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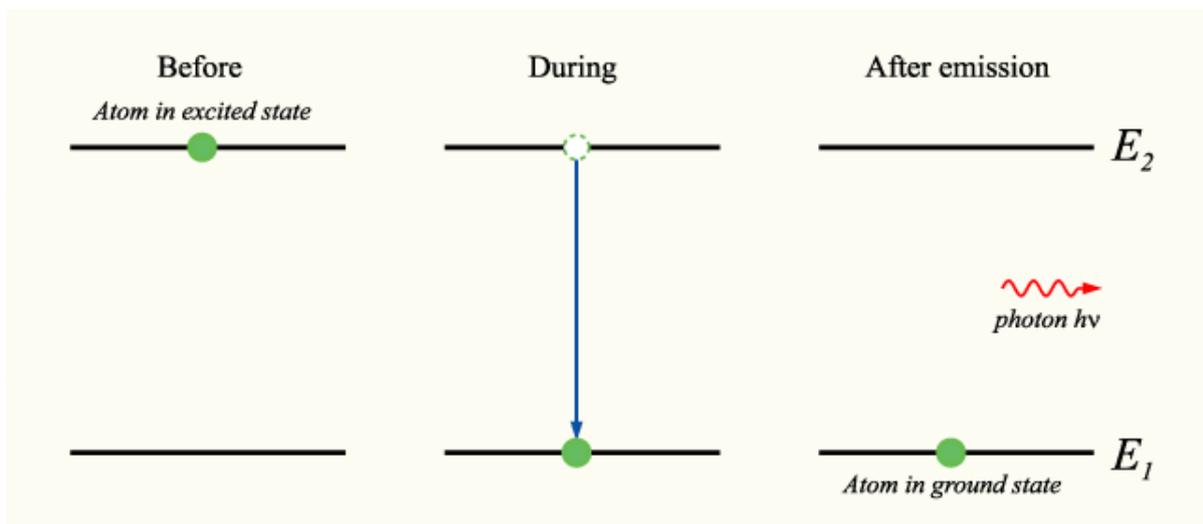
Al-Rasheed University College

DEP. OF MEDICAL INSTRUMENTATION TECHNIQUES ENGINEERING

Lecture 2 :

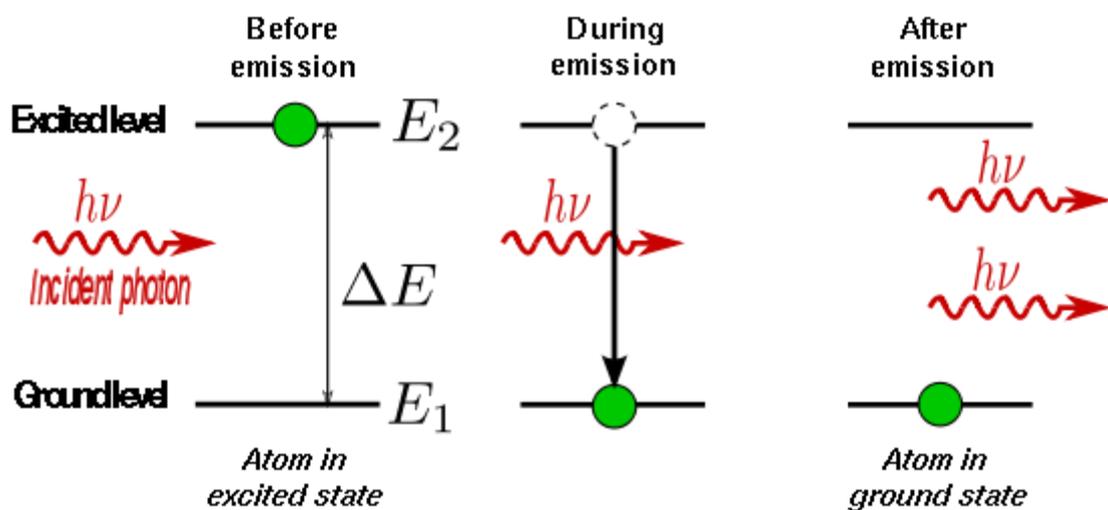
Spontaneous Emission & Stimulated Emission الانبعاث التلقائي والانبعاث المحفز

1. There are several ways an atom in the excited state can lose its energy and move to a lower energy-level such as :
 - a. Energy can be transferred to another atom .
 - b. It can be emitted as light .
2. There are two mechanisms by which light can be emitted :
 - a. Spontaneous emission
 - b. Stimulated emission
3. The absorption and spontaneous emission of a photon is shown in the following figure :



- A photon whose energy is exactly right to raise the atom from its ground – state to its excited-state is absorbed .
- The atom will stay in this excited – state for a period of time known as "spontaneous life time" which is a characteristic time known for a particular transition (\sim nanosecond ns or \sim microsecond μ s) ; However, notice that longer and shorter time are also known .
- Eventually , the atom will spontaneously emit the photon in a random direction .

4. The process of stimulated emission is shown in the following figure :



$$E_2 - E_1 = \Delta E = h\nu$$

- i. As before , a photon raise the atom to its excited –state .
- ii. A second photon with exactly the same energy as the absorbed photon interacts with the excited atom and stimulates it to emit a photon and return back to the ground-state . This must be done long before the spontaneous life-time has elapsed .
- iii. The second photon is not absorbed by the atom , but its presence causes the atom to emit a photon together with the stimulating photon.

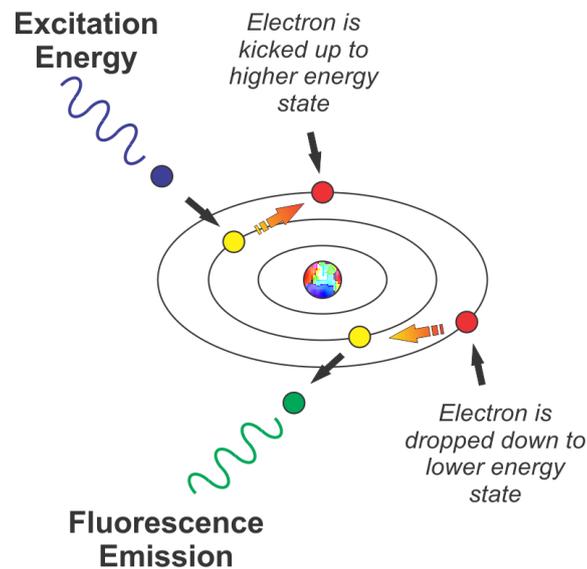
Notice

The stimulated emission of both photons has the following important properties :

- A. Both photons (emitting and stimulating light photons) are leaving in the same direction defined by the stimulating photon .
- B. Both photons have the same energy , hence they have the same wavelength (same frequency) .
- C. Both photons are in phase (same phase).

Remarks

1. There are unlimited number of energy-levels can be possessed by any material ; The first level E_0 is called the "ground-level " or " the normal-level" . The atoms in this level are usually in a stable-state .
2. Absorption process can be explained with the following figure :

