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Leveraging the Concept of Laser Physics in Healthcare

Abstract
Laser therapy is a type of radiation therapy in which a concentrated beam of light injures or kills the tissue. It is a cutting-edge scientific development that has been successfully applied to treating and managing a wide variety of diseases around the world with zero environmental impact. Pain and inflammation relief and tissue repair have all been examined, and their underlying mechanisms have been found and analyzed. A wide range of clinical conditions, including musculoskeletal pain, osteoarthritis, joint pain and inflammation, neuropathic pain, otitis, dermatitis, chronic, or non-healing wounds, and decubitus ulcers, can be alleviated with laser therapy, which employs light energy of varying wavelengths and power densities. Laser medicine has several therapeutic benefits. When using laser therapy techniques, all appropriate safety measures must be taken. This chapter introduces laser systems and their potential use in healthcare.

***Keywords*:** Laser optics, laser beam, photobiomodulation, optical emission spectroscopy, X-ray

1.1 Introduction

Light amplification by stimulated emission of radiation or LASER: Albert Einstein initially proposed the concept of stimulated emission, the physical mechanism that produces lasers, in 1917 [1].

The electromagnetic radiation spectrum, which includes visible light, has a photon as its energy unit. The energy of a photon is absorbed by an electron as it orbits a nucleus, and the electron then bounces to a higher orbit. When this occurs, they say that the atom is "stimulated."

When photons called "stimulating photons" strike electrons of atoms in an excited state, the electrons release the energy they receive in the form of photons that move in the same direction, phase, and wavelength as the

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stimulating photons. This process is known as "stimulated emission" as shown in Figure 1.1.

The light is amplified because of a process called stimulated emission, which requires the medium to reach a state called "population inversion" that has more excited atoms than in their resting state. To achieve this, an excitation source must be able to "pump" photons into the medium.

The medium is made up of two mirrors at either end that together forms an optical cavity where the emitted photons bounce back and forth. The light beams are magnified because the trapped reflected light causes the production of extra photons.

Eventually, a laser beam will be created when the amplified light is reflected off of one of the partially reflective mirrors.

Therefore, the laser beam is "unidirectional," "monochromatic," and "spatially coherent," making it distinct from regular light. A laser's beam may concentrate its power in a small area by maintaining its tiny profile even at large distances (collimation).

Ophthalmic lasers cover the visible light spectrum, which begins at 193 nm and extends to 10,800 nm (390–700 nm). The higher the frequency and energy of a laser's photons, the shorter its wavelength.

The duration of an emitted laser can range from a few femtoseconds to an infinitely long time (continuous wave laser).

Electronic shutters may generate pulses as short as 1 ms. Pulsed flash bulbs can generate pulses in the microsecond range. Nanosecond pulses (Q-switching) can generate pulses in the nanosecond range, and femtosecond pulses can generate pulses in the femtosecond range (mode locking) [2].

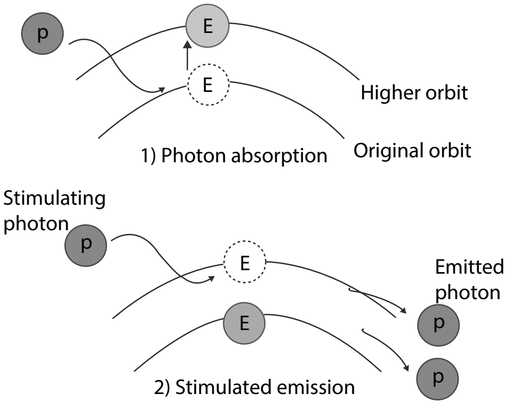


Figure 1.1 Mechanism of stimulated emission.

1.2 Physics of Laser

At its most basic level, a light beam produced by a laser device interacts with the target tissue to have an effect (this process is technically referred to as "laser–tissue interaction") as shown in Figure 1.2.

