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Department of Medical Physics
Laser Basics
Third Stage

كلية المستقبل الجامعة
قسم الفيزياء الطبية
اساسيات الليزر
المرحلة الثالثة

اساسيات الليزر

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Properties of light

Introduction

Light plays a vital role in our daily lives and has become an important tool in meeting the needs of our 21st century world. Light based technologies protect health and safety, provide sustainable energy, enable space explorations, advance lighting options in rural areas, enable communication via the Internet, and hold the promise of limitless possibilities to improve the human condition and protect the earth. Light is part of the electromagnetic radiation spectrum and is a form of energy. Light is usually considered to be the visible part of the spectrum. However, in physics, light can be defined as all portions of the electromagnetic scale, including invisible forms such as infrared, ultraviolet, X-rays, radio waves, and more.

Electromagnetic waves can be described by their wavelengths, energy, and frequency. Figure 1 shows Visible light is a small part of the electromagnetic spectrum.

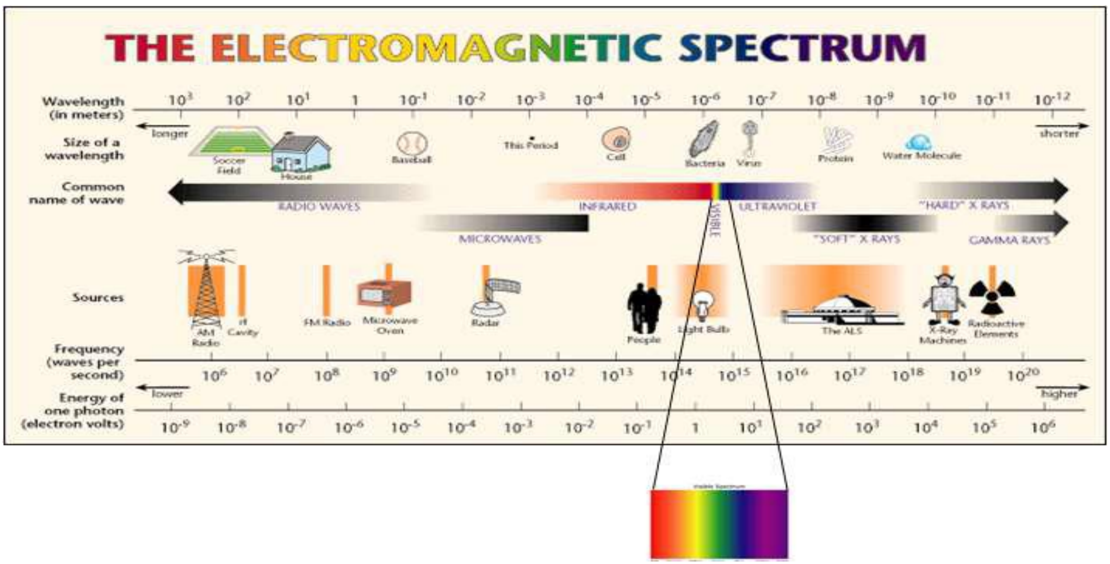

Figure 1: The Electromagnetic Spectrum

Wavelength (λ)-Light waves are vibrations in the electromagnetic field. The wavelength of a light wave is measured as the distance between two wave crests. Light wavelengths can vary greatly; for example, radio waves can be about the size of small buildings, while gamma rays are subatomic size.

Frequency (f)- is measured as the number of waves that pass a given point in one second. The unit for frequency is cycles per second, also called hertz (*Hz*). The frequency and the period are reciprocals of one another. If the wave speed and wavelength are known, the frequency can be calculated with the following equation:

$$f = 1/\tau = v/\lambda$$

(τ): cycle time or period , (v): a wave speed.

Energy (E)-The greater the energy, the higher the frequency and the shorter (smaller) the wavelength. Given the relationship between wavelength and frequency—the higher the frequency, the shorter the wavelength—it follows that short wavelengths are more energetic than long wavelengths. Figure 2 shows electromagnetic wave of blue and red lights.

