California State University Northridge
Department of Physics and Astronomy
Physics 464C Laser Safety Guidelines

I. INTRODUCTION

The increasingly widespread use of lasers requires more people to become familiar with the potential hazards associated with the misuse of this valuable new product of modern science. Applications exist in many technologies, including material processing, construction, medicine, communications, energy production, and national defense.

II. LASER HAZARD

The basic hazards from laser equipment can be categorized as follows:

1. Laser Radiation

   a. Eye- Corneal or retinal burns (or both), depending upon laser wavelength, are possible from acute exposure; and corneal or lenticular opacities (cataracts), or retinal injury may be possible from chronic exposure to excessive levels.

   b. Skin- Skin burns are possible from acute exposure to high levels of optical radiation. At some specific ultraviolet wavelengths skin carcinogenesis may occur.

2. Chemical Hazards- Laser induced reactions can release hazardous particulate and gaseous products.

3. Electrical Hazards- Lethal electrical hazards may be present, particularly in high-power laser systems.

4. Other Secondary Hazards- These include: cryogenic coolant hazards from some research lasers, excessive noise from some very high energy lasers, x radiation from faulty high-voltage (15 kV) power supplies, explosions from faulty optical pump lamps and fire hazards.

III. EYE HAZARDS

The ocular hazards represent a potential for injury to several different structures of the eye, generally depending upon which structure absorbs the most radiant energy per volume tissue. Retinal effects are possible when the laser emission wavelength occurs in the visible and near or infrared spectral regions (0.4 to 1.4 μm). Light directly from the laser or from a specular (mirror-like) reflection entering the eye at these wavelengths can be focused to an extremely small image on the retina. The incident corneal irradiance (or radiant exposure) will be increased approximately 100,000 times at the retina due to the focusing effects of the cornea and lens (Fig. 1).

Laser emissions in the ultraviolet and far-infrared spectral regions (outside 0.4 to 1.4 μm) produce ocular effects principally at the cornea, although laser radiation at certain wavelengths may reach the lens and cause damage to that structure (Fig. 2).

Effects of radiation at various wavelengths on various parts of the eye are shown in Fig. 2. Actinic ultraviolet, at wavelengths of 200 to 315 nanometers, is absorbed at the cornea; these wavelengths are responsible for welder's flash or photokeratitis. Actinic-UV radiation also

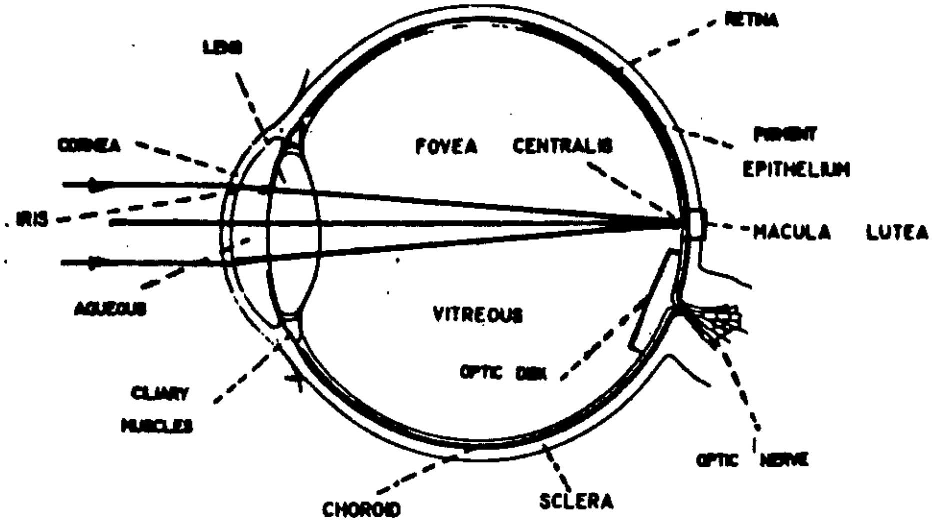

Figure 1. Schematic diagram of the human eye showing structures of interest. Parallel rays of light can be focussed to a very small area on the retina when the eye is "relaxed," i.e. focussed at infinity.