1.2.1 Principles of Optics

Photons are the fundamental particles that make up all forms of electromagnetic energy (quantum of light). Light particles or photons constantly move and travel through space at the speed of light (2,998×10^8 meters per second) in a sinusoidal wave pattern. For electromagnetic sine waves, the spectrum spans from extremely short (gamma rays) to extremely long (AM radio waves), depending on the frequency of the wave (Figure 1.3) [3].

The human eye can only detect electromagnetic radiation with a wavelength of 390 nm (violet) to 700 nm (red), hence, this is the narrow portion of the spectrum that contains visible light. Majority of medically important lasers operate at wavelengths between those of visible light and the electromagnetic spectrum's extended infrared end.

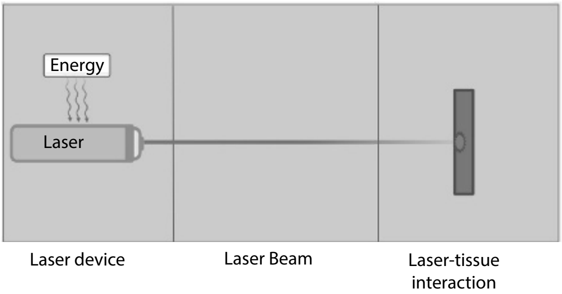


Figure 1.2 Schematic flowchart of a laser theory.

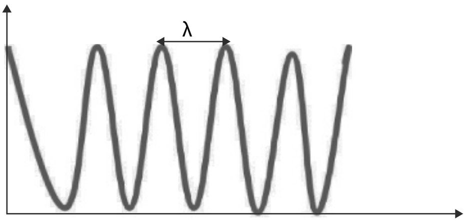


Figure 1.3 Electromagnetic wave.

1.2.2 Laser Gadget

Any laser apparatus primarily consists of an energy source and an optical resonator (Figure 1.4).

The photons are produced when electrons are stimulated from a ground state by the energy source. This power supply may be in the form of conventional light bulbs, electricity, and other lasers. The medium of an optical resonator is sandwiched between two mirrors, one of which is fully opaque and the other is only partially opaque, at the tube's ends (and therefore partially transmissible) [3]. It could be a solid, liquid, liquid crystal, or gas as the medium (with the distinction that liquid crystals have an atomic organization that is between that of solids and liquids). The medium in which a laser operates determines both its wavelength and the type of laser used (e.g., ruby, argon gas, CO_2, Er: Yttrium Aluminum Garnet (YAG), alexandrite, diode, Potassium Titanyl-Phosphate (KTP), argon, Nd: YAG).

The electrons in a medium can be stimulated by the addition of energy. Particles inside the tube emit light of a specific wavelength when they settle back to their starting place. To continue the spread of light, a "chain reaction" occurs when an electron in an excited state interacts with another photon of the correct energy, causing the electron to emit another photon of the same wavelength without absorbing it. One can generate a "laser beam" by using a partially transmitting mirror to direct a subset of photons moving in a parallel direction out of an optical resonator [3].

1.2.3 Laser Beam

Several characteristics of the resulting beam of light set it apart from the light produced by a regular incandescent flashlight or lamp. Polychromic, incoherent, and not collimated best describe incandescent illumination [3].

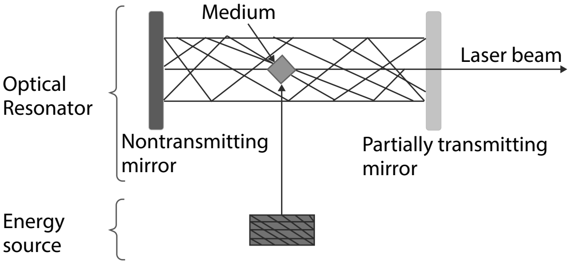


Figure 1.4 Laser components.

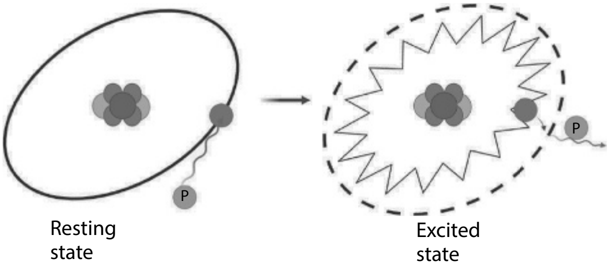


Figure 1.5 Electron excitement.

