Laser Safety

Light
Amplification by the
Stimulated
Emission of
Radiation

Brief Laser History

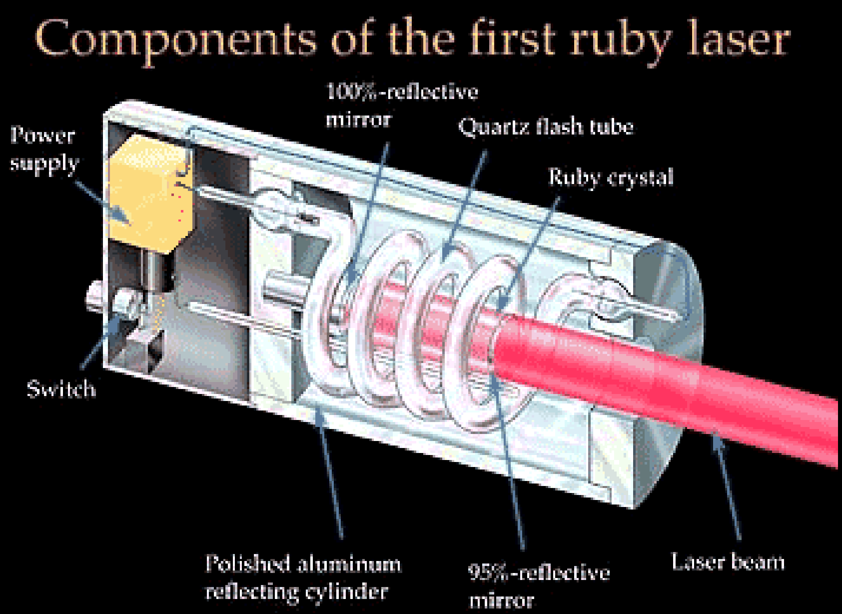
Stimulated emission, the basis of a laser beam, was first proposed in 1917, by Albert Einstein.

In 1954, American physicist Charles Townes created a device that amplified microwaves, the device was called a MASER.

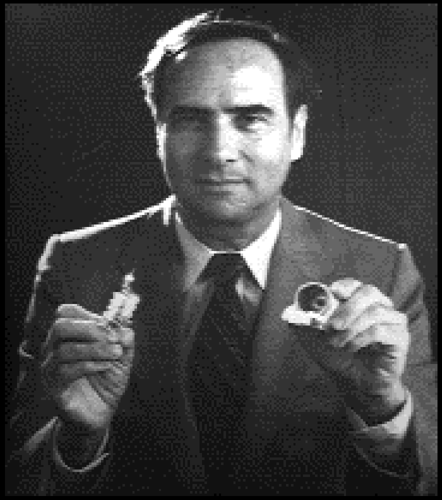
In 1960 American physicist Theodore Maiman built the first working laser with a ruby rod as the active medium, with a spiral lamp as the power source.

Iranian-born American physicist Ali Javan built a helium-neon laser a year later.

Brief Laser History



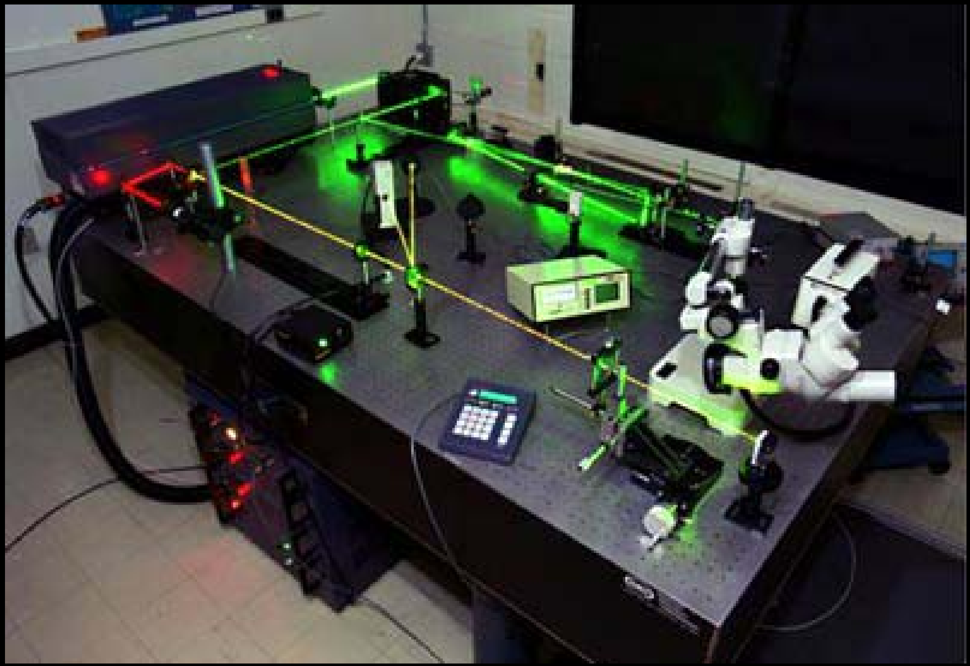
Ruby Laser Systems Laser Patent Number(s) 3,353,115



Theodore Harold Maiman
Born July 11 1927

Uses of Lasers

- Lasers are used in industry, communications, military, research and medical applications.

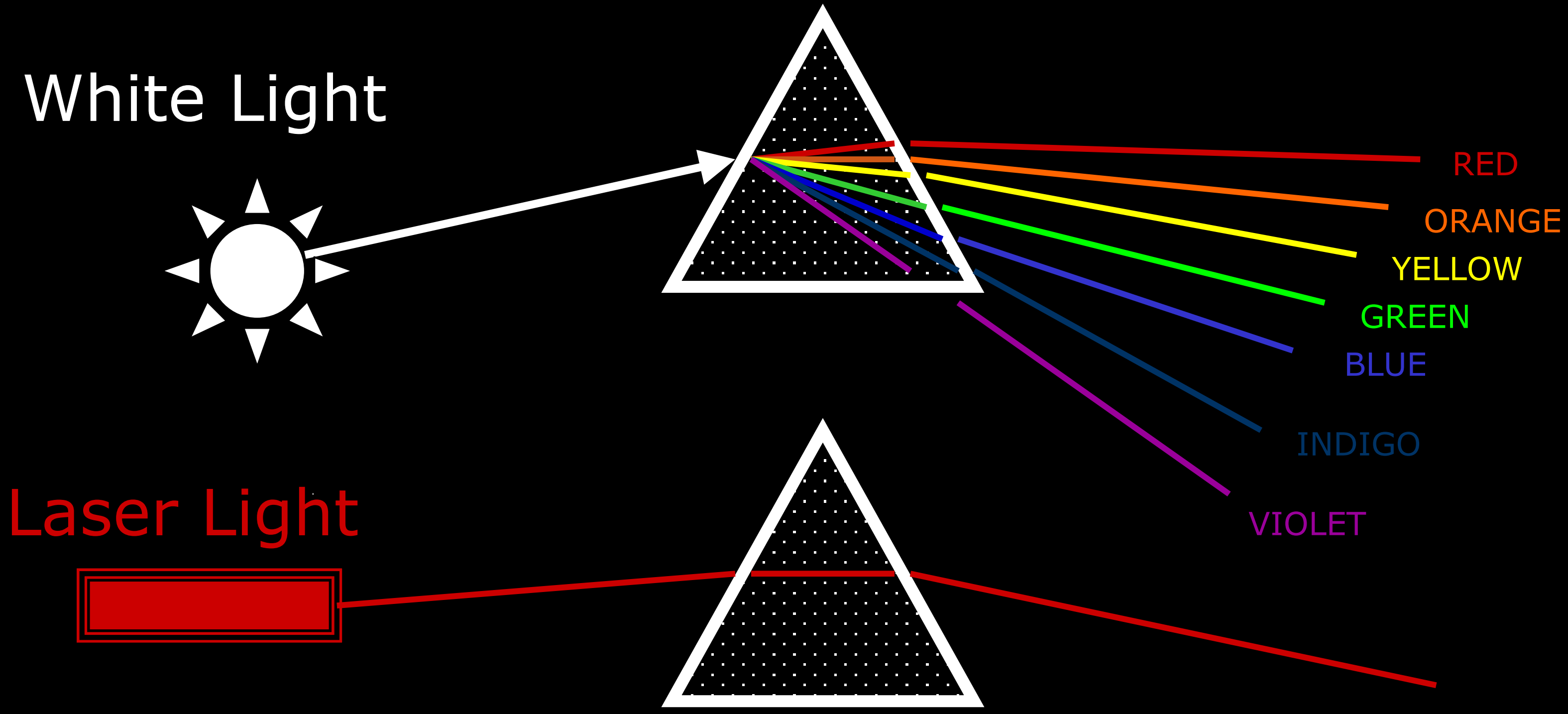


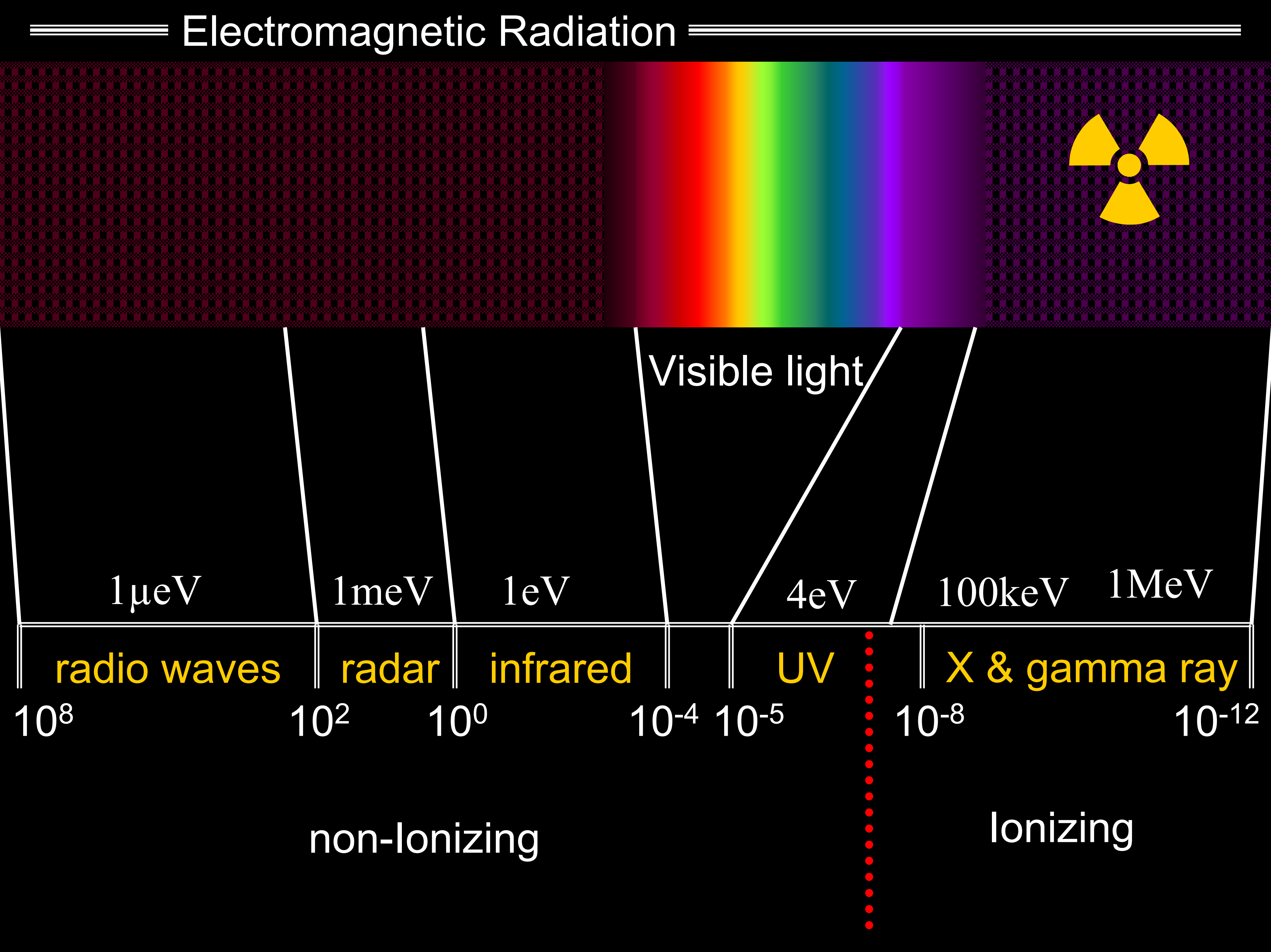
BASICS

Laser light

- Monochromatic

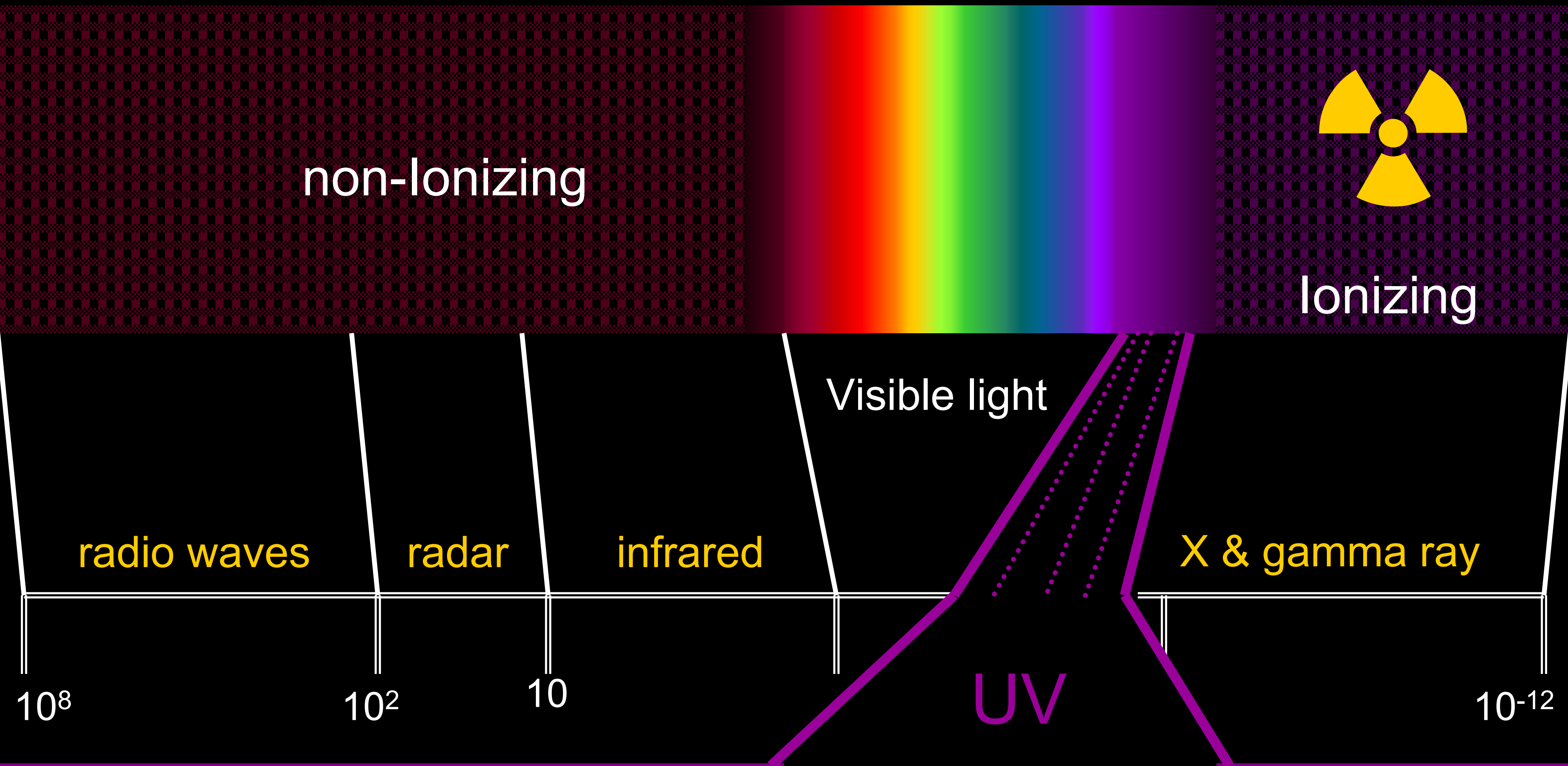
  All light is one wavelength or color





Electromagnetic Radiation
Visible light
1μeV
1meV
1eV
4eV
100keV
1MeV
radio waves
radar
infrared
UV
X & gamma ray
10^8
10^2
10^0
10^-4
10^-5
10^-8
10^-12
non-Ionizing
Ionizing

