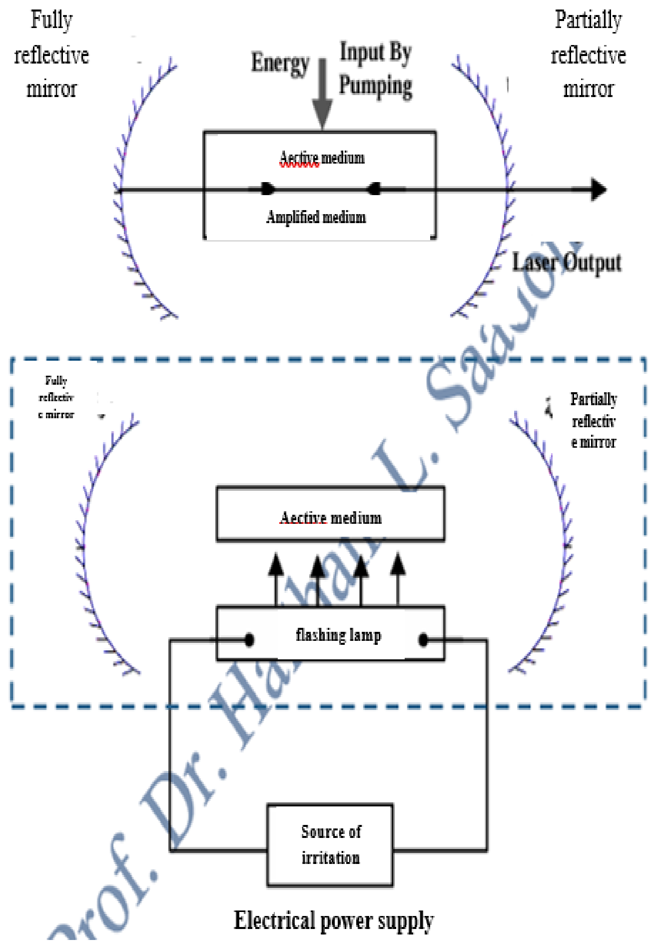
LASER



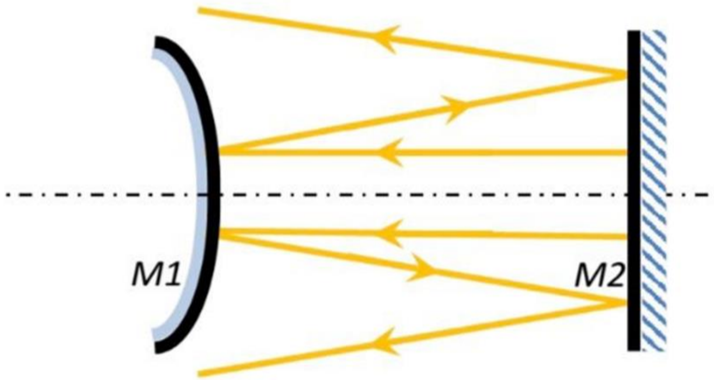
Basic diagram of a laser device

Stability Resonator

Generally, a resonator consists of two mirrors with different curvatures. The radius of curvature (R) of the mirror can be positive, as in a concave mirror, or negative (R), as in a convex mirror, or equal to infinity, as in a plane mirror. Therefore, the important calculations for any of these shapes lie in calculating the diffraction loss, the resonance frequency, and the amplitude of the oscillation mode. Depending on all of this, the resonator is classified into two main types:

Stable Resonator: In which the curvature of the two mirrors is such that it keeps the light close to the optical axis of the resonator.

Unstable Resonator: A resonator is described as unstable when the beam deviates after repeated reflections back and forth between the mirrors in a direction that moves away from the optical axis of the resonator. Figure shows a diagram of an unstable resonator.



Stable Condition of Resonator

From geometrical optics rules, the stability conditions of a general spherical resonator can be deduced. The stability condition depends on the geometrical properties of the resonator, i.e., on the parameters (L, R_1, R_2). To reach this condition, it is convenient to define two parameters specific to the laser cavity, where:

$$g_1 = 1 - L/R_1$$

$$g_2 = 1 - L/R_2$$

And the condition for resonator stability results from the product of the two parameters (g_1, g_2) such that it is greater than zero and less than one, according to equation (5):

$$0 < g_1 . g_2 < 1$$

Example: Investigate the stability of a spherical resonator with two mirrors, each with a radius of curvature (R).

Given that: The distance between the two mirrors (L) is:

(1) L = 2R

(2) L = R"

(3) L = R/2

Example: Check the stability of the resonator when

$L = 1.8\ r_1$

$L = 0.8\ r_1$

Example: Verifying the stability of the spherical resonator of mirrors when.

