Laser Hazards

Beam-Related Hazards

Improperly used laser devices are potentially dangerous. Effects can range from mild skin burns to irreversible injury to the skin and eye. The biological damage caused by lasers is produced through thermal, acoustical and photochemical processes.

Thermal effects are caused by a rise in temperature following absorption of laser energy. The severity of the damage is dependent upon several factors, including exposure duration, wavelength of the beam, energy of the beam, and the area and type of tissue exposed to the beam.

Acoustical effects result from a mechanical shockwave, propogated through tissue, ultimately damaging the tissue. This happens when the laser beam causes localized vaporization of tissue, causing the shockwave analogous to ripples in water from throwing a rock into a pond.

Beam exposure may also cause photochemical effects when photons interact with tissue cells. A change in cell chemistry may result in damage or change to tissue. Photochemical effects depend greatly on wavelength. *Table 2* summarizes the probable biological effects of exposure of eyes and skin to different wavelengths.

Table 2. Summary of Laser Biological Effects

Photobiological Spectral Domain	**Eye**	**Skin**
Ultraviolet C (200 nm - 280 nm)	Photokeratitis	Erythema (sunburn) Skin Cancer Accelerated skin aging
Ultraviolet B (280 nm - 315 nm)	Photokeratitis	Increased pigmentation
Ultraviolet A (315 nm - 400 nm)	Photochemical cataract	Pigment darkening Skin burn
Visible (400 nm - 780 nm)	Photochemical and thermal retinal injury	Pigment darkening Photosenstive reactions Skin burn

Infrared A (780 nm - 1400 nm)	Cataract and retinal burn	Skin burn
Infrared B (1.4µm - 3.0 µm)	Corneal burn, aqueous flare, cataract	Skin burn
Infrared C (3.0 µm - 1000 µm)	Corneal burn only	Skin burn

Types of Beam Exposures

Exposure to the laser beam is not limited to direct beam exposure. Particularly for high powered lasers, exposure to beam reflections may be just as damaging as exposure to the primary beam.

Intrabeam exposure means that the eye or skin is exposed directly to all or part of the laser beam. The eye or skin is exposed to the full irradiance or radiant exposure possible.

Specular reflections from mirror surfaces can be nearly as harmful as exposure to the direct beam, particularly if the surface is flat. Curved mirror-like surfaces will widen the beam such that while the exposed eye or skin does not absorb the full impact of the beam, there is a larger area for possible exposure.

A diffuse surface is a surface that will reflect the laser beam in many directions. Mirror-like surfaces that are not completely flat, such as jewelry or metal tools, may cause ***diffuse reflections*** of the beam. These reflections do not carry the full power or energy of the primary beam, but may still be harmful, particularly for high powered lasers. Diffuse reflections from Class 4 lasers are capable of initiating fires.

Whether a surface is a diffuse reflector or a specular reflector will depend upon the wavelength of the beam. A surface that would be a diffuse reflector for a visible laser may be a specular reflector for an infrared laser beam.

Eye

The major danger of laser light is hazards from beams entering the eye. The eye is the organ most sensitive to light. Just as a magnifying glass can be used to focus the sun and burn wood, the lens in the human eye focuses the laser beam into a tiny spot than can burn the retina. A laser beam with low divergence entering the eye can be focused down to an area 10 to 20 microns in diameter.

The laws of thermodynamics do not limit the power of lasers. The second law states that the temperature of a surface heated by a beam from a thermal source of radiation cannot exceed the temperature of the source beam. The laser is a non-thermal source and is able to generate temperatures far greater than it's own. A 30 mW laser operating at room temperature is capable of producing enough energy (when focused) to instantly burn through paper.

Per the law of the conservation of energy, the energy density (measure of energy per unit of area) of the laser beam increases as the spot size decreases. This means that the energy of a laser beam can be intensified up to 100,000 times by the focusing action of the eye. If the irradiance entering the eye is 1 mW/cm^2, the irradiance at the retina will be 100 W/cm^2. Thus, even a low power laser in the milliwatt range can cause a burn if focused directly onto the retina.

NEVER point a laser at someone's eyes no matter how low the power of the laser.

Structure Of The Eye

Damage to the eye is dependent upon the wavelength of the beam. In order to understand the possible health effects, it is important to understand the functions of the major parts of the human eye.

The **cornea** is the transparent layer of tissue covering the eye. Damage to the outer cornea may be uncomfortable (like a gritty feeling) or painful, but will usually heal quickly. Damage to deeper layers of the cornea may cause permanent injury.