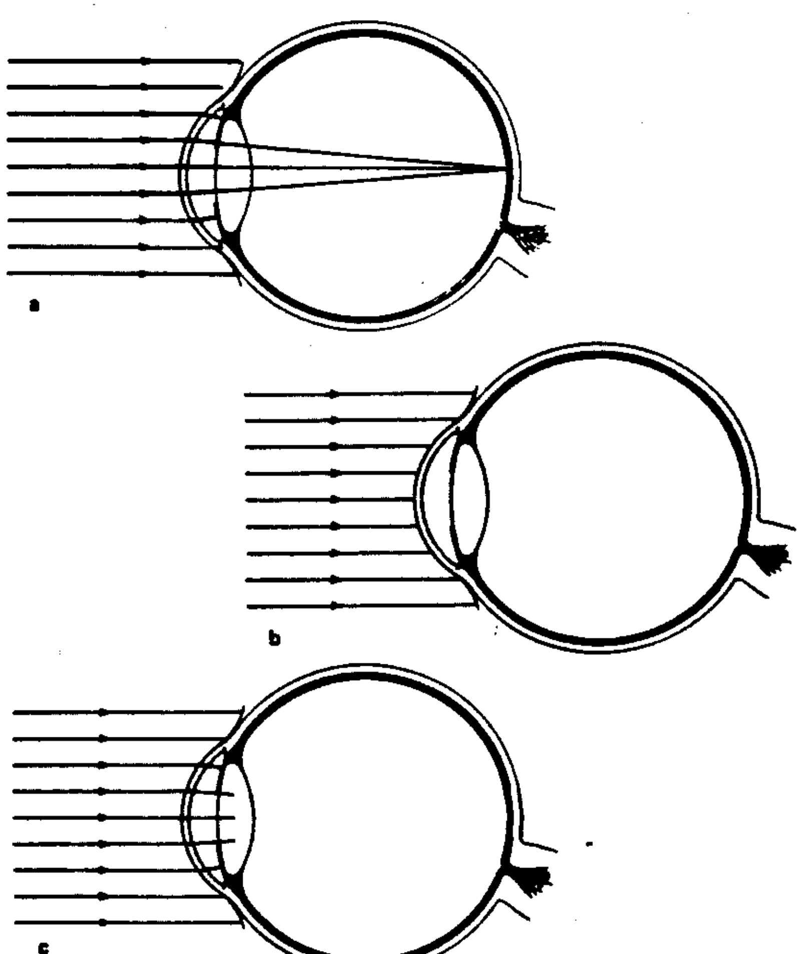

Figure 2. Absorption sites of (a) visible and near-infrared radiation (400-1400 nm); of (b) far-infrared (3 μm-1 mm) and middle-ultraviolet radiation (200-315 nm); and of (c) near-ultraviolet (320-390 nm) and middle infrared radiation (1.4-3 μm).

produces sunburn or erythema of the skin. Near-ultraviolet radiation between 315 and 400 nm is absorbed in the lens and may contribute to some forms of cataract. At high irradiances, these wavelengths also produce long-wave erythema of the skin.

Radiation at visible, 400 to 780 nm, and near-infrared, 780 to 1,400 nm, wavelengths is transmitted through the ocular media with little loss and usually is focused to a spot on the retina 10 to 20 μm in diameter. Such focusing can cause intensities high enough to damage the retina; for that reason 400 to 1,400 nm is termed the ocular-hazard region.

Although far-infrared radiation with wavelengths of 3 μm to 1 mm is absorbed in the front surface of the eye, some middle-infrared radiation between 1.4 and 3 μm penetrates deeper and may even contribute to glass blower's cataract. Extensive exposure to near-IR radiation also may contribute to such cataracts. The localization of injury is always the result of strong absorption in the specific tissue for the particular wavelength.

IV. SKIN HAZARDS

From a safe standpoint, skin effects are usually of secondary importance. However, with the more widespread use of lasers emitting in the ultraviolet spectral region, and certain high-power lasers, skin effects may assume a greater importance as a safety consideration.