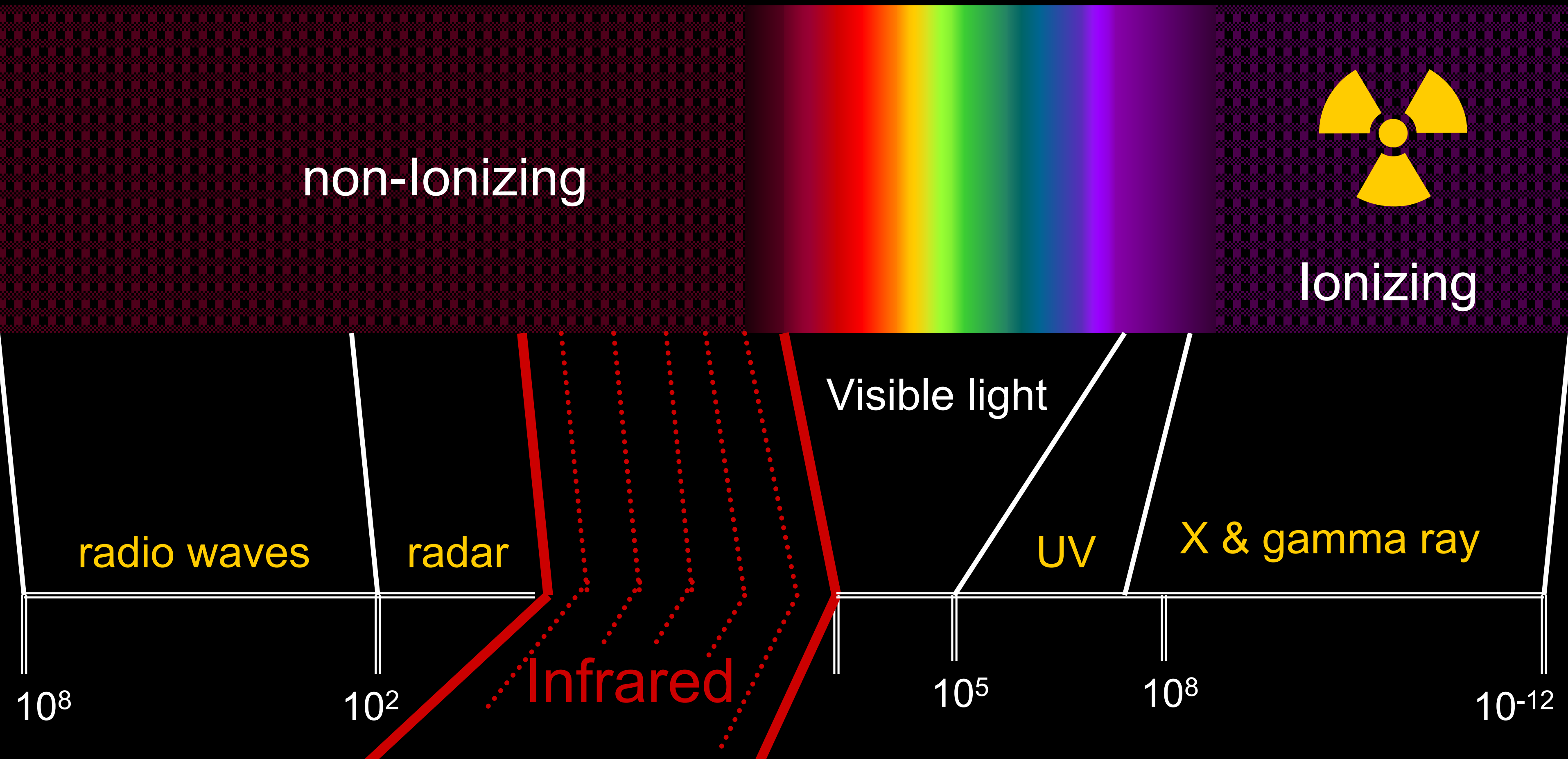
Electromagnetic Radiation



Common Ultraviolet Lasers

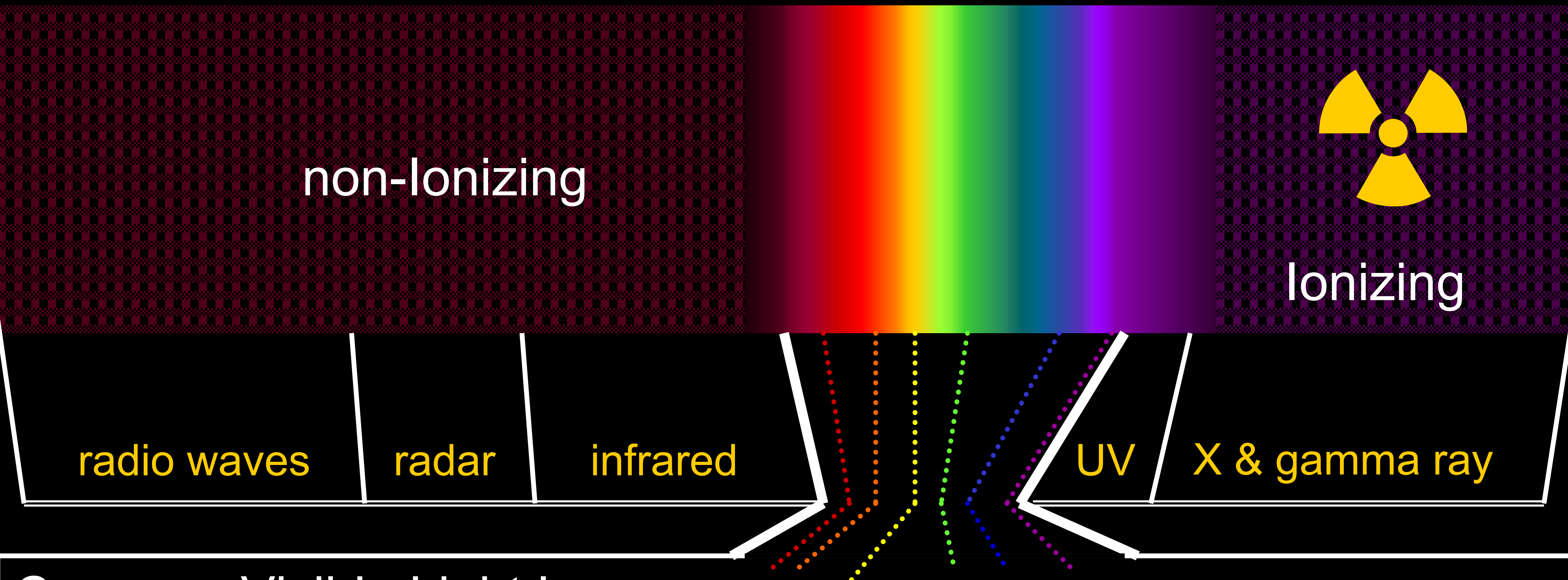
Argon fluoride	Krypton chloride	Krypton fluoride	Xenon chloride	Helium cadmium	Nitrogen	Xenon fluoride
193 nm	222 nm	248 nm	308 nm	325 nm	337 nm	351 nm

Electromagnetic Radiation



Common Infrared Lasers (near)							(far)	
Ti Sapphire	Helium neon	Nd:YAG	Helium neon	Erbium	Hydrogen fluoride	Helium neon	Carbon dioxide	Carbon dioxide
800 nm	840 nm	1,064 nm	1,150 nm	1,504 nm	2,700 nm	3,390 nm	9,600 nm	10,600 nm

Electromagnetic Radiation



Common Visible Light Lasers

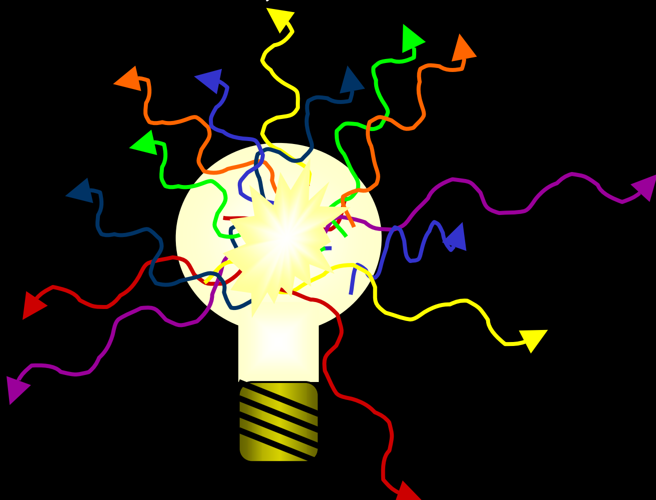
(wavelength nm)

Au vapor 627 **HeNe 633** **Kr 647** **Rohodamine (6G dye) 650** **Ruby ($CrAlO_3$) 694**	**HeNE 610**	**Kr 568** **Cu vapor 570** **Rohodamine (6G dye) 570** **HeNe 590**	**Cu vapor 510** **Ar 514** **Kr 528** **Nd YAG 532 (frequency2x)** **HeNe 543**	**Kr 476** **Ar 488**	**HeCd 441**

Laser light

Coherent

All waves of light are generated in phase with each other, the wave crests and troughs are "locked" together

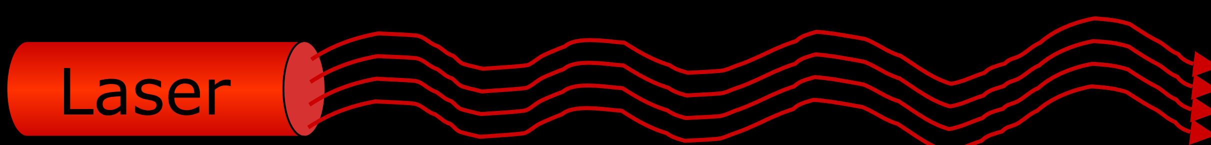


Non-coherent

- Polychromatic
- Non-directional

Coherent

- Monochromatic
- Directional



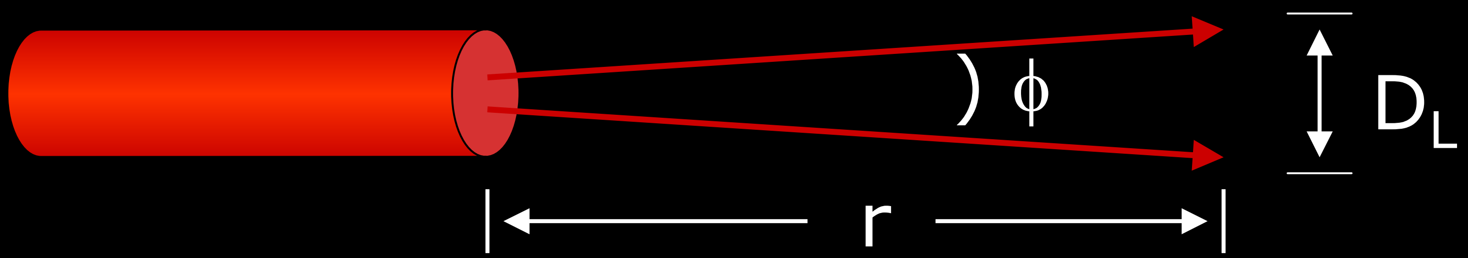
Laser light

Directional

Laser beam does not expand (diverge) as quickly as other light

Beam Divergence ϕ

- Is a natural diffraction occurrence
- Is measured in radians
- For a typical, small gas laser, it is about milliradian



$$\phi = D_L / r$$

How a Laser Works

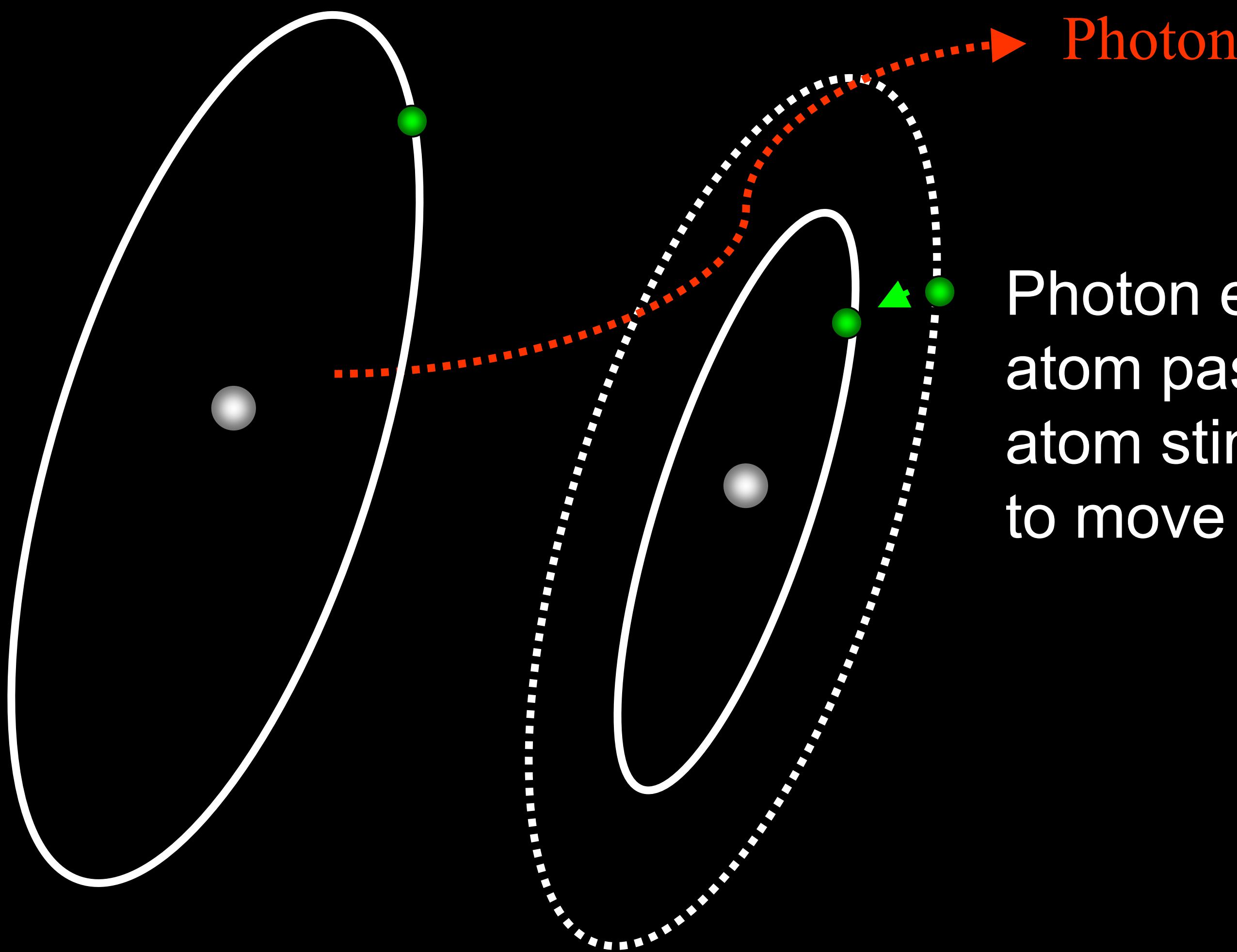
How normal light is produced

- electrons in atoms move from larger orbits to smaller orbits
- vast number of atoms are excited
- light emitted at random times, random directions, different wavelengths

How a Laser Works

How laser light is produced

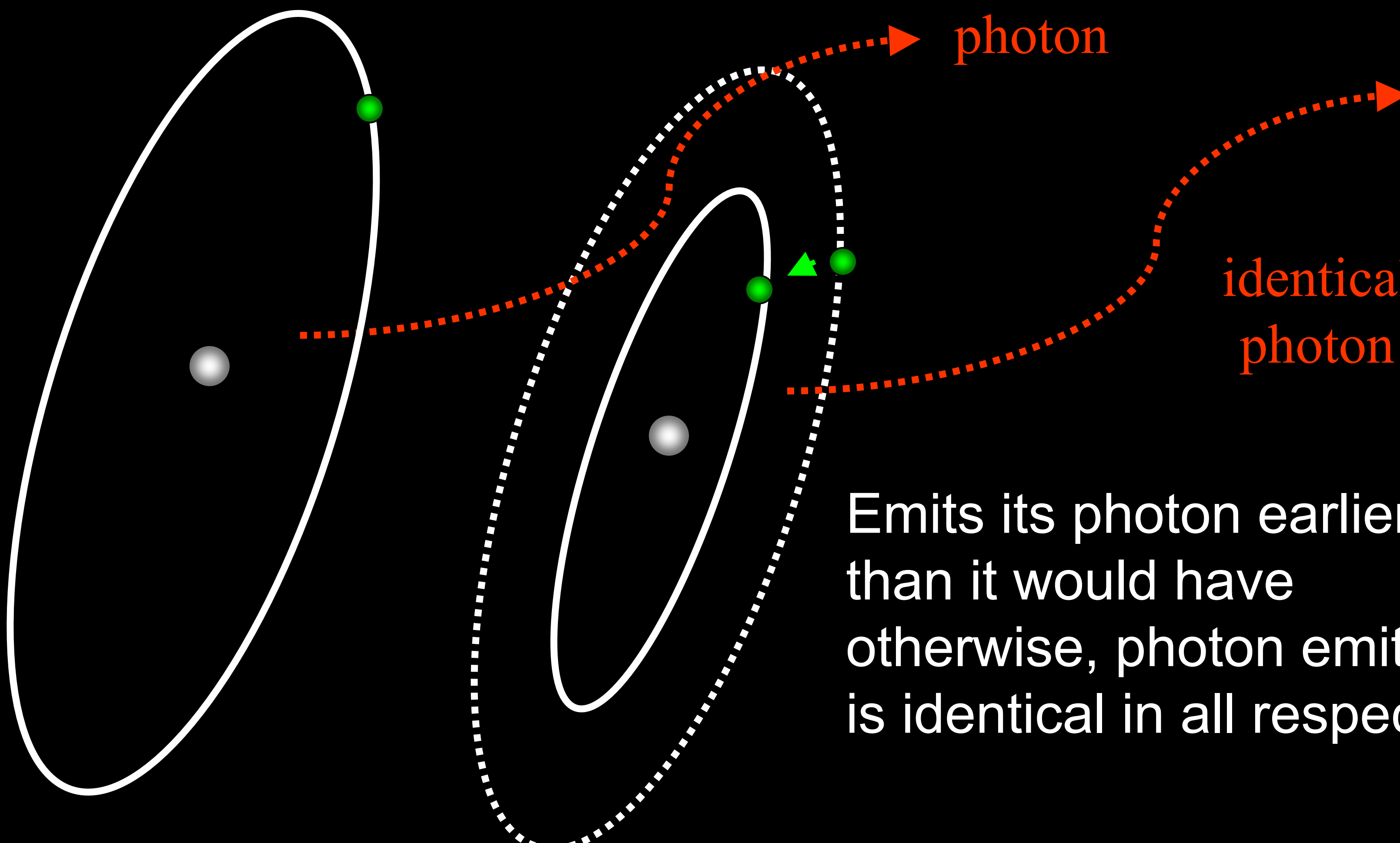
Stimulated Absorption



Photon emitted by one atom passes nearby atom stimulates electron to move to smaller orbit

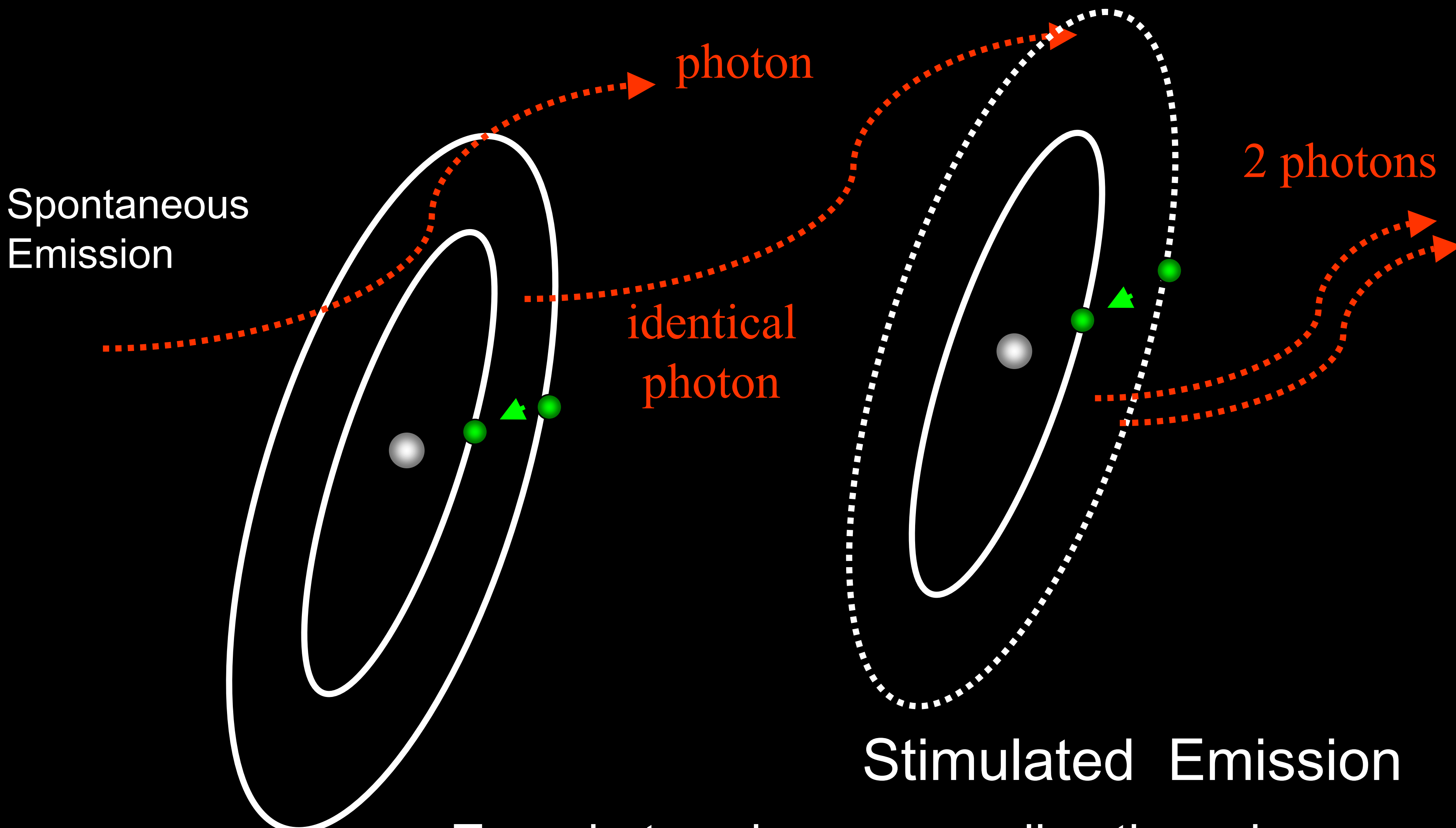
How a Laser Works

Spontaneous Emission



Emits its photon earlier than it would have otherwise, photon emitted is identical in all respects

How a Laser Works



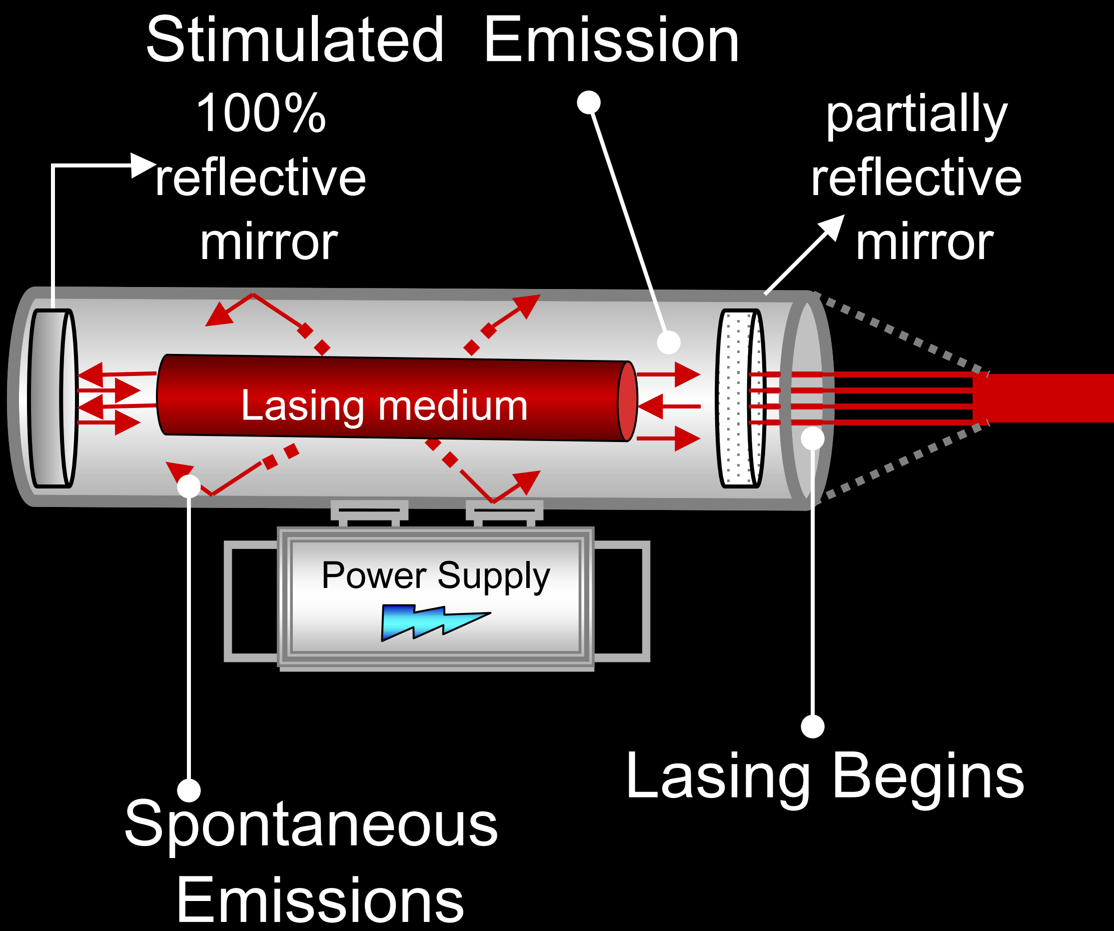
Two photons have same direction, phases, polarization, wavelength and energy

How a Laser Works

Active medium
- Solid State
- Semiconductor (diode)
- Liquid (dye)
- Gas (Excimer)

Excitation Mechanism
- Optical
- Electrical
- Chemical

Optical Resonator
- Resonator Mirrors
- Partially Reflective Mirror



Types of Lasers

Lasers can be described by:

- which part of the electromagnetic spectrum is represented:
  - Infrared
  - Visible Spectrum
  - Ultraviolet
- the length of time the beam is active:
  - Continuous Wave (CW)
  - Pulsed
  - Ultra-short Pulsed

Types of Lasers

Solid-State Lasers

Group of optically clear materials

Composed of a “host” crystal with an impurity “dopant”

- Operate in either pulsed or CW mode
- Energy input in form of bright light
- Light is absorbed by dopant
- Lasing occurs when atoms or ions return to normal energy states

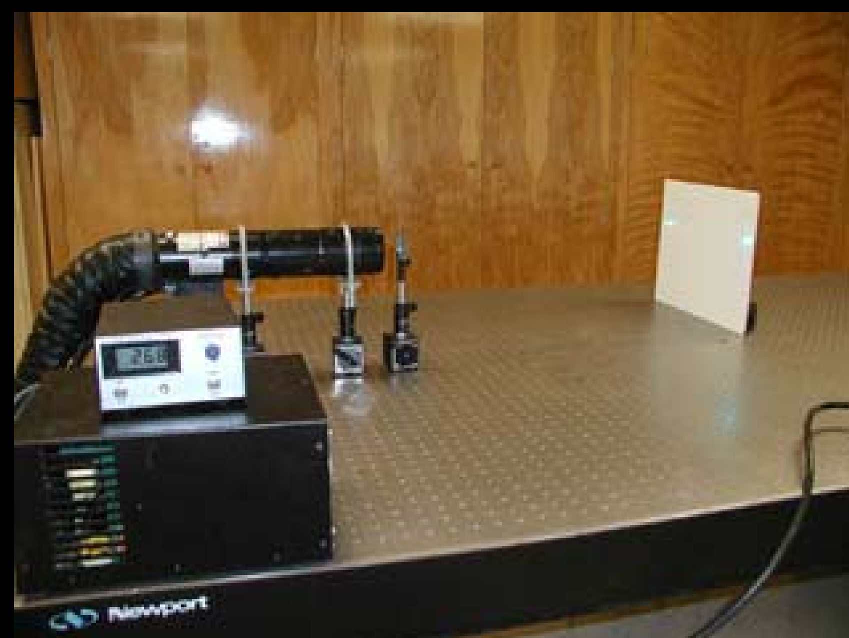
Types of Lasers

Gas Lasers

Generally operated as Continuous Wave (CW)

Most common gas lasers are:

- CO_2
- Argon
- HeNe
- Excimer



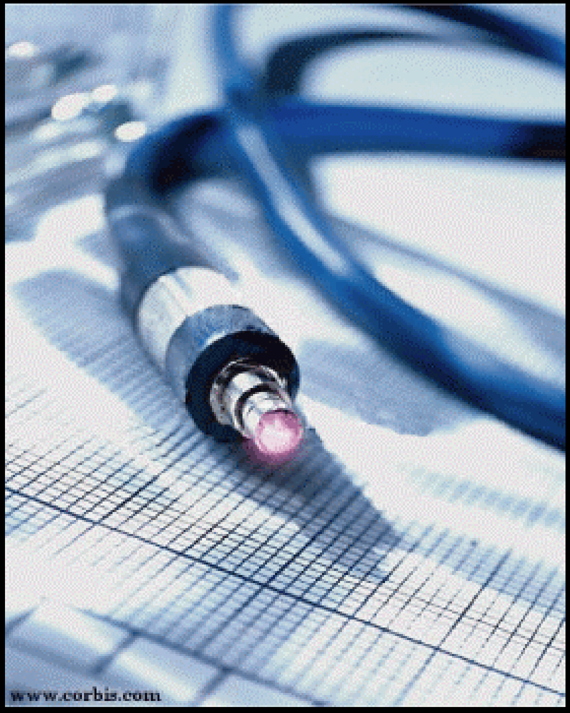
Types of Lasers

Semiconductor (Diode)

Most common laser today

- GaAlAs (Gallium/Aluminum/Arsenide)
  750-950 nm range

- InGaAsP (Indium/Phosphorus)
  1100-1650 nm range



Types of Lasers

Liquid (dye)

- Utilize a flowing dye
- Pumped by flash-lamp of other laser
- Operate as CW or pulsed
- Have tunable wavelengths

Radiometric Terms and Units

The light emitted by a laser is *non-ionizing electromagnetic radiation, that is, ultraviolet, visible, or infrared light.

Radiant Energy (Q)

-Energy emitted, transferred, or received in the form of *radiation

Unit: joule [J]

Radiometric Terms and Units

Radiant Power (Φ)

-Power emitted, transferred, or received in the form of *radiation

-Equal to the radiant energy (Q) divided by the corresponding time interval

-Also called radiant flux

Unit: watt [W]

Radiometric Terms and Units

Radiant Exposure (H)

-Radiant energy (Q) striking a surface divided by the area of that surface over which the radiant energy is distributed

Unit: joules per square centimeter [Jcm^{-2}]

Radiometric Terms and Units

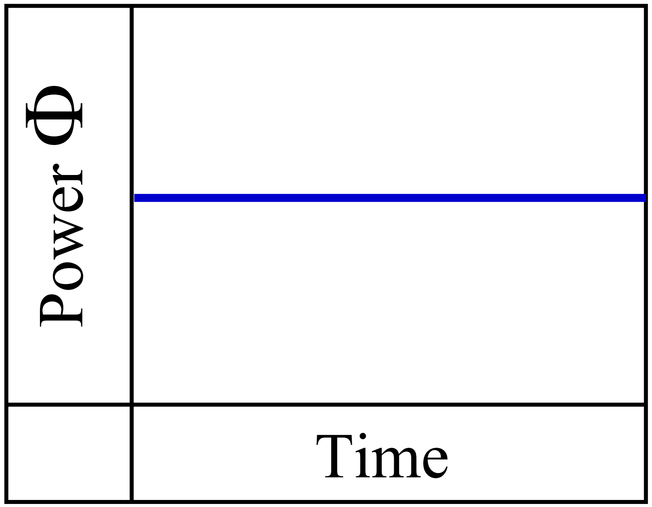
Irradiance (E)

-Radiant power (Φ) striking a surface, divided by the area of that surface over which the radiant power is distributed

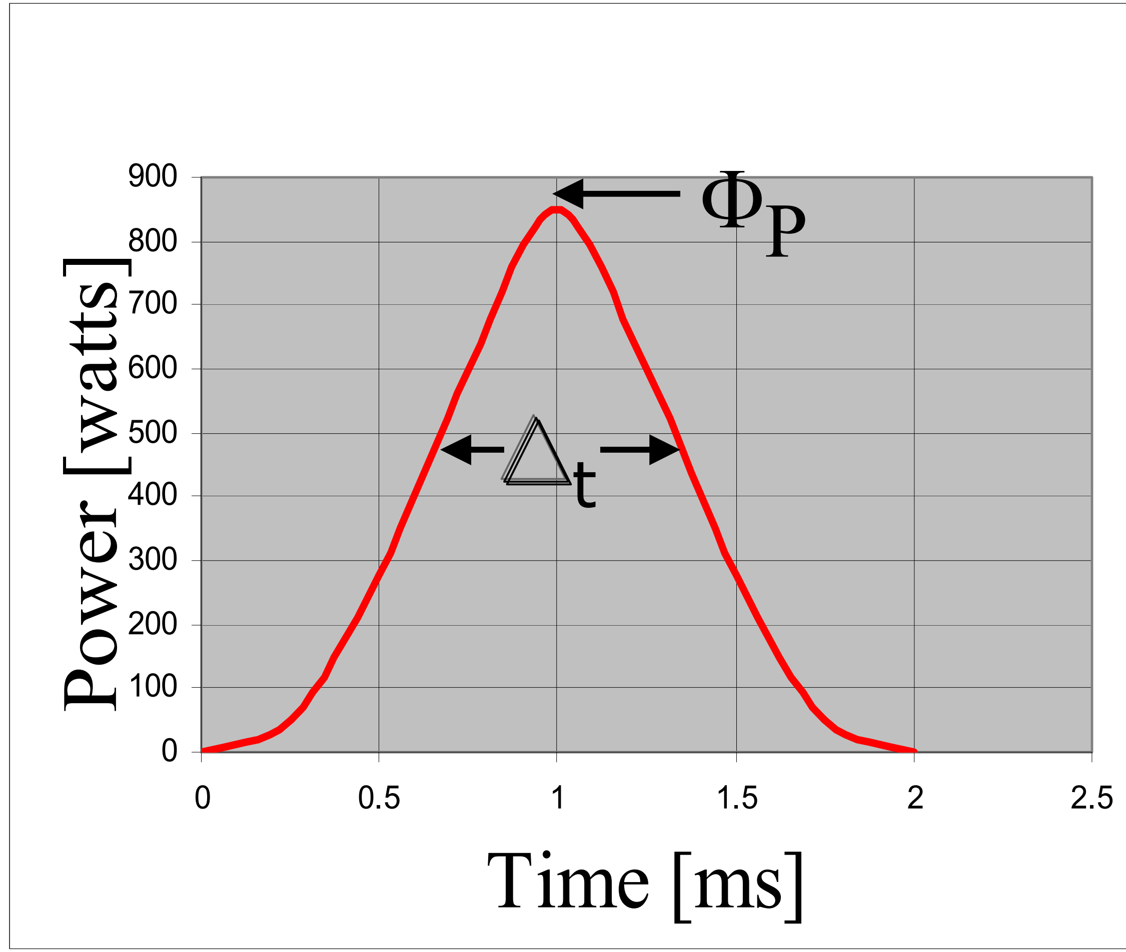
-Radiant exposure divided by the corresponding time interval

Unit: watts per square centimeter [Wcm^{-2}]

Characterizing Laser Output



Power vs. Time for Continuous Wave (CW) Laser

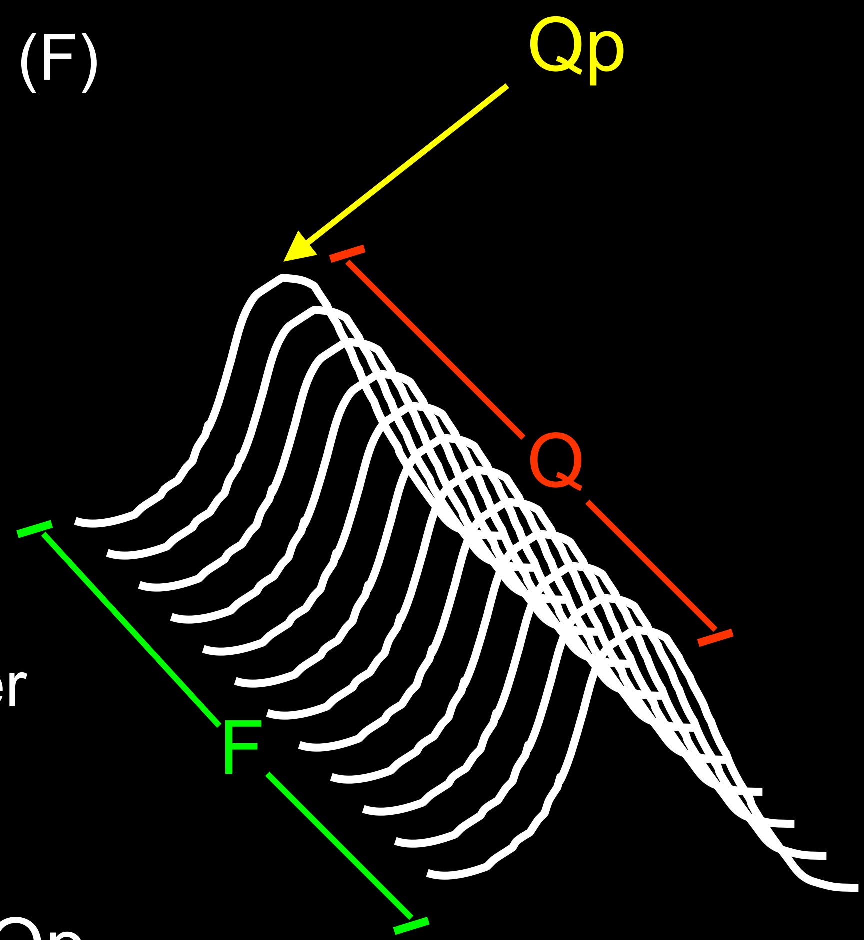


Power vs. Time for Single Pulse Laser

Characterizing the Laser Output

Pulse repetition frequency (F)

-measured in Hertz (Hz)
-20 Hz = 20 pulses/s



(Qp) is the energy of a single pulse

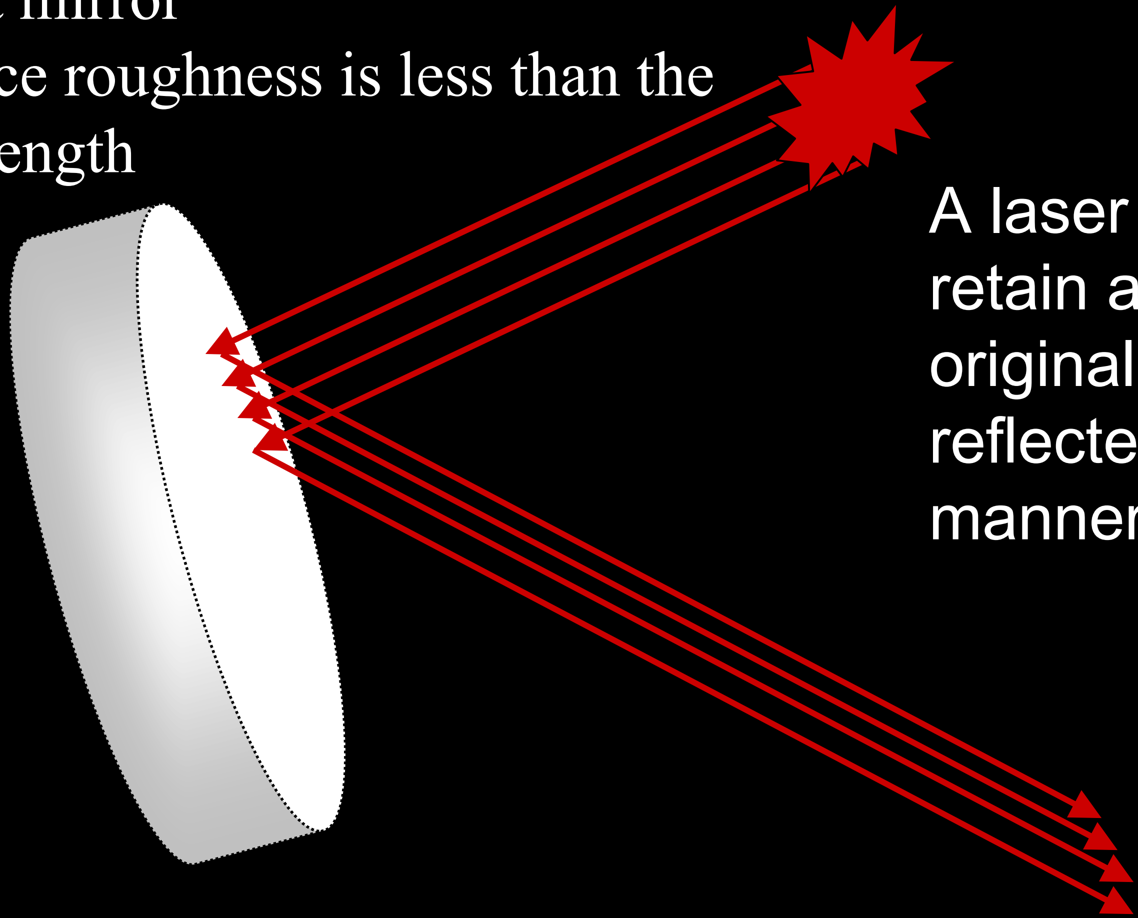
Total energy, Q = Qp x number of pulses

Average power, $\Phi_a = F \times Qp$

The interaction of light and matter

Specular Reflection

- like a mirror
- surface roughness is less than the wavelength



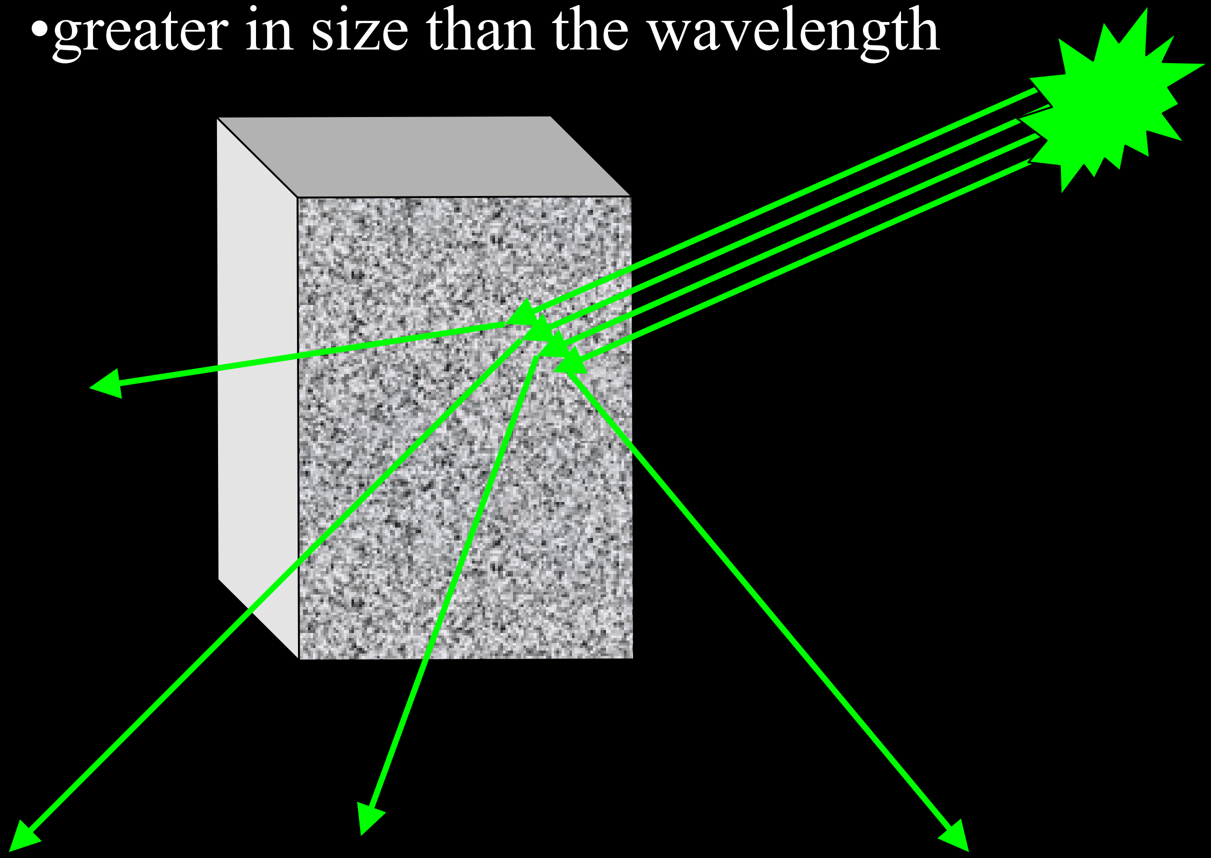
A laser beam will retain all of its original power when reflected in this manner.

–Note that surfaces which appear dull to the eye may be specular reflectors of IR wavelengths.

The interaction of light and matter

Diffuse Reflection

- surface irregularities are randomly oriented
- greater in size than the wavelength

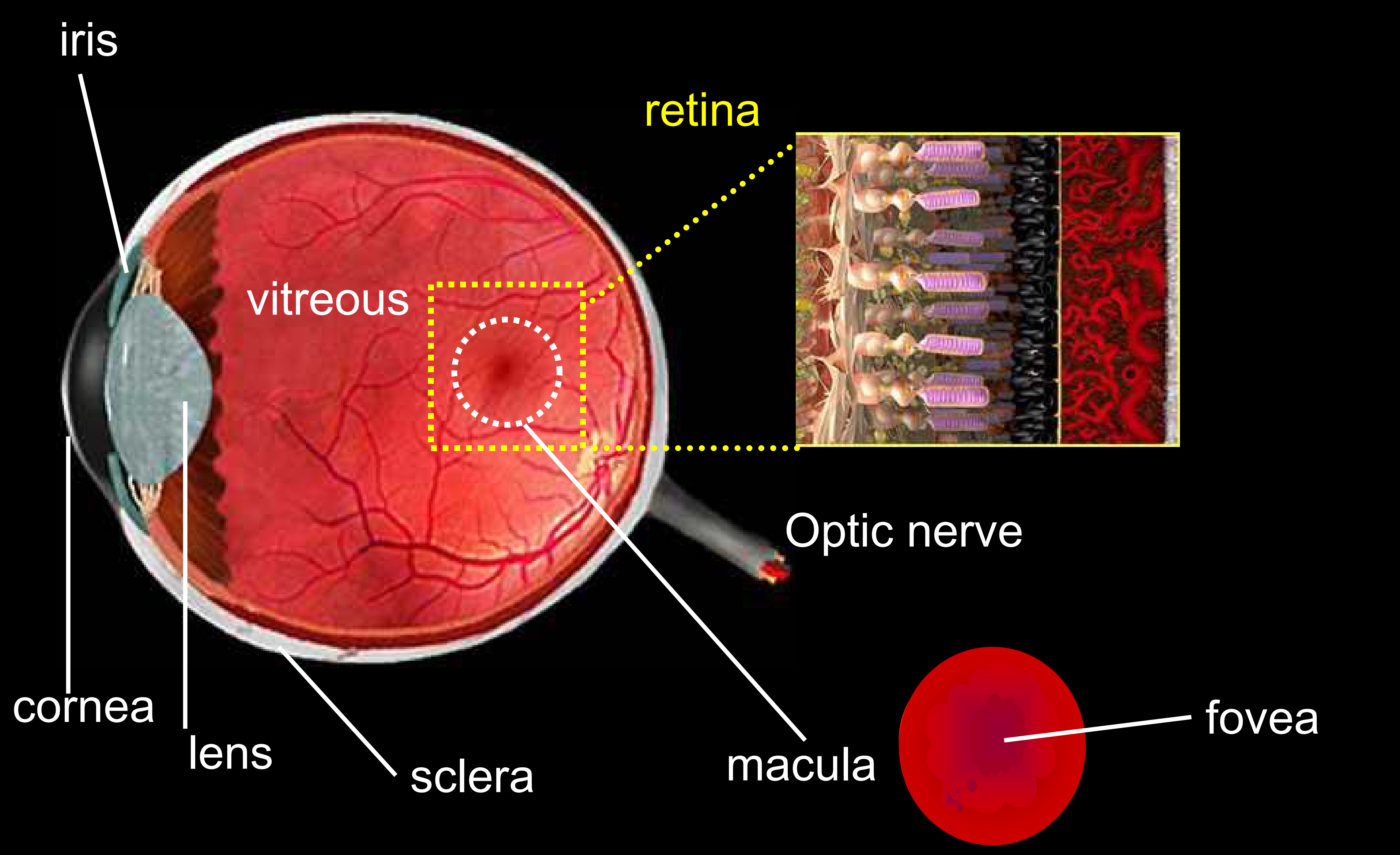


Diffuse laser light reflection from a high powered laser can result in an eye injury.

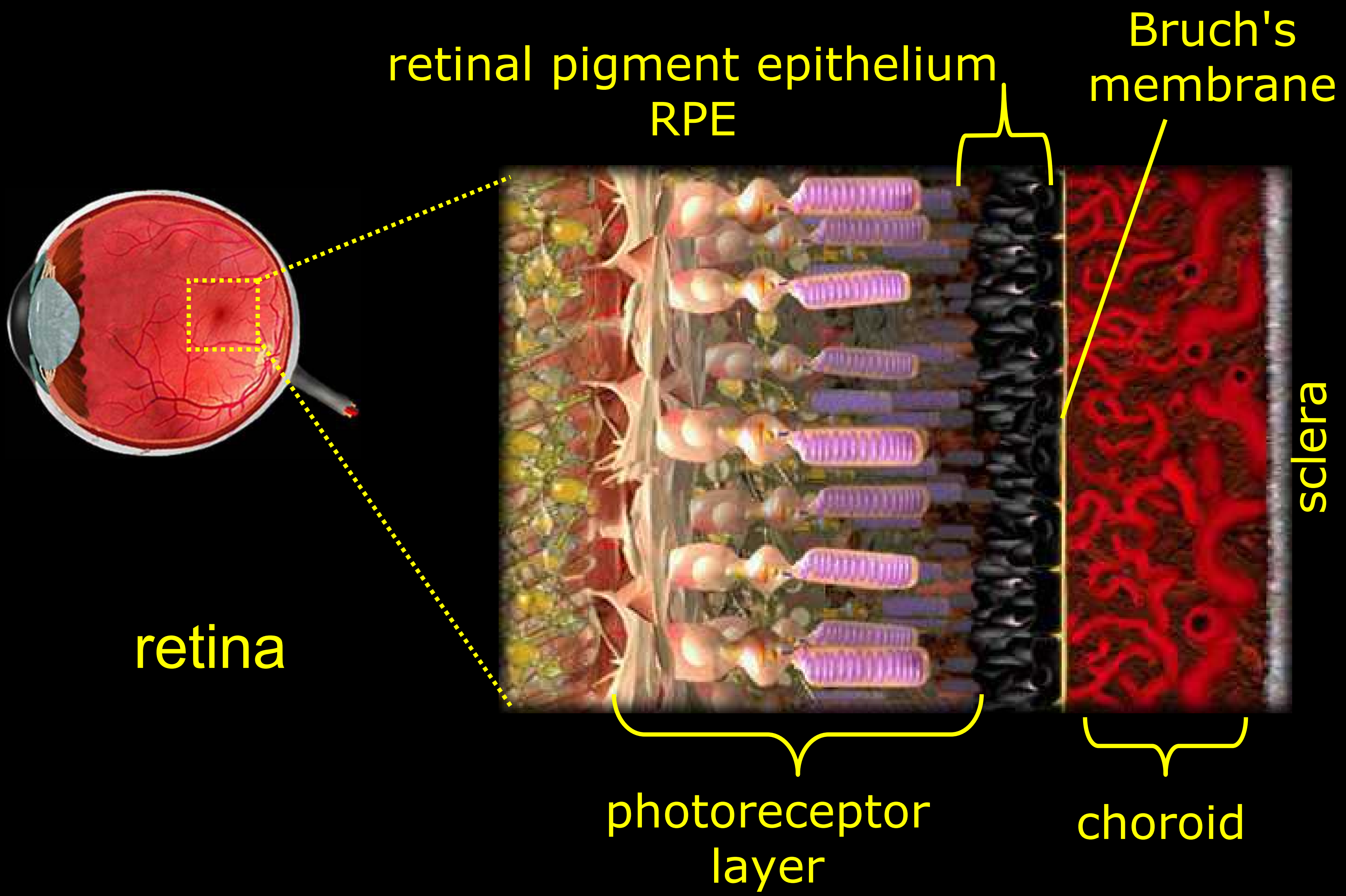
–Note that surfaces that appear shiny to the eye may be diffuse reflectors of UV wavelengths.

Laser Bio-Physics

Biology of the Eye



Biology of the Eye



effects

Pupil size

Pupil Size

Determines the amount of energy entering the eye

Typical Sizes

2 mm Daylight
3 mm Indoor
7 mm Dark Adapted
8 mm Dilated (for eye exam)

Laser thermal effects

Thermal Effects

Rate-process

Heat dissipation with time

Thermal damage is not cumulative, as long as the retina cools down between exposures.

Not limited by photon energy

Laser Photochemical effects

Photochemical

Wavelength Dependent

Individual photon interacts with molecule

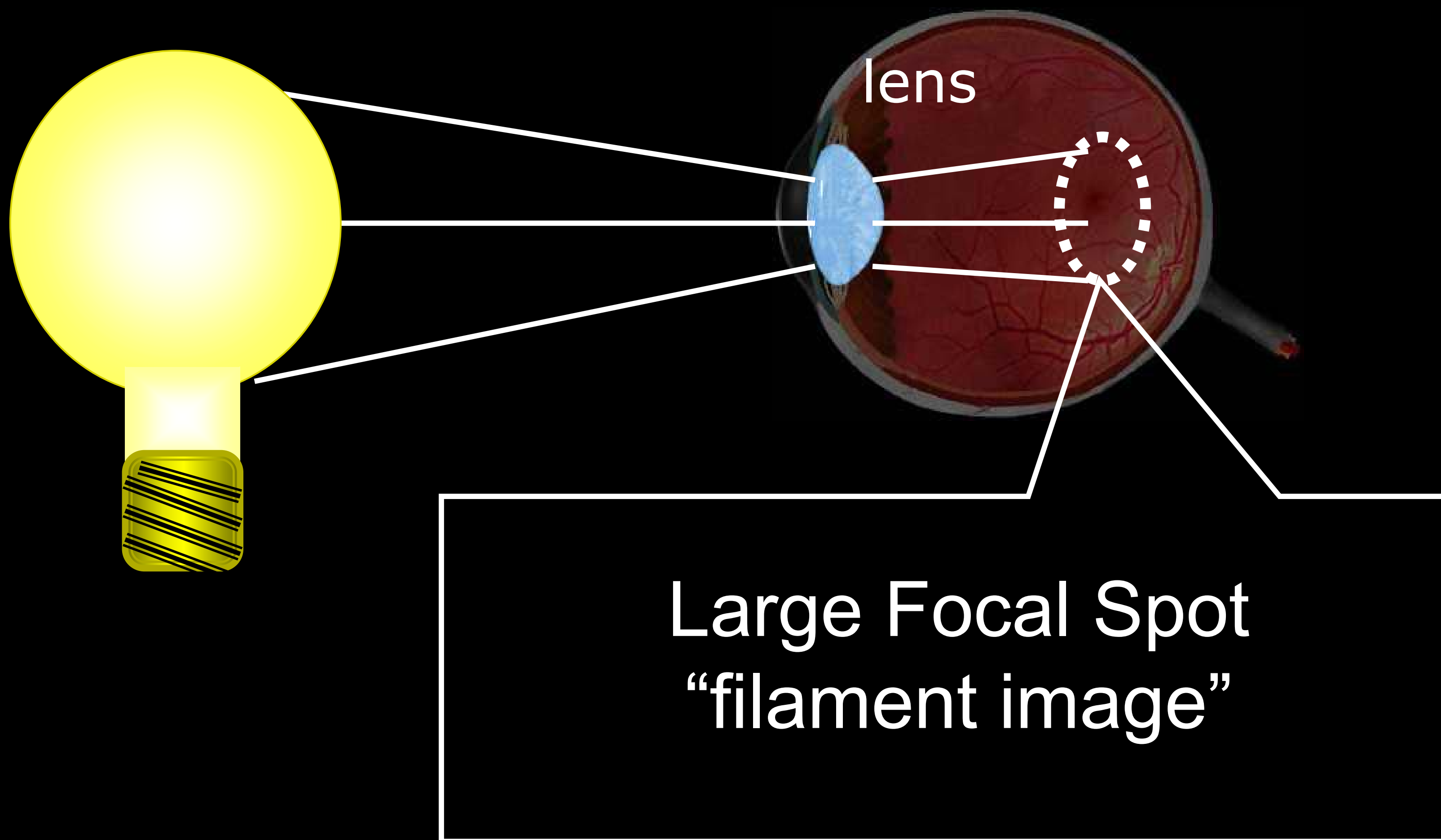
damage is severe at shorter visible wavelengths (violet & blue) and is cumulative over a working day.

Laser Acoustic effects

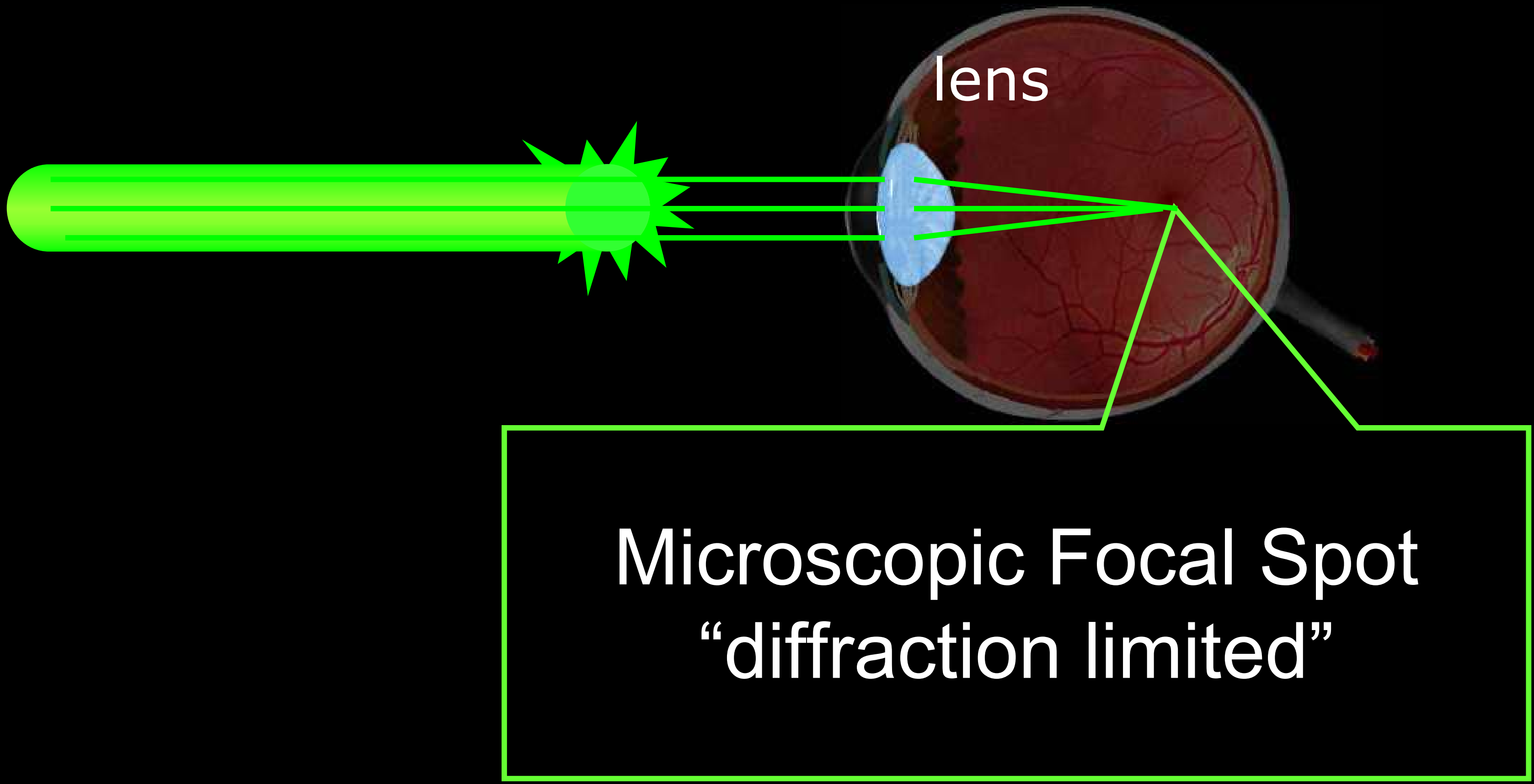
Acoustic shock

From exposure to high energy pulsed lasers results in physical tissue damage.

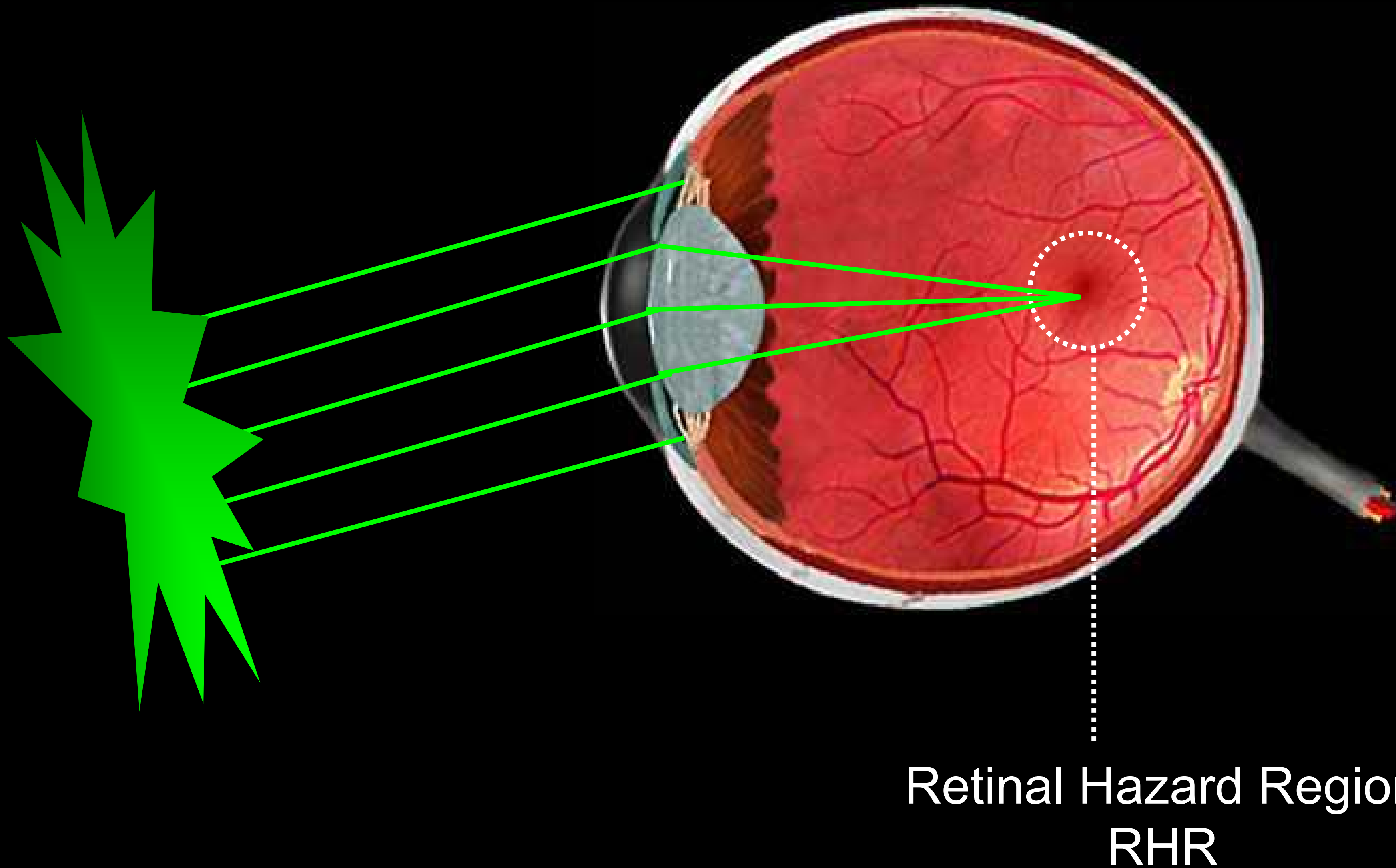
White light radiance effects



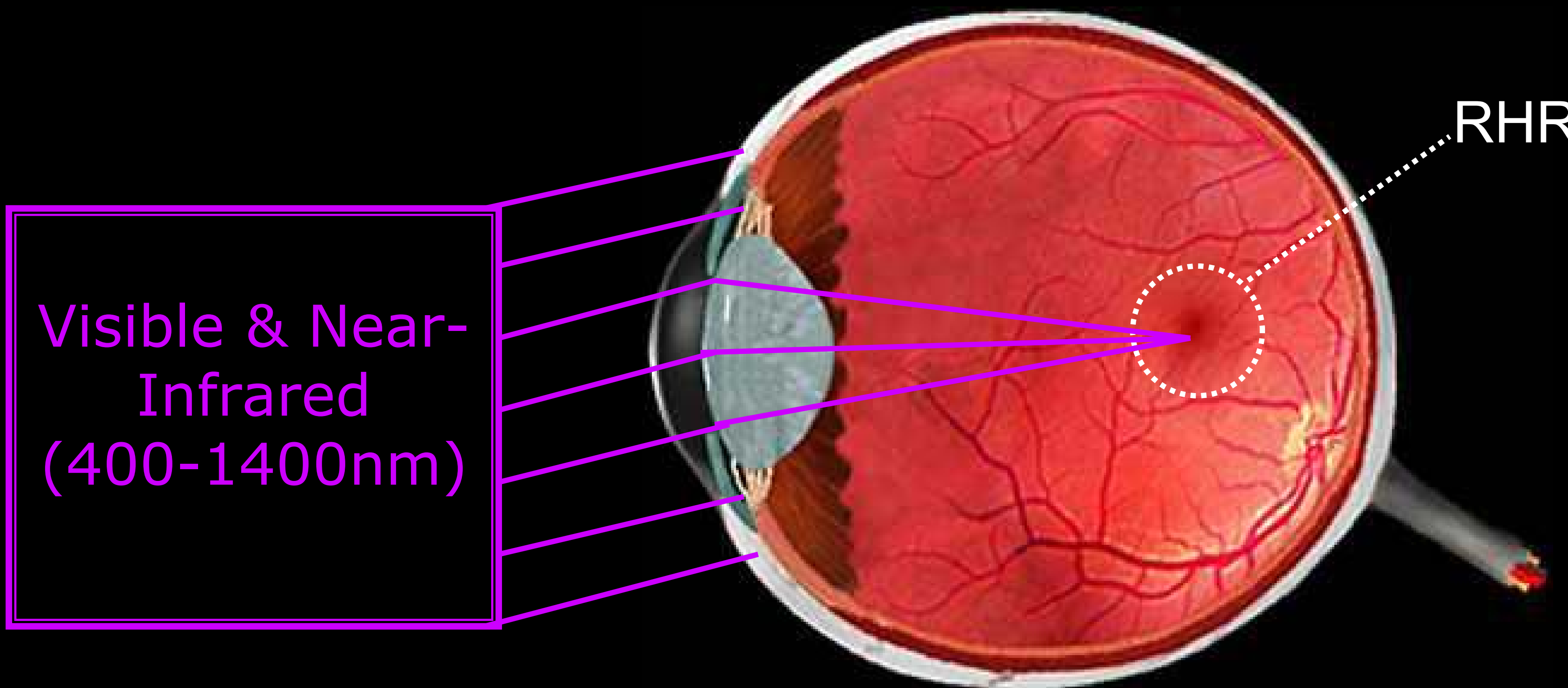
Laser radiance effects



Retinal Hazard Region



Ocular Absorption Site

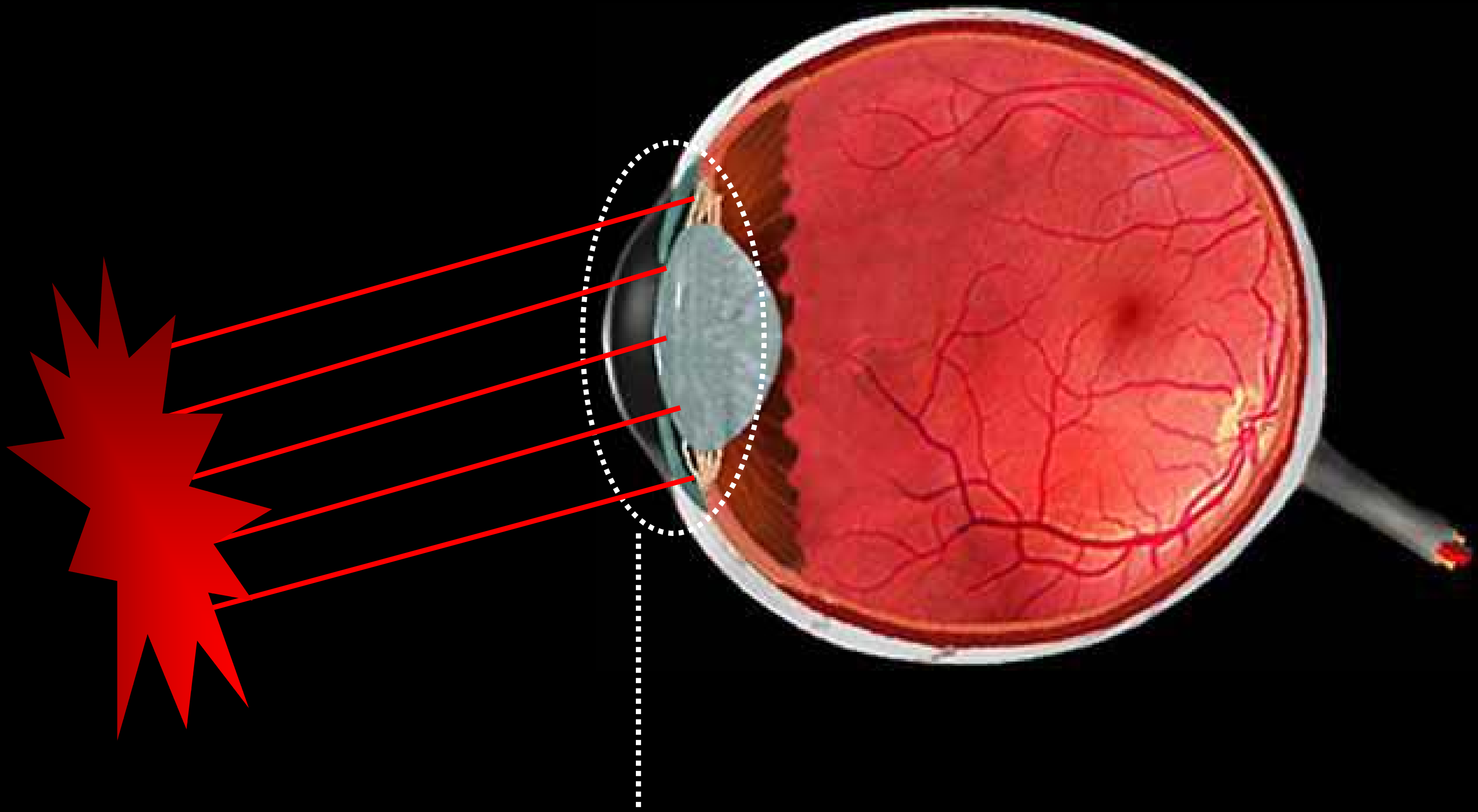


Wavelengths that focus on retina (400-1400 nm), optical gain is 100,000 times.
Irradiance entering is 1 mW/cm2, at retina will be 100 W/cm2

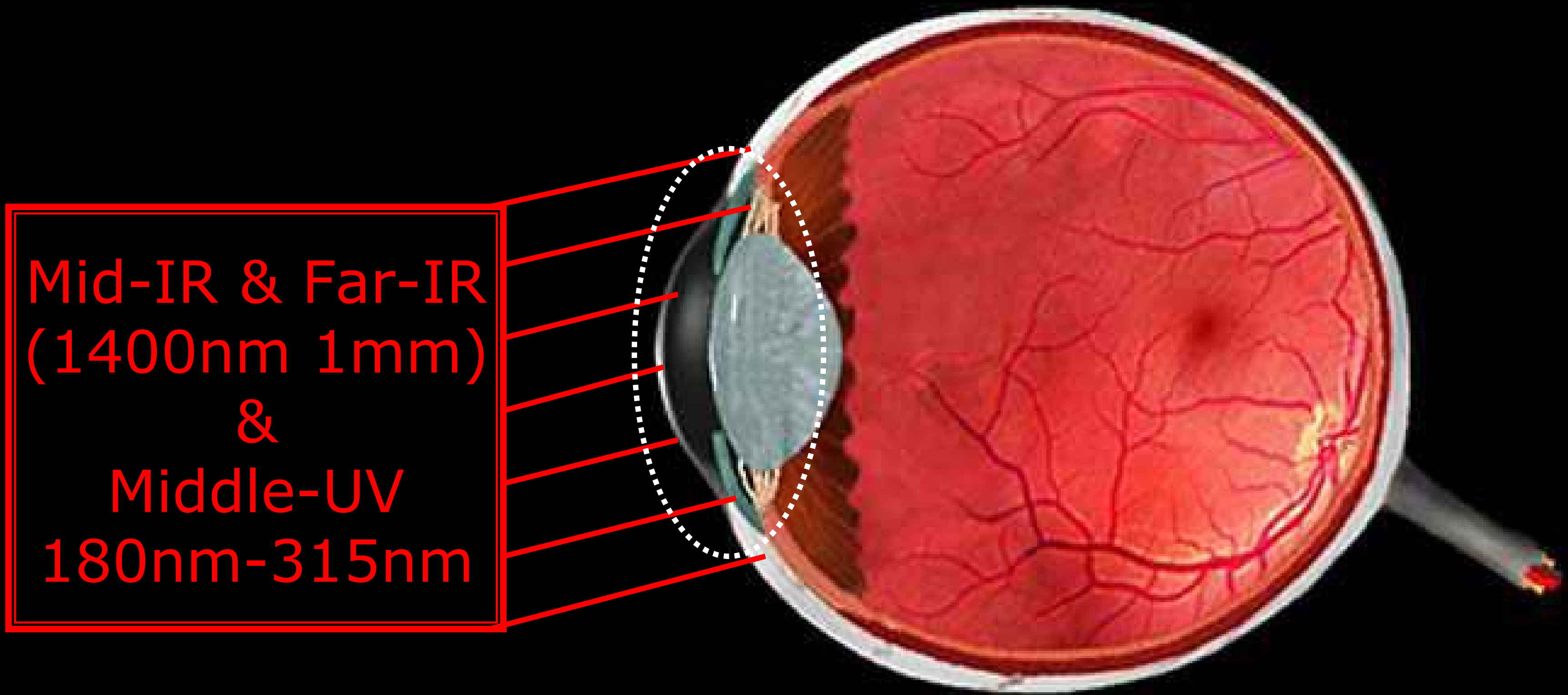
Retinal hazards

- 0.25 second: The human aversion time for bright-light stimuli (the blink reflex).
- 10 seconds: "worst-case" time period for ocular exposures to infrared (principally near-infrared)
- 600 seconds: “worst-case” period for viewing visible diffuse reflections during tasks such as alignment.
- 28,8000 seconds: The time period that represents a full 1-day (8-hour) occupational exposure.

Corneal & lens Hazard Region

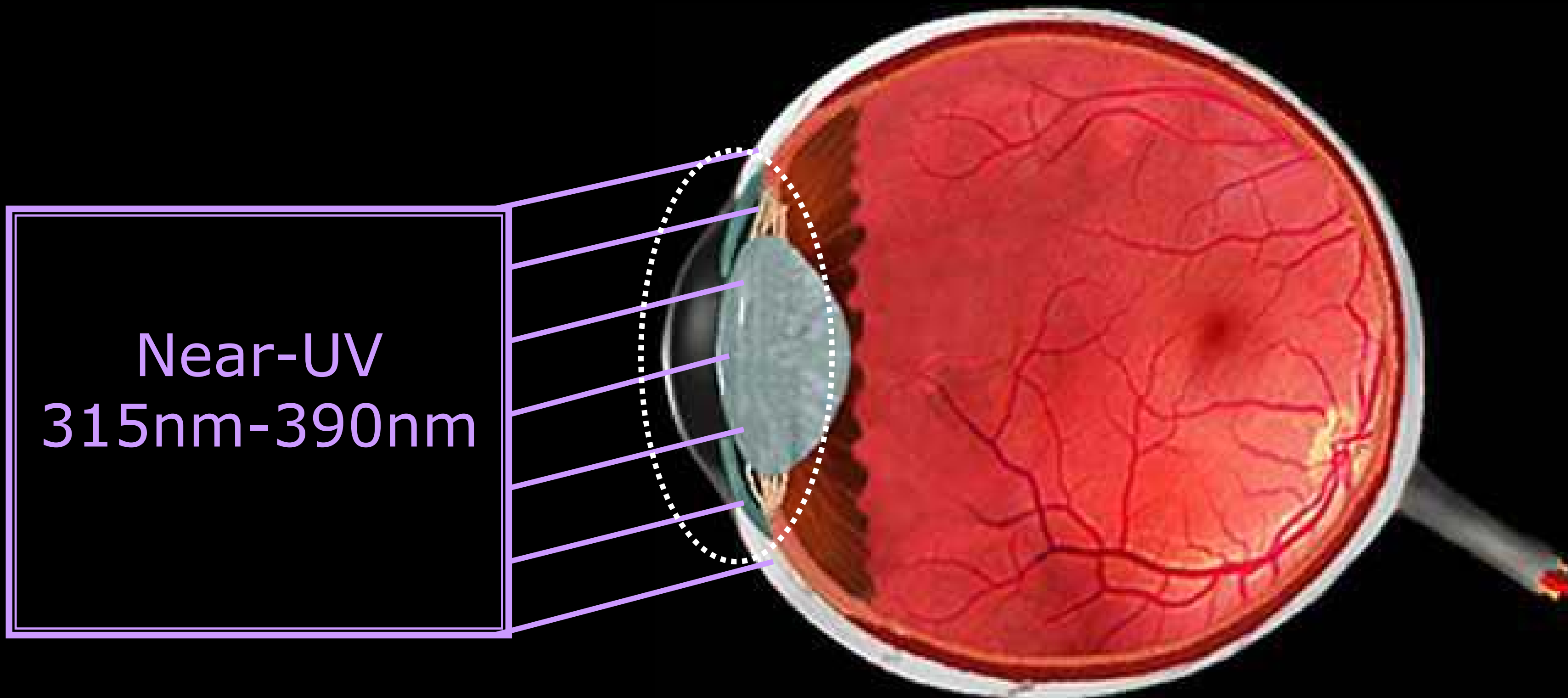


Ocular Absorption Site



Chronic exposure can cause cataract formation in the lens of the eye just as UV from the sun does.

Ocular Absorption Site

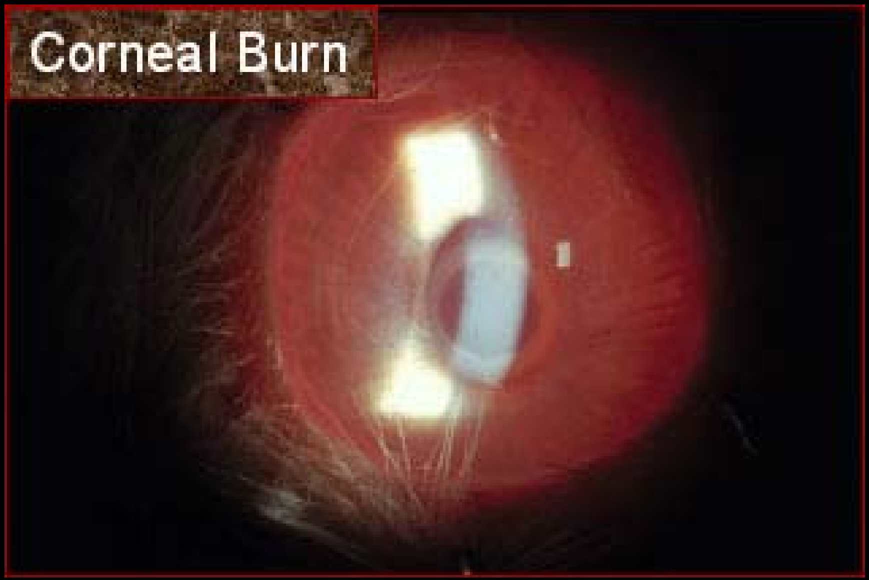


Inflammation injury to the cornea is caused by ultraviolet (UV) wavelengths (200-400 nm). This is the same type of injury that is caused by snow blindness.

Corneal injury

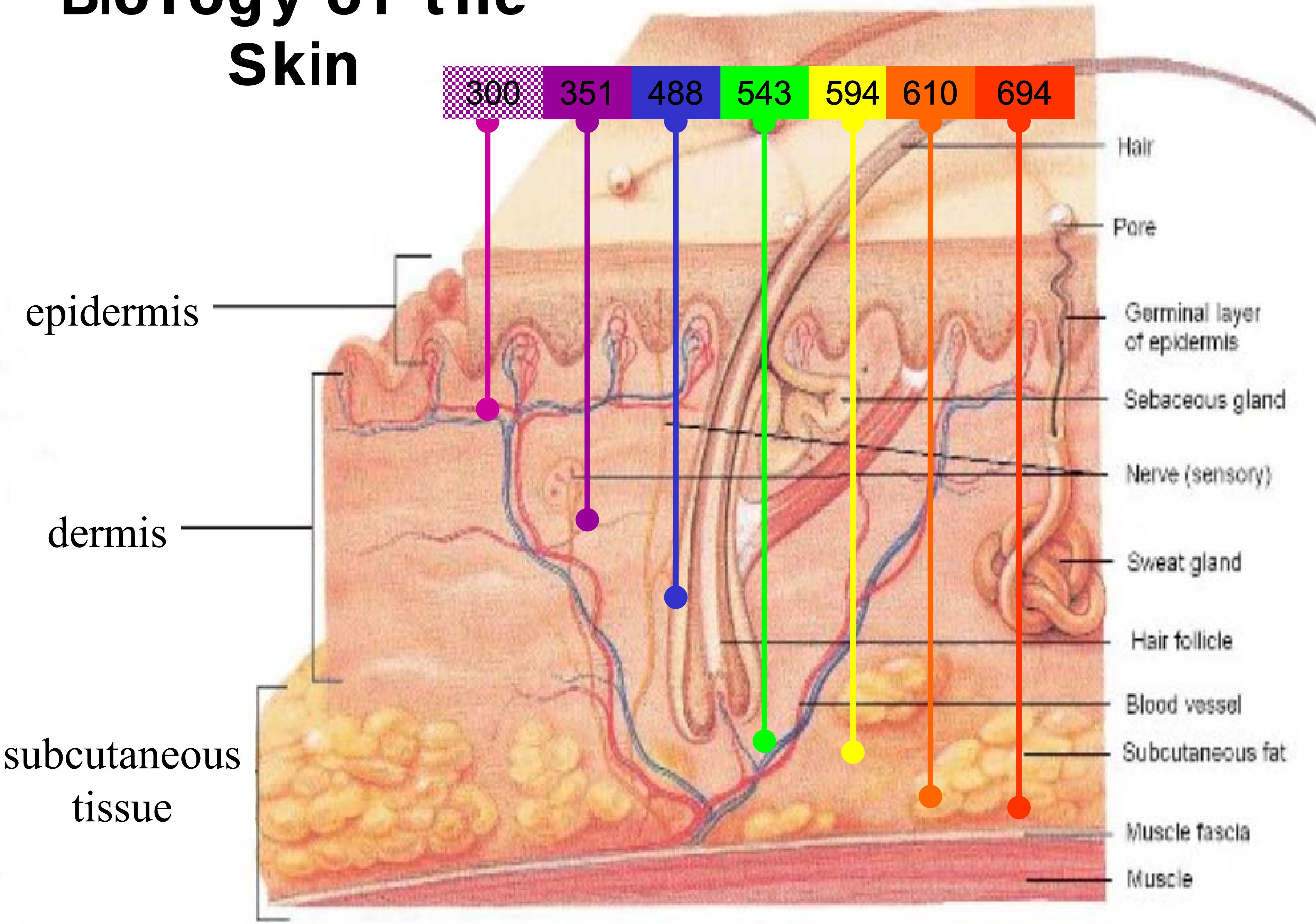
Superficial (Threshold) Injury - Epithelium repairs itself quickly and lesion clears within one or two days.

Deep Burns - Penetrating burns produce a permanent opacity and may require corneal transplant for repair



Skin

Biology of the Skin



Photochemical and Thermal Burns

Ultraviolet (UV)

- UV can cause skin injuries comparable to sun burn.
  - As with damage from the sun, there is an increased risk for developing skin cancer from UV laser exposure.

Thermal Injuries

- High powered (Class 4) lasers, especially from the infrared (IR) and visible range of the spectrum, can burn the skin and even set clothes on fire.

Photochemical and Thermal Burns

Thermal Skin Burns

- Rare; normally requires high exposure dose of at least several J/cm^2; most common from CO_2, 10.6 μm laser exposure.

  - First degree (erythema), second degree (blistering), and third degree (charring) burns are possible - dependent upon exposure dose.

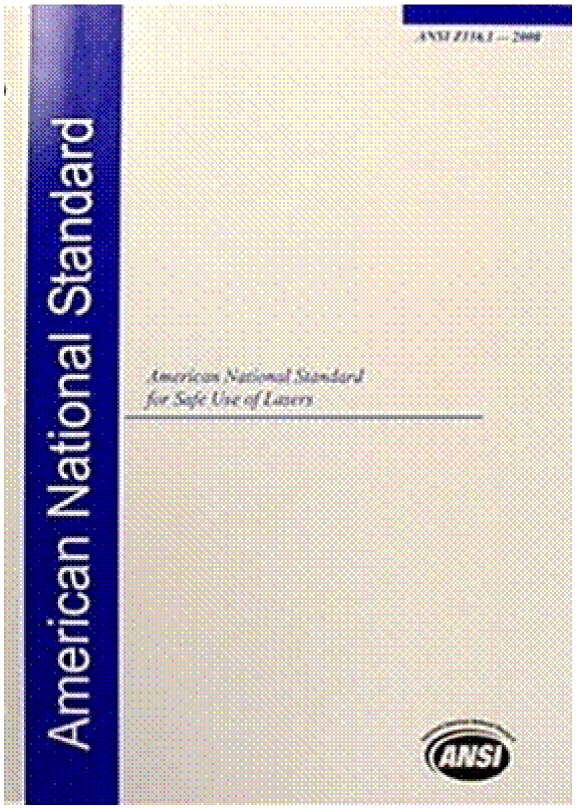
Regulations

Laser Safety Regulations

- NDSU Safe Operating Procedure

- Occupational Safety & Health Administration (OSHA)
  - No specific laser safety regulations, but will cite safety issues under the General Duty Clause 29 CFR 1910.132 & 133 and will enforce the ANSI standards for laser safety.
- American National Standards Institute (ANSI)
  - ANSI Z136.1, ANSI Z136.5-2000

Laser Safety Regulations



ANSI Z136.1 *Safe Use of Lasers*

- Principal U.S. safety standard for users
- Began in 1969 at request of US. Dept. of Labor
- April 26, 1973, final document approved
- Revised in 1976, 1980, 1986, 1993, 2000

Provides recommendations for the safe use of lasers and laser systems between 180 nm and 1 mm

Laser Safety Regulations

ANSI Z136.5 ***Safe Use of Lasers in Educational Institutions***

- Established in 2000
- Intended to address specific laser safety concerns in the educational environment
    - Teaching labs
    - Classrooms
    - Lecture halls
    - Science fairs

control

Laser Hazard Classes

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

Class I Lasers

This class cannot normally produce a hazardous beam because it is of extremely low power (exempt),

or

because it has been rendered *intrinsically safe* due to the laser having been completely enclosed so that no hazardous radiation can escape and cause injury.

Class II Lasers

These lasers are visible light (400-760 nm) continuous wave or pulsed lasers which can emit energy greater than the limit for Class I lasers and radiation power not above 1 mW.

This class is hazardous only if you stare directly into the beam for a long time, which would be similar to staring directly at the sun.

Eye protection is aversion response
CW upper limit 1 mW

Class IIIa Lasers

This class of intermediate power lasers includes any wavelength.

- hazardous under direct and specular reflection viewing
- diffuse reflection usually not hazardous
- Normally not a fire hazard
- CW upper limit is 0.5 W

Class IIIb Lasers

- Visible and near-IR lasers are very dangerous to the eye.
- Pulsed lasers may be included in this class.
- This class will not normally cause thermal skin burn or cause fires.

Requires written Standard Operating Procedures.

Class IV Lasers

These high-powered lasers are the most hazardous of all classes.

- Hazardous to eye and skin from direct viewing and diffuse reflection
- Fire hazard
- May produce laser generated air contaminants
- May produce hazardous plasma radiation

Requires written Standard Operating Procedures.

Purpose of control measures

- Reduce exposure to laser radiation to non-hazardous levels or below MPE levels

- Minimize other hazards associated with laser devices during operation, maintenance and service.

- Control exposure to non-beam hazards.

General provisions

- Use the minimum radiation necessary for the application
- Beam height should be at level other than that for a sitting/standing person
- Enclosure of equipment or beam path is preferred

Control types

Three types of controls

- Administrative & Procedural
- Engineering
- Personnel Protective Equipment
- Warning Signs and Labels

Appendix B, Tables B1 and B2, p. 22-23 of ANSI Z136.5

Maximum Permissible Exposure

The Maximum Permissible Exposure (MPE) is the highest level of radiation to which a person can be exposed without hazardous effects.

Maximum Permissible Exposure

The MPE is specified in W/cm^2 for continuous wave lasers and in J/cm^2 for pulsed lasers. The value depends on wavelength, exposure duration and pulse repetition frequency.

Exposure to radiation levels in excess of the MPE will result in adverse biological effects, such as injury to the skin and/or eyes.

TABLE III:6-6. SUMMARY: MAXIMUM PERMISSIBLE EXPOSURE LIMITS*

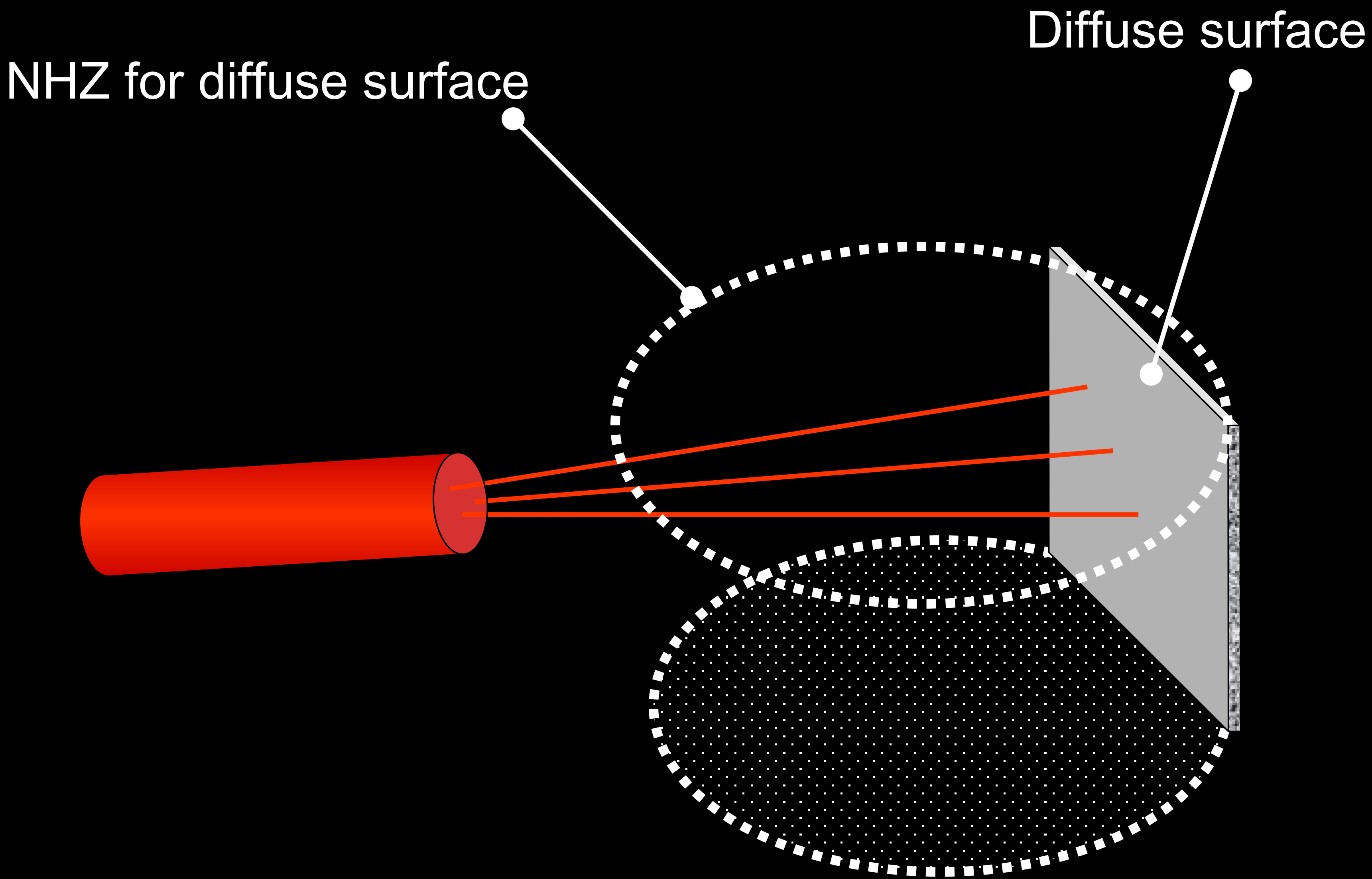
	Wavelength	MPE level (W/cm^2)			
Laser type	(μm)	0.25 sec	10 sec	600 sec	30,000 sec
CO_2 (CW)	10.6	---	100.0×10^{-3}	---	100.0×10^{-3}
Nd: YAG (CW)	1.33	---	5.1×10^{-3}	---	1.6×10^{-3}
Nd: YAG (CW)	1.064	---	5.1×10^{-3}	---	1.6×10^{-3}
Nd: YAG (Q-switched)	1.064	---	17.0×10^{-6}	---	2.3×10^{-6}
GaAs (Diode/CW)	0.840	---	1.9×10^{-3}	---	610.0×10^{-6}
HeNe (CW)	0.633	2.5×10^{-3}	---	293.0×10^{-6}	17.6×10^{-6}
Krypton (CW)	0.647	2.5×10^{-3}	---	364.0×10^{-6}	28.5×10^{-6}
	0.568	31.0×10^{-6}	---	2.5×10^{-3}	18.6×10^{-6}
	0.530	16.7×10^{-6}	---	2.5×10^{-3}	1.0×10^{-6}
Argon (CW)	0.514	2.5×10^{-3}	---	16.7×10^{-6}	1.0×10^{-6}
XeFl (Excimer/CW)	0.351	---	---	---	33.3×10^{-6}
XeCl (Excimer/CW)	0.308	---	---	---	1.3×10^{-6}

Nominal Hazard Zones

The *Nominal Hazard Zone (NHZ)*
is the space within which the level of the direct, reflected or scattered laser radiation during operation exceeds the applicable MPE.

Exposure levels beyond the boundary of the NHZ are below the applicable MPE.

Nominal Hazard Zones



Nominal Hazard Zones

When Class 3b and 4 lasers are unenclosed, a NHZ must be established.

People may be injured if they are within the perimeter of this zone while the laser is in operation.

Nominal Hazard Zones

The purpose of an NHZ evaluation is to define that space where control measures are required.

The following factors are required in NHZ computations:

- laser power or energy output
- beam diameter
- beam divergence
- pulse repetition frequency (prf) (if applicable)
- wavelength
- beam optics and beam path
- maximum anticipated exposure duration.

TABLE III:6-7. NHZ DISTANCE VALUES FOR VARIOUS LASERS

Laser type	Exposure criteria	----- Hazard range (meters) ----- Diffuse	Lens-on-laser	Direct
Nd:YAG 100 Watt 1.064 μm	8 hours	1.4	11.3	1410
	10 seconds	0.8	6.3	792
CO_2 500 Watt 10.6 μm	8 hours	0.4	5.3	309
	10 seconds	0.4	5.3	390
Argon 5.0 Watt 0.488 μm	8 hours	12.6	1.7×10^3	25.2×10^3
	0.25 seconds	0.25	33.3	240

Laser criteria used for NHZ distance calculations:

Laser parameter	Nd-YAG	CO_2	Argon
Wavelength (μm)	1.064	10.6	0.488
Beam power (Watts)	100.0	500.0	5.0
Beam divergence (mrad)	2.0	2.0	1.0
Beam size at aperture (mm)	2.0	20.0	2.0
Beam size at lens (mm)	6.3	30.0	3.0
Lens focal length (mm)	25.4	200.0	200.0
MPE for 8 hours (w/cm^2)	1.6×10^3	1.0×10^5	1.0
MPE for 10 seconds (w/cm^2) 5.1×10^3	1.0×10^5	---	2.5×10^3
MPE for 0.25 second (w/cm^2)	---	---	

Non – Beam Hazards

Non-beam hazards refer to anything other than the laser itself that can create a hazard.

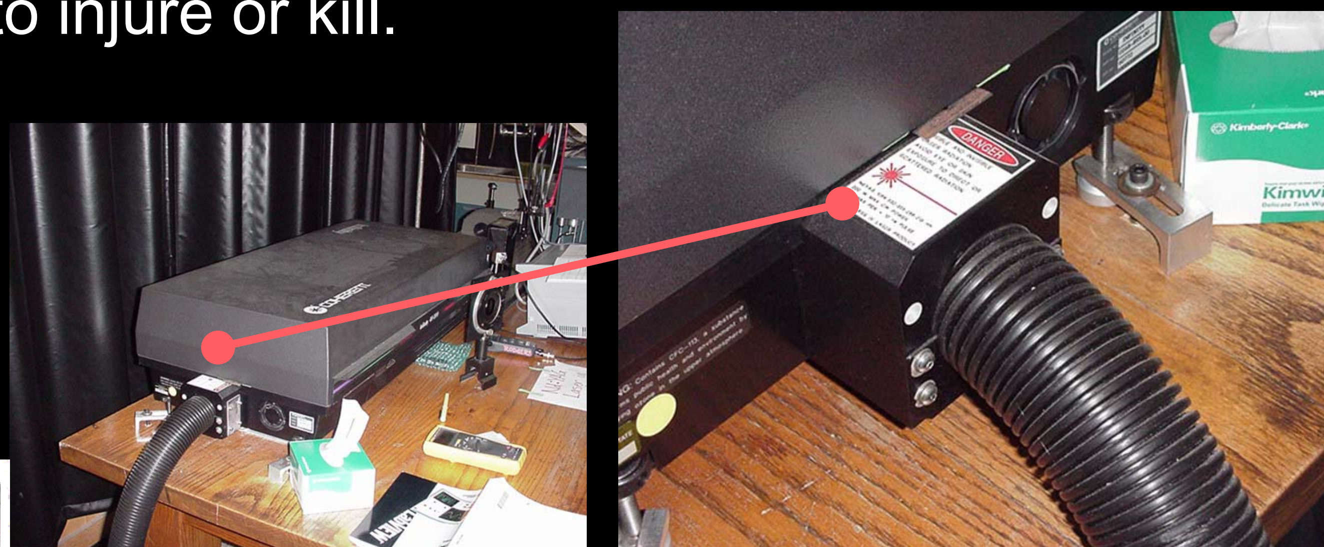
This type of hazard includes:

- Electrical Hazards
- Fire Hazards
- Laser Generated Air Contaminants (LGAC)
- Compressed Gases
- Chemical Hazards
- Collateral and Plasma Radiation
- Noise

Electric Shock

Electric Shock

Use caution when working on or near the high-voltage power supplies used for high-power Class 3 and 4 lasers; there is sufficient voltage in these power supplies to injure or kill.



Fire

Fire

High powered Class 4 lasers will easily ignite flammable materials .

The following laser components may produce fire hazards:

- Electrical circuits
- Laser gases
- Laser generated airborne contaminants
- Laser dyes
- Beam enclosures
- The beam itself

explosion

Explosion Hazards

May exist within laser, due to:

- High pressure arc lamps
- Filament lamps
- Capacitor banks

May exist outside the laser, due to:

- The target (flying particles)
- Elements of the optical train, which may overheat

Air Contaminants – LGAC

Air contaminated due to interaction of laser beam with target material can result in the production of toxic chemicals.

Target materials can produce:

Gas/vapor - state materials

Aerosols

- Viable
- Organic
- Metal Oxides

Chemicals

Hazardous chemicals used as part of the lasing medium can create special problems.

Dyes and solvents used in dye lasers are toxic and often carcinogenic and therefore must be handled with care. Make sure laser operators are familiar with the Material Safety Data Sheets for these chemicals.

Chemicals

Toxic gases, such as chlorine, fluorine, hydrogen chloride and hydrogen fluoride used for excimer lasers, will require special cabinets and air handling to prevent exposure to laser operators and release of toxic gases to the environment.

Cylinder hazards, compressed gas

Always secure cylinders and replace caps when not in use.

Collateral Plasma Radiation

Collateral radiation refers to radiation that is not associated with the primary laser beam. This collateral radiation may be produced by power supplies, discharge lamps and plasma tubes. This radiation can be any type of EM radiation, from x-rays to radio waves.

Noise

Noise generated by the laser system that is at 90 decibels or higher requires hearing protection.

If you have reason to believe that your laser is creating a hearing hazard during operation, OSEH can perform noise level monitoring to determine whether or not the noise associated with your laser is at this level.

Engineering Controls

- Protective housings
- Interlocks on Removable protective housings
- Service access panels
- Key control master switch (Class 3b & 4)
- Viewing Windows, Display Screens, Collecting Optics
- Beam path enclosures
- Remote interlock connectors (Class 3b & 4)
- Beam Stop or attenuator (Class 3b & 4)

PPE for Skin

Personnel Protective Equipment (PPE) for Skin exposed to Class 3b or 4 lasers:

- Ultraviolet lasers may require that tightly woven fabrics be worn to protect arms and hands. Sun screen may also be used to provide some additional protection.
- For lasers with wavelengths > 1400 nm, large area exposures to the skin can result in dryness and even heat stress.

PPE for Eyes

Personnel Protective Equipment (PPE) for eyes exposed to Class 3b or 4 lasers is mandatory. eyewear with side protection is best.

PPE is recommended for class 2 or 3a lasers when intentional direct viewing > 0.25 seconds is necessary.

PPE for Eyes

Consider these factors when selecting eyewear:

- Wavelength compatibility with laser
- Attenuation at that wavelength or *optical density*
- Visual transmittance
- Comfort and fit

TABLE III:6-8. OPTICAL DENSITIES FOR PROTECTIVE EYEWEAR FOR VARIOUS LASER TYPES

Laser type and power	Wavelength (mm)	---- Optical density for exposure durations ----			
		0.25 §	10 §	600 §	30,000 §
XeCl 50 Watts	0.308[a]	--	6.2	8.0	9.7
XeFl 50 Watts	0.351[a]	--	4.8	6.6	8.3
Argon 1.0 Watts	0.514	3.0	3.4	5.2	6.4
Krypton 1.0 Watt	0.530	3.0	3.4	5.2	6.4
Krypton 1.0 Watt	0.568	3.0	3.4	4.9	6.1
HeNe 0.005 Watt	0.633	0.7	1.1	1.7	2.9
Krypton 1 Watt	0.647	3.0	3.4	3.9	5.0
GaAs 50 mW	0.840[c]	--	1.8	2.3	3.7
Nd: YAG 100 Watt	1.064[a]	--	4.7	5.2	5.2
Nd: YAG (Q-switch)[b]	1.064[a]	--	4.5	5.0	5.4
Nd: YAG[c] 50 Watts	1.33[a]	--	4.4	4.9	4.9
CO_2 1000 Watts	10.6[a]	--	6.2	8.0	9.7

a. Repetitively pulsed at 11 Hertz, 12-nanosecond pulses, 20 mJ/pulse.
b. OD for UV and FIR beams computed using a 1-mm limiting aperture, which presents a "worst-case" scenario. All visible and NIR computations assume a 7-mm limiting aperture.
c. Nd:YAG operating at a less-common 1.33 μm wavelength.
Note: All OD values determined using MPE criteria of ANSI Z 136.1 (1993).

PPE for Eyes

INTRABEAM OPTICAL DENSITY DETERMINATION.

Based upon these typical exposure conditions, the optical density required for suitable filtration can be determined.

Optical density (OD) is a logarithmic function defined by:

$$OD = \log_{10} \frac{H_O}{MPE}$$

H_0 = Anticipated worst-case exposure [Power/Area] (J/cm^2 or W/cm^2)

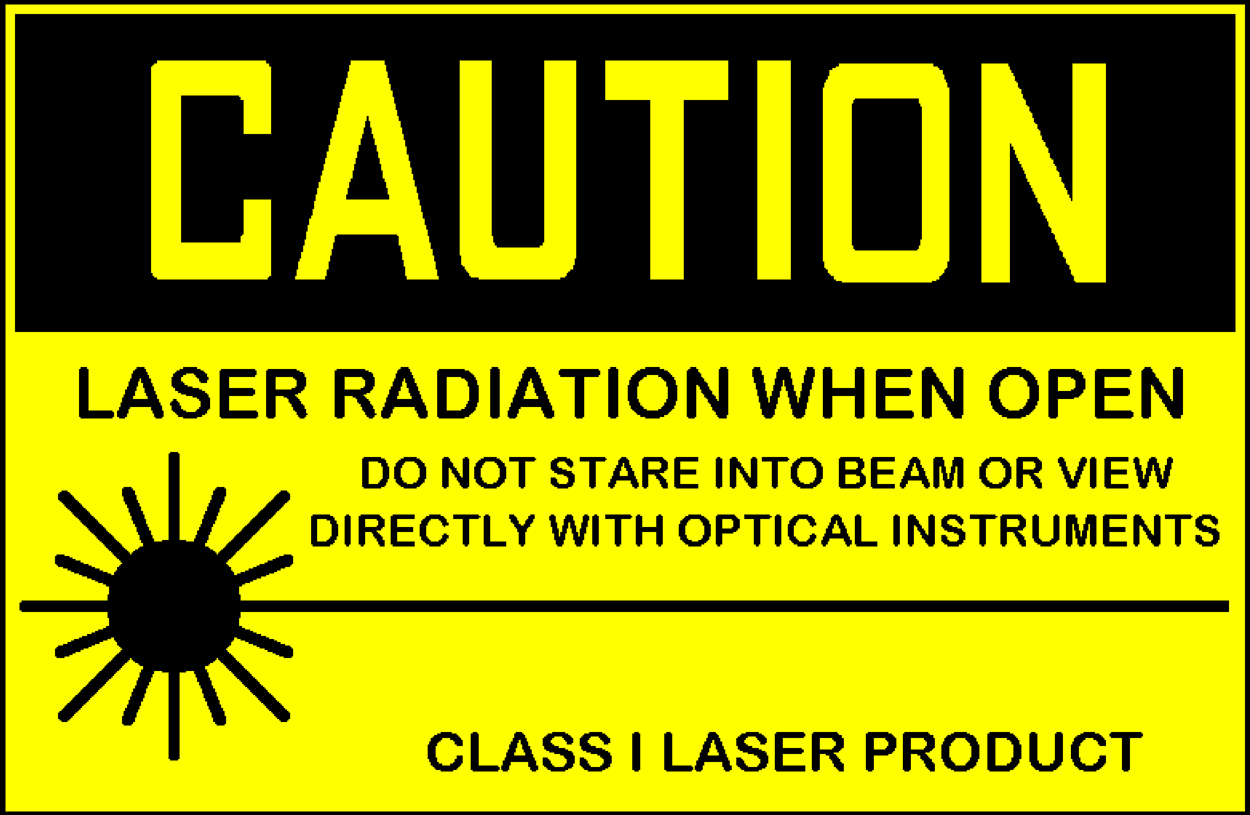
MPE = Maximum permissible exposure level expressed in the same units as H_0

Other PPE

PPE may also be required to provide protection from hazardous chemicals and gases.

Warning Labels

- Class 1:
  "Laser Radiation When Open – Do Not Stare into Beam"



Warning Labels

- Class 2, Class 3a (low irradiance):
  "Laser Radiation – Do Not Stare into Beam."

Warning Labels

- Class 3a (high irradiance):
  "Laser Radiation – Avoid Direct Eye Exposure."

Warning Labels

- <u>Class 3b</u>:
  “Laser Radiation – Avoid Direct Eye Exposure.”

Warning Labels

- Class 4:
  "Laser Radiation – Avoid Eye or Skin Exposure to Direct or Scattered Radiation."

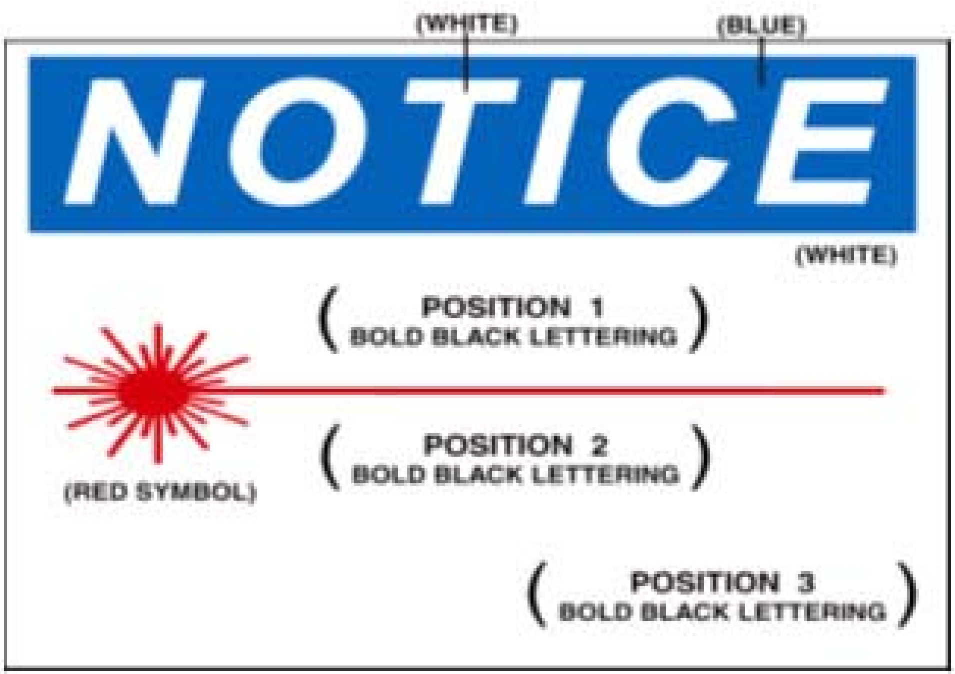
Warning Signs

All rooms with class 3a, 3b or 4 lasers must have appropriate signs posted at all entrances.

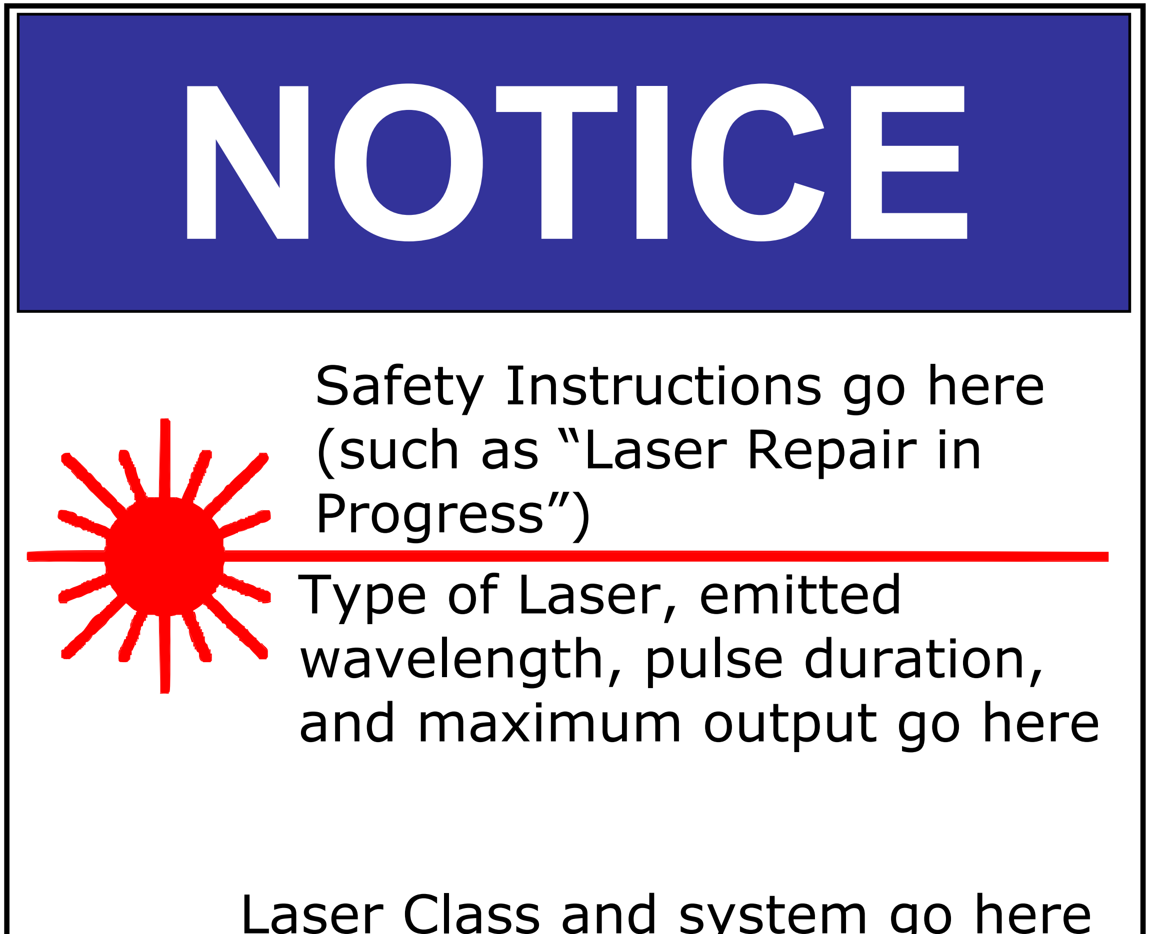
- Warn of the presence of a laser hazard in the area
- Indicate specific laser safety policies
- Indicate the relative hazard such as the Laser Class and the location of the Nominal Hazard Zone
- Indicate precautions needed such as PPE requirements for eyewear, etc.

Laser Warning Signs

NOTICE" does *not* indicate a hazardous situation. This sign should only be used to make people aware of facility policies regarding laser safety and/or to indicate that a repair operation is in progress.



"NOTICE" Sign for Laser Repair



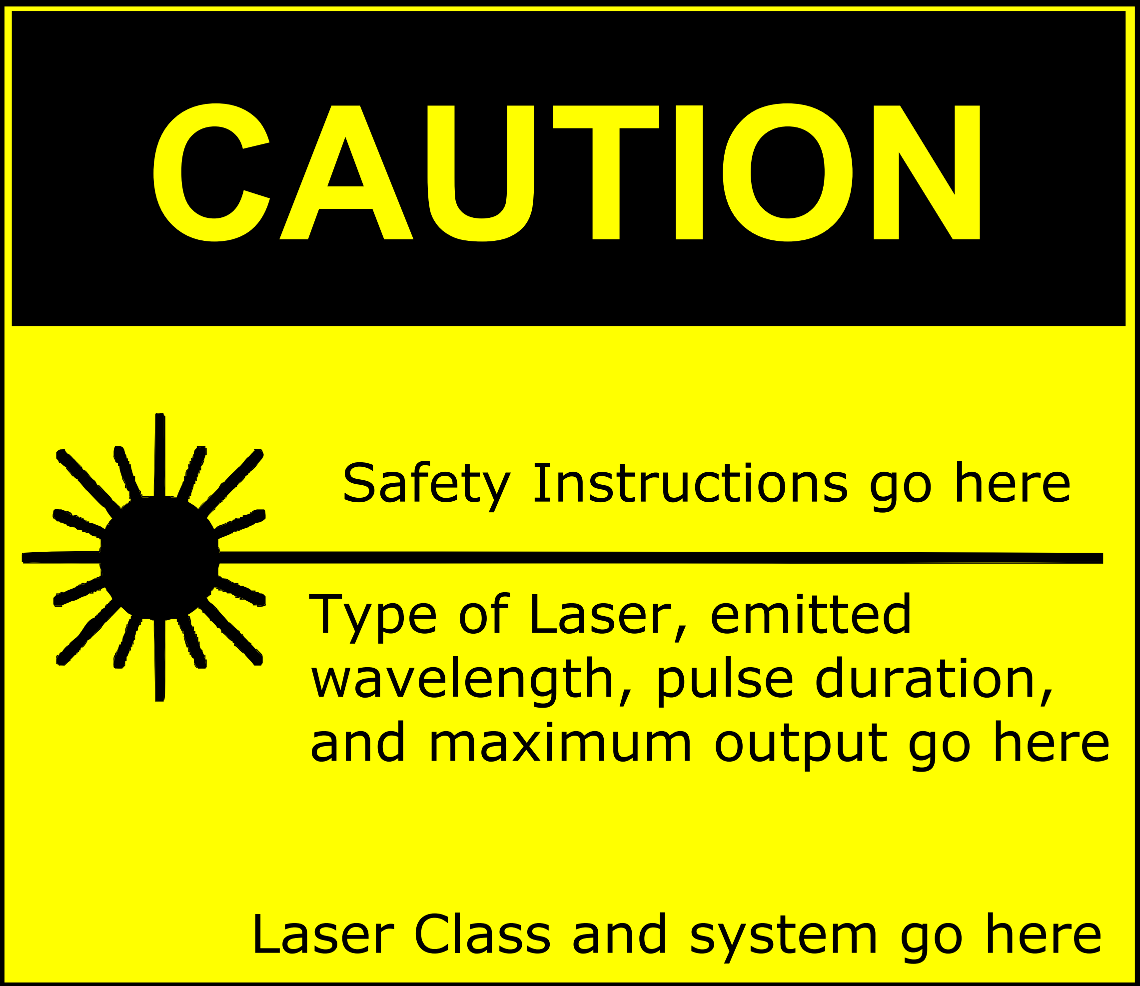
Safety Instructions may include:

- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

Laser Warning Signs

"CAUTION" indicates a potentially hazardous situation which could cause a less serious injury. This sign should be used for Class 2 and 3a (low irradiance) lasers.

"CAUTION" Warning Sign



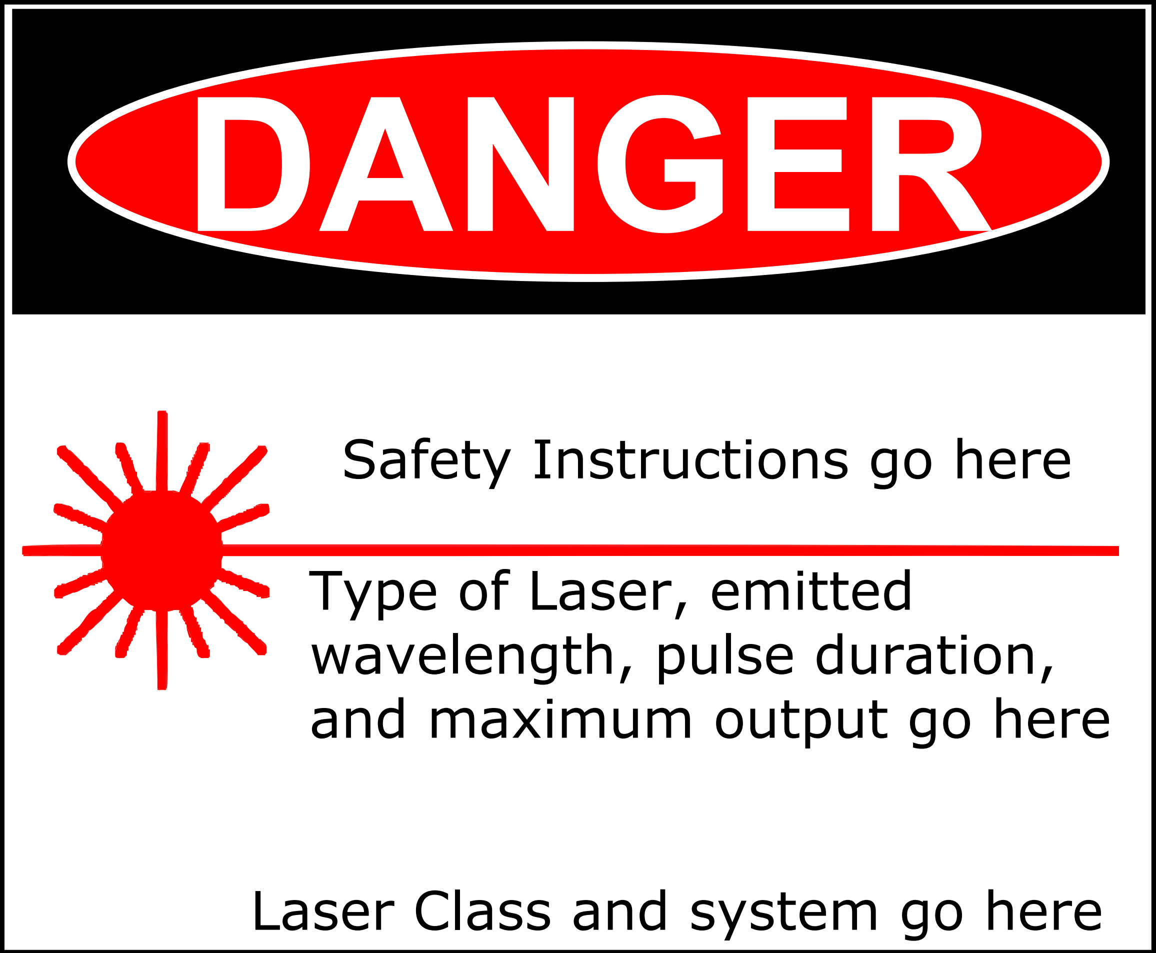
Safety Instructions may include:

- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

Laser Warning Signs

"DANGER" indicates a very dangerous situation that could result in serious injury or death. This sign should be used for Class 3a (high irradiance) Class 3b and 4 lasers.

“DANGER” Warning Sign



Safety Instructions may include:

- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

Additional Warnings

- The Nominal Hazard Zone (NHZ) must be marked so that the boundary of the NHZ is clearly defined.
- An audible alarm, warning light or a verbal “countdown” is required before activation.
- A visible warning light should flash when the laser is in operation and the light should be readily visible through protective eyewear.

Leading Causes of Laser Accidents

- Unanticipated eye exposure during alignment
- Available eye protection not used
- Equipment malfunction
- Improper methods for handling high voltage
  (This type of injury has resulted in death.)
- Inadequate training
- Failure to follow SOP
- Failure to provide non-beam hazard protection.
- Equipment improperly restored following service
- Incorrect eyewear selection and/or eyewear failure

Protect Your Eyes !

In a fraction of a second, your vision can go dark.

Protect Your Eyes !

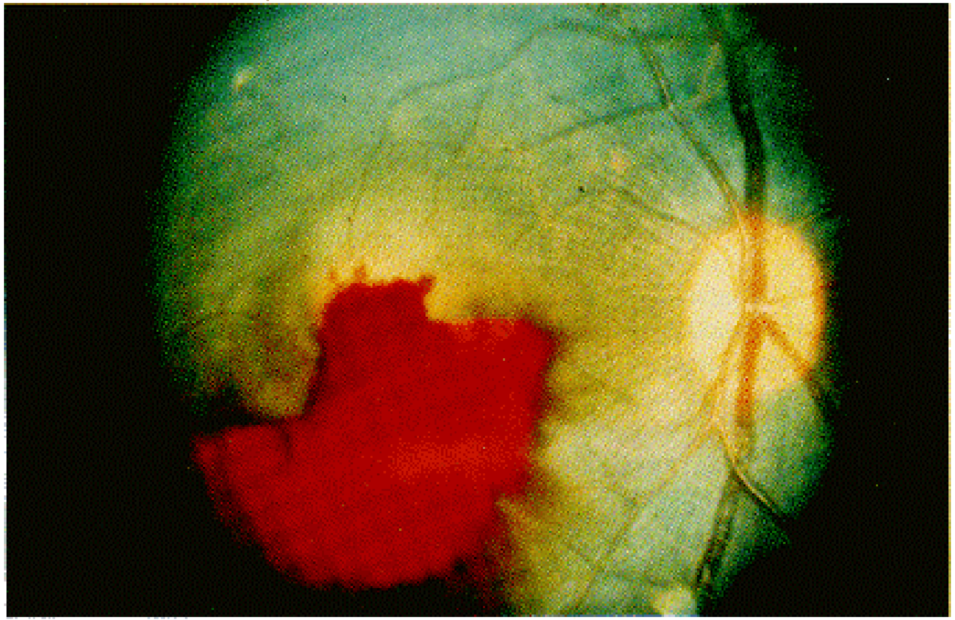
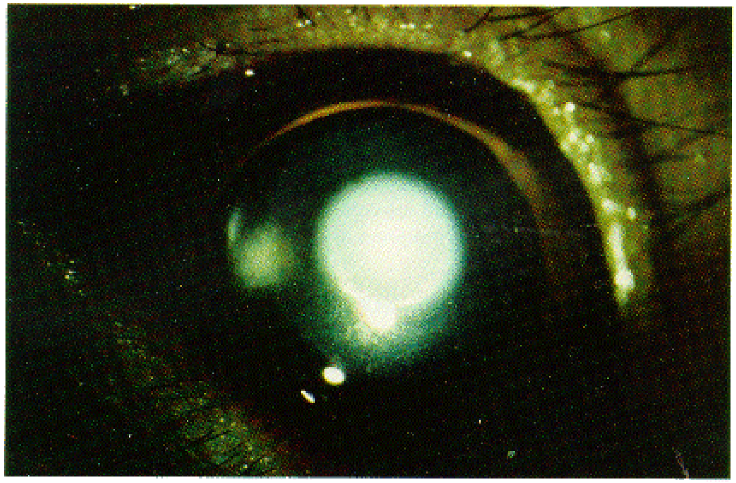


Figure 5. Profuse hemorrhage into the vitreous.



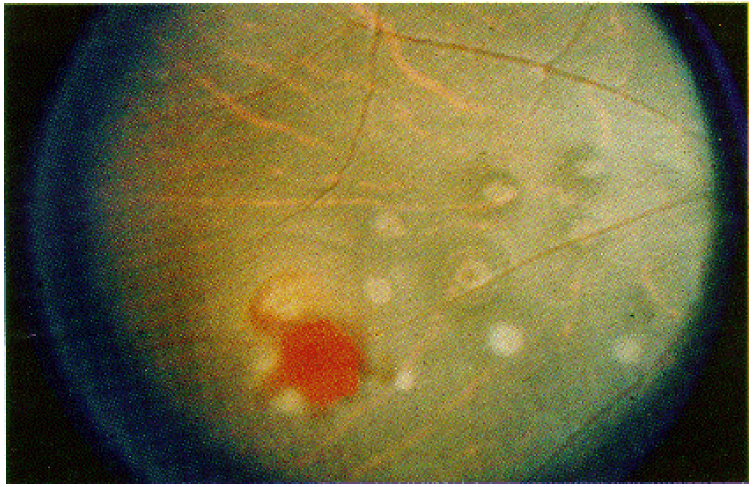


Figure 7. Multiple small laser burns with minimal hemorrhage.

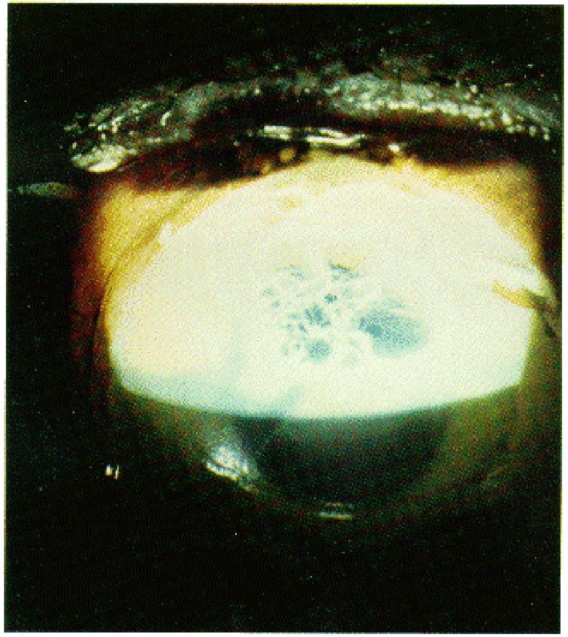


Figure 6. Corneal burns.

For More Information

- Find more info online through the OSEH web site (http://facilities-mgmt.ndsu.nodak.edu/oseh/).
- Find more info online through the OSHA web site (http://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_6.html)
- The ANSI Z136.1 Laser Safety Standard is the best reference to consult for laser safety information.
- Call OSEH at 1-7759 if you have additional questions about laser safety.

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