GENERAL INFORMATION ARTICLE

LIGHTS AND LASERS

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INTRODUCTION

The main objective of this article is to briefly explain Laser and how it works. The laser is one of those great achievements/inventions that man has to his service. Its applications are numerous: used in microsurgery, thermonuclear fusion, telecommunications, holography, etc. One of the most popular applications is in the "world of sound and video", with the compact disks, CD-ROMS and DVD (digital video disk), which is based in a laser systems/device for reading information.

What is laser?

"Laser" stands for: Light Amplification by Stimulated Emission of Radiation. In other words, the laser is a radiation source, or light beam composed of three basic parts: an active medium, a "pumping" system and a resonant cavity. Its principle of operation, as its name implies, is based in a physical phenomenon which is "stimulated light emission".

Discovery of laser

The first "strong theory" about lasers was in 1960 when the laser technique (stimulated light emission) was perfected after the discovery of stimulated emission by Albert Einstein. It is also important to mention the main difference between a laser and a conventional light source: the light emitted by laser is concentrated, and the beam of light can be directed to a specific objective, while the light emitted by a conventional light source is diffused or spread in all different directions, as shown in figure 1.

ABSORPTION AND EMISSION

The atom is a "system" that posses a specific level of energy. If this "system" is subject to a radiation (excited by "packets", or quantum of light), its level of energy will increase because the electrons that are small "particles" (very small mass), can easily "jump"from an orbit near to the nucleous (orbit of slow velocity / spin) to another orbit far away from the nucleous (fast velocity orbit); under these conditions we can say that the atom is in an excited state.

On the contrary, when the electrons go back to an orbit closer to the nucleous, the atom gives up an amount of energy, (as photons). Under these conditions we can say that the atom is again in its "basic" state (non-excited state). This is illustrated in figure 2.

In figure 2, part A, there is an atom in an initial state, with certain level of energy; this atom posses an electron in a certain orbit. If this atom releases a photon, the electron will "jump" toward an orbit closer to the nucleous. This is because the emitted photon represents a small loss in the electron's energy, therefore, it is now easier for the nucleous to attract the electron even more, (the energy of the nucleous attracts the electron,

