LASER PHYSICS

Laser History

The basis of "laser theory" was established as early as the 19th century with Neils Bohr's theory of "spontaneous emission" and the concept of optical resonators. The "Father of Lasers", Albert Einstein, developed the concept of laser physics in 1917 by means of his "stimulated emission" concept. But it was not until 1955, well after Einstein's death, that the first working model, as MASER (Microwave Amplification by Stimulated Emission of Radiation) was built by Gordon et al. In 1958, Schwalow and Townes independently described the physical principles of the MASER. In 1960, Theodore Maiman first produced visible light waves from a ruby rod laser by stimulated emission.

Albert Einstein

In 1961, C.K.N. Patel, working with Bell Laboratories first developed the CO_2 laser. Jako and Polanyi first described the absorption of human cadaver vocal cords when exposed to a pulsed Neodymium and then a CO_2 laser. These were the first impact of purely medical applications. In 1968, the development of some endoscopic delivery systems was noted. Jako first described the precision of the laser and noted the subsequent good wound healing. From this point, tissue reactions were accurately described as well as early contributions of the lasers in areas such as general surgery, ophthalmology, gynecology, ENT, orthopedics, neurosurgery, plastic surgery, and most recently the virtual bonding of dermatologic applications with laser technology.

Lasers have become an integral part of modern technology, revolutionizing industry and offering amazing alternatives for communications, energy, and our national defense. Today, one of the most fascinating applications for laser technology is in the field of medicine, especially the applications associated with the skin. By using flexible light guides, or fiber optics, we can deliver the healing powers of light to various areas of the body for both therapeutic and diagnostic arenas with little or no invasion of the body itself. Because of the unique characteristics of skin (water content, collagen, various pigmentations), laser light technology has taken biophysics to a new dimension by specifically predicting light wavelength, pulse duration, pulse rest time, and pulse frequency, as well as power and energy that is required to reach a desired outcome on varying skin components.

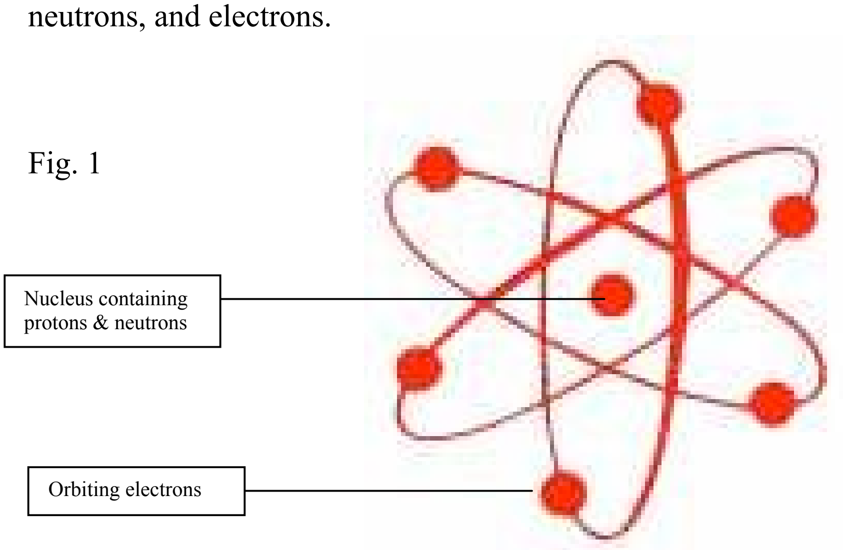
In order to fully appreciate the advantages offered to patients by use of lasers in medicine, it is necessary to have a basic understanding of the physics involved with the manufacturing of the brightest man made light known, the LASER.

The Basics:

The Atom

Laser light is the product of an external interference, of a particular nature, into a stable atomic or molecular structure. A basic atomic structure is symbolized in Fig. 1. All matter is made up of various atomic structures such as this example. This particular atom contains within its nucleus two protons, or positively charged particles, and two neutrons, or neutrally charged particles. Orbiting about this nucleus will be found the electrons, or the negatively charged particles of the structure. It is the electrons of the atomic structures that are acted upon by an external energy source to promote the emission of light. All atomic structures, of course, have a signature number of protons, neutrons, and electrons.

