Al-Mustaqbal University

College of Engineering & Technology

Biomedical Engineering Department

Subject Name: Medical Lasers in Engineering

Third Class, Second Semester

Subject Code: [Insert Subject Code Here]

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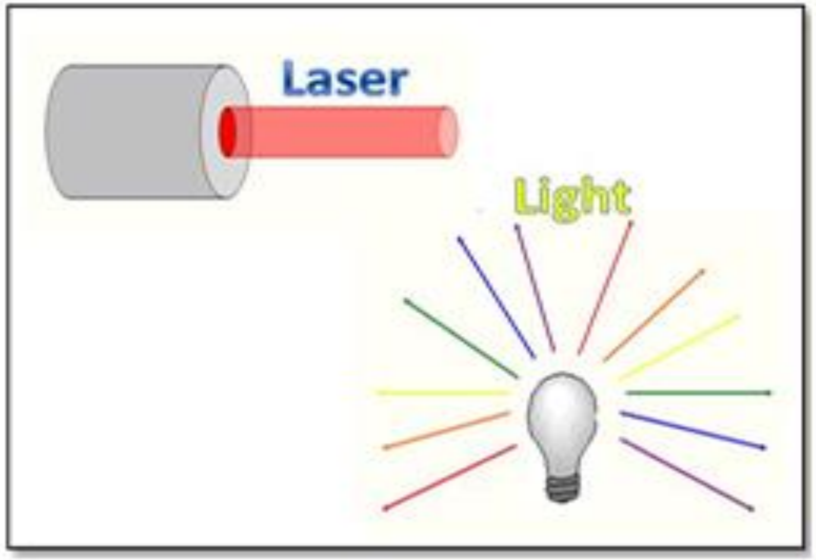
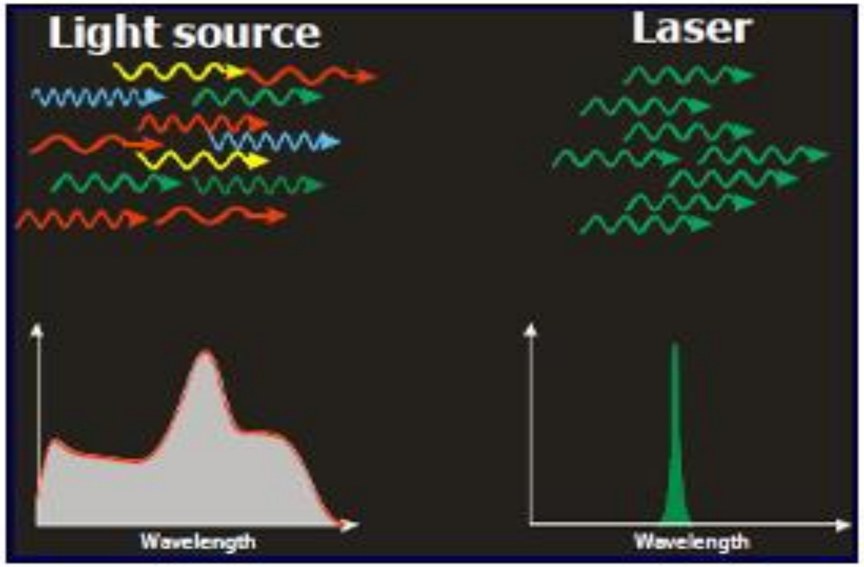
Lecture No.:-1

