# Lasers in Surgery

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# Objectives

For the safety of your patient, your team, and yourself, ChristianaCare requires that every professional involved in the use of a laser must be trained on laser safety.  Therefore, this educational  program has the following objectives:

- Discuss Basic Laser Physics
- Explain Laser-tissue Interactions
- Define Laser Safety Requirements

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# Fundamentals of Laser

Laser: a brief description of the process that creates laser light

- **L**ight
- **A**mplification by the
- **S**timulated
- **E**mission of
- **R**adiation

Light Therapy

- A laser transforms energy into a highly defined beam of exquisitely pure light.

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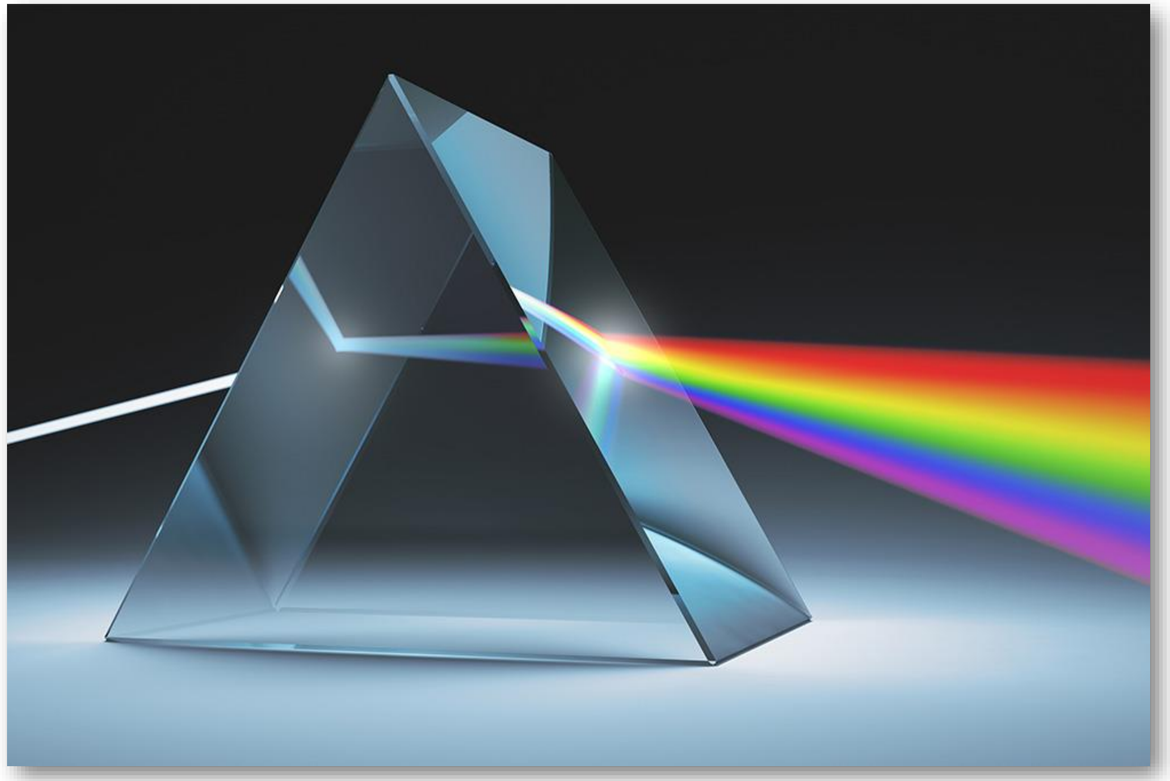
# Light Properties

- **Light – a beam or a ray**
- **Travels in a straight line until it impacts the  surface of an object**
  - Absorbed by the surface
  - Reflected back from the surface
  - Penetrate and be transmitted beyond the surface

# Wave vs Particle Theory



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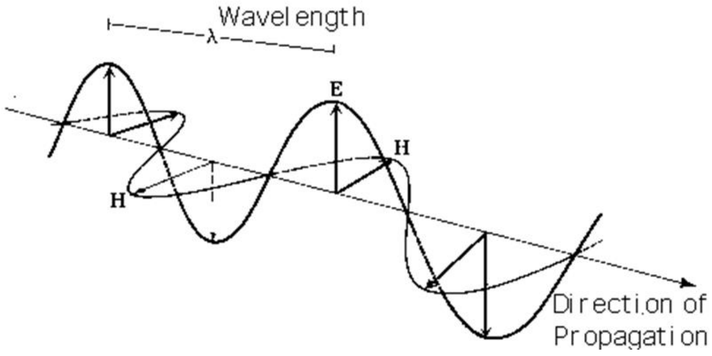
# Light Waves




## Characterized by four quantities

1) Wavelength: distance between two successive points on a period wave of the same phase

2) Frequency: number of waves passing a given point

3) Amplitude: vertical height – the higher the wave, the more power it containes

4) Velocity- ALWAYS constant in vacuum @ 186,300 miles per second

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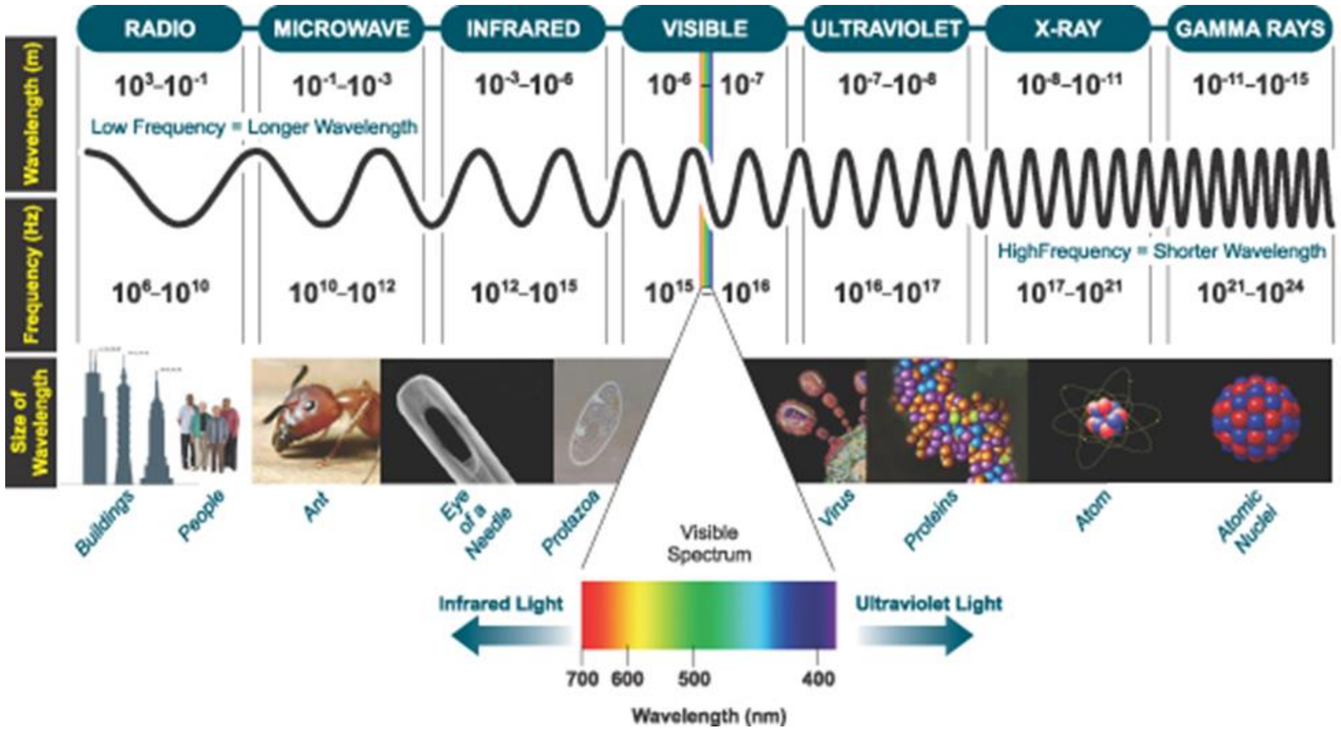
# Electromagnetic Spectrum

Medical lasers are only a small part of the spectrum

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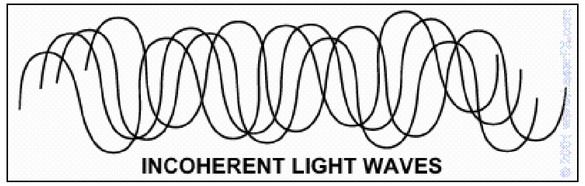
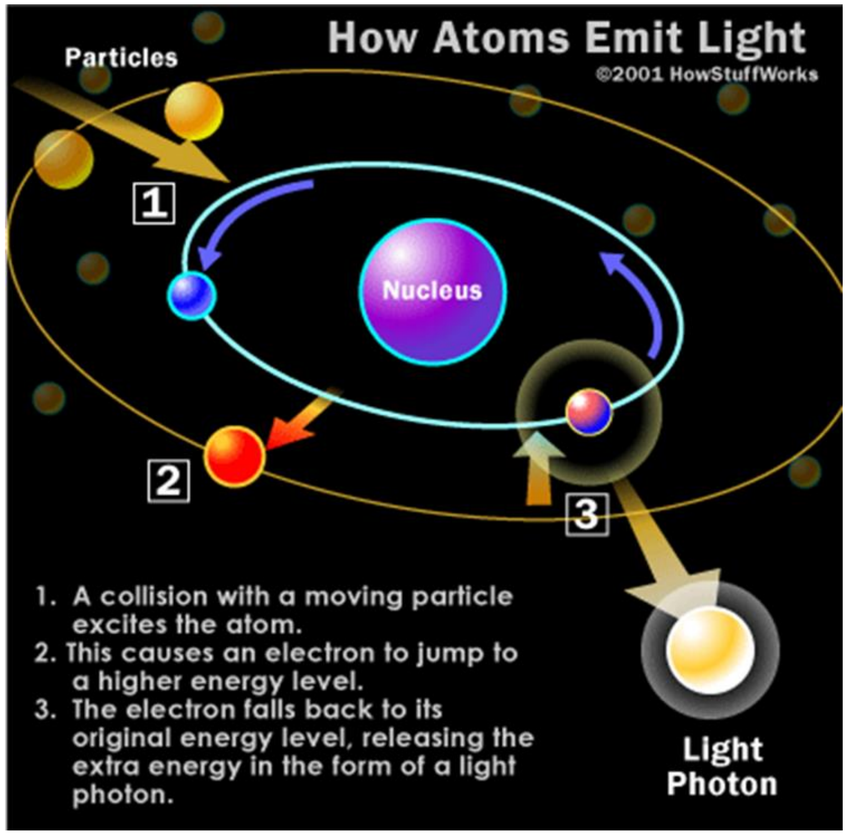
# Light Fundamentals

## Spontaneous emission

- Photon or “energy packet” has a frequency , or color, that exactly matches the distance the electron falls

- Produces incoherent light

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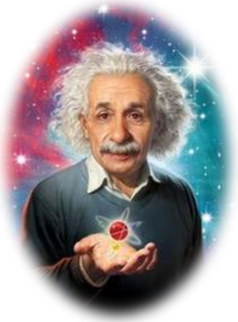
# Laser Energy

Einstein theorized:



- Just like spontaneous emission, energy is stored in the atom
- Before the photon is released, the atom is again stimulated with the same type of passing light
- Causes the amplification of the passing beam

