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LASER Physics& its Application in Dentistry – A Review

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Abstract: *Lasers has revolutionized the technology used in dentistry in this current era and is being utilized as a part of various dental treatment including its use in Endodontics, Periodontics, Oral Surgery, Oral Medicine as well as in Orthodontics.There are many types of LASERs available for use in dentistry. Henceit's very important to understand the physics behind lasers as well as its applications. The objective behind this review article is to elaborate different types of LASERs as well as its physics behind it.*

Key Words- *Laser, Maser, Specturm Of Light, Spontaneous Emission, Stimulated Emission*

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I. Introduction

'LASER' is an acronym for Light Amplification by Stimulated Emission of Radiation[1]. Most patients still associate the sound and vibration of the drill with pain. However, with the new inventions and advancements in this field, several options have become available to progressive dentists to allay fears and offer patients state of the art treatment. One such advancement is the advent of the laser technology presenting new vistas for dentists in fields of dentistry. A laser is a device which is built on the principles of quantum mechanics to create a beam of light where all of the photons are in a coherent state - usually with the same frequency and phase (most light sources emit incoherent light, where the phase varies randomly)[2]. Among the other effects, this means that the light from a laser is often tightly focused and does not diverge much, resulting in the traditional laser beam. The unique characteristics of the laser are that it is monochromatic, coherent and collimated. This allows concentration of tremendous amount of energy to a small area. With the development of thinner, more flexible and durable laser fibres, laser applications in endodontics have increased.

II. History Of Laser

The dental lasers of today have benefited from decades of laser research and have their basis in certain theories from the field of quantum mechanics formulated by Danish physicist Bhor(1900)[3].

The 1917 seminal paper by Einstein ZurQuantenTheorie der Starlung contained the elements for the conceptual basis for stimulated emission of radiant energy that was to form the foundation of modern laser physics[4].When combined with the principles of the quantum mechanics promulgated by Niles Bohr and the fabrication of optical resonators known in the nineteenth century, Gordon and others, much later in the 1955, were the first to demonstrate the stimulation of microwaves within the electromagnetic spectrum.40 years later, American Physicist in 1958, Schawlow and Townes[5] revealed that it was possible to stimulate emission of radiant energy in the form of photons and in the infrared and visible or optical portions of the spectrum extending the maser principle to the optical portion of the electromagnetic field, which rapidly led to development hence LASER (Light amplification by the stimulated emission of radiation).The first working laser was constructed by Theodore Maiman[5]in 1960 at the Hughes Research Laboratories in Malibu, CA, by exciting a ruby rod with intense pulses of light from a flash lamp. The first actual continuously generating laser was attributed to Javan and colleagues[6] in 1961 who used a mixture of helium and neon. In 1964, Patel at Bell Laboratories developed the CO2 laser[7].

The HeNe laser was of low power, but it advanced the concept of laser practicability by its continuous mode and continues to be used as a coaxial spotter for laser beams of more powerful lasers.

III. The Maser

A predecessor of the laser, called the MASER, for "Microwave Amplification by Stimulated Emission of Radiation", was independently developed in 1954 at Columbia University by Charles Townes and Jim Gordon and in Russia by Nicolay Basov and Alexandra Prokhorov.

These ammonia masers were two-energy-level gaseous systems that could continuously sustain a population inversion and oscillation. In 1956 Nicolaas Bloembergen proposed a three-level solid state maser at Harvard, demonstrated by researchers at Bell Labs that same year[8].

IV. History Of Laser In Dentistry

The early 1960s witnessed the beginning of dental laser investigations, with attention devoted to developing the basic laser parameters as they related to dental hard and soft tissues. Many of these initial investigators used the ruby laser to explore tissue interaction with enamel and dentine because synthetic ruby was the only material to be used routinely as the active medium in those early years. Stern and Sognaes[9] were the first to investigate the potential uses of the ruby laser in dentistry and reported in 1965 that a ruby laser could vaporize enamel. The thermal effects of continuous wave lasers at that time would damage the pulp.After initial experiments with the ruby laser, clinicians began using other lasers, such as argon (Ar), carbon dioxide (CO2), neodymium : yttrium – aluminium - garnet (Nd: YAG), and erbium (Er):YAG lasers[8]. The first laser use in endodontics was reported by Weichman and Johnson[9], who attempted to seal the apical foramen in vitro by means of a high power-infrared (CO2) laser. Although their goal was not achieved, sufficient relevant and interesting data were obtained to encourage further study. Practitioners and researchers began to find clinical oral soft tissue uses of medical CO2 and Nd: YAG lasers until in 1990 when the first pulsed Nd: YAG laser designed specifically for the dental market was released. Subsequently, attempts were made to seal the apical foramen using the Nd:YAG laser. TheFDA clearance of the first true dental hard tissue Er: YAG laser was seen in the year 1997 and the Er, Cr: YSGG a year later. Semiconductor based diode lasers emerged in the late 1990s as well.

V. What Is Laser?

The word laser started as an acronym for "light amplification by stimulated emission of radiation"[10]. In this usage, the term

L - “Light" includes electromagnetic radiation of any frequency, not only visible light, hence the terms infrared laser, ultraviolet laser, X-ray laser and gamma-ray laser. Laser light is monochromatic regular light is polychromatic

A- Amplification means that a very bright intense beam of light can be created. The laser may be activated by a few photons which then act to produce many more, and the initial light generated is computed to make a very bright compact beam.

S – Stimulated; Means that the photons are amplified by stimulating an atom to releases more photons.

E-Emission refers to the giving off photons. The exited atom emits a photon by absorbing energy. The term stimulated emission of radiation is based on the quantum theory of physics first postulated by Bohr.

R-Radiation mean giving or omitting photons.

