

CURRENT AND FUTURE  
APPLICATIONS OF LASER IN  
CARDIOVASCULAR AND THORACIC SURGERY

THESIS

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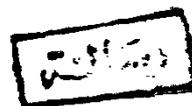
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## *Dedication*

*To my father, Prof. Dr. A. Abdel-Gawad;  
for guidance and inspiration.*

*To my mother, Prof. Dr. H. Gomaa;  
for being a mother*

*To my little sister and brother;  
for love and care*



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## Introduction

# Introduction

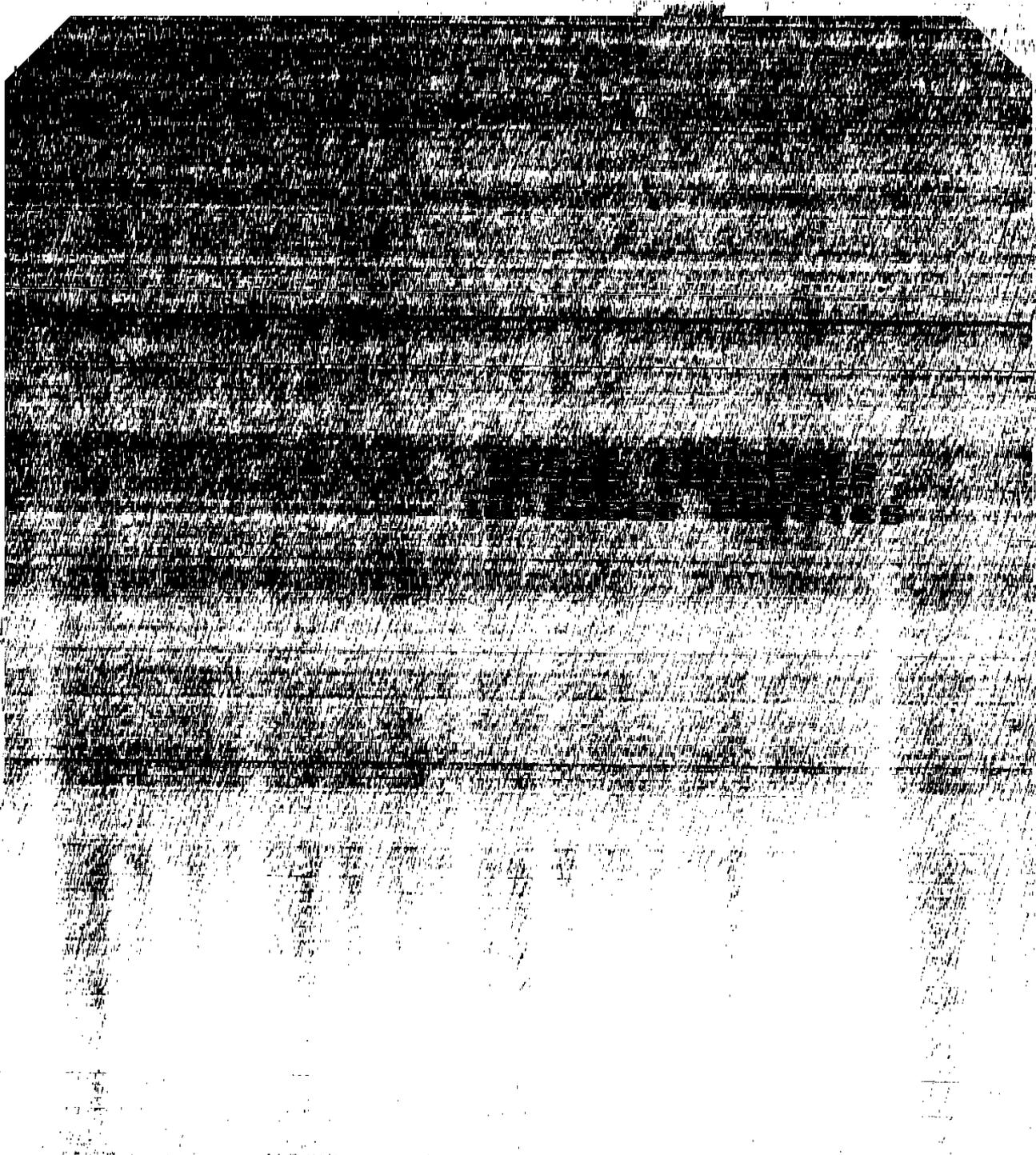
A laser is a device that produces high intensity light of a single wavelength, and in such a fine parallel beam that it can be focused to a very small spot. The name is an acronym derived from "Light Amplification by Stimulated Emission of Radiation".

The theoretic basis of laser energy was first proposed by Albert Einstein. He postulated that emission of light energy "photon" would occur if an electron excited to a higher energy state returns back to its original lower energy state. Einstein published his theories "The quantum theory of radiation" in 1917 and established the foundation of laser physics (Dolsky, 1984)

In 1955, Gordon et al published "The Maser" (Microwave Amplification by Stimulated Emission of Radiation) a new type of amplifier, with standard frequency and spectrometer which described this new technology. However, it was not until 1960 when Theodor Maiman, working for the Howard Hughes Aircraft Corporation, produced the first working laser, by stimulating a synthetic ruby Rod with light energy and producing a red laser beam with a wave length of 0.69  $\mu\text{m}$  (micrometer). This beam was then used in various medical experiments and gained access to the field of surgery.

The argon laser which was developed in the mid 1960's subsequently replaced the ruby laser because of its more useful absorption properties. The more powerful Neodymium - Yttrium Aluminum Garnet (Nd-YAG) was discovered few years later (Van Der Speck et al., 1988).

In 1966, at the American Optical Corporation Laboratories, Yahr and Strully discovered that carbon dioxide (CO<sub>2</sub>) laser can cut through tissues. Strong and Jako first appreciated the potential of the CO<sub>2</sub> laser for use in Otolaryngology in 1971. The development of the micromanipulator by Polanyi in 1974, enabling the CO<sub>2</sub> laser to be used with an operating microscope, greatly facilitated its use for microlaryngeal surgery. The argon laser has been used extensively in ophthalmic surgery and dermatology since about 1970, and Nd-YAG laser was first introduced in 1975 for the endoscopic treatment of gastrointestinal haemorrhage (Dolsky, 1984).



# Basic Concepts in Laser Physics

A knowledge of the physical properties of lasers enables a better understanding of their application in surgery and is essential for the implementation of effective safety measures.

Lasers are intense sources of electromagnetic radiation. To most people a laser is a device that generates a highly directional beam of monochromatic light (i.e., a single color), and this beam of laser light can produce intense power densities on a target at considerable distances from the laser source. These characteristics of a laser beam are quite different from those of light generated from conventional sources, such as incandescent lights, fluorescent lights, or the light produced by chemical combustion reactions in a candle flame or oil lamp. Conventional light sources, although ideal for illumination produce light with a wide distribution of frequencies or colors, and the light scatters in all directions. (Van Der Speck et al, 1988).

Before understanding the laser device, one requires an understanding of some properties and characteristics of light. Light is an electromagnetic radiation that has a frequency, phase, and amplitude. A beam of light consists of discrete packets of energy called "photons". Also, to understand the medical application of laser, it is important to realize that light is a form of radiant energy that is convertible into other forms

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of energy, such as electrical, heat, chemical, and kinetic energy. From the quantum theory, the energy of a photon of light is related to its frequency of oscillation in the electromagnetic spectrum and when the frequency of light increases, the energy per photon increases and the wavelength decreases. Light interacts with matter by the process of absorption, transmission, reflection, refraction and several types of scattering (Fuller, 1986)

Atoms and molecules are the chemical building blocks of matter and can exist in many different energy states. According to Bohr's theory, the electrons of an atom can be imagined to circle the nucleus in discrete orbits, the orbits populated by the electrons determine the energy level of the atom. Radiation is absorbed or emitted when electrons are transferred from one orbit to another. The frequency of the radiation emitted or absorbed is related to the energy difference of the two states according to the Bohr formula,  $E=h\nu$ , where  $E$  is the energy difference between two energy levels,  $h$  is Planck's constant and  $\nu$  is frequency. The basis of the quantum theory is that energy exists in discrete packages, quanta or photons. Atoms, molecules and ions undergo transition from a higher to a lower energy state with the emission of a photon as the electron drops from a higher orbit to a lower one in the case of an atom, or as a molecule changes from one vibrational state to another as, for example, in the carbon dioxide ( $\text{CO}_2$ ) molecule. An atom or any other quantum system tends to move from a higher to a lower energy state by spontaneous emission of discrete amounts of radiation. Spontaneous emission is propagated in any direction. Conversely, when an atom, molecule or ion at a lower energy level is exposed

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to specific amounts of radiation, it may absorb that energy and be "excited" with an electron raised to a higher orbit or a molecule changed to a different rotational or vibrational state (Van Der Spek, et al, 1988).

When, during stimulated emission, an atom in an excited state is exposed to the radiation (photonic energy) of a frequency matching the energy difference between two orbits (excitation energy), the atom can then emit the newly "absorbed", in addition to the existing, amount of "excited" energy by return of its electron to the lower level. Two photons are then emitted, the injected photon plus the photon emitted by the electron turning to the lower orbit; the atom reverses, thereby, to its lower energy level. The two emitted photons have the same energy level, frequency, phase and direction or, in other words, the "stimulated" radiation has the same frequency, phase and direction as the "stimulating" radiation (Fig. 1). The "stimulating" radiation has thus been amplified. For a predominance of stimulated emission to occur, a large majority of atoms need to be in a higher energy, or excited state rather than a lower state, in order to compensate for the loss of photons that escape without participating in the process. The resulting condition is called a "population - inversion", because normally the higher energy levels of atoms, ions or molecules are less populated than the lower ones. The method by which the higher energy levels are achieved is termed "pumping"; it is the process of supplying high intensity energy to the atoms or molecules and is accomplished by an electrical discharge or a radiant source such as another laser or an intense light source. The energy conversion process is usually rather inefficient, resulting in the generation of heat. A laser device provides

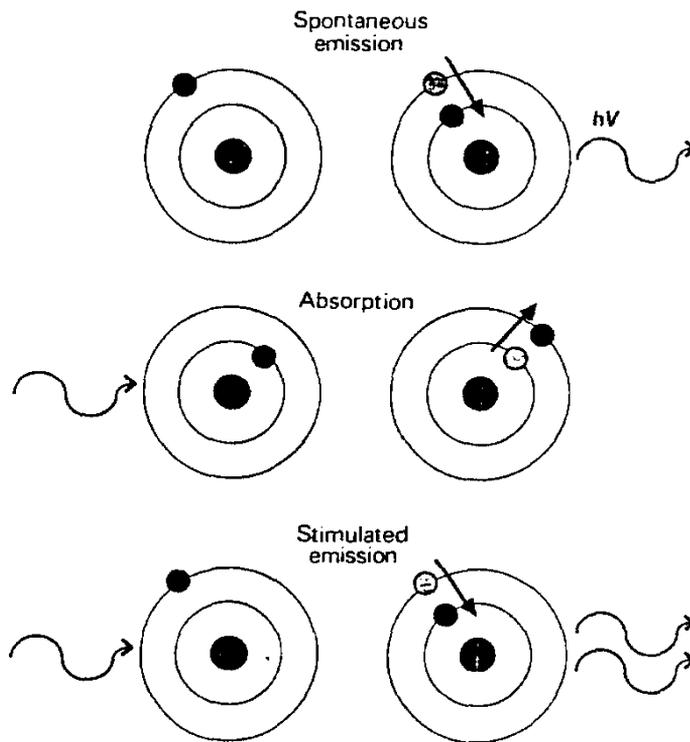


Fig. 1. The three processes of radiation (Van Der Spek et al, 1988).

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the conditions which optimize the process of population-inversion and stimulated radiation as well as the supply of energy. Because of the generation of heat, most laser devices require a cooling system (Fuller, 1986).

Laser devices have three components, a laser medium, an optical cavity and a pumping source (Fig. 2). The name of the laser refer to the type of material used within the optical cavity as the laser medium which may be solid, liquid or gas. The laser medium determines the wavelength of the emitted radiation. The most important lasers in medicine today are the CO<sub>2</sub>, the Neodymium-yttrium aluminum garnet (Nd-YAG), the Argon, krypton and the Eximer laser. The optical or resonator cavity provides the controlled environment to which the laser medium is confined. As energy is being supplied to the laser medium by the pumping process, its atoms are raised to their excited states followed by spontaneous emission. Emission occurs in all directions including the long axis of the cavity, the axis of propagation. Usually, two mirrors are positioned, one at each end of the axis of propagation. "Light" emitted along the axis of propagation is reflected back into the optical cavity at an angle depending on the curvature of the reflective surfaces. The reflectiv radiation may traverse along the long axis to reflect once again off the opposite mirror. Alternatively, the radiation may be absorbed by another atom in the cavity, raising the latter to a higher energy state or, if the atom was already excited, it may result in stimulated emission of the atom. If the latter process is set up along the axis of propagation, multiple reflections between the mirrors (oscillations) will enhance the absorptive and emissive

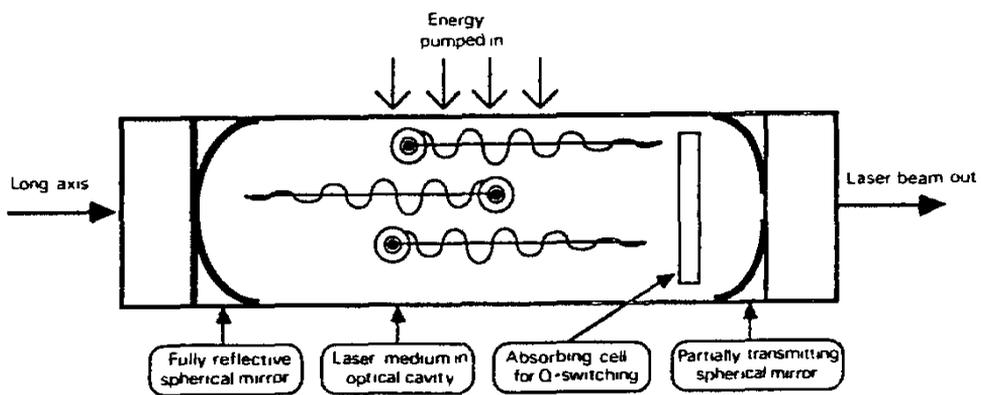


Fig. 2. Diagram of the components of a laser device, with three atoms emitting radiation parallel to the axis of propagation (Van Der Spek et al., 1988).