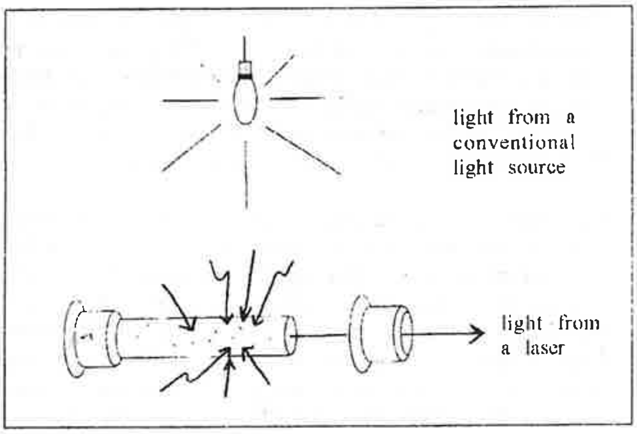

Figure 1. **Laser and conventional light source.**

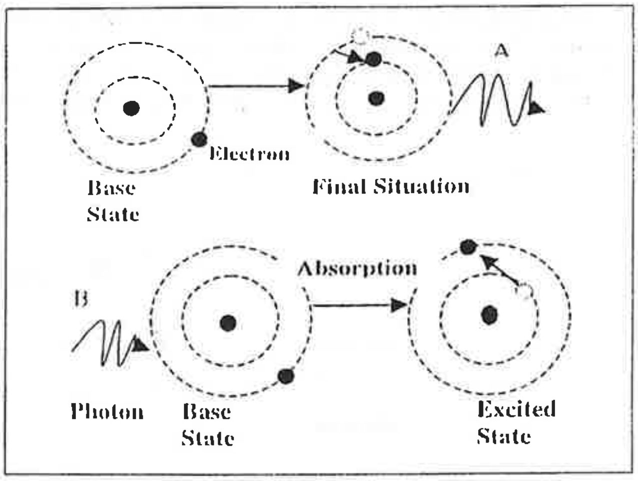

Figure 2. **Photons Emmision and Absorption's phenomenon.**

but the electron's velocity around an orbit, allows it the possibility of escape; there is a centrifugal force along with a centripetal force toward the interior of the atom. The interaction between these two opposite forces determines the distance of the electron's orbit around the nucleous). This is the phenomenon known as "emission", and it is the basic principle for the existence of light, since each emitted photon is really, emitted light.

In figure 2 part B, the inverse situation is illustrated. The energy level of the atom is increased, due to the arrival of a "packet" or quantum of energy. This phenomenon is known as "absorption". When this situation occurs, the initial amount of light decreases and the atom changes its initial state (non-excited state) to an excited state because it has gained energy, allowing the electron to move further away from the nucleous.

CONVENTIAL LIGHT SOURCES

Conventional light sources are simply, a candle, an incandescent lamp, the sun, etc. They produce light basically because their internal atoms have been excited beyond their stable state, therefore, their electrons are "jumping" to low energy level orbits, releasing during this process enough photons to produce light.

For example, the energy source for the incandescent light is the electrical current (which is only a huge amount of electrons) flowing from one point to another. During this flow, these particles collide against the electrons of the incandescent material of the device, making them to migrate to an orbit of higher energy level; but since this new state is not very stable, sooner or later the electrons will return to their normal orbit, releasing a photon during this process.

With the electrons back in their normal orbit, there is always a possibility of the arrival of a "travelling" electron and a collision that will send it back to a higher energy level. This process will repeat again and again while there is electric flow through the device's material. This same process occurs in the case of a candle, except

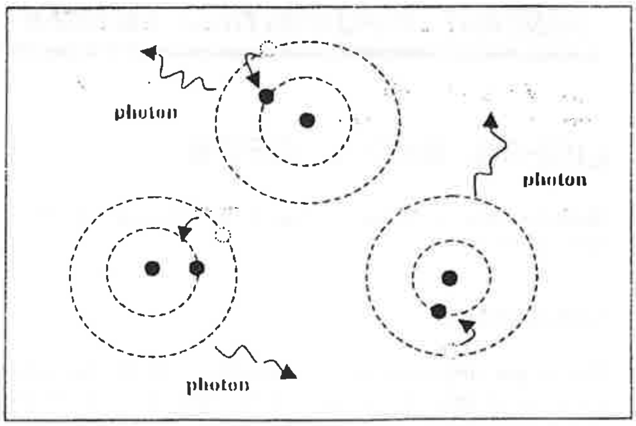

Figure 3. **Spontaneous emission.**

that the source of energy in that case is the combustion of the material.

Light produced by these sources is called "incoherent light", because it is produced as a "group of waves" that reinforce or cancel among themselves, depending on their travelling direction, as shown in figure 3.

The incoherence of this type of light is "spatial" because the light is randomly emitted by atoms located far away from one another, therefore, it arrives to one point, following different optical paths.

The incoherence is also in time (temporal) because, it is light emitted at different frequencies, characterizing it as polychromatic. In summary, light generated from conventional sources is spatial and time incoherent; on the other hand, light emitted from a Laser is spatial and time coherent. In other words; light from a laser is emitted as a beam of only one color; and light from other sources is propagated as radiation in different directions and is multicolored (polychromatic).