VI. Characteristics Of A Laser

Light is a form of electromagnetic energy that travels in waves at a constant speed, and photon being the basic unit of this radiant energy.

A wave of photons can be defined by amplitude (which is the total height of the wave oscillation from the top of the peak to the bottom) and wavelength (which is the distance between any two corresponding points on the wave).

The wavelength of laser energy is important in terms of both how this energy is delivered to the operative site and its effect on the tissue.

Ordinary white light seen by the human eye is the sum of the many colours of the visible spectrum; it is usually diffuse, non-focused, with many different amplitudes and wavelengths, whereas light produced by a laser has opposite properties, being monochromatic (one colour) and is very finely focused. The process of lasing occurs when an excited atom is stimulated to emit a photon before the process occurs spontaneously[10]. Spontaneous emission of a photon by one atom stimulates the release of a subsequent photon and so on. This stimulated emission generates a very coherent (synchronous waves), monochromatic (a single wavelength), and collimated form (parallel rays) of light that is found nowhere else in nature[11]. The laser beam is collimated, meaning there is a constant beam size and shape out of the laser similar to 8-radiation It is also coherent, a property unique to lasers, in that there are physically identical light waves all in phase with one another with identical amplitude. wavelength and amplitude.

Light can either be reflected or absorbed onencountering with matter where the photons of energy are not destroyed but rather used to increase the energy of the absorbing atom or molecule.

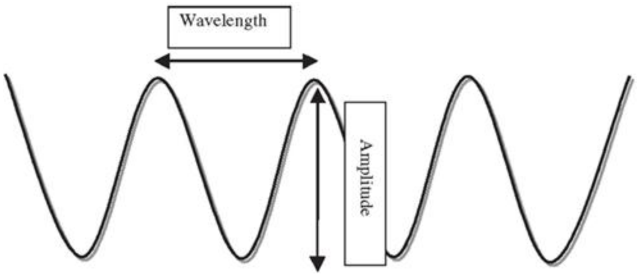

Fig.1 Wave of photons (light energy) can be defined both by amplitude and wavelength.

Electromagnetic Spectrum of Light[12]

The electromagnetic spectrum of light is composed not by thenaked/visible radiations but by visible ones. The cosmic radiations are generated from the radioactivity produced by the cosmos. Telluric radiations are also emittedfrom underground. The solar system emits a wide spectrum of radiations including ultraviolet, visible, and infrared radiations. The laser radiation, a human invention, belongs to the electromagnetic spectrum in different zones, depending on the specific wavelength produced.

Visible Spectrum of Light

The optical perception of human eyes does not recognize electromagnetic radiation beyond the violet zone of the spectrum (0.4 μm) or farther the red zone (0.7 μm). Accordingly, the spectrum of visible light covers a range approximately between 0.4 and 0.7 μm (400–700 nm); however, the border between visible and invisible spectrum is not precisely defined, depending on different factors, and is between 380 and 400 nm on one side and 700 and 800 nm on the other side.

Invisible Spectrum of Light

Beyond the violet zone, with a wavelength of less than 0.4 μm (400 nm), there is a zone called ultraviolet, between 0.4 and 0.01 μm. On the left side of this zone, with a decreasing wavelength, there are the X-rays extended to a wavelength of about 0006 μm. In the more external part, there are the gamma rays. Beyond the red spectrum of light, with a wavelength superior to 0.7 μm (700 nm), the infrared spectrum is located between 0.7 and 400 μm. On the right side of this zone, there are the microwaves and farther the radio waves (short1–100 m; medium 200–600 m; far >600 m).

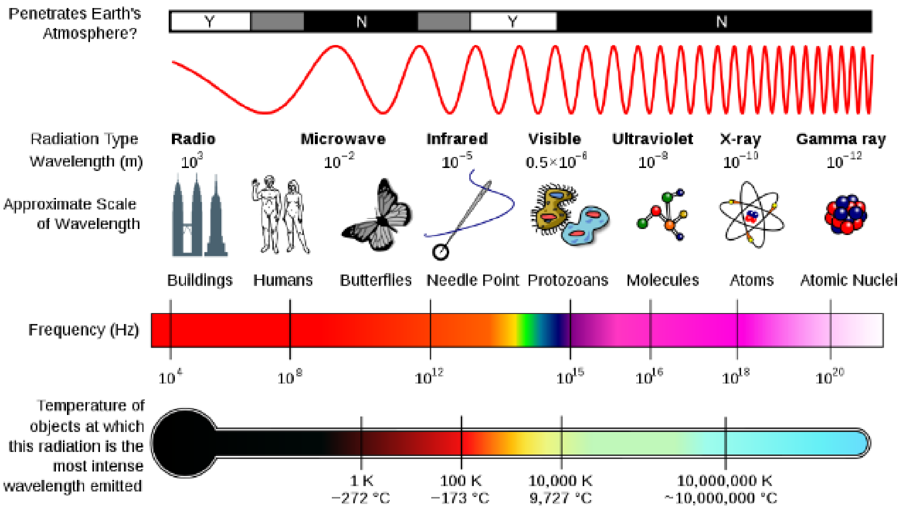

Figure 2 illustrates the electromagnetic spectrum of radiations[12].

