Laser Physics

“Light and How It Works”

L.A.S.E.R

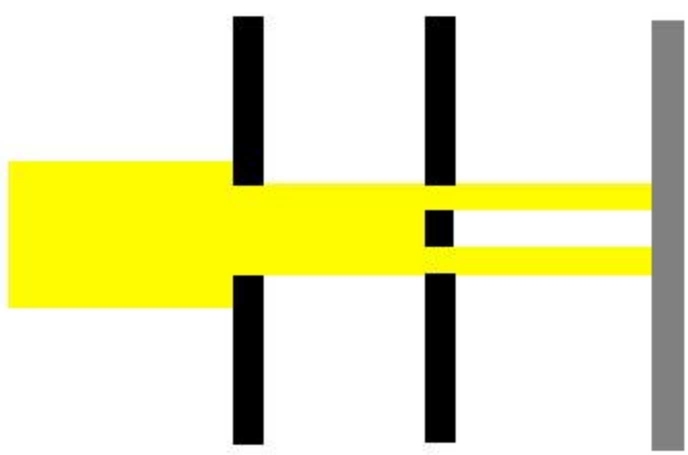
We all know that L.A.S.E.R stands for "Light Amplification by Stimulated Emission of Radiation". But what does all of that really mean? Let's break it down piece by piece. First we'll talk about light and its properties!

Light's properties can at first seem confusing and inconsistent because of the unique nature of light: light has the properties of both a wave and a particle. In some situations, light's behavior is more easily explained by thinking of light as a particle. In other situations, its behavior can only be explained if light is thought of as a wave. This duality of light between a particle and a wave is very difficult if not impossible to visualize. Instead it is much easier to see light demonstrate its properties in specific situations.

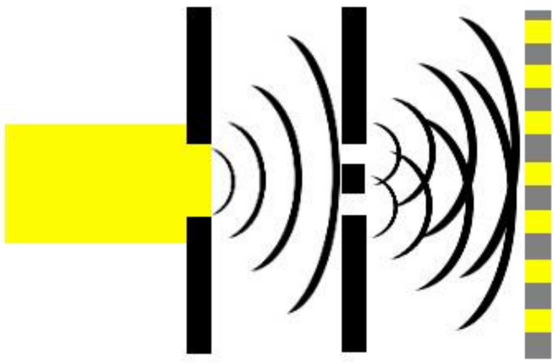
Light as a Wave

Before the nineteenth century, the physics community was split over the actual nature of light. Around 1800, Thomas Young devised an experiment designed specifically to settle the debate over the nature of light once and for all. The basic principle behind the experiment was how light would behave when it encountered an obstacle with a hole that was smaller than the beam of light. Young set up a beam of light to shine through a slit, and then the resulting light that made it through that slit was to pass through two more slits side by side.

If light behaves as a particle, it should pass through the first slit, then through the two small slits. But, it should not spread out after passing through the slits. Because of this if light behaves as a particle in this situation, only two stripes of light should end up passing through the entire slit system. The diagram below shows light behaving as a particle in Young's experiment.



These results were not what Young actually observed. Instead of seeing two stripes, Young saw a series of many stripes. This was definitely not consistent with the behavior of a particle. However, it was consistent with the behavior of a wave. When a wave passes through a slit, it spreads out on the other side. Also, when two waves pass over each other they can interfere with each other. These two properties of waves explain the behavior that Young observed. When the light waves pass through the slit, the waves spread out on the other side of the slit. When the two waves overlap, they interfere with each other.

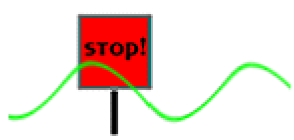


Dualities

Despite Young's findings, many other experiments have supported the theory that light exists as a particle. Max Planck's investigation into black body radiation could not be explained while light was thought to be a wave. Planck began to develop the idea of packets of light called photons. The idea of light being a particle was further developed by Einstein for his work on the photoelectric effect. This duality causes light to be very difficult for most people to visualize. Thinking of light as being a particle at times and also a wave at times is the only way to understand light's diverse properties.

Light

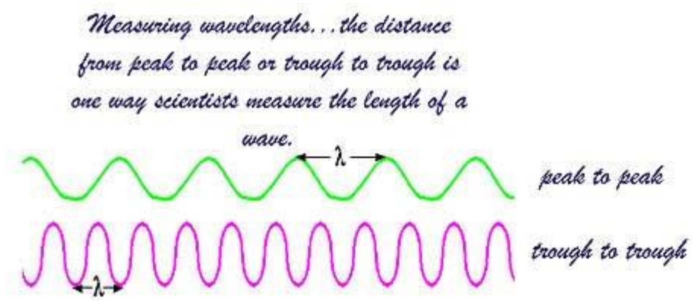
One important thing to know about light is that it travels and behaves as **waves**. Light also has the character of a **particle**, but we're going to just look at some basic stuff about light as a wave.



All light travels in the form of waves at a speed of about **300,000 (300 thousand) kilometers per second in a vacuum** such as space. That's about **186,000 miles every second**. That means light can travel almost eight times around the Earth in a second. That's pretty fast! Light has slightly slower speeds when it travels through denser material such as a planet's atmosphere or a piece of glass.

There are many different kinds of light besides the one you can see. What do you think is a good word to describe the light you see? Scientists often describe the light you can see as **"visible"** light. The entire range of different kinds of light including the ones the human eye cannot see is called the **electromagnetic spectrum**.

To describe the differences between types of light like visible and x-ray, scientists often talk about the length of the light's waves or "wavelength." The various types of light that make up the electromagnetic spectrum differ in the length of their waves. However, this doesn't mean the entire length of the wave train. The length of a light's wave or the wavelength is the distance between two nearest peaks (the highest places) or two nearest troughs (the place where it dips the lowest).



One common unit used to measure the length of light waves is not feet or inches but rather something called an **angstrom**.

Another thing scientists measure in waves is the wave's amplitude or height. What exactly do we mean by a wave's **"amplitude"**? That is, how do you measure the height or amplitude of a wave?

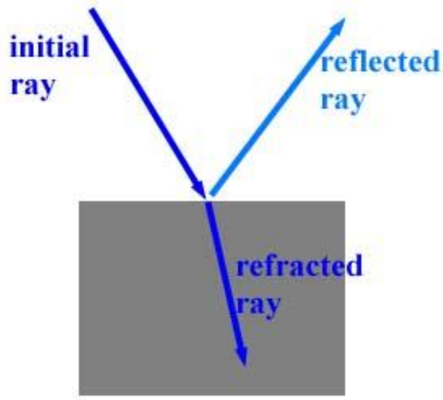
In astronomy, amplitude of a light's wave is important because it tells you about the intensity or brightness of the light relative to other light waves of the same wavelength. It's a measure of how much energy the wave carries.

So, if the light from Star A is brighter than the same type of light from Star B, you know that the light you see from Star A has the larger amplitude. It's very important to note that while amplitude gives you information about the intensity of the light, it is the wavelength, not the amplitude that tells you what kind of light it is.

Remember –
Wavelength tells you the *type of light*
And,
Amplitude tells you about the *intensity of the light*

The Basics of Refraction

When a ray of light passes from a transparent medium (such as air) into a different transparent medium (such as glass) part of the ray is bounced back into the original medium while some of the ray passes into the second medium. These two possibilities are known as reflection (bouncing back) and refraction (passing through).



Light that is refracted does not continue along its original path. Instead, it is *bent* slightly. The direction and amount of deflection depend on the nature of the medium the light was coming from and the nature of the medium that the light was entering.

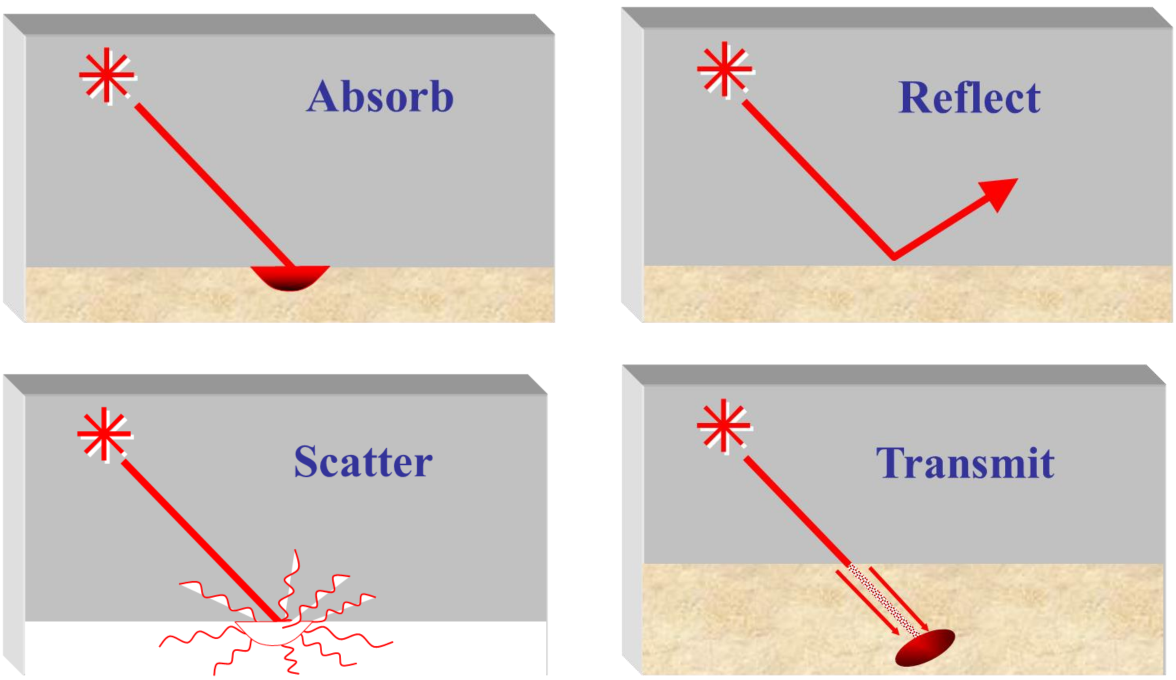
How does light bend? What happens when you dangle your feet in the pool? Or when you place a pencil in a glass of water? Does the object seem bent at the surface of the water? This phenomenon is due to the bending, or refraction of light at the interface between the water and the air. Notice that the words **refraction** and **reflection** are very similar but have two completely different meanings.