V. PRESENT LASER SAFETY STANDARDS

The basic approach of most recent safety standards has been to classify lasers by their potential hazard based upon their optical emission, and then specify control measures which are commensurate with the relative hazard of the classification. American National Standards Institute (ANSI) standard z-136.1, "Safe Use of Lasers (1980)", which was also adopted in "A Guide for Control of Laser Hazards" published by the American Conference of Governmental Industrial Hygienists (ACGIH). The ANSI scheme has four basic hazard classifications. The classification is based upon the intensity of the emitted beam from the laser (emission limit) if it is used by itself, or from the complete system if the laser is a component within a laser system where the raw beam does not leave the enclosure, but instead, a modified beam leaves the system. The four classifications are:

Class I	Exempt Lasers and Laser Systems;
Class II	Low Power Visible CW and High Pulse Rate Frequency Lasers and Laser systems;
Class III	Medium Power Lasers and Laser Systems;
Class IV	High Power Lasers and Laser Systems.

The basic philosophy for these four classes is as follows:

Class I

The Class I exempt classification includes all lasers or laser systems which cannot emit levels or radiation above the maximum permissible exposure under any exposure conditions inherent to the design of the laser. There are no warning labels or control measures required for exempt lasers. Unless the system contains a higher powered laser.

Class II

The Class II low-power visible CW laser classification, which requires only a warning label on the device as a control measure, is separated from higher classifications by virtue of the fact that such devices can only emit visible radiation of sufficiently low power that unexpected exposures can be avoided by an aversion response of the viewer. Consequently, the maximum emission from such a device is set at the MPE level for one-quarter second. This corresponds to a one-milliwatt average laser power in the ANSI standard (MPE is Maximum Permissible Exposure). The BRH requires the manufacturer to affix a caution label. It would resemble the ANSI label shown in Fig. 3.

Class III

The Class III medium-power classification includes all lasers that cannot emit levels of radiation which produce a hazardous diffuse reflection (except by some special focusing technique) and cannot be considered a fire hazard. This corresponds to a typical CW laser beam of 0.5 W or less. Numerous control measures are required for the medium power classification.

Class IIIa covers visible lasers that cannot injure a normal person when viewed with the unaided eye but may cause injury when the energy is collected and put into the eye, as with binoculars. For Class IIIa, BRH will require a label something like the ANSI label for Class II lasers, shown in Figure 4, but replacing "He-Ne Laser" with "Laser Radiation" and adding "Class IIIa Laser Product".

Class IIIb consists of lasers which can produce accidental injury if viewed directly. The danger from such a laser is the direct or specularly reflected beam. A warning label for this laser might resemble one from the ANSI standard shown in Fig. 5, but adding the words "Laser Radiation -avoid direct exposure to beam" and "Class IIIb Laser Product".

Class IV

Laser devices that can produce a hazardous diffuse reflection fall in the Class IV, high-power classification; consequently, more stringent control measures are required.

Class IV includes lasers which not only produce eye hazards but also can be a fire hazard. A Class IV laser may have the ANSI warning sign shown in Fig. 6. The BRH warning statement for this class would say, "Laser Radiation - avoid eye or skin exposure to direct or scattered radiation" and, in the lower right corner, "Class IV Laser Product". For the regulation being prepared by the Occupational Safety and Health Administration, danger and caution statements would be present with the laser sunburst symbol, but the precise ANSI dimensions and logo type would not be required.

All Classes

Aside from signs and labels, other control procedures required or recommended for the various hazard classifications are summarized in the accompanying tables.

Any completely enclosed laser is classified as a Class I (exempt) laser if emissions from the enclosure cannot exceed the MPE values under any conditions inherent to the laser design. During maintenance procedures, however, the appropriate control measures are temporarily required for the class of laser contained within the enclosure.