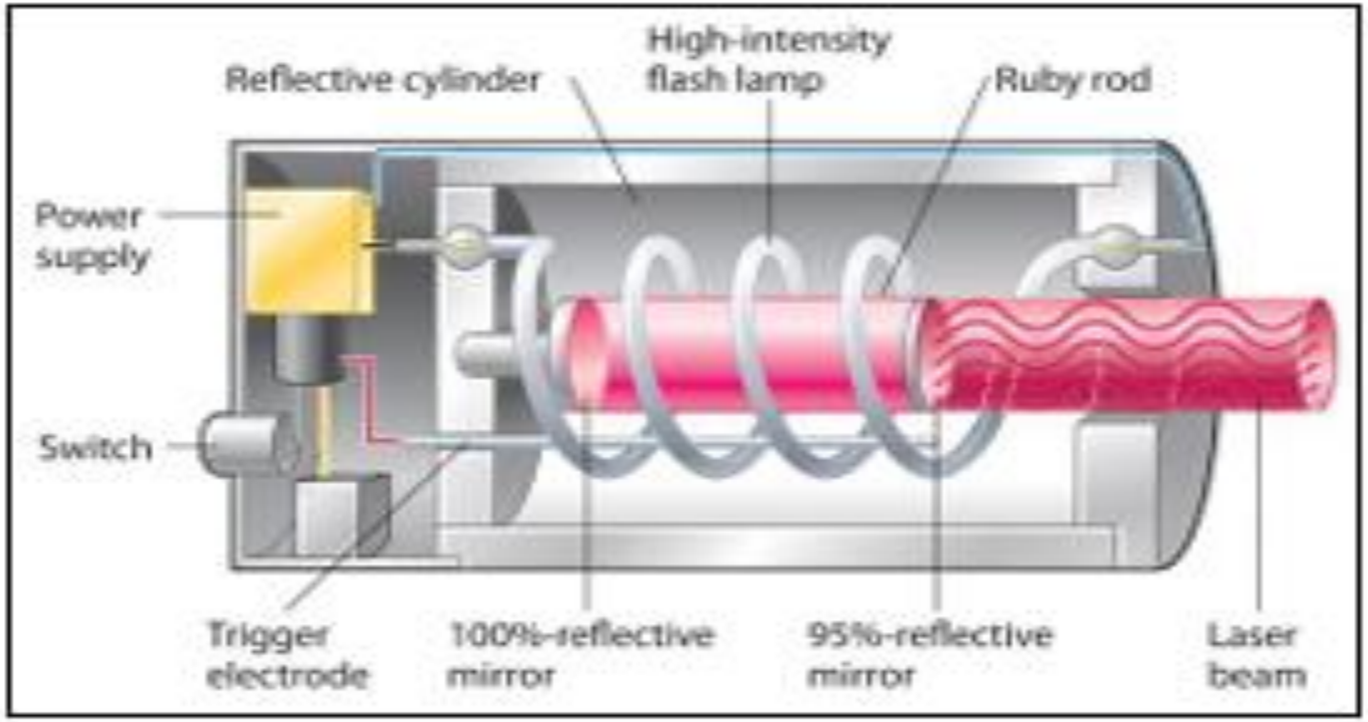
Lecture Title: [Introduction]

- The term "laser" is derived from the acronym "light amplification by stimulated emission of radiation.
- " A laser is a device that generates light through the process of **stimulated emission**. It has become an indispensable tool across various fields, ranging from medicine to communications.
- Laser produces a highly directional and high intensity beam with narrow frequency range than that available from the common types of light sources. So, laser is a light source but it is very much different from many traditional sources.





- Lasers are more widely used as a high power electromagnetic beam rather than a light beam.
- In 1960, the first laser (Ruby Laser) was produced – using a ruby crystal as the amplifier and a flash lamp as the energy source.



Quantum Behavior of Light

- In 1900, Max Plank proposed that light consists of discrete bundles of energy. The amount of energy of each bundles is “hv”. These bundles of radiant energy called quanta.
- In 1905, Einstein gave the name photon to the quantum of light energy.
- A photon represents the minimum energy unit of light. Each photon carries an amount of energy proportional to the frequency of the light wave, as given by:

$$E = hv$$

Where: h is Planck’s constant (h = 6.626 * 10-34 J.s), v is the frequency. It is obvious that the higher the frequency of a photon, the more energy it possesses.

- The interaction of light with matter is better explained using the concept of the photon rather than by the wave concept. When light interacts with matter, the energy exchange can take place only at certain discrete values for which the photon is the minimum energy unit that light can give or accept.

