LASERS in Ophthalmology

Health Care Technology Unit
ORBIS Flying Eye Hospital

Contents

- LASER history
- Wave theory
- Overview of LASER
- Application of LASERs in Ophthalmology
- LASER Safety

LASER history

- 1917 - A. Einstein: Laser possible.
- 1958 - C.H. Townes, A.L. Schawlow: Theoretical basis for lasers.
- 1960 - T. Maiman: Built first laser.
- 1963 - C. Zweng: First medical laser trial (retinal coagulation).
- 1965 - W.Z. Yarn: First clinical laser surgery.

Light is electromagnetic radiation

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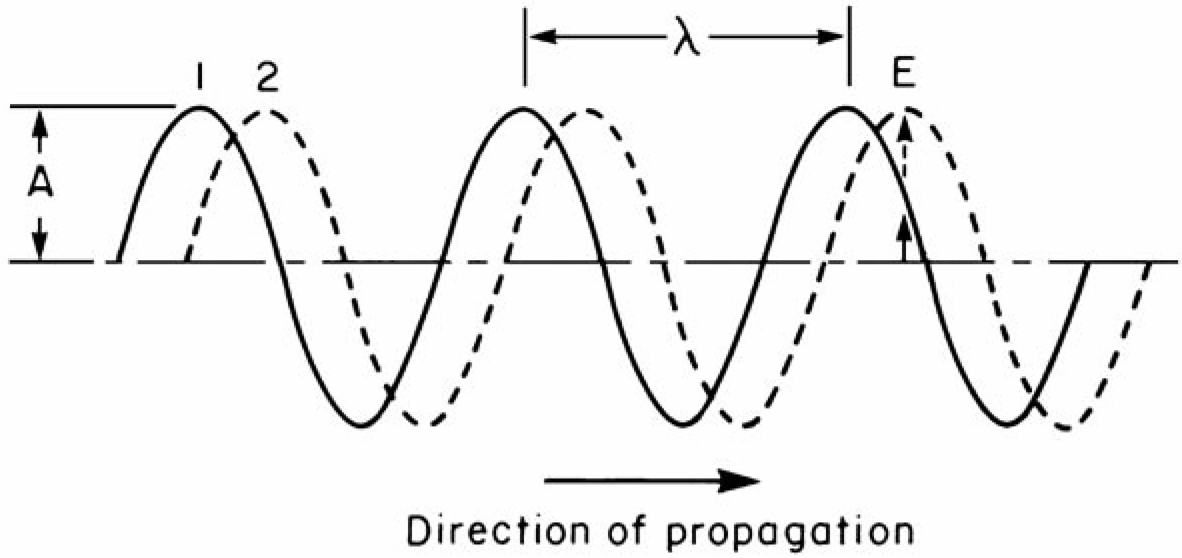

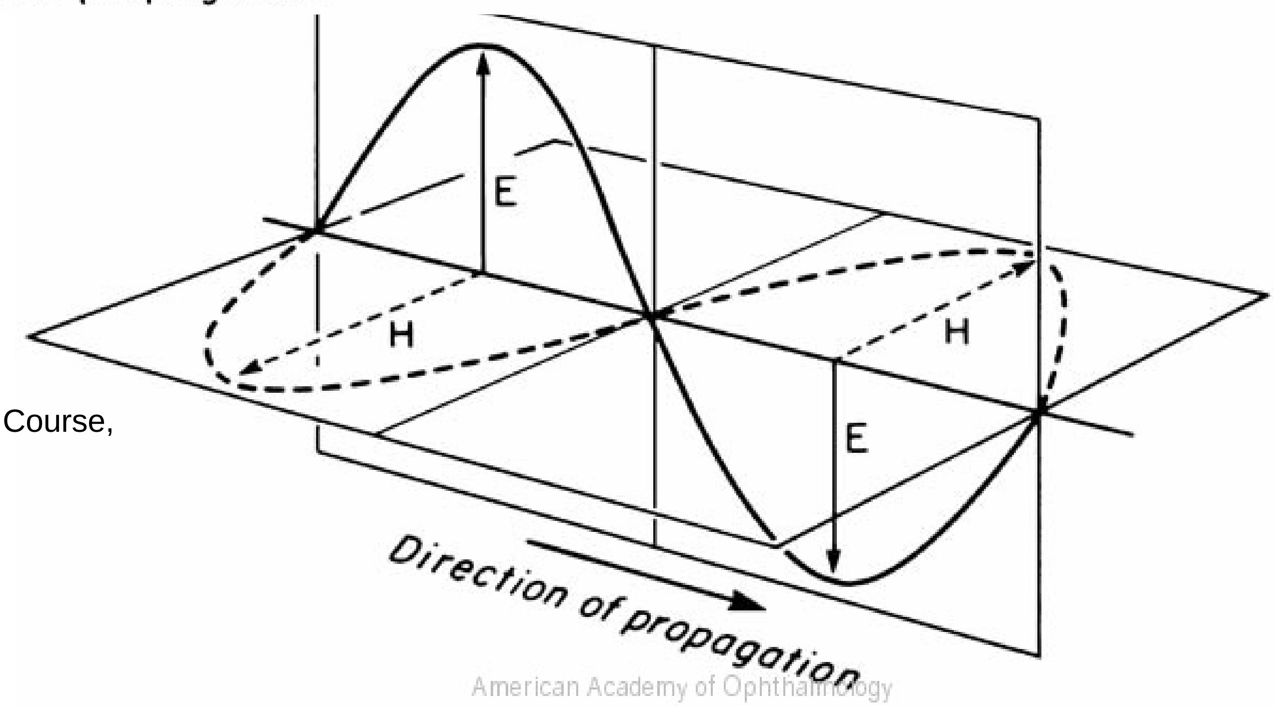

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"Let there be light..."

And the 4 Maxwell's equations where written...

$$\nabla \cdot \overline{D} = \rho$$

$$\nabla \cdot \overline{B} = 0$$

$$\nabla \times \overline{E} = -\frac{\partial \overline{B}}{\partial t}$$

$$\nabla \times \overline{H} = \overline{J} + \frac{\partial \overline{D}}{\partial t}$$

"***FIAT LUX***"

What is LASER?

- LASER is an acronym for:

L – Light

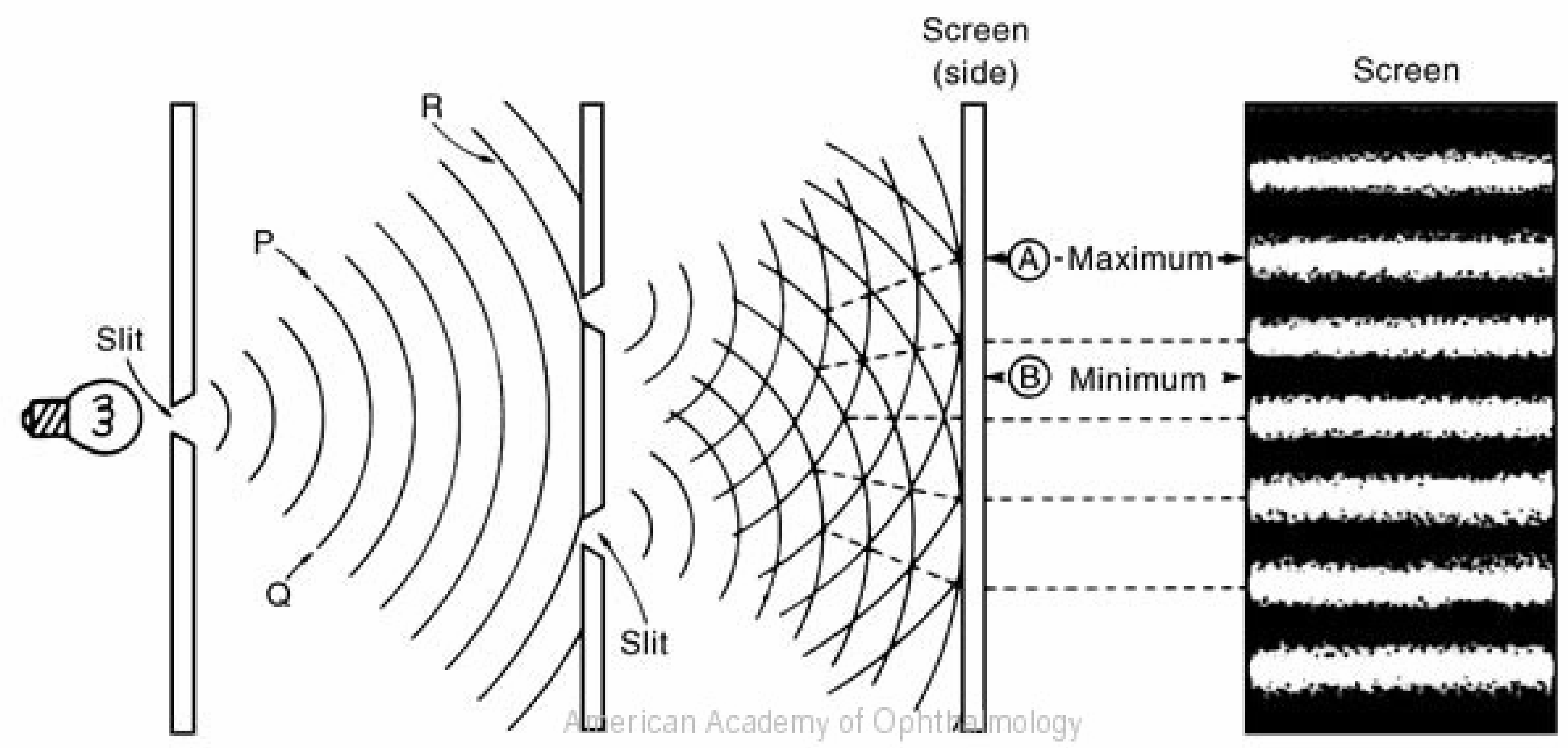
A – amplification by

S – stimulated

E – emission of

R – radiation

Interference and coherence



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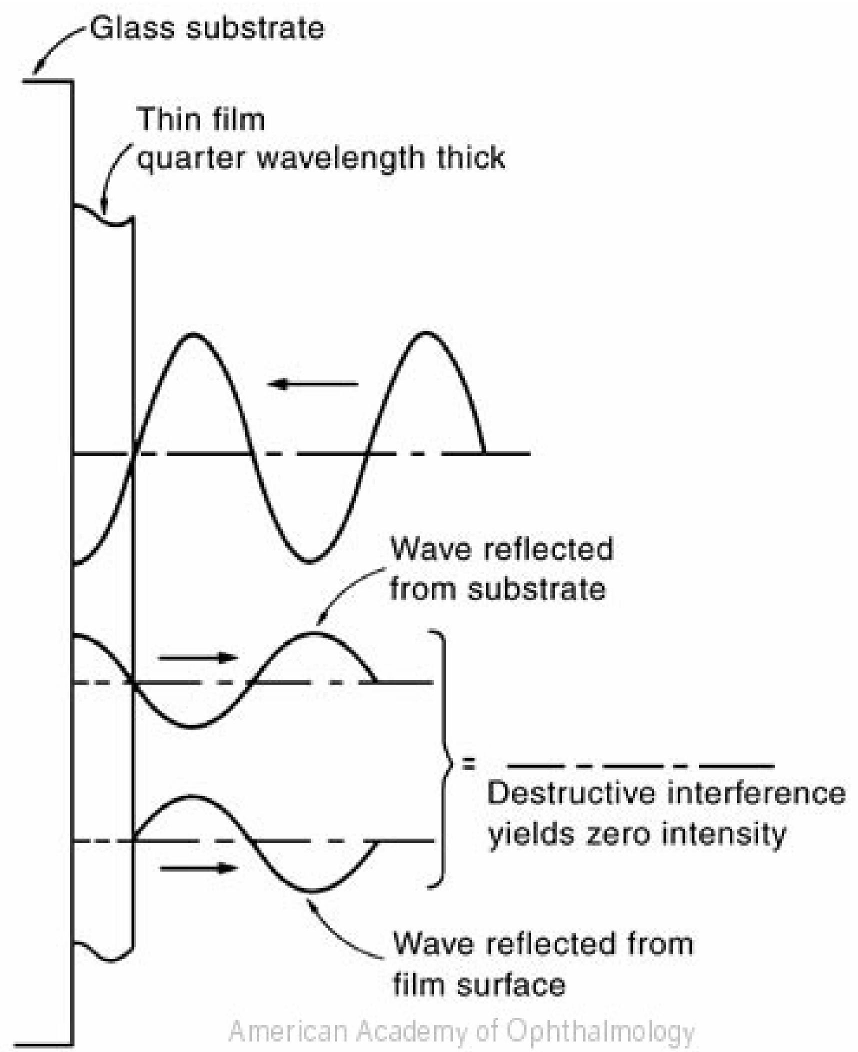
Interference and coherence



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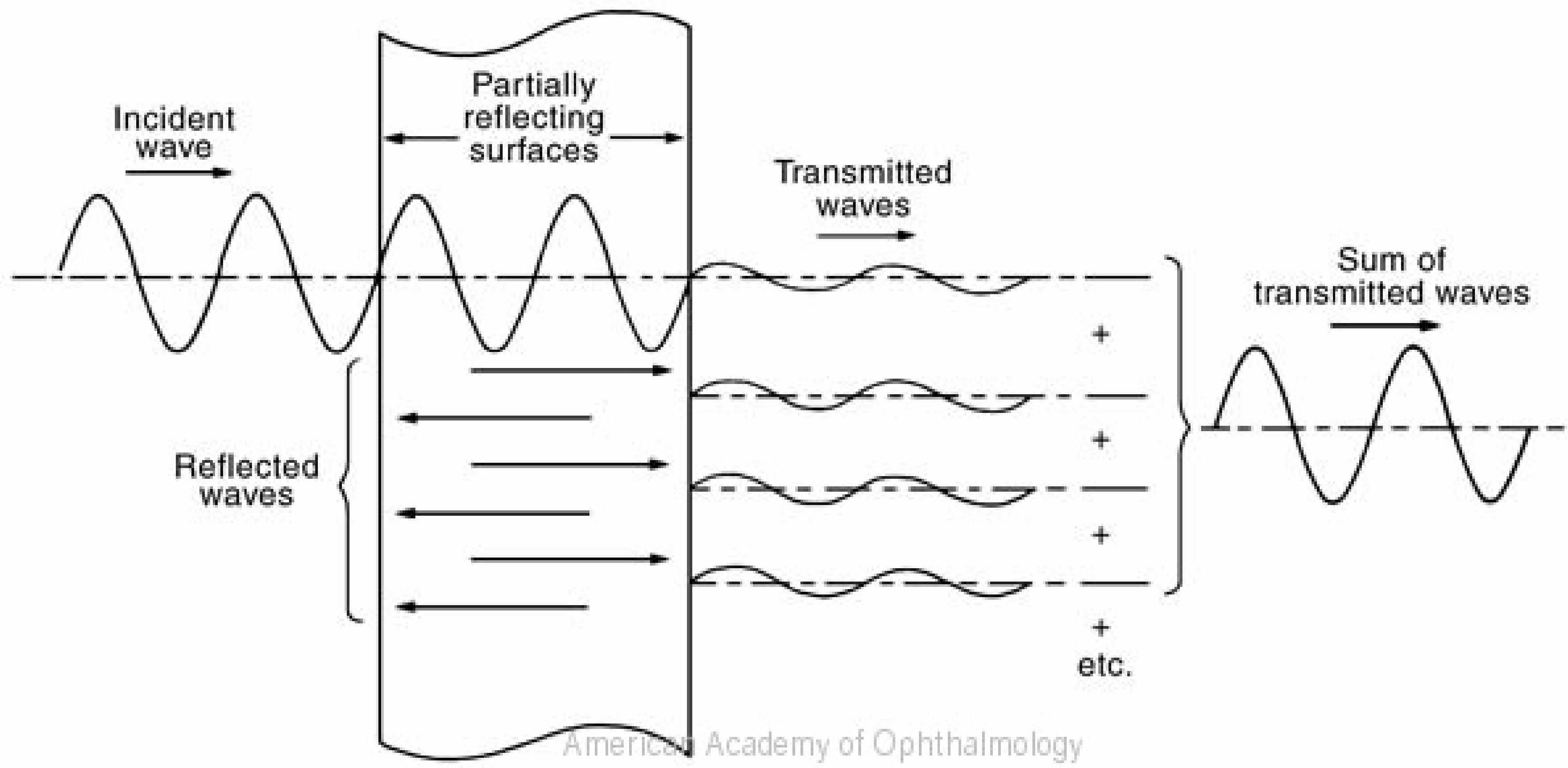
Interference and coherence



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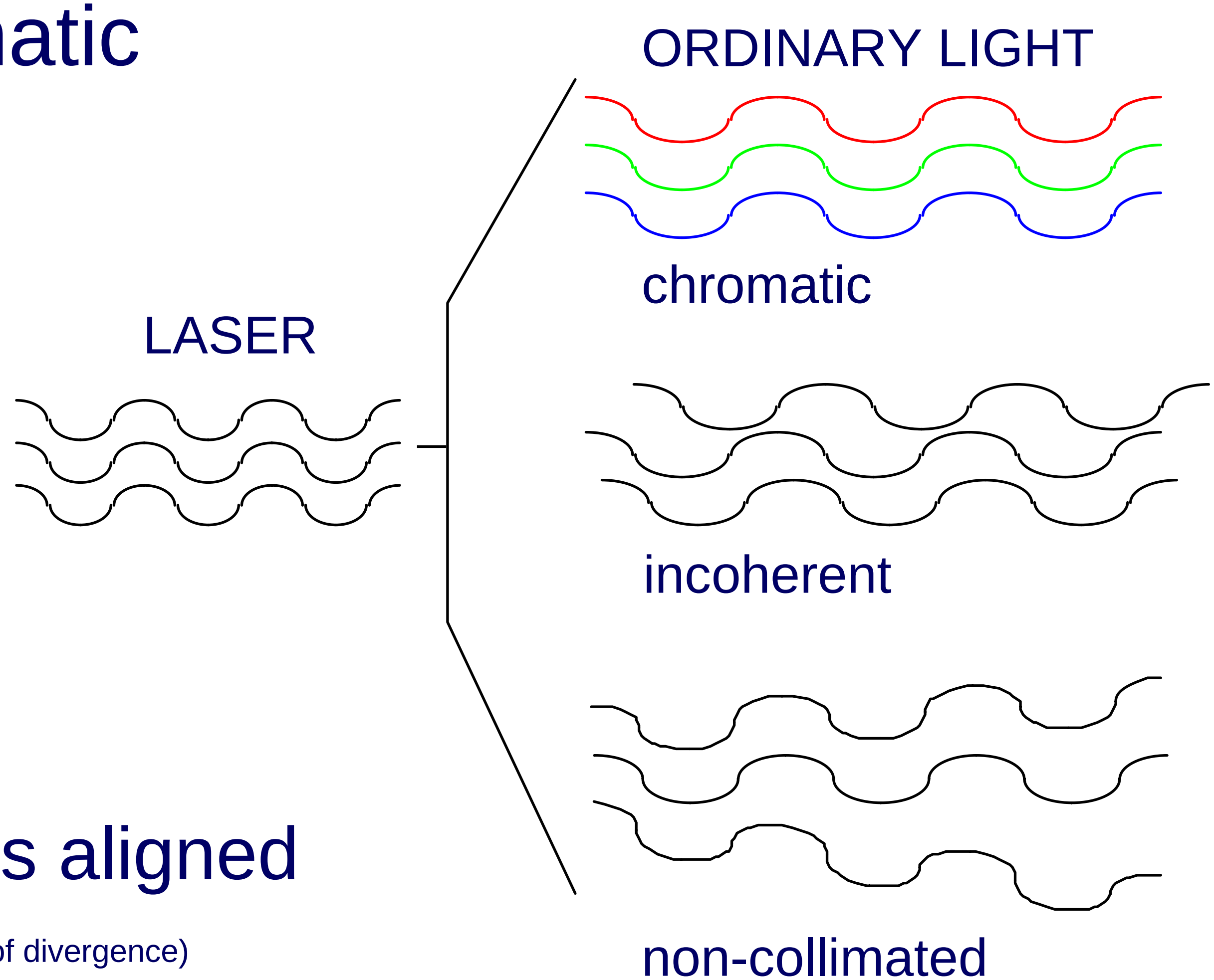
LASER Characteristics

- Monochromatic
  - One color
- Coherent
  - In-phase
- Collimated
  - Light waves aligned

(less than 0.1 degree of divergence)



How is LASER generated?

