# RED HOT ISSUE
# CUTANEOUS LASER MEDICINE
## I. UNDERSTANDING LASER LIGHT

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## Introduction

Lasers have come to occupy a unique and important role in the diagnostic and therapeutic armament of medicine. The main advantages of the laser in medicine can be summarized as follows:- 1) haemostasis, 2) high precision, 3) reduced instrumentation at the treatment site, 4) non-contact tissue removal (no contamination) and 5) minimal trauma to the surrounding tissue (no mechanical forces applied).

Cutaneous laser surgery focuses primarily on dermatologic applications of lasers. There is a growing number of skin lesion such as benign vascular and pigmented skin lesions including tatoos that are usually best treated by lasers. The list of laser responsive skin conditions has expanded recently to encompass warts, psoriasis and scars. Other exciting areas are skin resurfacing, hair transplantatin and hair removal.

The well informed dermatologist using lasers with skill and good judgement can help solidify the image and substance of laser medicine and dermatology. In doing so, he or she can also take better care of the patients. The goal of this article is to provide colleagues with the necessary information that they may need to understand cutaneous laser medicine. The essential information will be provided in a series under the title "Red Hot Issue: Cutaneous Laser Medicine". The first article is entitled "Understanding Laser Light". The following facts about laser physics are well worth consideration, since they have practical implications and affect the application of specific laser devices.

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## Electromagnetic Radiation

Solar energy is the primary source of different types of electromagnetic radiation [EMR]. A small portion of its spectrum stimulates the retina of the eye and can be perceived as visible light. During the 17th century, the English physicist Sir Isaac Newton showed conclusively that visible light consists of an admixture of waves or colour perceived as the colours of a rainbow. In the year 1800, another physicist, Herschel, extended Newton's study by placing a thermometer adjacent to the red colour emitted from a prism. He noted that the temperature was higher than at the visible light portion and coined the term infrared. Several years later, John Ritter conducted a similar experiment in which he placed a plate coated with silver chloride adjacent to the violet colour as it emerged from the prism. He observed that the plate had darkened. Ritter called this invisible area the "ultra violet wave region". Starting at the long wavelength, low photon energy end of the spectrum, EMR includes radiowaves, micrwaves, infrared (IR) radiation, visible light, ultraviolet (UV) radiation, and X-rays. Laser light is part of the electromagentic spectrum which may extend from the near the infrared to near the ultraviolet [see Fig. 1].

EMR and light exhibit the property of particles, as energy is carried in quanta known as photons. These particles propagate as waves, which behave similar to the ripples emanating from a pebble thrown into a pond [see Fig. 2]. Electromagnetic radiation can thus be understood as a continuous series of transverse vibrating waves of energy. These waves have a wave front [X] and an amplitude [Y]. The distance between these vibrations is called the wavelength. The international unit of wavelength is the nanometer ($10^{-9}$ meter). This is one-billion of a meter. The number of peaks that pass a given point per second, is the frequency and is measured in hertz [cycles per second]. The radiation is called electromagnetic because of an alternating electric and magnetic field [Z].

Since all electromagnetic waves travel at the same constant speed, which is about 186,000 miles per second, there are more waves per unit time for the shorter wavelenghts, than for the longer ones. Shorter waves, therefore, have greater frequency or more oscillations and greater energy per unit time, than do longer ones. Thus, frequency and wavelength vary inversely according to Planck's law. The energy of light is proportional to the frequency, hence light with higher frequency has a shorter wavelength and a higher energy. For example, each violet photon, at 400 nanometers, has twice the energy of each red photon, at 800 nanometers. As would be expected, the frequency of the violet wavelength is twice that of the red.

## Energy, Power, Irradiance and Fluence Rate

Light is a form of energy. the term "energy" is defined as the ability to do work. To accomplish work it is necessary that an effort or energy be expended. The units of energy are measured in joules in honour of Dr. James Prescott Joule. The rate at which energy is consumed, or the amount of energy needed for work to occur per unit time is described as power. The accepted unit of power is the watt (W), named in honour of James Watt. One watt is defined as the delivery of one joule per second. The power delivered per unit area on the air-tissue boundary is called the irradiance, or intensity, usually given in W/cm2. The energy per unit area withiin the tissue is called the fluence rate, sometimes called the dose, and usually given in $J/cm^2$.