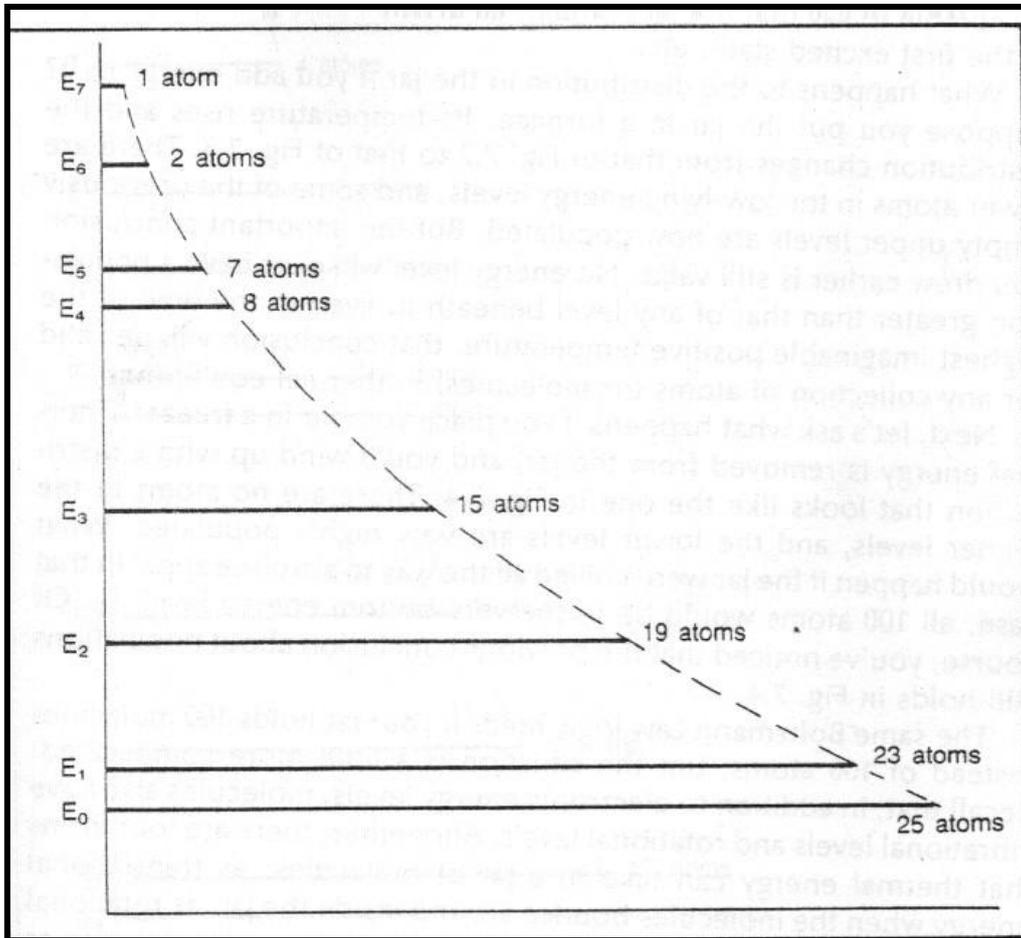


If a photon whose energy is exactly equal to $(E_1 - E_0)$ is incident on an atom in the ground-level, the atom will absorb this energy and get excited to the energy-level E_1 ; This phenomena is called "absorption".

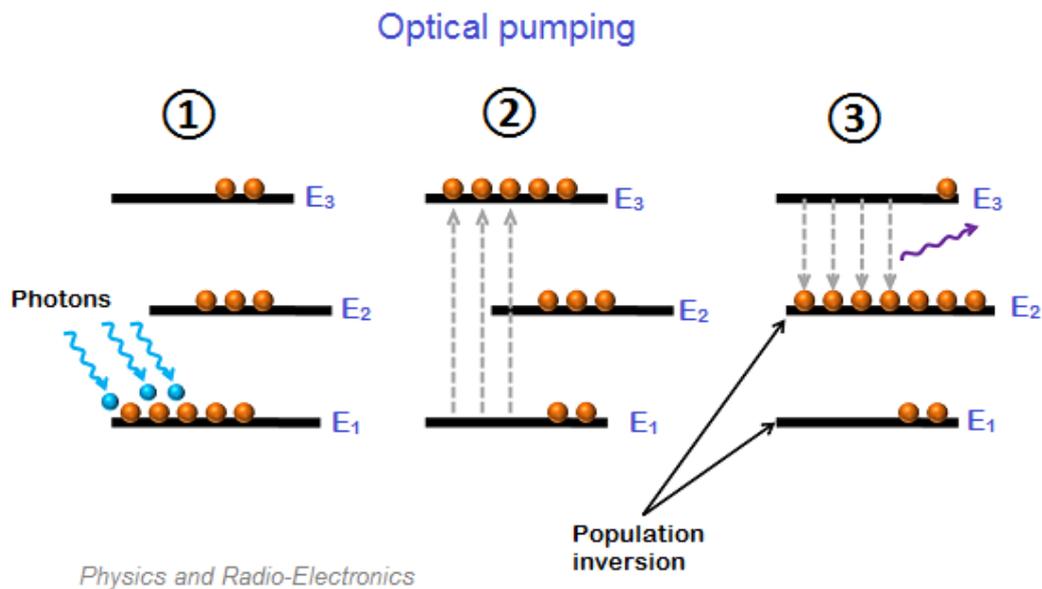
3. The atom will stay in the excited-state for a period of time (spontaneous life-time) which is (\sim ns or μ s) then, spontaneously emit the photon in a random direction and return back to the normal-state.
4. To control the emission with amplification, the stimulated emission is introduced. After absorption of a photon, a 2nd photon with exactly the same energy as the absorbed one can be interacted with this excited atom and stimulates it to emit a photon in a time long before the spontaneous life-time, then, return back to the ground-level.
5. This stimulated emission has characteristics that both photons are leaving with the same properties mentioned before.
6. Accordingly, we conclude that there will be a construction between the two light waves or it may said to be amplified. This the 1st step for lasing.