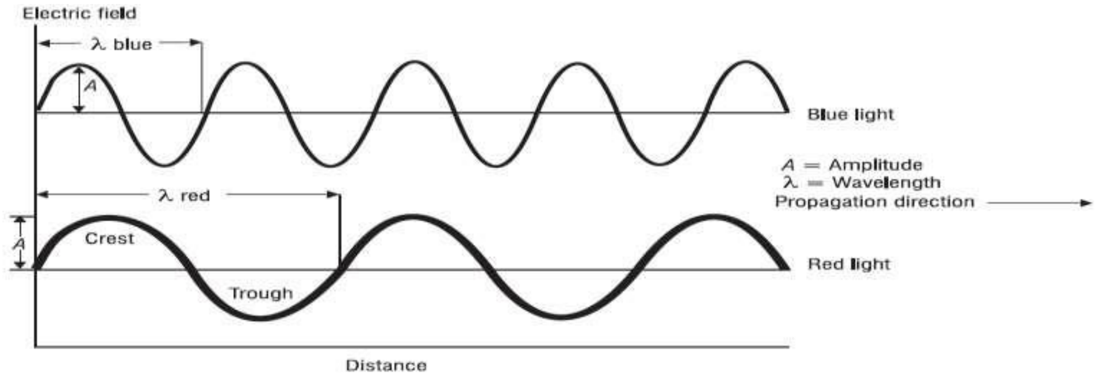

Figure 2: One-Dimensional Representation of The Electromagnetic Wave

The maximum value of the wave displacement is called the **amplitude**

(*A*) of the wave. The cycle starts at zero and repeats after a distance. This distance is called the **wavelength (λ).** Light can have different wavelengths, such as the blue light and red light shown in Figure 2. The inverse of the wavelength **(1/λ)** is the **wave number (N),** which is expressed in cm–1. The wave propagates at a **wave speed (v).** This wave speed in a vacuum is equal to *c* = 2.998* 10 8 m/ s, and is less than *c* in a medium.

$$C = \lambda f$$

At a stationary point along the wave, the wave passes by in a repeating cycle. The time to complete one cycle is called the **cycle time or period (τ)** and can be calculated using in the following equation:

$$\boxed{\tau = \lambda / v}$$

Example: for blue light in a vacuum, we can calculate the cycle time and frequency. The wavelength of blue light is 500 nm and the velocity of light in a vacuum is *c*.

$$\tau = \lambda / v = \frac{500 \times 10^{-9}\, m}{2.998 \times 10^{8}\, m/s} = 1.667 \times 10^{-15}\, s$$

Then we can calculate the frequency

$$f = 1/\tau = 1/1.667 \times 10^{-15}\, s = 5.996 \times 10^{14}\, Hz$$

H.W. For light with a wavelength (λ) of 408 nm determine:

(a) the frequency

(b) the wave number

Light sources

The light sources can be divided according to the emitting light process on natural (objects found in nature that produce light) and artificial (Human made objects that produce light) objects. Natural sources of light include sunlight, the stars, volcanoes, meteorological lightning, light of fire and biochemical sources. Artificial light sources can be classified as an incandescent bulbs, a halogen lamp, gaseous discharge light (metal halide, fluorescent tube, compact fluorescent tube), LED (light-emitting diodes) light (red LED, green LED, blue LED, , white LED). Despite the variety of natural sources of light, the most significant impact on humanity is had by the nearest star – the sun. Solar radiation is the main source of energy on earth. We may say that the earliest form of artificial light used to illuminate an area were campfires and torches. The next step was to use oil lamps. Later, candles were invented. With time, electric lamps improved lighting of the darkness. We want to present the different light sources and compare their spectra with the with that of the sun.

Wave properties of light

1. Reflection
2. Refraction
3. Diffraction
4. Interference

1.Reflection:

A highly polished surface, such as a mirror, reflects most of the light falling on it. the laws of reflection of light:

(i) The angle of incidence is equal to the angle of reflection,

(ii) The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.

These laws of reflection are applicable to all types of reflecting surfaces including spherical surfaces. Figure 3 shows reflection of light