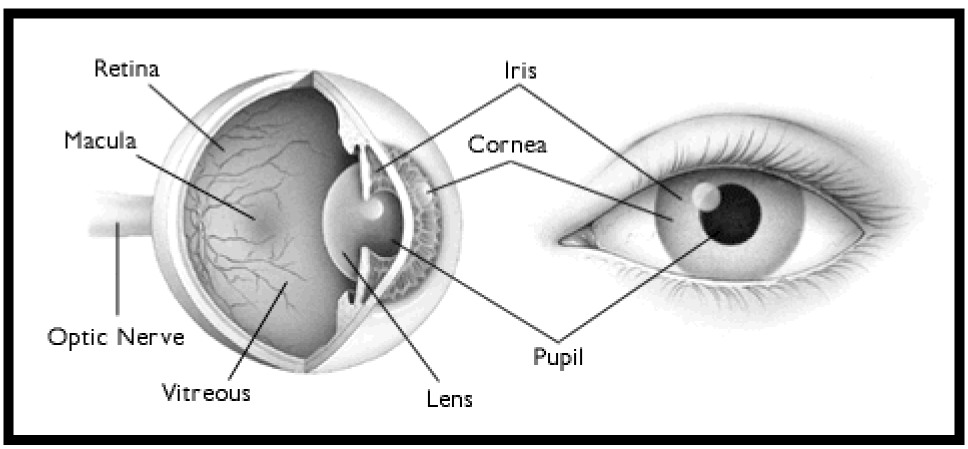


Figure 9. Cross section of the human eye.

The **lens** focuses light to form images onto the retina. Over time, the lens becomes less pliable, making it more difficult to focus on near objects. With age, the lens also becomes cloudy and eventually opacifies. This is known as a cataract. Every lens develops cataract eventually.

The part of the eye that provides the most acute vision is the **fovea** centralis (also called the **macula** lutea). This is a relatively small area of the **retina** (3 to 4%) that provides the most detailed and acute vision as well as color perception. This is why eyes move when you read or when you look as something; the image has to be focused on the fovea for detailed perception. The balance of the retina can perceive light and movement, but not detailed images (peripheral vision).

If a laser burn occurs on the fovea, most fine (reading and working) vision may be lost in an instant. If a laser burn occurs in the peripheral vision it may produce little or no effect on fine vision. Repeated retinal burns can lead to blindness.

Fortunately the eye has a self-defense mechanism -- the blink or aversion response. When a bright light hits the eye, the eye tends to blink or turn away from the light source (aversion) within a quarter of a second. This may defend the eye from damage where lower power lasers are involved, but cannot help where higher power lasers are concerned. With high power lasers, the damage can occur in less time than a quarter of a second.