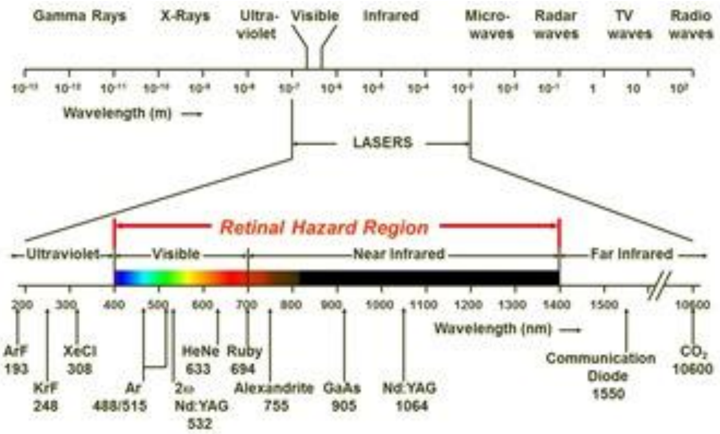

Figure 3 -Lasers in the electromagnetic spectrum of the light[12]

In the visible and invisible infrared spectrum of light, we find most of the wavelengths used in dentistry **(Fig.3).**

Spontaneous Emission

An atom can absorb a photon of light, which ceases to exist, and an electron (e-) within that atom jumps up to a higher energy level. This atom is now in an excited or pumped state relative to its resting or ground state. However, in the excited or pumped state the atom is unstable and undergoes spontaneous decay back to its resting or ground state, releasing the stored energy in the form of an emitted photon. This process is called spontaneous emission' and the interval between absorption and re-emission is very short.The first person to derive the rate of spontaneous emission accurately from first principles was Dirac in his quantum theory of radiation[13] the precursor to the theory which he later coined quantum electrodynamics[14]. In any given atom, only certain energy levels are possible. When a photon is absorbed, the atom jumps to one of the allowable energy levels. That is, each type of atom can only absorb photons of exactly the right energy or wavelength. Hence, each species of atom has a unique absorption spectrum.

Stimulated emission and light amplification[15]

While an atom is in its excited or pumped state, a photon of energy of the right wavelength enters its electromagnetic field and causes the decay of the excited $e^-$to the lower energy state before this process occurs spontaneously. This is accompanied by the release of the stored energy in the form of a second photon. The first photon is not absorbed but continues on to encounter other excited atoms[16]. The net result of this process of 'stimulated emission' is two photons of identical wavelength travelling in the same direction at the same time which are said to oscillate in phase (Figure 3b). In a collection of atoms, where there are more atoms in an excited than resting state, there is said to be a population inversion. This is a necessary requirement for production of a laser light.

Spontaneous emission of a photon from one atom will stimulate the release of a second photon from a second atom. These two photons will similarly go on to stimulate the release of a further two more photons; these four then yield eight photons; eight yields 16, and so on, producing a brief intense flash of monochromatic coherent light.

The resultant light produced from this photon chain reaction produces the coherent light characteristic of a laser

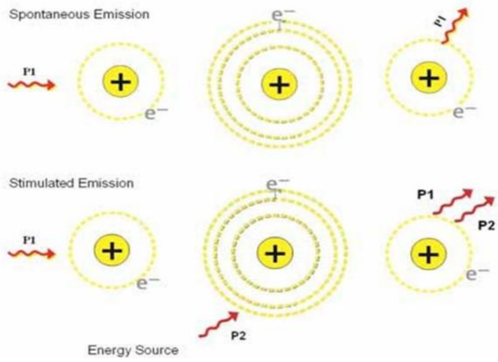

Figure 4. The concept of (a) Spontaneous' and (b) Stimulated' emission of photons of light energy on encountering an atom[17].

VII. Basic Component Of Laser[18]

There are 3 main parts of laser delivery system.
(1) Lasing or Active Medium
(2) Energy or Pumping Source
(3) Optical or Resonating Chamber
Other parts include:-
(4) Controller (or microprocessor)
(5) Cooling system
(6) Delivery system
(7) Handpiece and tips

Laser consists of a laser medium in a resonant cavity with a power supply and a cooling system with some form of control to the unit. Lasers are named after the chemical elements, molecules or compounds that comprise the core, or active medium, that is stimulated

(1) LASING OR ACTIVE MEDIUM

It is the material which can absorb the energy produced by the external source through subatomic configuration of its component molecules & subsequently giving the excess energy as photons of light. It can be solid, liquid or gas.

This active medium can be a container of gas, as in the case of a carbon dioxide laser, a solid crystal rod such as an erbium laser, or a solid-state electronic device in the case of a diode. The other available dental lasers have either solid-state semiconductor wafers made with multiple layers of metals such as gallium, aluminum, indium, and arsenic or solid rods of garnet crystal grown with various combinations of yttrium, aluminum, scandium, and gallium to which an element, such as chromium, neodymium, or erbium, is added (a process called doping). Lasers are generically named for the material of the active medium, which can be a container of gas, a crystal, or a solid-state semiconductor.

Laser	Abbreviation	Active medium	Hosting medium	Doping atom	Wavelength (nm)
Argon	Ar	Gas	–	–	488 and 514
Carbon dioxide	CO_2	Gas	–	–	9300; 9600 and 10,600
Diode	–	Semiconductor	–	–	445, 635–810 940–980–1064
Potassium titanyl phosphate	KTP	Solid	YAG crystal	Neodymium frequency doubled	532
Neodymium-doped yttrium aluminum garnet	Nd:YAG	Solid	YAG crystal	Neodymium	1064
Neodymium-doped yttrium aluminum perovskite	Nd:YAP	Solid	YAP crystal	Neodymium	1340
Erbium-doped yttrium scandium gallium garnet	Er,Cr:YSGG	Solid	YSGG crystal	Erbium and chromium	2780
Erbium-doped yttrium aluminum garnet	Er:YAG	Solid	YAG crystal	Erbium	2940

Table 1:- Active medium of lasers most used in dentistry

(2) ENERGY OR PUMPING SOURCE

It is used to excite or pump the atoms in lasing medium to their higher energy levels that are essential for laser production.It can be electrical, thermal, chemical or optical. The characteristics of the energy source are important for the generation of the laser pulse, especially for short-duration pulses (high peak power).

(3) OPTICAL OR RESONATING CHAMBER

The lasing medium is located within the optical chamber.

It is a cylindrical structure with fully reflecting mirror on one side & partially reflecting mirror on other side--parallel to each other. This arrangement allows reflection of photons of light, back & across the chamber.It will result in production of intense photo resonance within the medium.In the garnet and gas lasers, there are two mirrors, one at each end of the optical cavity, placed parallel to each other. The semiconductor lasers are similarly configured in the garnet and gas lasers, there are two mirrors, one at each end of the optical cavity, placed parallel to each other. The semiconductor lasers are similarly configured although the active medium is "sandwiched" between silicon wafers which have precisely polished edges of the wafer for reflection. One wafer is positively charged and one is negatively charged; and the discharge of current from one to the other, crossing over the active medium, releases the photons. Surrounding this core is an excitation source, either a flash- lamp strobe device or an electrical field or coil, which provides the energy to the active medium.

(4) Controller Subsystem and Cooler
The controller is a microprocessor that verifies the characteristics of the production of laser energy, the laser emission mode (continuous wave, mechanically interrupted or pulsed), the pulse frequency of repetition (pulses per second or pulse repetition rate, also improperly called Hz), and the length of the emission of the single pulse. The cooling system is necessary to 0dissipate the heat produced for the pumping process.

(5) Delivery System
Once generated, laser light must be conducted to the point of use. There are various systems of delivery, depending on the difference of the wavelength carried: optic fiber, hollow fiber, and the articulatedArm.

(6) Handpieces and Tips
All the delivery systems use angular or straight - ended handpieces. The ideal handpiece should be small, lightweight, and handy. Some hand - piece does not have any terminal tip, but a reflecting mirror which works at a distance from the tissue (tipless or noncontact or far-contact hand - piece). Some other has a terminal tip which works almost in contact with the tissue and/or within a root canal (close-contact handpiece). Others are hollow hand - pieces which permit the passage of the fiber up to the extremity (typically for the near-infrared laser).

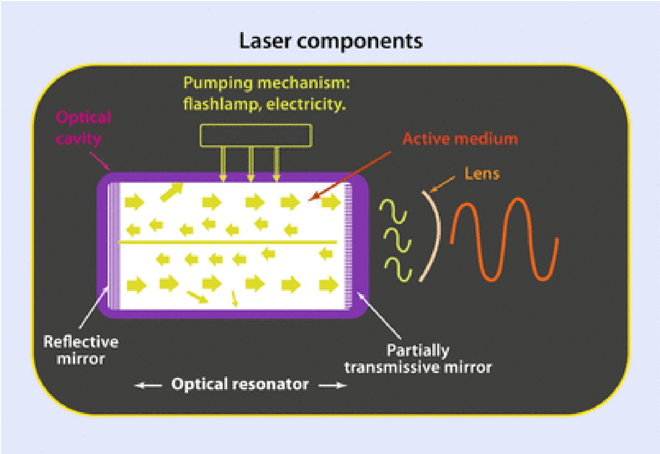

Figure 5 - Solid/ Gas laser[18]

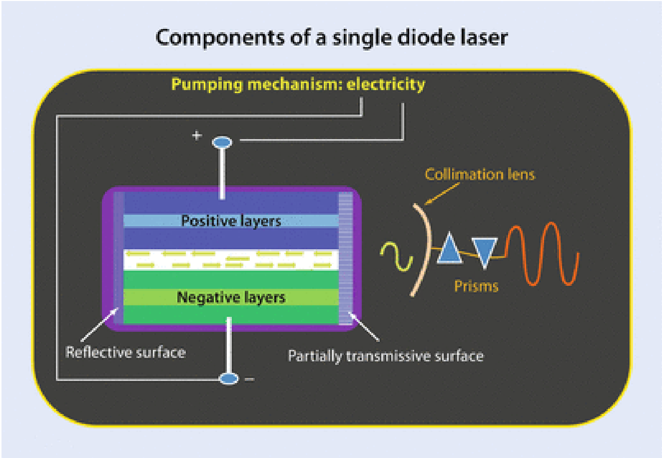

Figure 6 - Single Diode Laser[18]

VIII. Classification Of Laser [18]

I. According to the wavelength (nanometers)
1. UV (ultraviolet) range – 140 to 400 nm
2. VS (visible spectrum) – 400 to 700 nm
3. IR (infrared) range – more than 700 nm

Most lasers operate in one or more of these wavelength regions.

II. Broad classification
1. Hard laser (for surgical work)
i. CO2 lasers (CO2 gas)
ii. Nd:YAG lasers (Yttrium-aluminium-garnet crystals dotted with neodymium)
iii. Argon laser (Argon ions)
2. Soft laser (for biostimulation and analgesia)
i. He-Ne lasers
ii. Diode lasers

III. According to the delivery system
i. Articulated arm (mirror type)
ii. Hollow waveguide
iii. Fiber optic cable

IV. According to the type of active medium used :
Gas, solid, semi-conductor or dye lasers

V. According to type of lasing medium :
E.g. Erbium: Yttrium Aluminium Garnet

VI. According to pumping scheme
1. Optically pumped laser
2. Electrically pumped laser

VII. According to operation mode
1. Continuous wave lasers
2. Pulsed lasers

VIII. According to degree of hazard to skin or eyes following inadvertent exposure,
This laser classification system is based on the probability of damage occurring.
Class I- (< 39mw) Exempt; pose no threat of biological damage to stare into the beam for a long period of time. The normal aversion response or blinking should prevent you from staring into the beam. No damage can be done within the time it takes to blink.
Class IIIA - (<5OOmw) Can cause injury when the beam is collected by optical instruments and directed into the eye.
Class IIIB - (<5OOmw) Causes injury if viewed briefly, even before blinking can occur.
Class IV - (> 5OOmw) Direct viewing and specular and diffuse reflections can cause permanent damage including blindness.