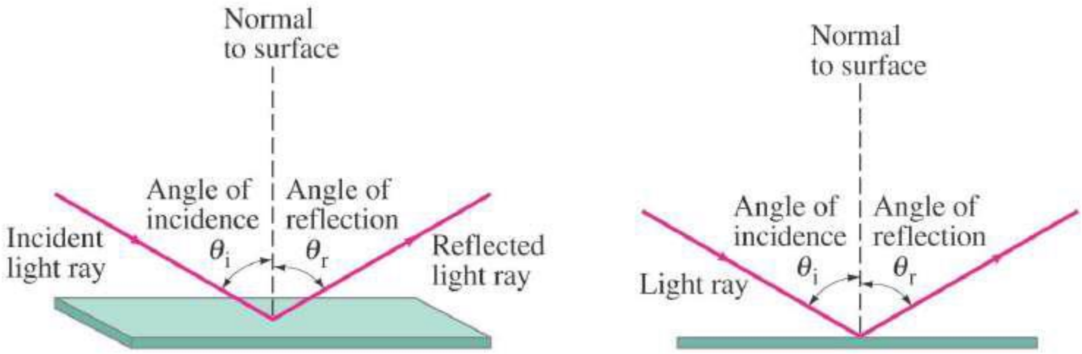

Figure 3: Reflection of Light

2. Refraction: Snell's Law

Light seems to travel along straight-line paths in a transparent medium. What happens when light enters from one transparent medium to another? Does it still move along a straight-line path or change its direction? We shall recall some of our day-to-day experiences. Have you seen a pencil partly immersed in water in a glass tumbler? It appears to be displaced at the interface of air and water, due to the light reaching you from the portion of the pencil inside water seems to come from a different direction, compared to the part above water. This makes the pencil appear to be displaced at the interface.

Snell's law is a formula used to describe the relationship between the angles of incidence and refraction, when referring to light or other waves passing through a boundary between two different isotropic media, such as water, glass, or air.

Snell's Law expression by $n_1 \sin \theta_1 = n_2 \sin \theta_2$.

Figure 4 shows incident and reflected rays , θ_1 and θ_2 of light.

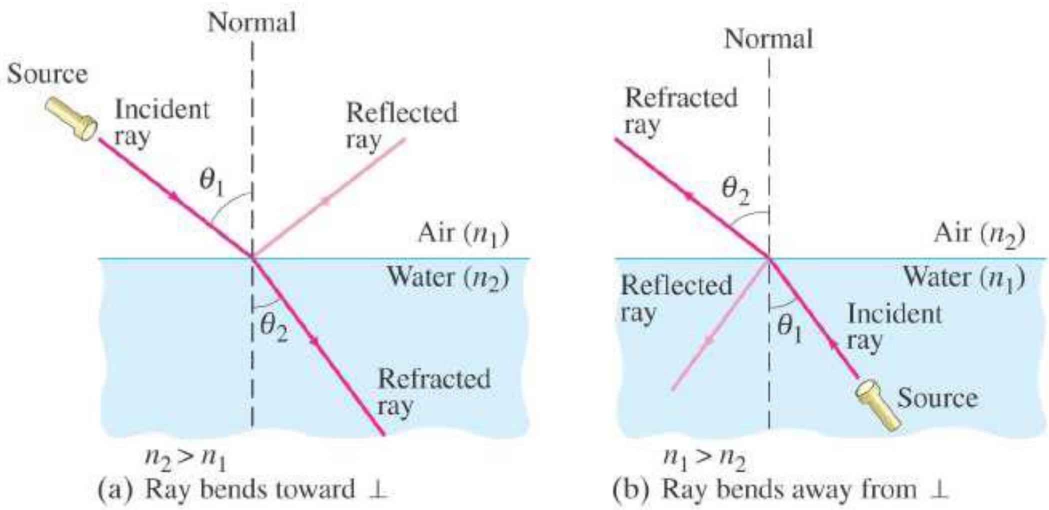

Figure 4: Refraction of Light

θ_1: incident angle

θ_2: Reflected angle

n: refractive index of media

3. Diffraction

When waves pass through a narrow gap, they spread out. This spreading out is called diffraction. Diffraction is defined as the spreading of a wave into regions where it would not be seen if it moved only in straight lines after passing through a narrow slit or past an edge. Diffraction of a light wave is illustrated in Figure 5.

