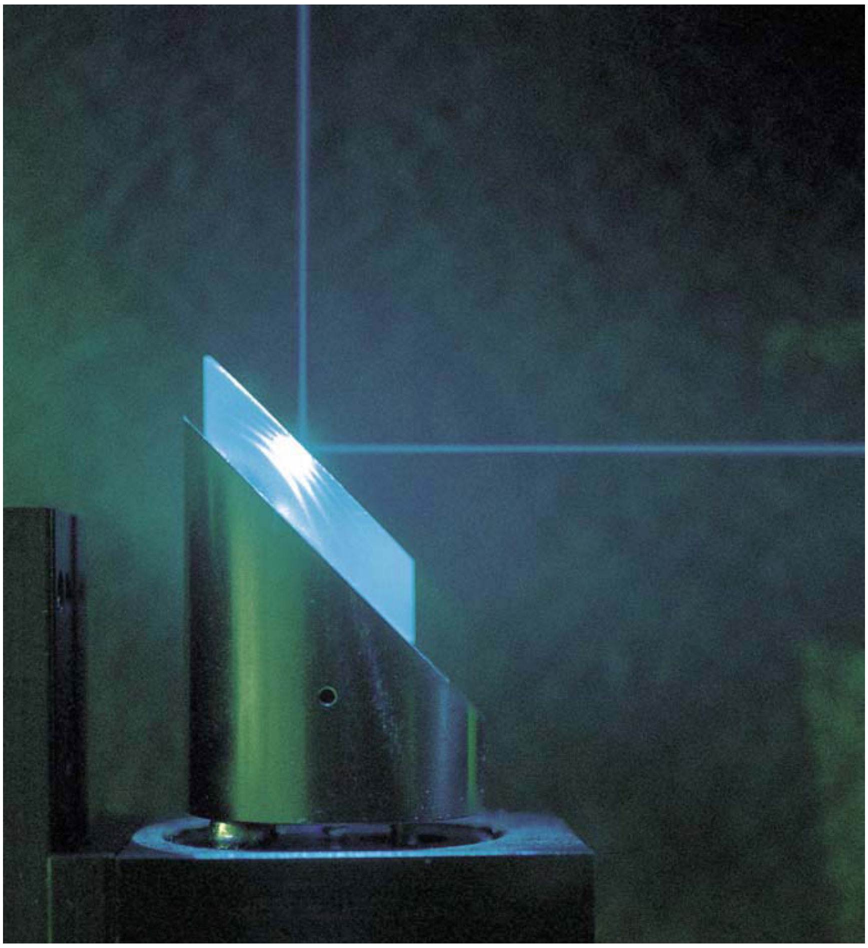
Notes on Laser Hazards



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I. Laser Fundamentals

The acronym **LASER** stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. This is a device to produce a beam of monochromatic light in which all the waves are in phase or are coherent.

Lasers contain four primary components regardless of style, size or application (Fig.1).

1. **Active Medium**

   The active medium may be solid crystals such as ruby or Nd:YAG, liquid dyes, gases like CO2 or Helium/Neon, or semiconductors such as GaAs. Active mediums contain atoms whose electrons may be excited to a metastable energy level by an energy source.

2. **Excitation Mechanism**

   Excitation mechanisms pump energy into the active medium by one or more of three basic methods; optical, electrical or chemical.

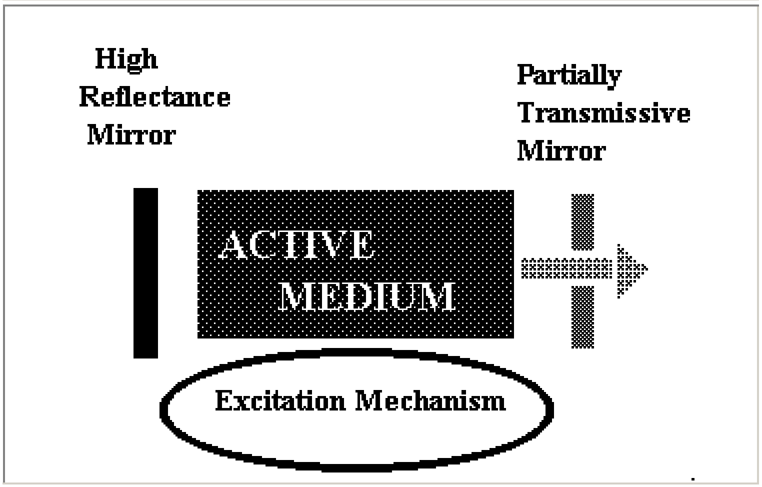
3. **High Reflectance Mirror**

   A mirror which reflects essentially 100% of the laser light.