## Quantum Theory of Radiation

In 1917, Einstein's quantum theory was extended by Niels Bohr to formulate the basic electronic structure of atoms and molecules. The Bohr atomic model consists of a small, but relatively heavy positively-charged nucleus surrounded by orbiting negatively-charged electrons forming an electrically neutral atom, somewhat analogous to planets in our solar system. The electrons circle the nucleus at defined energy levels that correspond to their distance from the nucleus. There are only specific "allowed" orbits in which the electrons can spin.

Almost all the interactions of photons with atoms are due to the electric field, which is capable of moving electrons from one orbit to another. When the energy of a photon coincides with the energy level of an electron's orbit, the photon energy is given up to an electron and absorption of energy and excitation will occur. When the energy content of a photon does not coincide with the energy level of an electron's orbit, the photon will be transmitted and no excitation will occur. Thus, Bohr's theory required that each photon would be absorbed by only a specific "allowed" electron orbit into whch it must fit. The allowed energy or photons that can be absorbed are predetermined by the unique pattern of electron orbits that characterize each atom. Because of the uniqueness of each atom and molecule a second postulate of quantum mechanics is that atoms and molecules can absorb only specifoc photons or wavelengths of light. A third postulate is that the absorption process is an all or none phenomenon.

When the electrons are in the orbit close to the nucleus, the atom is in the lowest energy level or the ground or resting stage [see Fig. 3A]. Atoms and molecules are normally found in this stage. When the energy of a photon is absorbed, the photon ceases to exist. The energy imparted to the atom, on the other hand causes the most weakly bound and outermost electron to move from the ground state and transfer to a more extended orbit with higher energy [see Fig. 3B]. The atom enters into a short-lived energy state rapidly converts to a more stable, longer-lived energy state called the "metastable or triplet state". This is not a stable situation and after a short time the atom will decay again to the lower energy level thereby emitting its energy surplus in the form of a light wave or photon. This decay, resulting in the emission of a photon, occurs even in the absence of any external influence and is therefore called spontaneous emission [see Fig. 3C]. Each type of atom has a number of well-defined energy states and emits radiation which is characteristic for the element (Na: yellow light, Ne: red light and Hg: ultraviolet light).

## Light amplification by stimulated emission of radiation [Laser]

Einstein theorized that if an atom in an excited state was irradiated with energy of the same wavelength or frequency that was previously absorbed, the atom would return to its resting state faster and the energy released upon remission, coupled with the stimulating or irradiating energy, would yield two waves of light energy or photons of the same frequency and wavelength travelling in the same direction and in perfect spatial and temporal phase [see Fig. 3D]. When this process repeats itself many times a photon avalanche will be produced and a strong light beam grows. The stimulated emission will dominate the absorption process only when more atoms are in an excited state than in the ground state, the so-called population inversion.

However, it was not until 1958 that Townes and Schalow produced stimulated emission of radiation using microwaves (termed Maser). Then on July 7, 1960 Maiman first observed stimulated emission of radiation with visible light using ruby crystals and coined the term Laser as an acronym to represent Light Amplification by Stimulated Emission of Radiation. With these observations the laser age was launched.

## Laser Light Characteristics

Laser light differs from other sources of light by three distinct qualities. The laser light is almost of one colour or wavelength, i.e. monochromatic. This quality of laser light is important therapeutically as it allows selective absorption of the energy by specific chromophores (light absorbing compounds). In contrast, ordinary light sources emit all colours across the visible electromagnetic spectrum into the near infrared thus producing visible light and heat. Secondly, laser light waves are all in phase with each other both in space [spatial coherence] and time [temporal coherence], much like a marching band crossing a field, accounting for the low divergence [see Fig. 4]. Normal light is incoherent with all of the particles out of sequence much like the people milling around a stadium after a game. Laser light may therefore be propagated over a large distance without a substantial loss of intensity. Compare this to an ordinary light source in which the intensity drops off rapidly as the beam spreads over a short distance [see Fig. 5]. The low degree of beam divergence and the ability to tightly focus the beam [collimation] allow lasers to be extremely high in intensity and to be the brightest sources of light.

## A Laser Machine

The first laser to be used, on humans was a ruby laser studied by Leon Goldman, a dermatologist, in the early 1960s. All lasers share a number of common components. The first is laser medium, which may be solid [e.g. ruby crystal], liquid [e.g. rhodamine dye] or gas [e.g. argon]. The laser medium is contained within a chamber or optical cavity [resonator] which is sealed and contains two mirrors, one at each end. One mirror reflects 100% of the photons back to the laser medium so that amplification may continue. The other mirror is partially transmitting allowing 5% - 10% of the light to travel out of the cavity and be directed externally as a bem of laser light. An energy source is needed to induce population inversion in the laser medium [see Fig. 6]. Energy sources include: AC power, light energy from another laser, optical flash pumping and chemical reactions. Most of the energy used to pump the laser medium will be lost in heating the laser tube rather than being used in activating the lasing medium and a cooling system will therefore be required. All lasers require a delivery system to bring the laser beam from the machine to the patient.