INDUCED EMISSION OR STIMULATED EMISSION

In this case, we have an atom in an excited state and

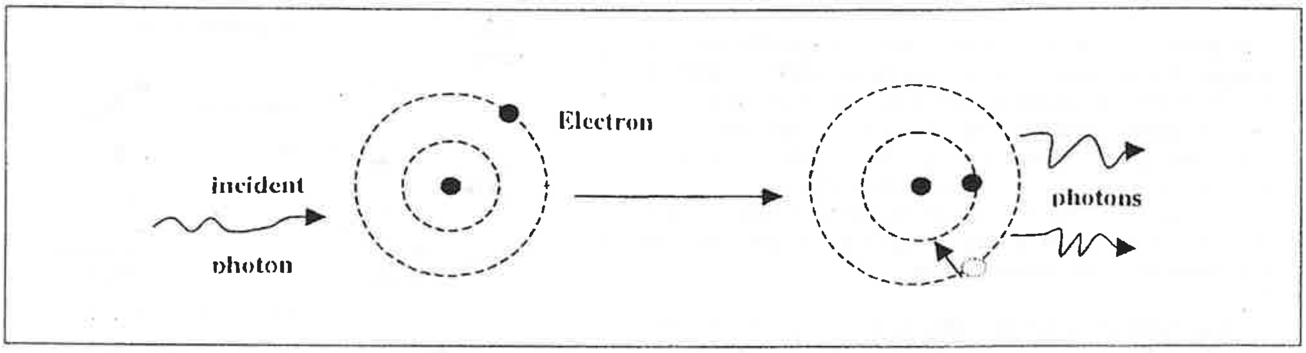

Figure 4. **Induced/stimulated emission.**

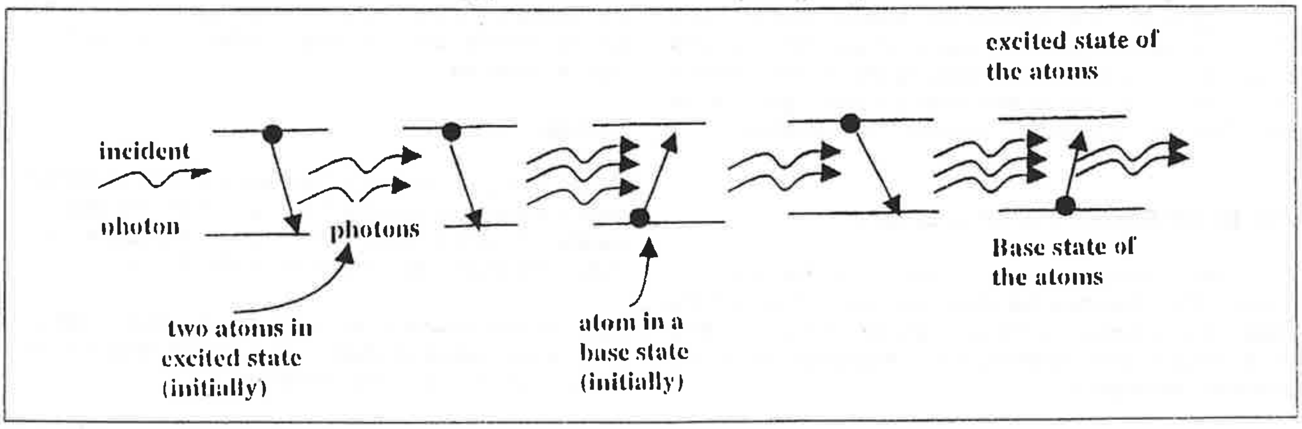

Figure 5. **Principle of the laser's amplification effect.**

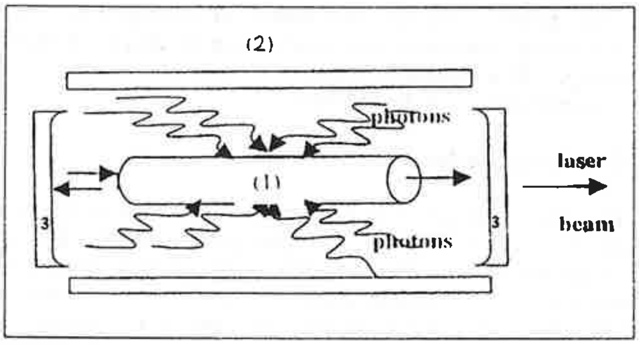

Figure 6. **Laser's basic structure,** 1. active medium, 2. "pumping system, 3. Resonant cavity.

colliding with a photon; as a consequence , this atom can release two photons and return to the energy level corresponding to its normal state, allowing the electron to migrate not to a higher orbit but to a lower one, as shown in figure 4.

