Basic principles of medical lasers

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INTRODUCTION

Lasers are devices that emit a single, coherent wavelength of electromagnetic radiation that is used to cut, coagulate, or ablate tissue for a variety of clinical applications. Laser systems produce a variety of wavelengths of varying pulse duration and energy levels. Computer-based imaging and guidance systems allow procedures to be performed precisely, quickly, and with greater control. Although lasers are commonly used superficially for cutaneous and ocular applications, smaller, efficient laser delivery systems are available for minimally invasive applications, including endoscopy, bronchoscopy, laparoscopy, and endovenous ablation.

The safe and appropriate use of lasers requires a trained clinician with a working knowledge of laser delivery systems and laser-tissue interactions to achieve the desired clinical effect while minimizing complications.

The basic principles of medical lasers will be reviewed here. The use and effectiveness of lasers for specific clinical indications are discussed in separate topic reviews. (See 'Clinical utility of lasers' below.)

ELECTROMAGNETIC SPECTRUM

Light is electromagnetic radiation within the range of wavelength that is visible to the human eye. Medical lasers produce photons of electromagnetic energy that can be within, above, or below this range (figure 1). The ranges of wavelength for each region of the electromagnetic spectrum are as follows:

- Gamma rays: <0.1 nm
- X-Rays: 0.1 to 10 nm
- Ultraviolet: 10 to 400 nm
- **Visible: 440 to 760 nm**
- Near-infrared: 700 to 1400 nm
- Mid-infrared: 1400 to 20,000 nm
- Far-infrared: 20,000 to 100,000 nm
- Microwaves: >100,000 nm

LASER PRINCIPLES

Lasers are devices that rely upon the stimulated emission of radiation to produce a beam of light. The word laser is an acronym for **l**ight **a**mplification by **s**timulated **e**mission of **r**adiation. Lasers are comprised of an energy source, a resonant chamber, and an active medium (figure 2).

In the unexcited state, electrons orbit the nucleus at their lowest energy level or ground state, occupying orbits that are closer to the nucleus. However, absorption of energy causes the electrons to become excited, moving to a higher orbit (figure 3). As the electrons return from the excited state back to ground state, they spontaneously emit photons of energy (electromagnetic radiation). In other words, they stimulate emission of radiation [1].

The radiation that is produced has unique properties, including monochromaticity, coherence, and collimation.

- Monochromatic means that all the photons in a laser beam are of the same wavelength. Thus, the laser beam achieves sufficient intensity to destroy tissue, the degree to which is based upon its wavelength and the scattering, reflection, and absorption coefficients of the target tissue. (See 'Tissue ablation' below.)

- Coherence refers to the synchronization of the laser beam in time and space. The photons of the beam are in-phase or coherent. By comparison, the photons in conventional light travel randomly.

- Collimation indicates that the elements of the laser beam are nearly parallel. Because there is little divergence, laser beams can be focused to a small area. This property differs from conventional light, which diverges substantially. Because of collimation, the energy emitted from a laser source can be captured and delivered through flexible optical fibers.

Energy source — The source of external energy, known as the pump source, used to excite the electrons can be electrical, optical, or chemical. In medical applications, the energy source is most commonly electrical (eg, electric current flowing through a laser medium) or optical (eg, from another laser). Chemical energy is often used in industrial applications. The pump power can be maintained continuously or switched on only for short intervals, which may help to limit the damaging thermal effects of the laser. (See 'Modes of operation' below.)

Resonant chamber — The resonant chamber or cavity contains the active laser medium and reflective mirrors. Photons reflect back and forth between mirrors. Since one of the mirrors is highly reflective and the other is only partially reflective, some of the laser light that is produced is permitted to exit the device and is directed to the tissues. (See 'Laser beam production' below.)

Active medium — The active medium contains the atoms that produce the electromagnetic radiation. The type of active medium usually gives the laser its name and, for medical applications, includes gas, solid crystalline materials, semiconductor materials, and liquid dye solutions.

