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With 108 Figures and 15 Tables

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Preface

The continual array of laser technology throughout the world has been nothing short of miraculous. Over the last fifteen years, this field has continued to grow and expand with the appearance of new technology. This book represents the most up-to-date description of the latest in laser and light-source technology. All the chapters are written by leading experts from both North America and Europe. After a chapter describing our latest understanding of laser physics, which also covers safety aspects, chapters are dedicated to laser treatment of vascular lesions, pigmented lesions and tattoos, unwanted hair, and ablative and non-ablative resurfacing and treatment for medical purposes. Each chapter begins with the core concepts. These basic points are followed by a history of the use of lasers for the cutaneous problem under discussion, currently available technology, and indications and contraindications. Each author then provides an example of his/her consent form and approaches to personal treatment.

What has become clear is that a significant understanding of lasers and light sources is required for optimum use of this technology. A basic understanding of laser physics is also fundamental to good laser treatment. Laser safety and minimizing risk to patients is at least as important as an understanding of laser physics. When these concepts, so clearly described in Chap. 1, are understood cutaneous laser technology can be safely and successfully used for a variety of purposes.

A wide variety of cutaneous vascular disorders can be successfully treated with modern lasers. The pulsed dye laser has enabled treatment of cutaneous vessels by following the principle of selective photothermolysis, a simple physics concept seen throughout laser dermatology. The pulsed dye laser is the most effective laser for treatment of port wine stains but purpura limits its acceptability by patients for more cosmetic indications. Both facial and leg vein telangiectasia can also be treated with lasers. Other cutaneous disorders such as psoriasis, warts and scars can be improved by targeting the lesion's cutaneous vessels with appropriate lasers. Chapter 2 describes our latest understanding of the laser treatment of vascular lesions.

When considering treatment of pigmented lesions, accurate diagnosis of the pigmented lesion is mandatory before laser treatment. For some pigmented lesions, laser treatment may even be the only treatment option. Tattoos respond well to Q-switched lasers. Amateur and traumatic tattoos respond more readily to treatment than do professional tattoos. Cosmetic tattoos should be approached with caution. Treatment of melanocytic nevi remains controversial, but worth pursuing. Chapter 3 describes our latest understanding of the laser treatment of pigmented lesions and tattoos.

A wide variety of lasers can now induce permanent changes in unwanted hair. Hair-removal lasers are distinguished not only by their emitted wavelengths, but also by their delivered pulse duration, peak fluence, spot size delivery system and associated cooling. Nd:YAG lasers, with effective cooling, are the safest approach for treatment of darker skin. Despite this, complications arising from laser hair removal are more common in darker skin types. Laser treatment of non-pigmented hair remains a challenge. Chapter 4 describes our latest understanding of the laser treatment of unwanted hair

Ablative and non-ablative laser resurfacing lead to improvement of photodamaged skin.

Ablative laser resurfacing produces a significant wound, but long lasting clinical results.

Non-ablative resurfacing is cosmetically elegant, but generally leads to subtle improvement only. Visible light non-ablative devices lead to a lessening of erythema and superficial pigmentary skin changes. Mid-infrared laser devices promote better skin quality and skin toning. Chapter 5 describes our latest understanding of ablative and non-ablative laser resurfacing.

Lasers and light sources have become more commonplace in the treatment of dermatological medical diseases. Topical ALA and adjunct light-source therapy (ALA-PDT) is a proven photodynamic therapy for actinic keratoses and superficial non-melanoma skin cancers. ALA-PDT, using a variety of vascular lasers, blue-light sources, and intense pulsed light sources, is also now being used to treat the signs of photoaging. PDT can also be useful therapy for acne vulgaris. Newer lasers and light sources are also now being used to treat psoriasis vulgaris, vitiligo, other disorders of pigmentation, and hypopigmented stretch marks. Chapter 6 describes our latest understanding of photodynamic therapy and the treatment of medical dermatological conditions.

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Contents

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Basic Laser Physics and Safety

1

Ronald G. Wheeland

Core Messages

- A significant understanding of lasers and light sources is required for optimal use of these technologies
- A basic understanding of laser physics is at the core of good laser treatments
- Laser safety and minimizing patient risk is at least as important as an understanding of laser physics.

History

What Is Light?

Light is a very complex system of radiant energy that is composed of waves and energy packets known as photons. It is arranged into the electromagnetic spectrum (EMS) according to the length of those waves. The distance between two successive troughs or crests of these waves, measured in meters, determines the *wavelength*. For the visible portion of the EMS, the wavelength determines the color of the laser light. The number of wave crests (or troughs) that pass a given point in a second determines the *frequency* for each source of EMS energy. The wavelength and frequency of light are inversely related to one another. Thus, shorter wavelengths of light have higher frequencies and more energetic photons than longer wavelengths of light which have lower frequencies and less energetic photons.

When Was Light First Used for Medical Purposes?

One must go back to about 4000 B.C. in ancient Egypt to find the earliest recorded use of light. It was at that time that sunlight coupled with a topical photosensitizer, like parsley or other herbs containing psoralen, to help repigment individuals suffering from vitiligo, where the skin becomes depigmented through a presumed autoimmune reaction. In Europe in the 19th century, sunlight was used as a treatment for cutaneous tuberculosis. However, it wasn't until 1961 that Dr. Leon Goldman, a dermatologist at the University of Cincinnati, first employed a ruby laser for the removal of tattoos and other pigmented cutaneous lesions. For his continuous efforts in promoting the use of lasers for medical purposes and for co-founding the American Society for Laser Medicine and Surgery, Dr. Goldman (Goldman et al. 1963) has been called the "Father of Lasers in Medicine and Surgery." Since those earliest days, many physicians in different specialties have played key roles in the advancement of the use of lasers in medicine such that today most specialties use lasers in either diagnosing or treating a number of different disorders and diseases (Wheeland 1995).

Who Invented the Laser?

Professor Albert Einstein (Einstein 1917) published all of the necessary formulas and theoretical concepts to build a laser in his 1917 treatise called The Quantum Theory of Radiation. In this treatise, he described the interaction of atoms and molecules with electromagnetic energy in terms of the spontaneous absorption and emission of energy. By applying principles of thermodynamics he concluded that stimulated emission of energy was also possible. However, it wasn't until 1959 that Drs. Charles H. Townes and Arthur L. Schalow (Schalow and Townes 1958) developed the first instrument based on those concepts, known as the *MASER* (*M*icrowave *A*mplification through the *S*timulated *E*mission of *R*adiation). Then, in 1960, the first true laser, a ruby laser, was operated by Dr. Theodore H. Maiman (Maiman 1960). The development of additional lasers occurred rapidly, with the helium-neon laser appearing in 1961, the argon laser in 1962, the carbon dioxide and Nd:YAG laser in 1964, the dye laser in 1966, the excimer laser in 1975, the copper vapor laser in 1981, and the gold vapor laser in 1982.

What Is a Laser?

The word "LASER" is an acronym that stands for *L*ight *A*mplification by the *S*timulated *E*mission of *R*adiation. For this reason, a laser is not just an instrument but also a physical process of amplification (Table 1.1). The last word in the acronym, "radiation," is a common source of patient anxiety since it is associated with the high energy ionizing radiation often associated with cancer radiotherapy. However, in the case of lasers, the word is employed to describe how the laser light is propagated through space as "radiant" waves. Patients should be assured that all currently approved medical lasers are incapable of ionizing tissue and have none of the risks associated with the radiation used in cancer therapy.

All lasers are composed of the same four primary components. These include the *laser medium* (usually a solid, liquid, or gas), the *optical cavity* or resonator which surrounds the laser medium and contains the amplification process, the *power supply* or "pump" that excites the atoms and creates population inversion, and a *delivery system* (usually a fiber optic or articulating arm with mirrored joints) to precisely deliver the light to the target.

Lasers are usually named for the *medium* contained within their optical cavity (Table 1.2). The gas lasers consist of the argon, excimers, copper vapor, helium-neon, krypton, and carbon dioxide devices. One of the most common liquid lasers contains a fluid with rhodamine dye and is used in the pulsed dye laser. The solid lasers are represented by the ruby, neodymium:yttrium-aluminum-garnet (Nd:YAG), alexandrite, erbium, and diode lasers. All of these devices are used to clinically treat a wide variety of conditions and disorders based on their wavelength, nature of their pulse, and energy.

The excitation mechanism, i. e., power supply or "pump," is a necessary component of every laser in order to generate excited electrons and create population inversion (Arndt and Noe 1982). This can be accomplished by direct electrical current, optical stimulation by another laser (argon), radiofrequency excitation, white light from a flashlamp, or even (rarely) chemical reactions that either make or break chemical bonds to release energy, as in the hydrogen-fluoride laser.

To understand stand how laser light is created it is important to recall the structure of an atom. All atoms are composed of a central nucleus surrounded by electrons that occupy discrete energy levels or orbits around the nucleus and give the atom a stable configuration (Fig. 1.1). When an atom spontaneously absorbs a photon of light, the outer orbital electrons briefly move to a higher energy orbit, which is an unstable configuration (Fig. 1.2). This configuration is very evanescent and the atom quickly releases a photon of light spontaneously so the electrons can return to their normal, lower energy, but stable inner orbital configuration (Fig. 1.3). Under normal circumstances, this spontaneous absorption and release of light occurs in a disorganized and random fashion and results in the production of *incoherent* light.

When an external source of energy is supplied to a laser cavity containing the laser medium, usually in the form of electricity, light, microwaves, or even a chemical reaction, the resting atoms are stimulated to drive their electrons to unstable, higher energy, outer orbits. When more atoms exist in this unstable high energy configuration than in their usual resting configuration, a condition known as *population inversion* is created, which is necessary for the subsequent step in light amplification (Fig. 1.4).

Table 1.1. Laser terminology

Absorption	The transformation of radiant energy to another form of energy (usually heat) by interacting with matter
Coherence	All waves are in phase with one another in both time and space
Collimation	All waves are parallel to one another with little divergence or convergence
Electromagnetic radiation	A complex system of radiant energy composed of waves and energy bundles that is organized according to the length of the propagating wave
Energy	The product of power (watts) and pulse duration (seconds) which is expressed in joules
Extinction length	The thickness of a material necessary to absorb 98% of the incident energy
Focus	The exact point at which the laser energy is at peak power
Irradiance (power density)	The quotient of incident laser power on a unit surface area, expressed as watts/cm^2
Joule	A unit of energy which equals one watt-second
Laser	An instrument that generates a beam of light of a single wavelength or color that is both highly collimated and coherent; an acronym that stands for light amplification by the stimulated emission of radiation
Laser medium	A material or substance of solid, liquid, or gaseous nature that is capable of producing laser light due to stimulated electron transition from an unstable high energy orbit to a lower one with release of collimated, coherent, monochromatic light
Meter	A unit length based on the spectrum of krypton-86; frequently subdivided into millimeters (10^{-3} m), micrometers (10^{-6} m), and nanometers (10^{-9} m)
Monochromatic	Light energy emitted from a laser optical cavity of only a single wavelength
Optically pumped laser	A laser where electrons are excited by the absorption of light energy from an external source
Photoacoustic effect	The ability of Q-switched laser light to generate a rapidly moving wave within living tissue that destroys melanin pigment and tattoo ink particles
Population inversion	The state present within the laser optical cavity (resonator) where more atoms exist in unstable high energy levels than their normal resting energy levels
Power	The rate at which energy is emitted from a laser
Power density (irradiance)	The quotient of incident laser power on a unit surface area, expressed as watts/cm^2
Pump	The electrical, optical, radiofrequency or chemical excitation that provides energy to the laser medium
Q-switch	An optical device (Pockels cell) that controls the storage or release of laser energy from a laser optical cavity
Reflectance	The ratio of incident power to absorbed power by a given medium
Scattering	Imprecise absorption of laser energy by a biologic system resulting in a diffuse effect on tissue
Selective photothermolysis	A concept used to localize thermal injury to a specific target based on its absorption characteristics, the wavelength of light used, the duration of the pulse, and the amount of energy delivered
Thermomodulation	The ability of low energy light to upregulate certain cellular biologic activities without producing an injury
Transmission	The passage of laser energy through a biologic tissue without producing any effect