To achieve stimulated emission of radiation by light, laser medium is placed into the optical cavity which is then "pumped" to an excited state using an energy source in the cavity. When the majority of the atoms are in population inversion, stimulated emission will produce more photons of the same frequency travelling back and forth along the same axis, promoting further stimulated emission, thus amplifying the process. Only those photons which are perpendicularly incident on the mirrors will be reflected back, interacting again with the laser medium. The build up of laser light in between mirrors will continue until equilibrium is obtained between the amount of light energy produced and the amount of light leaking out of the laser. An obliquely incident wave will leave the resonator after one or more reflections at the mirrors and will not take part in the process of amplification but it contributes to the energy loss of the laser. For most practical lasers the efficiency is not high. An Argon laser has a yield of less than 0.1% [e.g. 40 kW electrical energy power produces about 25 W of laser light power]. The wasted energy generates heat which has to be removed by cooling the laser medium.

To summarize, when one compares laser light to natureal sources of light, the analogy is that of music compared to noise. Laser light or photons can do only two things; namely absorption and scattering. The ability of tissues to absorb (laser) light and to convery laser energy into heat is the essence of thermal laser tissue interactions such as coagulation or vaporization. The forthcoming article will address these matters.

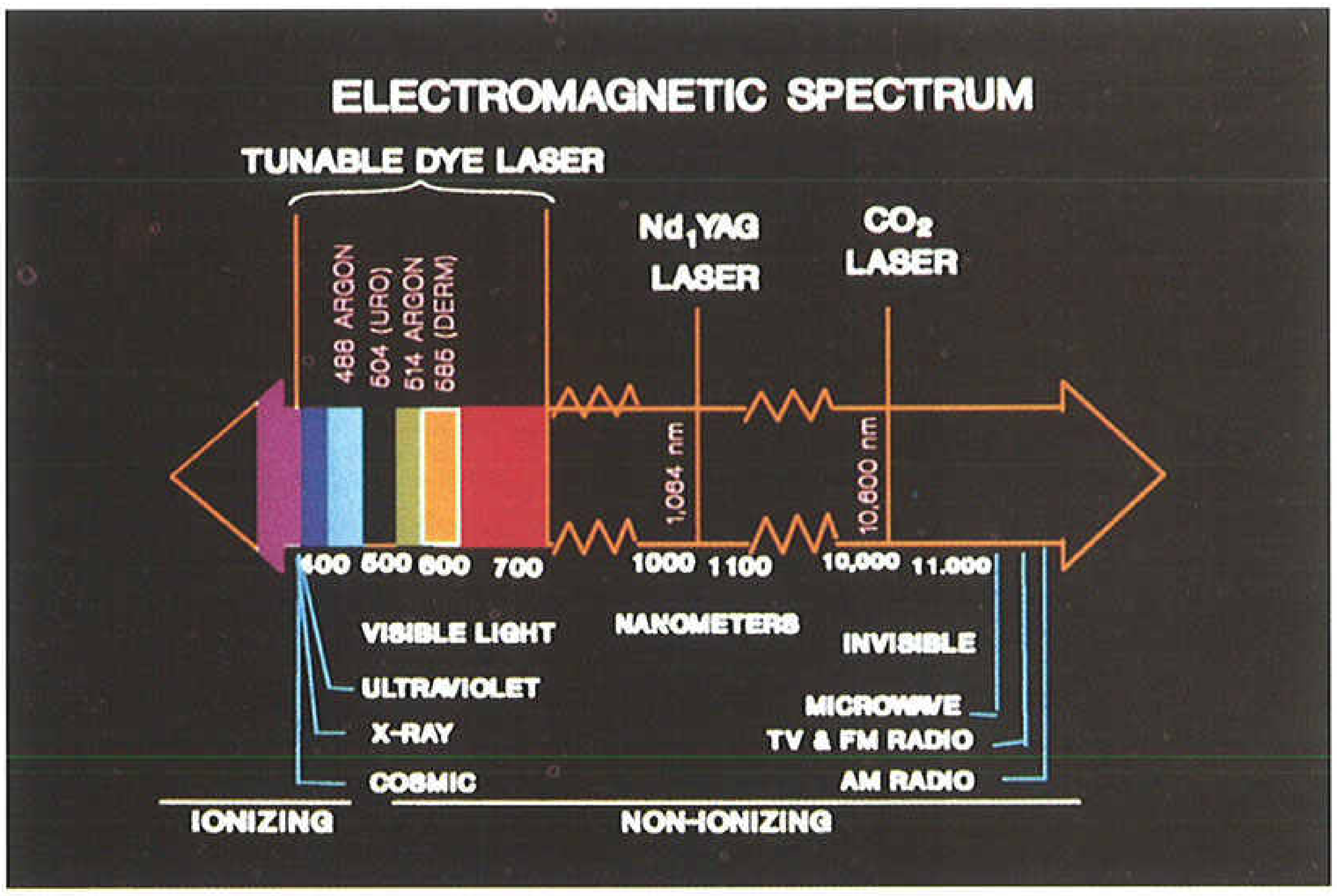


*Figure 1: Radiation of very short wavelengths, high energy- that is, gamma rays and X-rays can ionize molecules. The wavelengths between 200-400 nm are called ultraviolet wavelengths. Visible light ranges from about 400-800 nm. Radiation of wavelengths longer than 800 nm [infrared] only causes heat. Microwaves, radio-waves and longer wavelengths are not currently known to cause biologic effects. Laser light is part of the electromagnetic spectrum which may extend from the near the infrared to the near ultraviolet.*