- **Refraction** occurs when light passes into a transparent material.
  Reflection occurs when light bounces off an opaque material.

The tricky part of it is that we can have **both** things happening at the same time.

This is an image of a laser beam being refracted at a water surface.

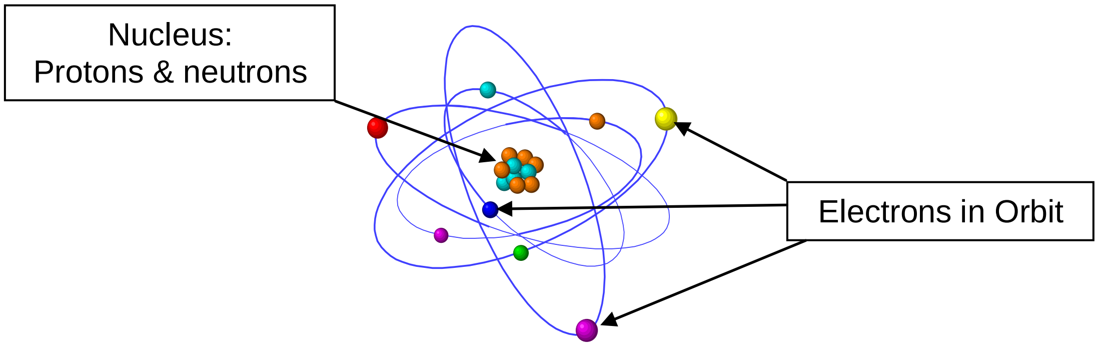
Laser-tissue reaction can be accomplished with the following ways that lasers work.



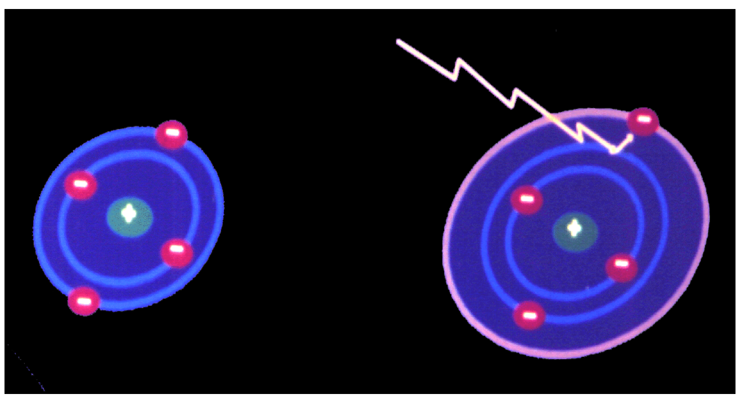
Absorption is necessary for an effect on tissue. This is called the Grothus-Draper Law.

Amplification:

Atoms of any substance are made up of electrons, protons and neutrons.



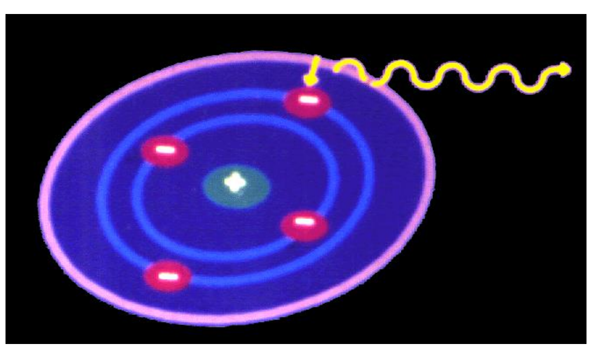
Electrons are usually in a "resting" stage; when they absorb a photon, they are raised to an "excited" stage.