This phenomenon is known as "induced emission" or "stimulated emission", and it is the basic principle for the operation of a Laser. It was discovered by Albert Einstein in 1917.

In essence, "stimulated emission" consist in the creation of suitable conditions for an atom in an excited state to return to its normal state. Those suitable conditions are really the collision of that atom with an

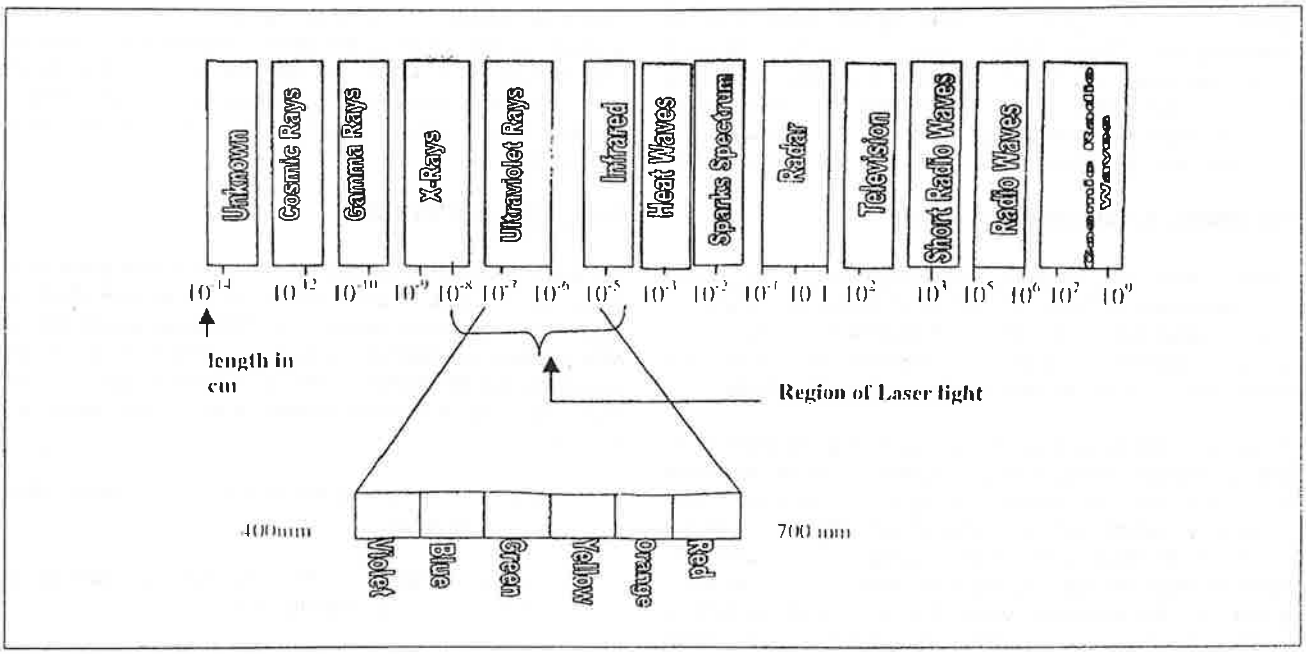

Figure 7. **Electromagnetic spectrum.**

incoming photon; this process will produce the emission of two photons with the same characteristics and propagation direction determined by the incident photon. Therefore, according to this phenomenon, light can be amplified via "stimulated emission" of radiation.

THE BASIC STRUCTURE OF A LASER

Consider a system with a group of atoms, some of them in their base/normal state and some in an excited state. If this system is hit by a photon, we could verify in its interior, both phenomena: induced emission and photons' absorption.

Stimulated emission will produce the emission of energy packets from some of the atoms, and the phenomenon of photons' absorption will create a tendency to make them "disappear". In other words; in one case the photon incident effect will be amplified while in other case, there is a tendency to nullify the effect. The final result will depend in the number of atoms in an excited state and atoms in the base/normal state. In order to have an amplification of the effect, is necessary that the number of atoms in an excited state be greater than the atoms in a base state. This is illustrated in figure 5.

Laser's Amplification effect

This effect is sketched in figure 5 above and a brief description is as follows: The upper horizontal lines represent the excited state of the atoms in the system being analyzed, and the bottom lines represent the base/normal state. When an incident photon hit an atom in the excited state, two photons are released/emitted by the atom and its energy level decays to its base state; afterwards, those two photons will hit another excited atom. This will produce the same amplification phenomenon. Those three "energy packets" will now be projected against an atom in its base state, releasing now only two photons and leaving this last atom in an excited state by absorbing energy. This process of photons' emission-absorption will continue on and on.

Conditions for amplification effect

In order for the induced emission amplification to prevail, it is necessary to have a number of atoms in an excited state greater than the number of atoms in a base state, which requires a "pumping" system that provides selectively, the necessary energy to some atoms.

Therefore, the objective of this "pumping" system is to provide a high energy flow to a certain number of atoms to induce the emission- absorption processes. This system is called "active medium" and it can be found in any of the three matter states: solid, liquid or gaseous, however even though the induced emission amplification effect can be achieved, when the "pumping" system is applied to the "active medium"; and since the time duration of each photon in this "active medium" is very small (photons travel at the speed of light), the stimulated emission process is not capable of extracting all the energy the "pumping" system provides to the "active medium".

Resonant Cavity

To solve this problem it is necessary to use an element/ device known as "resonant cavity", which consists in a couple of parallel mirrors located in the sides of the "active medium", as shown in figure 6.

Each of the photons reflected by the mirror, bounce back to the "active medium", allowing this way a greater "expansion" for photons' emission.

However, only one of the two mirrors will reflect all incident photons, and the other mirror, allows a small number of photons to "escape". This number of photons that escape from the "resonant cavity", constitute the laser beam. This emitted beam of energy has both coherence characteristics, spatial and temporal. In other words, this Laser's light is monochromatic and concentrated in a point/beam.

Clasifying the laser

Therefore, the Laser is a source of radiation integrated by an 'active medium", a "pumping" system, and a "resonant cavity"; the characteristics of this radiation, placed it in the visible region, infrared or ultraviolet of the electromagnetic spectrum, although, there is research going on to operate a laser in the X-rays wave-length region.

From the Modern Physics point of view, the main difference among the visible light, X-rays, infrared and ultraviolet light, radio waves, etc., is in the wavelength of the radiation. The electromagnetic spectrum includes a great variety of electromagnetic waves, (from cosmic rays whose wave-length is very small, to radio waves with an infinite wave-length). Human beings are able to perceive only a small fraction of the spectrum, as shown in figure 7.

FINAL CONSIDERATIONS

To summarize this article, it is emphasised here that, Laser is a light source produced and amplified by following a process known as **induced emission** or **stimulated emission**, which is different from the **spontaneous emission**, of the conventional light sources. The most important characteristics of a laser beam are the following:

a) Great intensity and the possibility of concentrating it in one object.

b) Spatial coherence, allowing for the light to be emitted from a specific point.

c) Temporal coherence, which makes this light almost monochromatic. In other words, the beam of light has only one color or one wave length only.

d) Directional; which allows the light beam to have a negligible divergence , in its width, (it is a concentrated beam of light) through great distances.

These characteristics make the laser very useful for use in medicine, nuclear fusion, telecommunication, and the general industry.