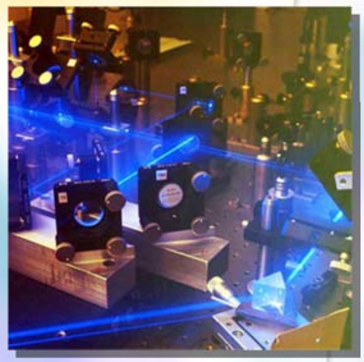
Physics Academy

Laser Physics

Introduction to Laser Essentials

Lecture 1



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Things you need to know

Before studying about lasers, you must be familiar with **basic terms** used to describe electromagnetic waves:

- **Wavelength (λ)**
- **Frequency (υ)**
- **Period (T)**
- **Velocity of light (c)**
- **Index of refraction (n)**

We will **briefly review** these terms, but it is much better if you are familiar with:

Some terms from **geometric optics** such as: refraction, reflection, thin lenses etc.

Some terms from "**Modern Physics**" such as photons, Models of atoms, etc.

Electromagnetic Radiation

Electromagnetic Radiation is a **transverse wave**, advancing in vacuum at a constant speed which is called: **velocity of light**.

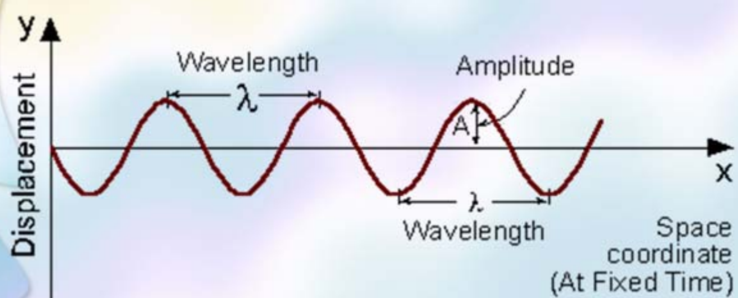
All electromagnetic waves have the same velocity in vacuum, and its value is approximately:

c = 300,000 [km/sec] = $3*10^8$ [m/sec]

One of the most important parameters of a wave is its **wavelength**.

Wavelength

Wavelength (λ) (Lamda) is the distance between two adjacent points on the wave, which have the same **phase**. As an example (see figure below) the distance between two adjacent peaks of the wave.



Frequency

In a parallel way it is possible to define a wave by its **frequency.**

Frequency (μ) is defined by the **number of times that the wave oscillates per second.**

Between these two parameters the relation is:

$$c = \lambda * \mu$$

From the physics point of view, **all electromagnetic waves are equal (have the same properties) except for their wavelength (or frequency)**.

As an example: the speed of light is the same for visible light, radio waves, or x-rays.

Wave Description

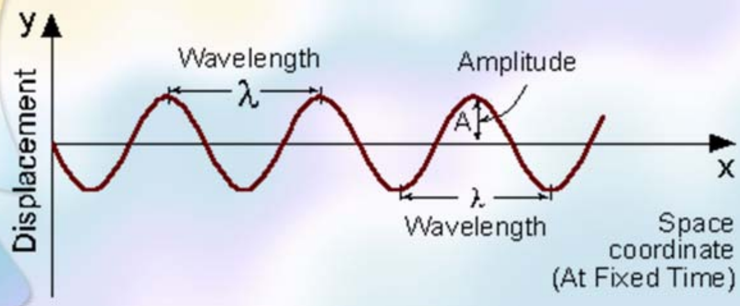
A **wave** can be described in two standard forms:

1. **Displacement as a function of space when time is held constant.**

2. **Displacement as a function of time at a specific place in space.**

Displacement as a function of space

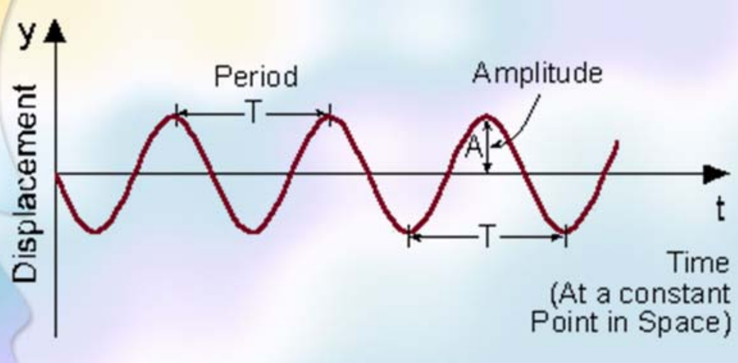
Displacement as a function of space, when time is "frozen" (held constant). In this description, **the minimum distance between two adjacent points with the same phase is wavelength (λ). Note that the horizontal (x) axis is space coordinate**



A = **Amplitude** = Maximum displacement from equilibrium.

