Laser Safety

The George Washington University
Office of Laboratory Safety
Ross Hall, Suite B05 202-994-8258

LASER

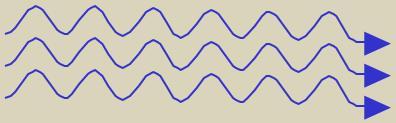
LASER stands for:

Light
Amplification by the
Stimulated
Emission of
Radiation

Laser Light

Laser light

- is *monochromatic*, unlike ordinary light which is made of a spectrum of many wavelengths. Because the light is all of the same wavelength, the light waves are said to be *synchronous.*
- is *directional* and focused so that it does not spread out from the point of origin.

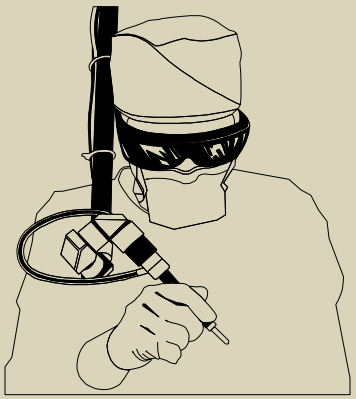


Synchronous, monochromatic, directional light waves

Asynchronous, multi-directional light.

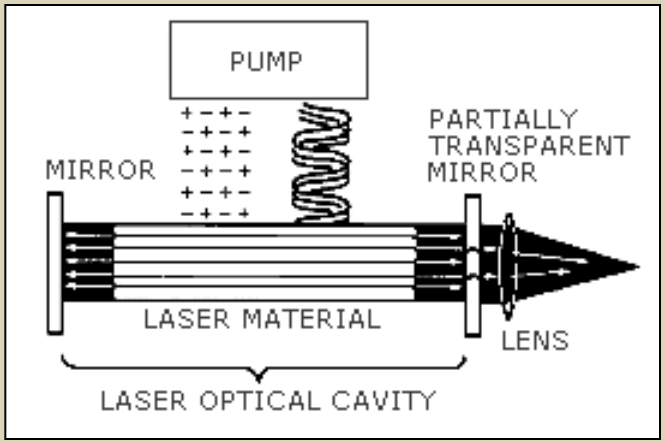
Uses of Lasers

- Lasers are used in industry, communications, military, research and medical applications.
- At GW, lasers are used in both research and medical procedures.



How a Laser Works

A laser consists of an optical cavity, a pumping system, and a lasing medium.



- The **optical cavity** contains the media to be excited with mirrors to redirect the produced photons back along the same general path.
- The **pumping system** uses various methods to raise the media to the lasing state.
- The **laser medium** can be a solid (state), gas, liquid dye, or semiconductor.

Source: OSHA Technical Manual, Section III: Chapter 6, Laser Hazards.

Laser Media

1. **Solid state** lasers
2. **Gas** lasers
3. **Excimer** lasers (a combination of the terms *excited* and *dimers*) use reactive gases mixed with inert gases.
4. **Dye lasers** (complex organic dyes)
5. **Semiconductor** lasers (also called **diode** lasers)

There are different safety hazards associated with the various laser media.