- Quantum mechanics: Planck's equation

$$E = n.h.\nu = n.h.c / \lambda$$

Where:

E : energy level

n : an integer (1, 2, 3, …)

h : Planck's constant (6.64×10^{-34} Js)

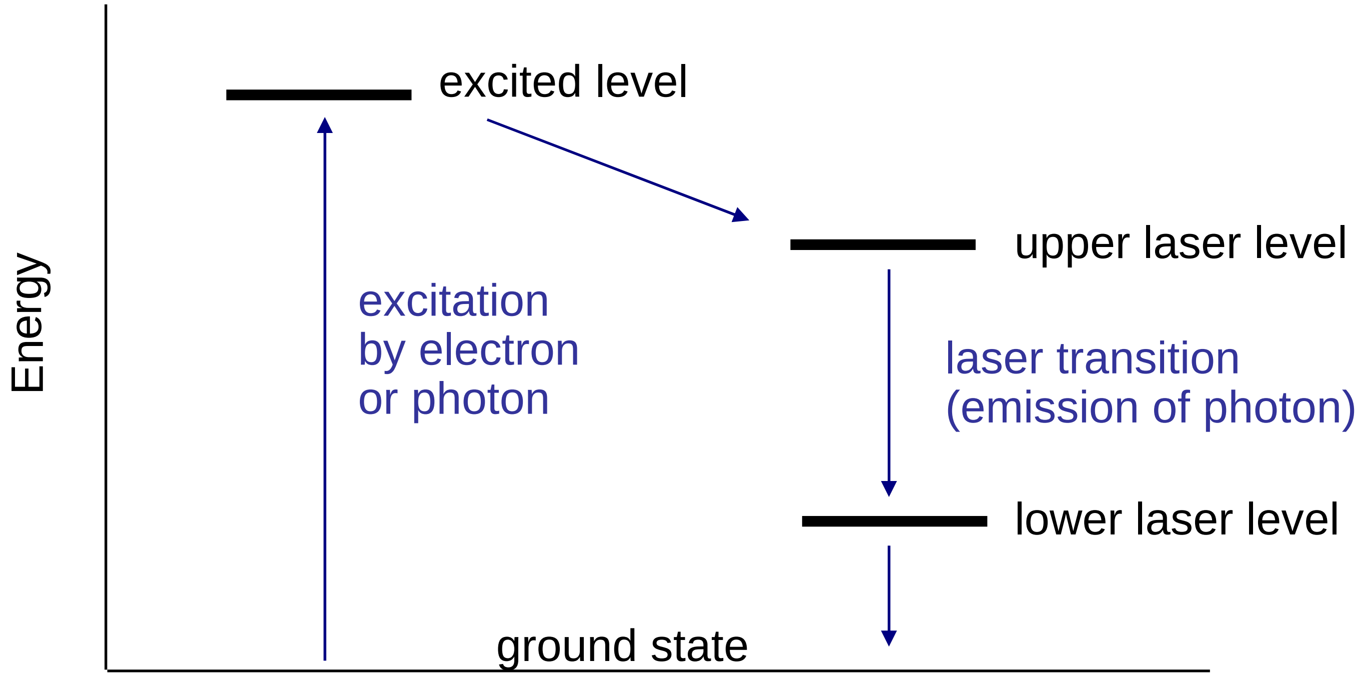
c : speed of light in vacuum (3×10^{8} m/s)

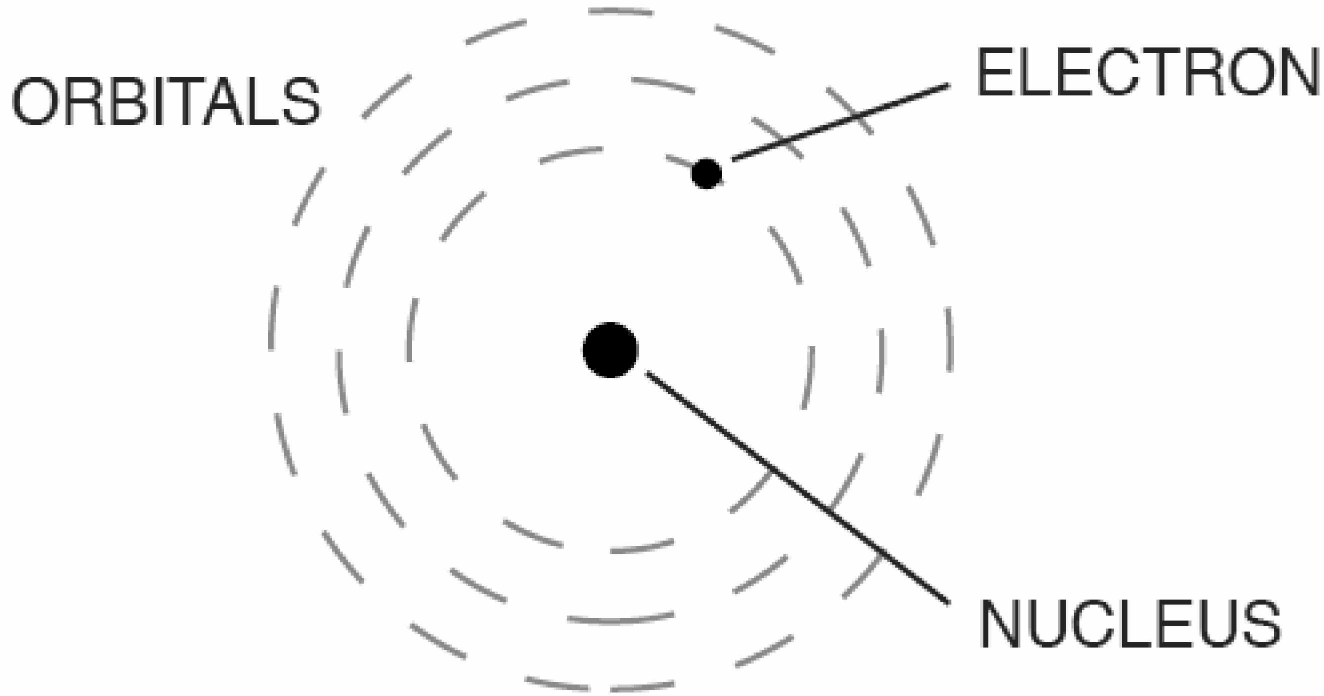
λ : wavelength of the emitted photon (m)

ν : frequency of the emitted photon (Hz)

LASER theory

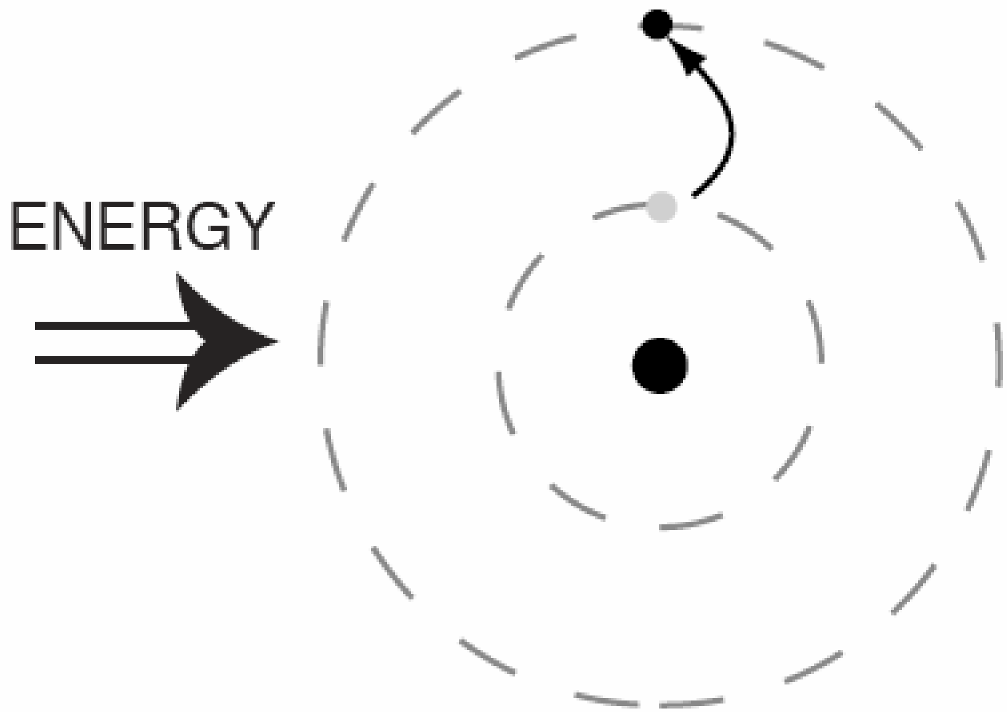
- Quantum Mechanics: Electrons must be excited to emit light.
  - Absorption vs. stimulated emission





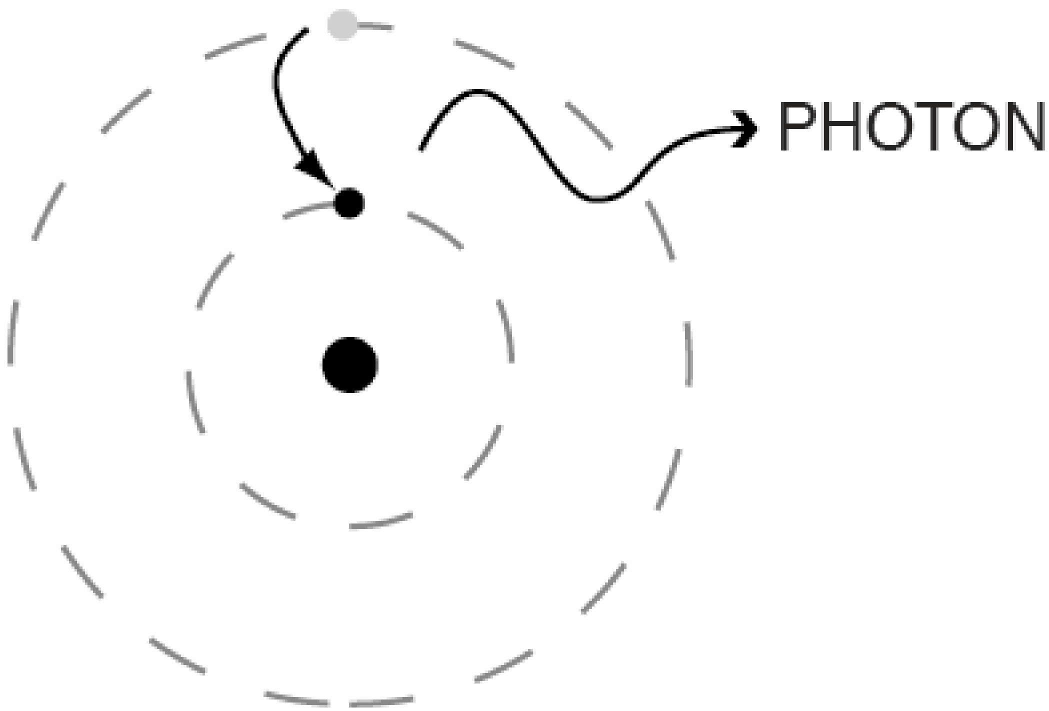
MODEL OF AN ATOM
WITH ELECTRON IN GROUND STATE

ABSORPTION



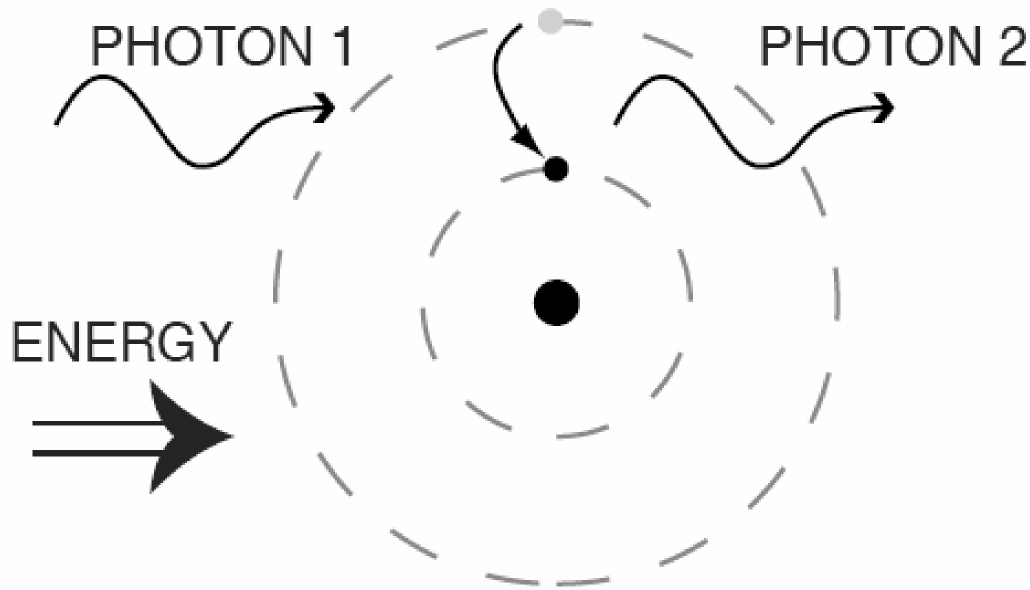
ENERGY INPUT TO ATOM - ELECTRON MOVES TO HIGHER ENERGY LEVEL

SPONTANEOUS EMISSION



ELECTRON IS UNSTABLE IN HIGHER ORBITAL -
DECAYS BACK TO GROUND STATE -
RELEASES ENERGY IN THE FORM OF A PHOTON

STIMULATED EMISSION



- ELECTRON IS EXCITED TO HIGHER ENERGY LEVEL

- PHOTON 1 INTERACTS WITH ATOM CAUSING ELECTRON TO DROP TO LOWER LEVEL AND RELEASE PHOTON 2

- THE TWO PHOTONS ARE IDENTICAL IN PHASE & WAVELENGTH

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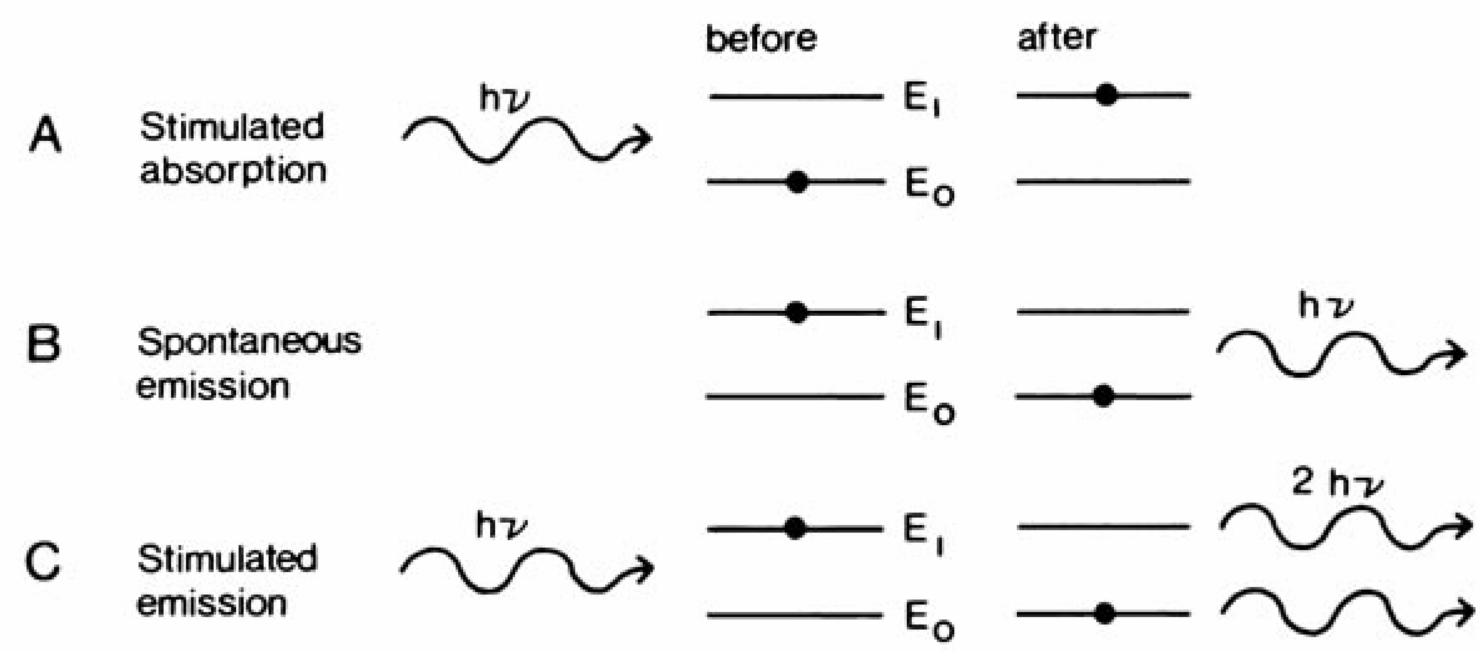
Laser theory

- Stimulated Emission



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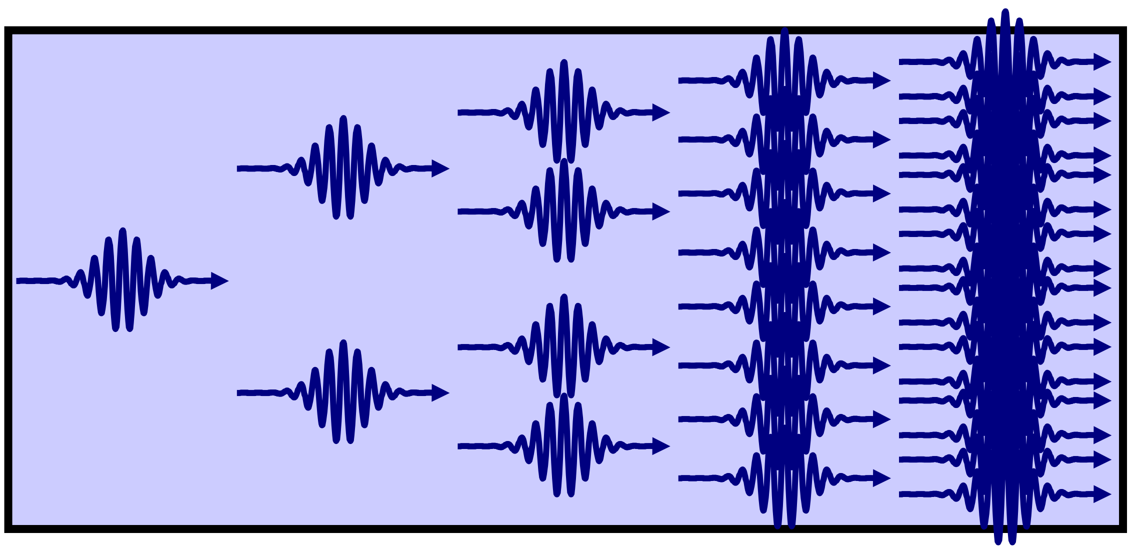
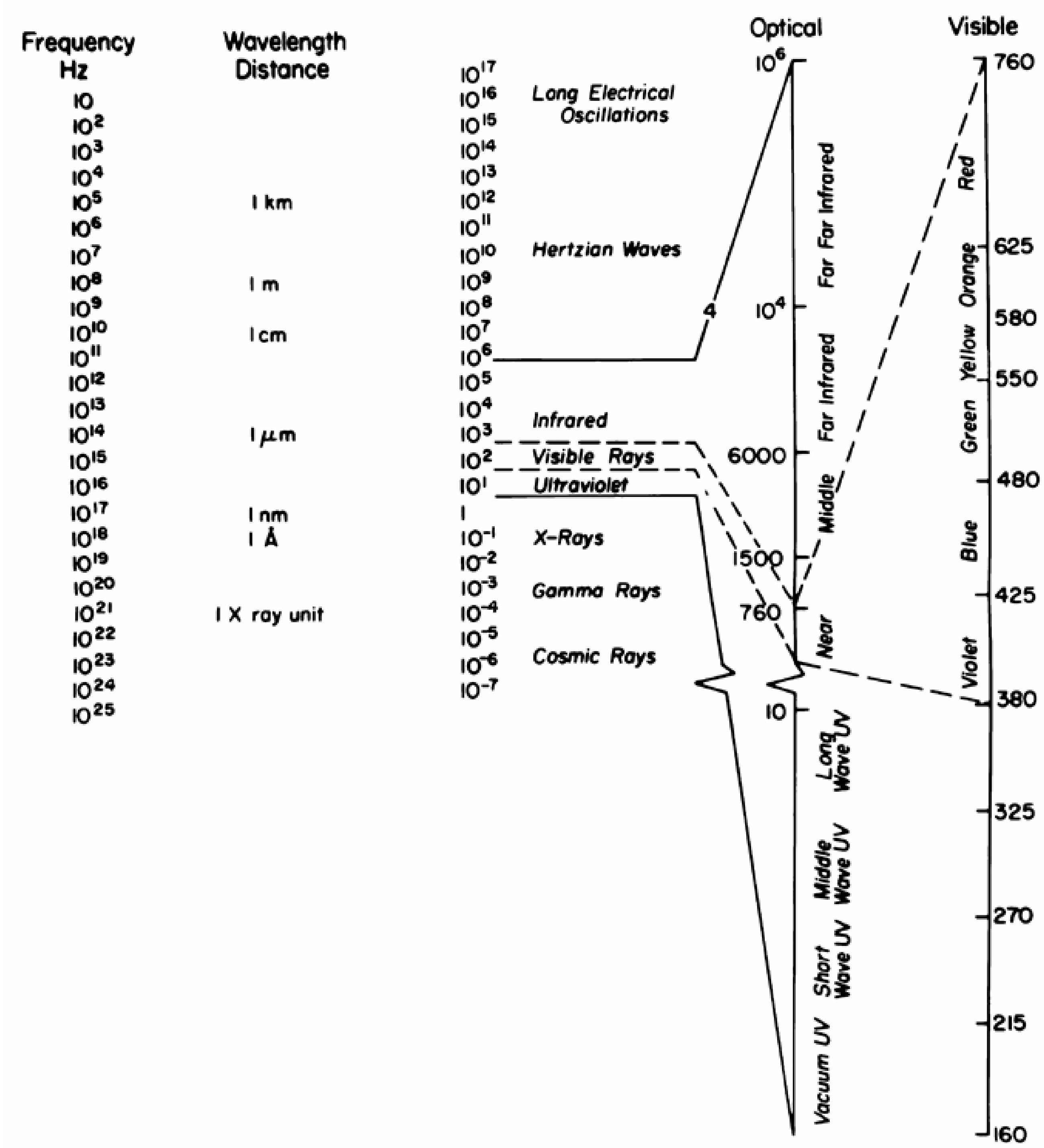
Stimulated emission leads to a chain reaction and laser emission

If a medium has many excited molecules, one photon can become many.

Excited medium



This is the essence of the laser. The factor by which an input beam is amplified by a medium is called the gain and is represented by G.



Electromagnetic energy

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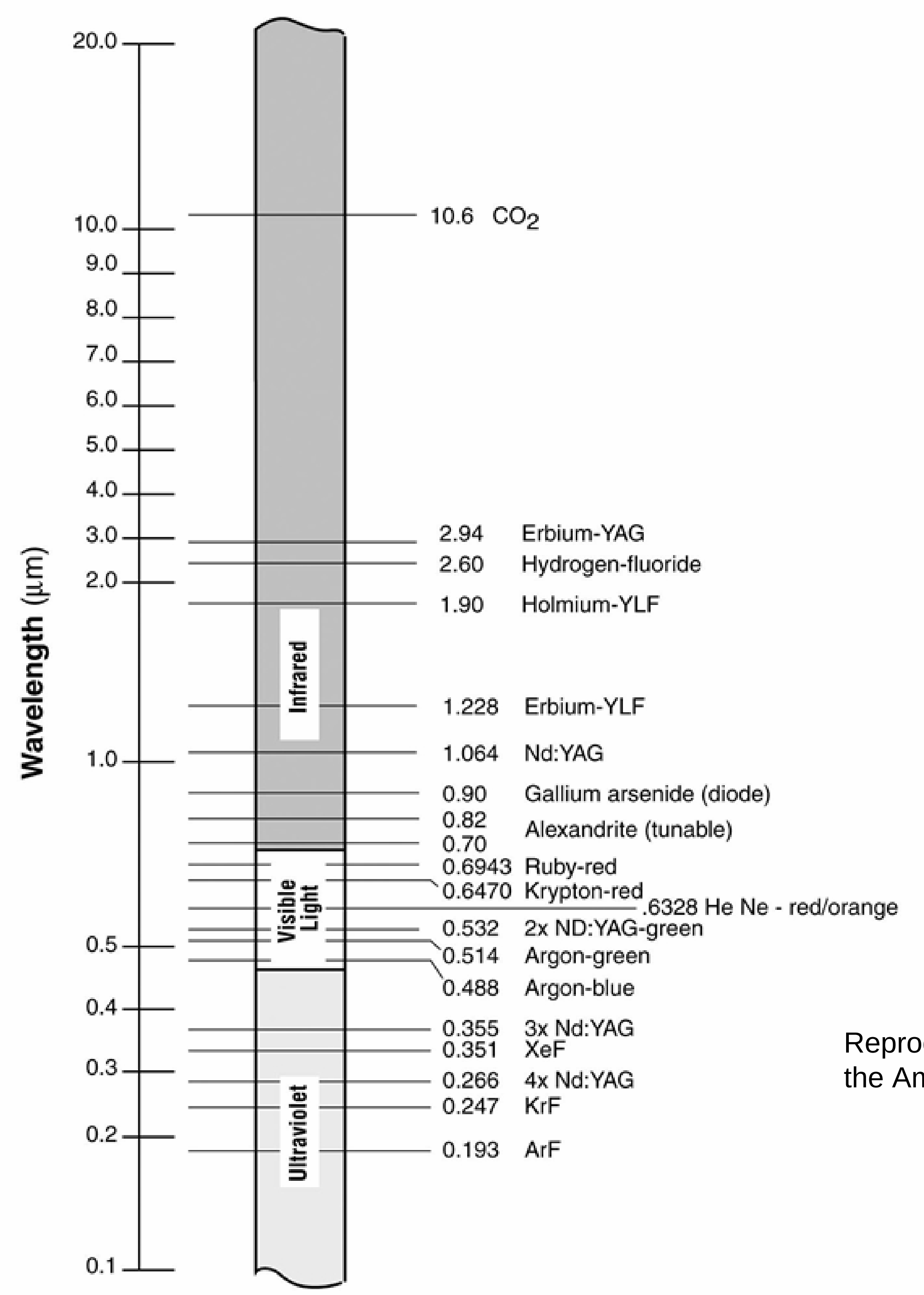

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Wavelengths of Laser systems

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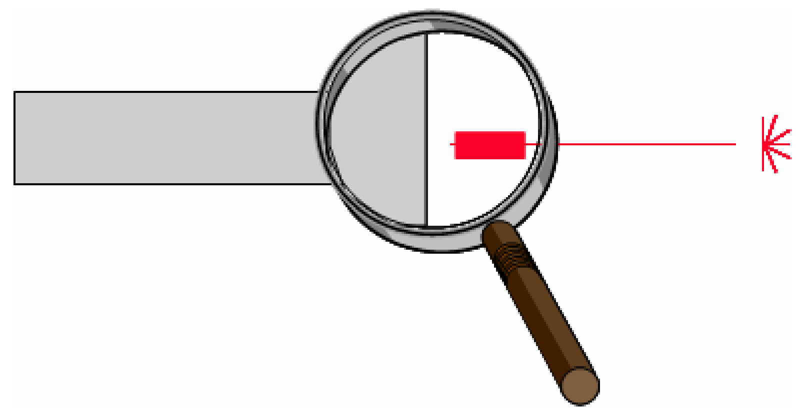
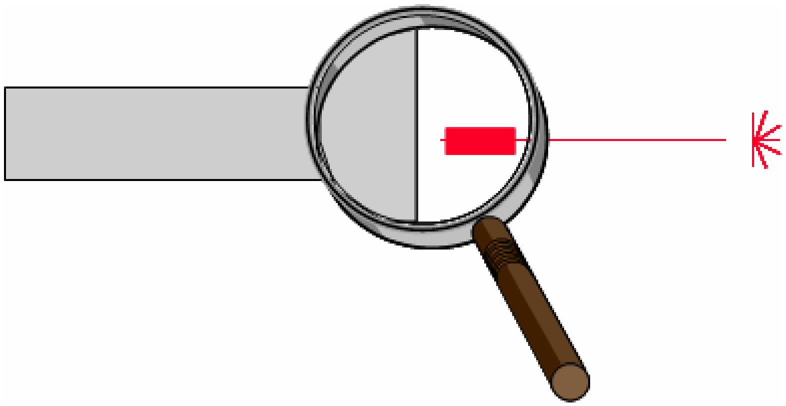
LASER properties



- Wavelength:
  - Ultraviolet
  - Visible
  - Infrared
- Power Density:
  - Milliwatts to Kilowatts
- Duration of Pulse:
  - Nanoseconds to Continuous

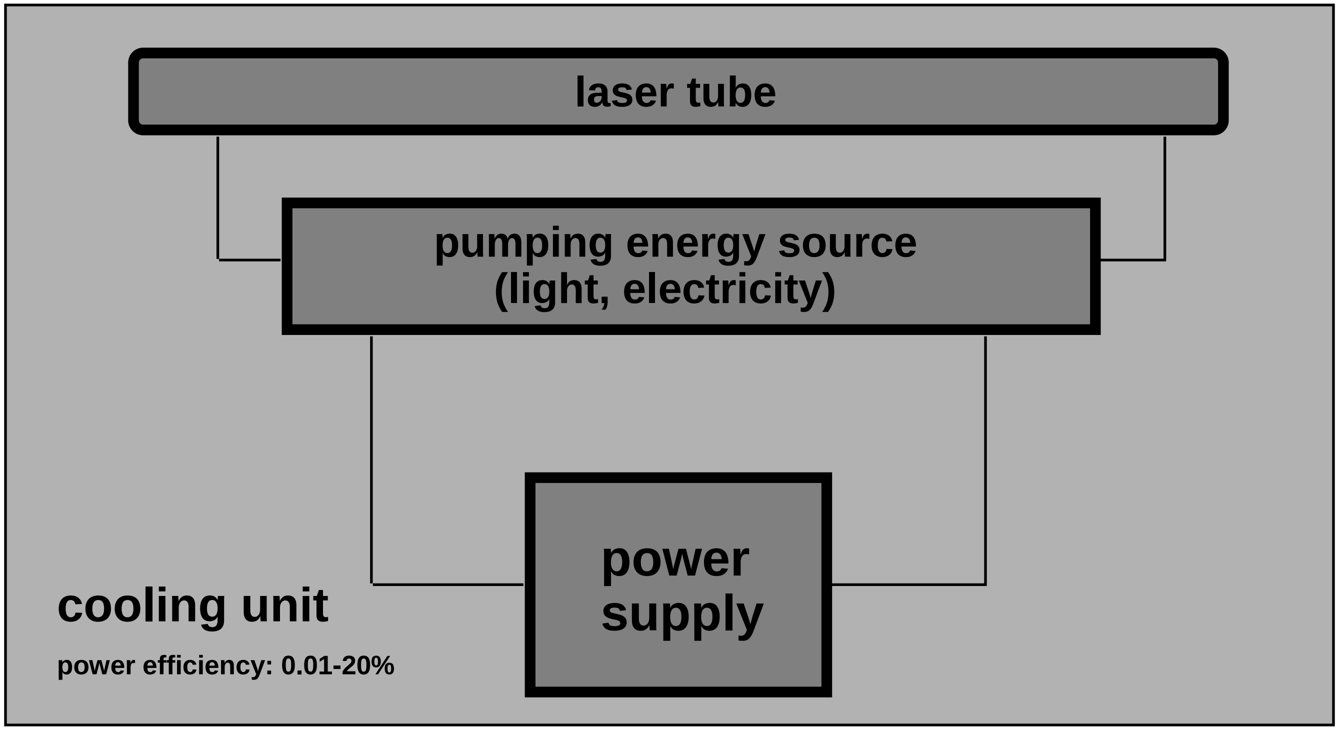
LASER properties



- Beam Divergence:
  - Less than 0.1 degree
- Coherence:
  - Millimeters to meters
- Efficiency, Power Requirements:
  - 0.01% to 20%

Basic Laser Components

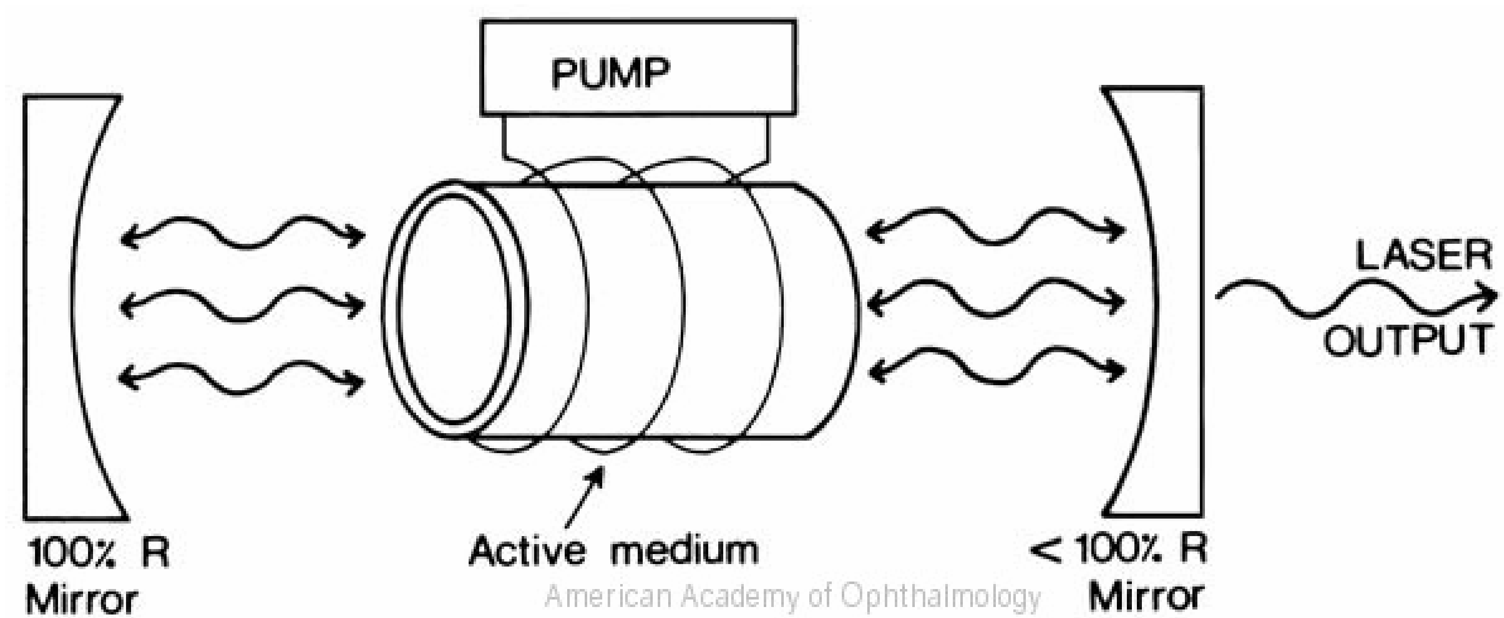
- Laser Tube (Laser medium + Resonating element or mirror)
- Pump or excitation source
- Power supply
- Cooling unit (water, air)



Note: Energy efficiency: Argon 0.01% - Excimer 2%

Basic Laser Components

- Laser tube and pump



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Laser medium and pump

- Energy (electrical, optical, or chemical) from an external source - the LASER PUMP - interacts with a substance within the optical cavity - LASER MEDIUM - of a laser to cause energy emission.

- The substance can be a crystalline solid, a gas, a liquid containing a dissolved organic dye, or a semiconductor. When these electrons return to their original state, they emit photons with identical wavelengths characteristic of the particular substance.

- Mirrors at either end of the laser tube selectively reflect photons traveling parallel to the tube axis, which strike other atoms and cause the spontaneous emission of more photons of identical wavelength. Photons moving in other directions are absorbed or reflected by the sides of the tube.

- Eventually, the remaining photons pass through the partially reflective mirror at one end of the tube to the laser delivery system in a coherent beam (one in which all photons are in phase and moving in the same direction) of extremely high irradiance (power density measured in watts/cm2).

Cooling unit

- Ophthalmic lasers are typically equipped with a water or air cooling system to prevent heat damage to the laser medium and pump.
- In most units, the cooling system is self-contained; others require water and drain connections.

Surgical Laser Terminology

- ABLATION — Removal of tissue using laser energy, usually by progressive VAPORIZATION of the tissue cells.
- ACTIVE MEDIUM —The core material of a laser that emits a specific wavelength of light; used to designate the laser type.
- ARGON LASER — Emits a green wavelength of 514 nm and a blue wavelength of 488 nm that are readily absorbed by pigmented tissue.
- AVERAGE POWER — The energy per pulse times the pulse rate.
- COAGULATION (COAG) — The application of laser energy at a density sufficient to cause thermal DENATURATION of protein without significant loss of tissue mass. Often used to achieve HEMOSTASIS or tissue NECROSIS.
- CONTACT-TIP METHOD — Nd:YAG LASER surgery conducted with a shaped tip that converts some laser energy to heat, causing a tissue effect only when the tip is in contact with the tissue.
- CO2 LASER — Carbon dioxide laser. Emits a mid-infrared beam of 10,600 nm that is absorbed by water.

Surgical Laser Terminology

- CUTTING — The application of laser energy at a density sufficient to incise or divide tissue, ideally without creating significant thermal tissue damage on either side of the cut.
- DENATURATION — The disruption of organic molecules (e.g., proteins, collagen) by application of energy (e.g., laser light, heat). Raising tissue temperature above 65°C will cause denaturation.
- ENERGY VERSUS POWER — Both express the laser emission's capacity to cause damage to or achieve a therapeutic effect in tissue. Energy, expressed in joules (J), causes the temperature to rise when applied to a volume of cells; the faster the energy is delivered, the higher the power, and the faster the temperature rises. Power, expressed in watts (W), is the rate of energy emitted (i.e., J/sec).
- FIBEROPTIC DELIVERY SYSTEM — A mechanism used to convey laser energy by internal reflection in a flexible, small-diameter fiber (usually silica) from the laser aperture to a treatment site.
- FREE-BEAM METHOD — Laser surgery conducted with the laser aperture either a short distance away from or just touching the target tissue.
- HEMOSTASIS — The stoppage of blood flow from severed vessels.

Energy Concepts

WATTS – (Power) Rate of Energy Delivery, but doesn't say how much energy (Dose).

JOULES – (Dose) Amount of Energy Delivered, but doesn't say how fast (Rate)

Joules = Watts x Time, i.e.;

1 Joule = 1000 watts x .001 seconds

Energy Concepts

POWER DENSITY: Spot Size & Power

Watts per Square Centimeter (W/cm^2)

Concentration of the Power within the spot size. Analogous to a magnifying glass and the sun. Small spots burn (or ablate) because they are more intense. Large spots don't burn as quickly because they are less intense. Spot size will change the power density faster than a change in power.

Energy Concepts

ENERGY DENSITY: Spot Size & Dose

Joules per Square Centimeter (J/cm^2)

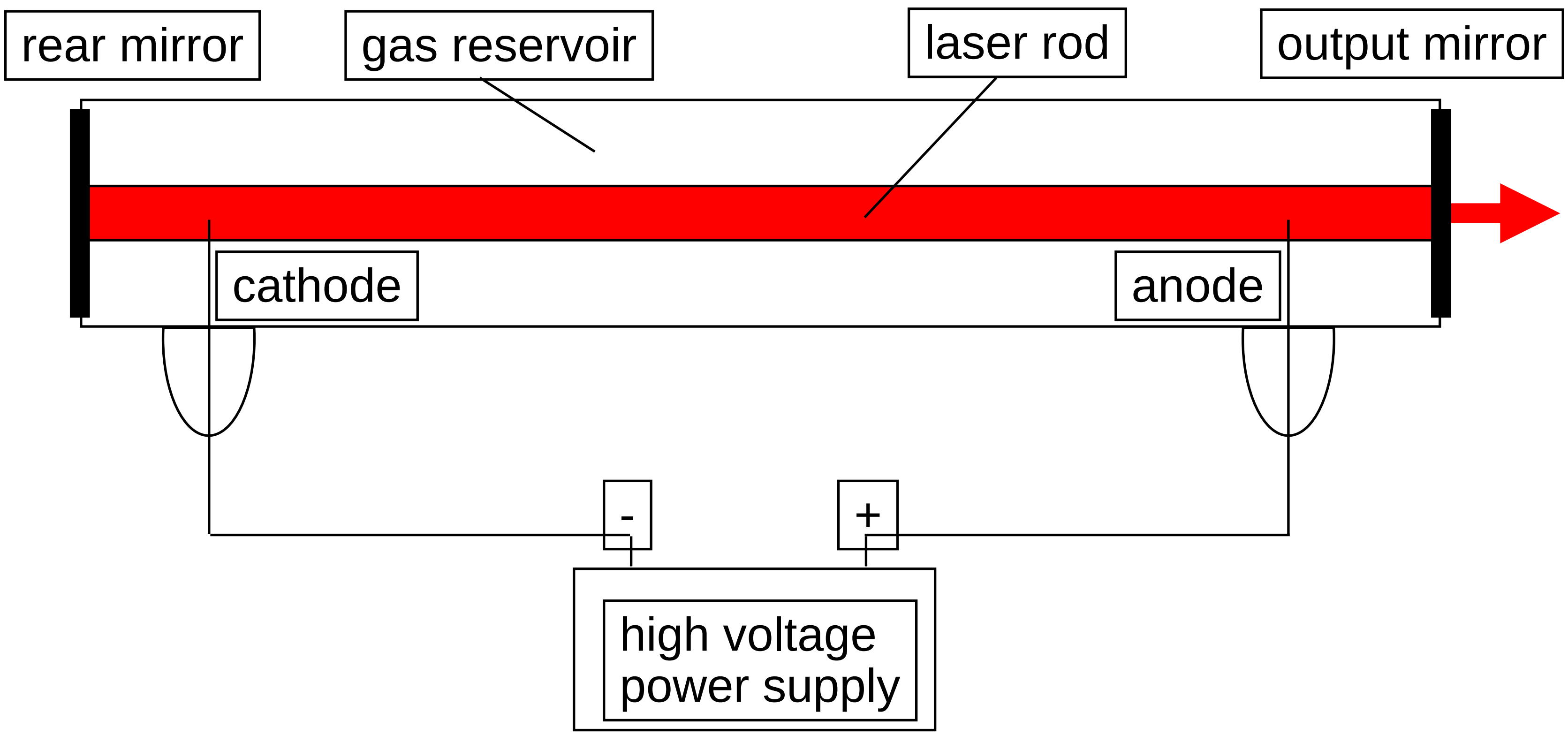
Concentration of the total “Dose” of light within the spot size. This considers both the Power Density and length of time.

Different Types of Lasers

- LASERS are referred to by the substance they use (e.g., argon, krypton); each type of laser produces light, either a characteristic wavelength or a set of discrete wavelengths:
  - Gas Laser
  - Insulating Crystal Laser
  - Solid-state PN Junction Laser
  - Excimer Laser

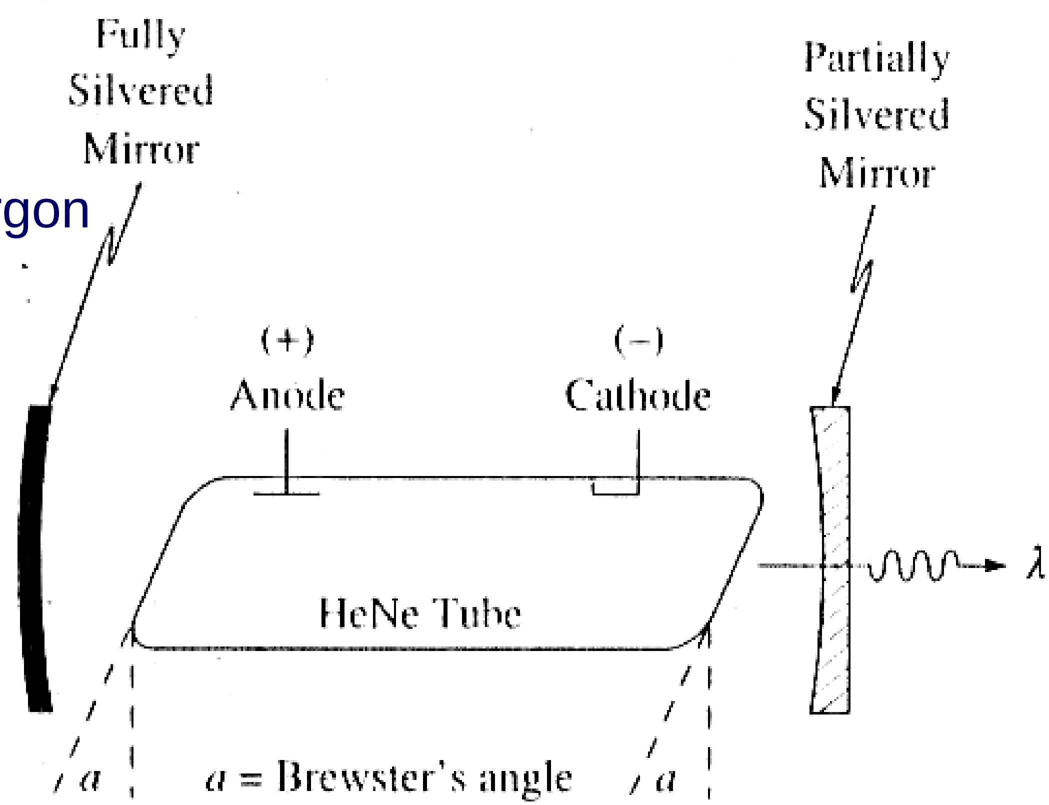
Gas LASER

- Types - Argon, Krypton, HeNe, Excimer



Gas Laser

- Laser materials: CO_2, He-Ne, Argon, Krypton
- Pump: electrical field (electrical pump)
- Laser wavelength:
  - 10600 nm for CO_2
  - 633 nm for He-Ne
  - 488 and 515 nm for Argon
  - 568 nm for Krypton



Gas LASER specifications

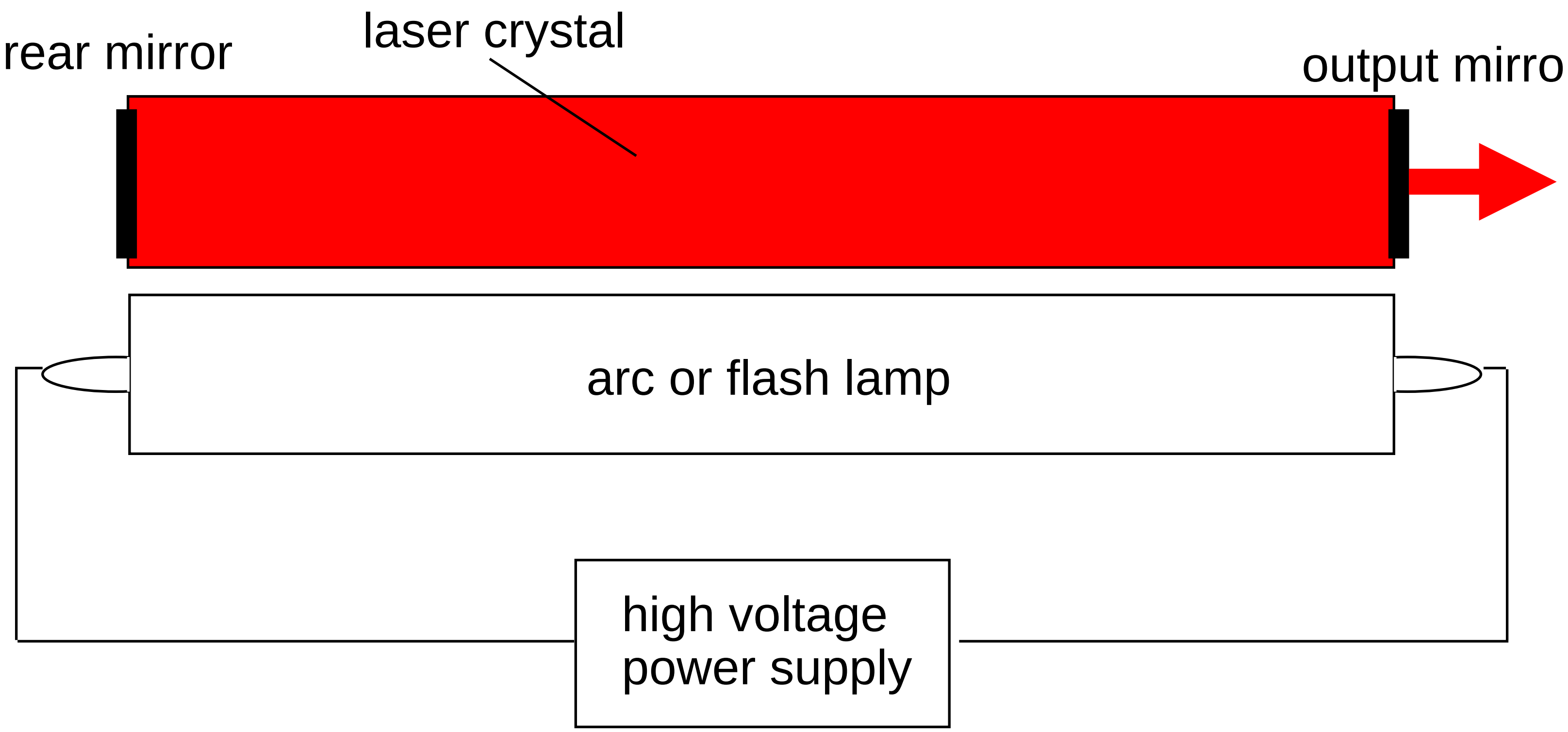
Argon:
expensive, high power
excitation: first 10 - 70 A, then 90 - 400 V
emission: 488, 514 nm, - 20 W, continuous
cooling: air (< a few Watts), water (higher)
lifetime: 1,000 - 10,000 hrs (factory refill)
cost: US$1,000s - 10,000s

Excimer:
expensive, very high power
emission: UV (~200 nm), < 100 W
pulsed (~100 ns, 10 - 1000 Hz)
lifetime: 100 - 1000 shots (user refill)
cost: US$35,000 - 50,000

HeNe:
inexpensive, low power
excitation: first 10 mA, then 2000 V
emission: 633 nm, 0.1 - 10 mW, continuous
lifetime: >10,000 hrs
cost: US$20 - 100

Solid state LASER

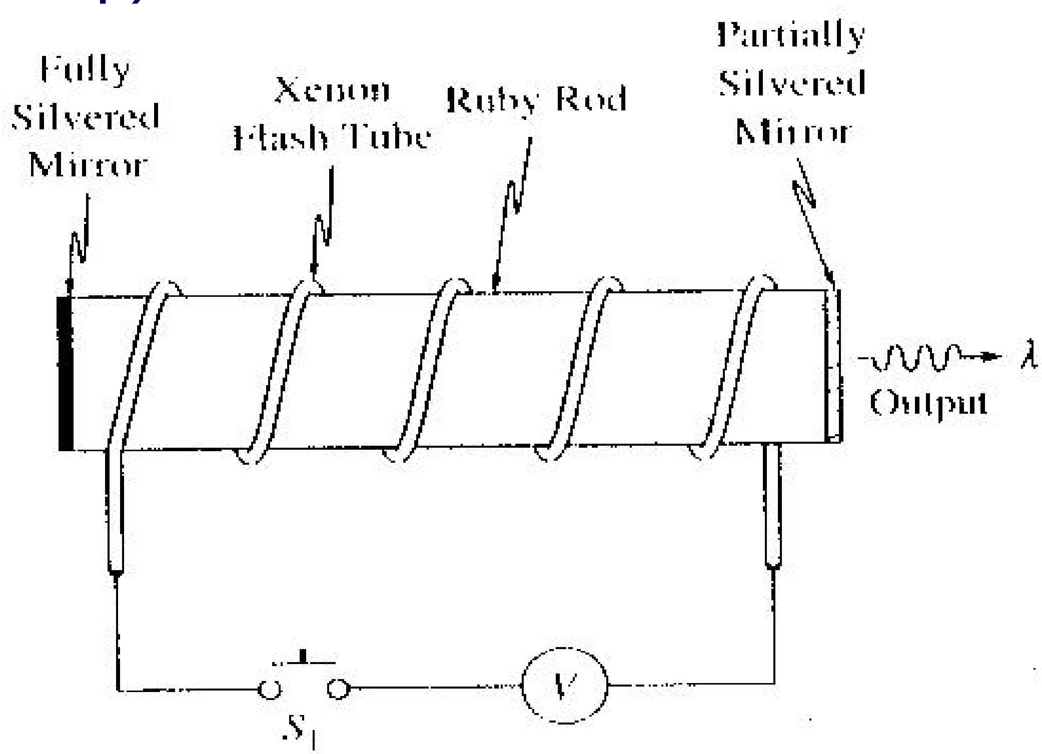
- Nd: YAG (neodymium in yttrium-aluminum-garnet)



- The photons emitted from the crystal when it is excited by light energy from the flash lamp are transmitted through the partially reflecting mirror to the delivery system.

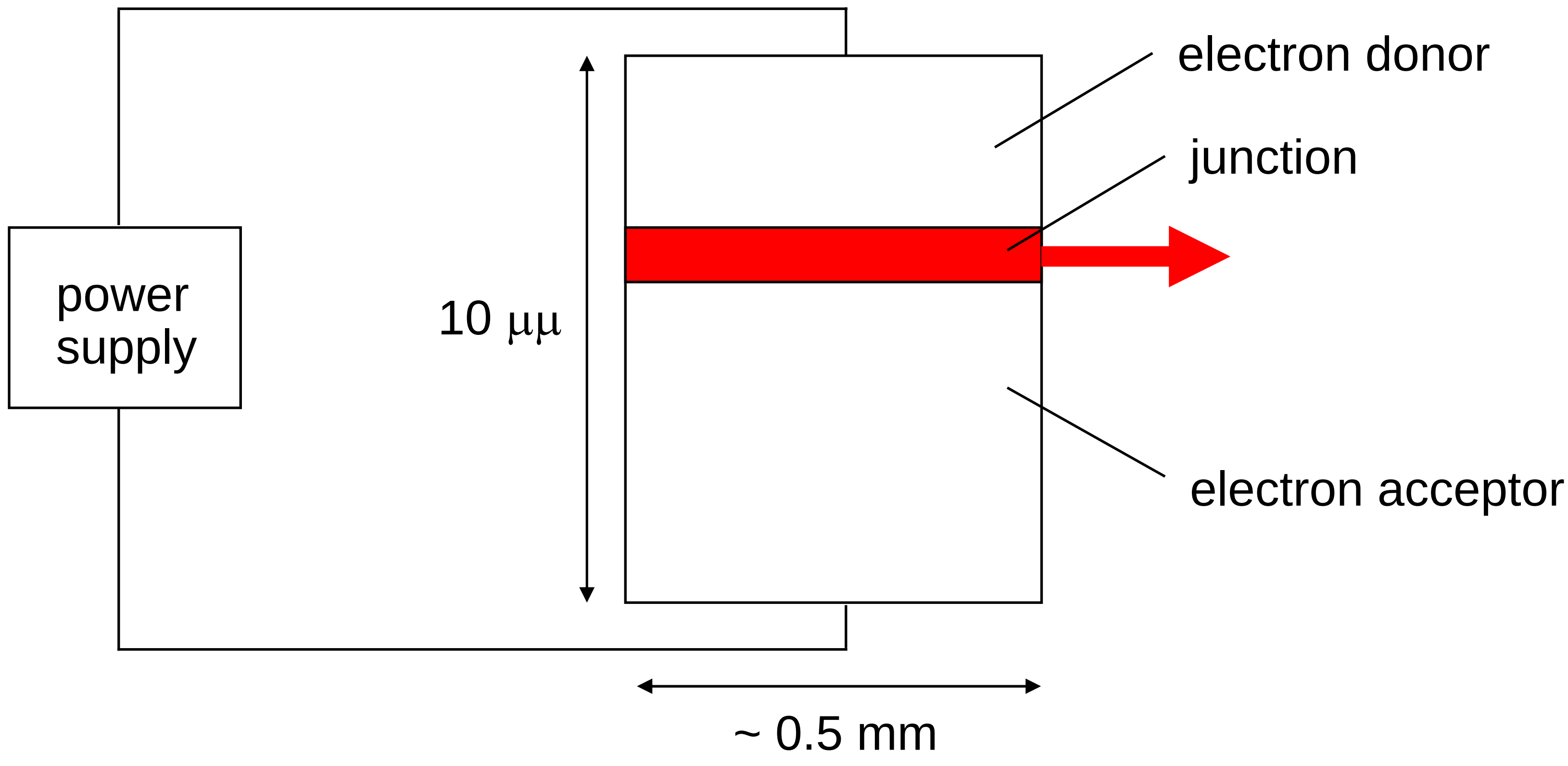
Insulation Solid Laser

- Laser materials: ruby (Al_2O_3), neodymium (Nd^{3+}) in yttrium-aluminum-garnet (YAG)
- Pumps: Xenon flash tube, Krypton arc lamp or tungsten-iodine lamp (optical pump)
- Laser wavelength:
  - 693 nm for ruby
  - 1060 nm for Nd: YAG



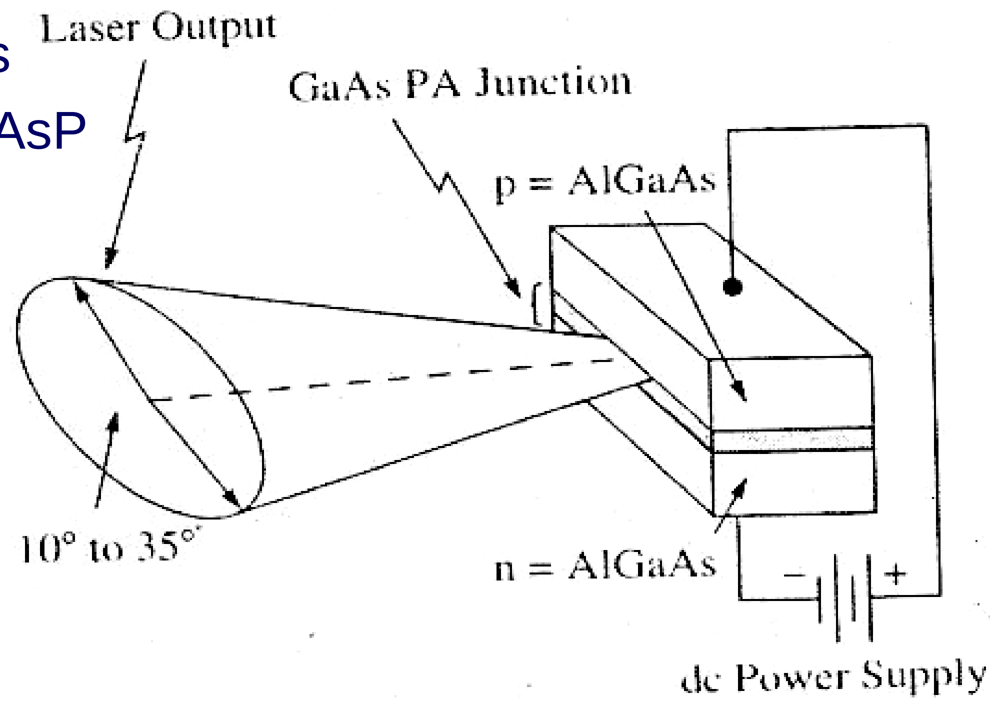
Semiconductor LASER

- Diode Laser



Solid-state PN Junction Laser (Diode Laser)

