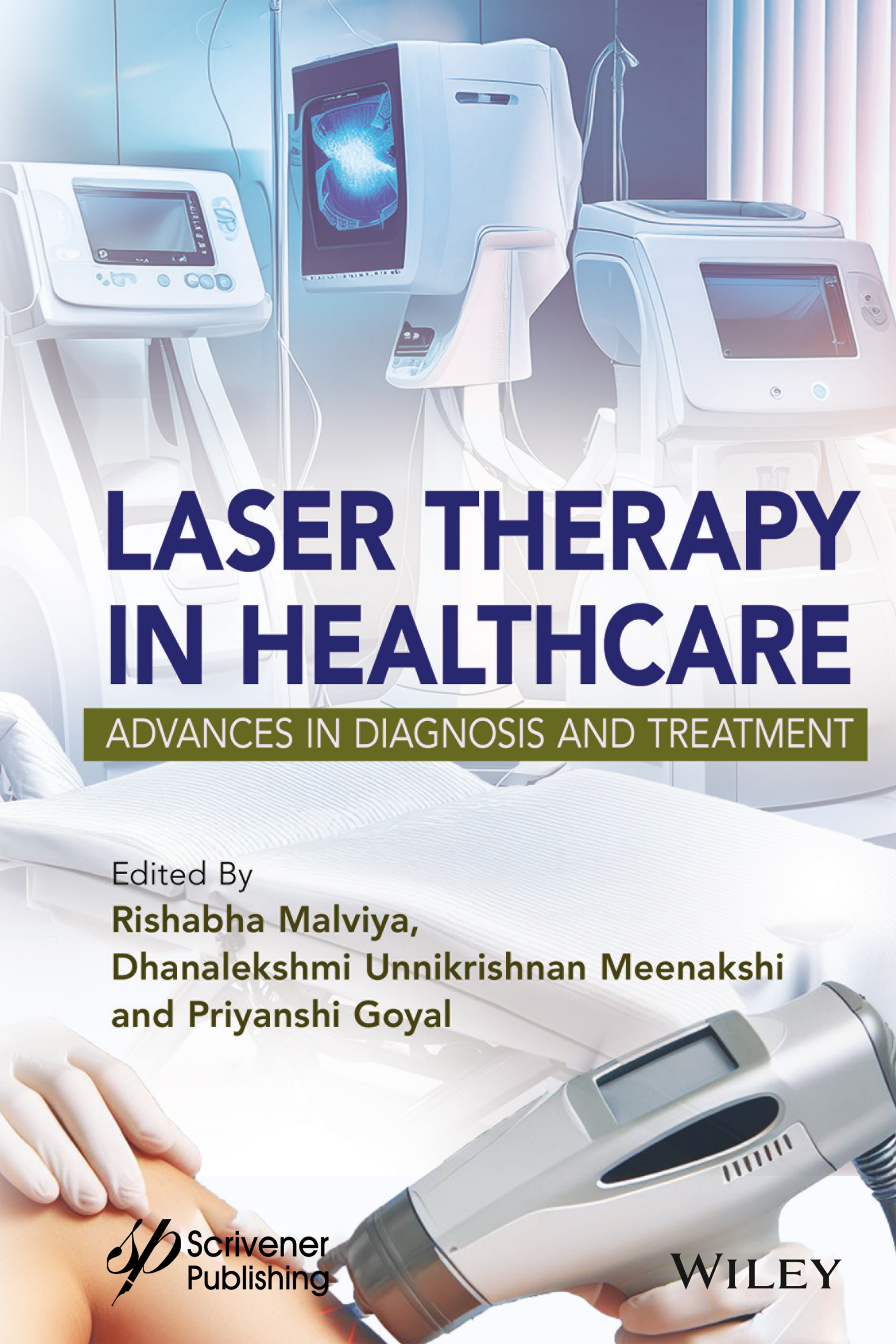

LASER THERAPY IN HEALTHCARE

ADVANCES IN DIAGNOSIS AND TREATMENT

Edited By
Rishabha Malviya,
Dhanalekshmi Unnikrishnan Meenakshi
and Priyanshi Goyal

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100 Cummings Center, Suite 541J
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Publishers at Scrivener
Martin Scrivener (martin@scrivenerpublishing.com)
Phillip Carmical (pcarmical@scrivenerpublishing.com)

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Edited by
Rishabha Malviya
School of Medical and Allied Sciences, Galgotias University, India
Dhanalekshmi Unnikrishnan Meenakshi
College of Pharmacy, National University of Science and Technology, Muscat, Sultanate of Oman
and
Priyanshi Goyal
School of Medical and Allied Sciences, Galgotias University, India

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Foreword

It is with great pleasure and enthusiasm that I submit this foreword to the amazing book, *Laser Therapy in Healthcare: Advances in Diagnosis and Treatment*, edited by Dr. Rishbaha Malviya and his team.

