Laser lectures Third class

Directed by Dr. Erada Al Dabbagh

University of Mosul
College of science
Department of Physics
Third Stage
Lecture 1

Laser

2024-2025

Lecture 1: Introduction to laser basic

Preparation
Dr. Erada Al- Dabbagh

25/9/2023

Introduction

There is nothing magical about laser, it can think of as just another type of light source. The word laser is an acronym for **Light Amplification by Stimulated Emission of Radiation**. The laser makes use of processes that increase or amplify light signals after those signals have been generated by other means. These processes include, 1) stimulated emission, a natural effect that was deduced by considerations relating to thermodynamic equilibrium, 2) optical feedback (present in most laser) that is usually provided by mirrors. Thus, in its simplified form, a laser consists of gain amplifying medium (where stimulated emission occurs), and as set of mirrors to feed the light back into the amplifier for continued growth of the developing beam, 3) pumping, see Fig. (1).

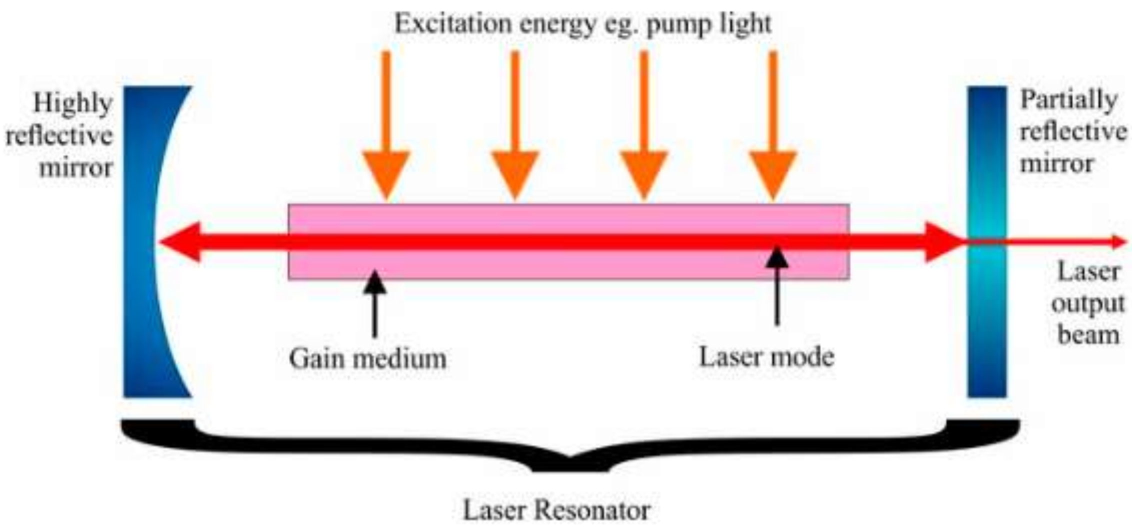


Figure (1): simplified schematic of typical laser

Simplicity of laser

The simplicity of a laser can be understood by considering the light from a candle radiates light in all directions, and therefore illuminates various objects equally if they are equidistant from the candle. A laser takes light that would normally be emitted in all directions, such as from candle, and concentrates that light into a single direction. Thus, if the light radiating in all directions from a candle were concentrated into a single beam of the diameter of the pupil of your eye (approximately 3mm), and if you were standing a distance of 1m from the candle, then the light intensity would be 1,000,000 times as bright as the light that you normally see radiating from the candle, *that is essentially the underlying concept of the operation of laser*. However, candle is not the kind of medium that produces amplification, and thus there are no candle lasers

Laser Spectrum and Wavelengths

Lasers span the wavelength range from the far infrared part of the spectrum (λ=1000 μm) to the soft -X-ray region (λ=3 nm), where soft X-rays: 1 nm to approximately 20-30 nm.

The Laser Idea:

There are three conditions to produce laser:

1. Population inversion.
2. Resonator.
3. Pumping scheme.

1. Population inversion

The Basic Transitions in Laser Medium:

Spontaneous, Stimulated Emission, and Absorption

Absorption Transition:

Consider two energy levels, 1 and 2 of some atoms or molecules, with energies E_1, and E_2 (E_2>E_1), where level 1 is the ground state or ground level.

Assume that the atoms initially lying in level 1. If this is the ground level, the atom will remain in this level unless some external stimulus is applied to it. If $\upsilon=\upsilon_o$ is incident on the material (where υ_o is the natural frequency of t material), in this case there is a finite probability that the atom will be raised to level 2 This is the **absorption process**.

Absorption is the process in which optical energy is converted to internal energy of electrons, atoms, or molecules. When a photon is absorbed, the energy may cause an electron in an atom to go from a lower energy level E_1 to a higher energy level E_2, see figure (1, a)

Spontaneous Emission

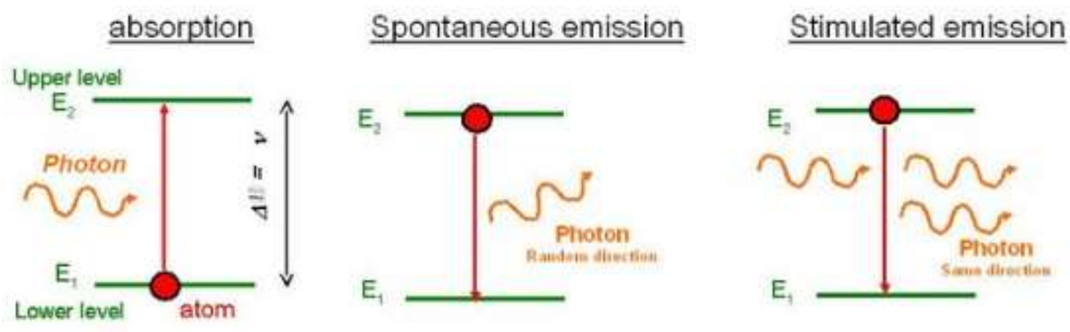
Let us assume that the atom is initially in level 2, Since E_2>E_1 the atom will tend to decay to level 1. The corresponding energy difference E_2- E_1 must therefore be released by the atom when this energy is delivered in the form of an electromagnetic (e.m) wave, the process will be called **spontaneous** or **radiative emission**. No photons are needed to initiate spontaneous emission. The frequency υ_o of the radiated wave is:

$\upsilon_o = (E_2 - E_1)/h$ ………1

where h is Planck's constant

$h\upsilon_o = E_2 - E_1$ ⟶ Photon energy ……….2

The decay can also occur in a non-radiative way, in this case the energy difference E_2-E_1 is delivered as (may go into kinetic or internal energy of the surrounding atoms or molecules), this phenomenon is called non-radiative decay, see figure (1. b)



a b c

Figure: (1) a: absorption transition, , b: spontaneous emission, c: stimulated emission

Stimulated Emission

Suppose that the atom is found initially in level 2 and that an e.m wave of frequency $\upsilon = \upsilon_o$ (i.e, equal to that of the spontaneous emitted wave) is incident on the material. Since this wave has the same frequency as the atomic frequency there is a finite probability that this wave with force the atom to undergo the transition 2→1. The energy difference E_2- E_1 is delivered in the form of an e.m wave that adds to the incident one. This is the phenomenon of **stimulated emission**, see figure (1, c).

What are the differences between spontaneous & stimulated emission?

1. **Spontaneous emission**→ the atoms emits an e.m wave that has
   a) **no definite phase relation with that emitted by another atom.**
   b) the wave can be emitted in any direction.
2. **Stimulated emissions** → since the process is forced by the incident e. m wave, the emission of any atom adds in phase to that of the incoming wave and along the same direction.

Rate Equations and Einstein Coefficients, or Probabilities for these emissions and absorption:

Let $N_2 \longrightarrow$ no. of atoms or molecules per unit volume which at time have lying in an energy level 2.

↓

"Population of high energy level"

$N_1 \longrightarrow$ no. of atoms or molecules per unit volume which at time have lying in an energy level 1.

↓

"Population of ground energy level"

The probability for the spontaneous emissions $\frac{dN_2}{dt}$

The rate of decay of the upper state population:

$$\left(\frac{dN_2}{dt}\right)_{sp} = -\left(\frac{dN_1}{dt}\right)_{sp} = -AN_2 \qquad \text{……………. 3}$$

(-) → time derivative is negative

(A)→ Einstein coefficient → rate of spontaneous emission, and it has units 1/s

$\tau_{sp} = 1/A \longrightarrow$ spontaneous emission life time

For non-radiative decay:

$$\left(\frac{dN2}{dt}\right)_{nr} = -N_2/\tau_{nr} \qquad \text{……………..4}$$

$\tau_{nr} \longrightarrow$ non- radiative decay life time.

for spontaneous emission, A and τ_{sp} depends only on the particular transition. For non- radiative decay, τ_{nr} depend not only on the transition but also on the characteristics of the surrounding medium.

The probability for the stimulated processes:

$$\left(\frac{dN_2}{dt}\right)_{st} = w_{21}N_2 \qquad \text{……………5}$$

where $\left(\frac{dN_2}{dt}\right)_{st} \longrightarrow$ the rate at which transitions 2→1occcur as a result of stimulated emission.

$w_{21} \longrightarrow$has the dimension of (time) $^{-1}$

w_{21} => depends on the particular transition and also on the intensity of the incident e. m wave. For a plane wave:

$w_{21} = \sigma_{21}$ F …………6

where F is the photon flux of the wave, σ_{21} is the stimulated emission cross section and depending on the characteristics of the given transition.

For absorption process:

$$\left(\frac{dN_1}{dt}\right)_a = -w_{12}N_1 \qquad ....7$$

where

$\left(\frac{dN_1}{dt}\right)_a \rightarrow$ the rate of the 1→2 transitions due to absorption.

$w_{12} \rightarrow \sigma_{12}$ F

$\sigma_{12} \rightarrow$ absorption cross section, which depends only on the particular transition.

For example, we can write the rate of absorption either as the change in population density with respect to time of the upper state or the change in population density with respect to time of the lower state.

$$-\left(\frac{dN_1}{dt}\right)_a = \left(\frac{dN_2}{dt}\right)$$

Summary:

1. In the spontaneous emission process, the atom decays from level of 2 to level 1 through the emission of photon.

2. In the stimulated emission process, the incident photon stimulates the 2 →1 transitions and we then have two photons.

3. In the absorption process, the incident photon is absorbed to produce the 1→2 transition.

Thus we can say that each stimulated emission process creates while each absorption process annihilates a photon.

https://www.google.com/search?q=laser+principles%2C+vedio&oq=laser+principles&gs_lcrp=EgZjaHJvbWUqBggAEEUYOzIGCAAQRRg7MgkIARBFGDsYgAQyBwgCEAAYgAQyCAgDEAAYFhgeMggIBBAAGBYYHjIICAUQABgWGB4yCAgGEAAYFhgeMggIBxAAGBYYHjIICAgQABgWGB4yCAgJEAAYFhge0gEKMTMxMTNqMGoxNagCCLACAQ&sourceid=chrome&ie=UTF-8#fpstate=ive&vld=cid:a94e395f,vid:R_QOWbkc7UI,st:0