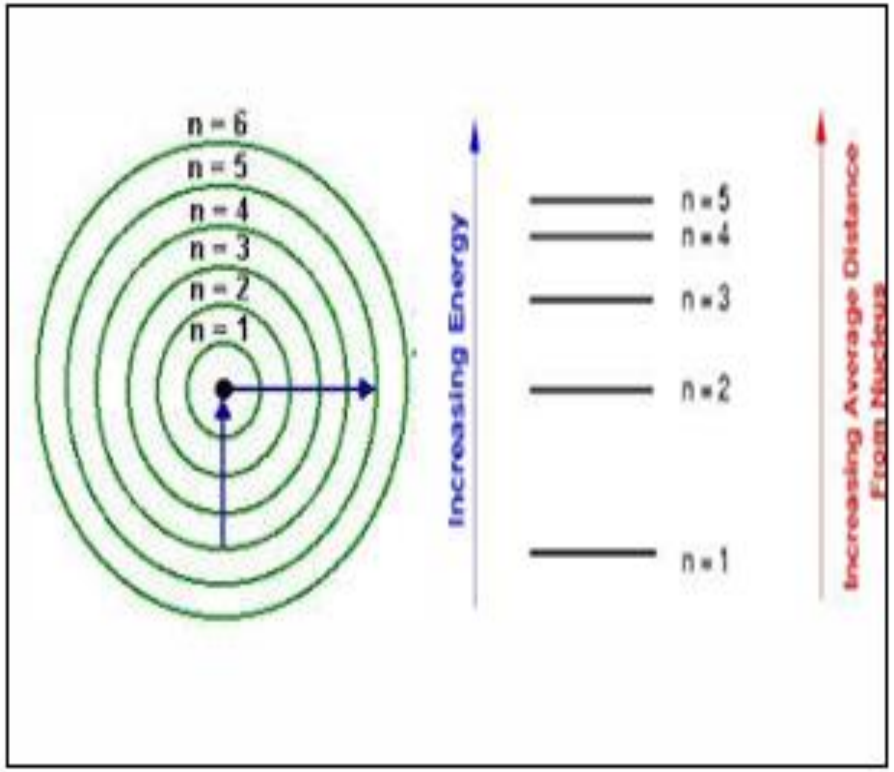
Photon energy is usually expressed in terms of electron-volts (e V). The photon energy (in e V) corresponding to light of wavelength λ is given by:

$$E = 12{,}400 / \lambda$$

Where λ is in Angstrom unit.

ENERGY LEVELS

- The light energy cannot take arbitrary values but must be multiples of photon energy hν. It was similarly established that the electrons in an atom cannot have arbitrary amounts of energy, but they take only discrete energies. This is a consequence of the Bohr's postulate of permitted orbits.
- In each of the permitted (stationary) orbits, the electron has a specific amount of energy and cannot possess any other energy value. The energy of electron at a very large distance from the nucleus is purely kinetic energy and it is assigned a positive value. As the distance between nucleus and electron decreases, the kinetic energy decreases.
- The energy levels are schematically represented by horizontal lines drawn to an energy scale. For example, electron orbits and the corresponding energy levels of the hydrogen atom are shown in figure below.



Electron orbits and the corresponding energy levels of the hydrogen atom.