4. **Partially Transmissive Mirror**

   A mirror which reflects less than 100% of the laser light and transmits the remainder.

Figure 1 - Laser Components



Lasing Action

Light is produced when energy is applied to an atom raising an electron to a higher unstable energy level. This electron will then randomly return to its stable energy level by releasing a photon of light. Light produced in this manner is called incoherent light (Fig.2) and has many different wavelengths (colours), directions and phases.
When energy is applied to a laser active medium (Fig.4) electrons are raised to an unstable energy level then spontaneously decay to a lower relatively long-lived metastable state. Electrons in this state will not spontaneously return to their ground energy level; therefore it is possible to pump large amounts of energy into the material thus obtaining a population inversion in which most of the atoms are in a metastable state. After this population inversion has been achieved, lasing action is initiated by an electron which spontaneously returns to its ground state producing a photon. If the photon released is of exactly the right wavelength it will stimulate an atom in a metastable state to emit a photon of the same wavelength (Stimulated Emission). Many of these stimulated photons will be lost when they hit the side of the lasing medium. However if the photons travel parallel to the long axis of the optical cavity they will continue to stimulate emissions of photons having the same wavelengths which combine coherently (Fig.3) until they reach the mirrored ends of the optical cavity. When the beam strikes the totally reflecting mirror in the optical cavity the beam is reversed and continues to stimulate emissions of photons which increase in intensity until the beam reaches the partially reflecting surface of the optical cavity. A small portion of the coherent light is released while the rest is reflected back through the lasing medium to continue the process of stimulating photons. Laser radiation will continue to be produced as long as energy is applied to the lasing medium.

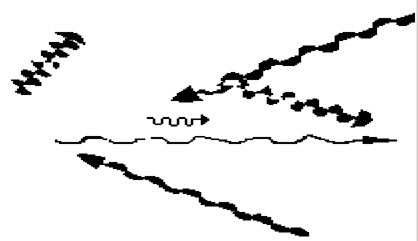
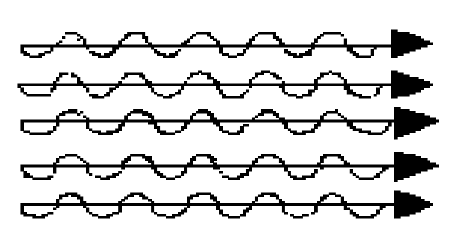
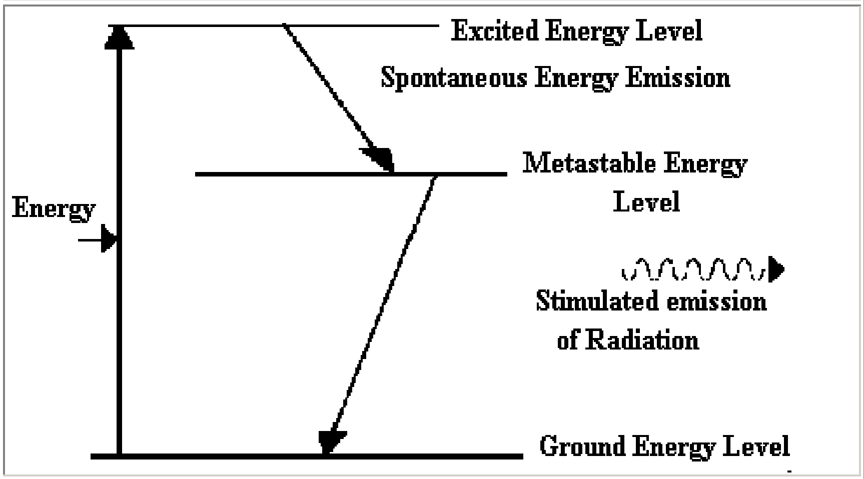
Figure 2 - Incoherent Light	**Figure 3 - Coherent Light**
	