Laser Hazard Classification

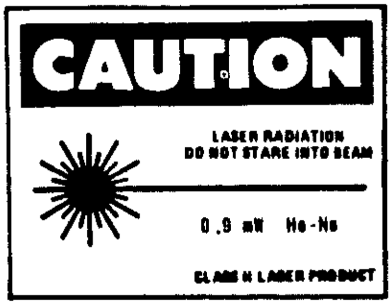

Figure 3

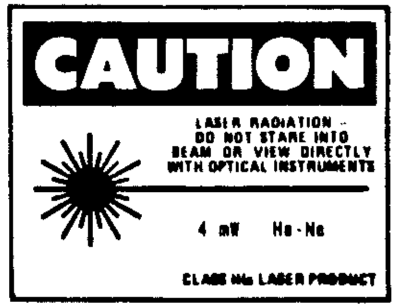

Figure 4

Figure 5

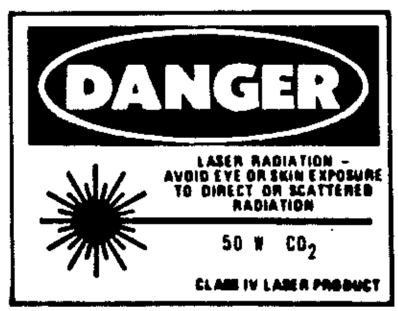

Figure 6

Federal government safety standards for lasers have been developed by the Bureau of Radiological Health(BRH) of the Department of Health, Education and Welfare, and by the Occupational Safety and Health Administration (OSHA) of the Department of Labor. The BRH standard is a product performance standard with which the laser manufacturer must comply, and the OSHA standard is a user standard which the laser user must follow. Both of these standards have adopted the ANSI classification scheme. The OSHA standard had not been published as of 1981.

VI. VIEWING LASER RADIATION

From a safety point of view the laser can be considered as a highly collimated source of extremely intense monochromatic electromagnetic radiation. Due to these unique beam properties, most laser devices can be considered as a point source of great brightness. Conventional light sources or a diffuse reflection of a Class II or Class III laser beam are extended sources of very low brightness because they radiate in all directions. This is of considerable consequence from a hazard point of view, since the eye will focus the rays from a point source to a small spot on the retina while the rays from an extended source will be imaged, in general, over a much larger area. Only when one is relatively far away from a diffuse reflection (sufficiently far that the eye can no longer resolve the image) will the diffuse reflection approximate a "point source". Diffuse reflections are only of importance with extremely high-power Class IV laser devices.

VII. SAFETY PROCEDURES

The hazard controls necessary for laser radiation vary with;

(1) the laser classification,
(2) the environment where the laser is used, and
(3) the people operating or otherwise within the vicinity of the laser.

The safety procedures can best be enumerated by grouping them by laser class. Then the user can determine which rules are relevant to his particular environment, considering the people who are potentially exposed to the optical radiation from his laser. In all cases, the safest user is the informed user, and some form of laser safety educational program (such as reading this guide) is recommended for all laser users.

1. Safety Rules for Class I Lasers

"Exempt" lasers, e.g., some small gallium-arsenide lasers, are by definition devices which cannot be considered hazardous even if all of the laser output were directed into the eye's pupil (if it could get it in) or focused into a 1-mm spot on the skin for a day (3×10^4 seconds), hence, there are no safety requirements. The Federal product performance standard and the ANSI Z136.1 (1980) Standard definition of Class I, Laser Product, (which includes enclosed lasers) both require that a warning sign should be located at an access panel to alert a user that more hazardous laser radiation is contained therein. Another panel covering the warning sign and access panel is permitted.

2. Safety Rules for Class II Lasers

Since "Low-Power" lasers are by definition incapable of causing eye injury within the duration of the blink, or aversion response (0.25 s), and must be visible (400 to 700 nm), a hazard can only exist if an individual overcomes his natural aversion to bright light and stares directly into the laser beam. The majority of Low-Power lasers today are helium neon devices with a CW power of one milliwatt or less. The product requirements for these lasers are two: to have a CAUTION label (Fig. 3), and to have an indicator light to indicate laser operation. The two operating safety rules are:

- (a) Do not permit a person to stare at the laser from within the beam; and
- (b) Do not point the laser at a person's eye.

Some laser-guide beams are looked into at great distances in certain applications, but only at comfortable exposure levels which have been calculated or measured to be well below permissible exposure limits.

3. Safety Rules for Class III Lasers

Although these "Medium-Power" lasers usually present a serious potential for eye injury resulting from intra-beam viewing, they generally do not represent a diffuse reflection hazard, a skin hazard for momentary unintentional exposure, or a fire hazard; hence, control measures are concentrated on eliminating the possibility of intra-beam viewing by:

- Never aiming a laser beam at a person's eyes.
- Using proper safety eyewear if there is a chance that the beam or a hazardous specular reflection will expose the eyes.
- Permitting only experienced personnel to operate the laser and not leaving an operable laser unattended if there is a chance that an unauthorized user may attempt to use it. A key switch should be used. A warning light or buzzer should indicate when the laser is operating.
- Enclosing as much of the beam path as possible.
- Avoiding placing the unprotected eye along or near the beam axis as attempted in some alignment procedures, since the chance of hazardous specular reflections is greatest in this area.
- Terminating the primary and secondary beams if possible at the end of their useful paths.
- Using beam shutters and laser output filters to reduce the beam power to less hazardous levels when the full output power is not required.