Amplification of light occurs in the optical cavity or resonator of the laser. The resonator typically consists of an enclosed cavity that allows the emitted photons of light to reflect back and forth from one mirrored end of the chamber to the other many times until a sufficient intensity has been developed for complete amplification to occur. Through a complex process of absorption and emission of photons of energy, the prerequisite for the development of a laser beam of light has been met and amplification occurs. The photons are then allowed to escape through a small perforation in the partially reflective mirror. The emerging beam of light has three unique characteristics that allow it to be delivered to the appropriate target by fiber optics or an articulated arm.

What Are the Unique Characteristics of Laser Light?

By stimulating the emission of light from a laser, laser light has three unique characteristics that differentiate it from nonlaser light. The first of these characteristics is that laser light is

Table 1.2. Types of lasers

Name	Type	Wavelength
ArFl	Excimer	193 nm
KrCl	Excimer	222 nm
KrFl	Excimer	248 nm
XeCl	Excimer	308 nm
XeFl	Excimer	351 nm
Argon	Gas	488 and 514 nm
Copper vapor	Gas	511 and 578 nm
Krypton	Gas	521–530 nm
Frequency-Doubled:YAG	Solid state	532 nm
Pulsed dye	Liquid	577–595 nm
Helium-Neon	Gas	632 nm
Ruby	Solid state	694 nm
Alexandrite	Solid state	755 nm
Diode	Solid state	800 nm
Nd:YAG	Solid state	1,064 and 1,320 nm
Diode	Solid state	1,450 nm
Erbium:Glass	Solid state	1,540 nm
Erbium:YAG	Solid state	2,940 nm
Carbon dioxide	Gas	10,600 nm

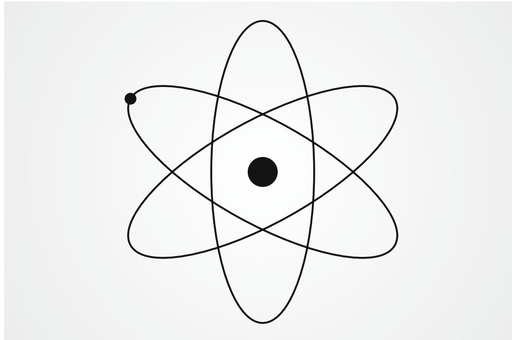

Fig. 1.1. Normal configuration of an atom with central nucleus and surrounding electrons in stable orbits

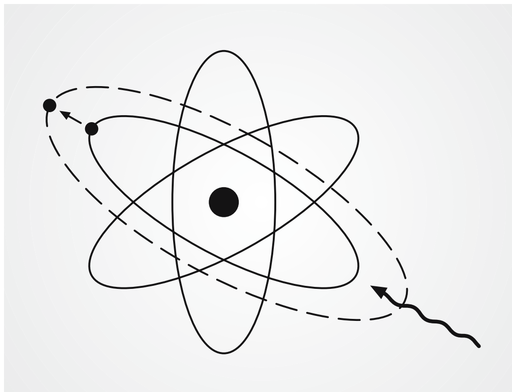

Fig. 1.2. Absorption of energy has briefly stimulated the outer electron into an unstable, but higher energy orbit.

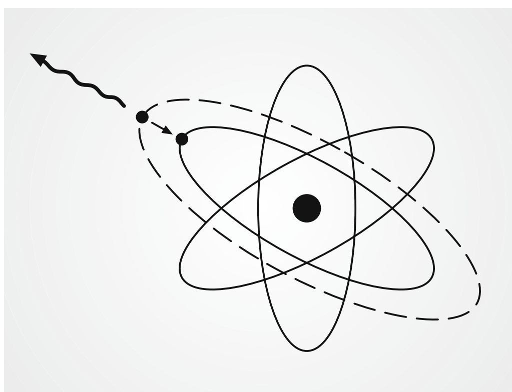

Fig. 1.3. The stimulated electron rapidly drops back to its normal orbit and assumes a stable configuration