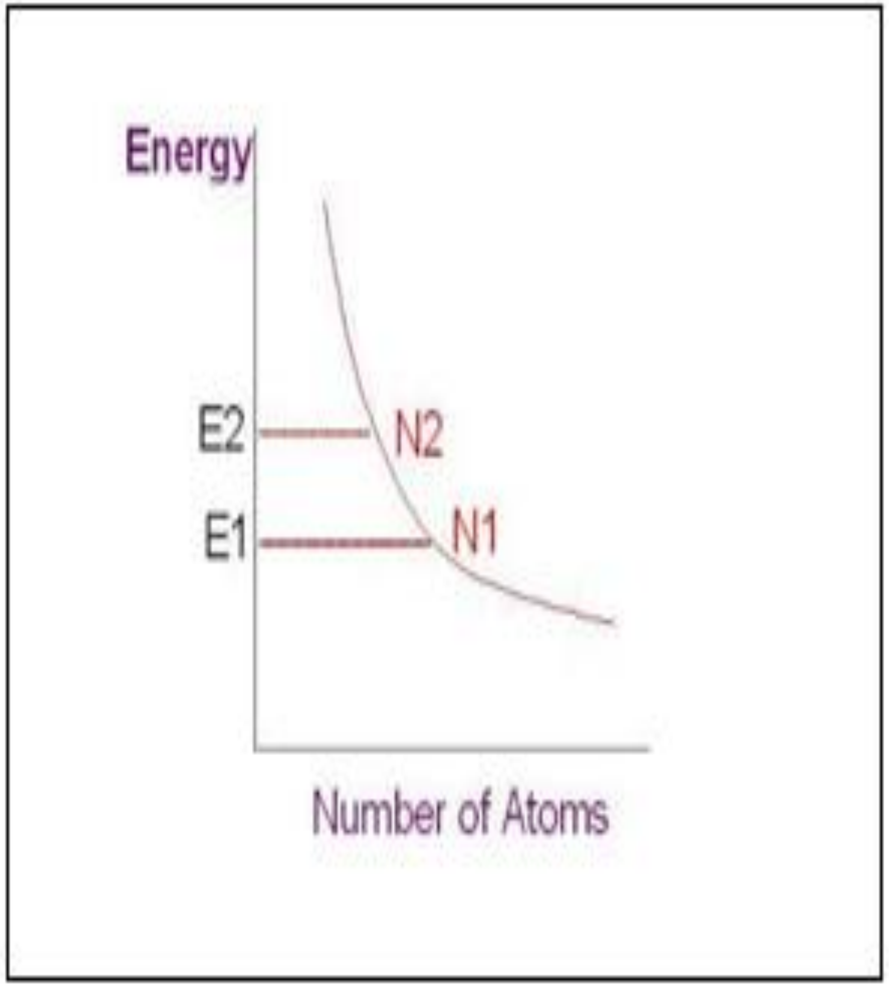
- The atom is in its lowest possible energy level when the electron is in the innermost orbit, closest to the nucleus. Then, the atom is said to be in the ground state. An electron in this ground state is stable and moves in this orbit continuously without emitting energy. If electron in ground state absorbs energy in some way, it will go to a higher energy level and the atom is said to be excited.
- The passing of an electron from one energy level to another level within the atom occurs in a jump which is called a quantum transition.
- The electron transitions may be induced by a variety of ways. Interaction with light photons is one of the means of supplying energy to orbital electrons which causes upward electron transitions and sends the atom into its excited state.

POPULATION

- The atoms of each chemical element have their own characteristic system of energy levels. The energy difference between the successive energy levels of an atom is of the order of 1 eV to 5 eV.
- - The number of atoms per unit volume that occupy a given energy state is called the population of that energy state. The population N of an energy level E depends on the temperature T. Thus,

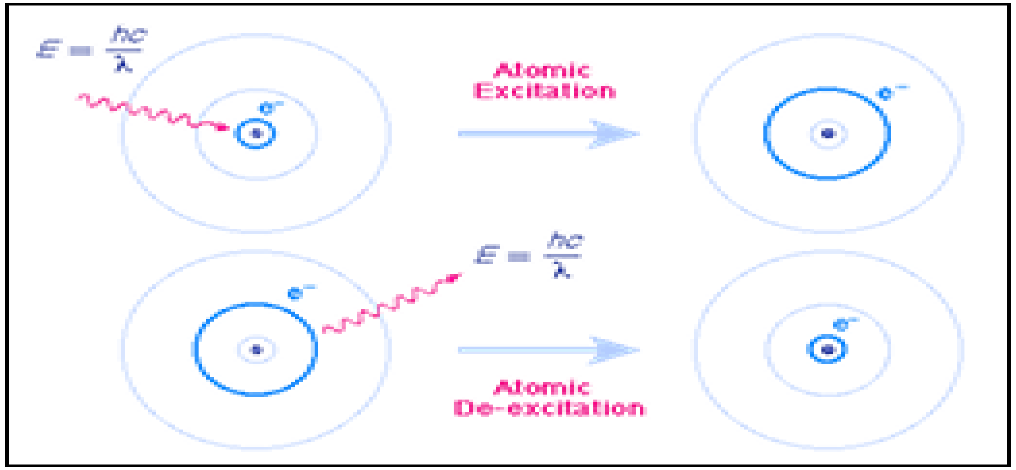
$$N = e^{-E/kT}$$

Boltzmann's equation Where k is known as the Boltzmann constant.