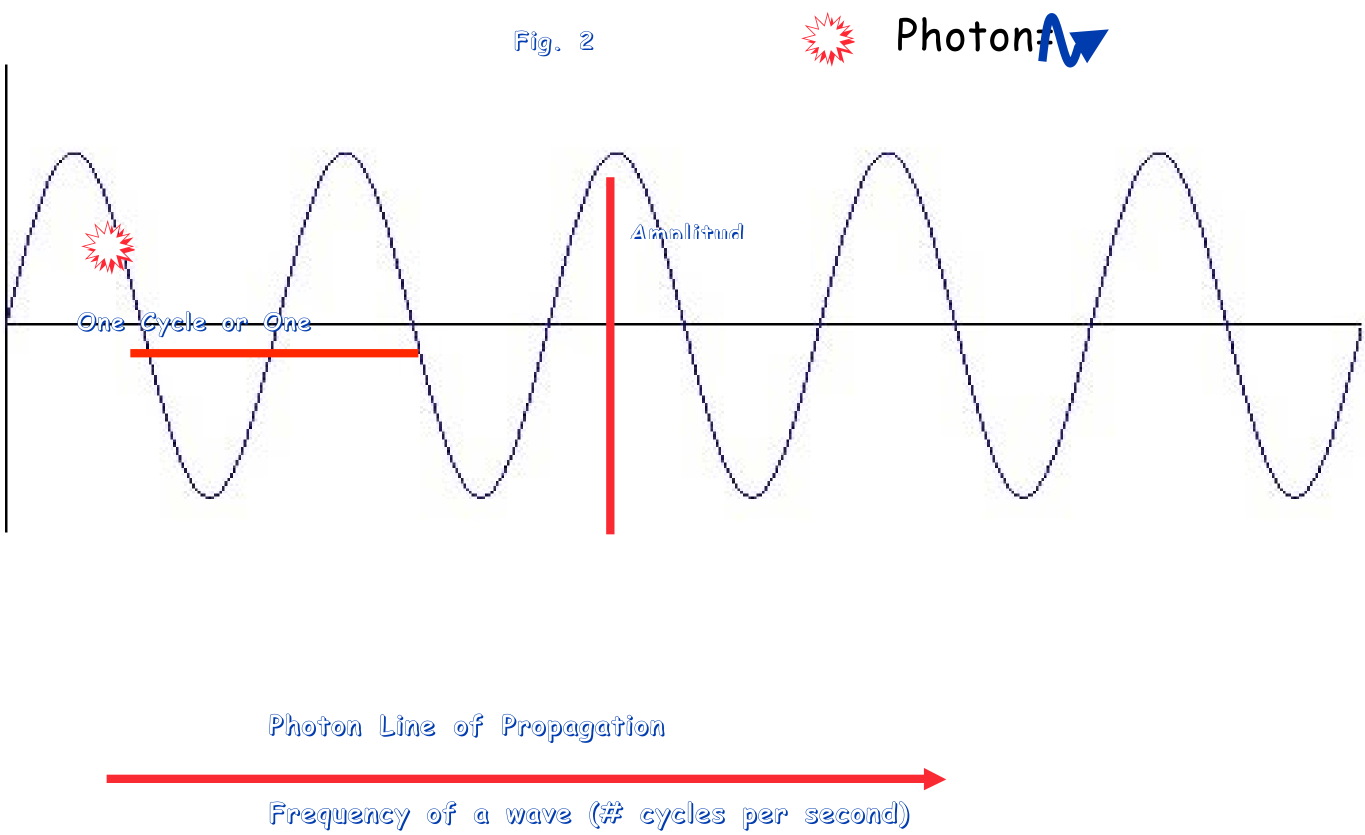
Fig. 1



The Wavefront

Referring to Fig. 2, the light physics student can view a light photon (a single packet or unit of light) as traveling along a line or propagation in the form of a wave. This path of travel has a consistent "wavelength" or distance from one point on the path, to the point on that wave that the wave begins to repeat itself. This "wavelength" is characteristic for the type of laser; ie. CO_2 is 10.6 microns or 10.6 x 10^{-6} meters. The Neodymium:YAG or Nd:YAG laser is 1.064 microns, KTP laser is a 0.532 microns or 532 x 10^{-9} nanometers. The "amplitude" of this wavelength is determined by the Power emitted from the laser. This is controlled by the operator of the laser.