$r_1 = 2L$

$r_1 = 1.2L$

Question: In a neodymium YAG laser, the upper state lifetime ($\tau_2 = 230$ sec) and the spectral linewidth $\Delta\nu = 3 \times 10^{12}$ Hz, while the refractive index of the medium is 1.82. Calculate the population inversion required to obtain a net gain coefficient of $1 m^{-1}$.

Question: Calculate the threshold pump power for a Neodymium-YAG laser, given that the critical population inversion is $(9x10^{21}\} m^{-3}$, the average spontaneous emission lifetime is 300 sec, and the energy of the upper laser level is 1.6 ev

Question: When a transition occurs between two energy levels (.89 ev) at room temperature, calculate the wavelength that is emitted?

Question: Calculate the ratio between two energy levels at room temperature 300 K according to the Boltzmann statistic if the wavelength incident on this system is 590 nanometers? Then find the energy required to make this ratio equal to half?

Prove that $R = (A/\ \rho_\nu B) = (e^{(h\nu/kT)} - 1)$

where R represents the ratio of spontaneous emission rate to stimulated emission rate.

1. Find the value of R for an incandescent lamp at a temperature of 2000 Kelvin and an emission frequency of 5×10^14 Hertz.

2. Find the value of R for yellow light (wavelength 5900 Angstroms) at room temperature (300 Kelvin).

3. At what temperature is the stimulated emission rate equal to the spontaneous emission rate for yellow light (wavelength 5900 Angstroms)?

4. What is the wavelength at which R=1 at room temperature?

Reverse Pumping and Threshold Condition

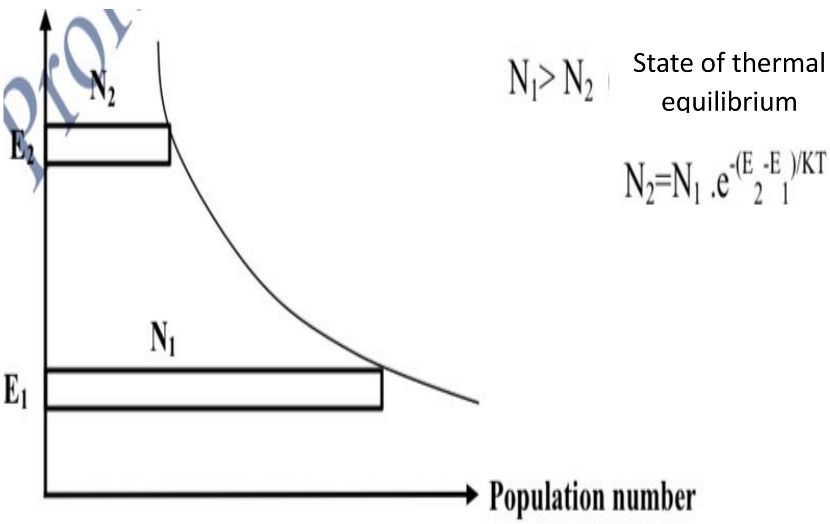
The gain and gain coefficient in the stimulated emission process are considered to be relatively small values. Therefore, it is necessary to minimize all sources of loss within the laser device, including losses resulting from absorption by the resonator mirrors. To reduce these losses, dielectric coatings with high reflectivity are used to coat the mirrors in multiple layers instead of a metal coating. These successive layers have a thickness of $\lambda / 4$ and their indices of refraction are successive

indices (high, then low), are deposited sequentially on the glass substrate. Due to the phase difference that occurs at the interface between any two layers, all reflected rays are in phase and interfere constructively. Typically, more than twenty layers are used to achieve a reflectivity close to 99.9%

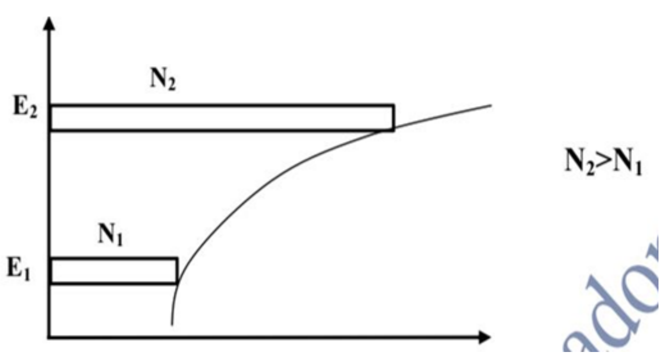
Population Inversion

In ordinary circumstances, and under thermal equilibrium conditions, the distribution of atoms or molecules in a system with multiple energy levels follows Boltzmann's distribution. This means that the number of atoms in a higher energy level is less than the number in a lower energy level. This is because at lower temperatures, most atoms occupy the ground state (lowest energy level). As the temperature increases, more atoms are excited to higher energy levels.