Population Inversion التوزيع العكسي

1. Boltzmann's law (which is one of the fundamental laws of thermodynamics) gives the population of each energy-level as shown in figure bellow.



2. If we add energy to the material (for example putting the container in a furnace) , the temperature will rise and the distribution will change.
3. When light source provides enough energy to the lower energy state E_0 electrons in the laser medium, they jump into the higher energy state E_3 . The processes of 3-level gain medium start and the population inversion can be achieved. **This is called optical pumping.**

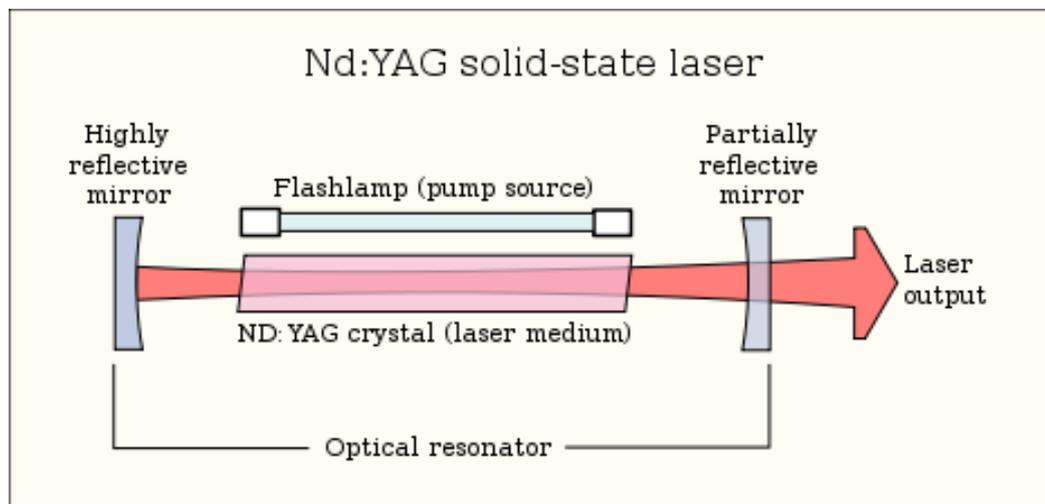


4. Population inversion is the state in which the number of atoms in higher energy state is more than those in lower energy state. It is required in laser **so that stimulated emission is more probable.**

Laser Device Construction بناء الجهاز الليزري

A laser is constructed from three principal parts:

- An energy source (usually referred to as the *pump source*),
- A *gain medium* or (*laser medium, active medium*) and
- Two or more mirrors that form an *optical resonator*.
-



1. Pump source

The *pump source* is the part that provides energy to the laser system.

Examples of pump sources include electrical discharges, flashlamps, arc lamps, light from another laser, chemical reactions and even explosive devices.

The type of pump source used principally depends on the *gain medium*, and this also determines how the energy is transmitted to the medium.

A helium–neon (HeNe) laser uses an electrical discharge in the helium-neon gas mixture, a Nd:YAG laser uses either light focused from a xenon flash lamp or diode lasers, and Excimer lasers use a chemical reaction.