Gas — Gas lasers apply an electric current through the gas. Gas lasers use noble gases (eg, argon, helium) and other types of gases (eg, carbon dioxide). The first gas laser used helium-neon (HeNe) to produce a coherent infrared beam.

- Carbon dioxide – The carbon dioxide (CO_2) laser uses carbon dioxide, nitrogen, and helium and was developed in 1964 [2]. It produces a mid-infrared wavelength (10,600 nm) (figure 1). The CO_2 laser is excellent as a cutting instrument because scattering is minimal, absorption in water is excellent, soft tissue vaporization is rapid, and the surrounding tissue damage is negligible. The CO_2 laser permits the coagulation of blood vessels smaller than 0.5 mm in diameter. This laser type is primarily used in otorhinolaryngology.

- Argon ion – Argon ion gas produces blue-green light at a wavelength of 488 to 514 nm (figure 1). The argon ion laser is used primarily for coagulation of blood vessels in dermatology, ophthalmology, and liver surgery. Soft tissue effects are unpredictable. Argon lasers are also used to pump dye lasers for phototherapy.

- Excimer – The excimer laser uses an active medium composed of excited dimers, which are a combination of a noble gas (eg, argon, krypton, or xenon) and a reactive gas (eg, fluorine or chlorine). The excimer laser emits ultraviolet radiation with enough energy to break chemical bonds between molecules but with no to little thermal damage. The excimer laser is used to remove surface material with almost no heating, and these lasers are often referred to as "cool" lasers. A good example is laser-assisted in situ keratomileusis, otherwise known as LASIK.

Solid state — Solid-state lasers use an active medium that is a solid. Semiconductor-based lasers are also in the solid state but are generally considered as a separate class from solid-state lasers. (See 'Semiconductor' below.)

Generally, the active medium of a solid-state laser consists of a glass or crystalline material (eg, sapphire, ruby) that is doped with neodymium, chromium, erbium, or other ions. Neodymium doped: yttrium aluminum garnet (Nd:YAG) lasers are perhaps the most commonly used solid-state laser. The medium is a rod composed of neodymium ions and crystals of yttrium-aluminum-garnet. Nd:YAG lasers emit light at mid-infrared wavelengths (1320 nm, 1064 nm) with pulse durations in the millisecond range (figure 1). The longer wavelength of the Nd:YAG laser penetrates deeper into the tissue and can cause collateral thermal damage.

Other solid-state lasers emitting radiation with millisecond pulse durations include the potassium titanyl phosphate (KTP) and alexandrite lasers. KTP lasers emit green light at 532 nm corresponding to the second oxyhemoglobin peak and overlapping the absorption peak of melanin. Alexandrite lasers emit red light at a wavelength of 755 nm, which is absorbed by deoxygenated hemoglobin and melanin.

Semiconductor — Semiconductor lasers (ie, laser diode) use an active medium that is formed by doping a thin layer on the surface of a crystal wafer to form a p-n junction, which comprises a diode. Semiconductor lasers are injection laser diodes as compared with the optically pumped laser diodes (solid-state lasers) described above. Diode lasers emit light at wavelengths between 800 and 900 nm (figure 1).

Dye — Dye lasers have liquid active medium. A fluorescent organic dye in liquid solution is injected into a tube. Pulse dye lasers (PDLs) emit yellow light at 585 and 595 nm, which corresponds to the second oxyhemoglobin peak (figure 4). These lasers produce pulse durations in the millisecond range and are used in cutaneous vascular applications.

Laser beam production — The composition and design of the laser device produces a coherent beam of electromagnetic radiation as a result of the following sequence of events [3,4]:

Atoms within the resonant chamber absorb energy from the energy source. As atoms in high-energy states spontaneously return to ground state, they release energy, some of which is absorbed by other atoms, causing them to achieve a high energy state. This phenomenon is known as "pumping." As more and more atoms become excited and then return to ground state, more and more energy is produced (amplification of stimulated emission). Eventually, stimulated emission of radiation becomes the primary source of energy within the chamber and eventually produces population inversion, meaning that there are more atoms in a high-energy state than in a low-energy state within the resonant chamber. The energy reflects between the mirrors in the chamber and becomes coherent and collimated. But, since one mirror in the chamber is only partially reflective, some energy is allowed to escape as a bright, monochromatic, coherent beam of laser radiation.