Even though there have been many classifications of lasers,
Professor Vipul Kumar Srivastava et al. proposed a new simplified classification of lasers based on the clinical use.[19]

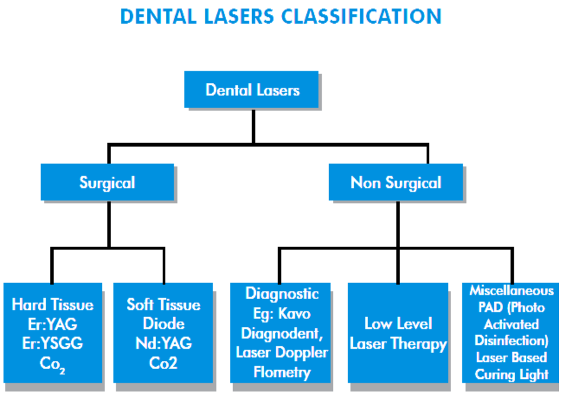

Figure 7 - Classification of lasers based on the clinical use[19].

The current soft lasers in clinical use are the:
•Helium-neon (He-N) at 632.8 nm (red, visible).
•Gallium- arsenide (Ga-As) at 830 nm (infra- red, invisible). Hard lasers (surgical) can cut both soft and hard tissues. Newer variety can transmit their energy via a flexible fiber optic cable
Presently more common type clinically used, under this category the medical lasers are:
•Argon lasers (Ar) at 488 to 514 nm
•Carbon-dioxide lasers (CO2) at 10.6 micro- meters
•Neodymium-doped yttrium aluminum garnet (Nd:YAG) at 1.064 micrometer.
•Holmiumyttrium-aluminum-garnet(Ho: YAG) at 2.1 micro-meter.
•Erbium, chromium yttrium-slenium-gallium- garnet (Er, Cr: YSGG) at 2.78 micro-meter.
•Neodymium yttrium-aluminum- perovskite (Nd: YAP) at 1,340 nm.

Ultraviolet	Visible	Near infrared	Medium infrared	Far infrared
Excimer 308 nm	Blue diode 445 nm	Diode 810 nm	Er,Cr:YSGG 2780 nm	CO_2 9300 nm
	Argon Blu 470-488 nm Green 514 nm	Diode 940 nm		CO_2 9600 nm
				CO_2 10,600 nm
	Green KTP 532 nm	Diode 970 nm		
	Red diode 635–675 nm	Diode 1064 nm Nd:YAG 1064 nm	Er:YAG 2940 nm	
		Nd:YAP 1340 nm		

Table 2:- Classification of lasers according to their wavelength position on the electromagnetic spectrum of light[19]

Soft tissue lasers	Hard and soft tissue lasers	LLLT	Diagnosis
Diodes 445>1064 nm	Er,Cr:YSGG Er:YAG	Diodes 445>1064 nm	405 nm 655 nm
Nd:YAG, Nd:YAP	CO_2 9300 nm		
CO_2 10,600 nm			

Table 2:- Classification of dental lasers according to clinical applications[19]

IX. Mechanism Of Action Of Laser

The word laser is an acronym standing for "Light Amplification of Radiation"[20]. A laser beam is created from a substance known as an active medium, which when stimulated by light or electricity produces photons of aspecific wavelength. Lasers are characteristically monochromatic, unidirectional, coherent, and emittedfrom a stimulatedactive medium. Once a laser beam is produced it will travel in one direction (unidirectional), though the divergence of the beam varies by type of laser and the associated transmission hardware. Coherence is the property that not only is a laser a single wavelength but all the peaks and valleys of each wave travel in unison. The active media in dentistry can be solid state, gas, or semiconductor. Solid state lasers are a crystal matrix host doped with the light emitting, excitable atoms; such as erbium laced yttrium, aluminium, and garnet (Er: YAG). CO2 is a popular laser where the active medium is sealed in an airtight chamber. Diode lasers have a semiconductor that when stimulated with electricity, laser light is emitted[20]. Stimulated emission is a phenomenon that occurs within the active medium. For example, in solid state Er: YAG lasers the erbium is stimulated by light from a flash lamp with a process known as optical pumping. As an erbium atom absorbs a photon, its electrons are elevated to higher energy level. When the electrons return to a lower energy state, two identical photons are emitted and these photons can further stimulate more atoms in a chain reaction, resulting in amplification of the light produced. Mirrors surrounding the active medium called a resonator further increase this light energy. One of the mirrors called the output coupler is less than one hundred percent reflective. Light leaks from the output coupler and these are the photons that form the laser beam. Once the beam is created it is carried to the target tissue by various types of beam transfer hardware. Mirrors in articulated arms and optical fibers are common examples of this hardware[20].

X. Laser Parametes[27]

The amount of energy emitted is calculated in Joule (J); normally each pulse energy ranges from few mJ (minimum 5 mJ) up to hundred mJ (maximum 1000 mJ or 1 J). When considering the energy emitted, it is important to know the irradiated surface area and the diameter of the delivering laser fiber/tip that conditions the density of energy applied to the target tissue. the diameter of the delivering laser fiber/tip that conditions the density of energy applied to the target tissue. This is fundamental in endodontics, considering how the diameter of the canal and the irradiated surface varies from the apical one-third to the cervical one-third.The measurement of the work completed over time is called power and is measured in Watts. One Watt equals 1 Joule delivered for 1 second, and the power can be selected by the operator on each device.

Fluence and irradiance

Irradiance is the intensity (power density) of the laser beam measured in W/cm2 and is inversely proportional to the square of the radius of spot size.[21]

Irradiance ¼ laser power/laser beam cross-sectional area ð pi ~ r2Þ

Thus, for a 50 W output laser with a beam diameter of 0.4 cm, irradiance is 400 W/cm2. By focusing the beam to a diameter of 0.2 cm and maintaining 50 W output, the irradiance increases to 1600 W/cm2.

It is important to note that for a given wave- length, thelarger thelaser beam diameter (spot size), the deeper the penetration. The larger the spot size, the less associated the scattering and the less the loss of energy with depth of penetration.[22]

Fluence

The fluence is the energy (in Joules) delivered per unit area.
Energy (Joules) ¼ Power (Watts) ~ Time (seconds) 1 Joule ¼ 1 Watt/second
Therefore, fluence is the product of irradiance and exposure time:
Fluence ðJ/cm2Þ ¼ Laser power output (W)
~ exposure time (seconds)/ laser beam cross- sectional area ðcm2Þ
Fluence describes the energy per unit area for a single pulse[23]. For a fixed beam diameter and pulse duration, fluence can be altered by changing the power of the laser or the exposure time. When short pulses are used in Q-switched lasers, fluence may be less than with longer pulses but the laser delivers very high power with each pulse[24].

Pulse duration (pulse width)

The pulse width is the time during which the laser output power remains continuously above half its maximum value. By modulating a continuous-wave light source pulse duration can be altered. Pulsed laser systems may be either long-pulsed such as PDL with pulse durations ranging from 450 ms to 40 ms, or very short-pulsed (5 – 100 ns) such as the quality-switched lasers.The pulse duration governs the spatial confinement of heat and should match the thermal relaxation time of the target. The thermal relaxation time is a measure of the cooling time of the target and is the time taken for the target to dissipate half of the incident thermal energy. This cooling time is primarily related to the physical size of the target: the larger the target, the longer the thermal relaxation time.If pulse duration is equal to or less than the thermal relaxation time of the target, then unwanted heat diffusion to adjacent tissue is reduced[25].The utilization of extended pulse durations allows the delivery of higher fluences of energy in a moregentle fashion. These greater fluences enable treatment of veins that are larger and deeper in location.

Pulse repetition rate

Pulse repetition rate or pulse repetition frequency is defined as the number of emitted pulses per second (Hz).Thermal effects depend on the type of tissueand the temperature achieved inside the tissue. Heat conduction is the mechanism by which heat is transferred to adjacent tissue structures. If the subsequent laser pulse arrives before sufficient thermal diffusion into the surrounding tissues occurs, a pronounced temperature riseand thermal damage can occur. Even ultrashort laser pulses with pulse durations shorter than 100 ps, each of them having no thermal effect, may add up to a measurable increase in temperature if applied at repetition rates higher than about 10 – 20 Hz[26].

The minimum quantity of energy necessary to generate a clinical effect of ablation or vaporization is called "threshold of ablation." [27]

Average power (P): expressed in Watt = E (J) × F (Hz or pps)
Energy (E): expressed in J
Frequency of pulsation (F): expressed in Hz or pps
Power density (Pd): expressed in W/cm 2
Fluence (Fl): expressed in J/cm 2
Peak power (PP): W = E (J) ÷ duration of the single impulse (s)
Density of energy (fluence = J/cm2)

Laser Power[27]

The power emitted by a laser is determined by the energy of each single pulse (expressed in J) multiplied by the number of pulse repetition in the time unit (pps or Hz). As previously reported for the energy, the power density is determined by power used per unit of surface of the irradiated area (expressed in W/cm2).

Power (W) = Energy (J) × Frequency of repetition (pps or Hz).
Power density (W/cm 2).
Peak power (PP) = W = E (J) ÷ duration of the single impulse (s).

The more power is applied, the faster thespeed of the effect on the tissue. The more energy is applied, the greater theeffect on the tissue.

XI. Laser Emission Mode And Delivery System[27]

There are two basic emission modes for dental lasers – continuous-wave and free-running pulsed.

Continuous wave means that energy is emitted constantly for as long as the laser is activated. A continuous emission of energy is not always advisable because of the excessive thermal effect released. Carbon dioxide and diode lasers operate in this manner. A gated or superpulsed laser is a variation of continuous-wave and is accomplished with an electronic control and/or a mechanical shutter. This "gating" helps to minimize some of the undesirable residual thermal damage usually associated with continuous-wave devices.Short time of emission (ton), of about 10–20 milliseconds (ms), is more correctly and effectively used in endodontics with KTP and diode lasers than continuous wave emission; shorter time, in the unit of microseconds, permits the use of higher power. Newest cutting-edge diode laser technology has frequency of emissionof thousand hertz (10,000–20,000 Hz). Examples are the Diode lasers which typically emit laser energy in such a mode.Free-running pulsed mode is produced by a flashlamp, where true pulses – on the order of a few ten-thousandths of a second – emanate from the instrument. Nd:YAG, Nd:YAP, Er:YAG, and Er,Cr:YSGG devices operate as free-running pulsed lasers. The energy of certain laser wavelengths can be delivered from the laser instrument to the target tissue via flexible, small-diameter glass fibers, which usually directly contact the tissue and are used in KTP, diode, Nd:YAG, and Nd:YAP instruments. Erbium and carbon dioxide devices use more rigid glass fibers, semi-flexible hollow wave-guides, or rigid sectional articulated arms. Some of these systems employ additional small quartz or sapphire tips, which attach to the operating handpiece. Other systems are used without contacting the tissue. In either emission mode, lenses within the laser instrument focus the beam. With hollow waveguides or articulated arms without a contact tip, there is a spot of a specific diameter where the beam is in sharp focus and where the energy is the greatest. That spot, called the focal point, should be used for incisional and excisional surgery. For the optic fiber and accessories, the focal point is at or near the tip. Conversely, if the beam is not in focus, the energy that is applied to the tissue is lessened; moreover, the beam diverges as it exits the tip, further decreasing the energy

The wavelength of the laser determines the best mode of delivery as fibre-optic cables are not efficient at transmitting all wavelengths. Wavelengths of 300 nm to 2400 nm are efficiently transmitted by optic cables, meaning that most of the energy put in comes out at the terminal end of the cable, whereas wavelengths above 2400 nm and below 300 nm are absorbed by the quartz fibre and the laser energy is merely converted to heat. Hence carbon dioxide laser energy at a wavelength of 10,600 nm is absorbed after only a few millimetres of travelling through an optic cable.

Dental lasers can be used either in contact or non-contact mode. Contact mode provides easy access to otherwise difficult to reach areas of tissue. The fibre tip can easily be inserted down a root canal to sterilize the canal, or into a periodontal pocket to remove small amounts of granulation tissue. In non-contact mode, the beam is aimed at the target at some distance away from it, which can be useful for following various tissue contours, but there is loss of tactile feedback which necessitates that the operator pays close attention to the tissue interaction with the laser energy. Dental lasers that operate in the invisible end of the spectrum are equipped with a separate aiming beam, which can either be laser or conventional light. The aiming beam is delivered along the fibre or waveguide in a separate channel and shows the operator the exact spot where the laser energy will be focused. In either modality, the beam is focused by lenses within the laser itself. With the hollow waveguide, there will be a precise spot at the focal point where the energy is greatest, and that spot should be used for incisional and excisional surgery. &or the optic fibre, the focal point is at or near the tip of the fibre, which again has maximum energy. When the handpiece is moved away from the tissue and away from the focal point, the beam is defocused, and becomes more divergent. At small divergent distance, the beam can cover a wider area, which would be useful in achieving haemostasis, for example. At a greater distance away, the beam loses its energy and dissipates away.

XII. Laser Interaction with Biological Tissues and the Effect on the Soft Tissues Of The Oral Cavity, The Hard Tissues Of The Tooth And The Dental Pulp[26]

The interaction between laser light and the target tissue follows the rules of physics. When laser energy hits a target tissue it may be reflected, scattered or absorbed.These optical tissue properties determine the total transmission of the tissue at a certain wavelength.[28]

- **Reflected**
- **Absorbed**
- **Diffused**
- **Transmitted**

1. Reflection is the phenomenon of a beam of laser light hitting a target and being reflected for lack of affinity. It is therefore obligatory to wear protective eyewear to avoid potential damage to the eyes.

2. Absorption is the phenomenon of the energy incident on tissue with affinity being absorbed and thereby exerting its biological effects. The greater the degree of absorption, the greater the degree of transformation to heat.

A given wavelength may be absorbed by one tissue and scattered by another. The main light absorbing components of tissue (chromophores) are haemoglobin, melanin, protein and water. In order to target a specific tissue one should select a wavelength which is strongly absorbed by a chromophore present in that tissue. Infrared light is absorbed primarily by water, while visible and UV light is primarily absorbed by haemoglobin and melanin, respectively (Figure 9). Absorption for competing chromophores can be managed by cooling the structure containing the competing chromophores to minimize collateral thermal injury. In general as the wavelength of light increases so does the depth of penetration into skin. However, in the far infrared where water absorption dominates, the depth of penetration falls. Because of the strong absorption of water at 418, 542 and 577 nm, depth of penetration is attenuated.

3. Diffusion is the phenomenon of the incident light penetrating to a depth in a non-uniform manner with respect to the point of interaction, creating biological effects at a distance from the surface.

4. Transmission is the phenomenon of the laser beam being able to pass through tissue without affinity and having no effect. The interaction of laser light and tissue occurs when there is optical affinity between them. This interaction is specific and selective based on absorption and diffusion. The less affinity, the more light will be reflected or transmitted .

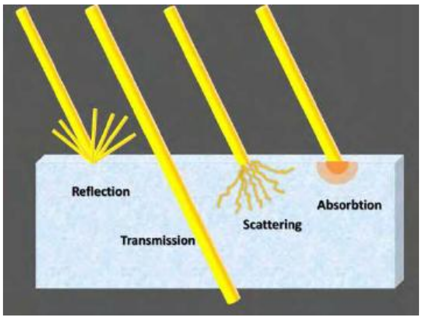

Figure 8 - Process of absorption, transmission, reflection and scattering of the laser beam[28]

Besides intrinsic optical properties of different wavelengths, the interaction depends also on the optical characteristics of the target and on the absorption coefficient of the specific chromophore of the target tissue for a specific wavelength (optical affinity). Accordingly, different interactions happen with the target tissues: dentin, smear layer, debris, organic remnants, bacteria, and irrigant fluids.
In summary, three groups of laser-tissue interaction can be identified:
• Laser radiation emitted in the visible blue-green spectrum of light, such as KTP laser (or neodymium duplicate at 532 nm) and argon lasers (488–514 nm), that produces effects of absorption and diffusion (scattering) of over- lapping entities, with penetration in tissue at intermediate depth
• Radiation emitted in the visible red spectrum (600–700 nm) and in the near infrared (from 810 to 1,340 nm), which renders scattering highly predominant over absorption, with deeper penetration in tissues
• Radiation emitted in the medium- or far- infrared spectrum (2,780–2,940–10,600 nm) that mainly produces absorption in tissue and in water, superficially with unimportant phenomena of diffusion
When the laser light interacts with the target tissue, for diffusion or absorption, it generates on it the biological effects responsible for the desired therapeutical results and for the unwanted collateral effects.

The main beneficial effect of laser energy is absorption of the light by the target tissue and the transfer of this laser energy, thus causing a tissue interaction (Photobiological effects). However there are four basic interactions that can occur following absorption of laser energy[29]:

1) **Photochemical[30-35]:** certain wavelengths of laser light are absorbed by naturally occurring chromophores or wavelength-specific light absorbing substances that are able to induce certain biochemical reactions at cellular level. Derivatives of naturally occurring chromophores or dyes have been used as photosensitizers to induce biological reactions within tissues for both diagnostic and therapeutic applications. Photochemical interactions include biostimulation, photodynamic therapy, and tissue fluorescence. Certain biological pigments, when absorbing laser light, can fluoresce, which can be used for caries detection within teeth. A laser can be used in a non-surgical mode for biostimulation of more rapid wound healing, pain relief, increased collagen growth and a general anti-inflammatory effect

2) **Photothermal**: light energy absorbed by the tissues is transformed into heat energy which then produces tissue effects:
3) **Photoablation** is the removal of tissue by vaporization and superheating of tissue fluids
4) **Coagulation and haemostasis**; and
5) **Photopyrolysis** or the burning away of tissue.

The amount of laser energy absorbed by tissues largely determines the thermal interaction produced and is in turn dependent on the wavelength of the laser light to a great degree, but also on other parameters such as spot size, power density, pulse duration and frequency, and the optical properties and composition of the tissue irradiated.

At tissue temperatures of 42–50^{o}C (hyperthermia) bond destruction and membrane alteration occur. If hyperthermia lasts for several minutes some of the tissue will undergo necrosis.
Beyond 50^{o}C – enzyme activity is reduced, cell immobility occurs and cell repair mechanisms are disabled.
At 60^{o}C – denaturation of proteins and collagen occurs which leads to coagulation of tissue and necrosis of cells.
At 80^{o}C – membrane permeability is increased.
At 100^{o}C – water molecules start to vaporize, dehydrating tissue, gas bubbles are formed inducing mechanical cell rupture and thermal decomposition of tissue (photoablation).
At temperatures exceeding 100^{o}C – carbonization occurs;

beyond 300^{o}C, melting can occur depending on the target material. In general, the exact temperature for the onset of cell necrosis is difficult to determine and is dependent not only on the temperature achieved but on the duration of this temperature. As mentioned above, the CO2 laser wavelength at 10,600 nm is highly absorbed by the water content of oral soft tissues, whereby 90% of the energy is absorbed within the first 100 microns of penetration of the tissue surface.Hence, even at relatively low power densities using a focused beam, there is rapid tissue vaporization of the water with charring and burning of the organic content of the tissue.

Photothermal interactions cause the irradiated target tissue to absorb the laser energy and converts it into heat, thereby producing a direct temperature rise in the irradiated tissue volume. When this energy is applied for long enough, heat conduction will cause a temperature rise in surrounding tissues as well. Hence, thermal effects, such as coagulation necrosis, are produced indirectly in collateral areas and are one of the mechanisms responsible for haemostasis when cutting or vaporizing with a laser.

Figure 9 - Location of thermal effects inside biological tissue[26]

Heat dissipation or diffusion from the irradiated tissue site will determine the extent of collateral damage seen and is largely dependant on the thermal conductivity of the tissue. The time required for diffusion of the heat or 'thermal relaxation time' is defined as the time required for the accumulated heat energy within the tissue mass to cool to 37% of its original value. The degree of heat conduction and rate of tissue cooling both determine the extent of collateral tissue damage for a given wavelength of laser light and tissue type. The composition of the tissue in terms of its structure, water content and vascularity will greatly determine heat conduction/tissue cooling and therefore collateral damage. In addition, factors such as the volume and surface area of tissue irradiated have influence on the rate of heat dissipation.

With continuous laser emission there is no thermal relaxation time, but with pulsed emissions there are brief periods of time allowing for heat dissipation or cooling between pulses. Tissues should be allowed a period of cooling approximately three times their thermal relaxation time to avoid accumulation of heat energy in surrounding tissue and therefore collateral damage. This can be managed effectively

Photomechanical and photoelectrical: these are non-thermal interactions produced by high energy short pulsed laser light. They include photodisruption, photodisassociation, photoplasmolysis and photoacoustic interactions. Absorption of laser energy pulses results in rapid expansion or generation of shock waves that are capable of rupturing intermolecular and atomic bonds (photodisruption or photodisassociation). Hence, there is transformation of the laser light energy to vibrational or kinetic energy. The pulse of laser energy on hard dentinal tissues can produce a shock wave, which could then explode or pulverize the tissue, creating an abraded crater. This is an example of the photoacoustic effect of laser light. Photoplasmolysis is a process of tissue removal through the formation of electrically charged ions and particles that exist in a 'plasma' state, a semi-gaseous, high-energy state which is neither solid, liquid, or gas. Ionization of atoms occurs at very high-energy densities followed by plasma formation. The plasma state is maintained by the absorption of energy from the incident laser beam and through electron vibrations causes the rapid expansion and contraction that produces the disruptive shock waves that break apart target materials in photoplasmolysis.

XIII. Application in Dentistry

1. Caries detection
2. Cavity preparation
3. Photodynamic therapy for endodontic disinfection
4. Peri-implantitis
5. Chronic periodontitis
6. Mucocutaneous oropharyngeal candidiasis
7. Osteomyelitis
8. Disinfection of carious tissue
9. Dentine hypersensitivity
10. Attenuation of gag reflex
11. Treatment for surgical operations and injuries
12. Neuropathic pain
13. Temporomandibular joint and facial pain
14. Frenectomy
15. Ankyloglossia
16. Gingival remodeling and gingivectomy

XIV. Conclusion

LASERS have been widespread used in dentistry since decades. Hence, basic understanding of Laser is of prime importance.

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