Ministry of Higher Education and Scientific Research
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Laser Physics

Introduction to Laser Essentials

First stage

Lecture1

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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.

1-Wavelength (**λ**)

2- Frequency (**υ**)

3- Period (**T**)

4- Velocity of light (**c**)

5-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 Velocity which is called: velocity of light

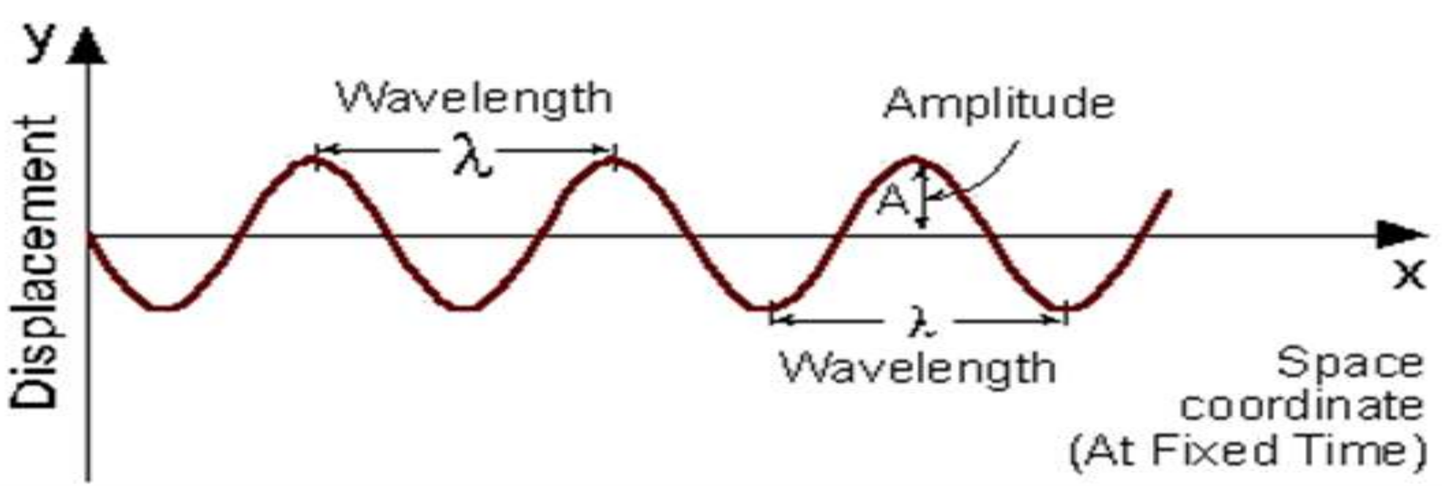
All electromagnetic waves have the same velocity in vacuum, and its value is approximately $c = 3x10^8$ [m/s]

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.

Figure 1: Wavelength (λ) , distance between two adjacent peaks.



Frequency

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

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

Between these two parameters the **relation** is:

$$c = \lambda \times \upsilon \qquad \text{......................(1)}$$

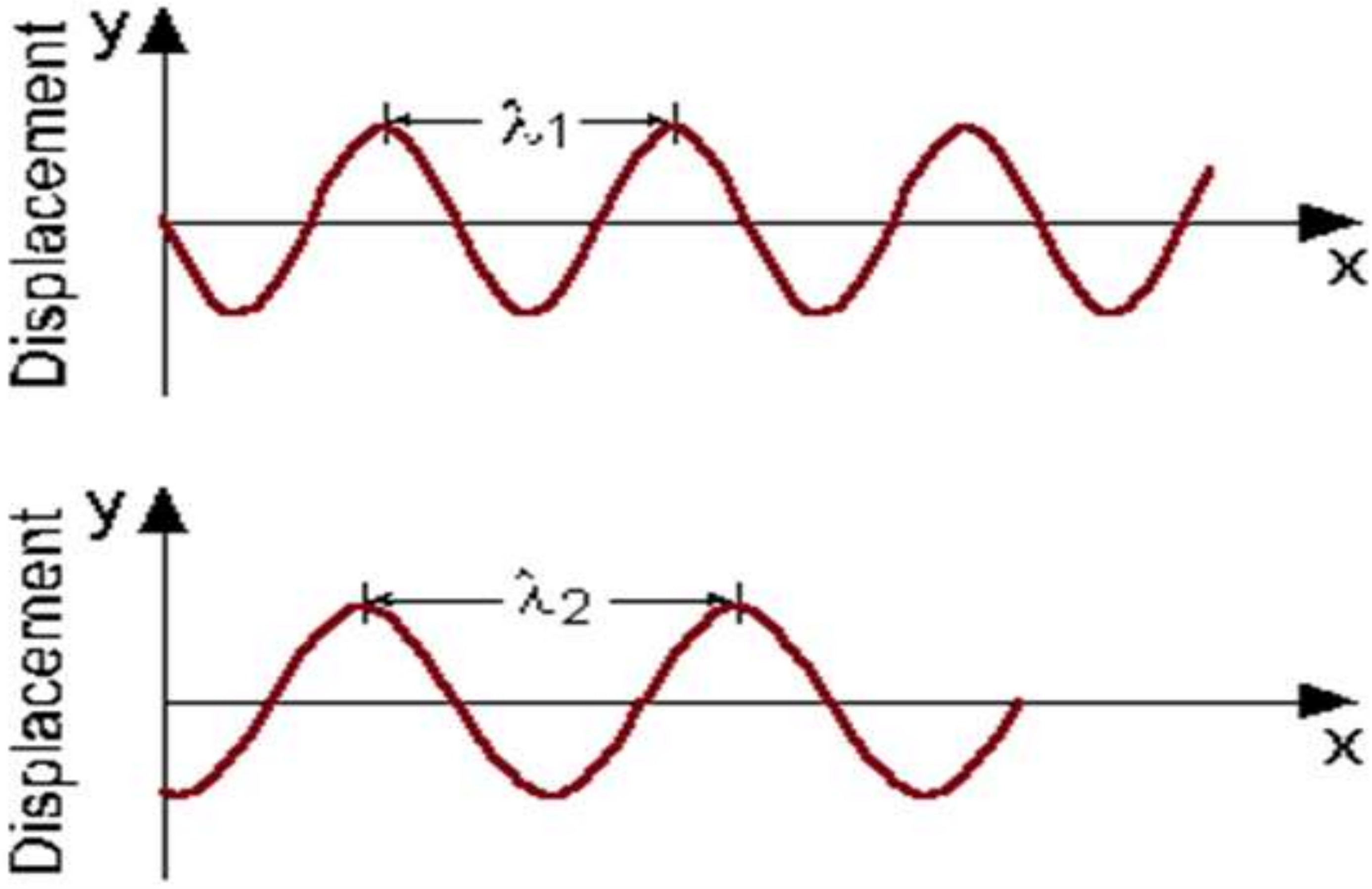
From the physics point of view , all electromagnetic waves are equal (have the same properties) except for their **wavelength** (**or** **frequency**).

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

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 .

Figure 2: wavelengths different.