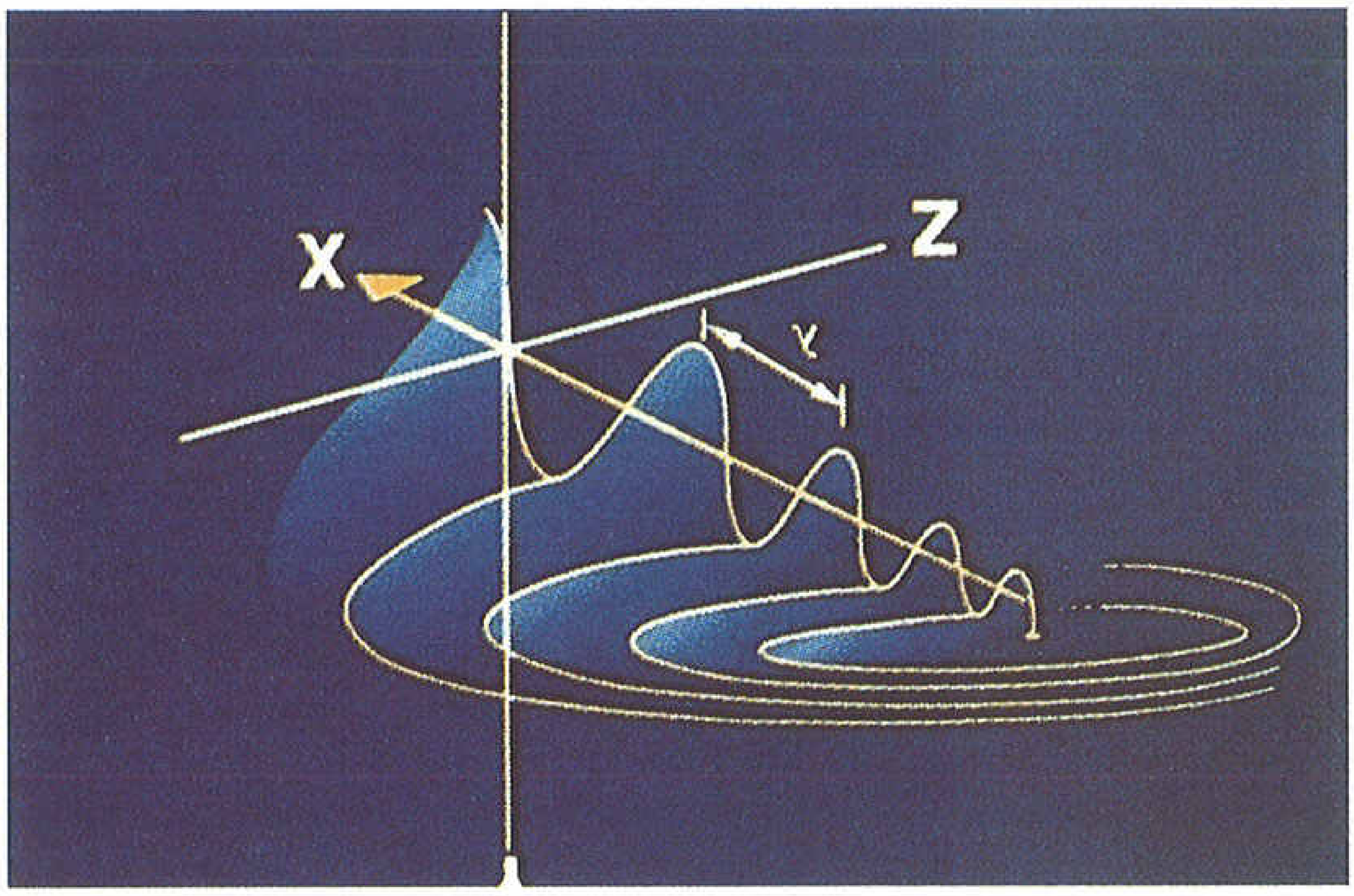


*Figure 2: Electromagnetic waves appear as a continuous series of transverse vibrating waves. The wave front is indicated by X, having an amplitude shown as Y. The vector Z represents a magnetic field perpendicular to the advancing wave front.*

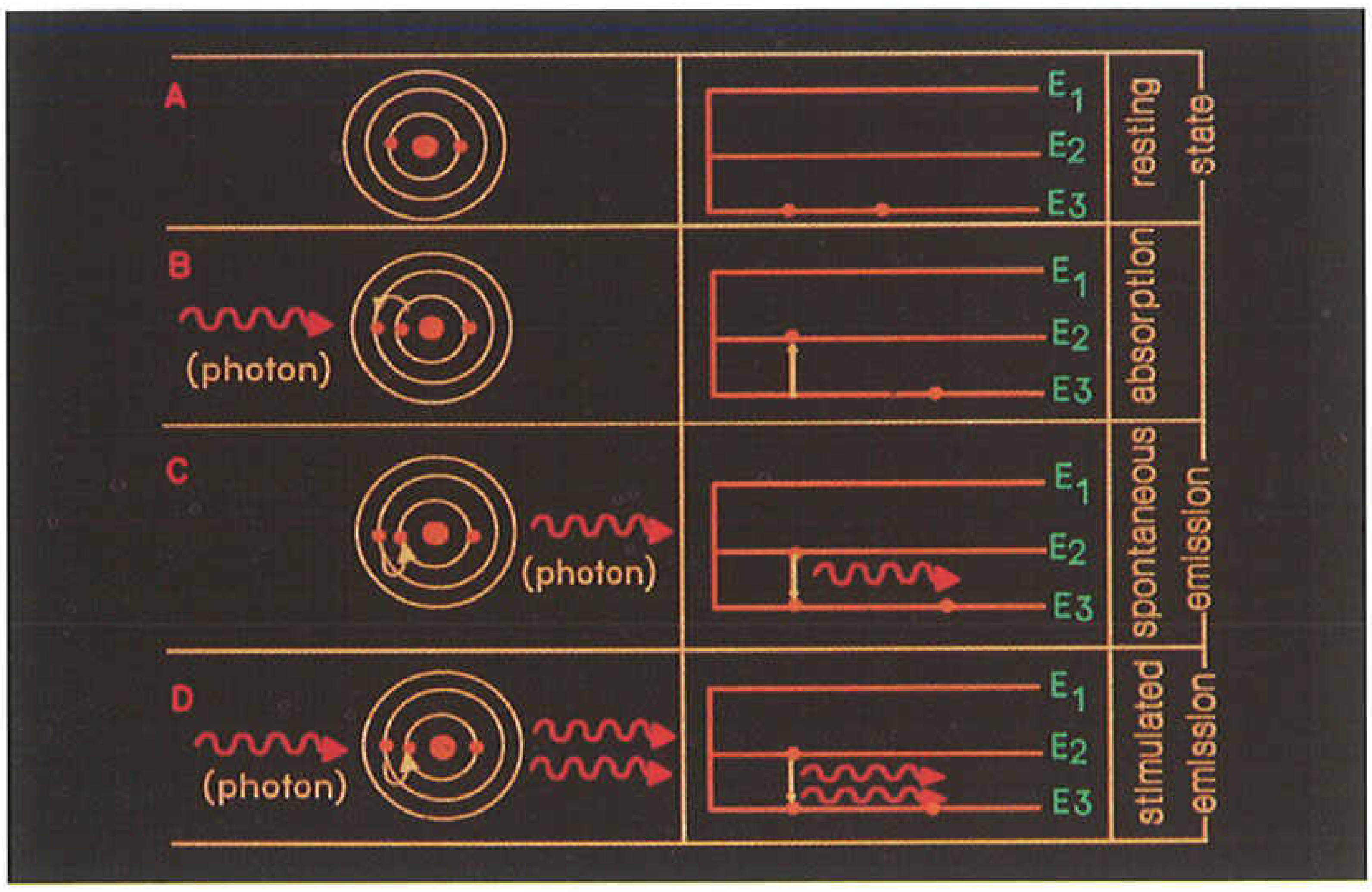