Resting Stage

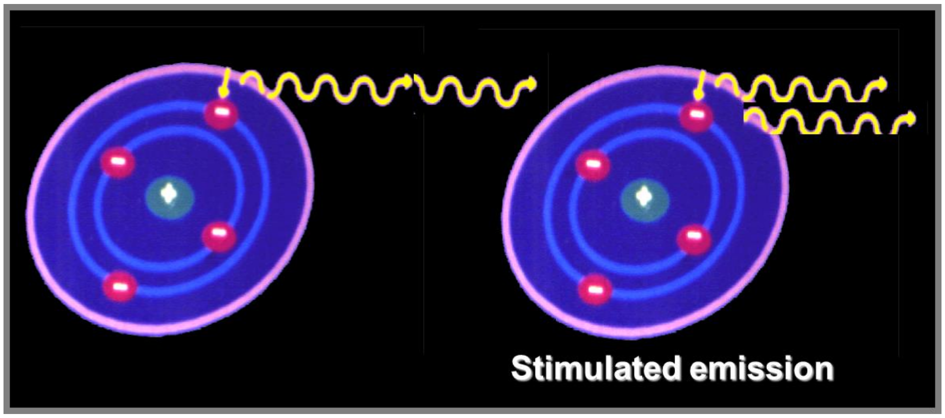
Excited Stage

Once raised to an "excited" stage, the electron naturally tends to return to its "resting" stage, and does so by emitting a photon (similar to the one absorbed): this is called <u>spontaneous emission</u>.



Spontaneous Emission

If the electron absorbs a second photon when in its "excited" stage, it then needs to emit two photons (similar to the ones absorbed): this is called stimulated emission.



A laser beam is generated by amplification, which is stimulated emission repeated innumerable times.

Selective photothermolysis is a concept developed by Rox Anderson in 1983. Selective photothermolysis means that laser light of a specific wavelength can destroy a target containing the adequate chromophore without damaging the surrounding tissue. This is possible if the thermal *relaxation time* of the target is longer than the duration of the laser pulse.

This is an important concept to understand, so let's dissect the paragraph above so we can understand it. "Photo" refers to light and thermolysis refers to heat. So this means that we are using light to generate heat. The chromophore for hair removal is melanin, or dark color, and our target is of course the hair. What this explains is how we can kill a hair (with heat) without damaging the skin! Alexandrite, ruby, and Nd:YAG lasers had been in existence for many years prior to laser hair removal. So the research and development that had to take place in order to adopt these lasers for hair removal was all about cooling systems! But the concept of selective photothermolysis had to be understood in order for it to work. Literally, what this means is that the amount of time that the laser pulse 'fires' is shorter than the amount of time it takes for the hair to cool down.

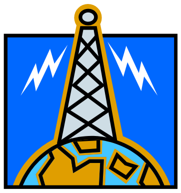
Let me give you an analogy that I think most of us can relate to. Let's say that you are cooking a baked potato in a microwave oven. You put the potato in the microwave and turn on the power for the recommended time for cooking a potato. When it is finished cooking, you take it out and place it on the counter. The potato continues to cook even after it is out of the oven.

What makes laser light "special"?

Laser light is *__NON-Ionizing__*. Other forms of *__non-ionizing__* light are:

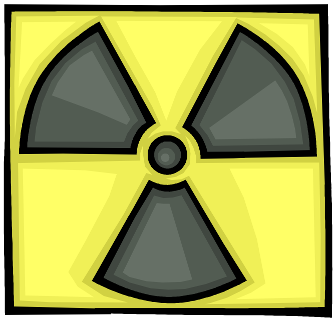
Heat

Radio Waves



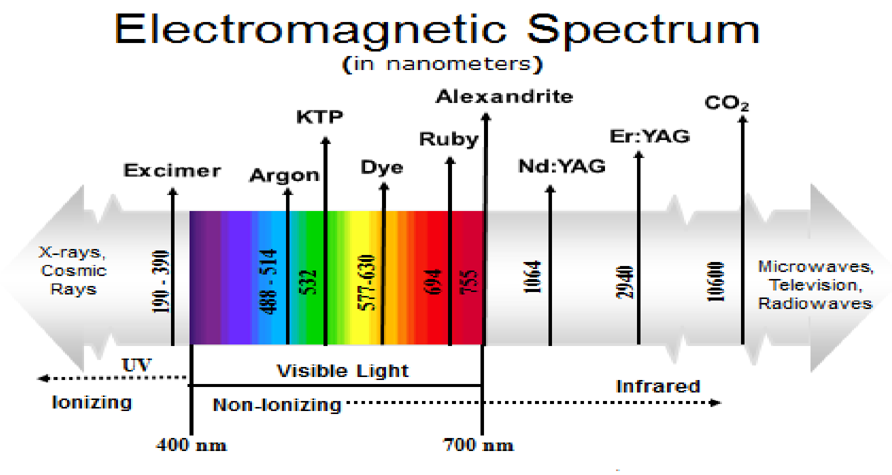
Incandescent Light

Laser light is NOT this kind of radiation!



There will be occasions when your patients will ask you how you know that this laser is safe, and this is your answer. The energy that our hair removal lasers emit is NOT like nuclear radiation or x-rays or gamma rays, which are ionizing radiation. Ionizing radiation can cause cell mutation which can lead to conditions such as cancer or even death!

Laser light is a form of <u>Electromagnetic Radiation</u>

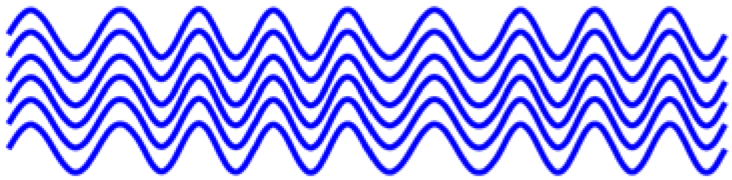


The Visible Spectrum of Light is Between 400 nm and 700 nm.

Laser light has three unique properties:

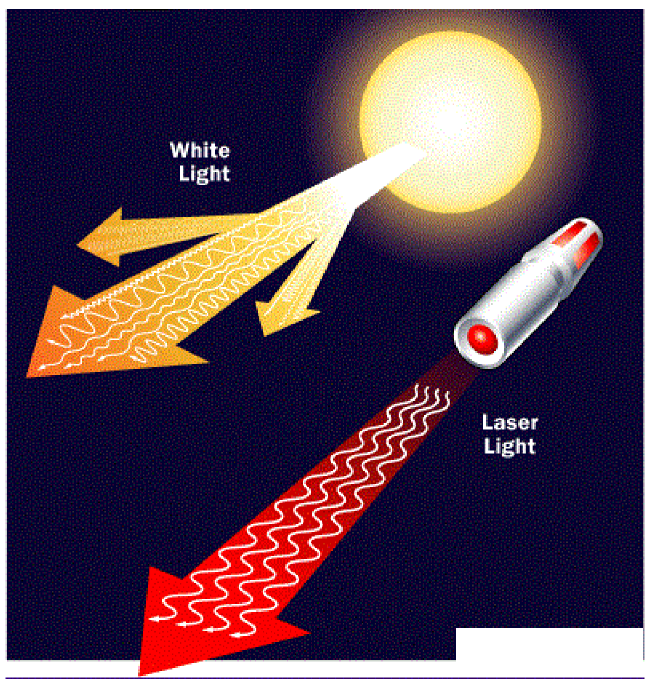
- Laser light is monochromatic
  - "Mono" means "1", and "chromatic" refers to "color", so this means that laser light is one color. In the case of an alexandrite wavelength, the color is red.

- Laser light is coherent
    - The light waves are spatially and temporally in phase. Each separate wave is exactly like the others being emitted from the same beam, and they are all going in exactly the same place – just like soldiers in formation.

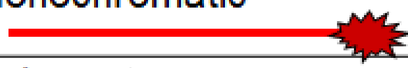
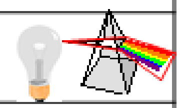
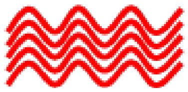
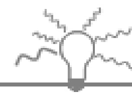
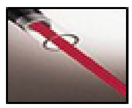


    - “Regular” light has many different wave lengths – short, long, compact – going in every direction.

- Laser light is collimated
    - The light waves are parallel and not divergent. I am sure that you have taken a flashlight into the woods at night. It doesn't matter how strong or bright the flashlight is, at a certain point the flashlight can't illuminate any further. As the light reaches out in the darkness, the pattern of light spreads out further and further making the light appear to be dimmer and dimmer. In contrast, the laser beam will keep the same pattern and intensity for as far as the energy source will project it. Because laser beams are collimated, we were able to determine the distance between the moon and the earth. They shot a laser beam (with a very powerful energy source!) to the moon and were able to measure how long it took for it to bounce back and determine how far away the moon is from the earth! No other light source has the properties that would have allowed that!