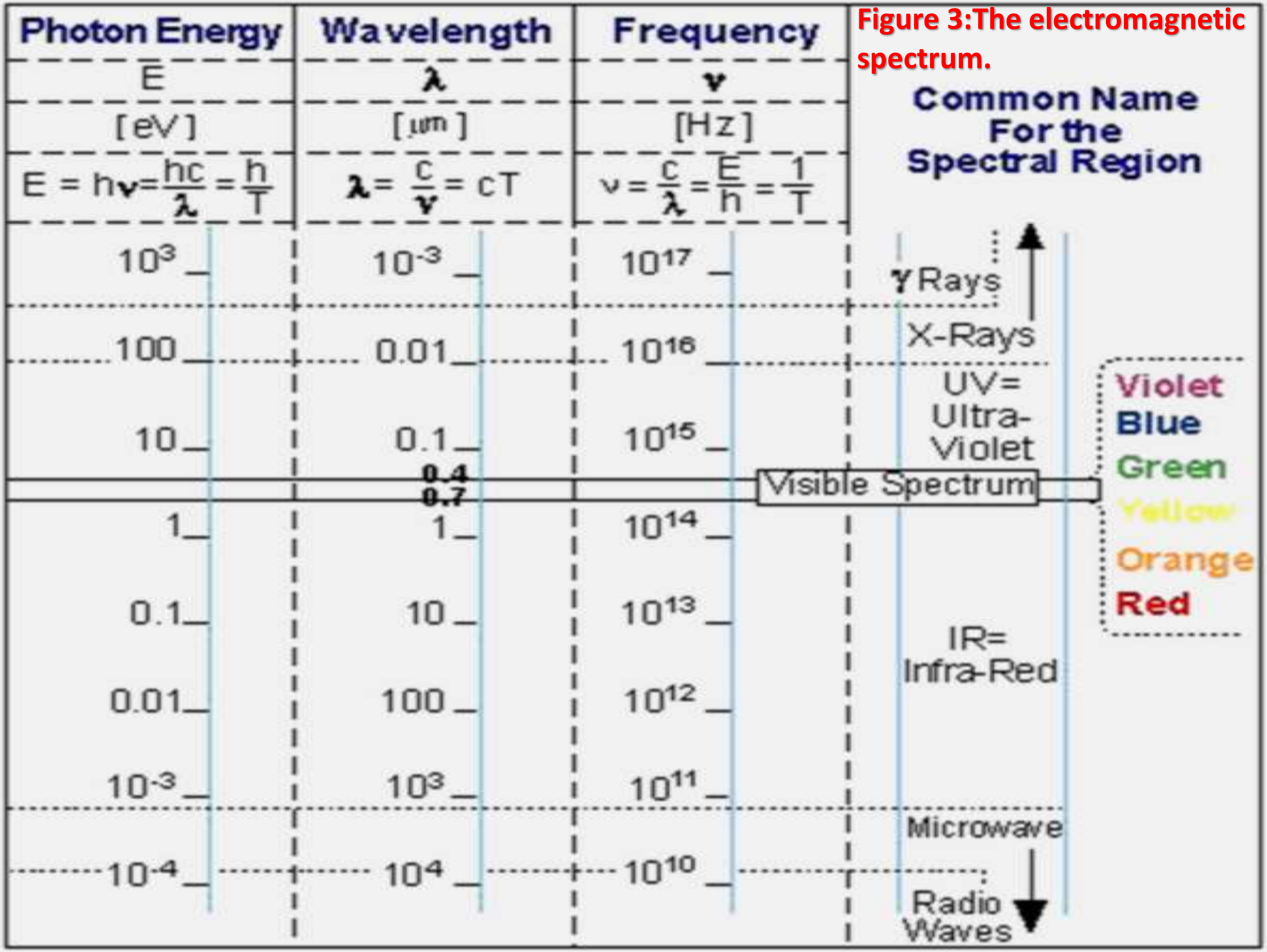


Figure 3:The electromagnetic spectrum.

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::

$v = c / n$ ……………….(2)

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

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

$n = c/v$ ……………………..(3)

Gases, including **air**, are usually considered as having index of refraction equal to vacuum **$n_0=1$**

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.

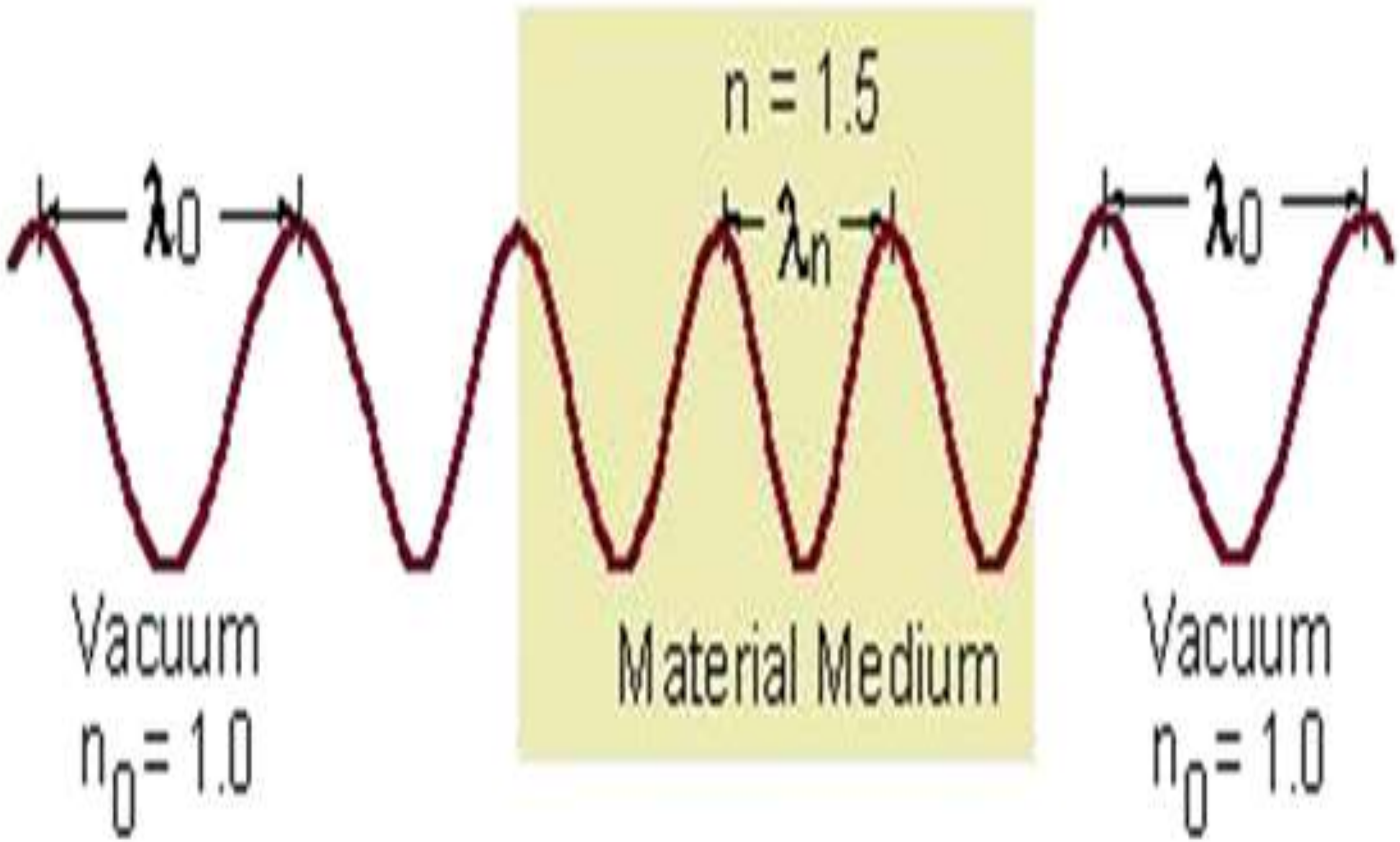


Figure 3: Wavelength in Matter.

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***.

$$n_1 \cdot \sin(\Theta_1) = n_2 \cdot \sin(\Theta_2) \qquad \text{..............(4)}$$

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 material with an index of refraction of 2.0, is 0.3 μm

Bohr model of the atom:

Lasing action is a process that occurs in matter.

Since matter is composed of atoms, we need to understand about the **structure** of the **atom**, and its energy states.

We shall start with the semi- classical model, as suggested in 1913 by Niels Bohr, and **called**: The **Bohr model** of the atom.

According to this model, every atom is composed of a very massive nucleus with a positive electric charge (Ze), around it electrons are moving in specific paths.

Z = Number of protons in the nucleus,

e = Elementary charge of the electrons:

e = 1.6×10^{-19} [Coulomb].

The figure illustrates a simple, but adequate, picture of the atom, the Bohr mode.

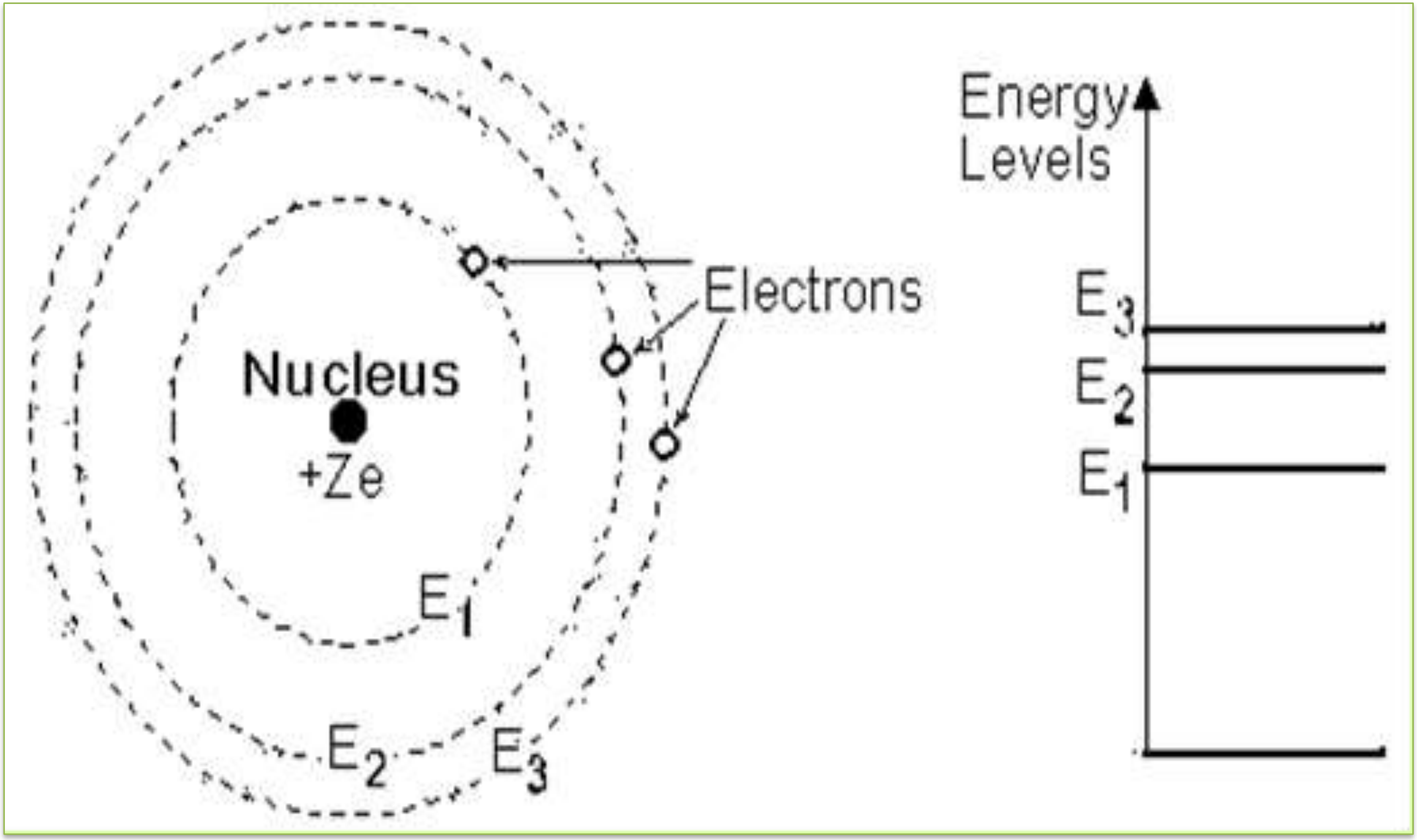


Figure 4:the Bohr mode of the atom.

Energy transfer to and from the atom:

Energy transfer to and from the atom can be performed in ***two different ways***:

1-Collisions with other atoms, and the transfer of kinetic energy as a result of the collision. This kinetic energy is transferred into internal energy of the atom.

2-Absorption and emission of electromagnetic radiation. Since we are now interested in the **lasing process**, we shall concentrate on the second mechanism of energy transfer to and from the atom.

Photons and the energy diagrams:

Electromagnetic radiation has, in addition to its wave nature, some aspects of "particle like behavior".

In certain cases, the electromagnetic radiation behaves as an ensemble of discrete units of energy that have momentum. These discrete units (**quanta)of** electromagnetic radiation are **called "*Photons*"**. The relation between the amount of energy (E) carried by the photon, and its **frequency** (υ),is determined by the formula (first given by Einstein) :

$E = h\upsilon$ ----------------------(1)

The proportionality constant in this formula is Planck's constant (h): , $h = 6.626*10^{-34}$ [Joule . sec]

This formula shows that the frequency of the radiation (υ), uniquely determines the energy of each photon in this radiation

$E = h\upsilon$

This formula can be expressed in different form, by using the relation between the frequency (υ) and the wavelength:

$c = \lambda \cdot \upsilon$ ------------------(2)

to get:

$E = h \cdot c / \lambda$ -----------------(3)

This formula shows that the energy of each photon is inversely proportional to its wavelength. This means that each photon of shorter wavelength (such as violet light) carries more energy than a photon of longer wavelength (such as red light).

Since h and c are universal constants, so either wavelength or frequency is enough to fully describe the photon.