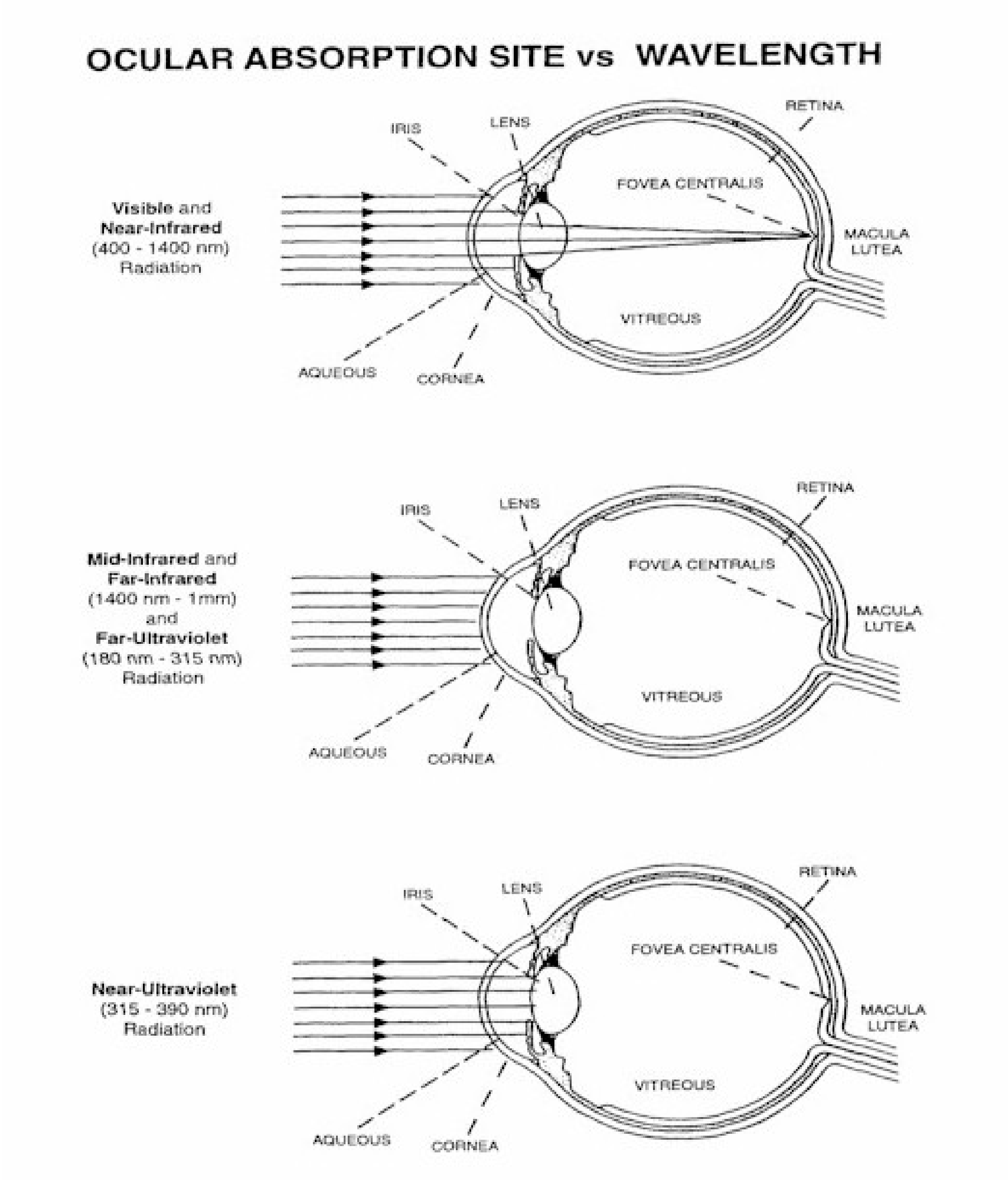
Symptoms of a laser burn in the eye include a headache shortly after exposure, excessive watering of the eyes, and sudden appearance of *floaters* in your vision. Floaters are those swirling distortions that occur randomly in normal vision most often after a blink or when eyes have been closed for a couple of seconds. Floaters are caused by dead cell tissues that detach from the retina and choroid and float in the vitreous humor. Ophthalmologists often dismiss minor laser injuries as floaters due to the very difficult task of detecting minor retinal injuries. Minor corneal burns cause a gritty feeling, like sand in the eye.

Several factors determine the degree of injury to the eye from laser light:

- **pupil size -** The shrinking of pupil diameter reduces the amount of total energy delivered to the retinal surface. Pupil size ranges from a 2 mm diameter in bright sun to an 8 mm diameter in darkness (night vision).
- **degree of pigmentation -** More pigment (melanin) results in more heat absorption.
- **size of retinal image** - The larger the size, the greater the damage because temperature equilibrium must be achieved to do damage. The rate of equilibrium formation is determined by the size of the image.
- **pulse duration -** The shorter the time (ns versus ms), the greater the chance of injury.
- **pulse repetition rate** - The faster the rate, the less chance for heat dissipation and recovery.
- **wavelength -** determines where the energy deposits and how much gets through the ocular media.

Eye Absorption Site vs. Wavelength

The wavelength determines where the laser energy is absorbed in the eye.



Lasers in the visible and near infrared range of the spectrum have the greatest potential for retinal injury, as the cornea and the lens are transparent to those wavelengths and the lens can focus the laser energy onto the retina. The maximum absorption of laser energy onto the retina occurs in the range from 400 - 550 nm. Argon and YAG lasers operate in this range, making them the most hazardous lasers with respect to eye injuries. Wavelengths of less than 550 nm can cause a photochemical injury similar to sunburn. Photochemical effects are cumulative and result from long exposures (over 10 seconds) to diffuse or scattered light. *Table 3* summarizes the most likely effects of overexposure to various commonly used lasers.

Table 3. Summary of Bioeffects of Commonly Used Lasers

LASER TYPE	**WAVELENGTH (µm)**	**BIOEFFECT Process**	**TISSUE EFFECTED**			
			Skin	**Cornea**	**Lens**	**Retina**
CO_2	10.6	Thermal	X	X		
HFl	2.7	Thermal	X	X		
Erbium-YAG	1.54	Thermal	X	X		
Nd-YAG [a]	1.33	Thermal	X	X	X	X
Nd-YAG	1.06	Thermal	X			X
Gas (diode)	0.78-0.84	Thermal	[b]			X
He-Ne	0.633	Thermal	[b]			X
Ar	0.488-0.514	Thermal/ Photochemical	X			X[c]
XeFl	0.351	Photochemical	X	X		X
XeCl	0.308	Photochemical	X	X		

[a] Wavelength at 1.33µ or more common in some Nd-YAG lasers has demonstrated simultaneous cornea/lens/retina effects in biological research studies

[b] Power levels not normally sufficient to be considered a significant skin hazard

[c] Photochemical effects dominate for long-term exposures to retina (exposure times more than 10 seconds

Skin

Lasers can harm the skin via photochemical or thermal burns. Depending on the wavelength, the beam may penetrate both the epidermis and the dermis. The epidermis is the outermost living layer of skin. Far and Mid-ultraviolet (the actinic UV) are absorbed by the epidermis. A sunburn (reddening and blistering) may result from short-term exposure to the beam. UV exposure is also associated with an increased risk of developing skin cancer and premature aging (wrinkles, etc) of the skin.

Thermal burns to the skin are rare. They usually require exposure to high energy beams for an extended period of time. Carbon dioxide and other infrared lasers are most commonly associated with thermal burns, since this wavelength range may penetrate deeply into skin tissue. The resulting burn may be first degree (reddening), second degree (blistering) or third degree (charring).

Some individuals are photosensitive or may be taking prescription drugs that induce photosensitivity. Particular attention must be given to the effect of these (prescribed) drugs, including some antibiotics and fungicides, on the individual taking the medication and working with or around lasers.

Non-Beam Hazards

In addition to the hazards directly associated with exposure to the beam, ancillary hazards can be produced by compressed gas cylinders, cryogenic and toxic materials, ionizing radiation and electrical shock.

Electrical Hazards

The use of lasers or laser systems can present an electric shock hazard. This may occur from contact with exposed utility power utilization, device control, and power supply conductors operating at potentials of 50 volts or more. These exposures can occur during laser set-up or installation, maintenance and service, where equipment protective covers are often removed to allow access to active components as required for those activities. The effect can range from a minor tingle to serious personal injury or death. Protection against accidental contact with energized conductors by means of a barrier system is the primary methodology to prevent electrical shock.

Additional electrical safety requirements are imposed upon laser devices, systems and those who work with them by the federal Occupational Safety and Health Administration the National Electric Code and related state and local regulations. Individuals who repair or maintain lasers may require specialized electric safety-related work practices training.

Another particular hazard is that high voltage electrical supplies and capacitors for lasers are often located close to cooling water pumps, lines, filters, etc. In the event of a spill or hose rupture, an extremely dangerous situation may result. During times of high humidity, over-cooling can lead to condensation which can have similar effects. A potentially lethal accident occurred at a university when a graduate student opened a laser to wipe condensation from a tube.

The following are recommendations for preventing electrical shocks for lasers for all classifications:

1. All equipment should be installed in accordance with OSHA and the National Electrical Code.
2. All electrical equipment should be treated as if it were “live”.
3. Working with or near live circuits should be avoided. Whenever possible, unplug the equipment before working on it.
4. A “buddy system” should be used when work on live electrical equipment is necessary, particularly after normal work hours or in isolated areas. Ideally, the person should be knowledgeable of first aid and CPR.

5. Rings and metallic watchbands should not be worn, nor should metallic pens, pencils, or rulers be used while one is working with electrical equipment.
6. Live circuits should be worked on using one hand, when it is possible to do so.
7. When one is working with electrical equipment, only tools with insulated handles should be used.
8. Electrical equipment that upon touch gives the slightest perception of current should be removed from service, tagged and repaired prior to further use.
9. When working with high voltages, consider the floor conductive and grounded unless standing on a suitably insulated dry matting normally used for electrical work.
10. Live electrical equipment should not be worked on when one is standing on a wet floor, or when the hands, feet or body is wet or perspiring.
11. Do not undertake hazardous activities when truly fatigued, emotionally stressed, or under the influence of medication that dulls or slows the mental and reflex processes.
12. Follow lockout/tagout procedures when working with hard-wired equipment.

Laser Generated Air Contaminants-The "Plume"

This is a term used to refer to the "cloud" of contaminants created when there is an interaction between the beam and the target matter. These air contaminants are mostly associated with Class 3b and 4 lasers, and range from metallic fumes and dust, chemical fumes, and aerosols containing biological contaminants.

Some examples include:

- polycyclic aromatic hydrocarbons from mode burns on poly (methyl methacrylate) type polymers;
- hydrogen cyanide and benzene from cutting of aromatic polyamide fibers;
- fused silica from cutting quartz;
- heavy metals from etching;
- benzene from cutting polyvinyl chloride; and
- cyanide, formaldehyde and synthetic and natural fibers associated with other processes.

Special optical materials used for far infrared windows and lenses have been the source of potentially hazardous levels of airborne contaminants. For example, calcium telluride and zinc telluride will burn in the presence of oxygen when beam irradiance limits are exceeded. Exposure to cadmium oxide, tellurium and tellurium hexafluoride should also be controlled.

Exposure to these contaminants must be controlled to reduce exposure below acceptable OSHA permissible exposure limits. The material safety data sheet (MSDS) may be consulted to determine exposure information and permissible exposure limits. In general, there are three major control measures available: exhaust ventilation, respiratory protection, and isolation of the process.

Whenever possible, recirculation of plume should be avoided. Exhaust ventilation, including use of fume hoods should be used to control airborne contaminants.

Respiratory protection may be used to control brief exposures, or as an interim control measure until other administrative or engineering controls are implemented. Use of respirators must comply with the University Policy on Respiratory Protection. Contact the MU EHS at 573-882-7018 if a respirator is needed.

The laser process may be isolated by physical barriers, master-slave manipulators, or remote control apparatus. This is particularly useful for laser welding or cutting of targets such as plastics, biological material, coated metals, and composite substrates.

Collateral and Plasma Radiation

Collateral radiation, i.e., radiation other than that associated with the primary laser beam, may be produced by system components such as power supplies, discharge lamps and plasma tubes. Such radiation may take the form of x-rays, UV, visible, infrared, microwave and radio-frequency radiation. "Home-built" lasers are again of particular concern and should be independently examined. In addition, when high power pulsed laser beams (peak irradiance of the order of 10^{12} watts/cm^2) are focused on a target, a plasma is generated which may also emit collateral radiation. X-rays may be generated by electronic components of the laser system (e.g., high voltage vacuum tubes, usually greater than 15kV) and from laser-metal induced plasmas.

Fire Hazards

Class 4 laser systems represent a fire hazard. Enclosure of Class 3 laser beams can result in potential fire hazards if enclosure materials are likely to be exposed to irradiances exceeding 10 watts/cm^2. The use of flame retardant materials is encouraged.

Opaque laser barriers (e.g., curtains) can be used to block the laser beam from exiting the work area during certain operations. While these barriers can be designed to offer a range of protection, they normally cannot withstand high irradiance levels for more than a few seconds without some damage, including the production of smoke, open fire, or penetration. Users of commercially available laser barriers should obtain appropriate fire prevention information from the manufacturer.

Operator of Class 4 lasers should be aware of the ability of unprotected wire insulation and plastic tubing to ignite from intense reflected or scattered beams, particularly from lasers operating at invisible wavelengths.

Compressed Gases

Many hazardous gases are used in laser applications, including chlorine, fluorine, hydrogen chloride, and hydrogen fluoride. The use of mixtures with inert gases, rather than the pure gases is generally preferred. Hazardous gases should be stored in appropriately exhausted enclosures, with the gases permanently piped to the laser using the recommended metal tubing and fittings. An inert gas purge system and distinctive coloring of the pipes and fittings is also prudent.

Compressed gas cylinders should be secured from tipping. Other typical safety problems that arise when using compressed gases are:

- working with free-standing cylinders not isolated from personnel
- regulator disconnects, releasing contents to atmosphere
- no remove shutoff valve or provisions for purging gas before disconnect or reconnect
- labeled hazardous gas cylinders not maintained in appropriate exhausted enclosures
- gases of different categories (toxics, corrosives, flammable, oxidizers, inerts, high pressure and cryogenics) not stored separately

The departmental Chemical Hygiene Plan has additional information about safely handling compressed gases.

Laser Dyes

Laser dyes are complex fluorescent organic compounds which, when in solution with certain solvents, form a lasing medium for dye lasers. Certain dyes are highly toxic or carcinogenic. Since these dyes frequently need to be changed, special care must be taken when handling, preparing solutions, and operating dye lasers. The MSDS for dye compounds should be available to and reviewed by all appropriate workers.

The use of dimethylsulfoxide (DMSO) as a solvent for cyanide dyes in dye lasers should be discontinued, if possible. The DMSO aids in the transport of dyes into the skin. If another solvent cannot be found, low permeability gloves should be worn by personnel any time a situation arises where contact with the solvent may occur.

Preparation of dye solutions should be conducted in a fume hood. Personal protective equipment, such as lab coats, appropriate gloves, and eye protection are necessary when preparing solutions.