2. Gain medium / Laser medium / Active medium

The *gain medium* is the **major determining factor of the wavelength of operation**, and other properties, of the laser.

Gain media in different materials have linear spectra or wide spectra. *Gain media* with wide spectra allow tuning of the laser frequency.

There are hundreds if not thousands of different gain media in which laser operation has been achieved.

The gain medium is excited by the pump source to produce a population inversion, and it is in the gain medium where spontaneous and stimulated emission of photons takes place, leading to the phenomenon of optical gain, or amplification.

Examples of different gain media include:

- Liquids, such as dye lasers. These are usually organic chemical solvents, such as methanol, ethanol or ethylene glycol.
- Gases, such as carbon dioxide, argon, krypton and mixtures such as helium–neon. These lasers are often pumped by electrical discharge.
- Solids, such as crystals and glasses. The solid *host* materials are usually doped with an impurity such as chromium, neodymium, erbium or titanium ions. Typical hosts include YAG (yttrium aluminum garnet),
- YLF (yttrium lithium fluoride), sapphire (aluminum oxide) and various glasses. Examples of solid-state laser media include Nd:YAG, Ti:sapphire, Cr:sapphire (usually known as ruby), Cr:LiSAF (chromium-doped lithium strontium aluminium fluoride), Er:YLF, Nd:glass, and Er:glass. Solid-state lasers are usually pumped by flashlamps or light from another laser.
- Semiconductors, a type of solid, crystal with uniform dopant distribution or material with differing dopant levels in which the movement of electrons can cause laser action. Semiconductor lasers are typically very small, and can be pumped with a simple electric current, enabling them to be used in consumer devices such as compact disc players. See laser diode.

3. Optical resonator

The *optical resonator*, or *optical cavity*, in its simplest form is two parallel mirrors placed around the gain medium, which provide feedback of the light.

The mirrors are given optical coatings which determine their reflective properties.

Typically, one will be a high reflector, and the other will be a partial reflector. The latter is called the output coupler, because it allows some of the light to leave the cavity to produce the laser's output beam.

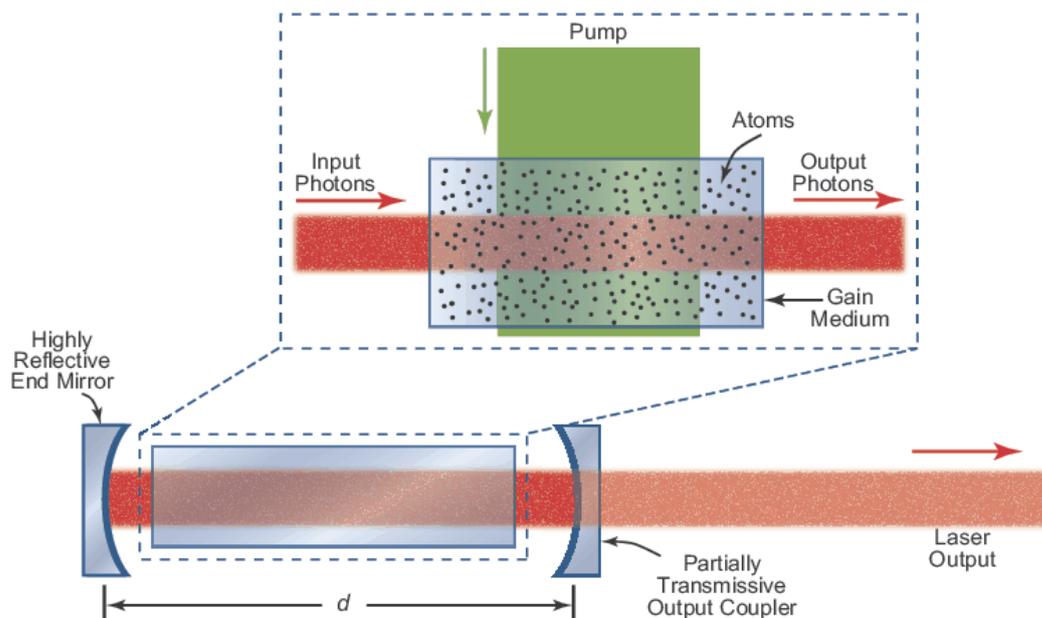
Light from the medium, produced by spontaneous emission, is reflected by the mirrors back into the medium, where it may be amplified by stimulated emission.

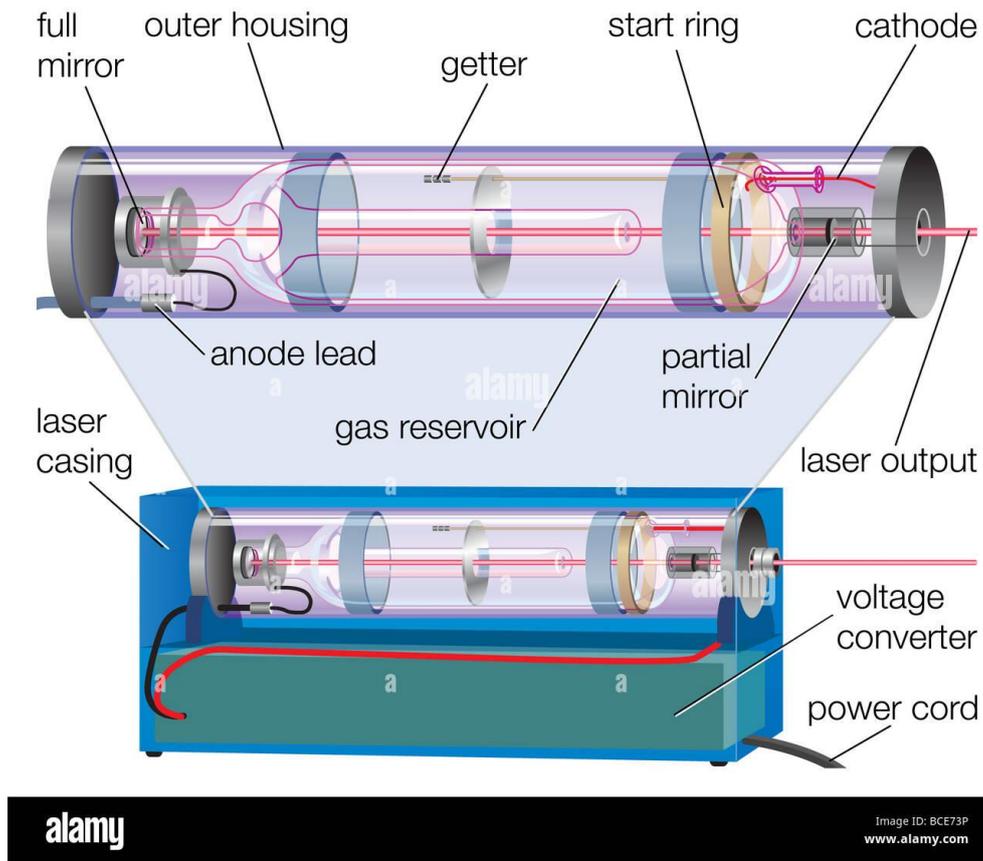
The light may reflect from the mirrors and thus pass through the gain medium many hundreds of times before exiting the cavity.

In more complex lasers, configurations with four or more mirrors forming the cavity are used.

The design and alignment of the mirrors with respect to the medium is crucial for determining the exact operating wavelength and other attributes of the laser system.

Other optical devices, such as spinning mirrors, modulators, filters, and absorbers, may be placed within the optical resonator to produce a variety of effects on the laser output, such as altering the wavelength of operation or the production of pulses of laser light.





Notice

There are four essential or basic components of laser, may be listed as:

- **Active medium.**
- **Excitation mechanism.**
- **Feedback mechanism.**
- **Output coupler.**

Operation of a Laser Principle

To generate population inversion, a multi level scheme is used:

- 1) Atoms are pumped into the highest of three levels.

- 2) Spontaneous de-excitation from the pump level to the metastable level.
- 3) Laser emission between the metaestable level and the ground state.
- 4) Alternatively, if a fourth excited level is included as lower laser level, which relaxes fast into ground state, lasing is favored since the bottom level involved is empty.