Light produced thru the Stimulated emission of radiation

- The term radiation is used because the beam radiates out from the laser

Very uncommon process in nature but is central to the operation of lasers

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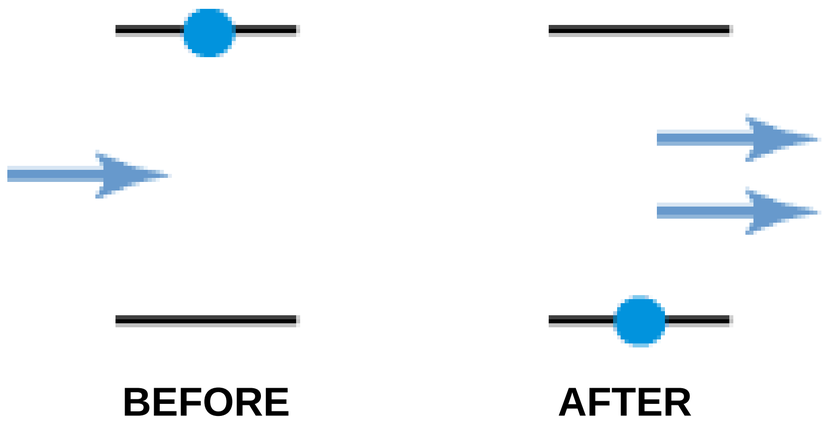
# Stimulated Emission

Basis of laser light generation

If the photon of light interacts with the excited electron, it can *stimulate* the return to the lower state

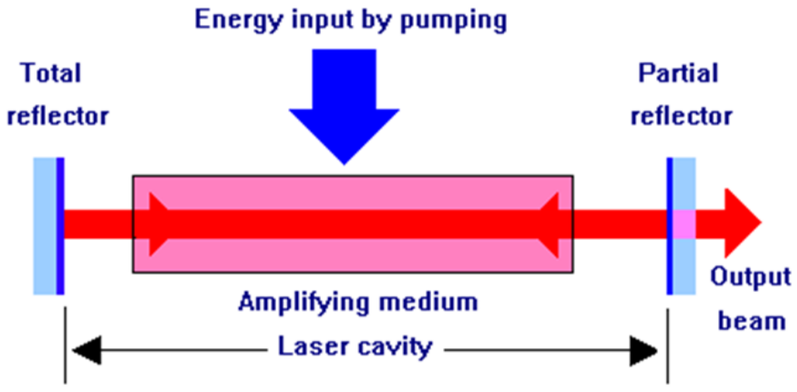
Results in two identical photons release

- In phase
- Amplification of light
- A match in the two energy levels



# Laser Components

All lasers have three general components:




- An energy source (usually referred to as the *pump* or *pump source*)
  - The power supply may be direct current, a flash lamp or another laser
- An active medium or laser medium
- Two or more mirrors that form an optical resonator.

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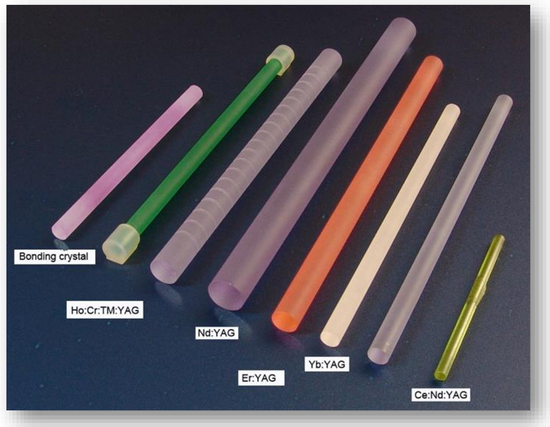
# Lasing Material

The **active laser medium** or **gain medium** is the substance used by the laser to produce light.




Solid State

- Ruby, Nd:YAG, HO:YAG
- Rare Earth Elements

Gases

- Mixtures of helium and neon (HeNe), nitrogen, argon, carbon monoxide, carbon dioxide
- Diode lasers: Gallium arsenide (GaAs), indium gallium arsenide (InGaAs), or gallium nitride (GaN)

Liquids

- Dyes

Excited Dimer

- Xeon Chloride

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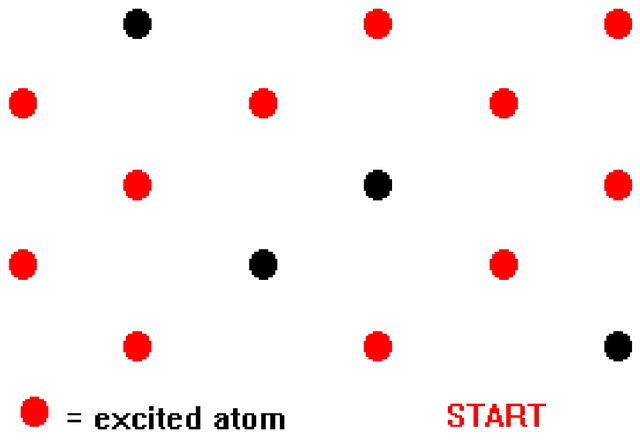
# Population Inversion

In order to lase, the active gain medium must be in a nonthermal energy distribution known as **<u>population inversion</u>**.

- When atoms in a high-energy state become more numerous than atoms in a low-energy state.

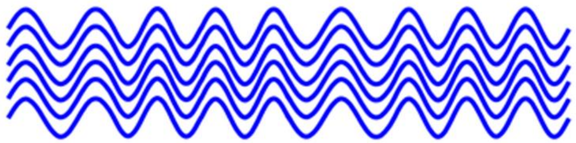
Prerequisite for lasing action



# End result of Stimulated Emission

- Multiple photons of precisely the same color – Monochromatic

- Coherent – wave patterns are locked in phase with each other



- Collimated – stays together as a tight beam of light

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# Laser/Tissue Interactions

Each type of laser exhibits differing biological effects

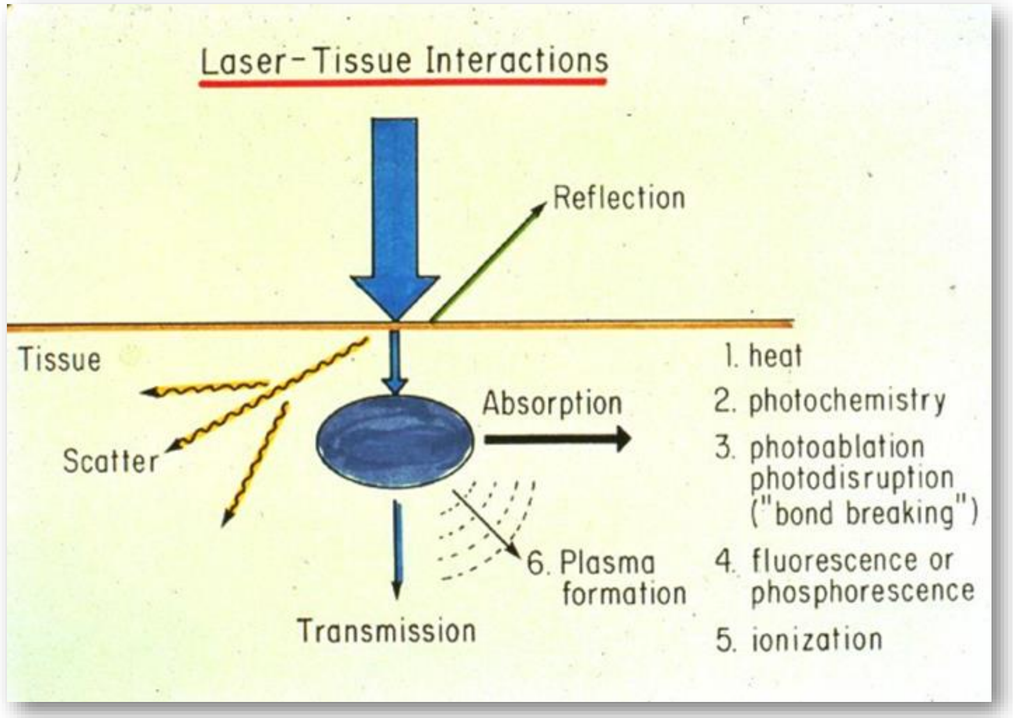
- Specific for wavelengths
- Tissue effects depend on absorption in target tissue and how the energy is delivered

Surgical effects of primary laser systems rely on heat transfer from the beam into tissue

The target determines the temperatures reached, *not the laser*

# Light Properties

- Reflection
- Transmission
- Scattering
- Absorption
  - Selective Photothermolysis
  - Unwanted tissue destruction

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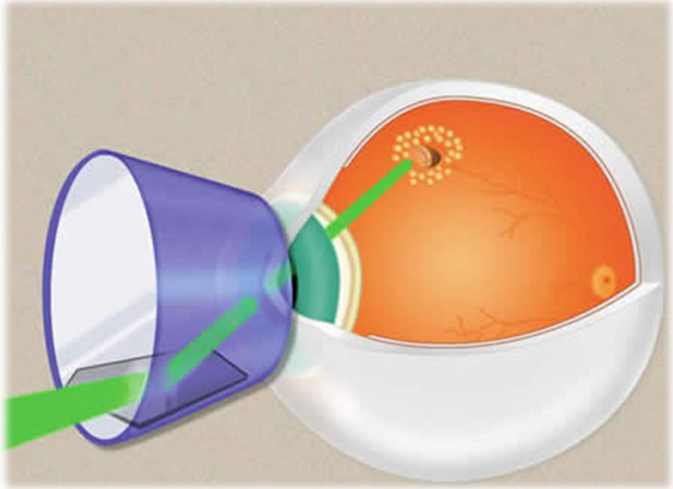
# Reflection & Transmission

Reflected or Transmitted through tissue

- No effect on outer layer
- Passage through a medium without absorption



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# Absorption & Scattering

Absorption

- Lasers dominated by water absorption heat the first layer of cells encountered

Scattering

- Heat a volume of tissue
- Requires increased power to achieve vaporization
- Best for deep coagulation

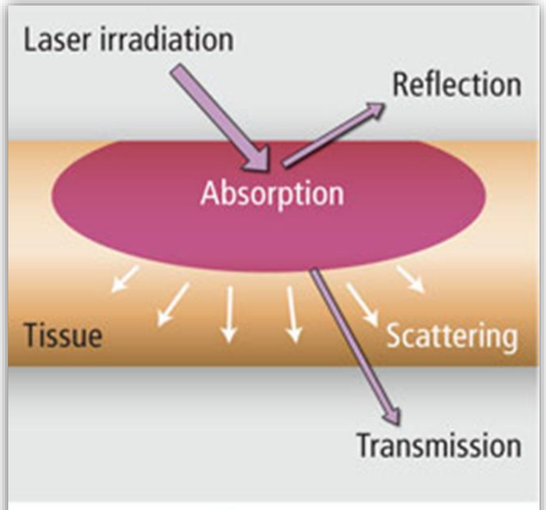

Fig. 1. Spectrum of light absorption in water.[10]