- Assuring that any spectators are not potentially exposed to a hazardous condition.

- Attempting to keep laser beam paths above or well below either sitting or standing position eye level.

- Attempting to operate the laser only in a well-controlled area, for example, within a closed room with covered or filtered windows and controlled access.

- Not permitting tracking of non-target vehicles or aircraft if the laser is used outdoors.

- Labelling lasers with appropriate Class III danger statements and placarding hazardous areas with danger signs if personnel can be exposed (Fig. 4).

- Mounting the laser on a firm support to assure that the beam travels along the intended path.

- Assuring that individuals do not look directly into a laser beam with optical instruments unless an adequate protective filter is present within the optical train.

- Eliminating unnecessary specular (mirror-like) surfaces from the vicinity of the laser beam path, or avoid aiming at such surfaces.

4. Safety Rules for Class IV Lasers

The "High-Power" lasers present the most serious of all laser hazards. Fortunately, these lasers are seldom found outside of the research laboratory, unless they are well enclosed. Besides presenting a serious eye and skin hazard these lasers can often ignite flammable targets, create hazardous airborne contaminants and usually have a potentially lethal high-current, high-voltage power supply. Most of the secondary "associated hazards" previously enumerated are limited to high-power laser operations. These rules should be carefully followed for all high-power lasers:

- Enclose the entire laser beam path if at all possible. If this is done, the laser device could revert to a less hazardous classification.

- Confine indoor laser operations to a light-tight room with interlocked entrances to assure that the laser cannot emit when a door is open.

- Insure that all personnel wear adequate eye protection, and if the laser beam irradiance represents a serious skin or fire hazard that a suitable shield is present between the laser beam (s) and personnel.

- Use remote firing and video monitoring or remote viewing through a laser safety shield where feasible.

- Use beam traverse and elevation stops on outdoor laser devices such as LIDAR to assure that the beam cannot intercept occupied areas or intercept aircraft.

- Use beam shutters and laser output filters to reduce the laser beam irradiance to less hazardous levels whenever the full beam power is not required.

- Assure that the laser device has a key-switch master interlock to permit only authorized personnel to operate the laser.

- Install appropriate signs and labels as shown in Figs. 5 and 6.

- Remember that optical pump systems may be hazardous to view and that once optical pumping systems for pulsed lasers are charged they can be spontaneously discharged, causing the laser to fire unexpectedly (as by a cosmic ray triggering a thyratron switch).

- Use dark, absorbing, diffuse, fire-resistant targets and backstops where feasible.

- Design safety into micro-welding and cutting equipment, and similar devices used in miniature work. Because of the increased use of the laser beam in the scribing of integrated circuit chips or trimming of resistors, the use of microscopes or other focusing optics integral to the laser system is becoming more common. These laser applications require special attention to their associated hazards. If at all possible such work should be accomplished in a light-tight or baffled interlocked enclosure to eliminate the requirements for eye protection and other Class-IV safety rules. Microscopes used for viewing the workpiece should either have a fail-safe method for insuring against hazardous levels of laser radiation from reflecting back through the optics, either by built in filters or separate optical paths for intermittent viewing and laser firing.

VIII. LASER SAFETY EYEWEAR

Although engineering controls, such as enclosure of the laser beam, are far more preferable than the use of eye protection, there are instances when the use of laser safety spectacles or goggles is the most effective safety measure. It is important that the eye protection be clearly marked to insure that it is not used for protection against laser wavelengths for which it was not intended. For example, the Glendale Optical NDGA goggle has an optical density (OD) of 14 at the Nd-YAG wavelength, but only an OD of about 1 at the HeNe wavelength.

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I have read the Laser Safety Guidelines and understand them. I have also been instructed in laboratory safety in general and agree to follow common sense rules.

Signed: ______________________ Student ID: ______________

Name: ______________________ Date: ____________________

Course: ______________________ Semester: ________________

Ticket #: ____________________

COMMENTS: