

Ministry of Higher Education and Scientific Research

Al – Zahraa University for Women

College of Medical and Health Technologies



Theoretical

Laser Fundamentals

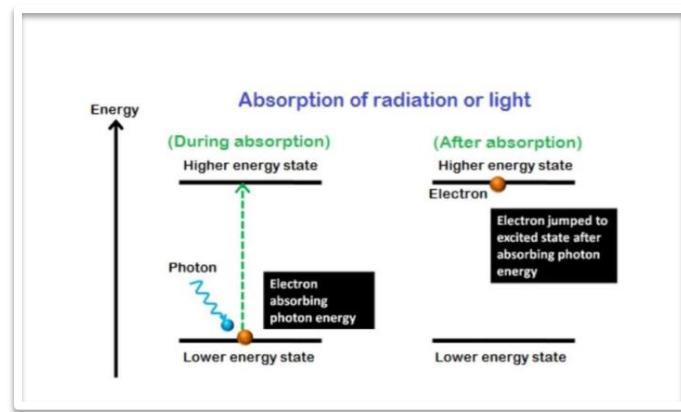
Lecture 2

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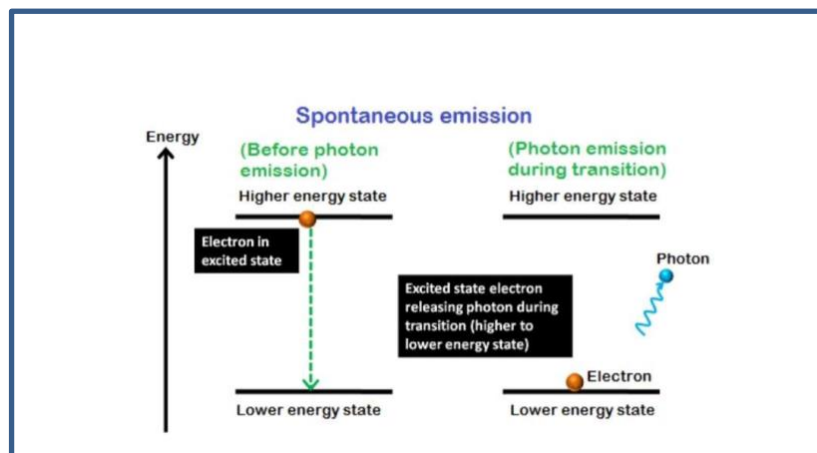
Laser Operating Principle

A- Absorption: The atoms of a material absorb the photons of radiation directed at them. The energy of the absorbed radiation raises electrons from low-energy orbits to high-energy orbits, placing the atoms in an excited state. Photons are only absorbed by a material if their energy exceeds the energy difference between the electron orbits of the atoms of that material. Therefore, materials are transparent to all radiation with frequencies below specific values determined by the atomic structure of those materials, such as glass.



Transfer an electron from one energy level to a higher energy level

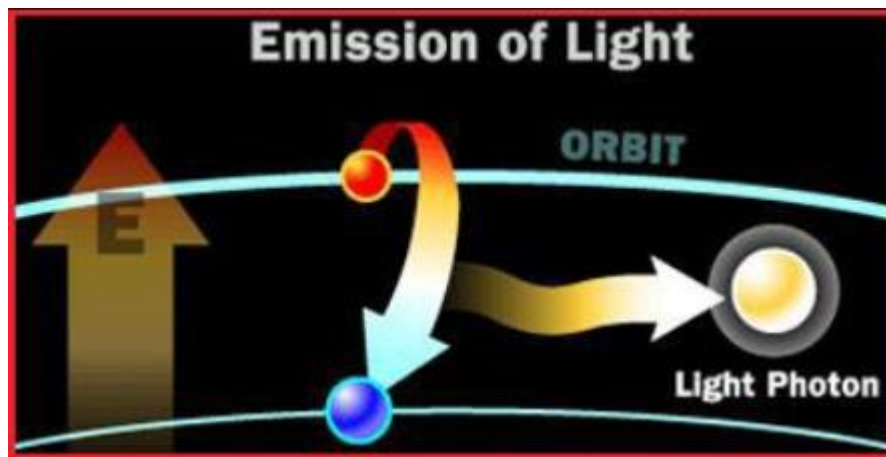
B-Spontaneous Emission: Excited atoms emit electromagnetic waves as electrons descend from high energy orbits to lower-energy orbits. The spontaneous radiation emitted by an excited material is called incoherent radiation because the electrons descend spontaneously and randomly between the atom's different orbits. Therefore, this radiation contains a very large number of frequencies [Ordinary light sources rely on the phenomenon of spontaneous emission in their operation]



How a photon is emitted when an electron moves from a higher energy level to a lower energy level