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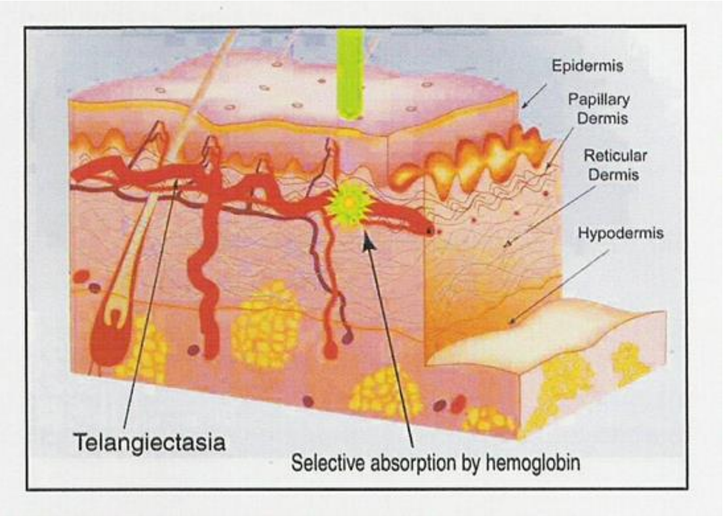
# Selective Photothermolysis

Laser energy absorption by a target chromophore without significant thermal damage to surrounding tissue

- Laser must produce Beam of light with
  - Wavelength preferentially absorbed by the chromophore in the lesion
  - Pulse duration shorter than the thermal relaxation time of the chromophore
  - Energy (fluence) must be high enough to destroy the chromophore with the pulse duration

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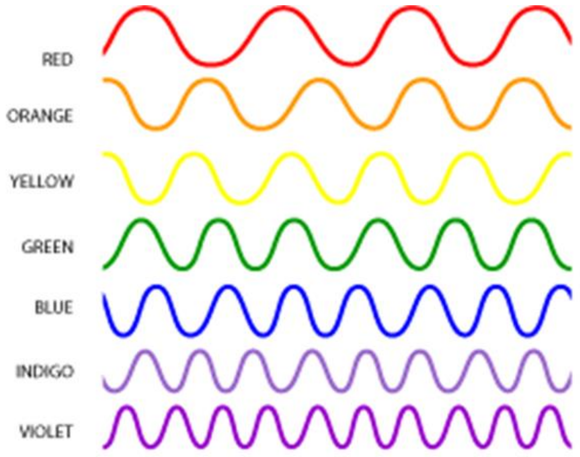
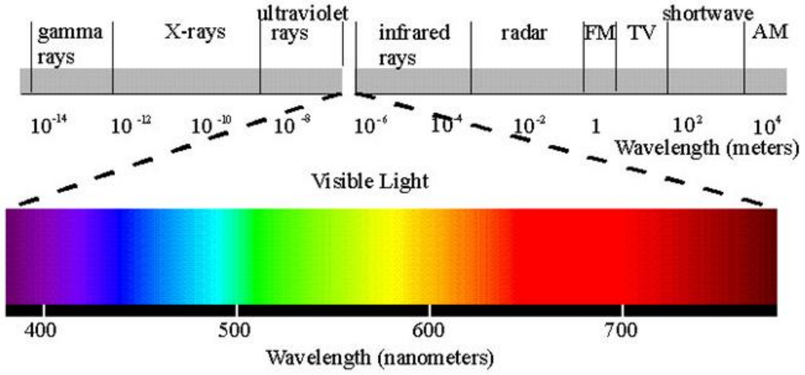
# Absorption Characteristics

Length of wave determines the color, visibility and effect of the light

- Visible light – 400 to 750 nm
  - Each color corresponds to a different wavelength
- Near-infrared – 750-3000 nm
- Mid-infrared – 3000-30,000nm
- Far-infrared – 30,000 nm – 1 mm

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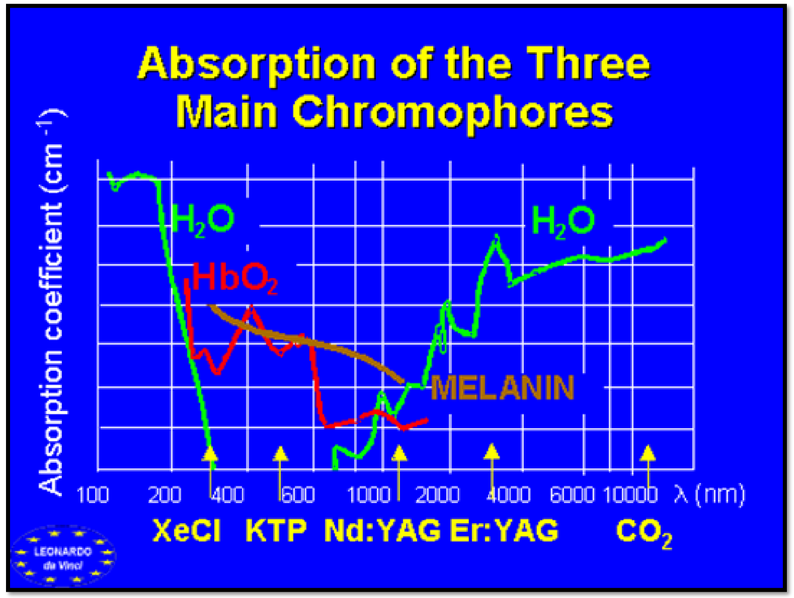
# Coefficient of Absorption

- **How a particular substance absorbs a specific frequency of light**
- **Three Main Chromophores**

1. Water
   - Soft tissue 70-90% water
   - Standard for biological tissues
2. Hemoglobin
3. Melanin

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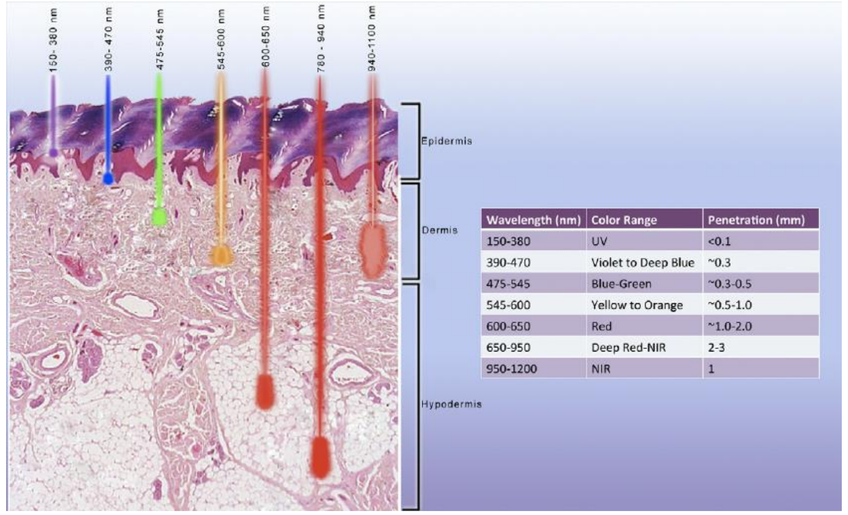
# Coefficient of Absorption

- Logarithmic factor describing how rapidly the particular frequency of electromagnetic energy will be absorbed *with depth*
- Low coefficients – very high percentages of scatter
- Nd:YAG scatters to a great degree, especially in tissue
  - Limits the penetration of the Nd:YAG in tissue

# Tissue absorption

Tissue absorption depends on:

- Tissue color, consistency and water content
- Chromophore content of the tissue
- Vascularity
- Wavelength of beam
  - Determines the color, visibility and effect of the light
- Power –Watts
- Beam Profile and Spot Size
- Exposure Time
  - Ability to use in a pulsed mode




| Wavelength (nm) | Color Range | Penetration (mm) |
|---|---|---|
| 150-380 | UV | <0.1 |
| 390-470 | Violet to Deep Blue | ~0.3 |
| 475-545 | Blue-Green | ~0.3-0.5 |
| 545-600 | Yellow to Orange | ~0.5-1.0 |
| 600-650 | Red | ~1.0-2.0 |
| 650-950 | Deep Red-NIR | 2-3 |
| 950-1200 | NIR | 1 |

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# Laser Effects

Tissue Heating (to a non-destructive level)

- Skin rejuvenation, non-ablative
- Tissue welding

Coagulation (destructive heating) occurs at or above 45º C

- Hemostasis, cautery
- Protein – with attendant necrosis

Vaporization – occurs at or above 100º C

- Cutting (Ablating along a fine line with traction)
- Debulking (Ablating volumes of tissues)

# Laser Tissue Interaction

- Non-linear effects – Photoacoustic
  - “Cold Cutting” –ophthalmic Nd:Yag
  - Photoacoustical “Lithotripsy”
  - Fragmentation of tattoo pigment via Q-switched lasers
- Photochemistry
  - Photodynamic Therapy (PDT)
- Photodisassociation
  - Nonthermal ablation of the cornea in ophthalmology

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# Energy Concepts

Thermolysis:

- Getting the right amount of the *right wavelength* of laser energy to the *right tissue* to damage or destroy *only* that tissue, and *nothing else*.
- Vaporization point
  - Cellular water -100ºC

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# Creation of the source of heat

Near and far infra-red

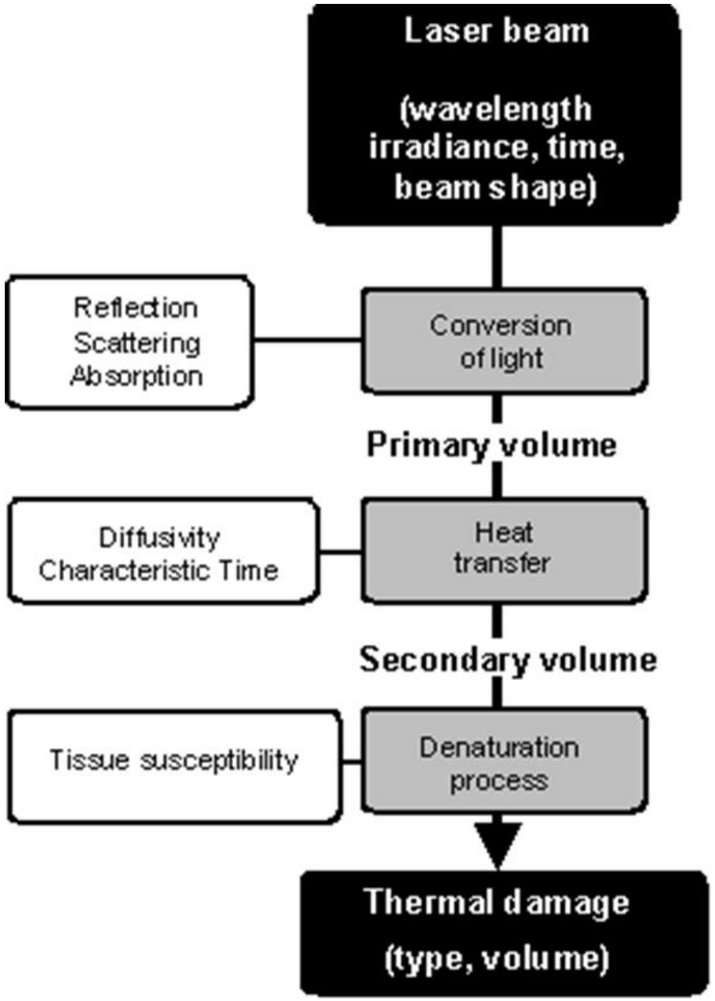
- Laser intensely absorbed by water
- It is the conversion of light absorbed to heat which produces the “primary” heat

Human cells

- 70 – 90% water

Cell destruction

- Protein denaturation occurs at and above 60º C

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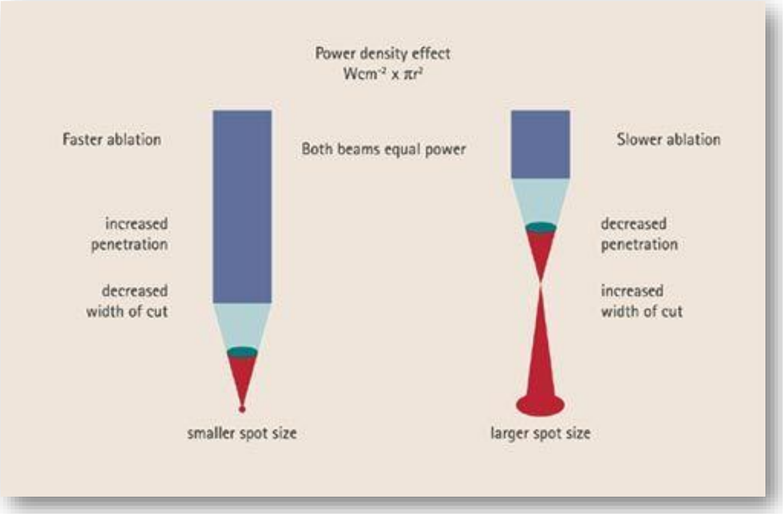
# Determining Amount of Energy Delivered to Tissue

Three Basic Parameters

1. Power
   - Watts
   - Joules
2. Spot size
   - The diameter of the minimum spot achievable with a given lens (millimeters)
3. Time
   - The longer the beam stays on tissue with a given power and spot size, the deeper that beam will cut

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# Laser Power

A Joule is a unit of Energy

- The heat energy generated by a human at rest in 0.01 second
- The food energy contained in 1/4 oz. of beer
- The energy needed for 10,000,000 mosquitoes to take flight

A Watt is a unit of power

- Also referred to as Horsepower, BTU/hr, Volt Amperes

Watts = Joules (Energy) divided by seconds (time)

# Power Density

- The amount of power distributed within the area of the spot
- Power incident upon the surface per unit area
- Determines rate of tissue removal


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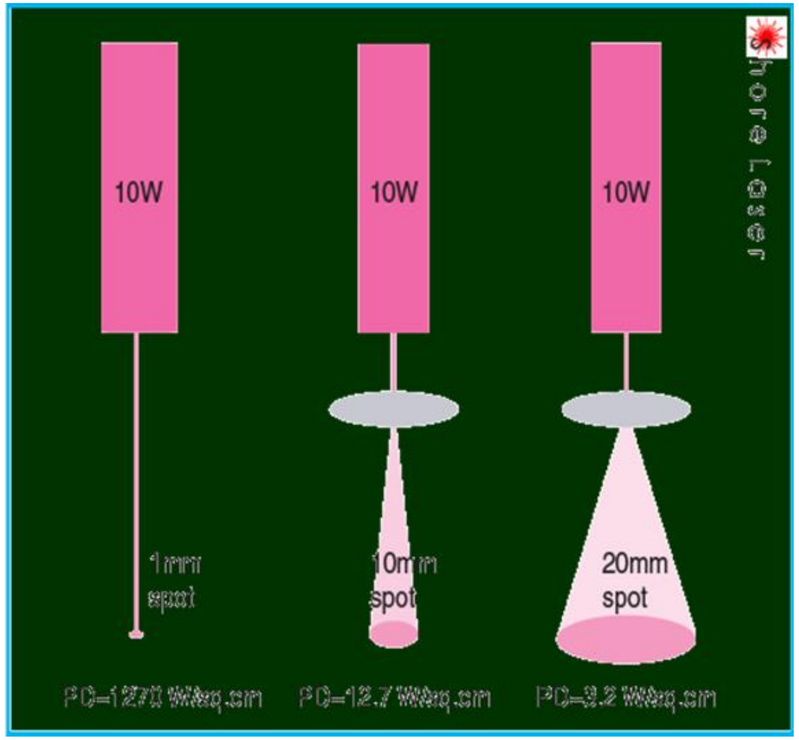
# Power density

Combines two of the three operating parameters – spot size and power

- Concentration of laser beam on the surface of the tissue
- Watts per square centimeter ($W/cm^2$)

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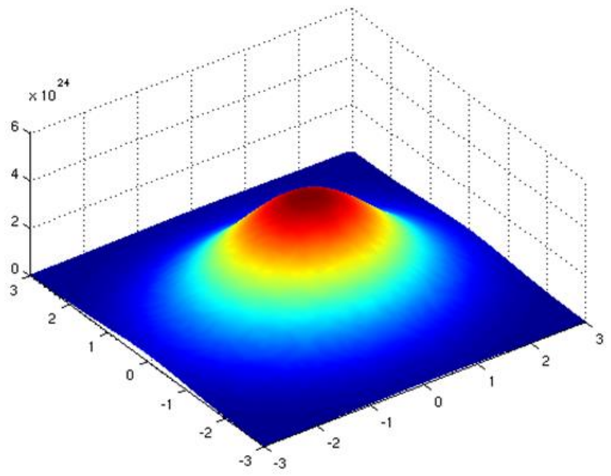
# Gaussian Distribution of beam

Beam profile effects:

- energy density
- beam concentration
- collimation of the light.

$CO_2$ and Nd:YAG beam operates on the fundamental transverse mode




$TEM_{oo}$ mode– Peak intensity is the center of the beam –ideal laser beam

Greater depth of focus

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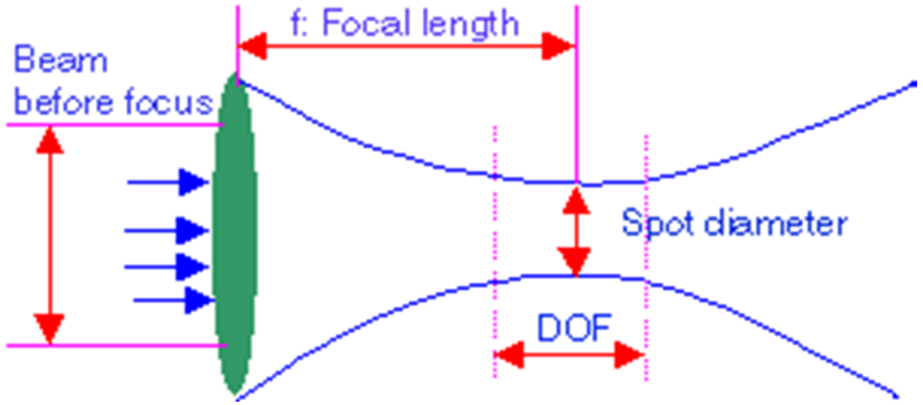
# Spot Size

- Spot size refers to the size of the focused beam
- A small spot will result in less scatter and increased depth of penetration
- A larger spot will result in greater scatter and decreased depth of penetration

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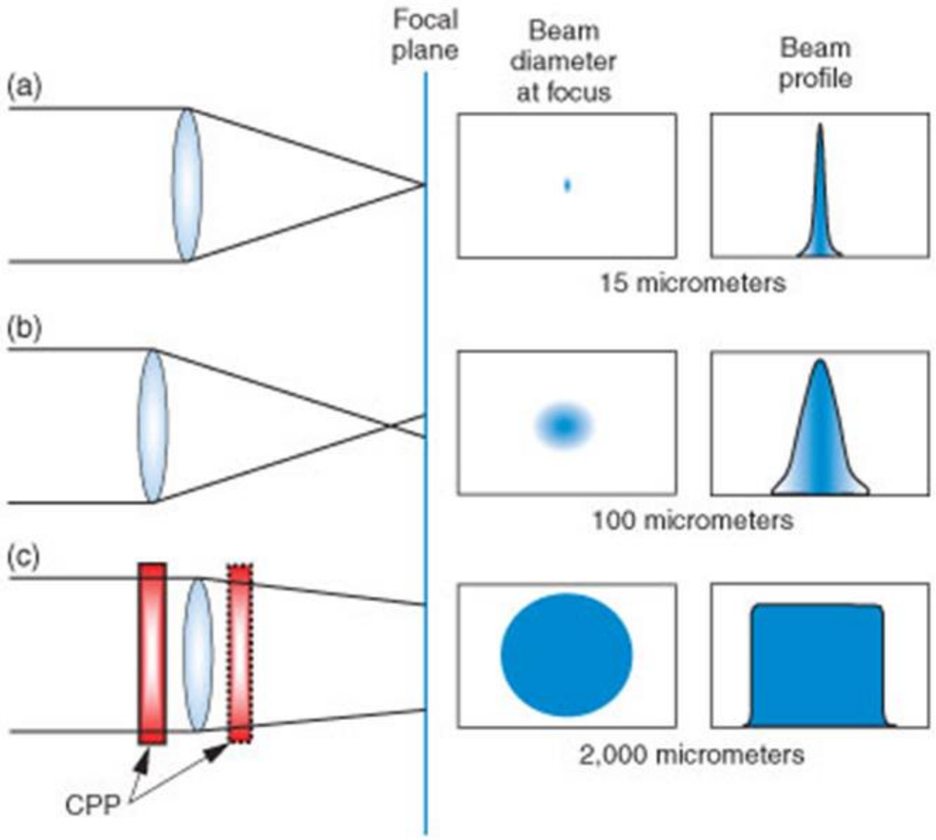
# Focal Point

The point of convergence of the rays

The focal length is the distance from the focusing lens where the laser beam has the smallest spot diameter

Fiberoptically delivered systems do not focus

- Diverge from end of fiber

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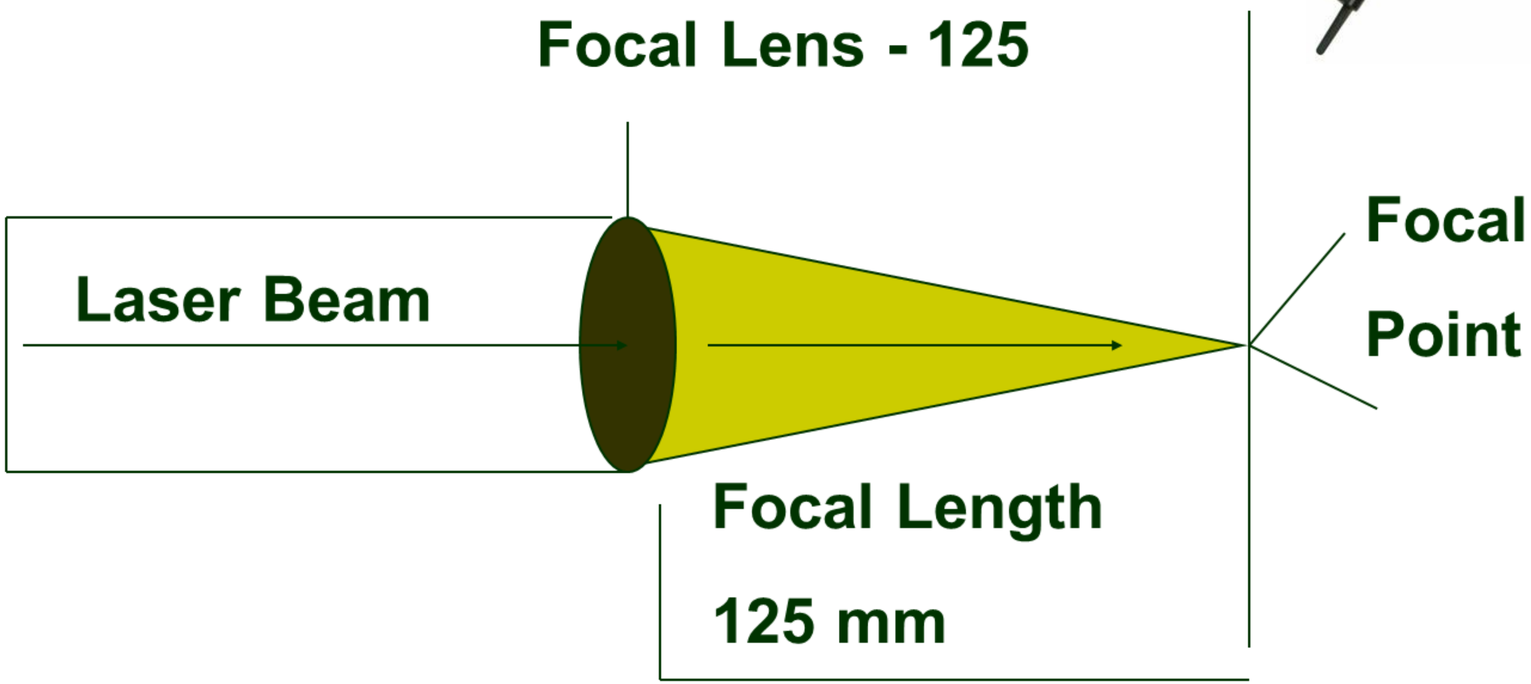
# Focal Length