Figure 4 - Energy states of Laser Active Medium



Continuous Wave (Figure 5)

If energy is continuously pumped into the active medium an equilibrium may be achieved between the number of atoms raised to a metastable state and the number of photons emitted resulting in a continuous laser output. Output for continuous wave lasers is expressed as Irradiance(E) which is the concentration of laser power incident on a given area or Power/Unit Area (W/cm2)

Figure 5 - Continuous Output

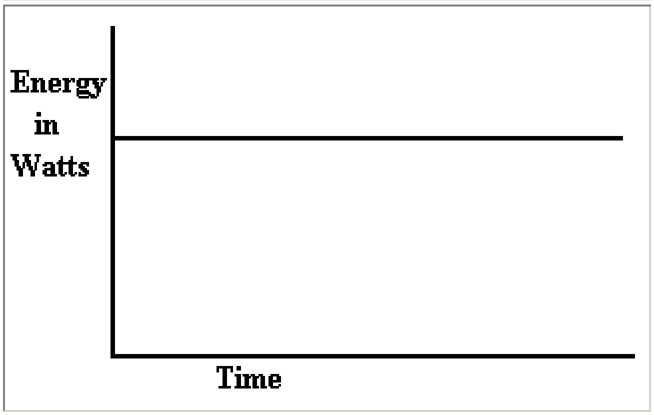
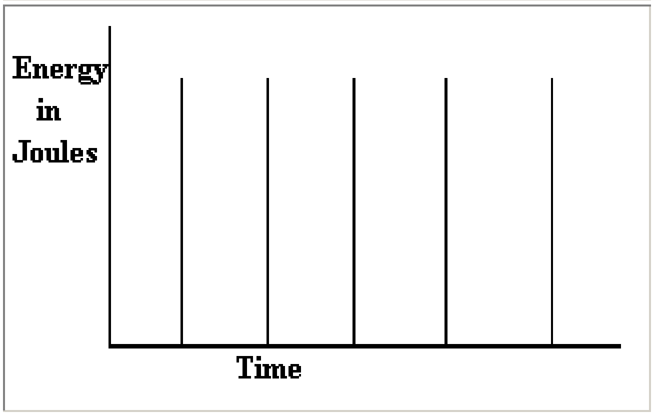


Figure 6 - Pulsed Output



Pulsed Lasers and Q-Switched Lasers (Figure 6)

Pulsed laser emissions are produced when the excitation medium is modulated producing a pulse of laser radiation lasting usually less than 0.25 sec. Pulsed output may also be produced by blocking the beam with a rotating mirror or prism.
Q-switching or Q-spoiling is a technique employed to produce a very high output pulse. Q- switching is accomplished by using a device to prevent the reflection of photons back and forth in the active medium. This produces a

higher population of electrons in the metastable state. At a predetermined instant the Q-switch is turned off allowing the lasing action to continue producing very intense short pulses of laser radiation. Q-switched lasers produce pulses of 10 to 250 nanoseconds (ns).
Output for pulsed lasers expressed as Radiant Exposure (H) which is the concentration of laser energy on a given area Energy/Unit Area (J/cm2).