In contrast, the light emitted by a laser is uniform in wavelength, coherent, and collimated (Figure 1.5).

1.2.3.1 Monochromatic

The photons making up a laser beam have all the same wavelength, making the beam monochromatic. In contrast, a flashlight can produce light at a wide range of wavelengths.

1.2.3.2 Coherent

A laser beam contains photons that are coherent because the waves are in phase with one another in both space and time.

1.2.3.3 Collimated

All the photons in the laser beam are aligned in the same direction, making the beam collimated. This means a laser beam can travel far without deforming significantly.

Because of this, the laser beam's energy density is raised. As a result of the process being so poorly efficient (just about 0.01% of the input energy is converted to laser output), the total amount of energy produced by a laser is quite small. Collimation, on the other hand, concentrates the beam's energy in a tiny space.

The ability of a laser to convert one form of energy (e.g., electricity or light) into a coherent, collimated beam of photons with a high energy output is what makes it such a powerful tool [3].

1.3 Laser Classification

According to their maximum output power or energy and wavelength, lasers can be divided into four separate groups. As a result, Class I lasers are the safest and least powerful type. Commonplace lasers include those found in things like grocery store scanners and other bar code reading devices. The visible spectrum is where Class II lasers shine (400–700 nm). Some laser pointers and medical lasers belong here. Prolonged exposure to the laser in the eye can cause damage [4–6].

Lasers utilized for therapeutic purposes are classified as Class III. To further categorize these lasers, Class IIIB lasers can be either continuously operating pulsed or continuous visible light or range from visible to infrared. Lasers in the Class IIIR variety are constantly emitting light within the visible spectrum but are weaker than Class IIIB lasers. The highest powerful lasers fall into the Class IV category and are commonly used in surgical procedures. They can cause severe burns or blindness [7, 8].

1.4 The Workings of a Laser Therapy

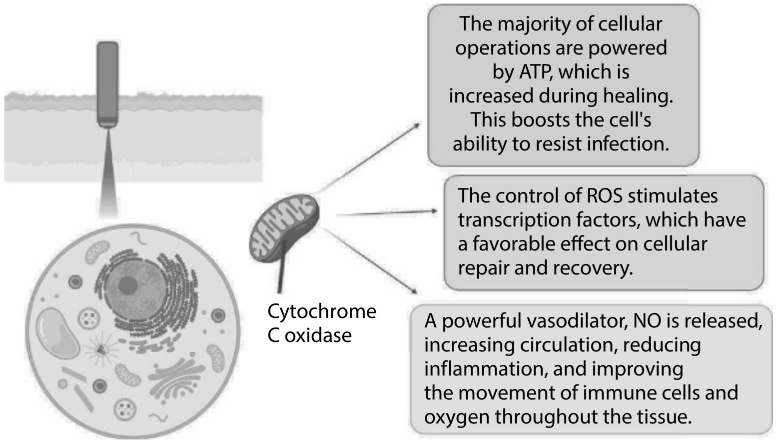
Researchers in the field are currently debating the mechanism of action related to photobiomodulation. It is envisaged that the targets and cell types being controlled would have different mechanisms of action. Photobiomodulation, or low-level laser therapy, is a painless, non-invasive treatment alternative that stimulates natural biological processes that promote quicker healing and pain relief. Just as plants use photosynthesis to convert sunlight into usable energy, so do cells in the body that uses laser energy to increase circulation, relieve pain, and contribute to the healing process. Laser therapy has no negative side effects and is increasingly being used as a drug and surgical alternative for chronic degenerative disorders [9, 10].

The mitochondrial inner cell membrane contains the cytochrome C system, which serves as a photoreceptor, and has received the greatest attention, and is the most often reported mechanism. Cytochrome C is a big molecule with features that cause it to absorb light with a wavelength between 500 and 1100 nm. Cytochrome C is stimulated after absorbing laser light, and this causes it to release nitric oxide (NO). The increased bonding with oxygen and the resulting increased production of the outcome of this mechanism is cytochrome C oxidase. The production of adenosine triphosphate (ATP) requires cytochrome C oxidase. It is required for cellular energy synthesis, and this in turn triggers several beneficial physiological responses or secondary processes, such as decreased pain and inflammation and improved tissue repair [11, 12].

Oxygen (O_2), the stable superoxide anion, and hydrogen peroxide (H_2O_2), its consequence (with the addition of two protons), have both been shown in a few studies to be generated by light's interaction with mitochondria in cells via cytochrome C oxidase [5]. Burdon and Davies independently demonstrated that a relatively low concentration of H_2O_2, between 0.1 and 0.5 mol/10^7 cells, elicited bio-stimulatory effects. It was recently revealed that the metabolic activities of human glioblastoma might be suppressed by low-average-intensity radiation pulsed at picosecond durations and near-infrared (1,552 nm) wavelengths. MTS is a metabolic test that was used to assess cellular metabolic activities across a range of fluence exposures.

Laser-induced metabolic inhibition can be mitigated to some extent by pre-treating the growth medium with the enzyme catalase before exposing the cells to the laser [13, 14].

Without catalase therapy, cellular metabolic activity reverts to its control/sham-exposed levels after initially increasing. However, the loss in cellular metabolic activity is greatly attenuated when catalase is present (the catalase acts by removing hydrogen peroxide that has traveled outside of the cells) [12, 15], indicating a functional role of H_2O_2 (Figure 1.6).



The majority of cellular operations are powered by ATP, which is increased during healing. This boosts the cell's ability to resist infection.

The control of ROS stimulates transcription factors, which have a favorable effect on cellular repair and recovery.

A powerful vasodilator, NO is released, increasing circulation, reducing inflammation, and improving the movement of immune cells and oxygen throughout the tissue.

1. A probe in contact mode with the skin's surface delivers laser light to the tissue at a wavelength of 670, 808, or 940nm.
2. The protein cytochrome c oxidase is one of the chromophores that absorb lights when it enters the cell's mitochondria, increasing its activity.
3. As a result three molecules are affected: ATP, ROS, and NO

Figure 1.6 Mechanism of laser therapy in tissue.

1.5 Implications of Lasers on Tissues

1.5.1 Photothermal Impacts

Tissue chromophores (pigments) convert laser energy into heat through an interaction with the laser's wavelength. Pigment, hemoglobin, and xanthophyll are some of the chromophores found in ocular tissue that absorb lasers at visible light wavelengths; proteins absorb at UV wavelengths; and water absorbs infrared radiation. Tissue reaction depends on both the absolute temperature and the length of exposure. Vaporization, coagulation, and necrosis are all possible outcomes [16].

1.5.2 Photochemical Effects

Photoreceptors undergo chemical changes when exposed to light; isomerization of 11-cis retinal to all-trans retinal is one example. A photosensitive dye is infused intravenously during photodynamic therapy, and a particular laser wavelength is used to stimulate the dye's molecules. Cell structures in regions where the dye concentrates, such as the walls of vascular tissue, are irreversibly oxidized when the excited photosensitizer passes its energy to tissue oxygen, creating radicals [17, 18].

1.5.3 Photomechanical Effects

Photo disruption results from a sudden increase in tissue temperature over the vaporization threshold brought on by laser absorption. High laser energy delivered in the microsecond-to-nanosecond range could ionize plasma status and vaporize transparent ocular tissues without pigment absorption, leading to temperatures above 100°C and explosive vapor bubbles that could rupture nearby tissue or eject fragments of tissue from surfaces. The excimer laser used in corneal operations works on this principle [19, 20].

1.6 Spectroscopy Using a Laser-Induced Breakdown Mechanism: Its Use in Medicine and Other Fields

In optical emission spectroscopy (also known as laser-induced breakdown spectroscopy, or LIBS) [21–23], high-energy laser beams interact with matter, creating plasma, whose light can then be used in many applications (solids, liquids, or gases). If the plasma's distinctive parameters have a large enough effect on the emitted light, then the atomic spectroscopic study of the light can reveal a wealth of information on the underlying physical processes and elemental structure of plasmas [24].

Over the past two decades, LIBS has attracted more and more attention due to its usefulness in a variety of fields, including manufacturing, ecology, medicine, and the forensic arts [25–27]. It is a useful and sensitive new tool for elemental analysis. With the added benefit of requiring little to no sample preparation, it is a highly adaptable method for determining the elemental makeup of samples in a short amount of time.

Recently, LIBS has been widely used in the investigation of human tissue samples and other biological and medical systems.

Generally speaking, there are two basic types of medical uses for LIBS [28]:

(1) Clinical specimens from humans (such as teeth, bones, urinary bladder and gallstones, liver tissues, or other tissue samples)
(2) Examining and analyzing microorganisms (such as bacteria, molds, yeasts, and viruses)

About the first type of use, Patlak used the LIBS method to investigate the contribution of individual factors to gallstone production (under emphysema and mucosal gall bladder conditions) [29]. The samples were collected in the Purvanchal area of Uttar Pradesh, India. The goal of the study was to determine whether or not gallstones developed in different environments (with different diets, for example) have significantly different elemental compositions. According to the results, gallstones are more common in female patients than in male patients. Patients who regularly used tobacco, chewed tobacco or smoked cigarettes, or imbibed alcoholic beverages were shown to be at increased risk. The researcher also pushed the LIBS method's boundaries by using it to examine human fingernails and baby teeth in real-time. The roots of caries can be revealed through elemental analysis of tooth samples, a major problem in oral health. Cairo University's Lasers and Emerging Materials (LLNM) Laboratory used LIBS for yet another medicinal application. It was used for the detection and staging of liver cancer [30]. The plasma on the liver's surface was started using radiation from a 532 nm neodynium-doped (ND): YAG laser at a power density of 5.7 108 W/ cm^2.

The emitted light was examined, and its analysis revealed the presence of cancerous tissue's trace constituents. The radiation emitted from the materials was captured using an Echelle-type spectrograph, and a 25 µm multimode quartz optical cable was used to transmit the signal. By linking an intensified charge coupled device (ICCD) camera to the spectrograph, the gathered light may be scanned over the spectrum (Figure 1.7). The Kestrel-Spec software directed the machine to take pictures from the available camera. A single-shot detection within the system extended from 200 to 1,200 nm in wavelength.

A spam 16 software spectrum analyzer was utilized to determine the various components. A low-pressure Hg- lamp was utilized to calibrate the emission spectrum's wavelengths, while all the relative intensities (sensitivity) in the emission Deuterium halogen lamp lights were used to calibrate the spectra. The researcher measured the levels of Mg, K, Ca, Na, Fe, Mn, and Cu in the liver tissues. To decide on cancer classification, an artificial neural network (ANN) was given the results from the LIBS approach. The neural network developed at LLNM is optimal for classifying a benign tissue from a cancerous tissue. There was a dramatic increase in the amounts of several trace elements in malignant tissues compared to normal tissues, and this increase occurred throughout all stages and grades of the disease. This used the LIBS approach, which allowed the researchers to draw the following conclusions:

The capacity to diagnose malignant cells and tissues, the method's ease of use, and the reduction in the chances of contamination and misdiagnosis all speak in favor of it.

Since reliable results can be obtained from a relatively small sample size, the procedure is non-invasive, and it provides real-time quantification of all

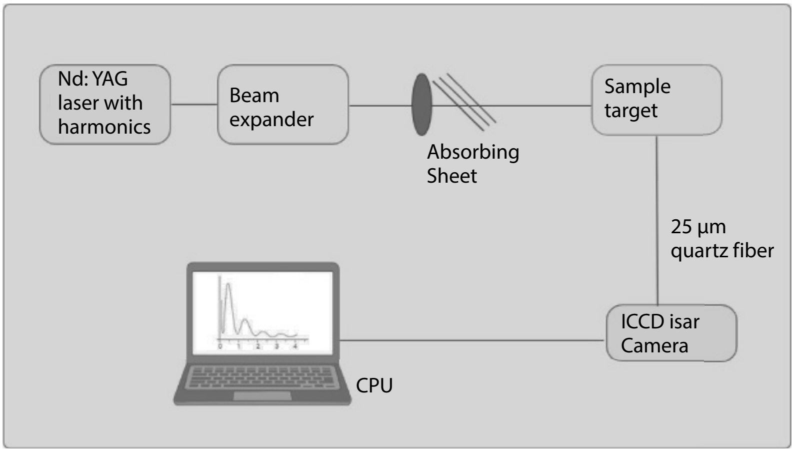


Figure 1.7 Experimental preparation for laser-induced breakdown spectroscopy.

trace components in tissue. The identification of microorganisms responsible for human disease falls under the second types of use LIBS applications [31–35]. This includes bacteria, molds, yeasts, spores on surfaces, and viruses. Therefore, the medical community is extremely interested in LIBS's potential as a diagnostic tool for quickly detecting and identifying harmful microorganisms. The present application of this method is in clinical settings, such as microbiology labs in hospitals or military field hospitals, where it is used to identify pathogenic microorganisms. Bacterial identification using LIBS is also applied in a variety of fields outside of medicine. *Salmonella enterica* serovar Typhimurium [36], a common source of food poisoning, can be quickly identified using LIBS in the food processing industry. There are applications for atomic absorption spectroscopy, mass-assisted laser desorption ionization time-of-flight mass spectrometry, and inductively coupled plasma mass spectrometry, but LIBS has greater applications in biological investigations. The LIBS apparatus is portable, adaptable, and user-friendly, making it ideal for immediate, fast, and accurate analysis of biological specimens in real time.

There is also a far higher signal-to-noise ratio compared to traditional spectroscopic techniques. This means that the LIBS technique will soon be available for application to a wide variety of biomedical fields, such as [36]:

- "Optical biopsies" performed in a variety of contexts, *in vivo* and *in vitro*
- Detection of ulcerated tissues *in vivo*
- Evaluation of stones in either an *in vivo* or an *in vitro* situation (e.g., kidney and gallbladder stones)
- Ability to detect caries in teeth in real time (cavities)
- Detection of heavy metal concentrations in tissues (such as distinct portions of high-resolution *in vivo* spatial measurements (e.g., of bone, joints, or the liver)
- Isolation of bacteria from human fluid samples

1.7 Applications of X-Ray and Computerized Tomography Technology in the Healthcare Industry

Radiologists can specialize in many subfields, such as diagnostic X-ray tomography [37, 38]. It is common knowledge that different regions of the body absorb X-rays at varying rates. Calcium, a heavy element in the body, has a substantially higher absorption rate for X-rays compared to lighter components consisting of hydrogen, oxygen, and carbon [39]. Due to this, X-rays provide a vivid picture of dense biological structures like bones. In an X-ray image, different types of soft tissue (such as fat, muscles, tumors, and organs like the liver and heart) are difficult to differentiate from one another due to their similar X-ray absorption. Because the shadows of everything in the X-ray line of sight are superimposed on the image, even healthy structures' shadows might obscure or confuse the shadows that indicate sickness in a standard X-ray [39]. Disease-indicating shadows are best seen when the X-ray images are obtained from a variety of angles, including from behind, to the side, and at an oblique angle. Tomography is the process of capturing X-ray images of cross-sections of the body.

Since its creation by Godfrey Hounsfield in 1972 [40], computerized tomography (CT) has vastly enhanced the quality of X-ray imaging. Together with Allan Cormack, he received the 1979 Nobel Prize in Medicine for their groundbreaking discovery. Images captured by an X-ray CT scanner are similar to those captured by a planar camera. First, the device may catch a wide range of perspectives by circling the patient's head in either discrete steps or a continuous motion. Second, it has a computer that combines the images to show organs including the liver, thyroid, brain, heart, and kidney in cross-section. Single- and multiple-head cameras obtain multiple projection views by mechanically rotating the heads around the patient; however, more sophisticated CT camera systems have either many heads or a ring of detectors [41]. When software is used to compare the image slices, a highly accurate three-dimensional model of the body can be constructed. To better see the area of the body being studied, a contrast injection may be administered intravenously before some types of CT scans. In 1998, the first four-slice spiral CT scanners appeared on the market and immediately ushered in a new era of diagnostic accuracy and patient safety in CT. Thanks to advancements in multi-detector row scanning, CT can now provide truly dynamic and three-dimensional imaging. The mysterious origins and progressions of many diseases were revealed through CT imaging. For instance, CT, in conjunction with the creation of suitable computer algorithms, allows for the early identification of breast cancer by locating microcalcifications in digitalized mammograms. In truth, X-ray CT has made significant contributions to medical practice. With the advent of optical tomography, a subset of CT that reconstructs images created from light transmitted and dispersed through an object, significant advancements in medical physics have been realized [42]. Since its effectiveness depends on the object being investigated being at least slightly light-transmissive or translucent, it is most frequently utilized in medical imaging studies. This makes it especially helpful for investigating soft tissues, such as breast and brain tissues.

Optical coherence tomography (OCT) uses light scattering from within optically scattering biological tissues to acquire micrometer-resolution, three-dimensional pictures [43]. Based on low-coherence interferometry, this medical imaging method typically makes use of near-infrared light. Light with a relatively long wavelength can go deeper into the scattering material.

Several distinct types of light sources are used in OCT. These can take the form of either super-luminescent diodes or ultrashort-pulsed or super-continuous lasers. This scan method boasts a high signal-to-noise ratio, allowing for rapid signal capture, and sub-micrometer resolution throughout a broad wavelength range (100 nm). Optical coherence tomography is a popular imaging method in modern medical diagnostics because it uses the coherence properties of laser light to produce a visualization of biological tissues with high resolution, in cross-section, and three dimensions, in real time [43]. It is utilized in ophthalmology and optometry, for example, to get high-resolution photographs of the retina [44, 45], only one of its many medical diagnostics uses. The field of interventional cardiology has also begun using it to aid in the diagnosis of coronary artery disease [46]. Moreover, it shows promise in dermatology for enhancing diagnostics, and it provides a potential alternative for imaging skin structures using faster and more penetrating technologies [47, 48]. Like ultrasonography, OCT may be used to rebuild images from the skin's upper layers, but with much greater spatial resolution. It can show the growth of a single layer in both the vertical and horizontal directions [49]. The characteristics of the tissues determine the actual imaging depth, which is typically around 1 mm [50].

Medical science and biomedical research have benefited greatly from recent developments in laser physics. Ophthalmology, dermatology, cosmetic surgery, cancer, dentistry, and many other medical specialties have all benefited from the use of lasers since their introduction in the 1960s [51–56]. Lasers are more efficient than conventional light sources in medicine because their light is coherent and operates within a narrow wavelength range. Their power densities and intensities are substantially higher, and they can be tuned to certain wavelengths. Thanks to their unique set of characteristics, lasers have found widespread applications in the medical fields of diagnosis and treatment.

The field of laser physics is investigating potential strategies for expanding lasers' usable wavelength range into the electromagnetic spectrum between the extreme ultraviolet and X-ray ranges, generating increasing interest in the medical sector. In 1985, scientists at the LLNM showed the world's first X-ray laser [57, 58]. With a wavelength of around 5 nm, the beam was a factor of 100 smaller than the wavelength of visible light. Because X-rays have 100 times shorter wavelengths than optical photons, their energy is also 100 times higher. This calls for an X-ray laser pumping energy roughly a thousand times that of visible-range optical lasers [58]. A coherent X-ray beam was created by pumping a thin foil of selenium with high-energy neodymium rays from glass lasers at the LLNM [58]. When the selenium foils are hit by the Nova beam, they instantly turn into plasma of selenium ions that look like neon. This coherent soft X-ray beam has a wavelength of 21 nm and is emitted by plasma selenium ions that are energized like neon (Figure 1.8).

It was with the LLNM's laser fusion program in mind that the Nova lasers were created, but they have since expanded their use to a wide variety of fields. Since they produce so much heat and need to be cooled after each pulse, these large, high-energy lasers are unfit to serve as power supplies for X-ray lasers used in medicine.

Nowadays, no cooling down period is needed and tabletop X-ray lasers use less energy [59]. These lasers are designed around the possibility of producing an X-ray laser beam with a picosecond pulse, requiring far less power than existing alternatives (5-joule). Using a DIY X-ray laser, Dunn showed that a 14.7-nm transition in a palladium scheme similar to nickel could be amplified. Laser chirped-pulse amplification is a method they devised in which a brief pulse is prolonged, amplified, and then shortened once more before being focused on a target [60]. Since the initial demonstration of X-ray lasing in plasmas comprising selenium ions with properties similar to neon and palladium ions with properties similar to nickel, physicists in a variety of laboratories have conducted extensive theoretical and experimental work to explore the possibility of generating X-ray lasing via other atomic transition mechanisms [61–63]. As a professor in the Physics Department of Cairo University's College of Science, El-Sherbini pioneered the investigation of the probability of transitions between laser levels and the radiative lifetimes of those levels in atomic systems.

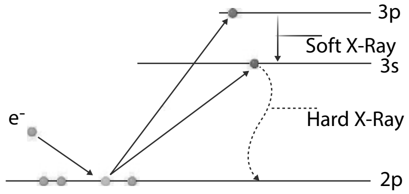


Figure 1.8 Selenium with neon-like energy levels.

To calculate the lifetimes of laser levels in singly ionized krypton, he ran multi-configuration HartreeFock (MCHF) simulations. Metastability was seen at several of these concentrations [64–66]. From the ion's ground state, he proposed a two-stage excitation up to the level of 4p4 5p, where certain metastable intermediate states present an alternative pathway for stimulation.

The LLNM expanded upon his work to explore the possibility of laser emissions from excited electrons in atomic isoelectronic sequences. These studies are important because they disclose unique laser lines that could be expanded into the X-ray spectral range [67, 68], which is important for further understanding atomic structure and ionizing phenomena. To better understand the potential for X-ray laser emission in a variety of isoelectronic systems, the atomic physics group at LLNM computed the level of population inversion and analyzed the gain coefficients in laser transitions [69]. He, Be, B, C, Ne, Na, mg, Al, Si, Ca, Sc, and Ni have been studied for their isoelectronic sequences [70–80]. Many heavy isoelectronic series elements have been found to emit soft X-rays with wavelengths between 5 and 50 nm. The transitions detected as stimulated emission in these ions are potentially useful for future research on soft X-ray laser system design.

There will be numerous medical and biomedical uses for X-ray lasers once they have reached a level of reliability, efficiency, and affordability. This will allow them to probe organisms and things far smaller than can be seen with the naked eye because of their short wavelength, coherence, and incredible brightness. They may also improve X-ray imaging and have significant implications for holography, medical imaging, medical diagnostics, and therapy.

1.8 Conclusion

Laser treatment is a growing field of study that shows promise as a useful tool for diagnosis to treat a variety of illnesses, and anecdotal evidence suggests it may have some subjective benefits, as well. Possible applications of laser therapy in wound healing, pain relief, and condition-specific rehabilitation (e.g., in osteoarthritis) are all areas that are being explored. Reducing pain and inflammation and promoting tissue healing are all effects for which the underlying mechanisms have been investigated and found. When researchers have a firm grasp on how light travels through tissue, they become better equipped to determine the ideal dose for each given ailment and the individual patient. There are many possible uses for photobiomodulation, and its regular use could pave the way for the discovery of even more. Applications are being researched for some of the most difficult health problems, and the area as a whole will expand as more is learned. Further clinical research is required, and practitioners using this technology are strongly encouraged to work together. Recent developments in therapeutic lasers are being covered by an expanding body of pedagogical materials.

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