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# Timed Exposure

General Rule:  the length of the laser pulse is as important as the wavelength or the power setting in determining its medical use

Thermal Relaxation Time (TRT) – the time it takes for an object to cool to 50% of the temperature achieved immediately after laser exposure

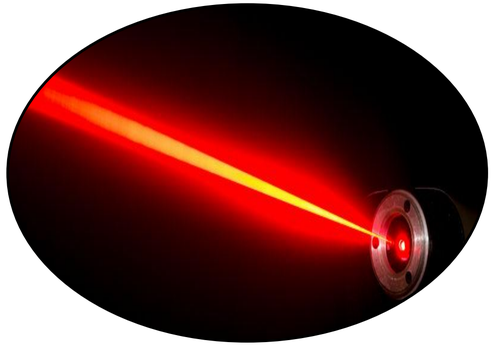
If a steady beam is held on tissue <u>longer</u> than the thermal relaxation time

- excessive heat will be conducted into normal tissue
- may delay healing
- may increase scarring

# Beam Delivery

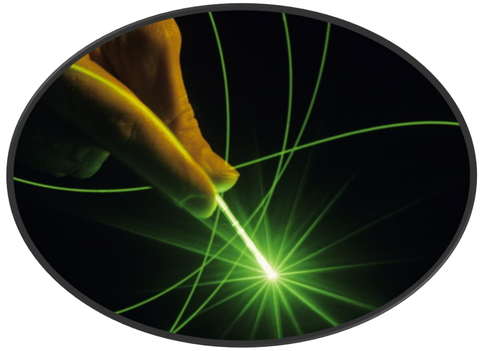
**How to safely deliver the laser light…**

**Free beam**



- Diode – Indirect Ophthalmoscope
- $CO_2$

**Fiber**



- KTP (Greenlight)
- Holmium
- Nd:YAG
- $CO_2$

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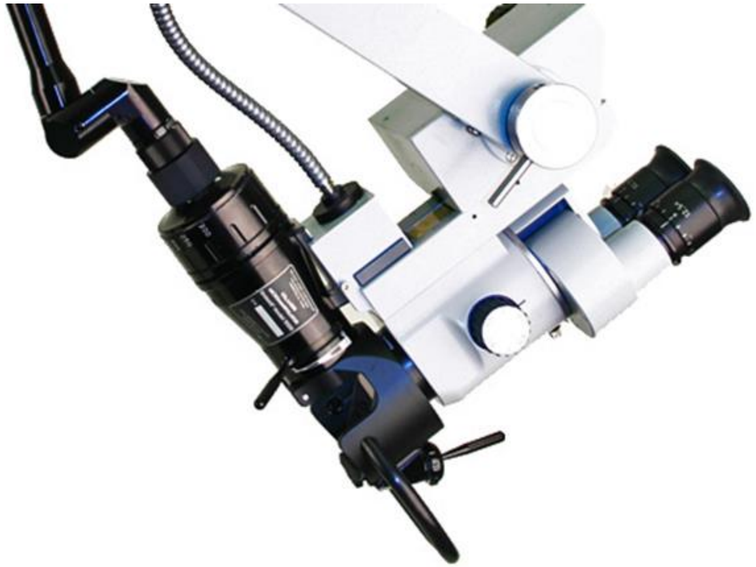
# Free Beam Delivery Adjuncts

Handpiece

Micromanipulator

Beam Align

Waveguide



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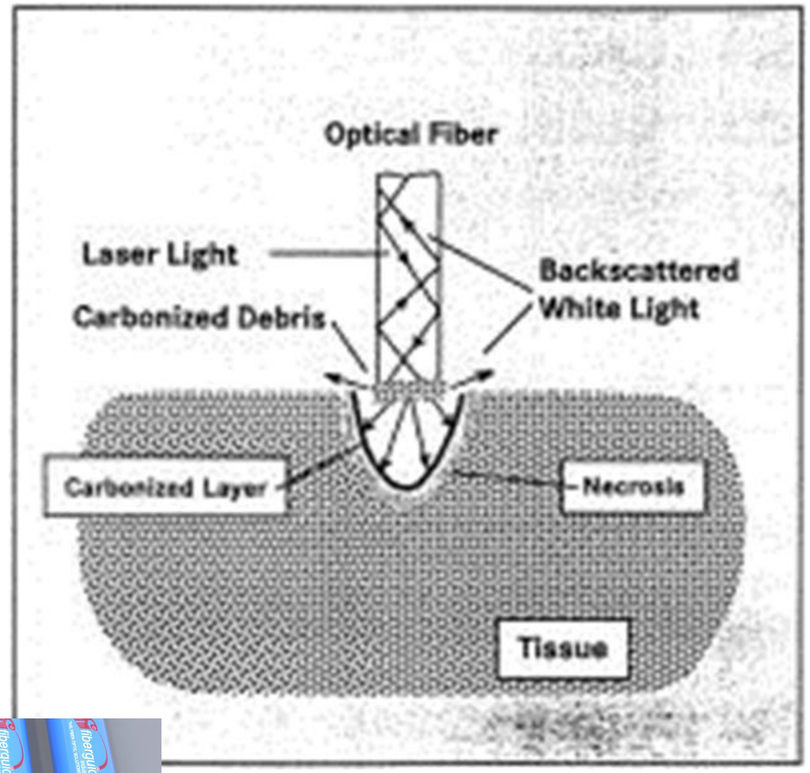
# Standard Quartz fibers

- Laser beam diverges rapidly from the end of the fiber
- Many different effects possible with simple distance change of the fiber to the tissue

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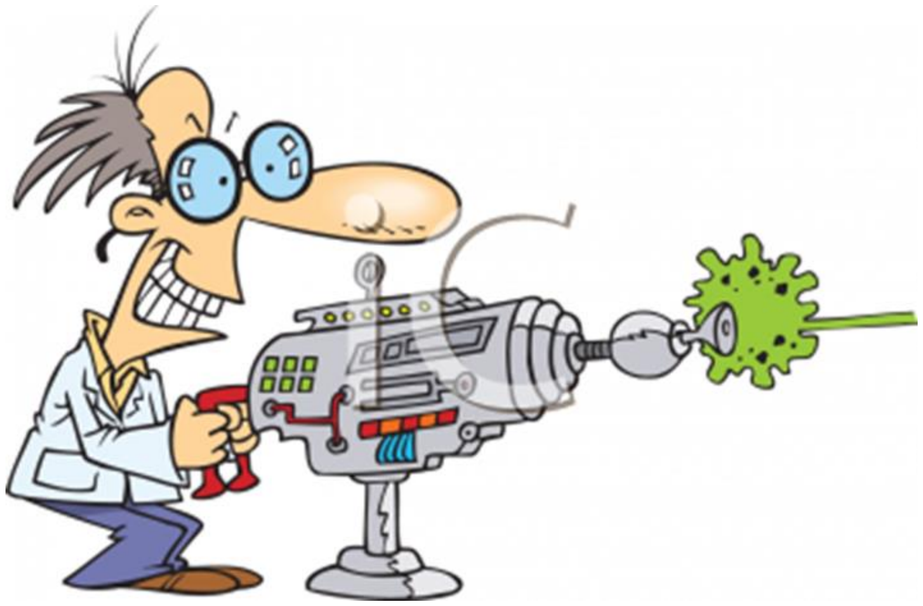
# Rate of Power Delivery



How much time on tissue is required to cut or ablate tissue to the depth desired.

- Single Pulse
- Repetition
- Super Pulse/Ultra Pulse
- Continuous Wave

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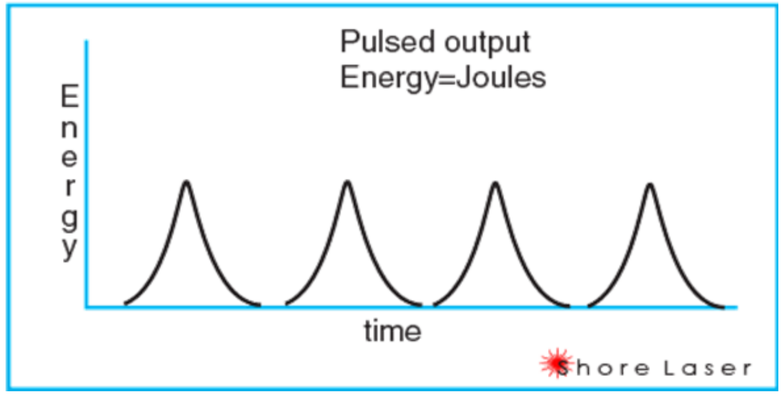
# Single Pulse




- Discontinuous burst of laser light
- High peak powers
- Peak powers per pulse higher than maximum attainable in the continuous wave mode
- Measured in milliseconds

# Repetition Pulse Mode

- Timed bursts of laser light with high peak powers in a short pulse rate
- Utilize a pulse “width” short enough to confine heating to the desired target without excessive heating of adjacent tissue
  - Milliseconds, nanoseconds
- Allows a short cooling period between pulses
- Q-switching –lower repetition rates with longer pulse durations
  - A technique by which a laser can be made to produce light pulses with extremely high gigawatt peak power…much higher than would be produced by the same laser operating in a continuous wave mode

# Super Pulse/Ultra Pulse

Rapid pulse repetition frequency

- Measured in Hz
- Fast pulsing output (250 to 1000 times per second)

Average Power is displayed on control panel

Excellent for incisions

- Small spot size
- Higher power densities

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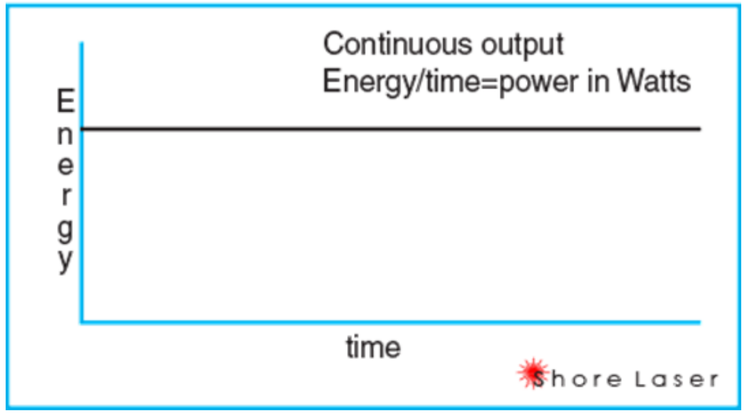
# Continuous Mode