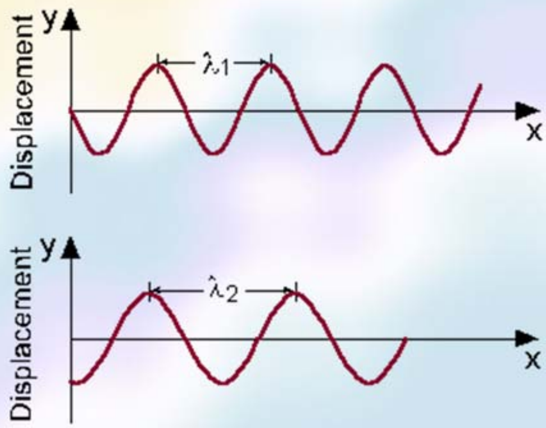
Displacement as a function of time

Displacement as a function of time, in a specific place in space, as described in figure. In this description, **the minimum distance between two adjacent points with the same phase is period (T). Note that the horizontal (x) axis is time coordinate**

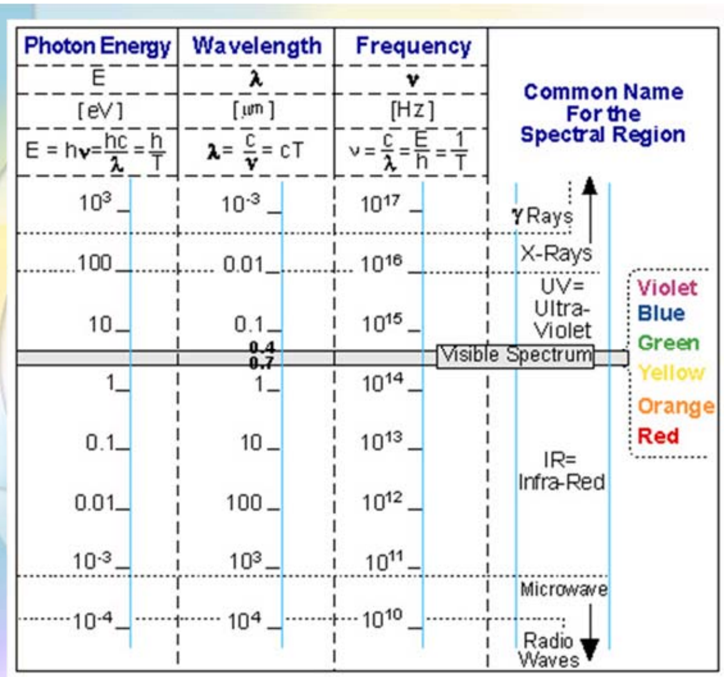


Wavelengths Comparison

The Figure describes how two different waves (with different wavelengths) look at a specific moment in time. Each of these waves can be uniquely described by its wavelength.



The electromagnetic spectrum



The most important ideas summarized in figure are:

1. Electromagnetic waves span over many orders of magnitude in wavelength (or frequency).
2. The frequency of the electromagnetic radiation is inversely proportional to the wavelength.
3. The visible spectrum is a very small part of the electromagnetic spectrum.
4. **Photon energy** increases as the wavelength decreases. The shorter the wavelength, the more energetic are its photons.

Examples for electromagnetic waves are:

- **Radio-waves** which have wavelength of the order of meters, so they need big antennas.
- **Microwaves** which have wavelength of the order of centimeters. As an example: in a **microwave oven**, these wavelengths can not be transmitted through the protecting metal grid in the door, while the **visible spectrum** which have much shorter wavelength allow us to see what is cooking inside the microwave oven through the protecting grid.
- **x-Rays** which are used in medicine for taking pictures of the bone structure inside the body.
- **Gamma Rays** which are so energetic, that they cause ionization, and are classified as ionizing radiation.

Electromagnetic Radiation in Matter

Light Velocity in Matter
When electromagnetic radiation passes through matter with **index of refraction n**, its **velocity (v)** is less than the **velocity of light in vacuum (c)**, and given by the equation:

$$v = c / n$$

This equation is used as a **definition of the index of refraction**

n = (speed of light in vacuum)/(speed of light in matter)

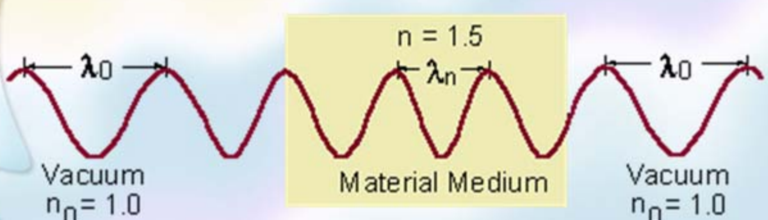
$$n = c/v$$

Gases, including air, are usually considered as having index of refraction equal to vacuum $\mathbf{n_0=1}$.

The values of the index of refraction of most materials transparent in the visible spectrum is between 1.4-1.8, while those of materials transparent in the Infra-Red (IR) spectrum are higher, and are 2.0-4.0.

Wavelength in Matter

We saw that the velocity of light in matter is slower than in vacuum. This slower velocity is associated with reduced wavelength: $\lambda = \lambda_0/n$, while the **frequency remains the same**



Refraction of Light Beam - Snell Law

Reducing the velocity of light in matter, and reducing its wavelength, causes **refraction of the beam of light**.

While crossing the border between two different materials, the light changes its direction of propagation according to the **Snell Equation**

$$n_1 \cdot \sin(\Theta_1) = n_2 \cdot \sin(\Theta_2)$$

Example

The velocity of Red light (λ_0= 0.6 μm) in a certain medium is 1.5*10^8 m/s. What is the wavelength of this light in this material?

Solution:

First find the index of refraction:

$$n = \frac{c}{v} = \frac{3 \cdot 10^8 \cdot \frac{m}{s}}{1.5 \cdot 10^8 \cdot \frac{m}{s}} = 2.0$$

Using n, calculate the wavelength in the material:

$$\lambda_n = \frac{\lambda_0}{n} = \frac{0.6 \cdot \mu m}{2.0} = 0.3 \cdot \mu m$$

Conclusion: The wavelength of Red light in a material with an index of refraction of 2.0, is 0.3 μm