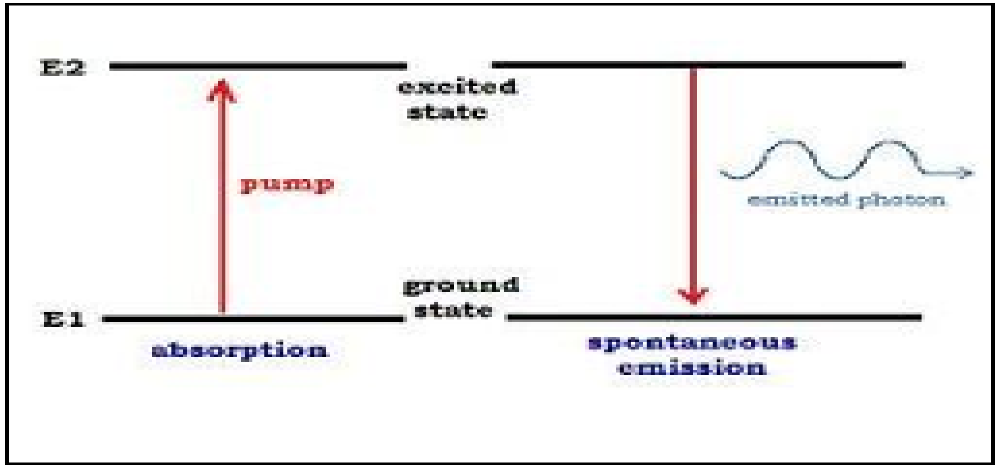


ABSORPTION AND EMISSION OF LIGHT

- In an atom, an electron in the ground state is stable and moves continuously in that orbit without radiating energy. When the electron receives an amount of energy equal to the difference of energy of the ground state and one of the excited states (i.e. outer orbits), it absorbs energy and jumps to the excited state. There are a variety of ways in which the energy may be supplied to the electron. One way is to illuminate the material with light of appropriate frequency $\nu = (E2 - E1)/h$. The photons of energy $h\nu = (E2 - E1)$ induce electron transitions from the energy level E1 to the level E2, as shown in figure below.



a) Absorbing energy, electron jumps from an inner orbit to an outer orbit.



b) Energy level representation of excitation and de-excitation of the atom.

- However, the electron cannot stay in the outer orbit (excited state) for longer time. The Coulomb attraction due to the positive nucleus pulls the electron back to the initial inner orbit and the electron returns to the ground state. The excited electron has excess energy equal to ($E2 – E1$) and it has get rid of this energy in order to come to the lower energy level. The only mechanism through which the electron can lose its excess energy is through the emission of a photon. Therefore, the excited electron emits a photon energy $h\nu = (E2 - E1)$ and returns to the ground state. This is the visualization of emission of light according to Bohr's quantum theory.
- When we see light from any source, we actually "see" electrons jumping from excited states to lower states. This type of emission of light which occurs on its own is known as spontaneous emission and is responsible for the light coming from candles, electric bulbs, fire, stars, sun etc. conventional sources of light.

EINSTEIN'S PREDICTION

- Einstein predicted in 1917 that there must be a second emission process to establish thermodynamic equilibrium. For example, if we illuminate a material with light of suitable frequency, the atoms in it absorb light and go to higher energy state.
- The excited atoms tend to return randomly to the lower energy state. As the ground state population is very large, more and more atoms are excited under the action of incident light and it is likely that a stage may be reached where all atoms are excited. Therefore, Einstein suggested that there could be an additional emission mechanism, by which the excited atoms can make downward transitions. He predicted that the photons in the light field induce the excited atoms to fall to lower energy state and give up their excess energy in the form of photons. He called this second type of emission as stymie on as **stimulated emission.**