- Constant, steady state delivery of laser power
- Can deliver energy at high <u>average</u> powers
- As long as the foot pedal is depressed, energy is being released!
- More conducive toward lateral spread of heat from intended site

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# Lasers in ChristianaCare

- $CO_2$
  - Free beam
  - Fiber
- Diode
- Excimer
- Ho:YAG
- Nd:YAG
- KTP (GreenLight)

**NOTE:**

**CO2, Ho:YAG, and Nd:YAG are the 3 most commonly used lasers in ChristianaCare.**

**Additional information related to the other types of lasers available upon request from the LSO.**

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# $CO_2$ Lasers

- Associated with cutting and vaporizing
- Has some hemostasis, but ***only against small vessels and capillary type oozing***
- Because of precise localization and sealing effects of laser beam, surrounding tissue exhibits minimal edema, scarring or stenosis.
- Penetration depth – less than 0.5 mm
- Depth controlled by power density and duration of exposure

# CO2 Lasers

- Cutting
  - Higher power + smaller focused beam
  - Add shorter exposure = ↓ thermal spread
- Debulking or coagulation
  - Defocusing the beam to enlarge the spotsize


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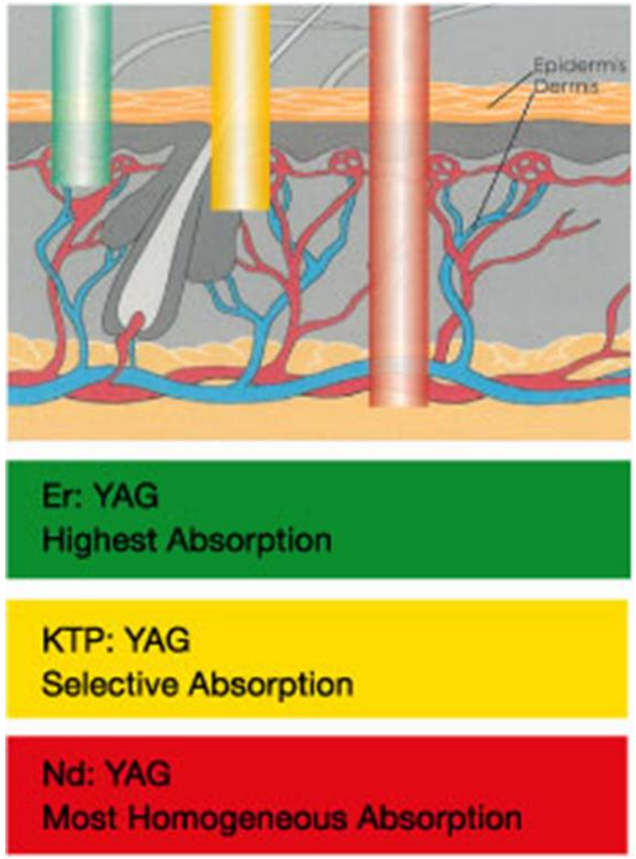
# Neodymium (Nd):YAG

Active medium, Neodymium (Nd) “doped” with Yttrium-Aluminum-Garnet (YAG)crystal

Operates in Continuous or Pulsed modes

1,064 nm.-Near Infrared - HeNe pilot beam

Fiberoptics usual mode of delivery

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# Tissue effects with Nd:YAG

- Cutting – results from high power densities just at the tip
- Vaporization occurs within a few millimeters of the tip
  - 1-2 mm of coagulation @ 20 Watts for 1-3 seconds
- Photocoagulation from 1 – 2 cm from the tip
- Absorption dependent on the protein and pigmentation of the biological tissue for process of heat conversion
- Color selectivity for darker tissues
  - Absorption depth of 2 to 6 mm
- May be transmitted through fluid

# Holmium (Ho): YAG

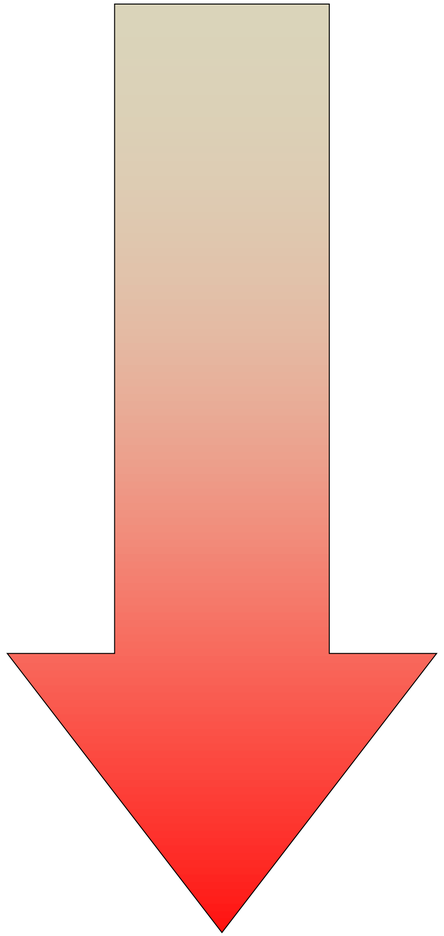
- Active medium – crystal “doped” with rare earth elements such as: Holmium, Thulium, and Chromium
- Excited with Flash Lamp
- Near infrared range (2100 nm)wavelength. NOTE: will not transmit through fluid, but is used in fluid atmosphere.
- Depth of penetration = 0.5 - 4.2 mm

# Laser Classification Used in Medical Settings

The ANSI Laser Safety Standard has defined ***Laser Hazard Classes***, which are based on the relative dangers associated with using these lasers.

Similar to ANSI, the FDA Classifies Laser hazards based upon the ability of the beam to cause biological damage to the eye or skin.

***Least Hazardous***



***Most Hazardous***

**Class 1**

**Class 1C**

**Class 1M**

**Class 2**

**Class 2M**

**Class 3R**

**Class 3B**

**Class 4**

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# Laser Classification Used in Medical Settings

| Class 3B Laser | Class 4 Laser |
| --- | --- |
| • Power output 5-500 mW for CW or less than 0.03 joule (J) for a pulsed system (i.e. pulse width less than 0.25 second).<br>• Will cause injury upon direct viewing of the beam and specular reflections.<br>• The radiation can be a hazard to the eye or skin. However, viewing of the diffuse reflection is safe<br>• Must be equipped with a key switch and safety interlock | • Power output greater than 500 mW CW or greater than 0.03 J for a pulsed system.<br>• Pose eye hazards, skin hazards, and fire hazards.<br>• Viewing the beam or specular reflections or exposure to diffuse reflections can cause eye and skin injuries.<br>• Must be equipped with a key switch and safety interlock |

**BOTH Class 3B and Class 4 lasers require safety training and specific safety measures designed to mitigate injury risks and fire hazards**

# Nominal Hazard Zone (NHZ)

- NHZ = area where the level of direct, scattered or reflected radiation during normal usage exceeds Maximum Permissible Exposure (MPE)

- MPE = the level of laser radiation (exposure) to which a person may be exposed without hazardous effects or adverse biological changes in eye or skin

- ***NHZ in ChristianaCare is the treatment area/room in which the laser is being used***

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# Laser Hazards

## Beam-Related

- Fires
- Explosions
- Skin and Tissue Burns
- Eye Injuries
- Laser radiation predominantly causes injury via thermal effects


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# Laser Hazards

Non-Beam

- Electrical
- Laser Generated Airborne Contaminants
- Electromagnetic interference
  - proper grounding
- Waste Disposal
- Hazardous gases (Pulse Dye Lasers)
- Room Design
  - Traffic patterns, reflectivity, viewing, electrical supply, drains

# Basic Principles of Laser Safety

- Where is the laser beam?
- Is it controlled?
- Is the patient protected?
- Am I protected?
- Is everyone else protected?

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# Basic Principles of Laser Safety

- Put the laser in stand-by when not in use
- Laser User has one foot pedal at a time
- Basin of $H_2O$ available at field
- The rectum should be packed with a wet sponge to prevent the release of methane gas
- If cotton tip applicators are used, they must be wet
- Appropriate laser safety precautions are implemented prior to activating laser

**Laser surgery ignites internal methane, burns patient *down there***

Cervical surgery left patient with nasty burns, sparks new gas therapy

By Simon Sharwood, APAC Editor 2 Nov 2016 at 08:02 28 SHARE ▼

**Mildly NSFW** Tokyo University Medical Hospital has published a pair of reports explaining an incident that left a woman badly burned after surgery.

The reports (PDF 1 and PDF 2) , which we've shoved through an online translate-o-tronic machine, tell the tale of a woman who last April underwent surgery known as a cervical conization. The procedure is sometimes diagnostic or designed to remove pre-cancerous cells.

The first report explain that when the laser was applied, something caught fire and left the patient with burns from the vagina to the anus. It then considers the possible causes of the fire and concludes that no flammable alcohol was used to clean objects or as a disinfectant. The laser was found to work as expected and that surgical drapes were not torn in ways that would have let the laser ignite a stray fibre.

All of which left the report's authors wondering if perhaps the patient's internal methane might have sparked the fire.

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# Free Beam Lasers

- Check for proper alignment
  - Preferably on the delivery system used
  - Wet Towel
  - Wet Tongue blade
  - Is the alignment correct?
- Where is the beam?