This means that under normal conditions and in thermal equilibrium, the number of atoms in the excited state is fewer than those in the ground state (the first level), as illustrated in the figure



However, in the case of population inversion, the number of atoms or molecules in the excited energy level (E2) is greater than the number in the ground state (E1). This condition is necessary to achieve stimulated emission, which is the fundamental principle behind laser operation.



Population inversion conditions

1There must be two energy levels E2>E1

2There must be a source to provide energy to the medium (pumping source).

3 The atoms must be raised to the excited state.

Einstein coefficient describes the probability of transition between energy levels.

Spontaneous or self-emission is of two types: radioactive decay accompanied by the emission of an electromagnetic wave, and non-radioactive decay not accompanied by the emission of an electromagnetic wave.

The basic condition for laser oscillation and its acquisition of the characteristics of coherence and directionality is **feedback**. Without this condition, the laser works only as an **amplifie**r of the narrow light beam and loses its basic features

Spectral line: When an atom moves from one energy level to another, it does not emit or absorb a specific wavelength or frequency, but rather a narrow range of frequencies described in terms of the shape of the spectral line of emission or absorption.

The shape of the spectral line is given by the Gauss function

Q: Compare between spontaneous, stimulated emission, and absorption.

A: Stimulated emission: The process of emitting photons from an atom under the influence of an external photon with suitable specifications, causing it to drop to a lower quantum state. (The light is coherent, monochromatic, high intensity, highly directional, and requires population inversion).

$dN2/dt = B_{21}N_2\ p(hv_{12})$

Emission spontaneous: This is the spontaneous emission of a photon from an atom as it transitions from a higher energy level to a lower energy level. The emitted light is incoherent, has different wavelengths, and travels in different directions. There is no need for a population inversion

Absorption: When light passes through a group of atoms, the atoms will absorb this light and thus gain energy. The probability of absorption is proportional to the intensity of the light and the number of atoms in the ground state, according to the equation:

dN1/dt = B12. N1.p(hv12)

Q: Compare between pulsed and continuous lasers:

A: Continuous laser: The amplitude of the laser wave is constant over time and continuous, as in helium lasers.

Pulsed laser: The amplitude of the laser wave varies with time between maximum and minimum values, as in ruby lasers.

What is the difference between laser and ordinary light?

Ordinary Light	Laser Light
• Spectral PurityLower spectral purity due to emission at various wavelengths	• Higher spectral purity as emission occurs at nearly a single wavelength
•	•
• Coherence Lower coherence due to lower spectral purity	• High temporal coherence due to high spectral purity
• Intensity Low intensity due to larger divergence	• High intensity due to concentration of emitted energy in a narrow beam
• obeys the inverse square law	• does not obey the inverse square law

Why do we study lasers?

Because it has unique properties such as directionality and coherence.

Q. On what does absorption depend?

The rate of decay of the population in the ground state

Photon density.

Q. On what does spontaneous emission depend?

The number of atoms in the excited state.

Q. What are the characteristics of photons resulting from stimulated emission?

1. The same energy as the incident photon.

2. The direction of the outgoing photon is the same as the direction of the incident photon.
3. The same phase as the incident photon on the atom.

Q. What are the conditions for laser induction?

1. If the ratio is less than one, the absorption process is greater in the system and the laser event does not occur.
2. If the ratio is equal to one, the absorption process is equal to the stimulated emission rate, and thus there is no net gain.
3. If the ratio is greater than one, the stimulated emission process is greater and the process of light amplification occurs, i.e., a laser output can be obtained.

Energy Difference: The difference between the energy value in the higher and lower levels."

Total Loss in a Laser Device:

There are several factors that cause loss in a laser device. Although their magnitudes vary depending on the type of laser, most of them share commonalities, the most important of which are:

Losses from the resonator mirrors: The resonator mirrors are made so that one of them has total reflection and the other has partial reflection, which is the mirror from which the laser exits. There are also other losses in the mirrors resulting from absorption, evaporation, and diffraction.

Losses in the active medium of the laser: This is due to the occurrence of other transitions unrelated to the laser transition. This occurs as a result of the medium's absorption of a broad range of pumping energy, in addition to the loss resulting from evaporation due to the loss of the active medium's homogeneity. This loss is particularly found in solid-state lasers.

All types of losses, except for losses due to reflection in the mirrors, are denoted by the quantity y. Consequently, the gain coefficient will decrease to (G-y). To calculate the gain at the threshold, we will calculate the amount of change in the intensity of radiation as a result of a single round trip within the resonator. Assuming that the medium fills the space between the two mirrors M1 and M2, which have a reflectivity of R1 and R2 respectively, and that they are a distance l apart:

$$\mathbf{I = Io\ e^{(G-y)L}}$$

After reflection from mirror M2, this intensity will become:

$$\mathbf{I = R2Io\ e^{(G-y)L}}$$

And after a complete round trip, the intensity becomes:

$$\mathbf{I = R1R2Io\ e^{2L(G-y)}}$$