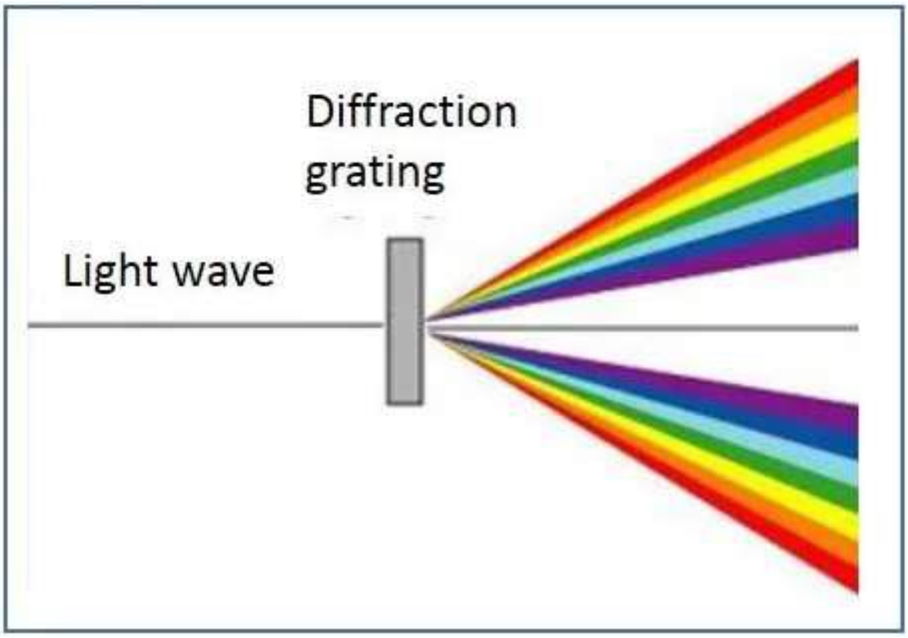

Figure 5: Diffraction of Light

Diffraction may also occur at an edge. When light travels through an aperture or passes the edge of an obstacle, it deviates from the straightline direction and appears to spread out. Water also exhibits diffraction.

The fact that light exhibits diffraction is a proof that light has wave properties. In Figure 6, diffraction is illustrated with two different sizes of aperture. It can be noted that the extent of the diffraction depends on the width of the gap compared with the wavelength. The greatest effect occurs when the wavelength is about the same size as the aperture.

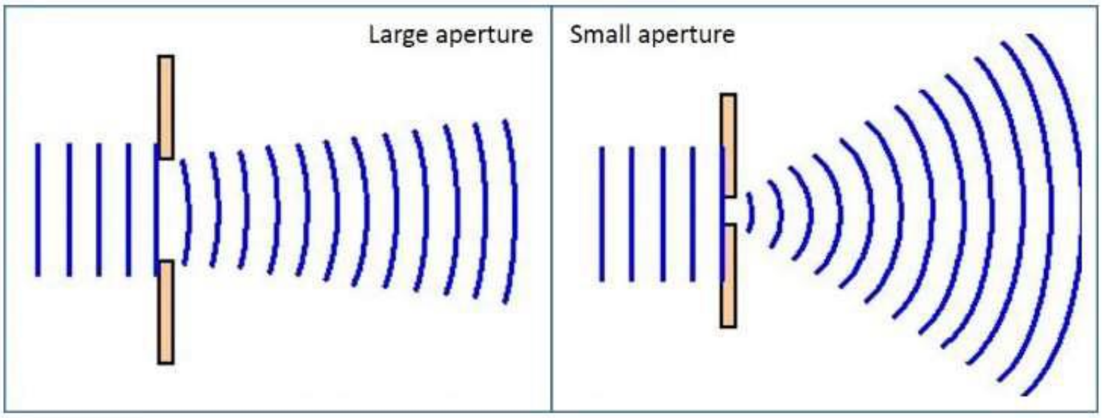

Figure 6: Diffraction at Different Size of Aperture

4.Interference

Interference is the phenomenon in which two waves superpose to form a resultant wave. The non-uniform distribution of energy due to the superposition of light waves in a medium is called the 'Interference of Light'.

Wave Interference is the phenomenon that occurs when two waves meet while traveling along with the same medium. In this process, waves superpose to form a resultant wave of greater, lower or the same amplitude.

There are two types of Interference

a. Constructive interference: Constructive interference takes place when the crest of one wave falls on the crest of another wave such that the amplitude is maximum. These waves will have the same displacement and are in the same phase.

b. Destructive interference: In destructive interference the crest of one wave falls on the trough of another wave such that the amplitude is minimum. The displacement and phase of these waves are not the same.

Figure 7 shows the two types of Interference

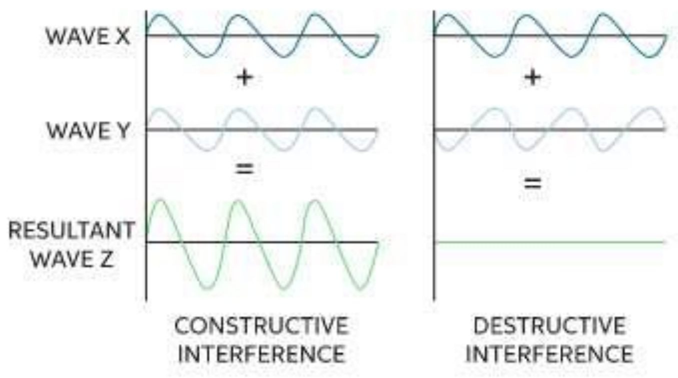

Figure 7: Constructive and Destructive Interference