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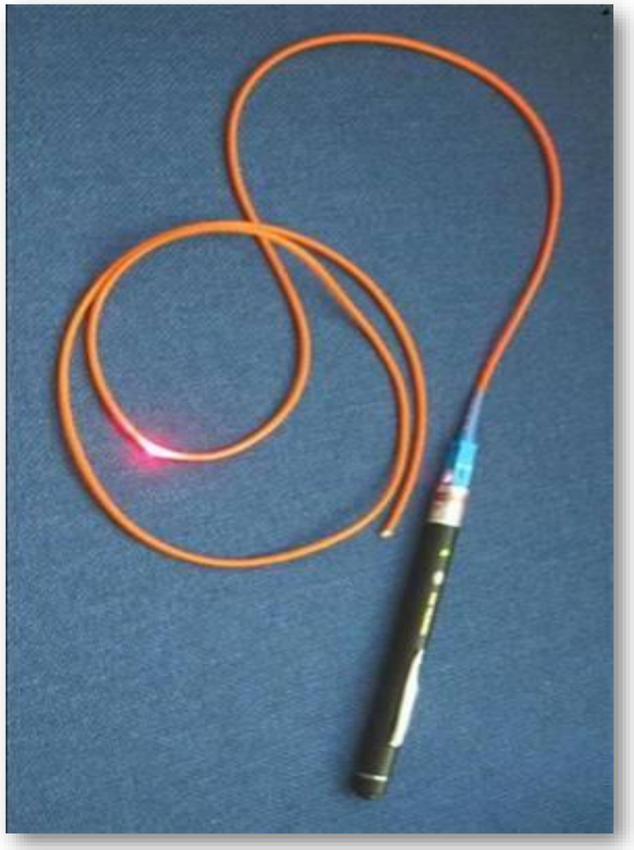
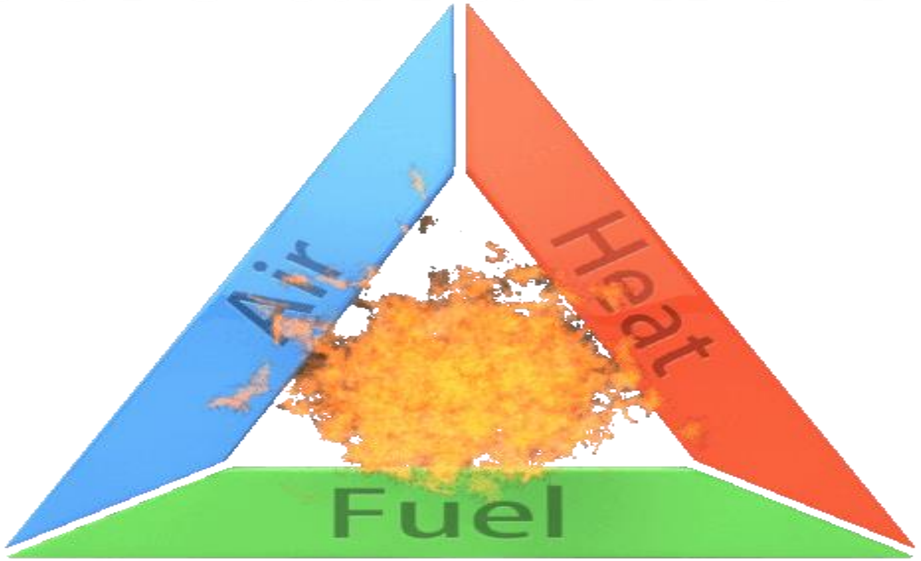
# Laser Fibers

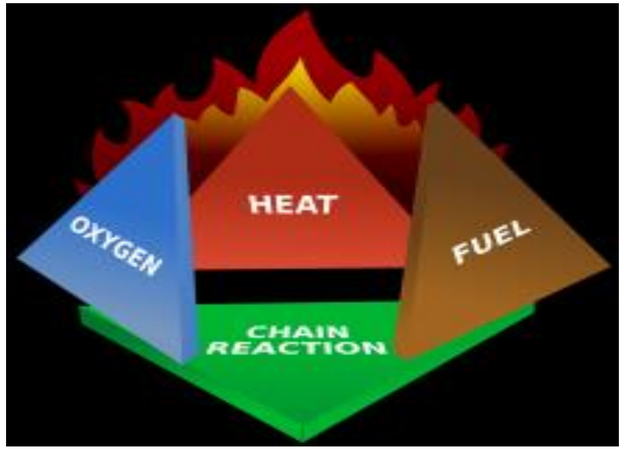
- Check the integrity of the fiber
- Inspect the distal and proximal ends of the fiber tips
- Do not clamp the fiber to the drape or coil tightly
- Cover tip with a wet sponge or towel
- Check the spot configuration of the fiber
- For fiberoptic use, extend the fiber until it is visualized



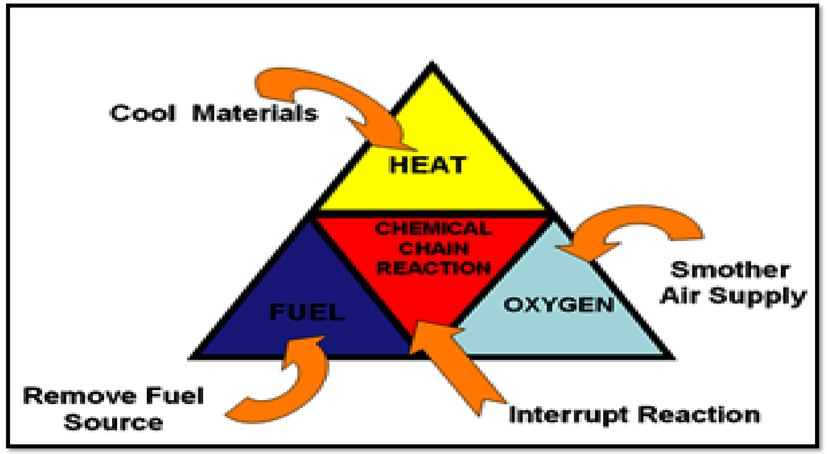
# Lasers and Fire Hazards




**Fire Triangle (standard)**




**Fire Tetrahedron model describes how the 3 sides of the fire triangle work <u>together</u> to cause a chain reaction (fire).**

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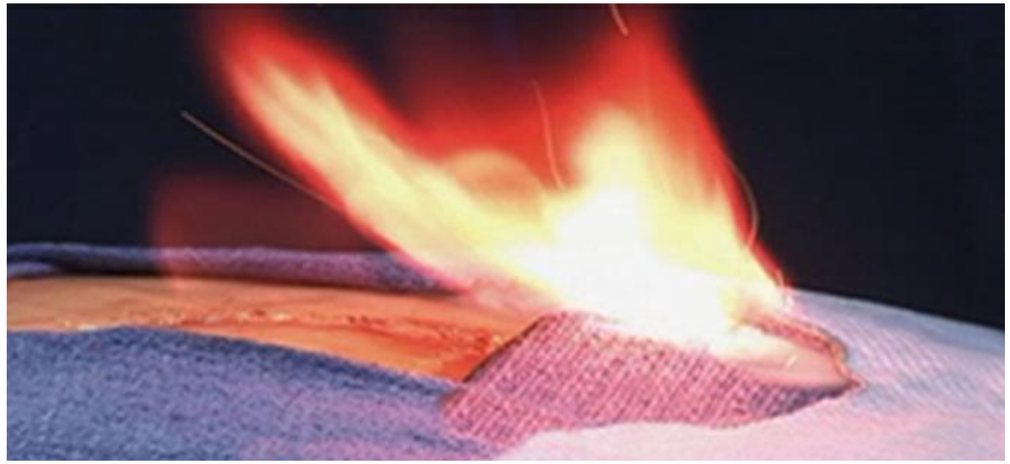
# Ignition and Fuel Sources

Fuel Sources

- Surgical drapes
- Sponges
- Polyvinylchloride ET tubes
- Clothing
- Anesthetic gases
- Methane gas

Ignition Sources

- Fiber optics
- Laser



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# Flammable Agents

- Fully dry flammable preps

  Pooled Prep Solutions under the drapes act as an accelerant

- Petroleum Based Ointments

- Hair - hair spray, gel, wax

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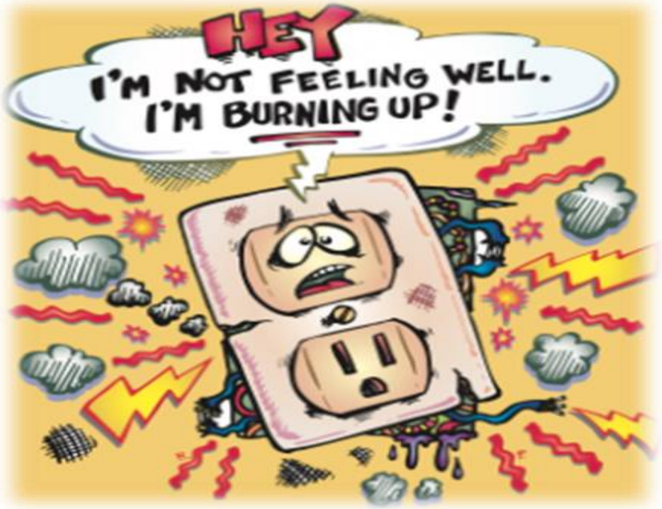
# Types of Fires

Contact

- Direct hit with laser beam
- Broken fiber

Flash

Arc – plugging into faulty wiring



# Joint Commission Report

Most common locations of fire on the patient – Airway, Head & Face

Most common items:

- ET tubes, $O^2$ tubing, masks & flammable preps

Most common causes

- Electrocautery – 68%
- Laser – 13%


$O^2$ Enriched environment present during 74% of all OR fires

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# Upper Airway Laser Procedures

When a laser is being used in ***or*** near the patient's airway, additional preventive measures must be initiated to prevent fires associated with the upper airway.

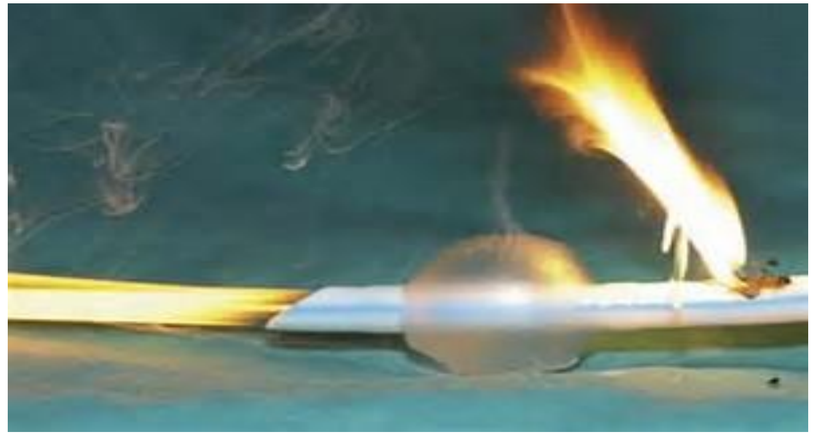
# Environment

Oxidant Enriched Atmosphere

- ***$O_2$ level exceeding 30%***
- Nitrous Oxide
- Medical compressed air

Anesthesia Compounds Entrapped

- Airways, Catheters, Trach Tubes
- Circuits, Breathing Tubes and Masks
- PVC ET Tubes will burn in 26% $O_2$



Endotracheal Tube and Fire

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# Guidelines for Head and Neck Procedures


Operate the laser at the lowest possible watts

All sponges in contact with the surgical site during activation should be moistened

Hair near the surgical site will be lubricated with a water soluble solution

If eye lubricate is used, it should be water soluble (Goniosol or GenTeal)

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# Open Oxygen Source

Open Airway –MAC Procedures with nasal prongs

- Fire Risk score is elevated
- Remove oxygen source for at least one minute
- Basin of $H_2O$ available at field

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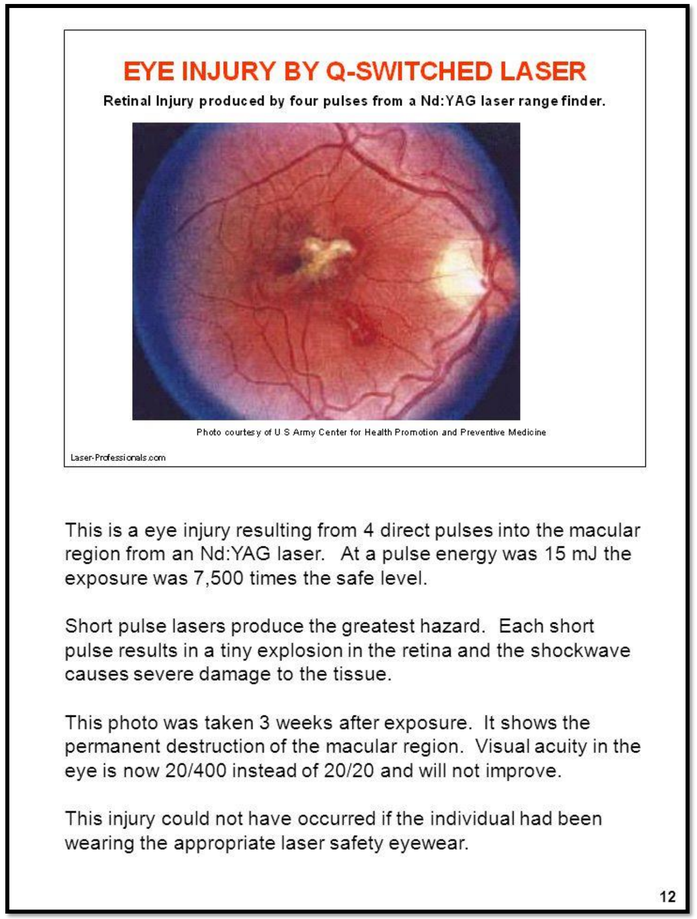
# Eye Injuries