Lasers vs. Pulsed-Light

Lasers	Pulsed Light Systems
Monochromatic 	Polychromatic 
Coherent 	Divergent (Incoherent) 
Collimated 	Non-Collimated 

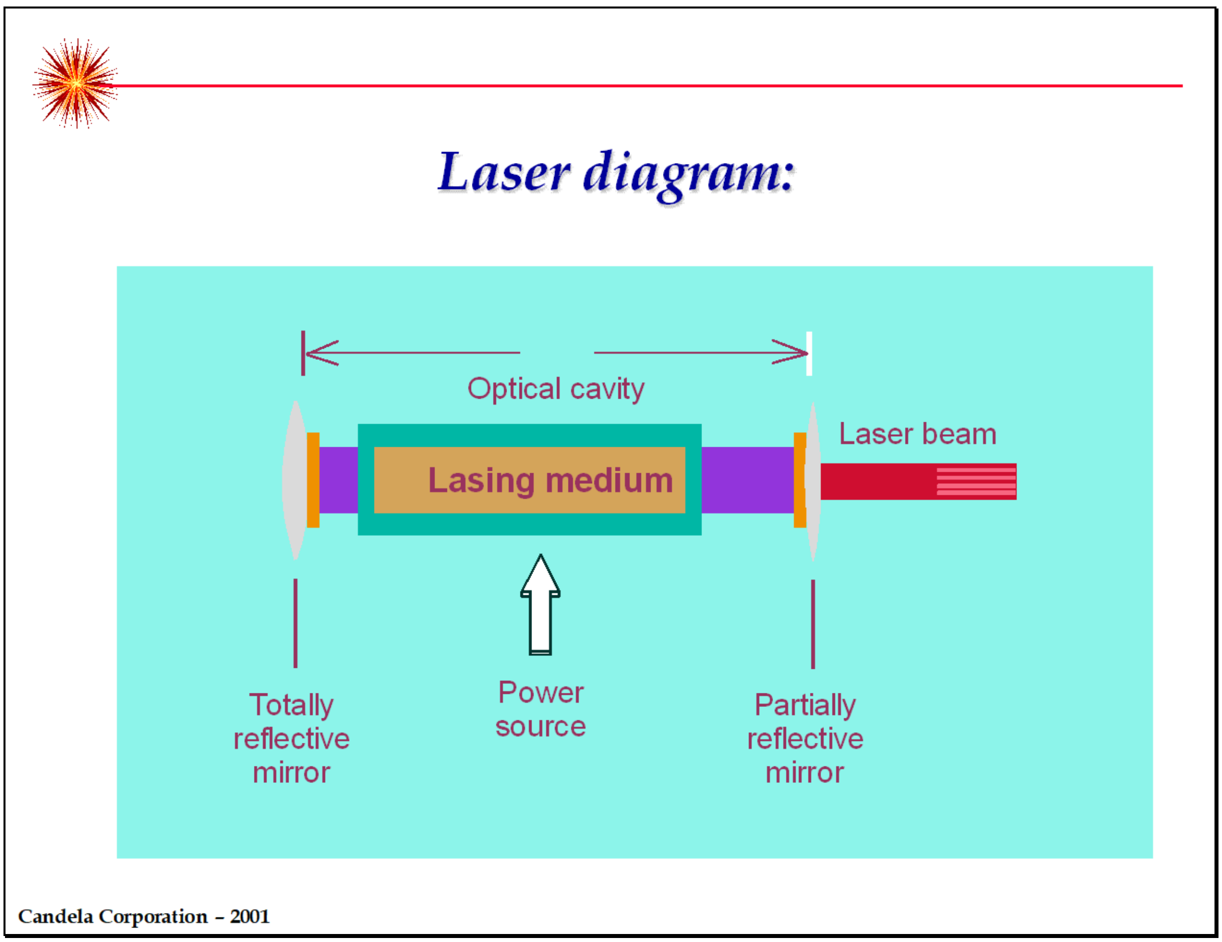
The Visible Light Spectrum

Color	Wavelength (nm)
Red	650 nm.
Orange	590 nm.
Yellow	570 nm
Green	510 nm.
Blue	475 nm
Indigo	445 nm.
Violet	400 nm

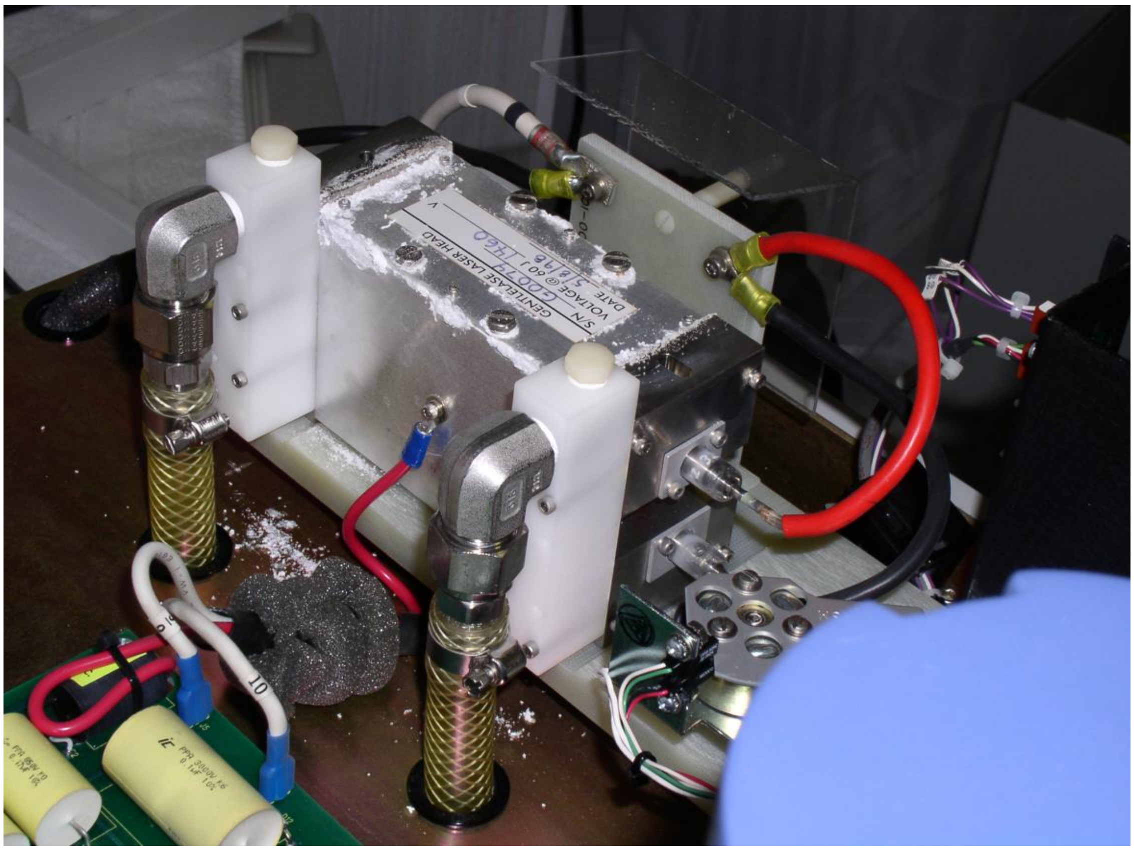
Components of a Laser

All lasers have four (4) basic components:

a. Lasing medium – alexandrite or YAG 'rod'
b. Optical cavity – the laser 'head'
c. Power source – usually a power supply much like the ones used for computers, but generally very expensive!
d. Delivery system – the pathway used to get the laser beam/energy to the patient's skin.



This photo is what an alexandrite laser looks like when you remove the sides and top. The silver box is the actual head (optical cavity) of the laser, and this one is damaged – time for a head 'rebuild'. The white powder that is present at every seam is an interior coating that is now leaking out of the head.



The **lasing medium** determines the wavelength of the laser. The lasing medium (located inside the optical cavity) is the substance that produces the laser beam.

This substance could be a

- GAS (argon, krypton, CO2),
- SOLID (alexandrite crystals, Nd:YAG crystals, ruby crystals),
- LIQUID (dye).

The power source is used to stimulate the lasing medium to produce the laser beam. Power sources include:

- Flashlamps – most hair removal lasers
- Other lasers – diodes
- Electricity

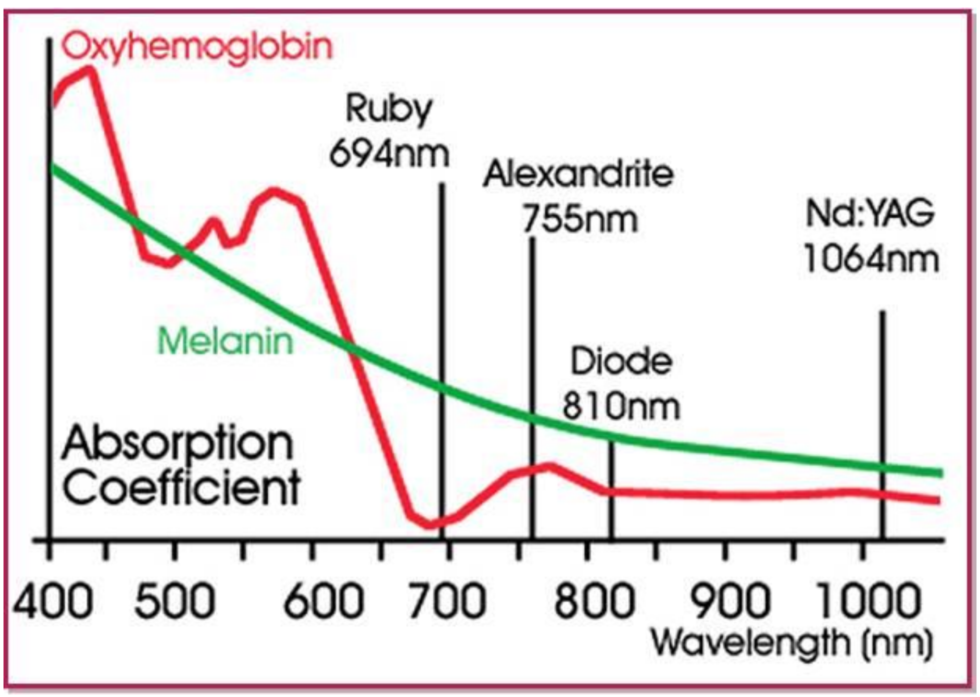
The **delivery system** modifies the laser beam and brings it from the optical cavity to the patient. Delivery systems include:

- Optical fibers – Most hair removal lasers implement the fiber optic lines. They are usually easy to replace when one wears out.
- Articulated arms – Early model ruby lasers had the articulating arm that had joints or elbow in the metal arm so it could be easy to manipulate – much like our lighted magnifiers used in our electrolysis practices.
- Focusing hand-pieces.

Delivery fibers (left, center), articulating arm with scanner (right)

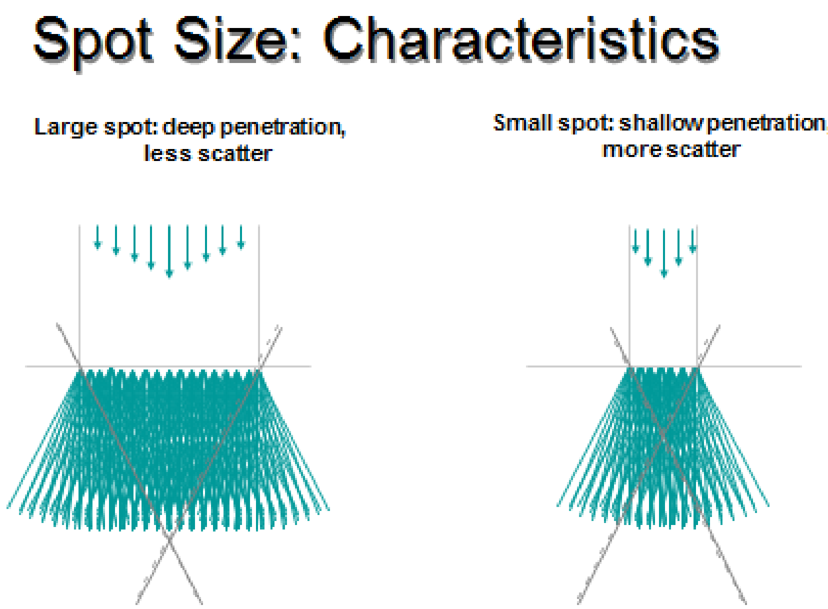
There are 4 basic laser parameters.

- Wavelength – The wavelength is determined by the lasing medium, and dictates the type of laser that it is, such as alexandrite, Nd:YAG, etc.
    - Measured in nanometers (nm)
    - A longer wavelength will penetrate deeper within the tissue.
    - Wavelength is chosen partly based on the absorption curve of the targeted chromophore.



- Pulse duration – how many milliseconds (ms) the laser beam is being emitted when the 'trigger' is depressed on the handpiece. Pulse duration is the length of time a set amount of energy is delivered to the tissue targeted. Longer pulse durations allow the skin to heat up slower and are safer for darker skin tones. Alternatively, shorter pulse durations can be more effective for treating fine and light colored hair. Most lasers vary greatly as to the pulse durations available.

- <u>Spot size</u> – the diameter of the laser beam when it is emitted from the hand piece and onto the skin. Spot sizes can vary from .5mm to 18mm. Most hair removal lasers use spot sizes of around 15mm – 18mm. Lasers vary widely on the spot sizes available for use. At least 3-5 mm is required for effective hair removal. Spot sizes determine the depth of penetration. In general, the larger the spot size, the greater the depth of penetration. This means more effective hair removal and less thermal damage. Smaller spot sizes are still useful because the operator can use higher fluences. The larger the spot size of the laser beam, the more fluence must be used to achieve the same result. Lasers have limits as to the amount of energy that can be used with the larger spot sizes. Another advantage of the larger spot size is the ability to treat larger areas of the body very quickly.



- <u>Fluence</u> – refers to how much power the laser beam is emitting. Fluence is the amount of energy delivered to a given area. It seems self-explanatory that higher fluences will achieve better hair removal results, but again risk thermal damage. Operator experience is extremely important in achieving effective results without side effects with all lasers.

References:

1996 UC Berkeley Regents

Arizona State University

LOYOLA UNIVERSITY CHICAGO · 1032 W. Sheridan Rd., Chicago, IL 60660

Shore Laser

Candela Corp.

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