- Laser materials: semiconductor PN junction
- Pump: electrical field (electrical pump)
- Laser wavelength:
  - 760-905 nm for AlGaAs
  - 1200-1550 nm for InGaAsP



Excimer Laser

- Laser materials: Rare gases (Argon, Krypton or Xenon) combined with chlorine, fluorine, iodine or bromine.
- Pump: electrical field (electrical pump)
- Laser wavelength:

Table 119–1. TYPICAL WAVELENGTHS OF THE RARE GAS MONOHALIDE EXCIMER LASER

Gas Fill	Wavelength (nm)
Argon fluoride (ArF)	193
Krypton chloride (KrCl)	222
Krypton fluoride (KrF)	248
Xenon chloride (XeCl)	308
Xenon fluoride (XeF)	351

New technology

- Frequency doubled YAG lasers
  - Also known as the KTP/532 LASER. Emits a green wavelength of 532 nm that is readily absorbed by pigmented tissue.
- Frequency doubled diode lasers
  - Pure green light
- Dual fibre lasers
  - Both infrared and visible
- Uses a frequency doubling crystal
  - Best crystals are made in China

LASER energy absorption by water

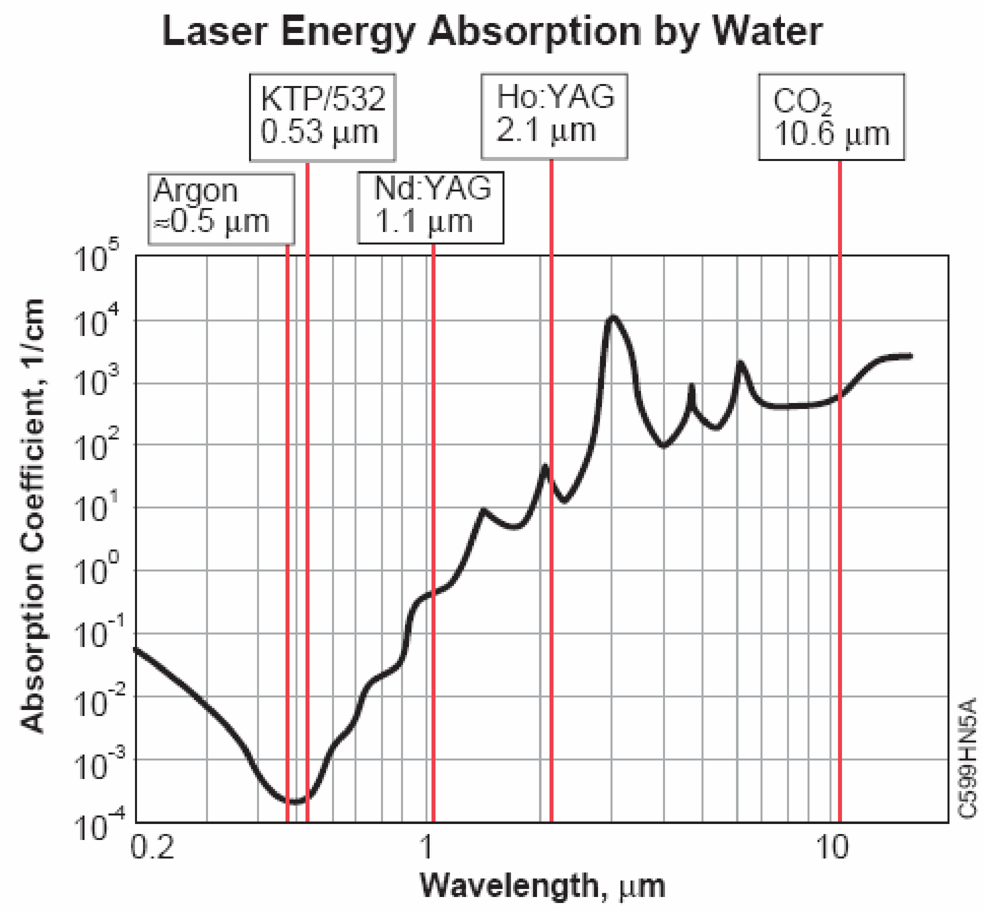


Figure . Absorption of laser energy by water at commonly used surgical laser wavelengths.

- Wavelengths which are readily absorbed by water (e.g., CO2) are able to cut precisely (by vaporizing cellular water) without causing significant thermal injury to adjacent tissue;
- However, this also precludes their use in liquid environments because the energy is absorbed before it reaches the target tissue.

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Tissue effects

- Laser energy typically produces three zones of damage when applied to tissue:

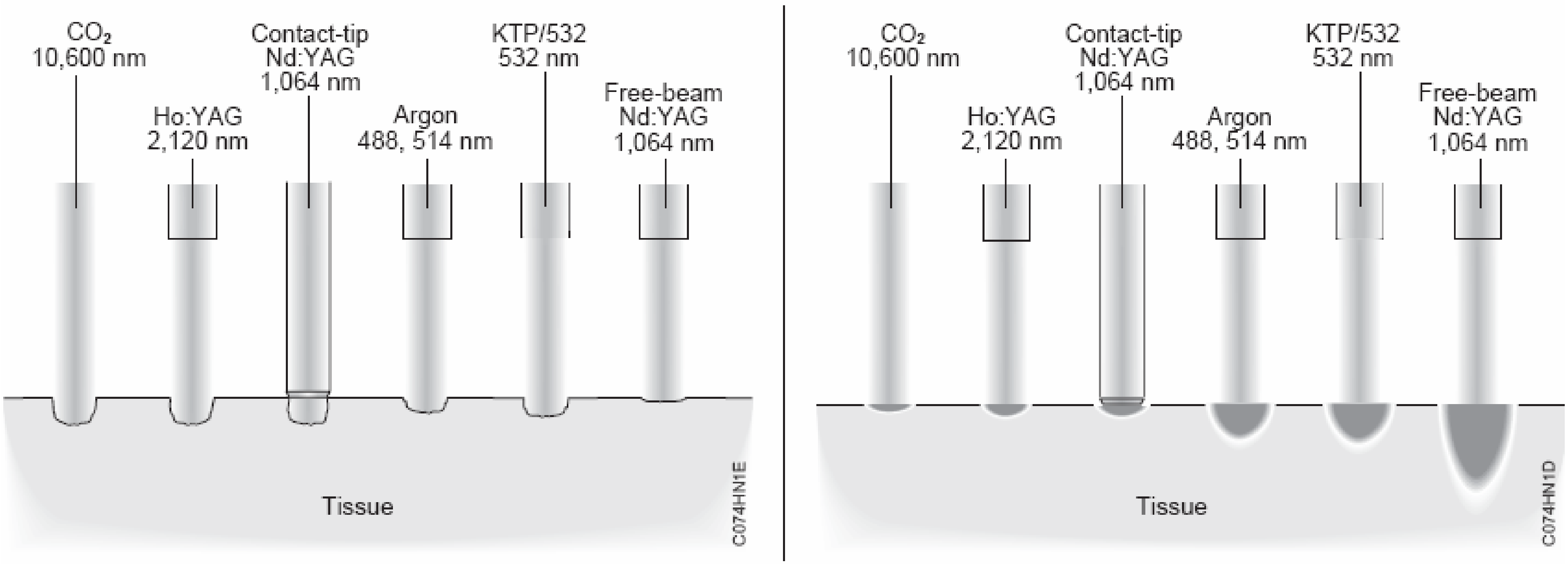
(1) a crater from which vaporized tissue is ejected;

(2) a zone of NECROSIS caused by “boiling” tissue;

(3) a zone of coagulation caused by thermal DENATURATION of collagen.

- Laser wavelengths produce depths of damage ranging from 50 μm for CO_2 to 4,000 μm for Nd:YAG energy using the FREE-BEAM METHOD.
- The depth of tissue effects for electrosurgery, by contrast, can range from 1,000 to 5,000 μm.

Vaporization versus Coagulation



Figures . Vaporization (left) and coagulation effects of several types of lasers; these effects are directly related to the thermal penetration of the laser energy in tissue. Note that with contact-tip Nd:YAG, the tissue effect will depend on the shape of the tip used.

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How do Lasers affect the tissue?

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Photo effects on mammal tissues:

- Photochemical damage:
  - Light of high intrinsic energy breaks the chemical bonds in a molecule and changes its conformation and causes dysfunction.
- Photothermal damage:
  - Light causes a rise in temperature within the tissue by energy absorption. The hydrogen bonds in molecules are relatively weak and readily destroyed by heating.
- Photodisruption damage:
  - Lights of short duration and high energy cause tissue to be ionized (plasma formed), which literally tears molecules apart.

Photo Effects on Mammal Tissue Versus Time

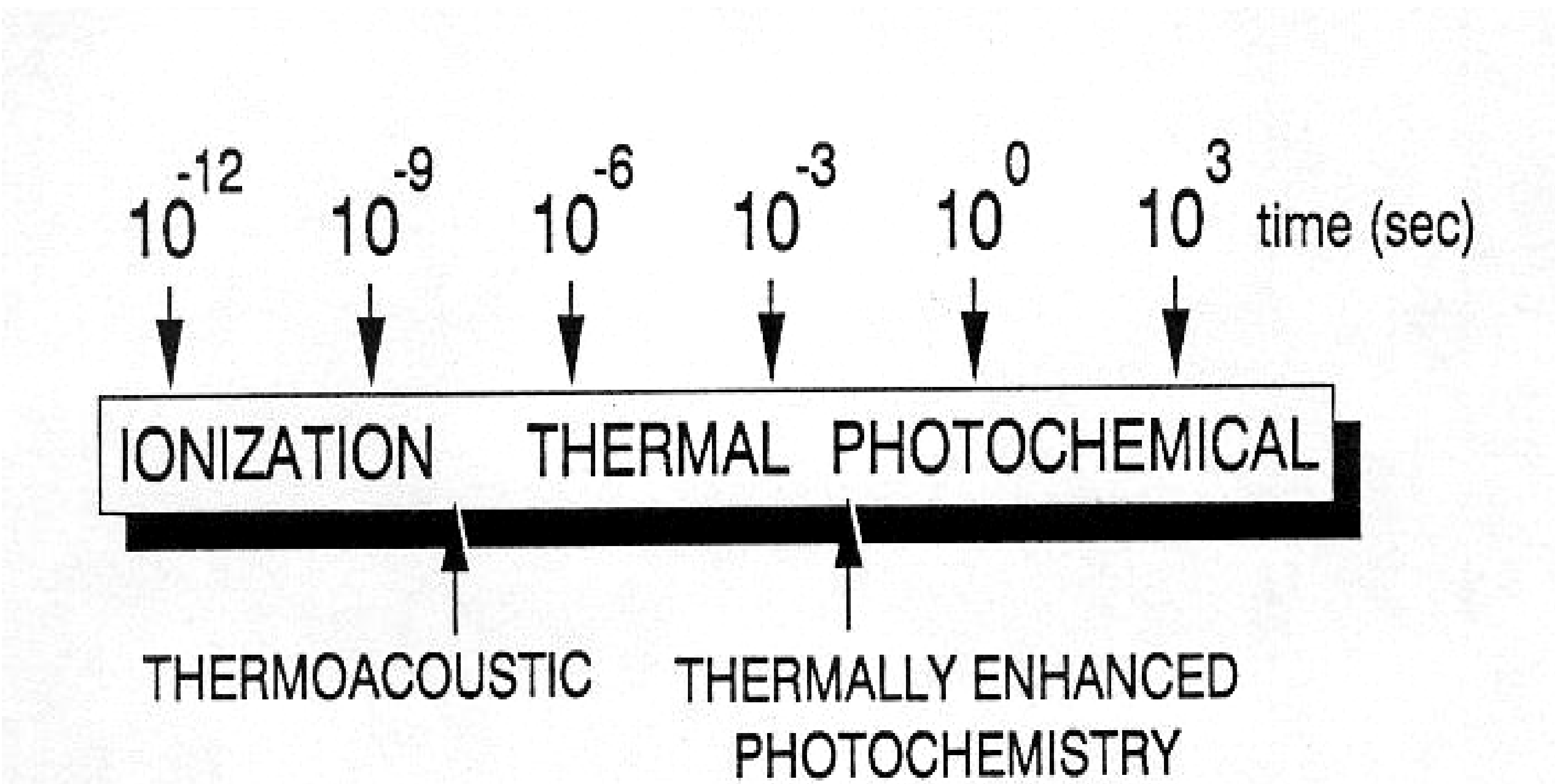

Photo Effects on Mammal Tissue Versus Wavelength

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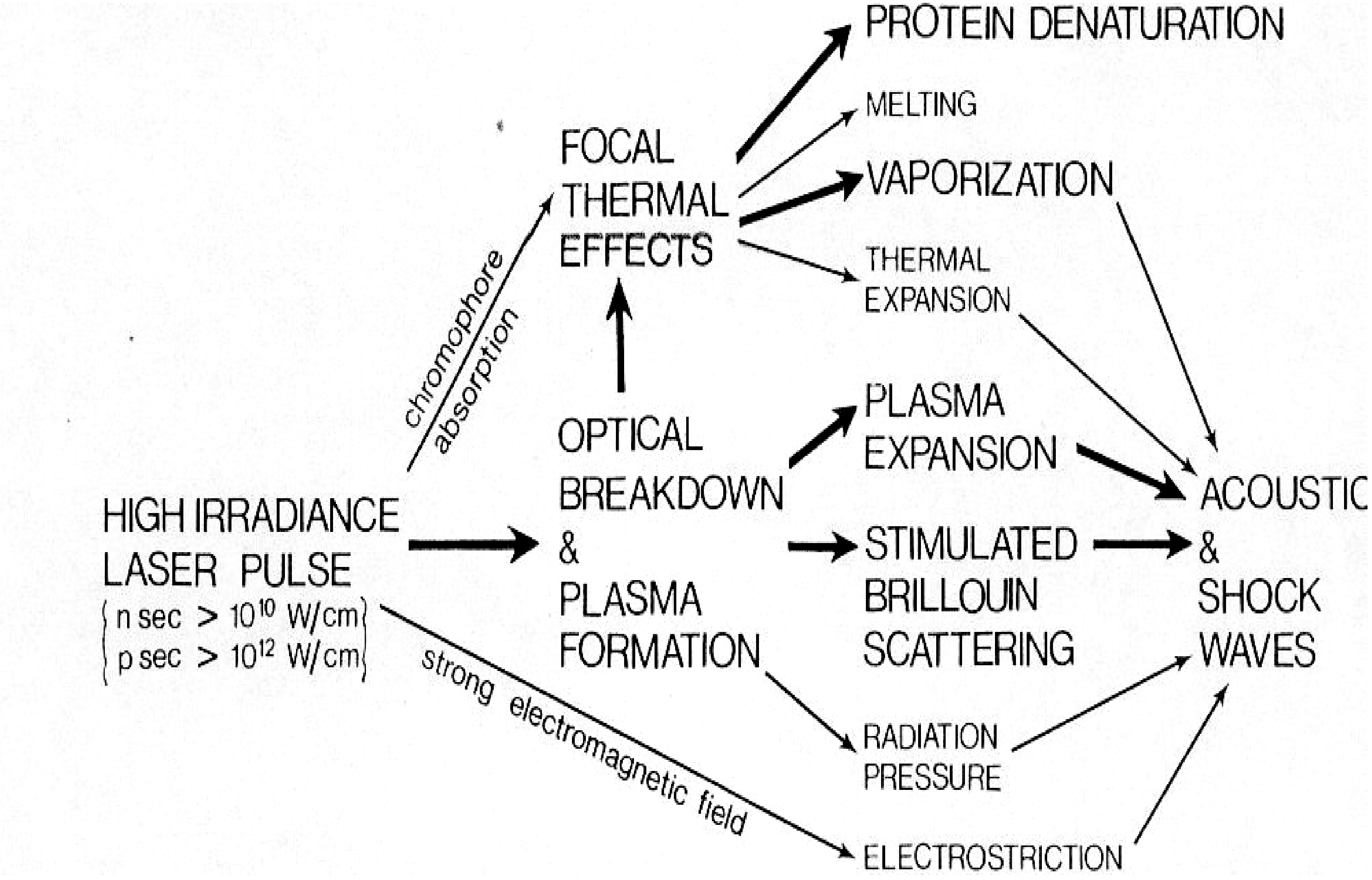
Table 116–1. THE DIVISION OF THE SPECTRUM OF OPTICAL RADIATION INTO DOMAINS WITH SIMILAR PATHOPHYSIOLOGIC ACTION

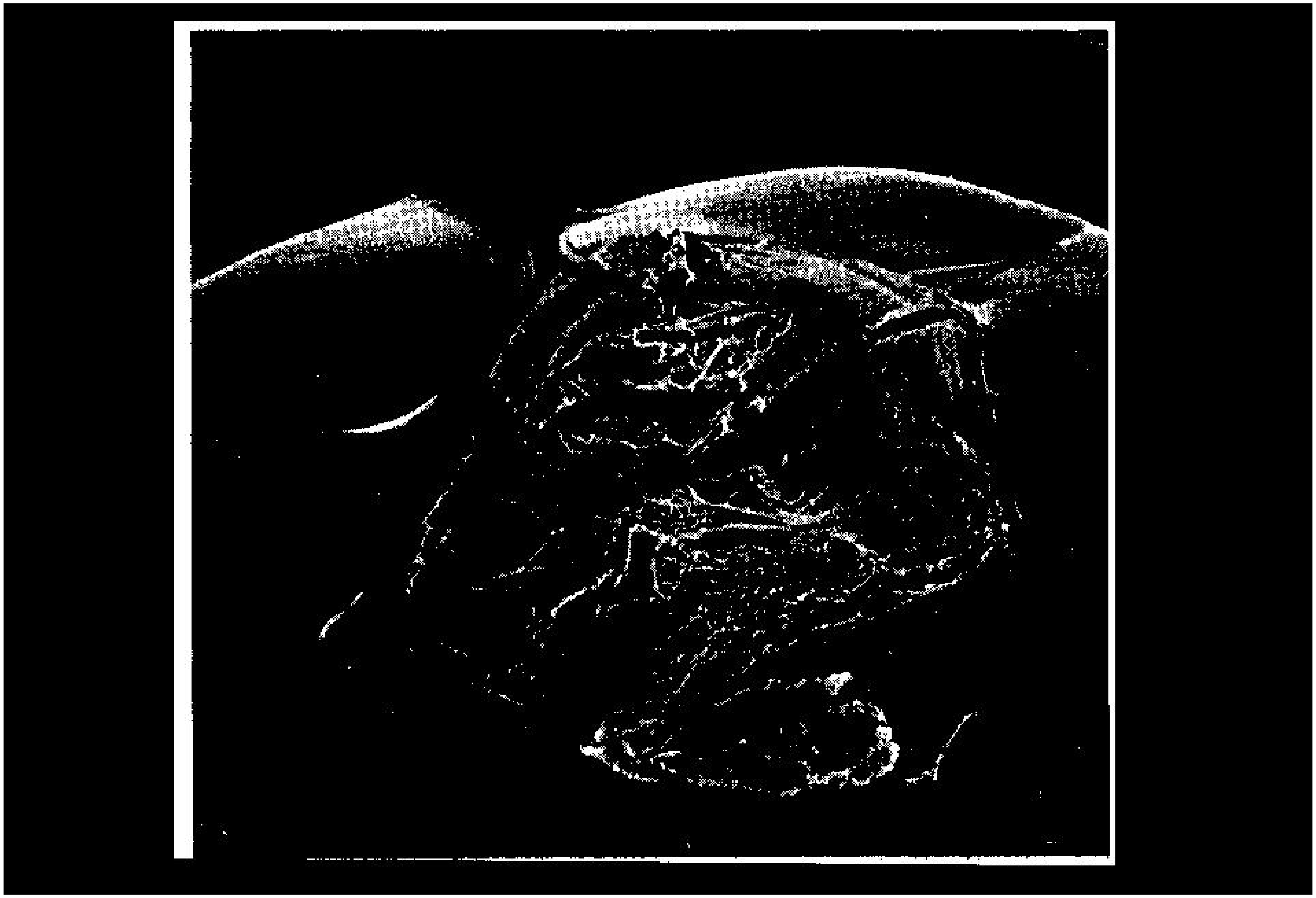
Spectral Domain	Wavelength (nm)	Tissue	Absorption Site	Nature of Damage
Ultraviolet C	200–280	Cornea	Epithelium	Photochemical: photokeratitis, corneal opacity
Ultraviolet B	280–315	Cornea	Epithelium	Photochemical: photokeratitis, corneal opacity
	295–315	Lens	Nucleus	Photochemical: cataract
Ultraviolet A	315–400	Lens	Nucleus	Photochemical: cataract(?)
Visible	400–780	Retina	RPE	Thermal (thermoacoustic): vision loss, intraocular hemorrhage
			Hemoglobin	Thermal: vision loss, intraocular hemorrhage
			Macular pigment	Thermal: central vision loss
			RPE, visual cells	Photochemical: insidious vision loss, color vision problems
Infrared A	780–1400	Retina	RPE	Thermal: vision loss
		Lens	Epithelium	Thermal: cataract
Infrared B	1400–3000	Cornea	Epithelium, stroma	Thermal: corneal opacity
		Lens(?)	Epithelium	Thermal: cataract
Infrared C	3000–10,000	Cornea	Epithelium	Thermal: superficial burns