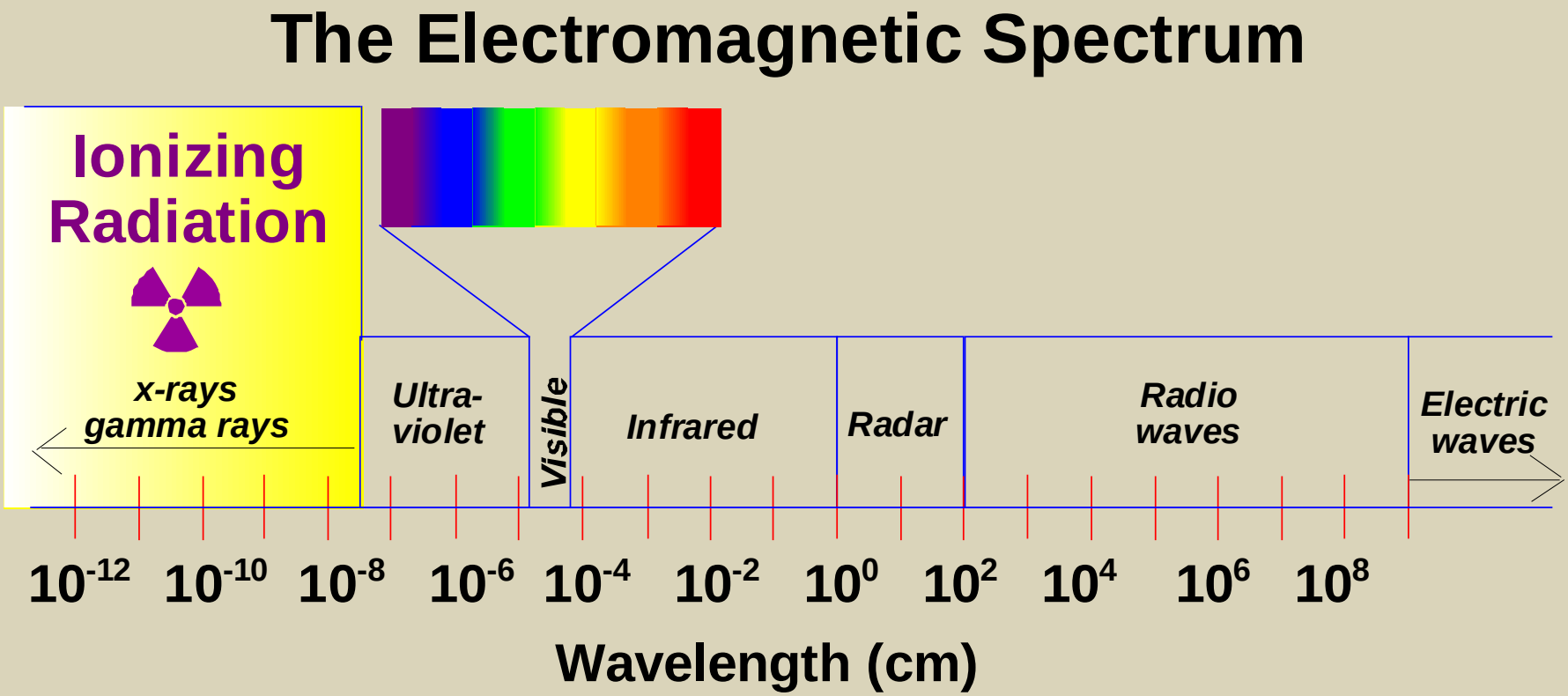
Types of Lasers

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
  - Pulsed
  - Ultra-short Pulsed

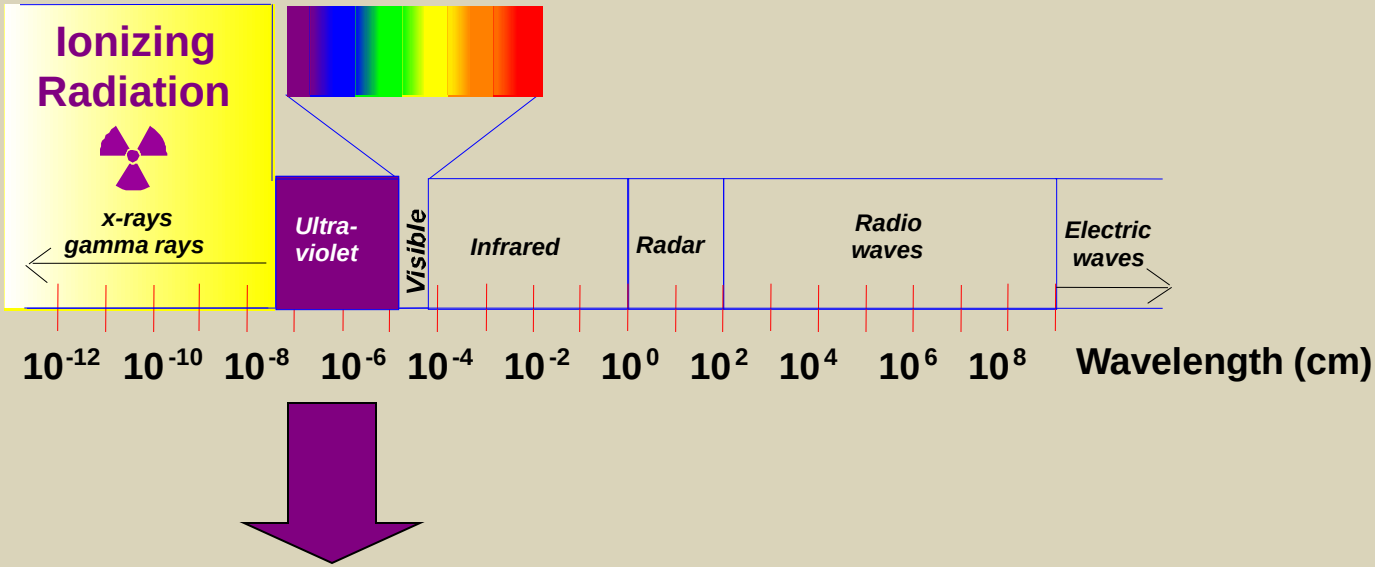
Electromagnetic Spectrum

Laser wavelengths are usually in the Ultraviolet, Visible or Infrared Regions of the Electromagnetic Spectrum.



Common Ultraviolet Lasers

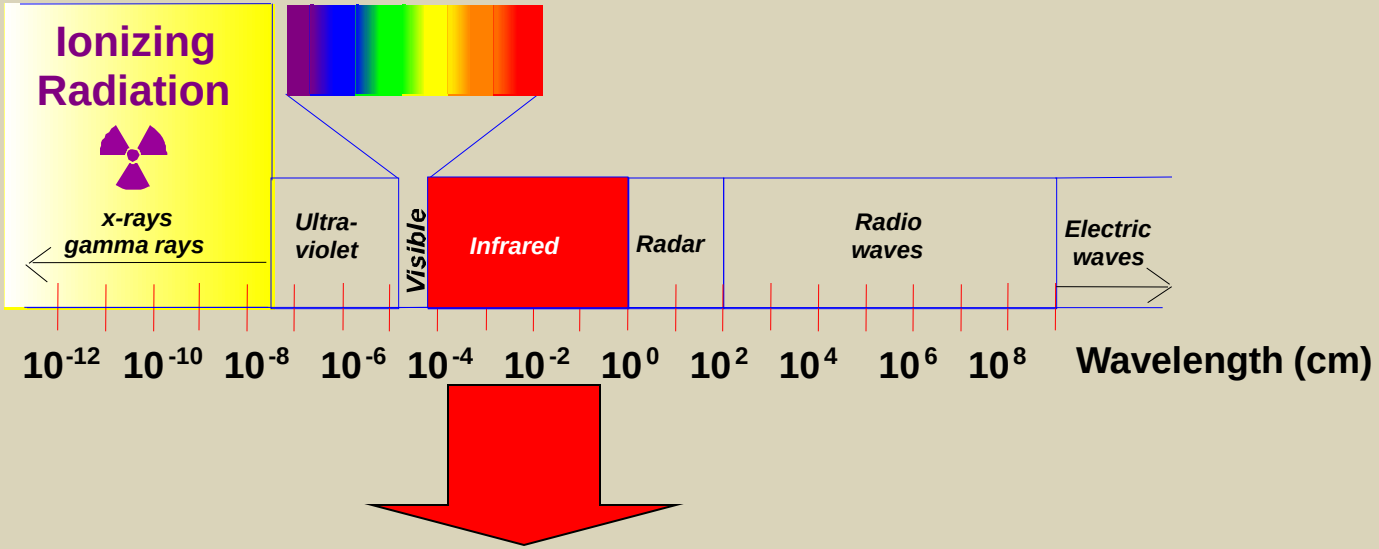
Ultraviolet (UV) radiation ranges from 200-400 nm.



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

Common Infrared Lasers

Infrared radiation ranges from 760-10,000 nm.



Common Infrared Lasers								
Near Infrared							Far Infrared	
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

Common Visible Light Lasers

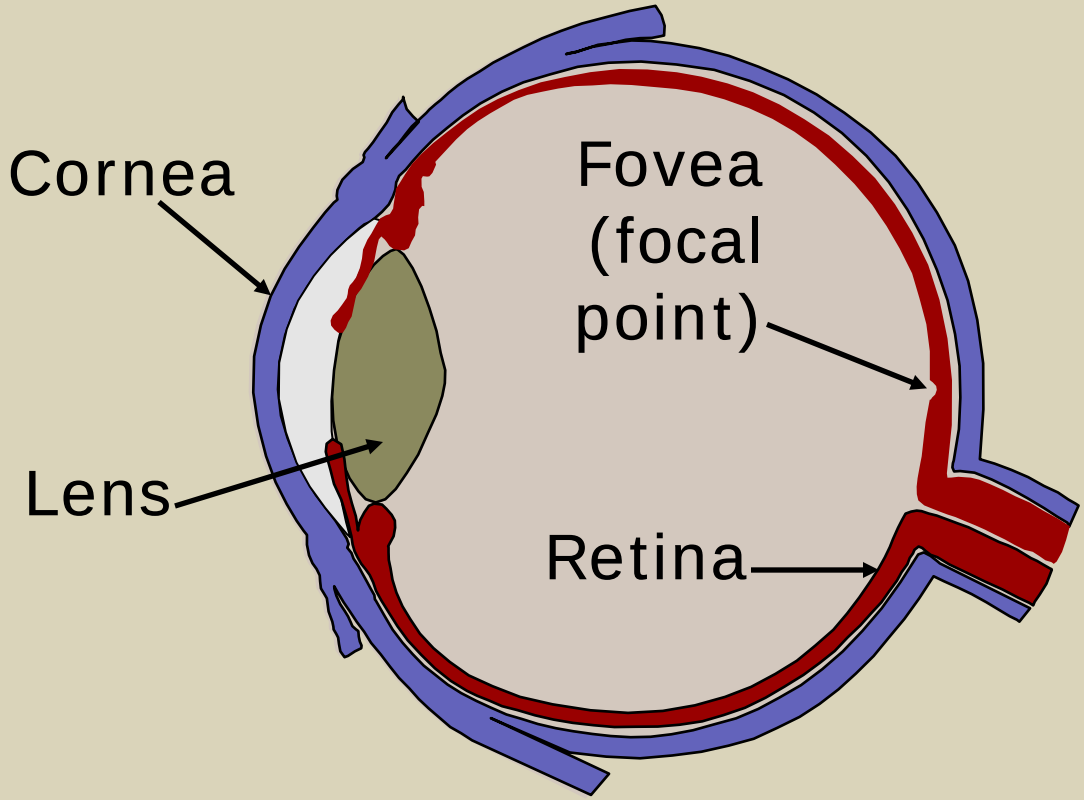
Violet	Helium cadmium	441 nm
Blue	Krypton	476 nm
	Argon	488 nm
Green	Copper vapor	510 nm
	Argon	514 nm
	Krypton	528 nm
	Frequency doubled Nd YAG	532 nm
	Helium neon	543 nm
Yellow	Krypton	568 nm
	Copper vapor	570 nm
	Rohodamine 6G dye (tunable)	570 nm
	Helium neon	594 nm
Orange	Helium neon	610 nm
Red	Gold vapor	627 nm
	Helium neon	633 nm
	Krypton	647 nm
	Rohodamine 6G dye	650 nm
	Ruby ($CrAlO_3$)	694 nm

The wavelength range for light that is *visible* to the eye ranges from 400-760 nm.

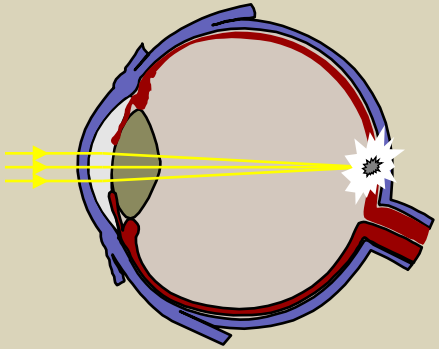
Light Reflection Hazards

- Types of Reflections
  - **Specular reflection** is a reflection from a mirror-like surface. 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.*
  - **Diffuse reflection** is a reflection from a dull surface.
    Note that surfaces that appear shiny to the eye may be diffuse reflectors of UV wavelengths.
- Diffuse laser light reflection from a high powered laser can result in an eye injury.

Biology of the Eye



Retinal Hazard Region



The wavelength range of light that can enter the eye is 400 to 1400 nm, though the range that we can actually see is only 400 – 760 nm.

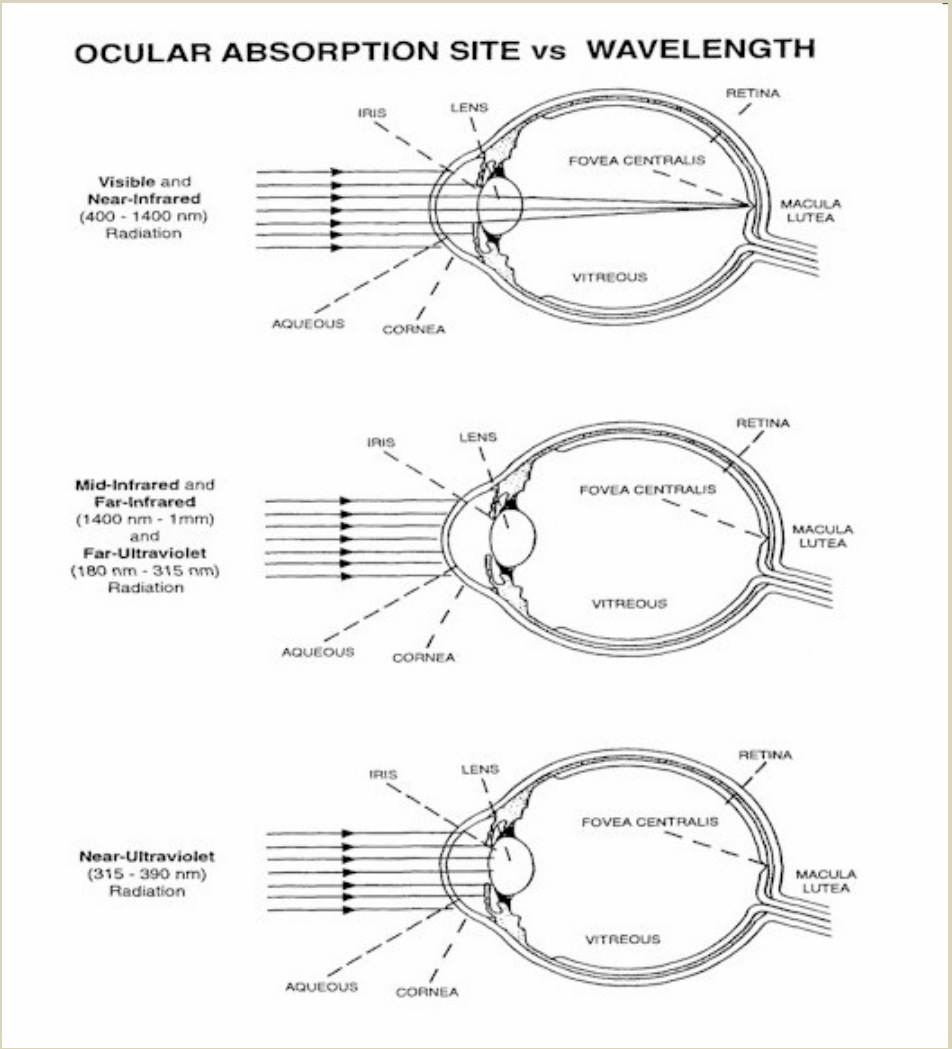
The eye can focus a collimated beam of light to a spot 20 microns in diameter on the retina (called the *focal point*).

This focusing ability places the retina at risk when exposed to laser light in the wavelength range that will penetrate to the retina, because even fairly low wattage laser light can impact the retina with 100,000 times the radiant power that entered the eye. Because of this optical gain, laser light in the 400 – 1400 nm is referred to as the ***Retinal Hazard Region***.

This is important to remember when working with infrared lasers, because the retina can be injured even though the laser is invisible.

Retinal Hazard Region Eye Injury

- Visible and Near-Infrared
- Far-Infrared and Far-Ultraviolet
- Near Ultraviolet

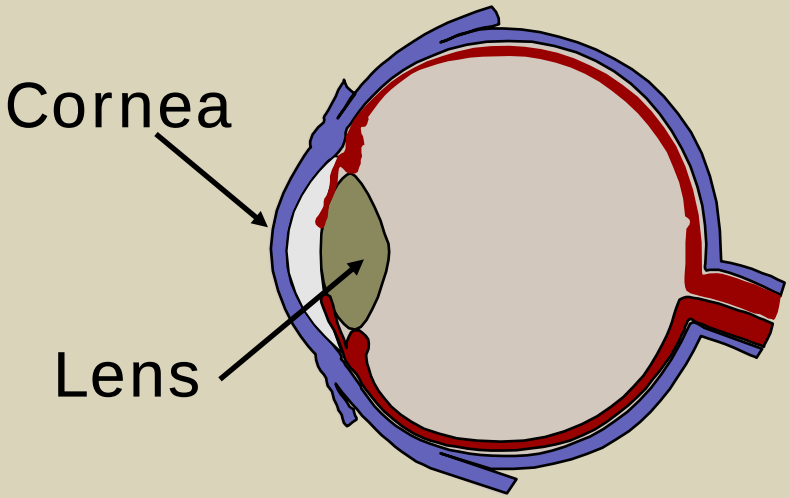


Biological Hazards - Retina

- *Thermal damage* to the retina occurs in the Retinal Hazard Region (from 400 nm – 1400 nm). Thermal damage is not cumulative, as long as the retina cools down between exposures.
- *Photochemical damage* is severe at shorter visible wavelengths (violet & blue) and is cumulative over a working day.
- *Acoustic shock* from exposure to high energy pulsed lasers results in physical tissue damage.

Biological Hazards – Cornea & Lens

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



Biological Hazards - Skin

- 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.

Laser Safety Regulations

- Occupational Safety & Health Administration (OSHA)
  - No specific laser safety regulations, but will cite safety issues under the General Duty Clause and will enforce the ANSI standard for laser safety.
- American National Standards Institute (ANSI)
  - ANSI Z136.1 (2007) Safe Use of Lasers
  - ANSI Z136.2-6 Specific references

Laser Hazard Classes

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

Class 1 Lasers

- Considered incapable of producing damaging radiation levels during operation.
- Any laser that has been rendered *intrinsically safe* due to the laser having been completely enclosed so that no hazardous radiation can escape and cause injury.

Class 2 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.
- Because class 2 lasers include only visible wavelengths, the ***aversion reaction*** will usually prevent us from permanently damaging our eyes. The ***aversion reaction*** refers to our tendency to look away from bright light.

Class 1M and 2M Lasers

- Classification for 1M and 2M Lasers are identical to the requirements for 1 and 2 respectively, however there is the potential for hazardous exposure if optical viewing aids are used.
- Only requirements for Class 1 and 2 are to prevent potentially hazardous optically aided viewing.

Class 3R Lasers

- This class of intermediate power lasers includes any wavelength.
- Potentially hazardous under direct and specular viewing, under very specific viewing criteria. However, injury probability is small.
- This class will not cause thermal skin burn or cause fires.

Class 3B Lasers

- Any laser that is considered hazardous under direct and specular viewing.
- This class will not cause thermal skin burn or cause fires.
- Requires a Laser Safety Officer and written Standard Operating Procedures.

Class 4 Lasers

- Visible and near-IR lasers will cause *severe* retinal injury and burn the skin. Even diffuse reflections can cause retinal injuries.
- UV and far-IR lasers of this class can cause injury to the surface of the eye and the skin from the direct beam and specular reflections.
- Even a diffuse reflection can cause injury.
- May also produce laser generated air contaminants (LGAC).
- This class of laser can cause fires.
- Requires a Laser Safety Officer and written Standard Operating Procedures.

Laser Safety Officer (LSO)

- The *Laser Safety Officer (LSO)* is someone who has authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.
- The LSO for GWU is Mariel Jais with the Office of Laboratory Safety (OLS).
- Designation of a Deputy LSO (DLSO) will vary according to the laser in question and usually be a faculty member or operator who has primary responsibility for routine work.

Maximum Permissible Exposure (MPE)

- The Maximum Permissible Exposure (MPE) is the highest level of radiation to which a person can be exposed without hazardous effects.
- 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 may result in adverse biological effects, such as injury to the skin and/or eyes.

Nominal Hazard Zones (NHZ)

- The *Nominal Hazard Zone (NHZ)* is the location around the laser within which a person can be exposed to radiation in excess of the MPE.
- When Class 3b and 4 lasers are unenclosed, the Laser Safety Officer must establish a NHZ.
- People may be injured if they are within the perimeter of this zone while the laser is in operation.

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

Non-Beam Hazards – Electric Shock and Fire

- **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**
  High powered Class 4 lasers will easily ignite flammable materials (such as paper or flammable liquids). You *must* have a fire extinguisher if you have a class 4 laser. In some circumstances, Class 3B lasers could also ignite flammable liquids.

Laser Generated Air Contaminants (LGAC)

- Air contaminated due to interaction of laser beam with target material can result in the production of toxic chemicals.
- During surgical procedures, biohazardous aerosols containing bloodborne pathogens are created.
  - The OSHA web site provides information on biohazardous air contaminants produced during surgery. Visit: http://www.osha.gov/SLTC/laserelectrosurgeryplume/index.html
- To prevent personnel from inhaling the LGAC and to prevent the release of LGAC to the environment, exhaust ventilation with special filters may be needed.
- If you are concerned that hazardous air contaminants may be generated by your laser, contact the Office of Lab Safety (OLS) or Environmental Health & Safety (EH&S).

Chemical Hazards

Lasers use a variety of lasing mediums, and some of these are comprised of toxic chemicals, such as dyes, solvents and hazardous gases.

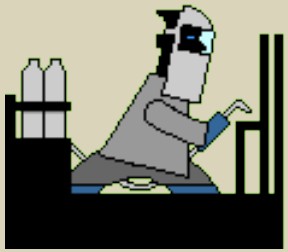
- Many laser dyes and solvents are toxic and carcinogenic.
- A few of the hazardous gases which may be part of your lasing system include chlorine, fluorine, hydrogen chloride and hydrogen fluoride. *Please contact OLS for assistance with the special ventilation precautions required for these gases.*
- As with all hazardous chemicals, you should review the Material Safety Data Sheet (MSDS) for the chemicals which are used in or around your laser.

Compressed Gases

- Compressed gas must be secured with approved cylinder supports
- Usage area must be well ventilated
- Prior approval of usage should be obtained
- Empty containers still have residual gas inside, do not throw containers away or attempt to empty them completely

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.
- High powered lasers can also produce *Plasma Radiation* from the interaction of the laser beam with the target material, especially when these lasers are used to weld metals. Plasma radiation may contain enough UV and/or blue light to require additional protective measures.



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, EH&S can perform noise level monitoring to determine whether or not the noise associated with your laser is at this level.

Control Measures

- There are several measures that can be taken to prevent injury from lasers. These measures include:
  - Engineering Controls
  - Administrative Controls
  - Personnel Protective Equipment
  - Warning Signs and Labels

Engineering Controls

- Engineering controls are measures that are incorporated into the laser system and are designed to prevent injury to personnel. Engineered safety controls are preferable to PPE or Administrative controls.
- Examples include
  - 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)

Administrative Controls

Administrative controls are procedures that are designed to prevent personnel from injury. Examples of administrative controls required for Class 3B & 4 lasers include:

- Designation of Nominal Hazard Zones (NHZ).
- Written *Standard Operating Procedures (SOP's)* which are enforced by the LSO and DLSO.
- Warning signs at entrances to room.
- Training for all personnel who will be operating a laser or in the vicinity of the laser while it is in operation. (Training is also required for those using Class 2 and 3R lasers.)
- Allow only authorized, trained personnel in the vicinity of the laser during operation.

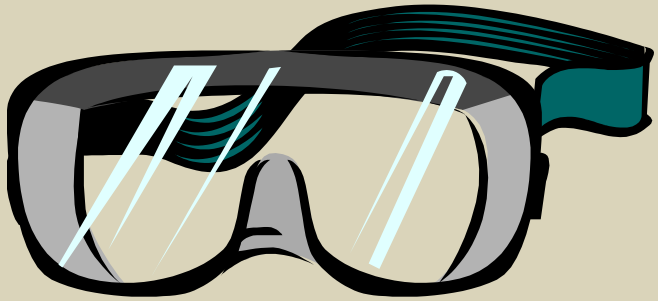
PPE for Skin

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

- Ultraviolet lasers and laser welding/cutting operations 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

- PPE is not required for class 2 or 3R lasers unless intentional direct viewing > 0.25 seconds is necessary.
- Personnel Protective Equipment (PPE) for eyes exposed to Class 3B or 4 lasers is mandatory. Eyewear with side protection is best. Consider these factors when selecting eyewear:
  - Optical Density (OD) of the eyewear
  - Laser Power and/or pulse energy
  - Laser Wavelength(s)
  - Exposure time criteria
  - Maximum Permissible Exposure (MPE)
  - Filter characteristics, such as transient bleaching



Protect Your Eyes!

