DALHOUSIE UNIVERSITY

LASER SAFETY MANUAL

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Laser Types And Operation

A. Basic Laser Operation:

The term ***"LASER"*** is an acronym. It stands for ***"Light Amplification by Stimulated Emission of Radiation".*** Thus, the laser is a device that produces and amplifies light. The mechanism by which this is accomplished was first postulated by Albert Einstein in 1917. The light which the laser produces is unique, for it is characterized by properties which are very desirable, but almost impossible to obtain by any other means.

B. Energy Levels:

Light can be produced by atomic processes, and it is these processes which are responsible for the generation of laser light. Changes in atomic energy levels can lead to the production of laser light.

The relationship between the electrons and the nucleus is described in terms of energy levels. Quantum mechanics predicts that these energy levels are discrete.

C. Radiative Transitions:

Electrons normally occupy the lowest available energy level. When this is the case, the atom is said to be in its ground state. Electrons can, however, occupy higher energy levels, leaving some of the lower energy states vacant or sparsely populated.

One way that electrons can change from one energy state to another is by the absorption or emission of light energy, via a process called radiative transition.

1. Absorption:

An electron can absorb energy from a variety of external sources. From the point of view of laser action, two methods of supplying energy to the electrons are of prime importance. The first of these is the transfer of all energy of a photon directly to its orbital electron. The increase in the energy of the electron causes it to "jump" to a higher energy level; the atom is then said to be in an "excited" state. It is important to note that an electron can accept only the precise amount of energy that is needed to move it from one allowable energy level to another. Only photons of the exact energy acceptable to the electron can be absorbed. Photons of slightly more or less energy will not be absorbed.

Another means often used to excite electrons is an electrical discharge. The energy is supplied by collisions with electrons which have been accelerated by an electric field. The result of either type of excitation is that, through the absorption of energy, an electron has been placed in a higher energy level than the one in which it originally resided.

2. Spontaneous Emission:

The nature of all matter is such that atomic and molecular structures tend to exist in the lowest energy state possible. Thus, an excited electron in a higher energy level will soon attempt to ***de-excite*** itself by any of several means. Some of the energy may be converted to heat.

Another means of de-excitation is the spontaneous emission of a photon. The photon released by an atom as it is de-excited will have a total energy equal to the difference in energy between the excited and lower energy levels. This release of a photon is called spontaneous emission. One example of spontaneous emission is the neon sign. Atoms of neon are excited by an electrical discharge through the tube. They de-excite themselves by spontaneously emitting photons of visible light.

3. Stimulated Emission:

In 1917, Einstein postulated that a photon released from an excited atom could, upon interacting with a second similarly excited atom, trigger the second atom into de-exciting itself with the release of another photon. The photon released by the second atom would be identical in frequency, energy, direction, and phase with the triggering photon. The triggering photon would continue on its way unchanged. Where there was one photon, now there are two. These two photons could proceed to trigger more photon releases through the process of stimulated emission.

If an appropriate medium contains a great many excited atoms and de-excitation occurs only by spontaneous emission, the light output will be random and approximately equal in all directions. The process of stimulated emission, however, can cause an amplification of the number of photons traveling in a particular direction.

A preferential direction is established by placing mirrors at the end of an optical cavity. Thus, the number of photons traveling along the axis of the mirrors increases greatly and ***"Light Amplification by the Stimulated Emission",*** may occur. If enough amplification occurs, ***LASER*** beam is created.

D. Population Inversion:

The process of stimulated emission will not produce a very efficient or even noticeable amplification unless a condition called ***"population inversion"*** occurs. If only a few atoms in several million are in an excited state, the chances of stimulated emission occurring are very small. The greater percentage of atoms in an excited state, the greater the probability of stimulated emission. In the normal state of matter most of the electrons reside in the ground level, leaving the upper excited levels largely unpopulated. When electrons are excited and fill these upper levels to the extent that there is of atoms in the excited state, the population is said to be inverted.

E. Laser Components:

A generalized laser consists of a lasing medium, a pumping system and an optical cavity. The laser material must have a metastable state in which the atoms of molecules can be trapped after receiving energy from the pumping system.

1. Pumping Systems:

< The pumping system imparts energy to the atoms or molecules of the lasing medium enabling them to be raised to an excited or ***"metastable state"*** creating a population inversion. Optical pumping uses photons provided by a source such as xenon gas flash lamp or another laser to transfer energy to the lasing material, in essence pumping atoms from the ground to the excited state. The optical source must provide photons which correspond to the allowed transition levels of the lasing material.

< Collision pumping relies on the transfer of energy to the lasing material by collision with the atoms (or molecules) of the lasing material. Again, energies which correspond to the allowed transitions must be provided. This is often done by electrical discharge in a pure gas or gas mixture in a tube.

< Chemical pumping systems use the binding energy released in chemical reactions to state.

2. Optical Cavity:

An optical cavity is required to provide the amplification desired in the laser and to select the photons which are traveling in the desired direction. As the first atom or molecule in the metastable state of the inverted population decays, it triggers via stimulated emission, the decay of another atom or molecule which is also in the metastable state. If the photons are traveling in a direction which leads to the walls of the container (usually in the form of a rod or tube), they are lost and the amplification process terminates.

In some cases these photons may actually be reflected at the wall of the rod or tube, but sooner or later they will be lost in the system and will not contribute to the beam.

If, on the other hand, one of the decaying atoms or molecules releases a photon parallel to the axis of the lasing material, it can trigger the emission of another photon and both will be reflected by the mirror on the end of the lasing rod or tube. The reflected photons then pass back through the material triggering further emissions along exactly the same path which are reflected by the mirrors on the ends of the lasing material. As this amplification process continues, a portion of the radiation will always escape through the partially reflecting mirror. When the amount of amplification or gain through this process exceeds the losses, laser oscillation is said to occur. In this way, a narrow concentrated beam of coherent light is formed.

3. Laser Media:

Lasers are commonly designated by the type of lasing material used. There are four types : ***solid state, gas, dye,*** and ***semiconductor.***

< ***Solid state lasers*** employ a lasing material distributed in a solid matrix. One example is the Neodymium: YAG laser (Nd:YAG). The term YAG is an abbreviation for the crystal - Yttrium Aluminum Garnet which serves as the host for the Neodymium ions. This laser emits an infrared beam at a wavelength of 1.064 µm. Accessory devices that may be internal or external to the cavity may be used to convert the output to visible or ultraviolet wavelength.

< ***Gas lasers*** use a gas or a mixture of gases within the tube. The most common gas laser uses a mixture of Helium and Neon (HeNe), with a primary output of 632.8 nm which is a visible red color. All gas lasers are quite similar in construction and behavior. The carbon dioxide (CO_2) gas laser radiates at 10.6 µm in the far infrared spectrum. Argon and krypton gas lasers operate with multiple frequency emissions principally in the visible spectra. The main emission wavelengths of an argon laser are 488 and 514 nm.

<	***Dye lasers*** use a laser medium that is usually a complex organic dye in liquid solution or suspension. The most striking feature of these lasers is their "tunability". Proper choice of the dye and its concentration allows production of laser light over a broad range of wavelengths in or near the visible spectra. Dye lasers commonly employ optical pumping although some types have used chemical reaction pumping. The most commonly used dye is Rhodamine 6G which provides tunability over 200 nm bandwidth in the red portion (620 nm) of the spectrum.

<	***Semiconductor lasers*** (diode lasers) are not to be confused with solid state lasers. Semiconductor devices consist of two layers of semiconductor material sandwiched together. These lasers are generally very small physically, and individually of only modest power. The most common diode laser is the Gallium Arsenide diode laser with a central emission of 840 nm.

F. Time Modes Of Operation:

The different time modes of operation of a laser are distinguished by the rate at which the energy is delivered.

<	**Continuous wave** (CW) lasers operate with a stable average beam power. In most higher power systems, the operator can adjust the power. In low power gas lasers such as HeNe, the power level is fixed by design and performance usually degrades with long term use.

<	**Single pulsed** (normal mode) lasers generally have pulse durations ranging from a few hundred microseconds to a few milliseconds. This mode is sometimes referred to as long pulse or normal mode.

<	**Single pulsed Q-switched** lasers are the result of an intracavity delay (Q-switch cell) which allows the laser media to store a maximum of potential energy. Under optimum conditions, emission occurs in single pulses; typically of 10 (-8) second time domain. These pulses will have high peak powers often in the range of
106 to 109 watts peak.

<	**Repetitively Pulsed** or scanning lasers generally involve the operation of pulsed laser performance operating at a fixed or variable pulse rate which may range from a few pulses per second to 20,000 pulses per second. The direction of a CW laser can be scanned rapidly using optical scanning systems to produce the equivalent of a repetitively pulsed output at a given location.

<	**Mode Locked** laser operate as a result of the resonant modes of the optical cavity which can effect the characteristics of the output beam. When the phases of different frequency modes are synchronized (locked together) the different modes will interfere with one another to generate a beat effect. The result is a laser output which is observed as regularly spaced pulsations. Lasers operating in this mode locked fashion usually produce a train of regularly spaced pulses, each having a duration of 10 (-15) to 10 (-12) seconds. A mode-locked laser can deliver extremely high peak power, often in the range of 10 (12) Watts peak.

G. Specific Laser Types:

<	***Helium Neon Laser.*** The first CW system was the helium neon (HeNe) gas mixture. Although its first successful operation was at an infrared wavelength of 1.15 µm, the HeNe laser is most well known for operating at the red 633 nm transition. Some HeNe lasers can emit at other wavelengths - 594 nm, 612 nm, 543 nm. Some earlier HeNe lasers were excited by radio frequency discharge but today virtually all HeNe lasers are driven by a small DC discharge between electrodes in the laser tube.

The HeNe laser operates by an excitation of the helium atoms from the ground state. This energy excess is coupled to an unexcited neon atom by a collisional process with the net result of an inversion in the neon atom population. Power levels available from the HeNe laser range from a fraction of a milliwatt to about 75 milliwatts. The HeNe laser is noted for its high frequency stability and single mode operation.

The HeNe laser is one today's the most widely used lasers. Its pencil-thin beam is used in surveying work, to align pipelines, to guide a saw in sawmills, and to align patients in medical x - ray units. It is also used in retail scanners, lecture hall pointers and display devices. Holograms are often made using the coherent light of HeNe lasers.

< ***Argon, Krypton and Xenon Ion Lasers.*** This family of ion lasers provides a source for over 35 different laser frequencies, ranging from near ultraviolet (neon at 322 nm) to near infrared (krypton at 799 nm). It is possible to mix the gases to produce either single frequency or simultaneous emission at ten different wavelengths, ranging from violet to the red end of the spectrum.

The basic design of an ion gas laser is similar to the HeNe. The major difference is that the electrical current flowing in the laser tube will be 10 - 20 amperes; sufficient to ionize the gas. Population inversion is obtained only in the ionized state of the gas. An important feature of these lasers is the very stable high output of up to 20 Watts/CW. Commercial models will normally have a wavelength selector within the cavity to allow operation at any of the available wavelengths. In addition, approximately single frequency operation can be achieved by placing an etalon inside the optical resonator cavity.