Modes of operation

- Continuous-wave lasers emit a continuous laser beam, provided the pump source is switched on by the operator. Examples of continuous-wave lasers include the argon, krypton, and some CO_2 lasers. Long periods of continuous exposure to the laser beam or insufficient cooling time can lead to excessive tissue heating. Automated scanning devices have been developed to move the laser beam in predetermined patterns to minimize excessive exposure, but these are not always effective. As a result, continuous-wave lasers have been largely replaced by pulsed lasers.

- Pulsed lasers emit energy in the form of brief pulses rather than continuously. The power output of short-pulse lasers is in the megawatt-to-gigawatt range, heating the target so quickly that the tissue is disrupted mechanically by shockwaves. Long-pulse lasers produce peak powers in the kilowatt range, damaging collateral tissue minimally.

  Different methods of pulse generation produce pulses of varying duration, energy, and repetition rate and include Q-switching, gain switching, and mode-locking.

  - Q-switching uses an electro-optical switch to release energy stored in the laser chamber in a brief pulse with high peak power. Nanosecond-pulse, high-energy laser beams are produced with Q-switched solid-state lasers, including ruby, alexandrite, and Nd:YAG lasers. Excimer lasers produce nanosecond ultraviolet laser energy.

  - Mode-locked lasers produce short pulses with high repetition but with lower peak power than Q-switched lasers. Picosecond pulses can be produced with mode-locked solid-state, fiber, or semiconductor lasers.

  - Gain-switched lasers produce shorter pulses, usually in picoseconds, and are used to pump certain solid-state and dye lasers. Lower-energy nanosecond pulses can be produced with gain-switched semiconductor, fiber lasers. Longer-pulse lasers (1 to 50 milliseconds) include the 595 nm pulsed dye laser (PDL) or the alexandrite 755 nm laser.

- Quasi-continuous-wave operation refers to a mode for which the pump source is automatically switched on and off. The laser is optically in a state of continuous-wave operation. The interval of time over which the pump source is turned on, which may only be a small percentage of the total time, is short enough to decrease tissue heating and negative thermal effects but long enough to maintain the laser at a steady state. Quasi-continuous-wave lasers include the potassium titanyl phosphate (KTP) lasers.

LASER DELIVERY

Once produced, the laser beam is delivered to the tissue directly or via flexible optical fibers primarily for dissection or ablation of tissue. Technology that uses lasers to perform high-resolution imaging of tissues is an area of active clinical research.

Tissue ablation — Absorption of light is necessary for the laser to have any effect upon the tissue. Molecules that absorb light are called chromophores (the part of a molecule responsible for its color) and include melanin, oxyhemoglobin, bilirubin, and water (figure 5). The effects on the tissue are due to the dissipation of the absorbed energy by conversion to other forms of energy, including thermal, mechanical, or chemical energy.

- **Photothermal** – Laser therapy of many tissues is based upon the concept of selective photothermolysis, whereby thermal injury is induced with limited damage to the surrounding structures [5-7]. The wavelength of light is chosen based upon the chromophore of the target structure and its depth. Thermal effects include denaturation of proteins, coagulative necrosis, and vaporization.

- **Photoablative** – Photoablation refers to the mechanical disruption of tissue due to delivery of energy that is sufficient to produce thermal explosions or shock waves within the tissue leading to its disintegration.

- **Photochemical** – Photochemical reactions occur following laser treatment of tissue after injection of a photosensitizer of a specific wavelength. Although the photosensitizer is absorbed by other cells in the body, it is preferentially absorbed by malignant cells that maintain levels of the photosensitizer after the agent has left normal cells. Exposure of the tissue to the photosensitizer wavelength selectively destroys the malignant cells through chemical reactions (usually production of oxygen radicals) or activation of the immune system. Photosensitizers can also be applied to the surface of tissues to achieve a photochemical effect, such as in dental bleaching [8].

Laser parameters — When laser energy strikes the tissue surface, energy can be absorbed, reflected, transmitted, or scattered. The effect of the interaction between the laser and tissue depends upon the active medium, wavelength, power density, properties of the target tissue, and duration of tissue exposure [9]. Wavelength and pulse duration are the most important laser parameters that govern the effects of laser light on the tissue. Fluence, power, and spot size are additional laser settings that influence clinical effectiveness. With optimal laser settings, laser energy can be directed precisely to a target chromophore, avoiding damage to healthy tissue.

- **Wavelength** – The wavelength of the laser beam determines the degree of tissue penetration, absorbed energy, and scattered energy. Longer wavelengths penetrate more deeply (near infrared>red>yellow>green>blue>ultraviolet) (figure 6). Scattering is the laser energy that is directed away from the original laser target. Light scattering decreases with increasing wavelength. A laser with a low scattering coefficient makes an excellent scalpel because the laser energy is absorbed in a confined area. By comparison, a laser with a high scattering coefficient may result in good photocoagulation. The laser wavelength should be chosen to be near the maximum absorption of the target chromophore, long enough to penetrate to the depth of the target and away from the target range of competing chromophores.

- **Pulse duration** – The optimal pulse duration is determined from the thermal relaxation time of the target chromophore. The thermal relaxation time is the time needed for the tissue temperature to return to its baseline temperature after heating [5]. If a tissue is heated for a period less than or equal to its thermal relaxation time, the accumulated heat and subsequent damage is confined to the target object, whereas if a target is heated for longer than its thermal relaxation time, heat conduction leads to heating of surrounding structures.

- **Spot size** – Spot size is the diameter of the beam emitted from the laser as it strikes the tissue surface. Energy entering the target tissue is attenuated more rapidly with a small spot size compared with a larger spot size because scattering is greater with small spot size.

- **Energy delivery** – Energy is measured in Joules (J), and fluence, a measure of radiant exposure, is energy over area (J/cm^2). The destruction of very large structures usually requires high fluence (20 to 50 J/cm^2) due to the amount of tissue that needs to be heated to achieve thermal coagulation. Although fluence is commonly used in discussing pulsed lasers, power density (ie, irradiance) is preferred for continuous wave devices.

  Power describes the rate of energy delivery measured in Joules per second (J/sec) or watts. Power density, the power transmitted per unit area of cross-section of a laser beam ($watts/cm^2$), is inversely proportional to the square of the diameter of the spot size [10]. Low power density produces slow heating that coagulates tissue, while high power density heats tissue quickly and can vaporize tissue [4]. At extremely high power density, heating is so rapid that the target tissue disintegrates from photomechanical disruption rather than vaporization.

Tissue imaging — Confocal microscopy uses a low-energy laser to provide a pinpoint light source that increases spatial resolution for tissue imaging. This technology requires tissue fluorescence and intravenous or topical contrast agents depending upon the type of tissue being studied. The pinpoint laser is focused to a particular tissue depth, and fluorescent light reflected from that plane passes through the confocal aperture, whereas scattered light from above or below that plane is not detected.

A confocal laser endomicroscope can be integrated into the distal tip of a conventional endoscope, bronchoscope, laparoscope, or cystoscope [11-14]. A dedicated single optical fiber serves as the illumination point source and the detection aperture. The use of laser endomicroscopy for imaging gastrointestinal tissue is discussed in detail separately. (See "Confocal laser endomicroscopy and endocytoscopy" and "Imaging studies after bariatric surgery".)

CLINICAL UTILITY OF LASERS

Lasers are used in a variety of clinical applications commonly related to external structures that are easily reached, such as the skin and cornea. Minimally invasive technology allows access to deeper structures, including the gastrointestinal mucosa, biliary tree, bronchial structures, and urinary tract via endoscopy and hollow or solid organ surfaces via laparoscopy and thoracoscopy. Most commonly, tissue ablation occurs because of thermal effects.

- **Dermatology** – Progress in laser and light therapy technology has led to the development of safer and more efficient methods of achieving the desired effects on skin. Skin cooling limits inadvertent damage to tissues adjacent to the targeted sites. The principles that govern the interactions between skin and laser light or intense pulsed light (IPL) and the types of these devices used in the treatment of skin are discussed elsewhere. (See "Principles of laser and intense pulsed light for cutaneous lesions" and "Removal of unwanted hair" and "Ablative laser resurfacing for skin rejuvenation" and "Laser therapy for hypertrophic scars and keloids" and "Laser and light therapy of lower extremity telangiectasias, reticular veins, and small varicose veins" and "Laser and light therapy for cutaneous vascular lesions" and "Laser and light therapy for cutaneous hyperpigmentation" and "Overview of lasers in burns and burn reconstruction".)

- **Gastroenterology** – Pulse dye lasers and Q-switched solid-state lasers are used to fragment gallstones identified during choledochoscopy and ablate mucosal tumors. Confocal laser endomicroscopy has aided in the differentiation between dysplastic and malignant tissue. (See "Confocal laser endomicroscopy and endocytoscopy" and "Laser lithotripsy for the treatment of bile duct stones".)

- **Pulmonary medicine and surgery** – In bronchoscopy, lasers are used to either photocoagulate or vaporize tissues obstructing the airway (picture 1). They can also be used to make concise radial incisions to enhance airway dilation in central airway strictures. Lasers have also been used to remove blebs and bullae during thoracoscopy. (See "Bronchoscopic laser in the management of airway disease in adults".)

- **Cardiology and cardiac surgery** – Laser energy is used to create transmural channels in ischemic myocardium to restore myocardial perfusion in a procedure called transmyocardial laser revascularization. The procedure can be performed using a carbon dioxide or holmium: YAG laser. (See "Transmyocardial laser revascularization for management of refractory angina".)

- **Ophthalmology** – The excimer laser is used to remove a precise amount of corneal stroma during laser-assisted in-situ keratomileusis (LASIK), which is one of the most common applications of laser. (See "Laser refractive surgery".)

- **General surgery** – In general surgery, laser energy can be used to provide hemostasis or to ablate tumors identified in solid organs such as the liver. (See "Overview of electrosurgery", section on 'Laser' and "Instruments and devices used in laparoscopic surgery", section on 'Laser fulguration'.)

- **Gynecology** – The Nd:YAG or carbon dioxide laser is used for tissue ablation in a variety of gynecologic applications. (See "Female infertility: Reproductive surgery", section on 'Excision and ablation' and "Condylomata acuminata (anogenital warts): Treatment of vulvar and vaginal warts", section on 'Laser ablation' and "Cervical intraepithelial neoplasia: Diagnostic excisional procedures", section on 'Laser conization'.)

- **Urology** – Lasers can be used to fragment ureteral stones but are becoming more popular for the treatment of benign prostatic hyperplasia. (See "Kidney stones in adults: Surgical management of kidney and ureteral stones", section on 'Ureteroscopy' and "Surgical treatment of benign prostatic hyperplasia (BPH)", section on 'Photoselective vaporization of the prostate (PVP, laser TURP)'.)

- **Vascular surgery** – Lasers are commonly used to manage the visible signs of chronic venous disease. Several types of lasers might be used depending upon the size and depth of the vein to be treated (table 1). Laser is one form of energy used to effect closure of veins that demonstrate reflux. (See "Laser and light therapy of lower extremity telangiectasias, reticular veins, and small varicose veins" and "Techniques for endovenous laser ablation for the treatment of lower extremity chronic venous disease".)

- **Dentistry** – Although incoherent light may be used in conjunction with photoactive dental bleaching systems, coherent light produced from a diode laser has also been found to be effective [8].

LASER SAFETY

In contrast to most industrial applications of laser in which the laser beam is enclosed, medical and research use of lasers can expose the user and other people in the vicinity to potentially hazardous laser radiation. Adverse health effects of exposure to laser radiation are theoretically possible across the entire optical spectrum, but the risk of retinal injury due to radiation in the visible and near-infrared regions is of particular concern [15]. The biological effects induced by optical radiation are essentially the same for both coherent and incoherent sources for any given wavelength, exposure site and area, and duration. However, laser radiation is a special case because the radiant exposures and irradiances that can be achieved are potentially much higher compared with conventional optical sources [16]. Thus, most states have training regulations for personnel who use lasers [17].

The eye and skin are the most susceptible to damage by laser radiation. As with other tissues, the biological effects of laser on the eye vary depending upon the wavelength and exposure duration [18]. Thermal injury to the retina is the predominant effect for exposure durations <10 seconds due to pigmented epithelial injury [19]. Photochemical injury predominates in the ultraviolet spectral region and is also the principal type of injury from lengthy exposure (>10 seconds) to short-wavelength visible radiation (principally "blue light") [15]. Pulsed lasers of <0.1 msec duration can lead to hemorrhagic injury from thermoacoustic mechanisms, and optical breakdown and plasma formation become important with sub-nanosecond exposures.

Because of these mechanisms, eye protection is essential when operating lasers. In the workplace, eye protection is required by the United States Occupational Safety and Health Administration (OSHA) [18].

SUMMARY AND RECOMMENDATIONS

- **Lasers** – Lasers rely on the stimulated emission of radiation to produce a single, coherent wavelength within the ultraviolet, visible, or infrared portion of the electromagnetic spectrum. Lasers are comprised of an energy source, a resonant chamber, and an active medium. The active medium determines the wavelength produced. Laser beam production can be continuous, pulsed, or quasi-continuous depending upon the characteristics of the active medium and switching mechanism of the device. (See 'Laser principles' above.)

- **Laser delivery** – Lasers in medicine are used predominantly as a source of energy to cut, coagulate, or ablate tissue, but also provide a coherent energy source for phototherapy or confocal microscopy, which allows for real-time imaging of tissues. (See 'Laser delivery' above.)

- **Mechanisms of tissue ablation** – Lasers destroy tissue through production of heat (photothermal), disruption of chemical bonds (photoablative), or reactions with a photosensitizer (photochemical). Selective photothermolysis describes the use of specific wavelengths of laser energy to target specific chromophores and thus minimize damage to adjacent tissues. The interaction between the laser and tissue depends upon the wavelength, power, duration of exposure, and properties of the target tissue. (See 'Tissue ablation' above.)

- **Clinical utility** – Lasers are used in a variety of clinical applications commonly related to external structures that are easily reached, such as the skin and cornea. However, minimally invasive technology allows access to deeper structures including the gastrointestinal mucosa, biliary tree, bronchial structures, and urinary tract via endoscopy, and hollow or solid organ surfaces via laparoscopy and thoracoscopy. (See 'Clinical utility of lasers' above.)

- **Laser safety** – The eye and skin are the organs that are most susceptible to damage by laser radiation. The biological effects induced by nonionizing radiation are similar for coherent and incoherent sources; however, laser radiation produces greater radiant exposures. Complications related to laser treatments are reduced with guidance systems that allow lasers to be applied more precisely and with greater control. In the workplace, eye protection is required by the United States Occupational Safety and Health Administration (OSHA). (See 'Laser safety' above.)

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Topic 2883 Version 19.0

Electromagnetic spectrum and medical laser wavelengths

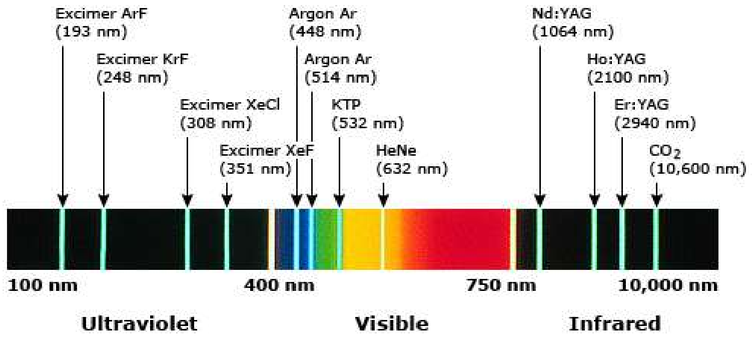

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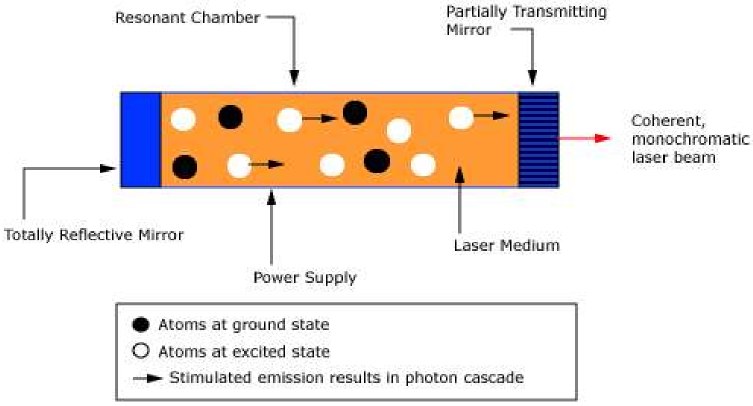
Diagram of laser components



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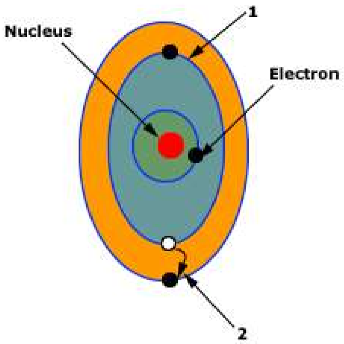
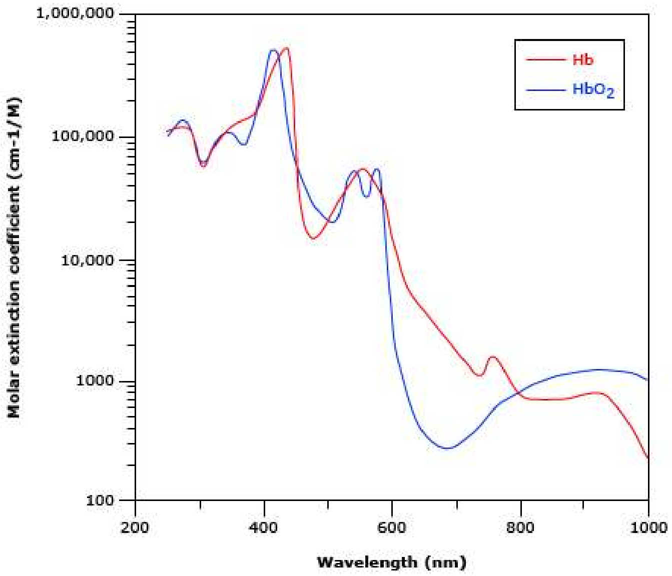
Atom with electrons orbiting the nucleus



With excitation, an electron moves from an inner shell (1) to an outer shell (2), thereby defining the atom at ground state and excited state.

Graphic 61725 Version 2.0

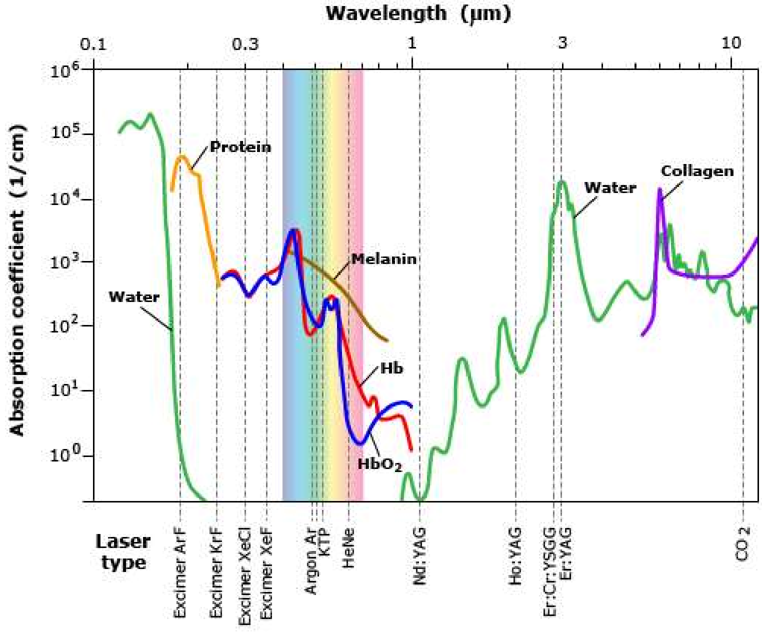
Hemoglobin absorption spectra



The oxyhemoglobin (Hb02) contained within red blood cells has three major absorption peaks at 418, 542, and 577 nm, with an additional infrared absorption around 1000 nm.

Graphic 63932 Version 2.0

Absorption of laser and light by various tissues



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Electromagnetic spectrum

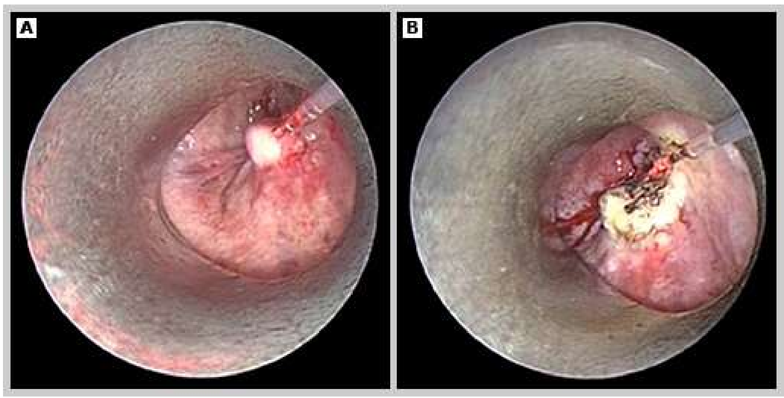
Gamma rays	X-rays	Ultraviolet*	Visible	Near infrared	Far infrared	Microwaves and radiowaves
<0.1 nm	0.1-10 nm	10-400 nm	400-760 nm	760-1000 nm	1000-100,000 nm	>100,000 nm

*** Ultraviolet spectrum divisions and wavelengths (nm)**

Vacuum ultraviolet	10-200
UVC	200-290
UVB	290-320
UVA2	320-340
UVA1	340-400

Graphic 70045 Version 4.0

Bronchoscopic laser coagulation



(A) During rigid bronchoscopic resection, coagulation is obtained using a bare laser fiber and Nd:YAG laser energy at low power density, causing tissue blanching.

(B) Tissue vaporization and char tissue formation are visible when high power density is used.

Graphic 81276 Version 2.0

Laser and light sources for treating leg veins

Type	Wavelength (nm)	Vein diameter (mm)	Skin type	Disadvantages
Nd:YAG	1064	0.3 to 3	I,II,III,IV	Pain
PDL	595	<1.5		Bruising
Diode	800 to 900	to 4	I,II,III,IV	
KTP	532	0.5 to 1.0		Pigmentation changes
Alexandrite	755	>0.4	I,II,III	Bruising, telangiectatic matting
IPLS*	500 to 1000	<1 (red)		

Nd:YAG: neodymium-doped yttrium aluminum garnet; PDL: pulse dye laser; KTP: potassium titanyl phosphate; IPLS: intense pulsed light system.

* Not a laser.

Data from:

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Graphic 80164 Version 5.0

Contributor Disclosures

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