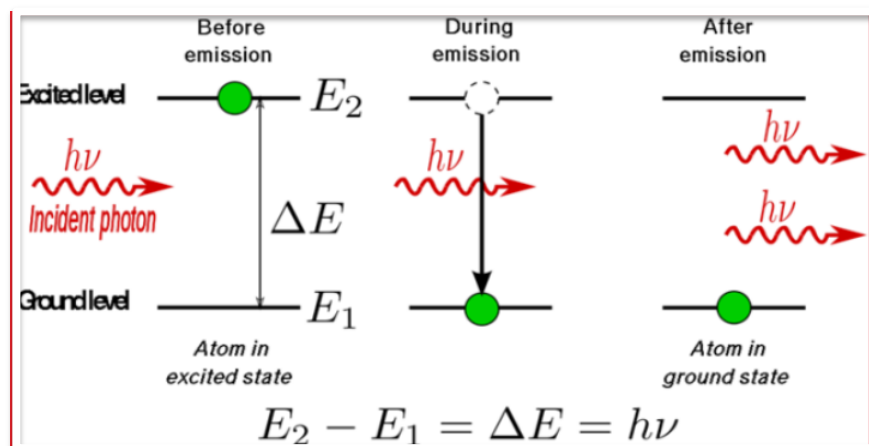
Stimulated Emission: In this, excited atoms emit electromagnetic waves as a result of electrons descending from high-energy orbits to lower-energy orbits. However, this does not occur spontaneously and randomly, as in spontaneous emission, but rather as a result of being stimulated by radiation of a specific frequency. The

stimulated radiation emitted by an excited material is called coherent radiation because the electromagnetic waves resulting from the descending electrons have a frequency and phase that are exactly equal to the frequency and phase of the waves that stimulated the electrons to emit radiation. Therefore, this radiation theoretically has a single frequency. The frequency of the radiation emitted by the material can be calculated by dividing the energy difference between the two orbits between which the electron moved by Planck's constant



The frequency of the radiation emitted by the material through the energy difference between the two orbits between which the electron moved

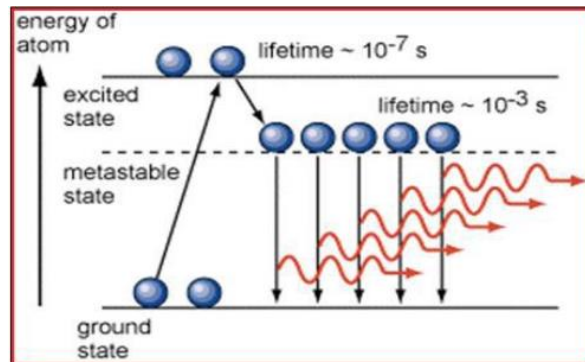
The stages of this phenomenon can be summarized as follows:



The phenomenon of stimulated emission

Population Inversion:

If the atomic system is not thermal equilibrium, the number of atoms in higher levels is greater than those in low-energy levels. This is contrary to Boltzmann distribution, see figure, meaning that the distribution of atoms in this case is inversed, it is called Population Inversion, see figure. This process increases probability of stimulated emission, it is the basis of producing laser. It happens when there is sufficient pump intensity, it is achieved by the presence of an energy level with a relatively longer lifetime and this level is called the metastable state.



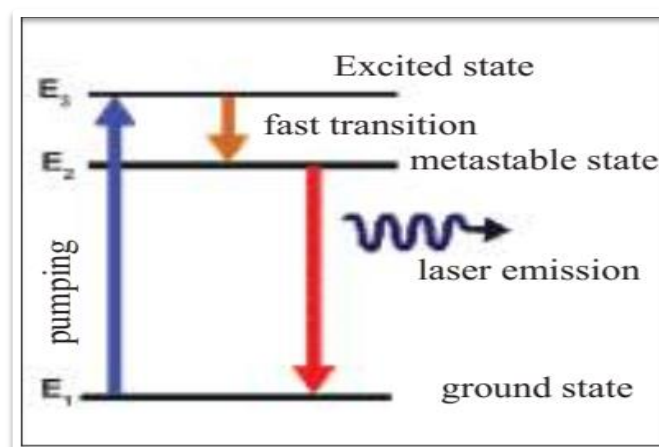
The inverted electron population distribution

Laser levels systems

Can be classified according to energy levels, which participate to achieve population inversion of the active medium in to two types:

1. Three- level system.
2. Four -level system.

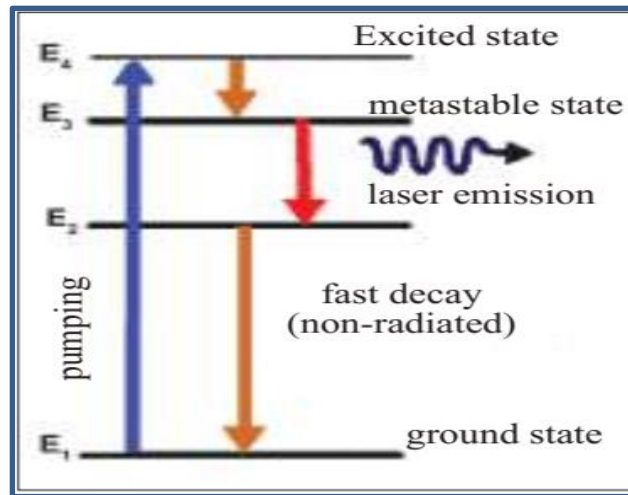
Three-level System: In this system, three energy levels are involved. These levels are: ground state of energy (E_1), intermediate state of energy (E_2) (metastable state), and excited state of energy (E_3), see figure .When most atoms or molecules are in the ground state of energy (E_1), this means that the active medium is in a stable state. But, when the active medium is excited by any of the pumping techniques, these atoms or molecules will be excited to (E_3). Which lifetime is short, around (10^{-8} s). To generate laser, there should be sufficient pumping energy to achieve population inversion. These atoms soon descend spontaneously from (E_3) level to metastable state (E_2) by thermal emission. The lifetime of this level is longer, around (10^{-3} s), which gathers atoms in level (E_2) larger than level (E_1), thus population inversion is achieved between these levels .Stimulated emission of laser happens. These systems require high pumping energy so that the number of excited atoms increases and becomes larger then ground state. Consequently, population inversion is achieved.



Three-level System

Four-level systems: In this system, four levels are involved (E_1 , E_2 , E_3 , E_4). In this process, ground state atoms (E_1) are pumped into excited state (E_4) of energy. See figure , then, these atoms soon fall to energy level (E_3). Thus, atoms gather at energy level (E_3) (metastate state in this system). Then, population inversion is

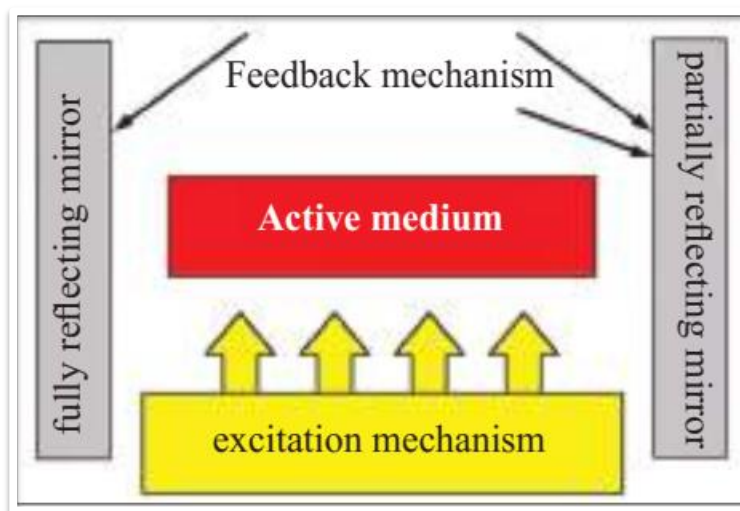
achieved between levels (E_3) and (E_2), with a minimum number of atoms at level (E_3), while level (E_2) is almost empty because of the fast fall of atoms. This system requires less pumping energy to achieve population inversion compared to three-level system.



Four-level systems

The diagram shown in figure, shows the most important components required in laser devices:

1. Active medium .
2. Optical resonator.
3. Pumping technique.



Laser construction diagram

1.Active medium: It is atoms, molecules or ions of matter whether its gaseous, liquid or solid state at which population inversion can takes place when the active medium is excited enough.

2.Optical resonator: A cavity with particular design consisting of two mirrors, the active medium is placed between them. The mirrors are facing each other; one of them reflects light totally, while the second is partially reflecting light (reflection depends on wavelength of generated laser), the incident ray on one of the mirrors reflects parallel to the optical axis of the two mirrors then incidents on the other mirror, then it reflects back and forth inside the optical resonator. In each reflection, stimulated emission happens, thus number of photons generated by stimulated emission increase enormously which causes amplification. Partial reflection mirror allows permeability of some incident light outside the optical resonator, as for the remaining light, it is reflected back again to perpetuating amplification process. See figure.

3.Pumping technique: It is a technique by which atom energy is prepared for use in the active medium by transforming it from stability state to excitation state. Pumping energy is obtained to excite the stable atoms in medium so that proper population inversion is achieved. This population inversion ensures generating laser.

There are three types of Pumping techniques:

a. **Optical Pumping:** it is used to generate lasers, which work within the visible or infrared region close to visible spectrum, like ruby laser and Neodymium laser. As flashing or continuous lights are used with high illumination power to excite the active medium, the walls of flashing lamps are made of quartz material and filed with different gases depending on the type of active medium, and they are in different shapes, spiral or straight. There is another technique for optical pumping in which a specific laser beam is used to make this beam excited the active medium to achieve population inversion and obtain a wave length laser that differs from the pumping laser beam.

b. **Electrical pumping technique:** this technique uses electrical discharge the gas placed inside the electric discharge tube. A high potential difference is applied between its sides of the tube, accelerated electrons collide with gas atoms or molecules. This exciting them into higher energy level. This technique is often used in gas lasers. This technique is also used in producing semiconductor laser.

c. **Chemical pumping technique:** in this technique, the chemical reaction between components of active medium is the source of providing energy to generate laser. This technique does not require an external power source.