The integration of laser technology and healthcare has resulted in an important transformation in how we detect and treat a wide range of medical diseases. Dr. Malviya's passion was invaluable in assembling this extensive investigation of laser therapy's applications across several medical specialties. This book shows the combined knowledge and continuous work of the contributors who have meticulously explained all aspects of laser physics, its applications in medicine, and its revolutionary potential. Dr. Malviya's editorial leadership has guided this compilation to excellence, comprising a wide range of issues, from fundamental laser physics to advanced therapeutic approaches.

As I read through the contents of this book, I was overwhelmed by the range and depth of knowledge included within its chapters. Each chapter reveals the scientific integrity, from the explanation of laser surgery in modern healthcare to the sensitive discussion on controlling neurological illnesses and wound healing.

This book is more than just a collection of information; it is a source bringing healthcare professionals, researchers, and aspiring minds to a place where technology and medicine connect for the good of human health. May this book serve as a model, stimulating additional research, creativity, and improvements in the ever-changing field of laser therapy in healthcare.

Dr. Ayon Bhattacharjee
Professor,
Department of Physics, National Institute of Technology,
Meghalaya, India

Preface

The implementation of cutting-edge technologies has upended the paradigms of diagnosis and treatment in the ever-changing world of healthcare. Among these breakthroughs, the introduction of laser therapy stands out as a transformative moment, presenting a tremendous range of possibilities across a wide range of medical areas.

Laser Therapy in Healthcare: Advances in Diagnosis and Treatment is the outcome of considerable research, combined experience, and a passionate study of lasers' diverse uses in modern medicine. This thorough book navigates the complex field of laser physics, clinical applications, and novel treatment interventions that are transforming the healthcare sector.

This book acts as a roadmap through the various aspects of laser-based diagnostics and treatment modalities, from the basic chapters that explain the fundamentals of laser physics and its significant effects on tissues to the in-depth investigation of laser surgery in modern healthcare. Each chapter focuses on a different aspect of laser therapy, emphasizing its critical role in the treatment of many medical problems, from neurological disorders to oncology, dentistry, wound healing, and more.

The collaborative efforts of eminent contributors have shaped the contents of this book to serve as a vital guide for medical practitioners, researchers, academicians, and students seeking to understand the nuanced complexities and transformative potential of laser therapy.

The book explores the intersection of laser technology and healthcare, highlighting its applications, challenges, and potential future in medical practice.

We hope that you find this book to be informative and inspiring, and we extend our thanks to Martin Scrivener and his entire team for their dedicated support during publication.

Rishabha Malviya
Dhanalekshmi Unnikrishnan Meenakshi
Priyanshi Goyal

1

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].

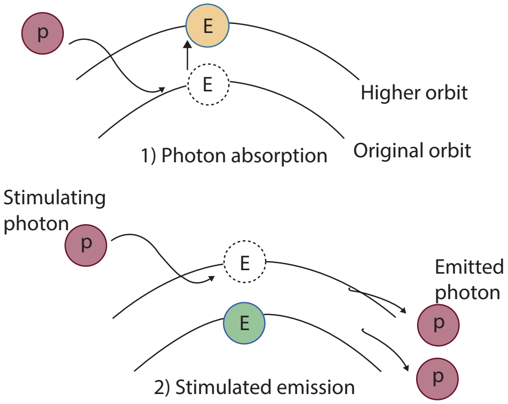


Figure 1.1 Mechanism of stimulated emission.

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 ($2{,}998\times10^8$ 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.

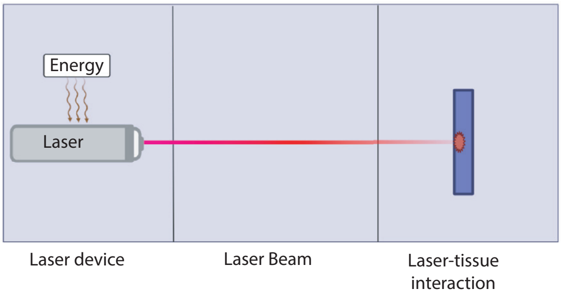


Figure 1.2 Schematic flowchart of a laser theory.

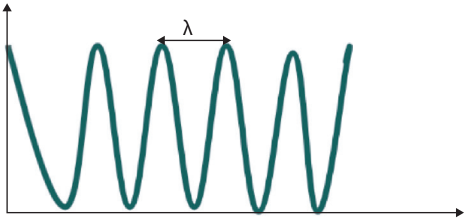


Figure 1.3 Electromagnetic wave.