Laser Effects on Mammal Tissue



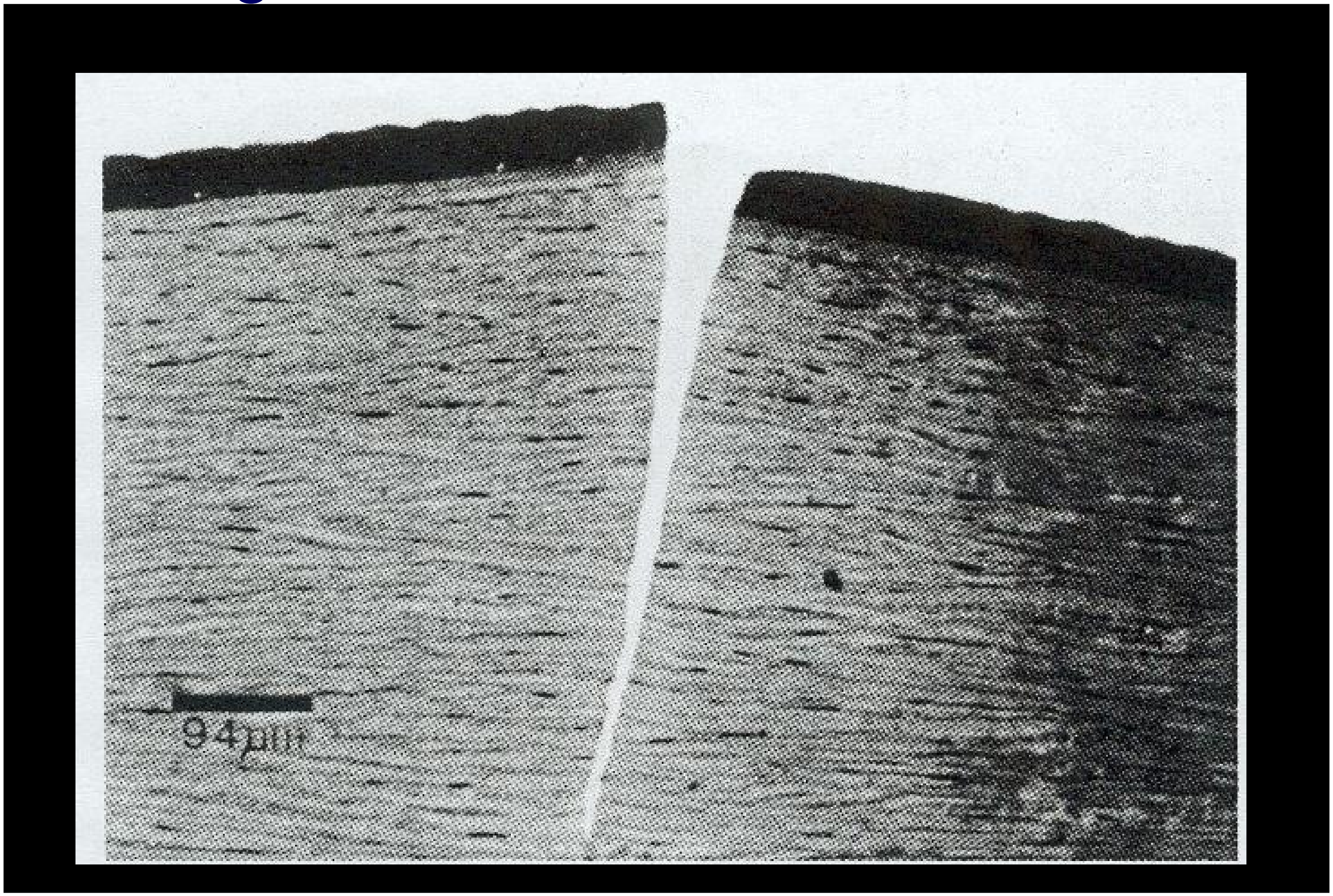
Example 1

- Burning on mammal cornea



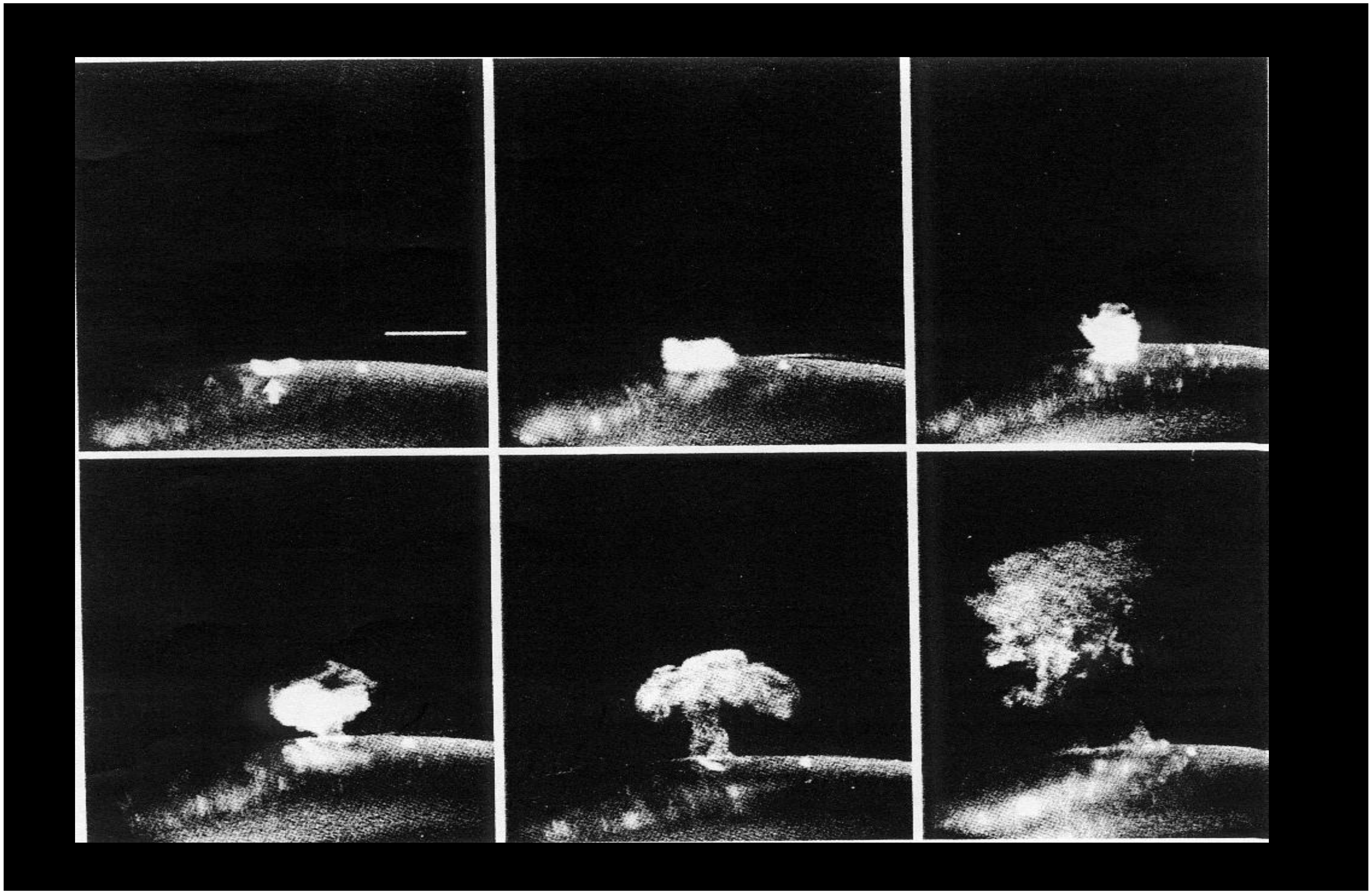
Example 2

- Cutting on mammal cornea



Example 3

- Cutting on mammal cornea



Lasers Application in Ophthalmology

- Photocoagulation
- Photodisruption
- Photorefraction

Photocoagulation

- The photocoagulation effects on eyes depend on the properties of both laser and target (tissue).

Common photocoagulation Lasers:

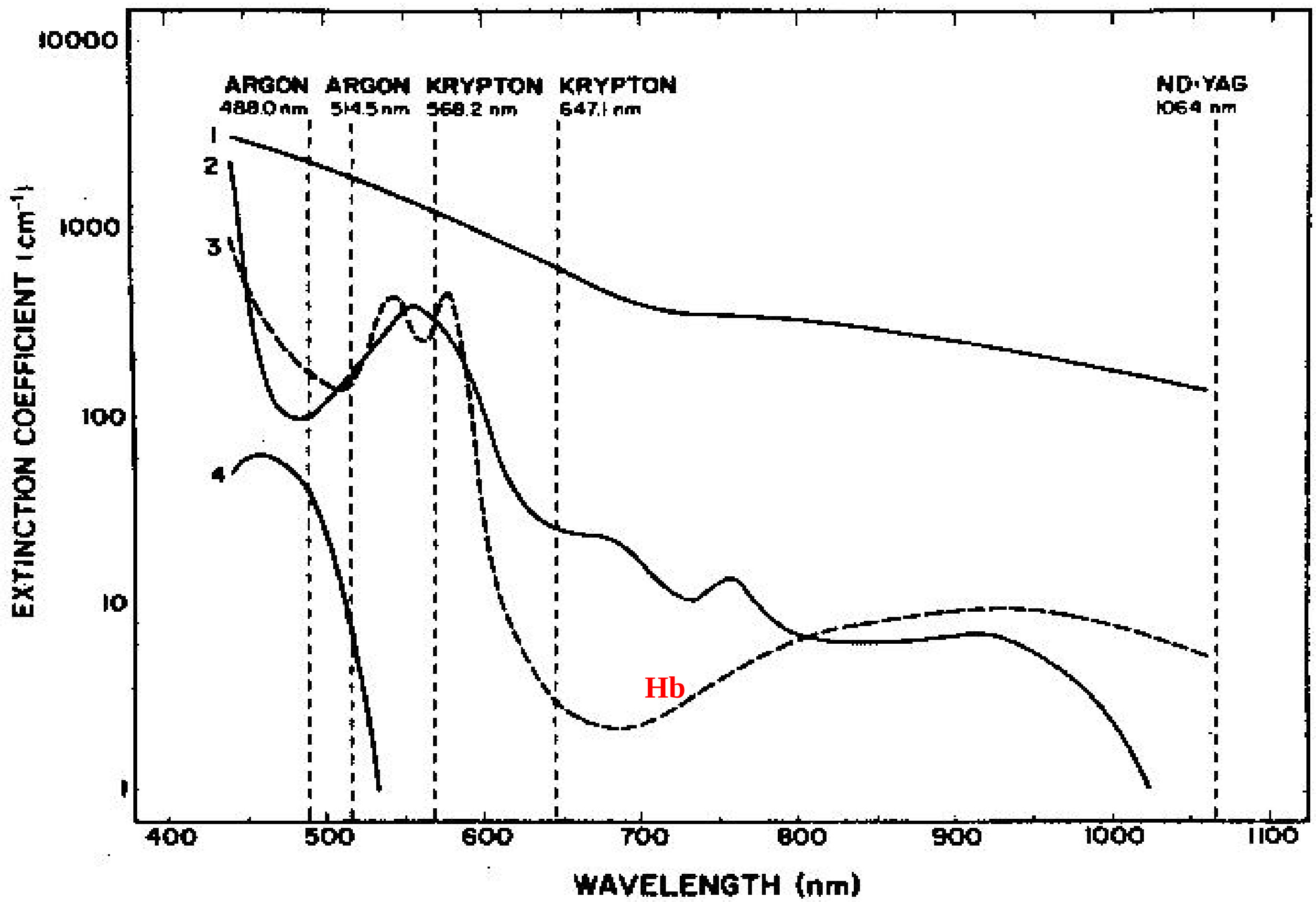
Table 117–1. PRINCIPAL WAVELENGTHS OF COMMON PHOTOCOAGULATION LASERS

Laser	Wavelength (nm)
Argon (blue-green)	488.0
Argon (green)	514.5
Frequency-doubled Nd-YAG	532.0
Krypton (yellow)	568.2
Krypton (red)	647.1
Tunable dye	Variable (most 570–630), depending on dye
Diode	Variable (most 780–850), depending on diode
Nd-YAG	1064.0

- Note: Nd:YAG laser for photocoagulation is of continuous wave.

Photocoagulation

- Extinction coefficient versus wavelength for hemoglobin



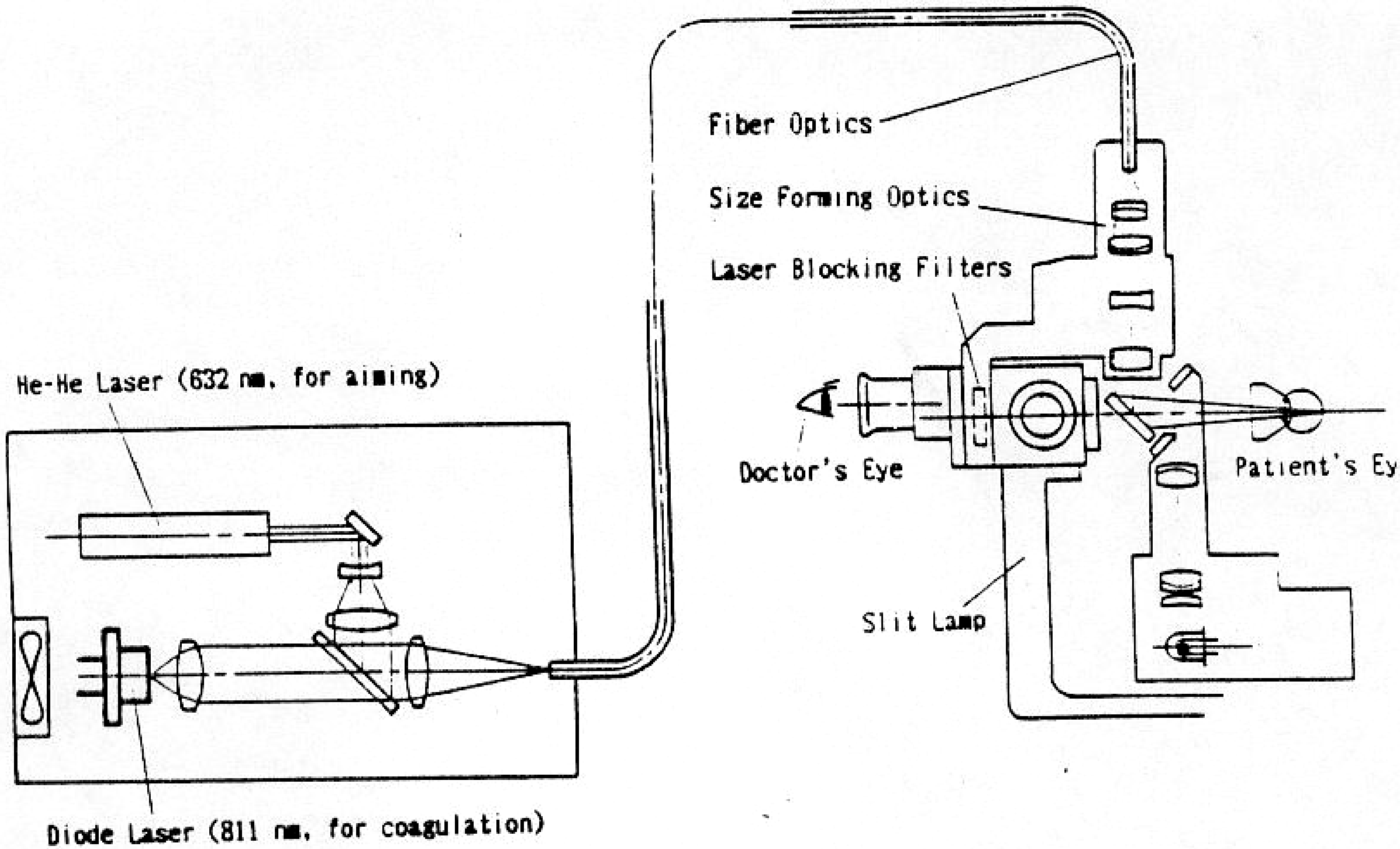
Photodisruption

- Short-pulsed YAG Laser
- Wavelength: 1064 nm
- With He-Ne laser as aiming beam

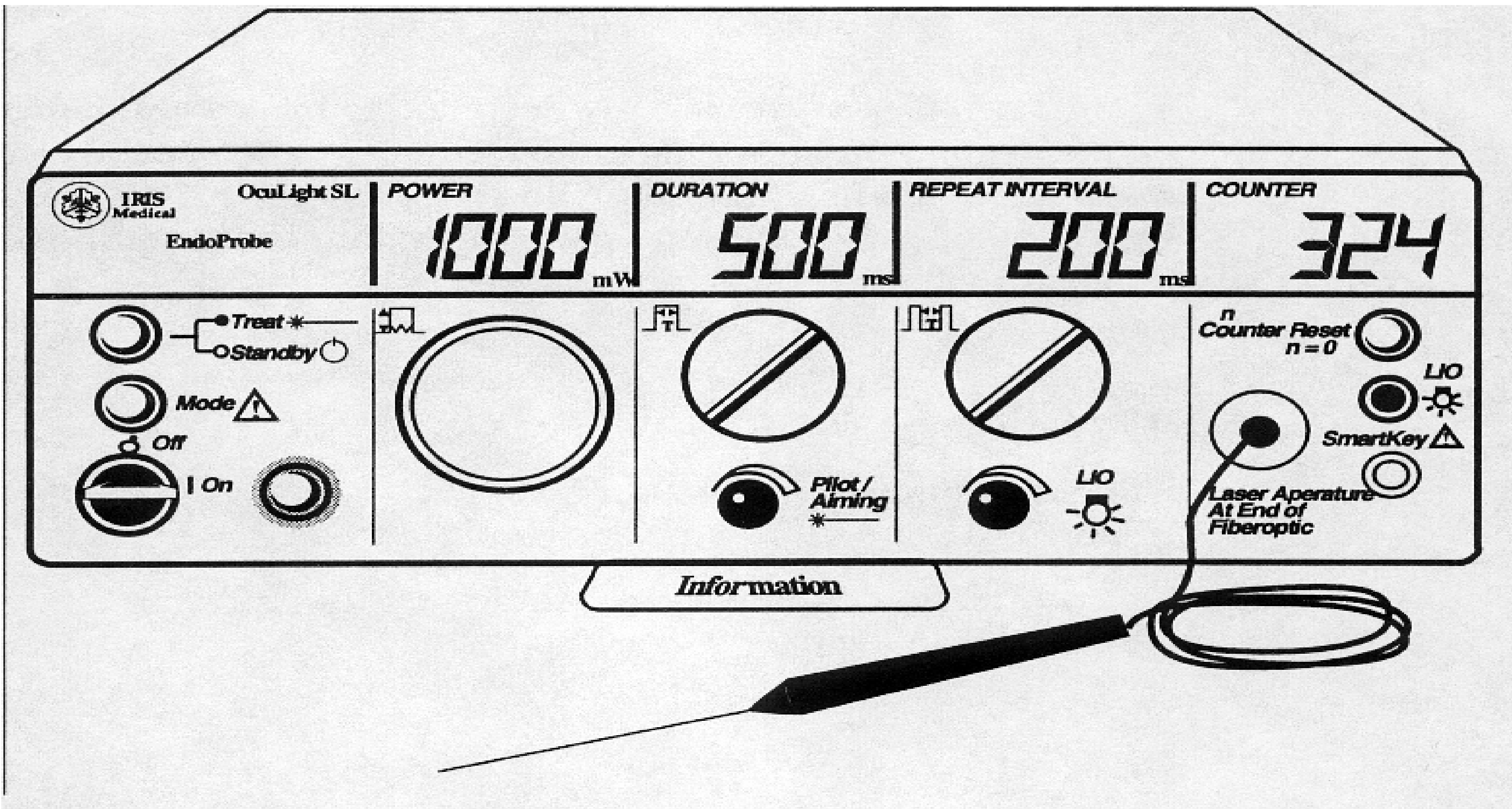
Delivery Systems

- Most ophthalmic laser systems consist of a laser module — a laser medium, laser pump, and cooling system that is typically coupled to a slit-lamp biomicroscope by a flexible fiberoptic cable.
- Other laser-energy delivery systems include indirect ophthalmoscopes, intraocular probes, and interfaces for operating microscopes.
- The ophthalmologist views the structures within the patient's eye and aims and focuses the laser through the optics of the slit lamp; when the laser is fired, the energy is delivered through these optics or through coaxial optics.

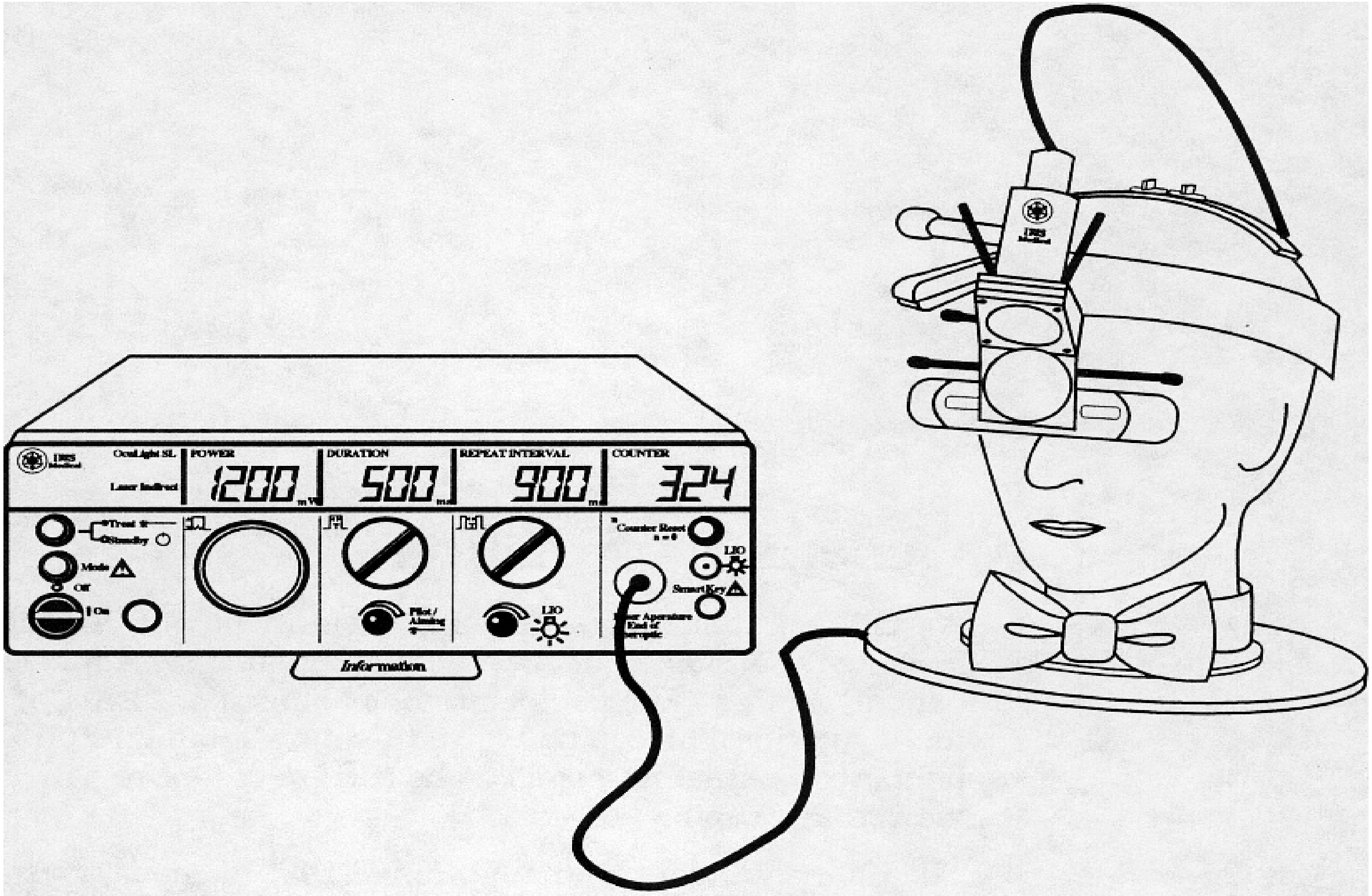
Examples of Laser Devices: Diode Laser with Slit Lamp



Diode Laser with Endoprobe



Diode Laser with Indirect Ophthalmoscope



LASER APPLICATIONS

ORBIS
saving sight worldwide

OFFICE- BASED | OPERATING THEATER

In both cases, the main parameters of interest are:

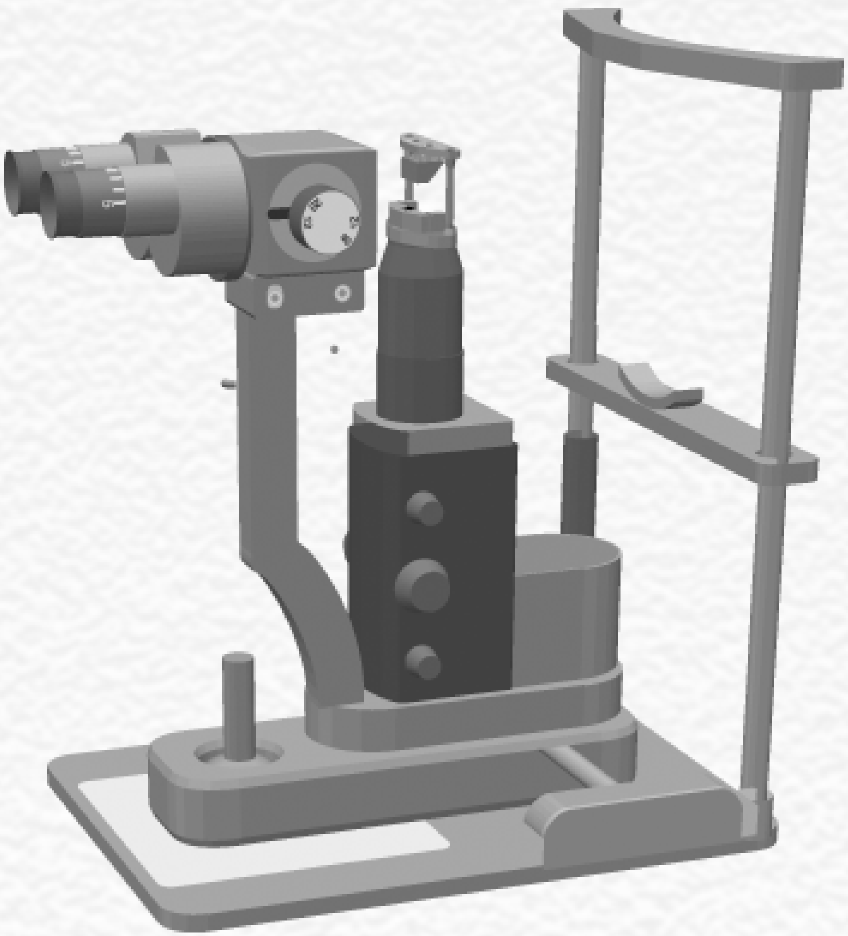
POWER - measured in Watts

EXPOSURE TIME - measured in Seconds

Typical settings:
0.5 watts power
and
0.1 seconds
exposure

LASER APPLICATIONS - Office Based

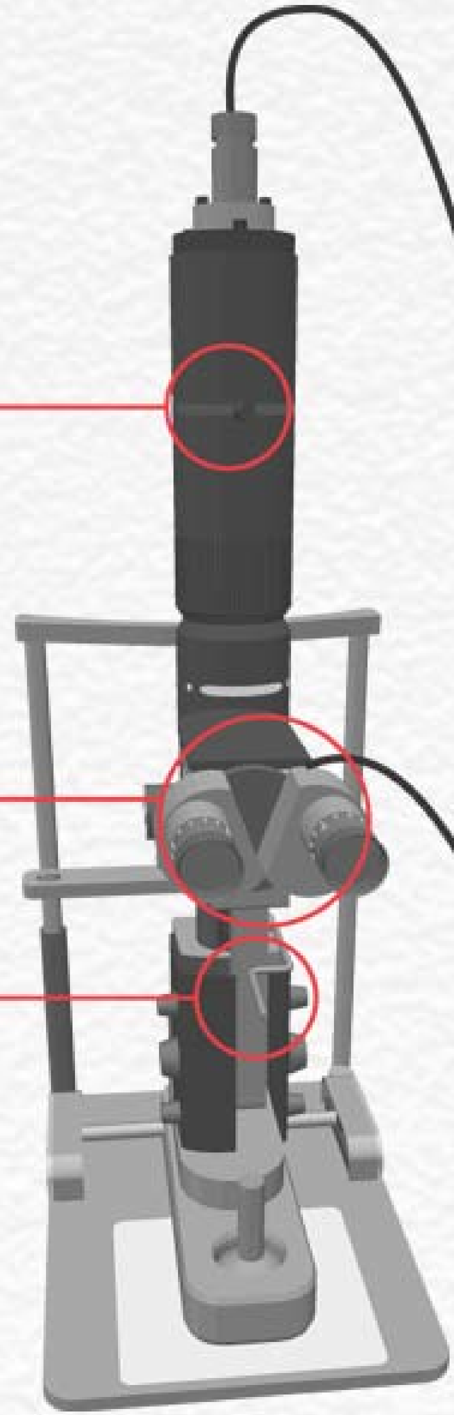
Laser is connected to a Slit Lamp, with a Laser Adaptation.

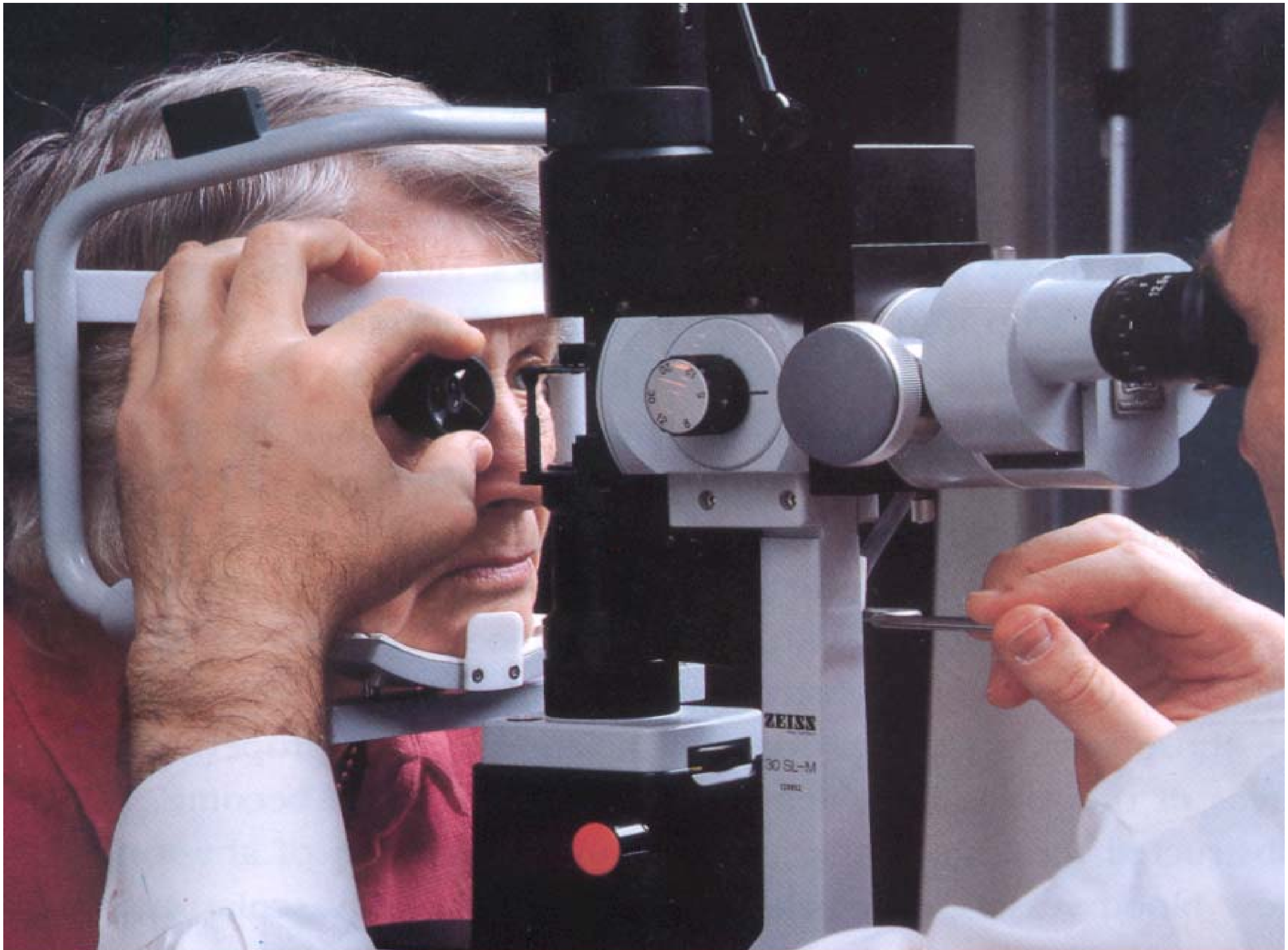


Zeiss 30 Slit Lamp

Slit Lamp with Adaptation

Slit Lamp with Laser Adaptation





patient

doctor doing laser surgery

Laser
Surgery

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LASER APPLICATIONS - Office Based

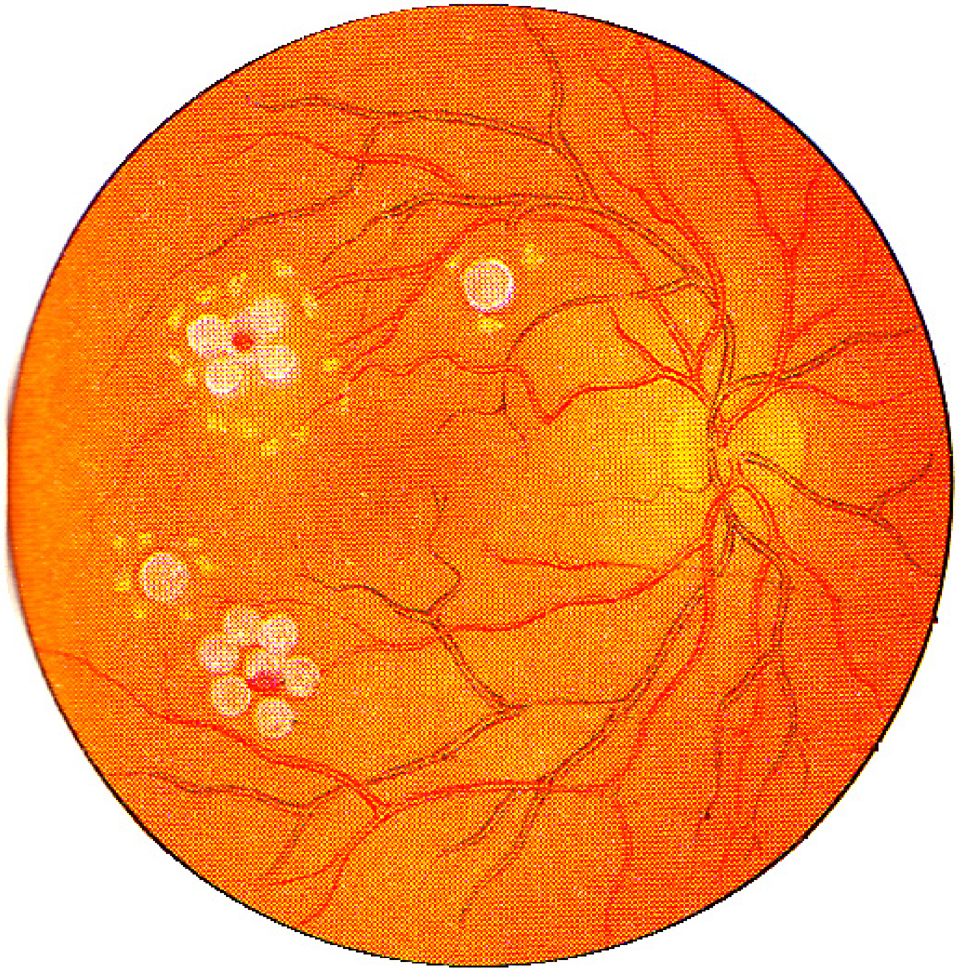
Most common treatment procedures are for:

Diabetic Retinopathy
Macular Degeneration
Retinal Tears & Detachments
Vein Oclusion

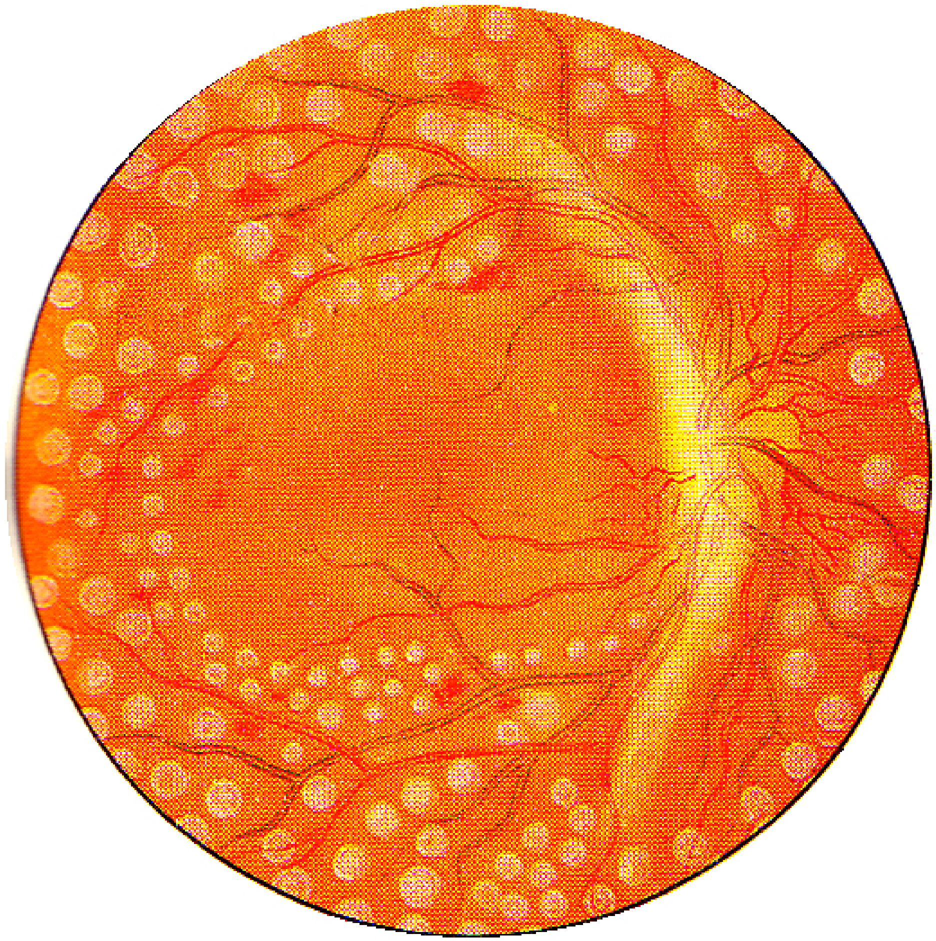
Laser treatment for these conditions involve burning a series of small spots around the retina, to seal vessels and stabilize the retina as required.

Refered to as Photocoagulation (PC).

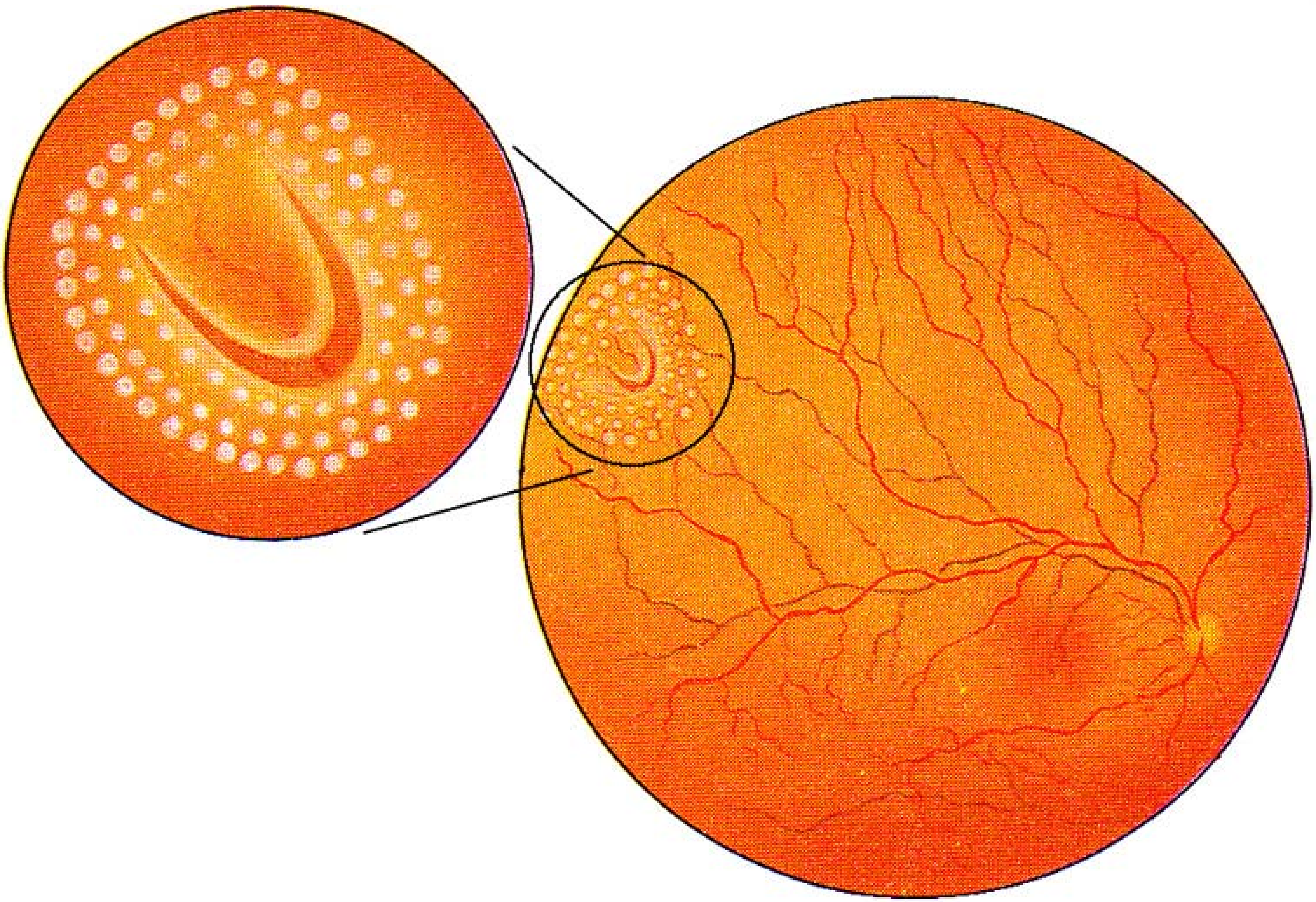
Where a large number of shots are needed, refered to as Pan-Retinal Photocoagulation (PRP).



Low-level PC to control specific problem areas.



PRP to stabilize advanced retinopathy.



Moderate PC to stabilize retinal tear.

LASER APPLICATIONS - Operating Theater

Laser used mostly in conjunction with vit surgery, to control bleeding and hemmorrhaging.

Delivery is through Endoprobe or Laser Indirect Ophthalmoscope (LIO).

Endoprobe

LIO

LASER APPLICATIONS - Endoprobes

Used with O.R. microscope, with interlocked Dr. Filter.

LASER APPLICATIONS - Ophthalmoscope

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Used with Indirect Lens.

Dr Filter element is permanently mounted in headset.

Fiber Optic connection to laser

Electric connection for illumination

Indirect Lens

LASER Safety

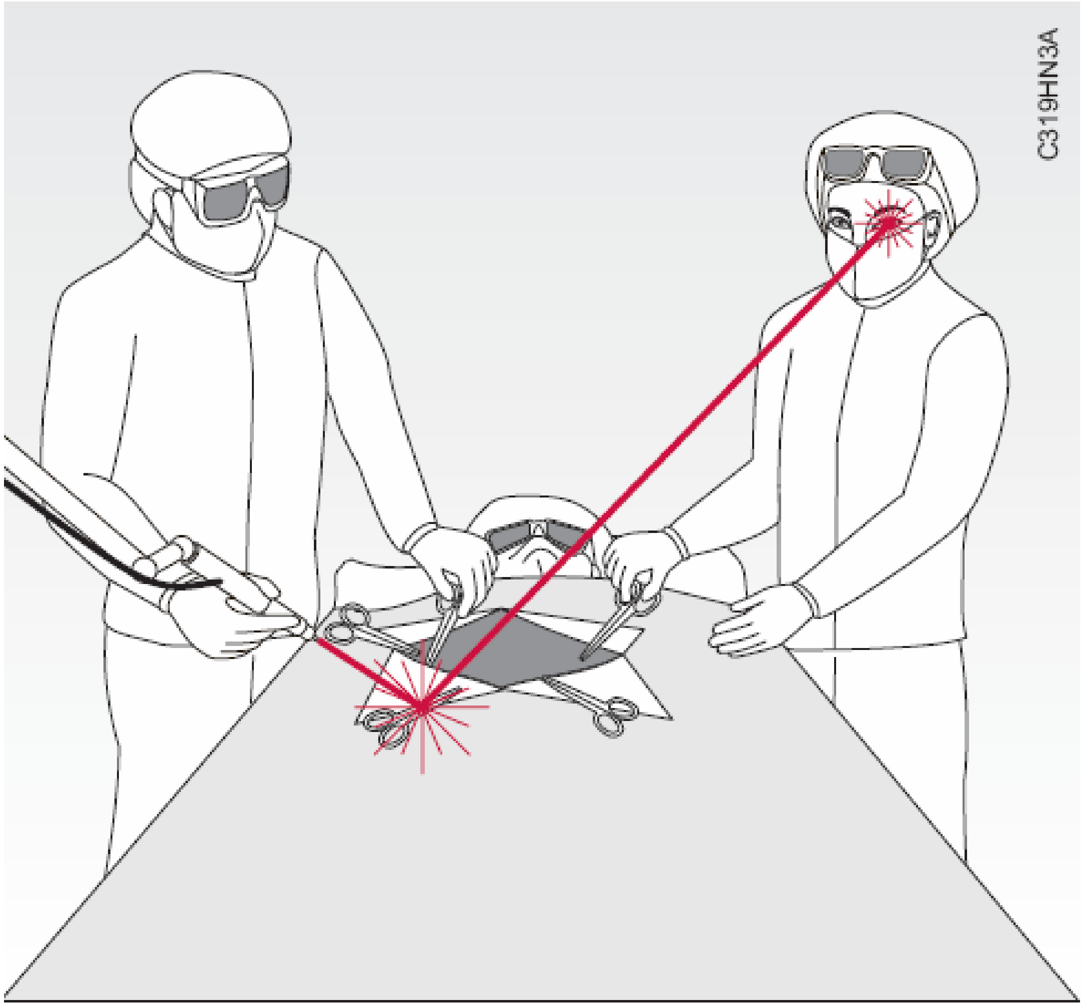

Figure . A surgical laser accident.

Reproduced from Health Devices, ECRI. April 1993 Vol. 22 No. 4

LASER Safety

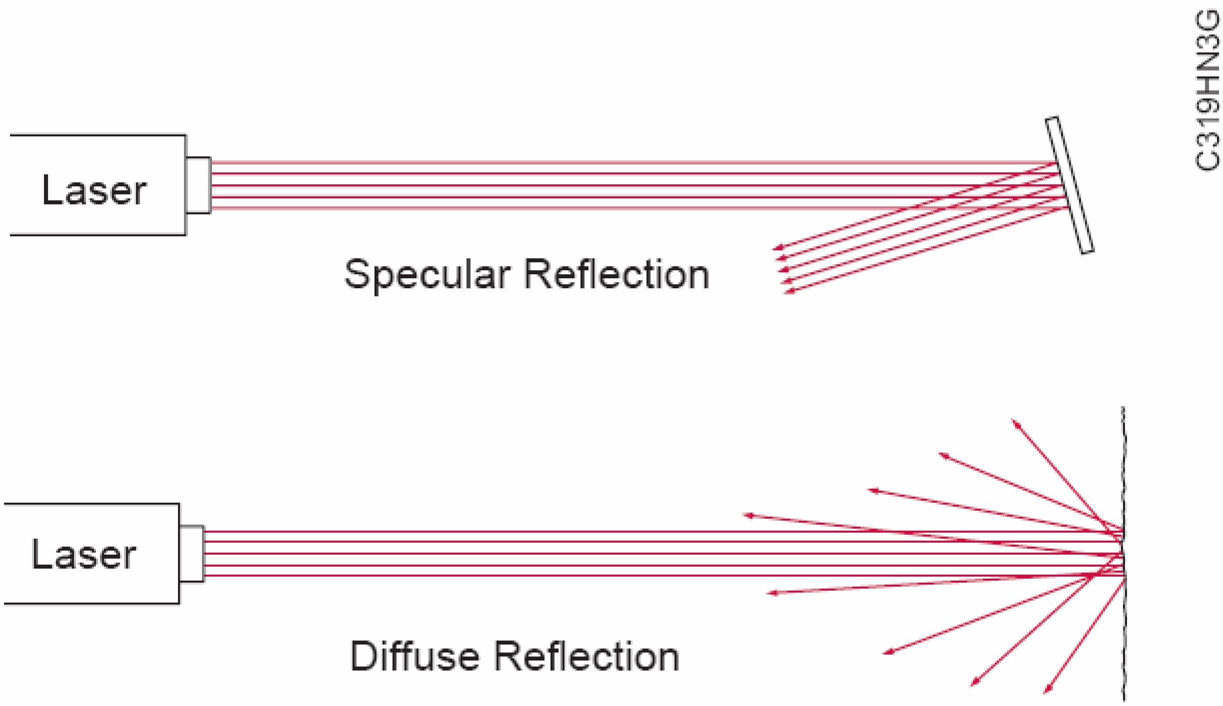

Figure . Specular reflection (top) and diffuse reflection of laser beam.

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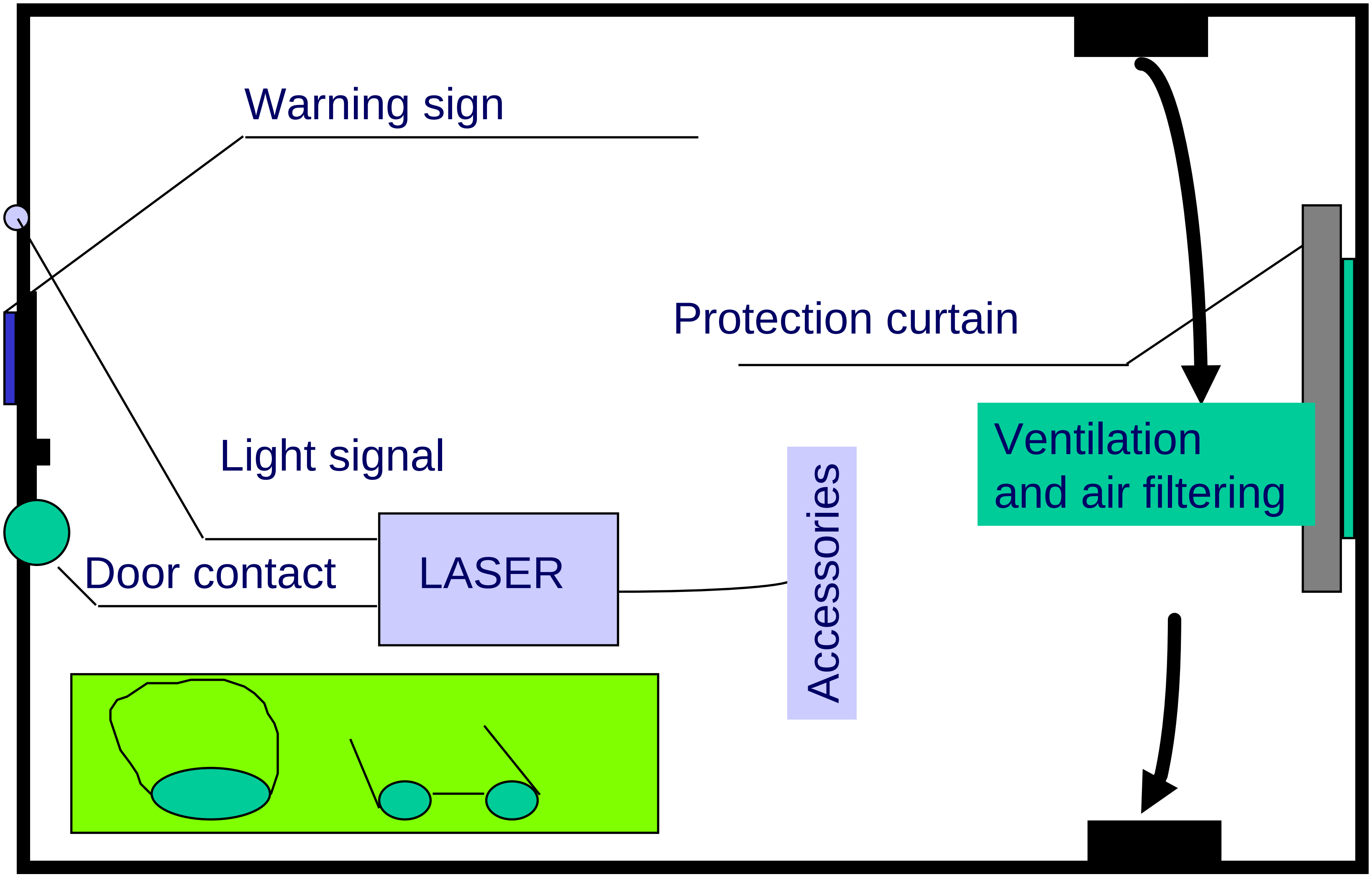
LASER SAFETY



Laser Safety -
Laser Classifications

ANSI (American National Standard Institute)

- Class I: Very low power, safe to view.
- Class II: Low power, safe to see for short time.
- Class III: Medium power, not safe for brief viewing, but no diffuse reflection hazard.
- Class IV: High power, not safe for brief viewing; reflection hazard.

Laser Safety - Safety Measures

- Safety goggles: Correct optical density for laser wavelength
- Safety signs
- Training
- Proper maintenance

Laser Safety - Safety Goggles

Photo 3.
AURA Nd:YAG Spectacles

Photo 4.
Typical Elvex Spectacles

Photo 5.
Typical Elvex Wraps

Photo 6.
Glendale CO_2 Goggles
(clear lenses)

Photo 7.
Glendale Nd:YAG Goggles

Photo 8.
Typical Glendale Spectacles
(also come with clear lenses)

Reproduced from Health Devices, ECRI. April 1993 Vol. 22 No. 4

DANGER

LASER SURGERY IN PROCESS - EYE PROTECTION REQUIRED

ARGON LASER (800 mW for 1 Seconds maximum)

Class IV

DANGER

LASER SURGERY IN PROCESS - EYE PROTECTION REQUIRED

Nd:YAG LASER (10mJ of Energy for 3nanosecond maximum)

Class IV

DANGER

LASER SURGERY IN PROCESS - EYE PROTECTION REQUIRED

ARGON LASER (2.5 Watt for 5 Seconds maximum)

Class IV

DANGER

LASER SURGERY IN PROCESS - EYE PROTECTION REQUIRED

DIODE LASER (2 Watt for 9 Seconds maximum)

Class IV

NOTICE

LASER REPAIR IN PROGRESS

Do Not Enter Unless Emergency

EYE PROTECTION REQUIRED

Laser safety summary

- The power output of some ophthalmic lasers places them in the highest category of risk (American National Standards Institute [ANSI] Class IV); stringent safety precautions are necessary to protect staff, patients, and service personnel.
- Protective shutters built into the equipment, filters incorporated into the slit-lamp biomicroscope, and divergence of the beam at the exit optics help reduce the risk of injury to clinicians during photocoagulation and/or photodisruption procedures carried out through a biomicroscope.
- Accessory lenses placed on the patient's eye during treatment should have an antireflective coating (ARC) because reflected laser light may exceed occupational exposure limits for momentary viewing if bystanders are within the laser's nominal hazard zone (the area in which direct, reflected, or scattered radiation exceeds safe exposure levels).
- When a handpiece is used in place of biomicroscopy, precautions must be taken to minimize the chance of specular reflection from instruments, which could injure observers' eyes. Protective goggles should be used, and warning signs listing the laser's type and class should be posted at all entrances to the laser suite.

Maintenance of Laser Devices

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Typical problems *:

Symptom:	Possible cause:
no laser output	power supply fiber optics cooling system
burn point is off	aiming beam is not aligned with laser beam
incorrect output power	output power need calibration fiber optics is partially broken

* manufacturer authorized maintenance is recommended

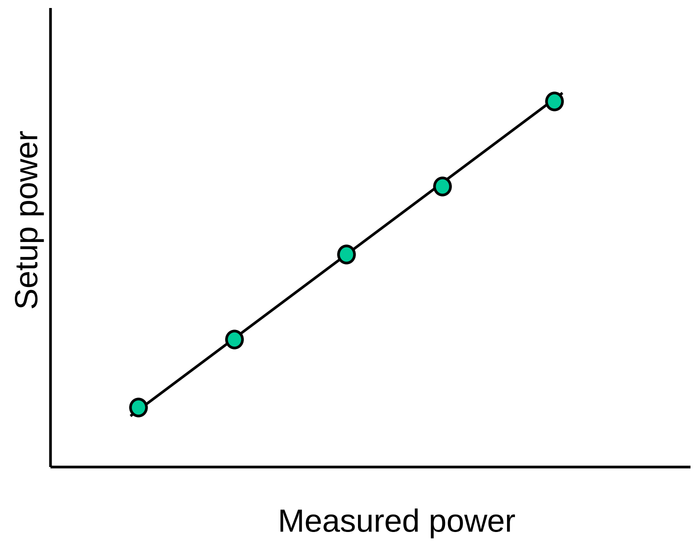
Power Calibration of Laser Devices

Tools required:

- laser power meter;
- service manual;

Basic principle:

- select testing point;
- compare the setup power with meter reading;
- adjust the output level until it meets the reading on the laser meter.



Acknowledgements

- ALCON Laboratories

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