Fig. 2



Absorption

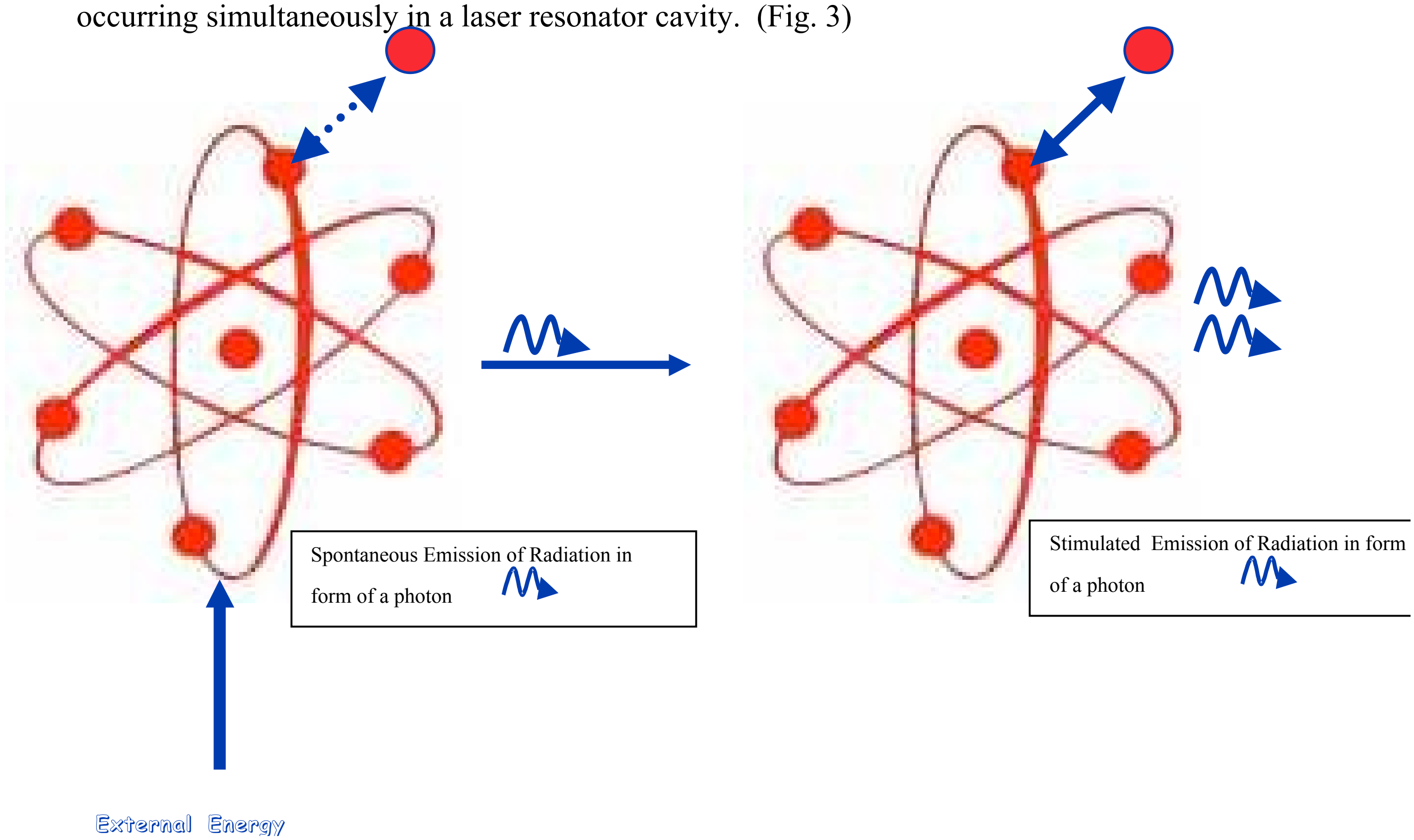
Electron transitions from one orbital state to another occur by the input of a specific incoming energy source that can be absorbed into the system causing a transition of that electron to a higher orbit or energy state. The source of that energy causing the excitation is called the "excitation mechanism" of that system containing the electrons to be placed in transition. Depending on the laser system, the "excitation mechanism" can be in the form of electricity, a high intensity flashlamp, or even one type of laser used to excite another type of laser.

Spontaneous Emission

As described by Niels Bohr in the 19th century, electrons that have been "excited" to a higher energy state cannot remain in that state for any extended period of time. This is considered an "unstable" state for them, and if allowed to, will "spontaneously" drop back down to their "resting or ground" state of origin. When this occurs, this formally absorbed energy is released in the form of another photon. Thus described is the process of "spontaneous emission".

Stimulated Emission

When an atom in the "excited state is struck by an previously emitted photon, this atom spontaneously returns to the "ground state", thus emitting an identical photon of identical frequency, wavelength, and in perfect spatial and temporal harmony (in phase with time and space). This process is thus called, "Stimulated Emission of Radiation". The three processes of absorption, spontaneous, and stimulated emission or radiation are occurring simultaneously in a laser resonator cavity. (Fig. 3)



Basic Components of a Laser Cavity

The four basic components of the laser cavity are:

1. External Power Source or Pumping System
2. Resonate Cavity (where lasing process occurs)
3. Cooling Method
4. Delivery System

(See Fig. 4)

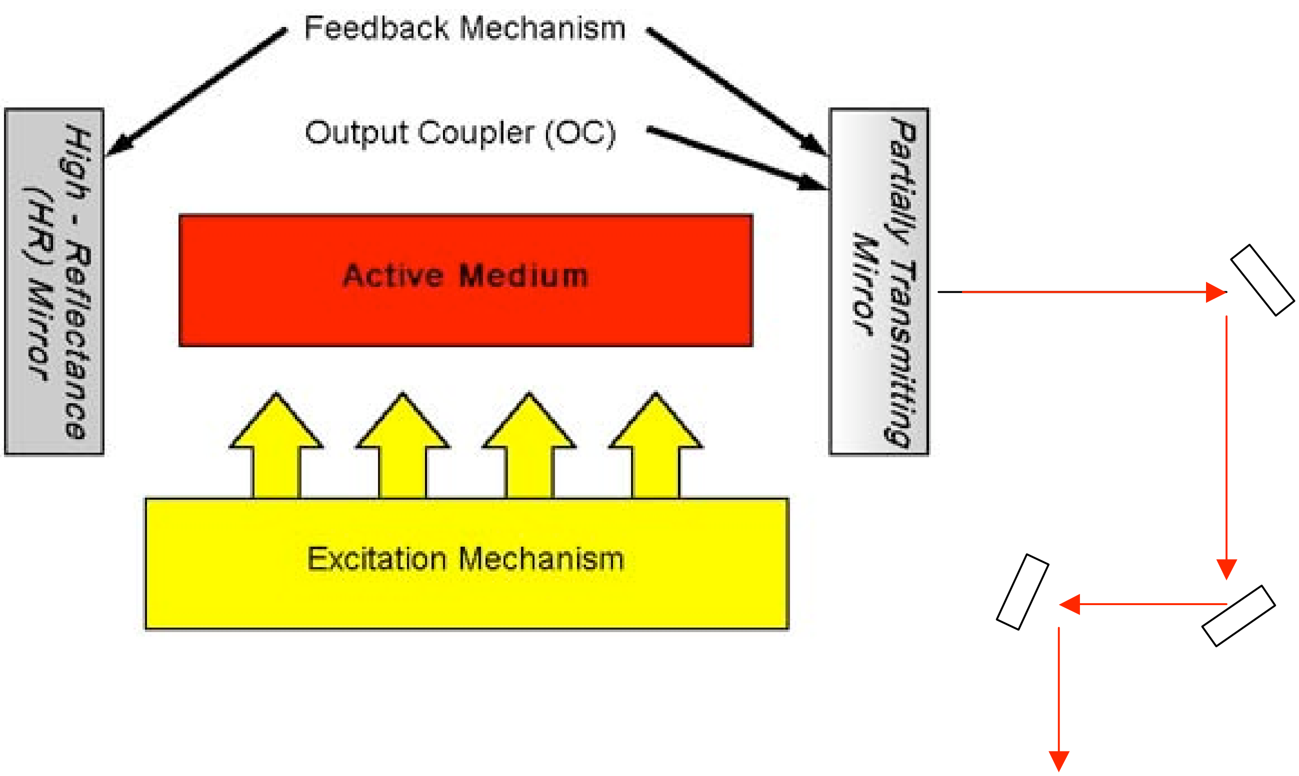
All lasers require some method of pumping or exciting the atoms or molecules from a resting state to the excited state. This state is also called a “population inversion”, showing more of the atoms in the excited state than the ground or resting state. This pumping system may be in the form of electrical current, optical pumping system mechanical, or a chemical method. The specific pumping system is determined by the absorptive needs of the active media, or that substance that is to be lased.

The resonate cavity of the laser consists of the active media, or the material to be “pumped” or excited for lasing, and the primary laser optics. These optics include two mirrors mounted on either end of the active media to facilitate the lasing activity in the active media. One mirror is nearly 100% reflective and reflects all optical activity incident upon it. This is commonly known as the “high reflector”. The mirror mounted on the opposite end of the laser cavity is less that 100% reflective and is commonly known as the “output coupler”. The OC mirror allows a small amount of transmission of the optical activity produced in the resonate cavity, thus producing the laser output of the system. These mirrors are coated with a specific material of a specific thickness in terms of nanometers to produce the desired optical activity. The mirrors are mounted perfectly parallel to each other along the optical axis of the resonant cavity. Misalignment can cause drastic reduction in laser output or cessation of laser output. It is this resonant cavity that produced the “light amplification” chain reaction.

The delivery systems of each laser are also determined by the type of laser. Most non visible lasers will require some sort of aiming device, often times another low wattage visible laser, coaxially aligned with the system in order to determine the therapeutic beam path. Some longer wavelength lasers, such as the CO_2 laser require delivery of the therapeutic beam through an articulated arm that is a series of mirrors along an enclosed tube beam path. This is necessary due to the unavailability of useable fiber optics for the CO_2 wavelength.

Most other types of surgical lasers can be delivered into a fiber optic or "light guide". These flexible fibers allow for delivery of the laser beams into body areas that before were inaccessible by means other than invasive methods or onto the skin surface easily.

Fig. 4



Laser Types

Lasers are basically typed by the content of the active media. These may include solid, liquid, molecular gas, ion gas, and semi conductor.

The solid lasers are a solid rod or "boule" of material with the lasing element homogeneously mixed through the boule before solidification. An example of this type of laser is the **Nd:YAG** where **N**eo**d**ymium is homogeneously mixed in a solution of

Yttrium **A**luminum **G**arnet before solidification. These lasers are generally excited optically by a flashlamp. Other examples of solid rod lasers are the **Nd: YAG** or Neodymium Yttrium Aluminum Garnet. The **KTP laser** is actually an Nd:YAG laser with a special frequency doubling optical device that _ the wavelength from 1.064 microns to 0.532 microns (invisible Infra Red wavelength to a visible Green wavelength). The Erbium (Er:YAG) is another type of YAG rod laser. These lasers most often are excited by means of a flashlamp mechanism that emits energy that is specifically suited to the type of laser rod to be excited.

The liquid lasers are commonly known as “dye” lasers. These lasers have an active media of a dye mixture that is activated by optical means; either a flashlamp or even another laser in some cases.

An example of the molecular gas laser is the CO_2 laser. This laser uses a mixture of CO_2 gas, helium, and nitrogen. An example of the ion gas laser is an Argon laser.

Semiconductor lasers use two layers of semiconductor material such as gallium arsenide as the active media. These devices are often light, extremely portable, and are known for their high efficiencies. An example of a semiconductor laser can be found as both surgical and cosmetic lasers.

Unique Properties of Laser Light

Laser light has three major properties that prove it to be unique from other forms of light:

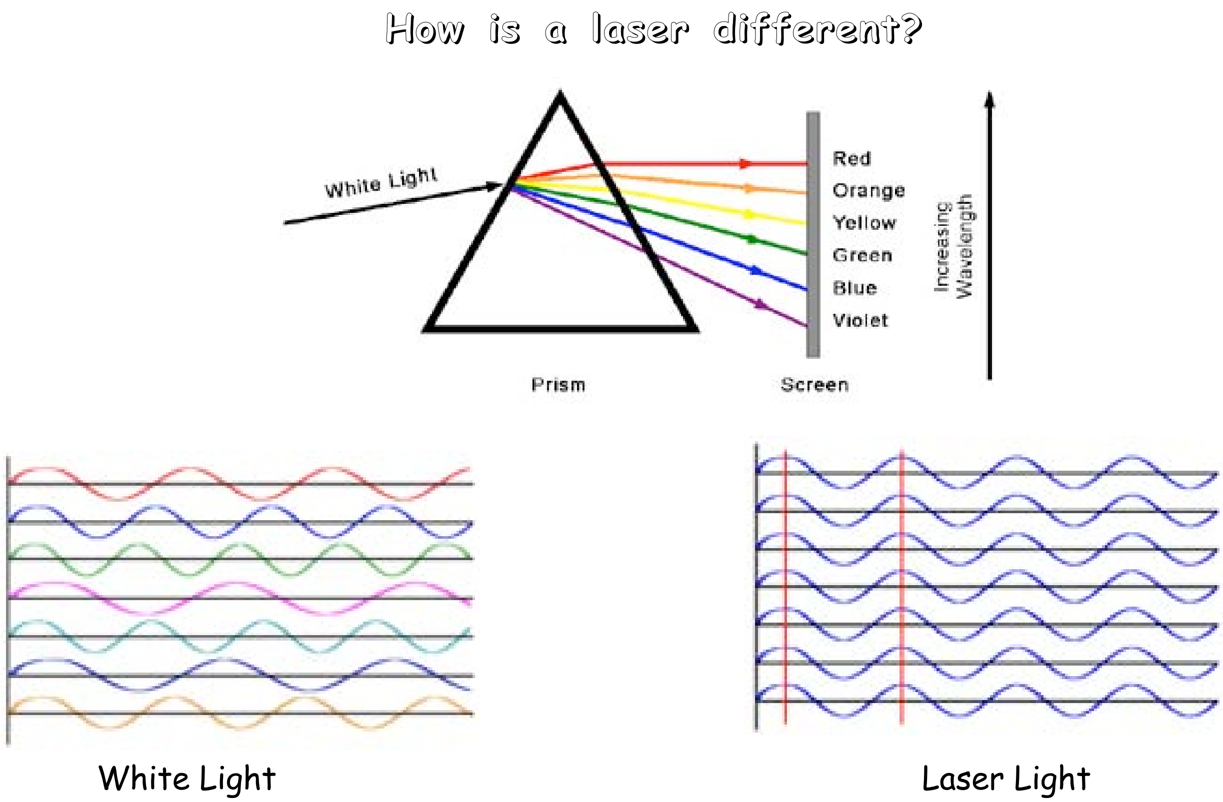
1. Monochromoticity (one color or wavelength)
2. Collimation (all photons are traveling along a parallel beam path, with little “spreading” of the beam pattern after it leaves the laser device
3. Coherence (all wavefronts are “in phase” with each other)

The term “monochromatic” indicates that this light is of one color, one wavelength, one frequency, or composed of a very small band of wavelengths. Whitelight contains many colors or wavelengths. If laser light is processed through a refracting prism, the optics student would find that only a small band of light is emitted out of the prism, all bent at the same angle. However; if white light were processed through the same refracting prism, the light waves would be bent at a variety of angles, corresponding to the wavelengths. The shorter the wavelength, the more acute the bend of the light. The white light through the prism produces the “prism” effect of a variety of component colors or wavelengths. White light is called “polychromatic”.

Collimated light, laser light, is light propagating in one direction with little or no significant light divergence. The rays are parallel to each other, allowing for high concentration of light at the target tissue, and ability to focus the light at small spot sizes.

Coherent light indicates that the collimated beams have crests and troughs that are coincident with each other allowing for "constructive" interference with each other. This constructive interference allows for light intensity to multiply in laser light.

Fig. 5

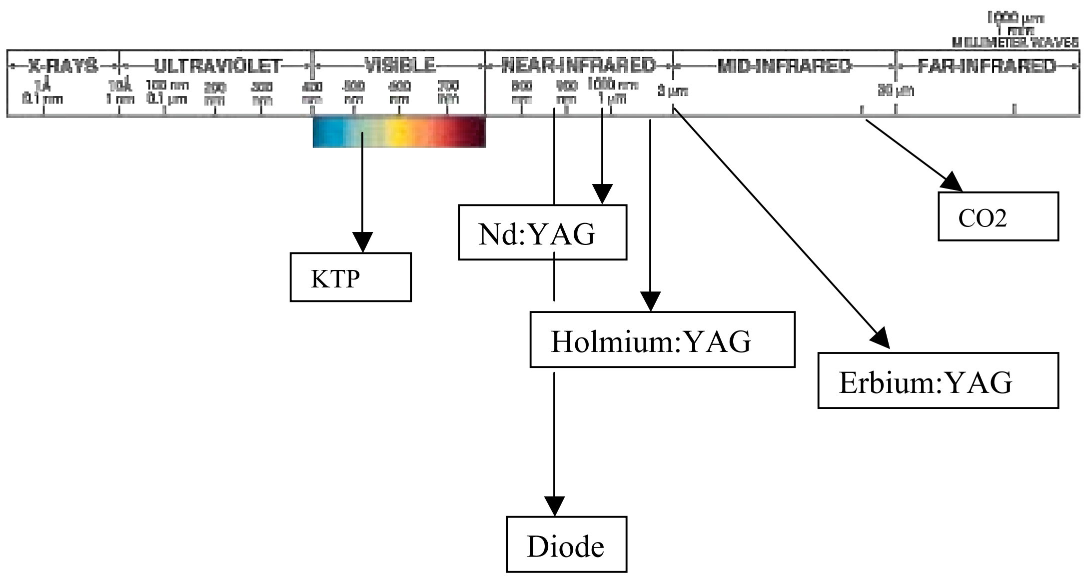


The Electro-magnetic Spectrum

The Electro-magnetic Spectrum is a graph describing the frequencies and wavelength of energies originating from atomic systems. A small portion of the Electro-magnetic spectrum is shown if Fig. 6. This is the portion of the graph most commonly involved with medical lasers. Generally, commonly used medical lasers will be found in the infrared and visible spectrum of this spectrum. It is important to notice the position of the "ionizing or UV radiation" in relation to the invisible infrared lasers. Commonly used lasers in surgery and Skin applications are found in the "non ionizing" portion of the spectrum, that is in the visible or longer (Infra Red).

Note that the longer the wavelengths of the spectrum, the lowers the frequency of a laser system. It can be noted that the frequency of a laser system can be determined by taking the reciprocal of the wavelength, and vice versa. (Fig. 5)

Fig. 6



Clinical Laser Training "Laser Physics"

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