Argon ion lasers produce the highest power levels and have up to 10 lasing wavelengths in the blue-green portion of the spectrum. These lasers are normally rated by the power level produced by all of the six major visible wavelengths from 458 to 514 nm. The most prominent are the 514 and 488 nm lines. Wavelengths in the ultraviolet spectrum at 351 and 364 nm are available by changing resonator mirrors.

To dissipate the large amount of generated heat, the larger argon ion laser tubes are water cooled. Although some lasers have separate heat exchangers, most use tap water.

Simple pulsed versions of argon ion lasers are available. Since the duty cycle is low, the heat energy generated is small, and usually only convective cooling is needed. The average power output may be as high as several watts, though the peak powers can be as high as several kilowatts. Pulse widths are approximately 5 - 50 µseconds, with repetition rates as high as 60 Hz

< ***Carbon Dioxide Laser***. The Carbon dioxide laser is the most efficient and powerful of all CW laser devices. Continuous powers have been reported above 30 kilowatts at the far infrared 10.6 µm wavelength.

An electrical discharge is initiated in a plasma tube containing carbon dioxide gas. CO_2 molecules are excited by electron collisions to higher vibrational levels, from which they decay to the metastable vibrational level. Establishing a population inversion between certain vibrational levels can result in lasing transitions at 9.6 µm.

Although lasing can be obtained in a plasma tube containing CO_2 gas alone, various gases are usually added., including N_2, He, Xe, CO_2 and H_2O. Such additives are used to increase the operating efficiency of CO_2 lasers.

Carbon dioxide lasers are capable of producing tremendous amounts of output power, primarily because of the high efficiency. The principal difference between CO_2 and other gas lasers is that the optics must be coated, or made of special materials, to be reflective or transmissive at the far infrared wavelength of 10.6 µm. The output mirror can be made of germanium.

There are three common laser cavity configurations of the CO_2 laser. The first is the gas discharge tube encountered with the discussion of the HeNe laser. Secon is the axial gas flow, where the gas mixture is pumped into one end of the tube and taken out at the other. The gas flow allows for the replacement of the CO_2 molecules depleted by the electrical discharge. Nitrogen is added to the CO_2 to increase the efficiency of the pumping process and transfers energy by collisions. Helium is added to the mixture to further increase the efficiency of the process of pumping and stimulated emissions. The third method is the transverse gas flow. This technique can produce laser emissions at power levels approaching 25 kilowatts.

The CO_2 laser has a strong emission wavelength at 10.6 µm. There is another strong line at 9.6 µm and a multitude of lines between 9 and 11 µm. CO_2 lasers are highly efficient, give high output powers, and applications outdoors can take advantage of low transmission loss atmospheric window at about 10 µm.

< Nd:YAG Laser Systems

(YAG), commonly designated Nd: YAG. In addition, other hosts can be used with Nd, such as calcium tungstate and glass.

The Nd: YAG laser is optically pumped either by tungsten or krypton pump lamps and is capable of CW outputs approaching 1000 W at the 1.06 µm wavelength. The ends of the crystal, which are usually in the form of a rod, are lapped, polished, and may be coated to provide the cavity mirrors.
Nd: YAG lasers belong to the class of solid state lasers. Solid state lasers are powerful, rugged and simple to maintain.

Although solid state lasers offer some unique advantages over gas lasers, crystals are not ideal cavities or perfect laser media. Real crystals contain refractive index variations that distort the wavefront and mode structure of the laser. High power operation causes thermal expansion of the crystal that alters the effective cavity dimensions and thus changes the modes. The laser crystals are cooled by forced air or liquids which are used for solid state lasers with high repetition rates.

The most striking aspect of solid state lasers is that the output is not continuous, but consists instead of a large number of often separated power bursts.

Normal mode and Q-switched solid state lasers are often designed for a high repetition rate operation. Usually the specific parameters of operation are dictated by the application.

For example, pulsed YAG lasers operating 1 Hz at 150 joules per pulse are often used in metal removal applications. As the repetition rate increases, the allowable exit energy pulse decreases.

<	**Excimer Lasers**

People have searched for high power ultraviolet lasers for over 25 years. Theoretically, such a laser could produce a focused beam of submicrometer size and be useful in laser microsurgery and microlithography. Excimer lasers operate using reactive gases such as chlorine and fluorine mixed with inert gases such as argon, krypton or xenon. The various gas combinations, when electrically excited, produce a pseudo molecule, called a ***dimer*** with an energy level configuration that causes the generation of a specific laser wavelength emission which falls in the UV spectrum as illustrated below:

Laser Media	Wavelength (µm)
Argon Fluoride	193
Krypton Chloride	222
Krypton Fluoride	248
Xenon Chloride	308
Xenon Fluoride	351

Excimer laser reliability has made significant strides over the past several years. Systems operating at average powers from 50 - 100 watts are now commercially available. A typical excimer operates in repetitively pulsed mode of 30 - 40 ns pulses at pulse rates up to 50 Hz with pulse energies of 1 - 2 joules/pulse. Some systems use x-rays to preionize the excimer laser's gas mixture so as to enhance lasing efficiency and increase the overall output power.

Until fairly recently, excimer lasers were more commonly found in the research laboratory where they are used as a specific UV source. In other cases, serve as a"pumping" or exciting source to generate visible laser emissions. In the latter case, the excimer's UV output is directed into a tunable dye laser or Raman shifter module and converted into a modestly high power visible frequency emission.

Excimer lasers are now making the transition from the lab to the production area for a few unique uses in industry or in the operating room for exploratory surgical applications.

< **Semiconductor Diode Lasers:**

The semiconductor or diode injection laser is another type of solid state laser. The energy level scheme is constructed by charge carriers in the semiconductor. They may be pumped optically or by electron beam bombardment, but most commonly, they are pumped by an externally applied current. Although all of these devices operate in the infrared region, visible laser diodes are being made today. A useful feature is that many can be tuned by varying the applied current, changing temperature, or by applying an external magnetic field.

Laser diodes are used extensively for communications, in CD players, retail scanners, printers and ophthalmology.
Semiconductor lasers are used in distance detectors and remote sensing systems, rangefinders, and for voice and data communications.

Many diode lasers may be operated on a continuous wave basis. The most common diode uses a gallium - arsenide junction which emits a fan shaped infrared beam at 840 nm.

< **Other Lasers:**

Dye lasers were the first truly tunable lasers. Using different organic dyes, a dye laser is capable of producing emissions from the ultraviolet to the infrared. Most operate in the visible with tunable emissions of red, yellow, green, or blue laser.

The more common organic dye lasers are optically pumped. The most common dye used is Rhodamine - 6G in solution. Such lasers may either be flashlamp pumped, or more commonly pumped by another laser such as argon or nitrogen laser. To obtain reliable CW operation the dye is made to flow through a thin cell. Using the appropriate dye solutions, an argon - ion laser as a pump, and a prism, the dye laser is tunable across most of the visible spectrum. Tunable dye lasers are now widely used in high resolution atomic and molecular spectroscopy.

H. Laser Classifications:

All laser are classified by the manufacturer and labelled with the appropriate warning labels. An unclassified laser or a modified laser not properly classified must be classified prior to use. The following criteria are used to classify lasers:

1. ***Wavelength.*** If the laser is designed to emit multiple wavelengths the classification is based on the most hazardous wavelength.

2. For continuous wave (CW) or repetitively pulsed lasers the ***average power*** output (Watts) and ***limiting exposure time*** inherent in the design are considered.

3. For pulsed lasers the ***total energy per pulse*** (Joule), ***pulse duration, pulse repetition frequency*** and ***emergent beam radiant exposure*** are considered.

CLASS 1 LASERS

These are lasers that are not hazardous for continuous viewing or are designed in such a fashion that prevents access to laser radiation. So Class 1 consists of low power lasers and higher powered embedded lasers (such as those used in laser printers)

CLASS 2 VISIBLE LASERS (400 to700 nm)

Lasers emitting visible light which, because of normal human aversion responses (blinking), do not normally present a hazard, but which would be dangerous if viewed directly for extended periods of time.

CLASS 2A VISIBLE LASERS (400 to 700 nm)

Lasers emitting visible light not intended for viewing, and under normal operating conditions would not produce an eye injury if viewed directly for less than 1000 seconds (Bar code scanners)

CLASS 3A LASERS

Lasers that normally would not cause eye injury if viewed momentarily but would present a hazard if viewed using collecting optics such as fibre optics loupe or telescope.

CLASS 3B LASERS

Lasers that present an eye and skin hazard if viewed directly. Both intrabeam viewing and specular reflections present hazards Class 3B lasers do not produce a hazardous diffuse reflection except when viewing in close proximity.

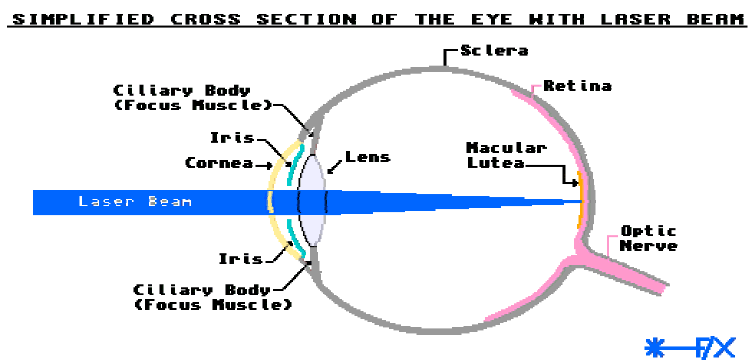
CLASS 4 LASERS

Lasers that present an eye hazard from direct, specular and diffuse reflections. In addition such lasers may present hazards and produce skin burns.

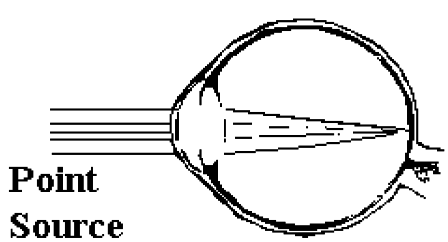
I. Laser Hazards:

Eye Hazards

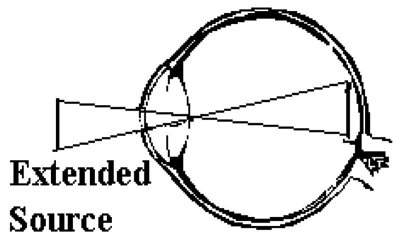
The potential for injury to the different structures of the eye depends upon which structure absorbs the energy. Laser radiation may damage the cornea, lens, or retina depending upon the wavelength, intensity of the radiation and the absorption characteristics of different eye tissues.



Wavelengths between 400 nm and 1400 nm are transmitted through the curved cornea and lens and focused on the retina. Intrabeam viewing of a point source of light produces a very small spot on the retina resulting in a greatly increased power density and an increased 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 and is called an extended source. An extended source produces a relatively large image on the retina and energy is not concentrated on a small area as in a point source.



Details of Irradiation Effects on Eyes:

Ultraviolet B & C (100 - 315 nm)

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

Ultraviolet A (315 - 400 nm)

The cornea, lens and aqueous humour absorb ultraviolet radiation of these wavelengths and the principal absorber is the lens. Photochemical processes denature proteins in the lens resulting in the formation of cataracts.

Visible Light & Infrared A (400 - 1400 nm)

The cornea, lens, and vitreous fluid are transparent to electromagnetic radiation of these wavelengths. 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 - 700 nm, the aversion reflex, which takes 0.25 seconds, may reduce exposure causing a person to turn away from the bright light source. This will not provide protection if the intensity of the laser is great enough to produce damage in less than 0.25 seconds or when light of 700 - 1400 nm is used, as the eye is insensitive to these wavelengths.

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

Corneal tissue will absorb light with a wavelength longer than 1400 nm. 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 - 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.

Skin Hazards:

Skin effects have generally been considered of secondary importance except for high power infrared lasers. However, with the increased use of lasers emitting in the UV spectral range, skin effects have assumed a greater importance. Erythema, skin cancer and accelerated skin aging may be produced by emissions in the 200 - 280 nm range. Increased pigmentation results from exposure to light with wavelengths of 280 - 400 nm. Photosensitization has resulted from the skin being exposed to light from 310 - 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.

Laser Output Wavelengths And Organs Affected

Electromagnetic Spectrum Region	Wavelength Range	Affected Organ
Ultraviolet	200 - 400 nm	Cornea, lens, skin
UV -C	200 - 280 nm	Cornea & Conjunctiva
UV - B	280 - 315 nm	Cornea & Conjunctiva (cataract formation)
UV - A	315 - 400 nm	Lens (cataract formation)
Visible light	400 -780 nm	Retina
Near Infrared	780 nm - 1.4 µm	Retina, lens, skin
IR - B	1.4 - 3.0 µm	Cornea & skin

Electromagnetic Spectrum Region	Wavelength Range	Affected Organ
IR - C	3.0 µm - 1 mm	Cornea & skin

Associated Hazards:

Electrical Hazards

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

Chemical Hazards

Many dyes used as lasing mediums are toxic, carcinogenic, corrosive or pose a fire hazard. Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. The quantity, composition and chemical complexity of these contaminants depends greatly on the beam irradiance and the chemical content of the target material.

Cryogenic fluids are used in cooling systems of certain lasers. As these materials evaporate, they displace 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 may be needed 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 present in inadequately ventilated areas, and gases of different categories stored incorrectly.

Collateral Radiation

Radiation other than that associated with the primary laser beam is called collateral radiation. Examples are:

< Ionizing radiation - X-rays could be produced from two main sources in the laser laboratory. One is high voltage vacuum tubes found in laser power supplies such as rectifiers, thyratrons, and crowbars. The other is electric - discharge lasers.

< UV and Visible - UV and visible radiation may be generated by laser discharge tubes and pump lamps. The levels produced may be high enough to 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 emit hazardous UV emissions.

< Radiofrequency (RF) - Q switches and plasma tubes are RF excited components. Unshielded components may generate RF fields.

J. General Laser Safety Recommendations & Requirements:

Eye protection - Principal investigators or staff who operate or supervise the operation of a laser are responsible for determining the need for laser eye protection (See Appendix). If required eye protection, ***shall*** be provided by the supervisor for staff and visitors to the area.

The minimum laser radiant energy or laser power level required for the application should always be used.

Beam control - To minimize direct eye exposure

< Do not intentionally look directly into the beam or at a specular reflection, regardless of its power.

< Terminate the beam at the end of its useful path.

< Position the beam path at a point other than eye level when standing or sitting at a desk.

< Orient the laser so that the beam is not directed toward entry doors or aisles.

< Minimize specular reflections.

< Securely mount the laser system on a stable platform to maintain the beam in a fixed position during operation and limit beam traverse during adjustments.

< Confine primary beams and dangerous reflections to the optical table.

< Clearly identify beam paths and ensure that they do not cross populated areas or traffic paths.

< Locate the laser system so that the beam will be outside the normal eye level range, which is between 1.2 and 2 meters from the floor, when the beam path is not totally enclosed. A beam path that exits from a controlled area must be enclosed where the beam irradiance exceeds exposure limits. See Appendix

Additional controls for Class 1 & Class 2 lasers

< If the laser has not been labeled by the manufacturer, attach a label on the laser with its classification and relevant warning information.

Additional controls for Class 3 & Class 4 lasers

< All principal investigators are required to write standard operating procedures (SOP) for all laser operations involving Class 3 and Class 4 lasers detailing alignment, operation and maintenance procedures. The SOP must be posted.

< SOP's must include procedures to address when:

a) use of eyewear, shields and access control requirements

b) two or more Class 3 or Class 4 lasers will be used in the same area by different operators without permanent, intervening barriers

c) an interlock bypass is installed

d) A Class 3 or Class 4 laser will be used by non - university personnel

e) a laser installation does not include all the required controls specified

f) a Dalhousie University laser is operated off campus

g) other hazards (i.e. acutely toxic gases, unattended operations)

< A log must be maintained showing periods of use, service, maintenance and incidents

< A laser classification label must be affixed to the laser housing so that it is readily seen

< Each entrance to the laboratory must be posted with the appropriate danger

sign

- Entrances to laboratories with a Class 3B or Class 4 laser shall have a lighted warning sign that is fail safe interlocked with the laser to activate when the laser is energized. The sign must be tested monthly and appropriate records maintained.

- Access doors to a controlled laser area in which Class 3B or Class 4 lasers are operated must be equipped with safety interlocks to prevent laser operation when the interlock circuit is broken

- All protective enclosures that surround laser devices and high voltage electrical sources must be equipped with interlocks to prevent operation of the equipment. Interlocks must be tested quarterly and appropriate records maintained.

- Interlocks must be designed so that after they are actuated, the capacitor banks, shutters, or power supplies cannot be re-energized except by manually resetting the system

- The responsible individual in a laser area controlled by a laser warning light is permitted to temporarily override door interlocks to allow access of authorized persons only if all of the following conditions are met:

  a) there is no laser radiation at the point of entry

  b) the necessary protective devices are worn by personnel entering the area

  c) an interlock bypass circuit is designed into the control system. This bypass circuit must only be operated from inside the interlocked area. It must delay no more than 15 seconds before shutting down the system

- If interlocks are not feasible , the principal laser operator may consider the use of alarms or voice warnings in consultation with the RSO.

- Laser laboratories and controlled areas must be designed so that personnel can safely enter and leave under emergency condition.

- Lasers must have a master switch with a key or coded access that prevents use once the key has been removed or a code has been entered. The key must be secured when the laser is not in use

- An alarm, a warning light, or a verbal “count down” command must be used during activation and start up

< Lasers must have a permanently attached beam stop or attenuator and emission delays

< Laser controlled areas shall be established which have limited access, covered windows and doors, and only diffuse reflective material. The facility must be fully enclosed with floor to ceiling walls. Access to the laser area during operation requires the permission of the responsible operator

< Class 3B and Class 4 infrared laser beams with a wavelength greater than or equal to 710 nm must be terminated with fire resistant material

< Securely fasten all mirrors, prisms, beam stops, etc. in the beam path. Ensure that the laser is also securely fastened.

< Circuit breakers must be identified for each laser

< The entire beam of Class 3B and Class 4 lasers, including the target area, should be surrounded by an enclosure equipped with interlocks that allow operation of the laser system only when the enclosure is properly secured. When total enclosure of the beam path is not practical, both the non enclosed laser beam and any strong reflections must be terminated at the end of their useful path using devices such as backstops, shields or beam traps

< Materials that diffusely reflect laser radiation must be used in place of specularly reflective surfaces whenever possible

< To minimize personnel exposure, specularly reflecting surfaces that are needed for beam path control should be enclosed or shielded

< UV and IR lasers require visual or audible beam warning devices where personnel may be exposed to radiation in excess of regulatory requirements (see appendix). These warning devices must be clearly identified and visible from all areas of potential exposure. Shielding must be installed that will attenuate UV radiation to levels below regulatory limits for the wavelength being used. Hazardous concentrations of by-products formed by the reaction of intense UV radiation with materials in the area must be controlled. IR beam enclosures and backstops must be fabricated of IR absorbent material. For Class 4 lasers the absorbent material must also be fire resistant

< Controlled laser areas must be surveyed with appropriate measuring devices to locate and identify direct and reflected beams that exceed regulatory requirements - shielding may be required

< Personnel must never look directly into any laser beam unless such action is specifically approved by the Radiation Safety Office

< The primary beam and specular reflections of Class 3B or Class 4 lasers are particulary hazardous. In those cases where it may be necessary to directly view a beam, special provisions such as filters are mandatory

< High power laser optical systems must never be aligned by direct beam viewing if the radiant exposure or irradiance exceeds regulatory limits

< Using optical systems such as cameras, telescopes, microscopes, etc. to view laser beams may increase the eye hazard. Collecting optics must incorporate suitable means

< Laser protective eye wear shall be worn when required

< Consult eye wear manufacturers for proper selection of eye protection for the wavelength in question

< The user shall periodically inspect the eyewear checking for pitting and cracking of the attenuating material, mechanical integrity and light leaks in the frame

< Protect the skin through the use of proper clothing to cover normally exposed skin areas

< When lasers are to be left unattended, de-energize the power supplies or capacitor banks and remove the keys from power switches or master interlocks to prevent unauthorized activation of the equipment

Controlling Associated Hazards

Electrical equipment and systems

< Always be aware of the high risk of injury and fire in laser operations because of the presence of electrical power sources

< The installation, operation, and maintenance of electrical equipment and systems must conform to regulatory standards

Lighting

< Adequate lighting is required in controlled areas

< If lights are turned off during laser operation, provide light switches in convenient locations or install a radio controlled switch

< Use luminescent strips to identify table and equipment corners, switch locations, aisles, etc.

< When natural light is not sufficient for safe egress from a laser area during an electrical power failure, install emergency lighting

Ionizing & non- ionizing radiation

< A laser operation may involve ionizing radiation that originates from the presence of radioactive materials or the use of electrical power in excess of 15 kV

< Microwave and RF fields may be generated by laser systems or support equipment

Hazardous materials

< All hazardous materials must be properly used, stored and controlled

< Do not allow laser beams and strong reflections to impinge on combustible materials, explosives, highly flammable liquids or gases or substances that decompose into highly toxic products under elevated temperatures, without providing adequate controls

Dyes and solutions

< Dye lasers normally use a lasing medium composed of a complex

fluorescent organic dye dissolved in an organic solvent. These dyes vary greatly in toxicity.

< Treat as hazardous chemicals. Most solvents suitable for dye solutions are flammable and toxic by inhalation and/or skin absorption

< Refer to MSDS sheets for all dyes and solvents

< Use and store all dyes and solvents in accordance with university policy

< Prepare/handle dye solutions in a chemical fume hood

< Wear a lab coat, eye protection and gloves

< Pressure test all dye laser components before using dye solutions

< Install spill pans under pump and reservoirs

< Be alert to contaminated parts

< Keep dye mixing areas clean

Laser Inspection Form

Surveyors Name:______________________ **Date of Inspection:__________________**

Location of Laser:____

Principal Investigator:__________________ **Phone #:___________________________**

Lab Contact:__________________________ **Phone #:___________________________**

LASER POSTING, LABELING AMD SECURITY

		YES	NO	N/A
1.	Entrance properly posted	____	____	____
2.	Security adequate	____	____	____
3.	Interlock system in place	____	____	____
4.	Interlock functioning	____	____	____
5.	Laser status indicator in place	____	____	____
6.	Laser class label posted	____	____	____
7.	Label hazard label posted	____	____	____
8.	Laser aperture label in place	____	____	____

LASER UNIT SAFETY CONTROLS

		YES	NO	N/A
9.	Protective housing in place	____	____	____
10.	Interlock on housing	____	____	____
11.	Interlock on housing operational	____	____	____
12.	Beam shutter present	____	____	____
13.	Key operation	____	____	____
14.	Laser activation indicator on console	____	____	____
15.	Beam power meter	____	____	____
16.	Emergency shutoff available	____	____	____

ENGINEERING SAFETY CONTROLS

		YES	NO	N/A
17.	Laser secured to table	____	____	____
18.	Laser optics secured	____	____	____
19.	Laser not at eye level	____	____	____
20.	Beam is enclosed	____	____	____
21.	Beam barriers in place	____	____	____
22.	Beam stops in place	____	____	____
23.	Remote viewing of beam	____	____	____

24. Beam condensed or enlarged ____ ____ ____
25. Beam focused ____ ____ ____
26. Beam intensity filtered ____ ____ ____
27. Fiber optics used ____ ____ ____
28. Windows in room covered ____ ____ ____
29. Reflective materials not in beam path ____ ____ ____
30. Check for stray beams ____ ____ ____
31. Class 4 diffuse reflection hazard ____ ____ ____

ADMINISTRATIVE CONTROLS

32. SOP's up to date ____ ____ ____
33. SOP posted ____ ____ ____
34. Emergency contacts posted ____ ____ ____
35. All users have reviewed safety procedures ____ ____ ____

OTHER LASER SAFETY MEASURES

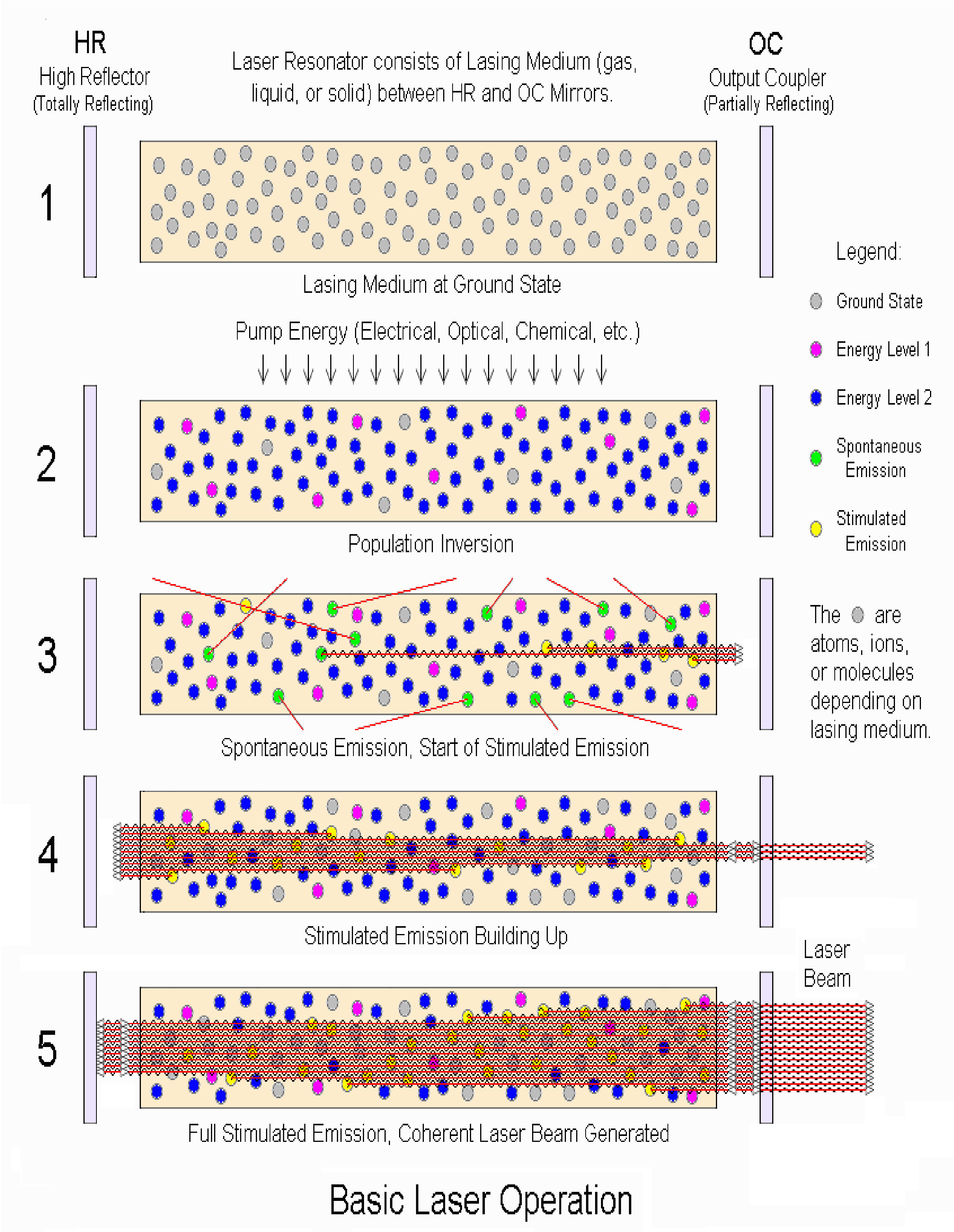
36. Eye examination performed ____ ____ ____
37. ***Proper*** eye protection available ____ ____ ____
38. Eye protection worn ____ ____ ____
39. Proper skin protection in use ____ ____ ____

NON BEAM HAZARDS

40. Toxic laser media in use ____ ____ ____
41. Hazardous media properly stored ____ ____ ____
42. Fume hood for dye mixing ____ ____ ____
43. Cryogens in use ____ ____ ____
44. Compressed gas in use ____ ____ ____
45. Gas cylinders restrained ____ ____ ____
46. All belts, pulleys, fans guarded ____ ____ ____
47. High voltage power hazard ____ ____ ____
48. Electrical panels unobstructed ____ ____ ____
49. Optical tables grounded ____ ____ ____
50. Collateral radiation hazard ____ ____ ____
51. Explosion hazard ____ ____ ____
52. Fire hazard ____ ____ ____

ADDITIONAL COMMENTS

____
____
____
_



Laser Safety Measures For Class 3 & Class 4 Lasers

M **Required**
R **Recommended**
O **Optional**

Control Measure	Class 3B	Class 4
Protective housing	**M**	**M**
Interlocks on protective housing	**M**	**M**
Key switch master	**R**	**M**
Remote interlock connector	**R**	**M**
Service access panel	**M**	**M**
Assessment of open beam path	**M**	**M**
Beam stopper or attenuator on laser	**R**	**M**
Beam stopper or attenuator on bench	**R**	**M**
Warning system for activation/operation	**R**	**M**
Controlled area	**M**	**M**
Labels	**M**	**M**
Area posting	**M**	**M**
Written SOP's	**R**	**M**
Written alignment procedures	**M**	**M**
Education & training	**M**	**M**
Access controls (authorized persons)	**M**	**M**
Eye protection	**R**	**M**
Pre-placement eye exam	**O**	**O**
Inventory	**M**	**M**

Glossary of Terms

Absorption - Transformation of radiant energy to a different form of energy by interaction with matter

Attenuation - The decrease in the radiant flux as it passes through an absorbing or scattering medium

Aversion response - Movement of the eyelid or the head to avoid an exposure to a noxious stimulant or bright light. It can occur within 0.25 seconds, including the blink reflex time

Beam - A collection of rays which may be parallel, divergent or convergent

Beam diameter - The distance between diametrically opposed points in that cross-section of a beam where the power per unit area is1/e (0.368) times that of the peak power per unit..

Coherent - A light beam is said to be coherent when the electric vector at any point in it is related to that at any other point by a definite, continuous function

Continuous Wave (CW) - The output of a laser which is operated in a continuous rather than a pulsed mode

Controlled area - An area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards

Cornea - The transparent outer coat of the human eye which covers the iris and crystalline lens. The cornea is the main refracting element of the eye

Diffuse reflection - Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium

Divergence - The increase in the diameter of the laser beam with distance from the exit aperture. The value gives the full angle at the point where the laser energy or irradiance is 1/e (36.8 %) of the maximum value.

Diffraction - Deviation of part of the beam determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

Electromagnetic radiation - The flow of energy consisting of orthogonally vibrating electric and magnetic fields lying transverse to the direction of propagation.

Embedded laser - A laser that is contained within a protective housing of itself or of the laser system in which it is incorporated.

Hertz (Hz) - The unit which expresses the frequency of a periodic oscillation in cycles per second

Irradiance (E) at a point of a surface - Quotient of the radiant flux incident on an element of surface containing the point at which irradiance is measured, by the area of that element. Units are watt per square centimeter (W- cm2)

Joule - A unit of energy. 1 joule = 1 watt/second

Laser - A device which produces an intense, coherent, directional beam of light by stimulating electronic or molecular transitions to lower energy levels. An acronym for Light Amplification Stimulated by Emission of Radiation

Limiting aperture - The maximum diameter of a circle over which irradiance and radiant exposure can be averaged

Maximum Permissible Exposure (MPE) - The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin

Protective housing - An enclosure that surrounds the laser or laser system that prevents access to laser radiation above the applicable MPE level. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing may enclose associated optics and a work station and shall limit access to other associated radiant energy emissions and to electrical hazards associated with components and terminals

Pulse duration - The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse

Pupil - The variable aperture in the iris through which light travels to the interior of the eye

Q-Switch - A device producing very short (< 30ns) high power pulses

Radiance (L) - Radiant flux or power output per unit solid angle per unit area

Radiant energy (Q) - Energy emitted, transferred or received in the form of radiation (Joule)

Radiant exposure (H) - Surface density of the radiant energy received. (Joules/ cm 2)

Radiant flux (W) - Power emitted, transferred or received in the form of radiation (Watt)

Specular reflection - A mirror like reflection