- Coherence of laser light and focusing mechanism of eye can cause retinal damage
  - Increase of 10º C can destroy retinal photoreceptors
  - Visible to near infrared (400-1400)
    - Penetrate eyeball and cause heating of retina
  - Less than 400 nm and greater than 1400 nm
    - Largely absorbed by the cornea and lens
    - Cataract formation or burn injuries
- 10-15% of light will be reflected off of surface

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# Eye Protection

- What type of laser is being used?
- Use of the laser can be dangerous if you do not follow the correct safety measures!
- Anyone in the Nominal Hazard Zone must wear protective eyewear
- Eyewear should be readily available

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# Eye Protection

- Must cover the entire ocular area
- No scratches/lens damage
- Cleaned according to manufacturer's recommendations
- Must be for wavelength of laser being used
- Optical Density value should equal laser manufacturers' recommendations
- Always ensure that the patients' eyes have been protected properly

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# Patient eye protection

Based on:

- Type of procedure
- Location of procedure
- Type of anesthesia

- Types of protection
  - Periorbital goggles or corneal shields
  - Safety goggles
  - Wet sponges


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# Laser-Generated Air Contaminants

Blood

Hydrogen Cyanide

Carbonized tissue

Mutant RNA & DNA

Formaldehyde

Hydrocarbons

Potential viruses and bacteria

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# Surgical Smoke

- Plume:  Aerosolized vapor created by vaporization of tissue or metals.
- Cellular debris
- Noxious or infectious materials might be contained in the vapor
- All laser suction filters and tubing must be disposed in red hazard bags
  - Single use
- In-line filters should be replaced after laser procedure

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# Laser Plume

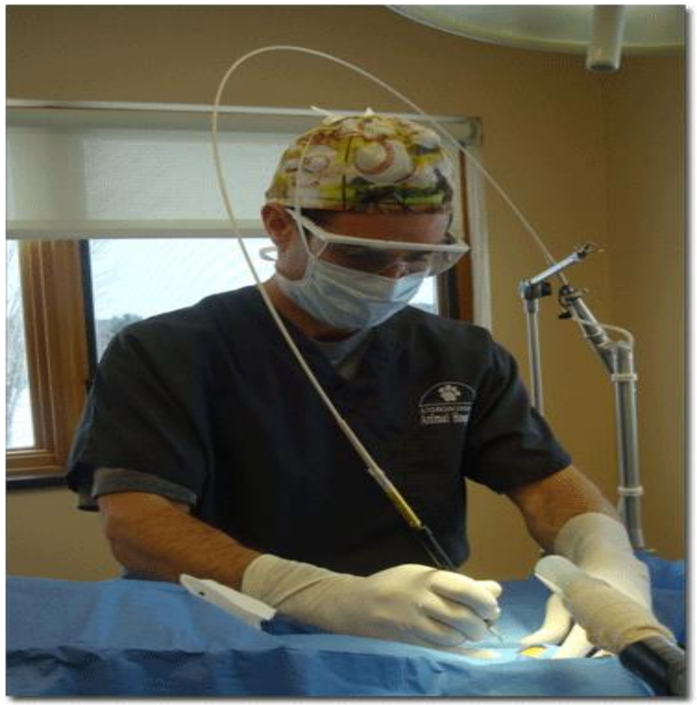
Use a Laser Smoke Evacuator

Wear appropriate surgical face mask

Protect the patient

Suction equipment

In-line filters



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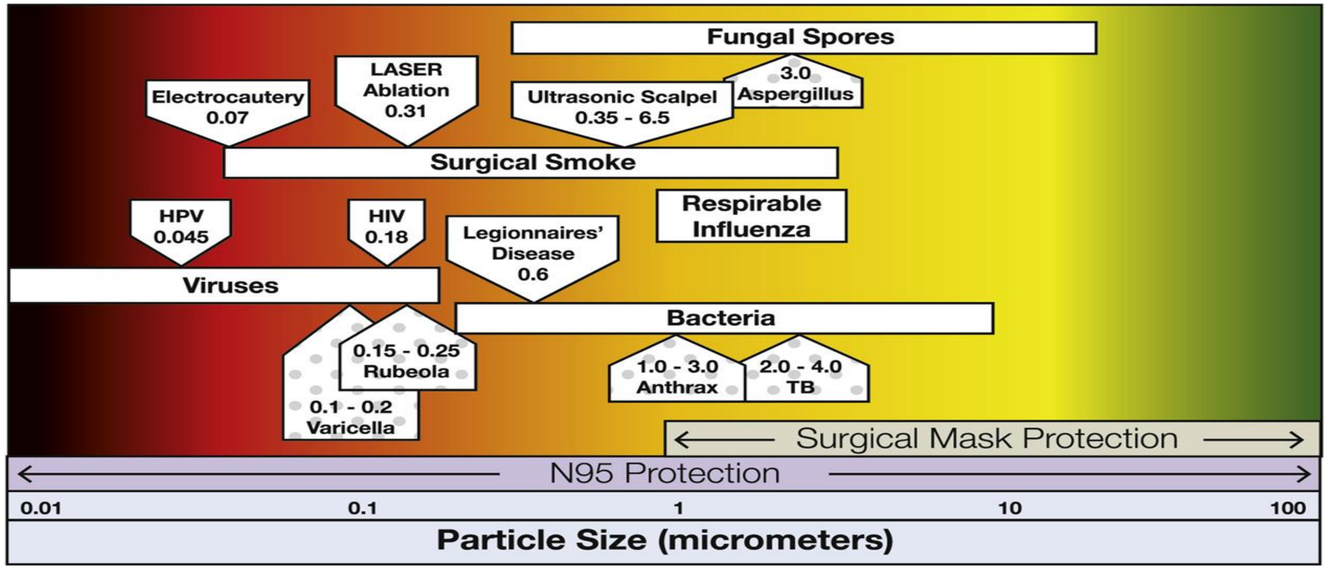
# Laser Plume

Vaporization of tissue by laser, produces a plume of smoke and fine particulates sized within the range of particles that are efficiently transported and deposited in the alveoli

Inhalation can cause:

- Eye, Nose, and Throat Irritation
- Headaches
- Tearing
- Nausea



# Laparoscopic Procedures

- Absorption of smoke into the tissues can cause high methemoglobin levels
- Patient many have the following post procedure:
  - Postoperative dizziness
  - Nausea
  - Visual disturbances
- Important to use in-line filters!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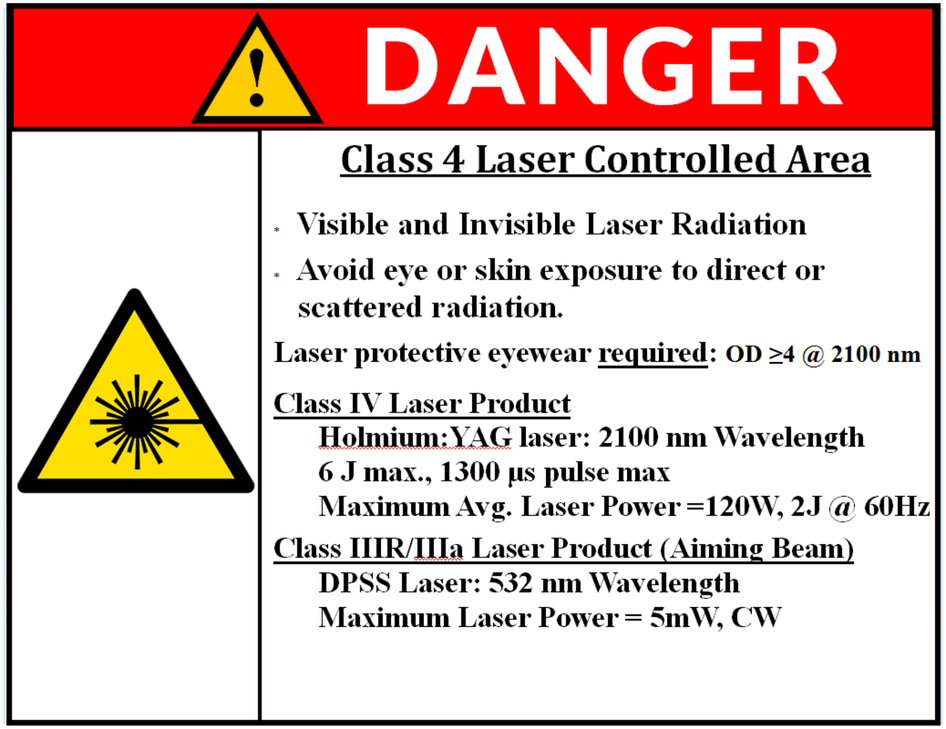
# Pay strict attention to the Warning Signs

***Do not*** **open the door unless wearing appropriate eyewear!!!**

**An extra pair of laser safety glasses should be with the warning sign - Put them on before entering!!!**

**The Warning sign tells you:**

- **What eyewear is needed**
- **Which laser is being used**

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# OSHA: Use of Medical Lasers

All users must have

- Detailed training in laser safety
  - Documented and retained on file
- Credentialing process
  - Training in the safe clinical use of the laser
  - Maintenance of a safe environment in compliance with defined standards, and local, state and Federal requirements

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# Physician Credentialing and Laser Privileges

Most serious concerns of laser use are generally:

- Not due to inherent hazards of the actual laser
- Due to inappropriate medical/surgical technique and errors in medical judgment in their application

***Quality hands-on training is the single most important factor in the safe use of laser instrumentation***

# Physician Credentialing Process

- Didactic presentations on principles of laser use and safety
  - Basic Theory
  - Surgical techniques of laser control
  - Comparison of the tissue effects of various lasers
- Clinical presentation in the physicians own specialty
  - Taught by another physician in that specialty
- Hands-on session with the specific types of laser(s) to be used

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# Who can operate lasers in CCHS?

- Laser Operator- the person controlling the application of laser energy to the patient

- Laser Assistant – A trained professional responsible for setting up the laser prior to use or who operates the console to control the laser parameters under supervision of the Laser Operator


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# Physician Responsibilities

- Must meet Credentialing Requirements
  - Submit evidence of proper training
- Attending orientation session prior to performing initial laser procedure
- Checks beam alignment, necessary accessory equipment and test fires the laser according to manufacturer’s recommendations prior to patient use

# Physician Responsibilities


- Controls the laser foot pedal
- Know the wavelength and action of the laser
- Selects the power wattage, mode, appropriate lens or fiber for each procedure
- Collaborate with other staff to ensure laser procedures are performed safely.

# Questions?

# Thank You.

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