Wave Lengths of Common Laser Types

Laser Type	Media	Wave Length (s)	Nanometers
Excimer Gas Lasers	Argon Fluoride	(UV)	193 nm
	Krypton Chloride	(UV)	222 nm
	Krypton Fluoride	(UV)	248 nm
	Xenon Chloride	(UV)	308 nm
	Xenon Fluoride	(UV)	351 nm
Gas Lasers	Nitrogen	(UV)	337 nm
	Helium Cadmium	(UV)	325 nm
	Helium Cadmium	(Violet)	441 nm
	Argon	(Blue)	488 nm
	Argon	(Green)	514 nm
	Krypton	(Blue)	476 nm
	Krypton	(Green)	528 nm
	Krypton	(Yellow)	568 nm
	Krypton	(Red)	647 nm
	Xenon	(White)	multiple
	Helium Neon	(Green)	543 nm
	Helium Neon	(Yellow)	594 nm
	Helium Neon	(Orange)	612 nm
	Helium Neon	(Red)	633 nm
	Helium Neon	(NIR)	1,152 nm
	Helium Neon	(MIR)	3,390 nm
	Hydrogen Fluoride	(MIR)	2,700 nm
	Carbon Dioxide	(FIR)	10,600 nm
Metal Vapor Lasers	Copper Vapor	(Green)	510 nm
	Copper Vapor	(Yellow)	570 nm
	Gold Vapor	(Red)	627 nm
	Doubled Nd:YAG	(Green)	532 nm
	Neodymium: YAG	(NIR)	1,064 nm

	Erbium: Glass	(MIR)	1,540 nm
	Erbium: YAG	(MIR)	2,940 nm
	Holmium: YLF	(MIR)	2,060 nm
	Holmium: YAG	(MIR)	2,100 nm
	Chromium Sapphire (Ruby)	(Red)	694 nm
	Titanium Sapphire	(NIR)	840-1,100 nm
	Alexandrite	(NIR)	700-815 nm
Dye Lasers	Rhodamine 6G	(VIS)	570-650 nm
	Coumarin C30	(Green)	504 nm
Semiconductor Lasers	Galium Arsenide (GaAs)	(NIR)	840 nm
	Galium Aluminum Arsenide	(VIS/NIR)	670-830 nm

II. Classification of lasers:

Lasers are classified to describe the capabilities of a laser system to produce injury to personnel.

Class I lasers are low powered devices that are considered safe from all potential hazards. Some examples of Class I laser use are: laser printers, CD players, CD ROM devices. No individual, regardless of exposure conditions to the eyes or skin, is expected to be injured by a Class I laser. *No* safety requirements are needed to use Class I laser devices.

Class II lasers (Visible Lasers: 400 to 700 nm) are low power (< 1mW), visible light lasers that could possibly cause damage to a person's eyes. Some examples of Class II laser use are: classroom demonstrations, laser pointers, aiming devices and range finding equipment. If class II laser beams are directly viewed for long periods of time (i.e. > 15 minutes) damage to the eyes could result. Avoid looking into a Class II laser beam or pointing a Class II laser beam into another person's eyes. Avoid viewing Class II laser beams with telescopic devices. Realize that the bright light of a Class II laser beam into your eyes will cause a normal reaction to look away or close your eyes. This response is expected to protect you from Class II laser damage to the eyes.

Class IIIa lasers are continuous wave, intermediate power (1-5 mW) devices. Some examples of Class IIIa laser uses are the same as Class II lasers with the most popular uses being laser pointers and laser scanners. Direct viewing of the Class IIIa laser beam could be hazardous to the eyes. *Do not* view the Class IIIa laser beam directly. *Do not* point a Class IIIa laser beam into another persons eyes. *Do not* view a Class IIIa laser beam with telescopic devices; this amplifies the problem.

Class IIIb lasers are intermediate power (c.w. 5-500 mW or pulsed 10 J/cm^2) devices. Some examples of Class IIIb laser uses are CW and pulsed dye lasers used in spectroscopy and entertainment light shows. Direct viewing of the Class IIIb laser beam is hazardous to the eye and diffuse reflections of the beam can also be hazardous to the eye. *Do not* view the Class IIIb laser beam directly. *Do not* view a Class IIIb laser beam with telescopic devices; this amplifies the problem

