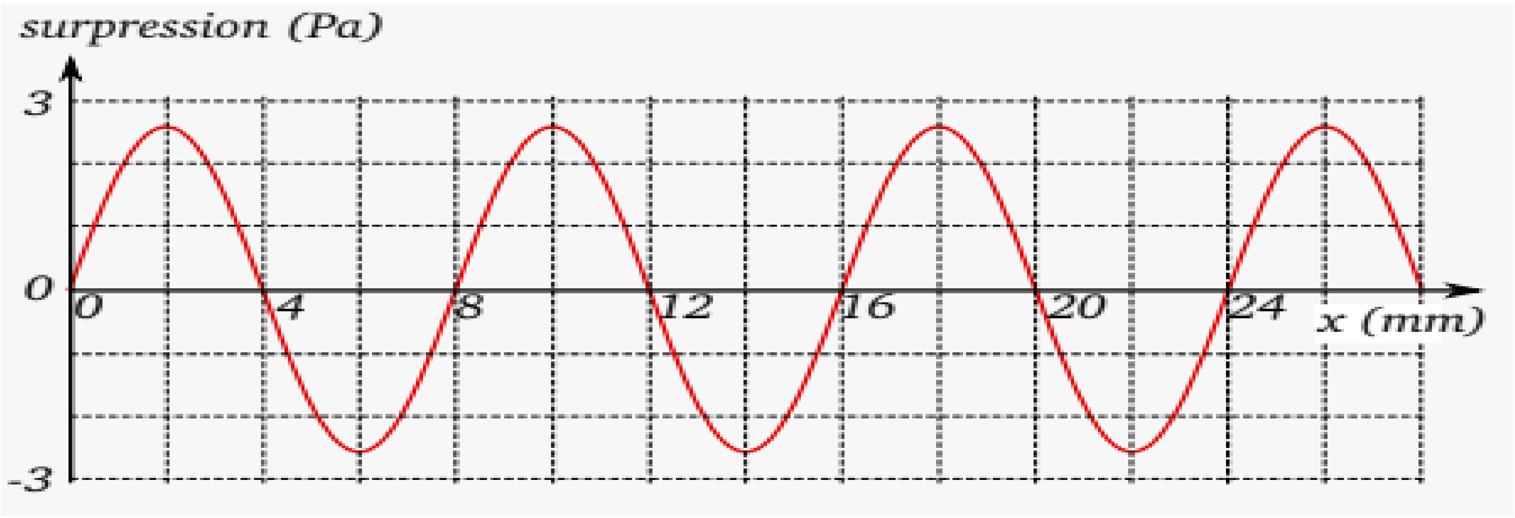



In this sinusoid:

- ✓ Sketch the period, the wavelength.
- ✓ Indicate the wavelength, the period, and the frequency band used.

## Application 2

A medium is traversed by a sound wave with a velocity ( v = 500 m/s). The overpressure in this medium at a given time is represented in the figure below.




a. What are the characteristics of this wave?
b. Determine the wavelength, period, and frequency of the wave?

# Propagation in a Medium

## Refractive index of a medium

The ratio between the speed of light in vacuum and the speed at which it propagates in the considered medium : $n = \frac{c}{v}$

With v expressed in m/s (meters per second).

Thus, the smallest possible index is 1, and n > 1.

| | |
|---|---|
| **Vacuum** | 1 |
| **Water** | 1.3 |
| **Glass** | 1.5 |
| **Diamond** | 2.42 |

Example of refractive index of certain media:

## Light dispersion, dispersive media

It's not just the nature of the medium that influences the speed of light propagation, but also its frequency (its color).

Indeed, **the index of a medium depends on the frequency of the vibration propagating through it; such a medium is called a dispersive medium**.

**Example of a dispersive transparent medium:** **Glass** is a dispersive medium for light waves since blue light (high frequency) propagates slower than red light (low frequency). The refractive index of glass for blue light is greater than the refractive index of glass for red light.

**Example of a non-dispersive medium:** **Air** is not a dispersive medium for sound waves since all frequencies propagate at the same speed (approximately 340 m/s).