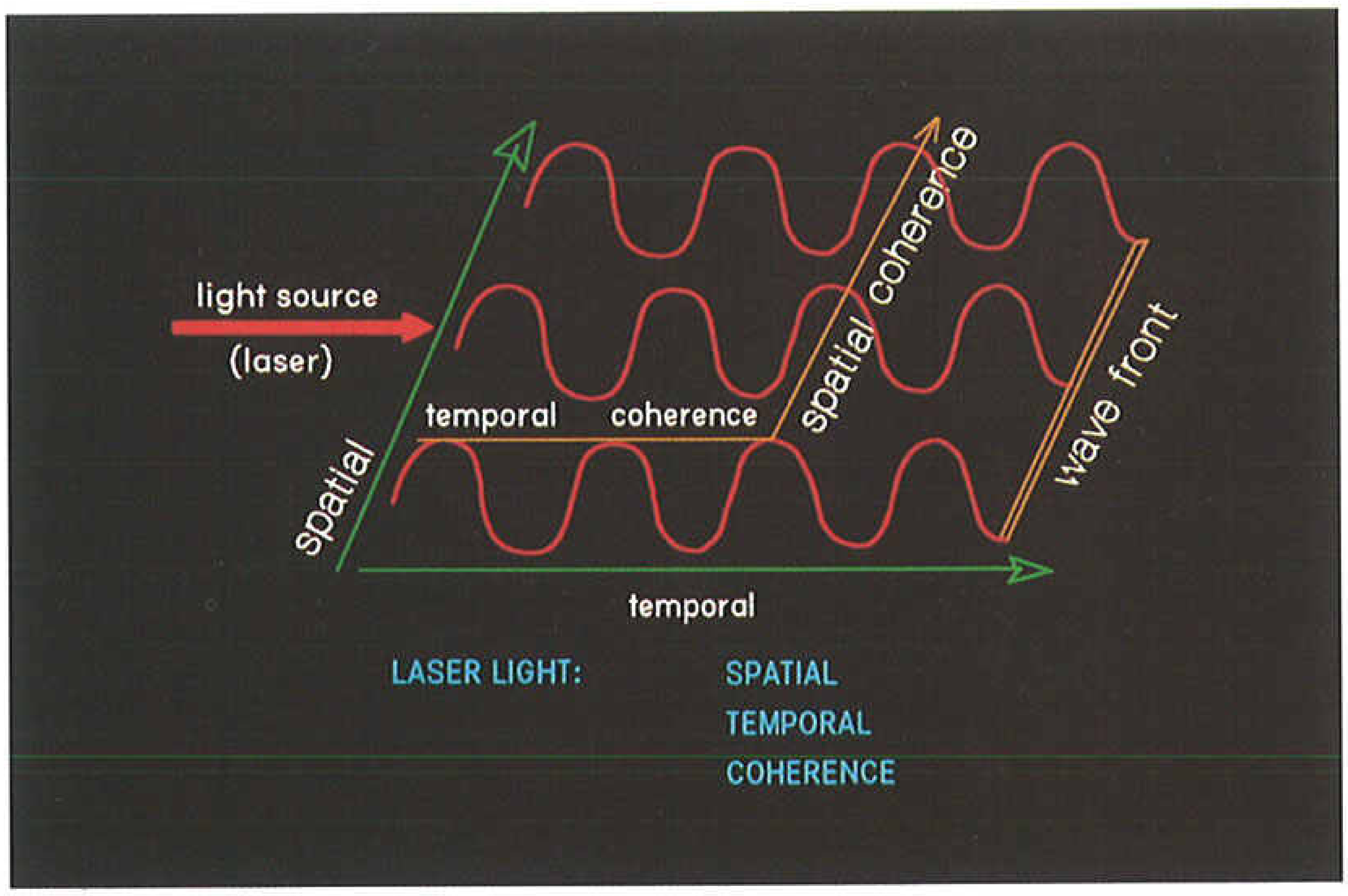