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].

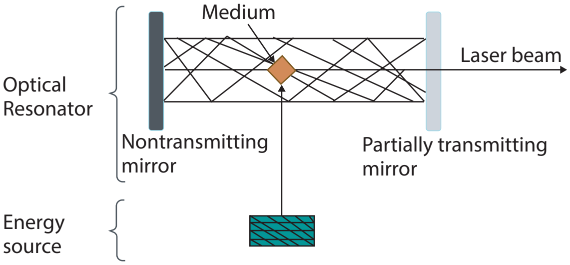


Figure 1.4 Laser components.

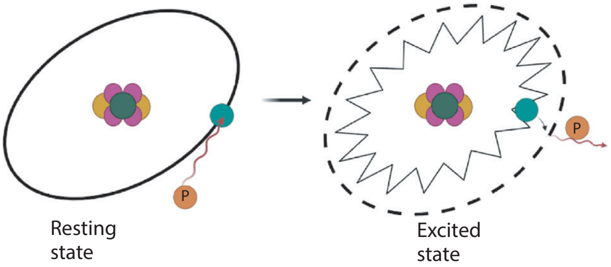


Figure 1.5 Electron excitement.

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

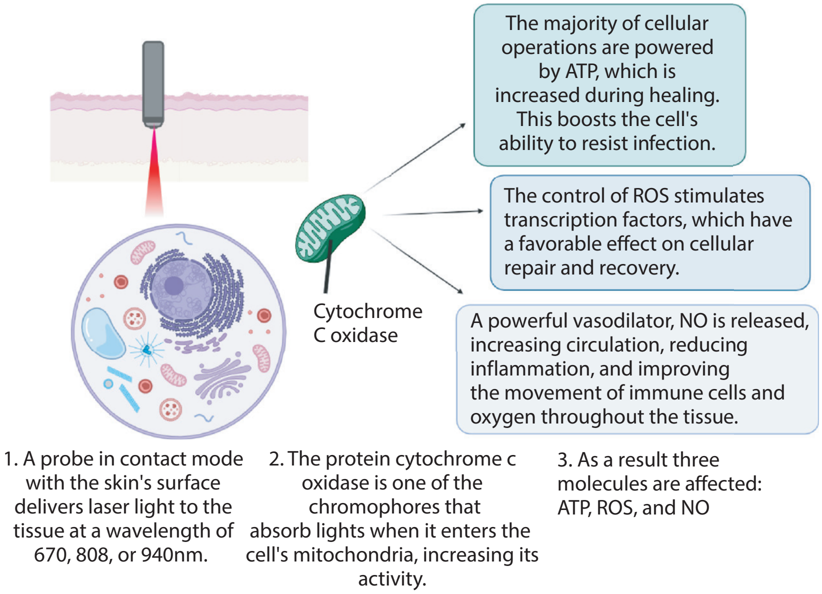
Researchers in the field are currently debating the mechanism of action related to photobiomodulation. It is envisaged that the targets and cell types being controlled would have different mechanisms of action. Photobiomodulation, or low-level laser therapy, is a painless, non-invasive treatment alternative 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

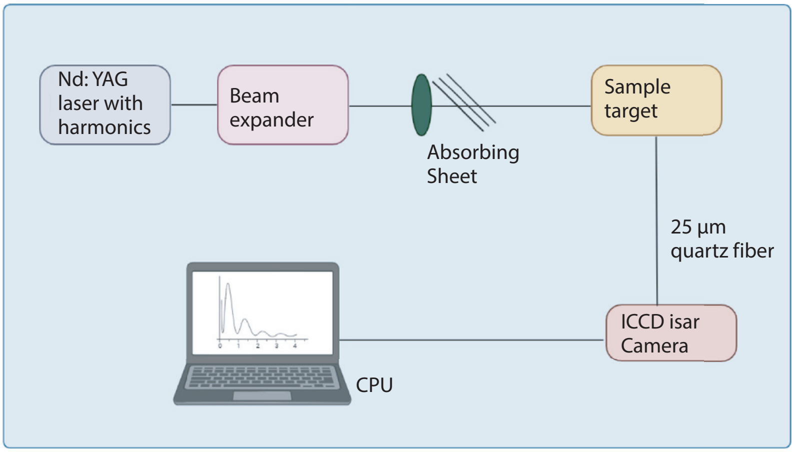


Figure 1.7 Experimental preparation for laser-induced breakdown spectroscopy.