## Medium and wavelength

| Color | Wavelength interval | Frequency interval |
|---|---|---|
| violet | ~ 430 to 380 nm | ~ 700 to 790 THz |
| blue | ~ 500 to 430 nm | ~ 600 to 700 THz |
| cyan | ~ 520 to 500 nm | ~ 580 to 600 THz |
| green | ~ 565 to 520 nm | ~ 530 to 580 THz |
| yellow | ~ 590 to 565 nm | ~ 510 to 530 THz |
| orange | ~ 625 to 590 nm | ~ 480 to 510 THz |
| red | ~ 740 to 625 nm | ~ 405 to 480 THz |

Low-frequency colors are **red**, high-frequency colors are **blues** and **violets**.

Nano: $10^9$
Tera: $10^{12}$

If we apply the definition of the wavelength of radiation in a vacuum to a dispersive medium, we see that this wavelength depends on the medium:

$$\lambda_{\text{medium}} = v \times T = \frac{c}{n} \times T = \frac{\lambda_{\text{Vacuum}}}{n}$$

**To remember:**

**The greater the frequency of the vibration (the smaller its wavelength), the slower the propagation speed, and the larger the index of the medium.**

## To isolate a ray ?

Consider a light beam emitted from a flashlight, for example:
Is it possible to **isolate a ray of light**? By what means? What happens?
Indeed, it is **not possible** to isolate a ray from a beam using, for example, a small hole because beyond a certain size limit of the hole, the beam does not narrow but instead **spreads out**. In fact, the light will spread even more as the hole gets smaller: this is **diffraction**

## Propagation medium

**Transparent:** The term "transparent" here refers to a non-absorbing medium.

**Homogeneous:** The physical properties (density, refractive index, etc.) are the same at every point in the medium. Example of a non-homogeneous medium: the air just above a road; this non-homogeneity gives rise to mirages.

**Isotropic:** The physical properties are identical in all directions of propagation of the light ray. Example of a non-isotropic medium (anisotropic): quartz crystal, the speed of propagation of the light ray is not the same in all directions.

**Homogeneous: The properties of the medium are the same at every point in space.**

**Isotropic: The properties of the medium are the same in all directions.**

## Three fundamental laws

### Rectilinear propagation

***To remember***
***In a homogeneous and isotropic medium, light rays are straight lines.***

One can notice that it represents the shortest path from one point to another. Therefore, geometry allows us to construct the path of light, hence the name geometric optics.

### Inverse light return

***To remember***
***Light propagates from A to B or from B to A, following the same trajectory (A and B are on the same light ray).***

### Independence of light rays

***To remember:***
***There is no interaction between two light rays; one ray cannot deflect another.***

# Snell-Descartes laws

## For reflection

The light ray is called **incident** before it meets the reflecting surface and is called **reflected** afterward.

The point where the incident ray meets the reflecting surface is called the **point of incidence**.

The line perpendicular to the reflecting surface at the point of incidence is called the **normal** (to the reflecting surface).

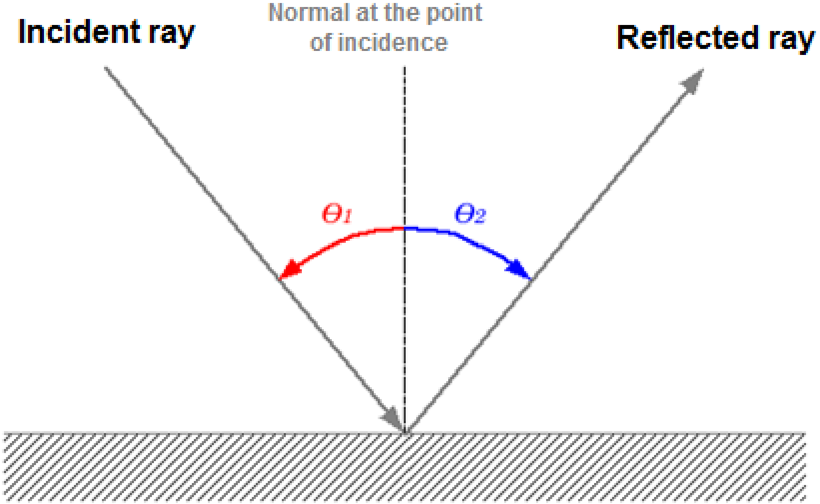
The plane containing the incident ray and the normal to the reflecting surface at the point of incidence is called the **plane of incidence**.