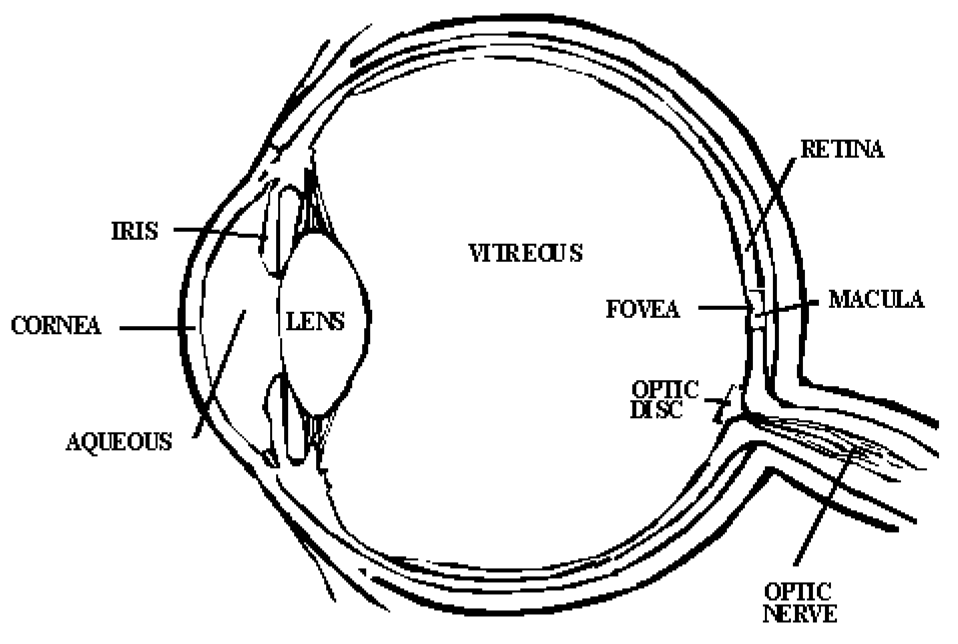
Class IV lasers are high power (c.w. >500mW or pulsed >10J/cm^2) devices. Examples of Class IV laser are: Argon ion and Nd:YAG lasers used to pump CW and pulsed dye lasers. The direct beam and diffuse reflections from Class IV lasers are hazardous to the eyes and skin. Class IV laser devices can also be a fire hazard depending on the reaction of the target when struck. Much greater controls are required to ensure the safe operation of this class of laser devices. Whenever occupying a laser controlled area, wear the proper eye protection. Most laser eye injuries occur from reflected beams of class IV laser light, so keep all reflective materials away from the beam. Do not place your hand or any other body part into the class IV laser beam. The pain and smell of burned flesh will let you know if this happens. Realize the dangers involved in the use of Class IV lasers and please use common sense.

III. Laser Hazards

Eye Hazards

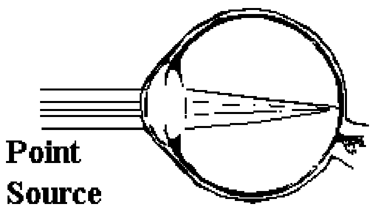
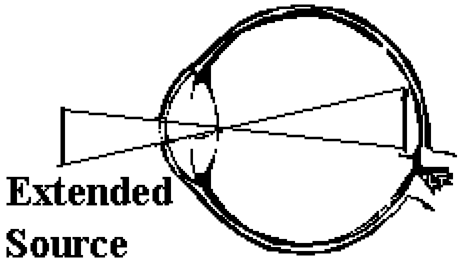
The potential for injury to the different structures of the eye (figure 7) depend upon which structure absorbs the energy. Laser radiation may damage the cornea, lens or retina depending on the wavelength, intensity of the radiation and the absorption characteristics of different eye tissues.

Figure 7 - Structures of the Eye



Ocular Image

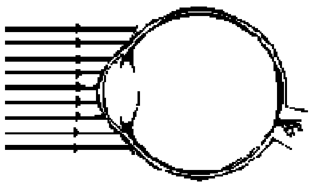
Wavelengths between 400 nm and 1400 nm are transmitted through the curved cornea and lens and focused on the retina. Intra beam viewing of a point source of light (figure 8) produces a very small spot on the retina resulting in a greatly increased power density and an increase chance of damage. A large source of light such as a diffuse reflection of a laser beam produces light that enters the eye at a large angle is called an extended source. An extended source produces a relatively large image on the retina (figure 9) and energy is not concentrated on a small area the retina as in a point source.

Figure 8 - Point Source Viewing	Figure 9 - Extended Source Viewing
	

Details of Irradiation Effects on Eyes

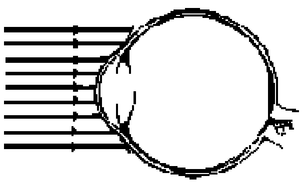
Ultraviolet-B+C (100 - 315 nm)

The surface of the cornea absorbs all UV of these wavelengths (Figure 10) which produce a photokeratitis (welders flash) by a photochemical process which cause a denaturation of proteins in the cornea . This is a temporary condition because the corneal tissues regenerate very quickly.

Figure 10 - UV-B+C & IR-B+C


Ultraviolet –A (315 - 400 nm)

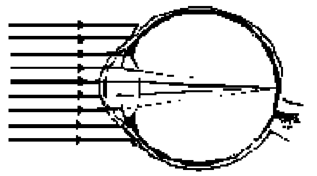
The cornea, lens and aqueous humour allow Ultraviolet radiation of these wavelengths (Figure 11) and the principal absorber is the lens. Photochemical processes denature proteins in the lens resulting in the formation of cataracts.

Figure 11 - UV-A


Visible light and Infrared-A (400 - 1400 nm)

The cornea, lens and vitreous fluid are transparent to electromagnetic radiation of these wavelengths (Figure 12). Damage to the retinal tissue occurs by absorption of light and its conversion to heat by the melanin granules in the pigmented epithelium or by photochemical action to the photoreceptor. The focusing effects of the cornea and lens will increase the irradiance on the retina by up to 100,000 times. For visible light 400 to 700 nm the aversion reflex which takes 0.25 seconds may reduce exposure causing the subject to turn away from a bright light source. However this will not occur if the intensity of the laser is great enough to produce damage in less than 0.25 sec. or when light of 700 - 1400 nm (near infrared) is used as the human eye is insensitive to these wavelengths.

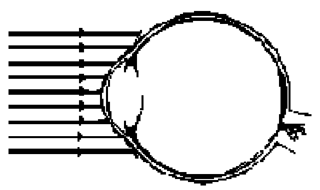
Figure 12 - Visible & IR-A



Infrared-B and Infrared-C (1400 to 1.0 x 10+6 nm)

Corneal tissue will absorb light with a wavelength longer than 1400 nm (Figure 13). Damage to the cornea results from the absorption of energy by tears and tissue water causing a temperature rise and subsequent denaturation of protein in the corneal surface. Wavelengths from 1400 to 3000 nm penetrate deeper and may lead to the development of cataracts resulting from the heating of proteins in the lens. The critical temperature for damage is not much above normal body temperature.