*Figure 3: [A] The atom is in the resting state, with two electrons in the inner orbit. [B] An electron absorbs a photon, causing it to jump into a higher orbit, the atom goes into an excited state. [C] The electron returns to its original orbit, and the atom goes back into the resting state; there is spontaneous emission of a photon. [D] When an atom in excited state is irradiated with a photon of the same wavelength that was absorbed, the atom will return to its resting state faster will yield two photons or light energy of the same frequency travelling in the same direction. This stimulated emission is necessary for laser light.*



light source

(laser)

spatial

temporal coherence

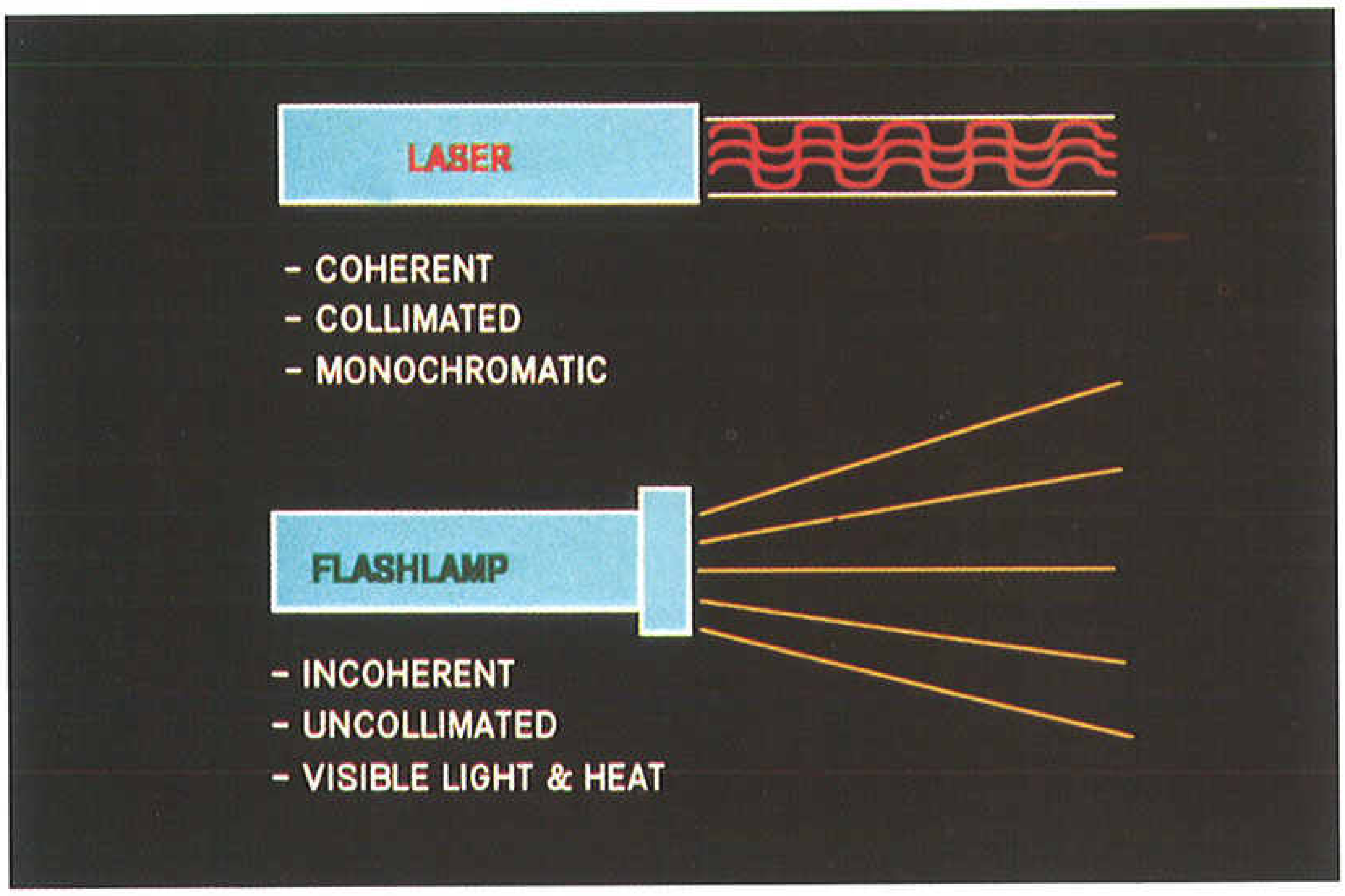
spatial coherence

wave front

temporal

LASER LIGHT: SPATIAL
TEMPORAL
COHERENCE

*Figuge 4: The laser beam has coherence. That means it remains in phase across time and space.*



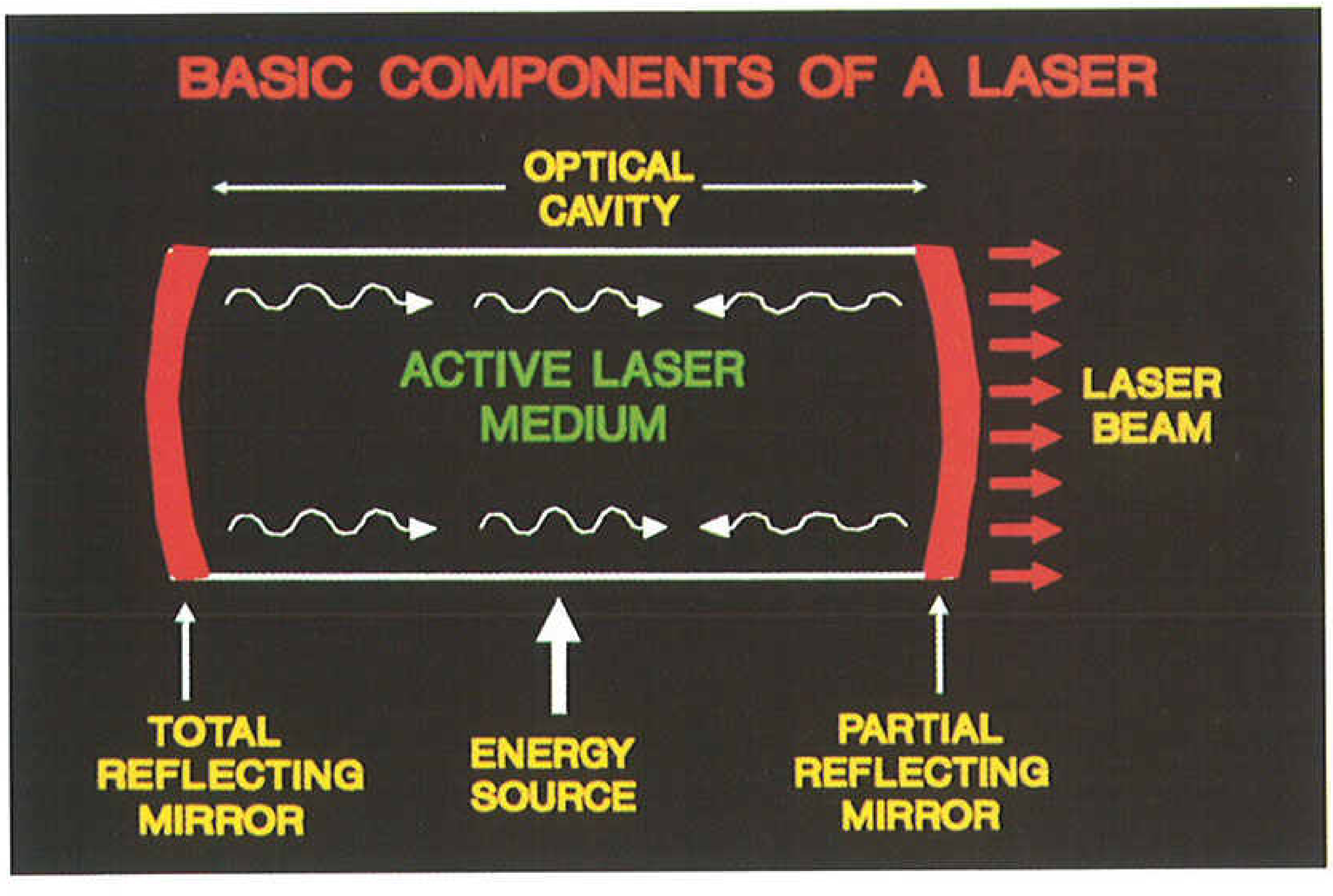
LASER

- COHERENT
- COLLIMATED
- MONOCHROMATIC

FLASHLAMP

- INCOHERENT
- UNCOLLIMATED
- VISIBLE LIGHT & HEAT

*Figure 5: Laser light is monochromatic, coherent, and collimated. Ordinary light produces all the wavelengths across the visible spectrum into the infrared region. It is in coherent and uncollilmated.*



BASIC COMPONENTS OF A LASER

OPTICAL CAVITY

ACTIVE LASER MEDIUM

LASER BEAM

TOTAL REFLECTING MIRROR

ENERGY SOURCE

PARTIAL REFLECTING MIRROR

*Figure 6: chematic presentation of a typical laser machine*

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