The **directed angle θ1** between the normal at the point of incidence and the incident ray is called the **angle of incidence**.

The **directed angle θ2** between the normal at the point of incidence and the reflected ray is called the **angle of reflection**.

Angles θ1 and θ2 are **positive** if oriented in the **counterclockwise** direction (as per trigonometric convention), negative otherwise.

# Snell-Descartes laws

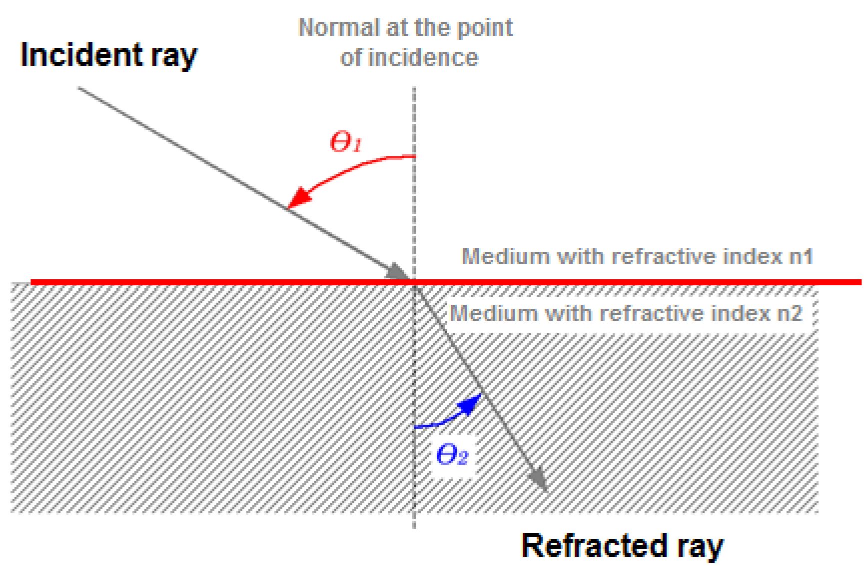



Reflection

$\theta_1 = -\theta_2$

$| \theta_1 | = | \theta_2 |$

**Dioptre** is a surface separating two transparent, homogeneous, and isotropic mediums with different refractive indices.




Refraction

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

$n_1 \theta_1 = n_2 \theta_2$

# Snell-Descartes laws

## For refraction

The change in direction of a light beam when crossing a barrier separating two different mediums is expressed through the refractive index 'n' of each medium. Each medium is characterized by its ability to slow down light, modeled by its refractive index 'n', expressed as: **n = c/v**), where c is the speed of light in a vacuum, and v is the speed of light in the given medium.

The light ray is called incident before it encounters the refracting surface (called a dioptre), and it is called refracted afterward.

The point where the incident ray meets the dioptre is called the point of incidence.

The plane containing the incident ray and the normal to the dioptre at the point of incidence is called the plane of incidence.

The **directed angle θ1** between the normal at the point of incidence and the incident ray is called the **angle of incidence**.

The **directed angle θ2** between the normal at the point of incidence and the refracted ray is called the **angle of refraction**.

Angles **θ1** and **θ2** are **positive** if oriented in the **counterclockwise** direction (as per trigonometric convention), negative otherwise.

# Snell-Descartes laws

## For refraction

The law of refraction is stated as follows:

- **First law of Descartes**: the refracted ray, the incident ray, and the normal (to the dioptre) lie in the same plane, the plane of incidence; the incident ray and the refracted ray are situated on either side of the normal.

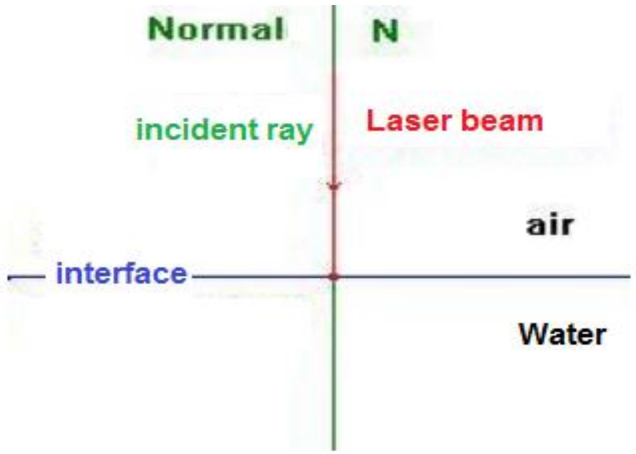
- **Second law of Descartes**: the relationship between the refractive indices n1 and n2 of each of the mediums and the incident angle θ1 and refracted angle θ2, known as the Snell-Descartes relation, is written as:

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

**The medium is more refractive as the refractive index 'n' increases.**

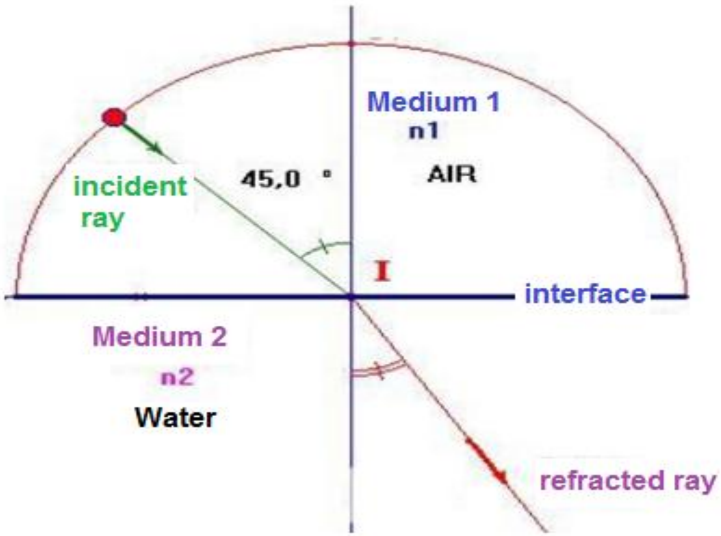
## Exercise 1

An aquarium is filled with water. The surface of the water is illuminated using a red laser beam




1) The laser is oriented perpendicular to the surface of the water. What is the value of the angle of incidence?

2) Using the second law of Descartes, deduce the value of the angle of refraction.




3) Now, the surface of the water is illuminated with an incidence of 45°. What will be the value of the angle of refraction?

Given : Refractive index of water (n_water) = 1.33

**Exercise 2:** Create a diagram based on a description

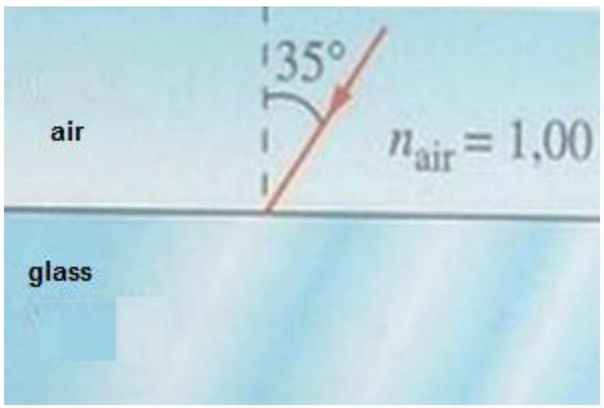
1) One of the rays of a light beam, propagating in air, arrives at a flat surface of glass. Given data: Refractive index of glass ($n_{glass}$) = 1.52. Illustrate the situation schematically, depicting the phenomenon of refraction.

2) Give the second law of Descartes.

3) Deduce the value of the angle of incidence required to obtain a refraction angle of 20°.

**Exercise 3:** Determine the refractive index of a glass

A light ray emanating from a laser source travels through the air and strikes the surface of polycarbonate.




1. To replicate and complete the diagram on the left, indicating the angle of incidence and the normal to the surface separating the two mediums.

2. The observed angle of refraction in the material is 21°. Represent the path of light in this material on the diagram.

3. Provide the expression of the second law of Descartes.

4. Express the refractive index n2 of the material and deduce its value.

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