Figure 13 - UV-B+C & IR-B+C

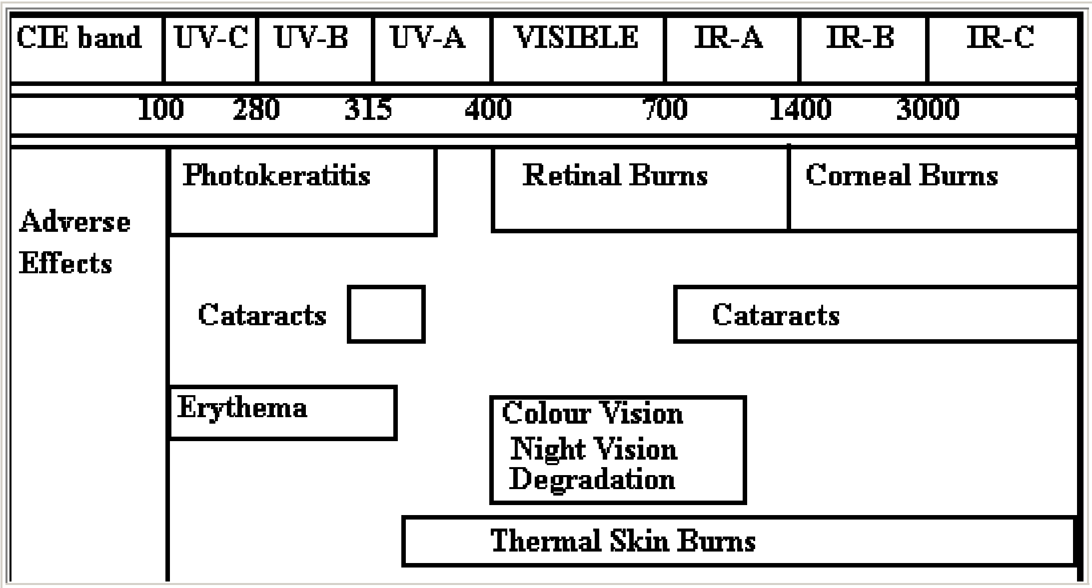


Laser Radiation Effects on Skin

Skin effects are generally considered of secondary importance except for high power infrared lasers. However with the increased use of lasers emitting in the ultraviolet spectral region, skin effects have assumed greater importance. Erythema (sunburn), skin cancer and accelerated skin aging are produced by emissions in the 200 to 280 nm range. Increased pigmentation results from exposure to light with wavelengths of 280 to 400 nm. Photosensitization has resulted from the skin being exposed to light from 310 to 700 nm. Lasers emitting radiation in the visible and infrared regions produce effects that vary from a mild reddening to blisters and charring. These conditions are usually repairable or reversible however depigmentation, ulceration, and scarring of the skin, and damage to underlying organs may occur from extremely high powered lasers.

Summary of Wavelengths of Light and their Effects on Tissues

Below is a summary of interaction of optical radiation and various tissues. The wavelengths are divided into bands as defied by the International Commission on Illumination (CIE).



IV. Associated Hazards

Electrical Hazards

The most lethal hazard associated with lasers is the high voltage electrical systems required to power lasers. Several deaths have occurred when commonly accepted safety practices were not followed by persons working with high voltage sections of laser systems.

Safety Guidelines

1. Do not wear rings, watches or other metallic apparel when working with electrical equipment.
2. Do not handle electrical equipment when hands or feet are wet or when standing on a wet floor.
3. When working with high voltages , regard all floors as conductive and grounded.
4. Be familiar with electrocution rescue procedures and emergency first aid.
5. Prior to working on electrical equipment, de-energize the power source. Lock and tag the disconnect switch.
6. Check that each capacitor is discharged, shorted and grounded prior to working in the area of the capacitors.
7. Use shock preventing shields, power supply enclosures, and shielded leads in all experimental or temporary high-voltage circuits.

Chemical Hazards

Laser dyes

Most dyes come in a solid power form, which must be dissolved in solvents prior to use in the laser system. Improper use of dyes or solvents may present a range of hazards for the laser researcher.

Although little is known about them, many organic laser dyes are believed to be toxic and/or mutagenic. Because they are solid powders, they can easily become airborne and possibly inhaled and/or ingested. When mixed with certain solvents (DMSO), they can be absorbed through unprotected skin. Direct contact with dyes and with dye/solvent solutions should always be avoided.

A wide variety of solvents are used to dissolve laser dyes. Some of these (alcohols) are highly flammable and must be kept away from ignition sources. Fires and explosions resulting from improper grounding or overheated bearings in dye pumps are not uncommon in laser laboratories. Dye pumps should be inspected, maintained, and tested on a regular basis to avoid these problems. Additionally, dye lasers should never be left running unattended.

Some of the solvents used with laser dyes may also be skin irritants, narcotics, or toxics. You should refer to the Material Safety Data Sheet (MSDS), which is supplied by the solvent manufacturer for additional information on health effects.

Powered laser dyes should never be handled where the airborne dust could be breathed. Dyes must be mixed only in a properly functioning fume hood. The proper protective equipment (PPE = safety glasses, chemical gloves, and lab coat) should always be used by the person handling the dye. The gloves being used should be resistant to the solvent being handled. Mixing of dyes and solvents should be done carefully, so as to avoid spilling. Any spills or leaks should be cleaned up immediately using appropriate PPE. Avoid breathing fumes from the solvent being used. Clearly identify and mark containers used for mixed dye/solvent solutions. Practice good hygiene and wash your hands well after handling dyes.