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

Other PPE

PPE may also be required to provide protection from hazardous chemicals and gases. Consult with OLS if you need assistance with determining the appropriate PPE for use with your laser.

Warning Labels

Only Class 1 lasers require no labels. All other lasers must be labeled at the beam's point of origin.

- Class 2:
  "Laser Radiation – Do Not Stare into Beam."
- Class 2M:
  "Laser Radiation – Do not Stare into Beam or View Directly with Optical Instruments."
- Class 3R:
  "Laser Radiation – Avoid Direct Eye Exposure."
- Class 3B:
  "Laser Radiation – Avoid Direct Exposure to Beam"
- Class 4:
  "Laser Radiation – Avoid Eye or Skin Exposure to Direct or Scattered Radiation."

Warning Signs

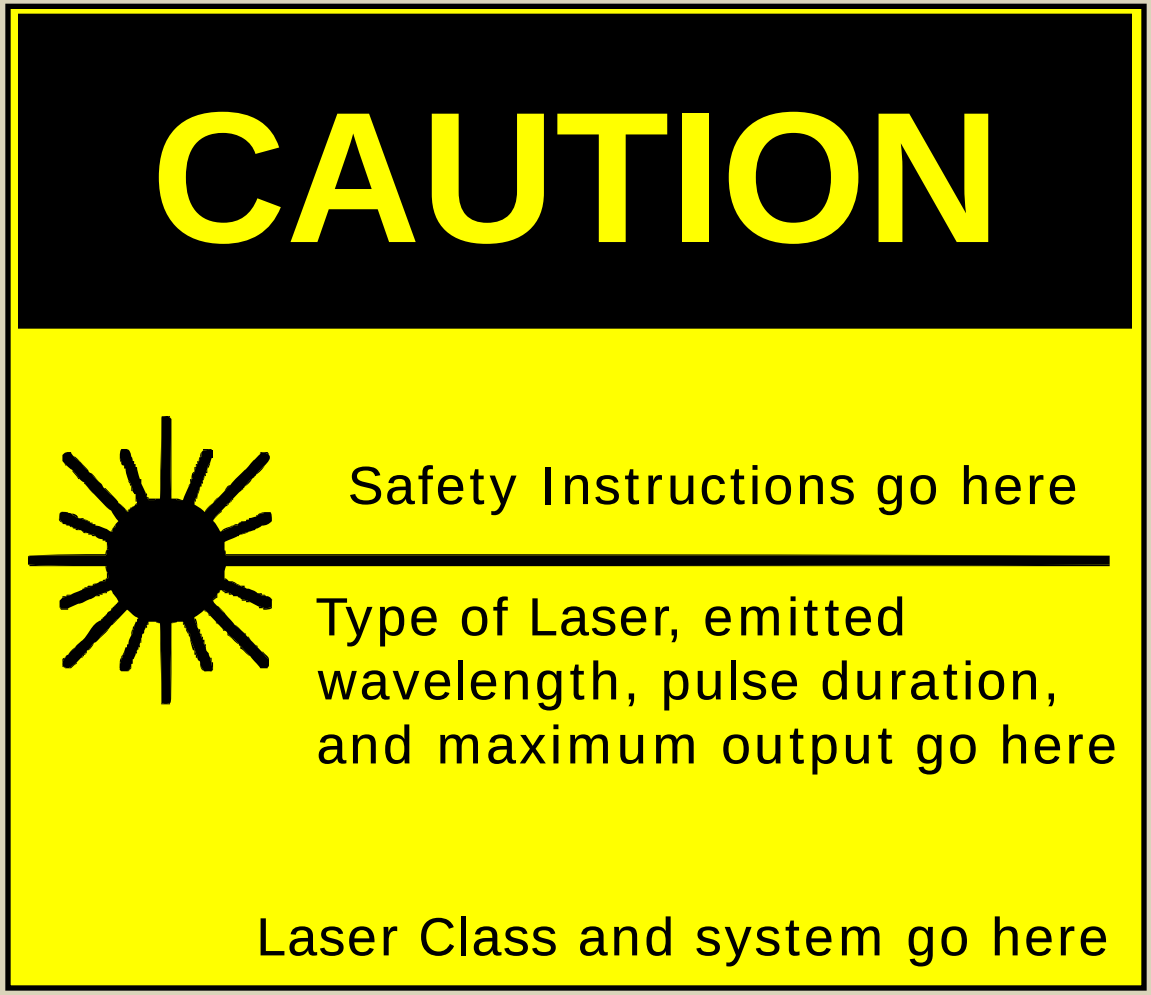
All rooms with class 3R, 3B or 4 lasers must have appropriate signs posted at all entrances. Signs must:

- 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

- "**DANGER**" indicates a very dangerous situation that could result in serious injury or death. This sign should be used for Class 3R, 3B, and 4 lasers.
- "**CAUTION**" indicates a potentially hazardous situation which could cause a less serious injury. This sign should be used for Class 2 and 2M lasers.
- "**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 service operation is in progress.

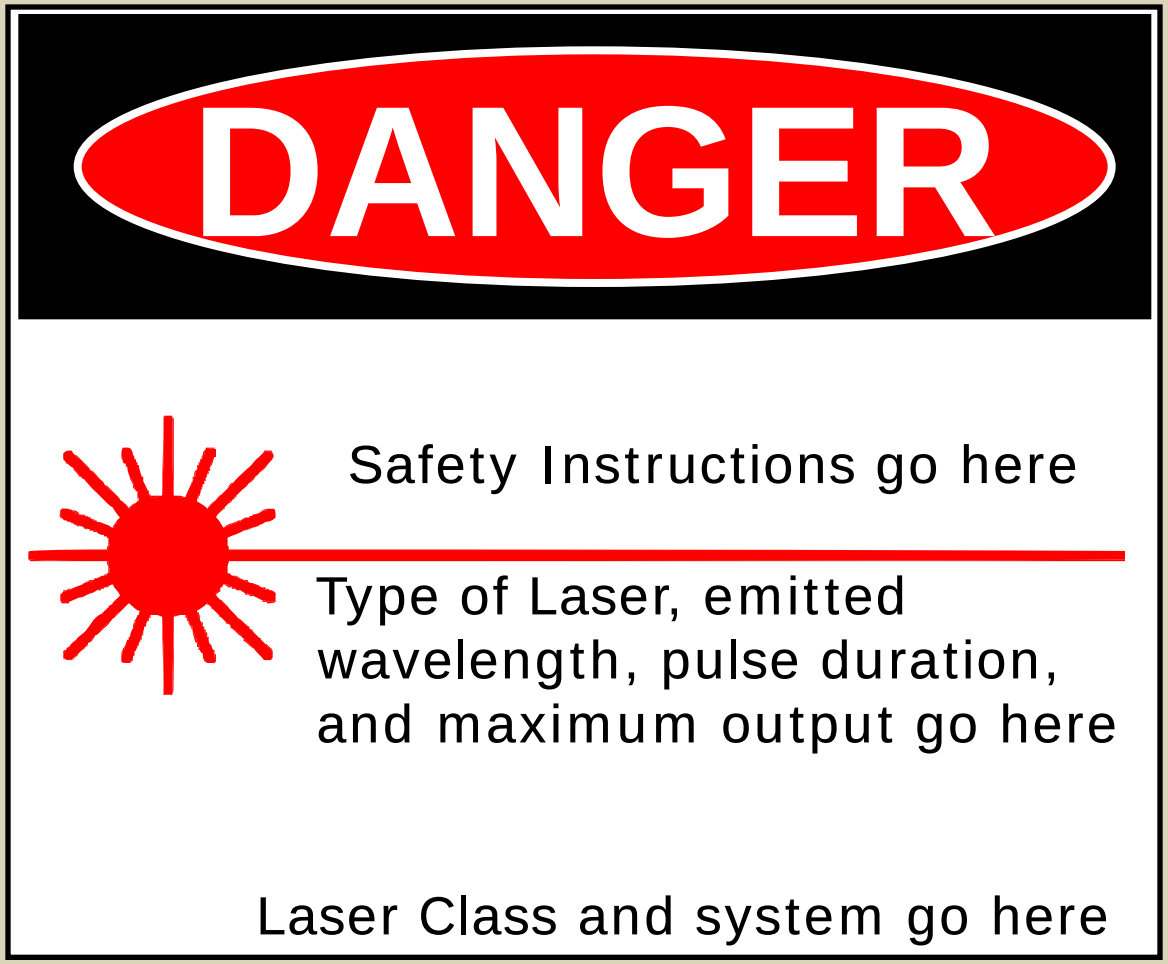
“CAUTION” Warning Sign



Safety Instructions may include:

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

“DANGER” Warning Sign



Safety Instructions may include:

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- Invisible laser radiation
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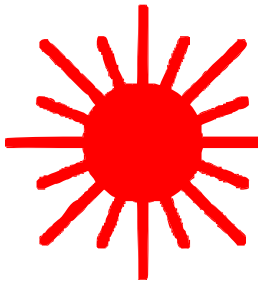
“NOTICE” Sign for Laser Repair

NOTICE



Safety Instructions go here (such as “Laser Repair in Progress”)

Type of Laser, emitted wavelength, pulse duration, and maximum output go here

Laser Class and system go here

Safety Instructions may include:

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

Additional Warnings for 3B & 4 Lasers

- 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

Medical Surveillance

- Medical surveillance may be available through the department for individuals who work with or around Class 3B and 4 lasers.
- Contact the OLS for assistance in arranging a medical evaluation.
- Currently there is no routine medical surveillance necessary on campus for laser operators.

For More Information

- The ANSI Z136.1 Laser Safety Standard is the best reference to consult for laser safety information.
  - One copy is available for viewing in Ross Hall B05, OLS (This copy will not be loaned out.)
  - You can also purchase a copy of the standard through the Laser Institute of America web site (http://www.laserinstitute.org).
- Call OLS at 4-8258 if you have additional questions about laser safety.