Limit the amount of mixed dye/solvent being stored in the laboratory. Once mixed, the dye/solvent should be stored in sealed unbreakable plastic containers (beware of solvent incompatibility) until ready to use. Be sure to check transfer lines and pump connections for continuity prior to each use with the dye/solvent. All pumps and dye reservoirs must be placed in trays with sufficient capacity to contain all of the dye/solvent should it leak. This "double containment" method should prevent dye stains on floors and other surfaces.

Note that dyes and dye/solvent solutions are considered hazardous wastes and must be disposed of properly.

Cryogenic fluids

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they replace the oxygen in the air. Adequate ventilation must be ensured. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. Although the quantities of liquid nitrogen that are used are small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes.
Compressed gases used in lasers present serious health and safety hazards. Problems may arise when working with unsecured cylinders, cylinders of hazardous materials not maintained in ventilated enclosures, and gases of different categories (toxins, corrosives, flammable, oxidizers) stored together.

Collateral radiation

Radiation other than that associated with the primary laser beam is called collateral radiation. Examples are X-rays, UV, plasma, radio frequency emissions.

Ionizing Radiation

X-rays could be produced from two main sources in the laser laboratories. One is high-voltage vacuum tubes of laser power supplies, such as rectifiers, thyratrons and crowbars and the other is electric-discharge lasers. Any power supplies which require more than 15 kilovolts (keV) may produce enough X-rays to cause a health hazard. Interaction between X-rays and human tissue may cause a serious disease such as leukemia or other cancers, or permanent genetic effects which may show up in future generations.

UV and Visible

UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may exceed the Maximum Permissible Exposure (MPE) and thus cause skin and eye damage.

Plasma Emissions

Interactions between very high power laser beams and target materials may in some instances produce plasmas. The plasma generated may contain hazardous UV emissions.

Radio Frequency (RF)

Q switches and plasma tubes are RF excited components. Unshielded components may generate radio frequency fields which exceed federal guidelines.

Fire Hazards

Class 4 lasers represent a fire hazard. Depending on construction material beam enclosures, barriers, stops and wiring are all potentially flammable if exposed to high beam irradiance for more than a few seconds.

Explosion Hazards

High pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. These components are to be enclosed in a housing which will withstand the maximum explosive force that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently care must be used to provide adequate mechanical shielding when exposing brittle materials to high intensity lasers.

V. Laser Accidents

Below are summaries of reported laser accidents in the United States and their causes from 1964 to 1992. They indicate that the majority of injuries involve the eye and occur during alignment procedures, or because the protective eyewear was either inappropriate or not used (Figure 14 and 15).

Figure 14 - Cause of Laser Accidents

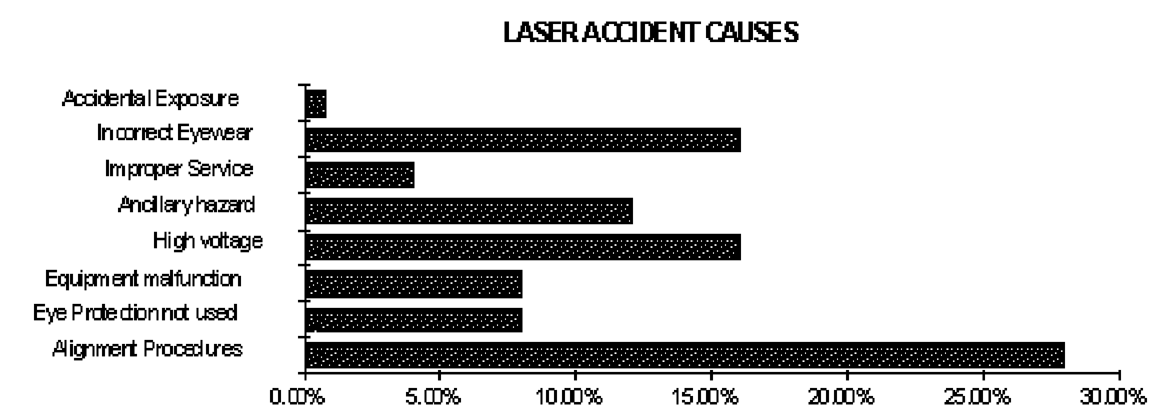


Figure 15 - Summary of Laser Accident Types