Maynooth University
National University of Ireland Maynooth

Review Version 1 Draft 5
Approved
Laser Safety Officer Signature
Head of Department Signature
Date

Guidance Document and Risk Assessment on the safe use of Lasers in the Laser laboratory in the Department of Electronic Engineering Maynooth University

Contents

Section 1

Introduction

1.1 Scope

This guidance document is part of the Laser Safety program in the Department of Electronic Engineering and is intended to provide a framework for good practice regarding the use of laser systems and users. It identifies the hazards associated with the use of lasers, the assessment of risk and the implementing of control measures in the laser laboratory. Many of the technical aspects in this guidance are explained at a level accessible to those without a background in lasers or optical physics.

The document is for guidance purposes in relation to training, identifying hazards, assessing risks and implementing management control measures. Together with training courses, the guidance facilitates registration of the user to carry out work with lasers. However, any particular experiment can only be done following an authorised risk assessment procedure.

Regulations are in place under the Safety, Health and Welfare at Work act of 2007 (general application regulations), amended in 2010 to include the Control of Artificial Optical Radiation at Work Regulations 2010 (S.I. No. 176 of 2010), (ref. EU Directive 2006/25/EC). The Regulations set out requirements relating to the control of artificial optical radiation at work, including exposure limit values, assessment of risks, control measures and training.

This document will be reviewed biennially and is available to all laser users in the department.

1.2 Responsibilities

It is important to ensure that all laser users are not exposed to levels of optical radiation above the Maximum Permissible Exposure levels (MPE), this is the level of laser radiation to which persons may be exposed without suffering immediate or long term adverse effects, see Appendix 10 and 11. All laser users have a responsibility in ensuring the health and safety of themselves and that of others who may be affected by their work. Specific duties are designated to the Department of Electronic Engineering Laser Safety Officer (LSO) to help implement the management control measures, outlined in this document.

1.1.1. Responsibilities of the Laser Safety Officer

A Department LSO has been appointed with the responsibility for administering and managing the laser safety procedures. The LSO's responsibilities are to:

- Provide training of new staff, undergraduate and postgraduate students, postdoctoral researcher, and to arrange supervision of visitors to the laboratory.
- Identify/Register new users, laser systems and designated facilities.
- Provide advice and help regarding laser systems and safety equipment
- Inspect new, and carry out routine inspection of existing, laser systems and facilities
- Investigate incidents and accidents when they occur.
- Ensure all safety labelling is accurate for the lasers and laboratory in accordance with Section 3.2.13
- Ensure compliance with the control measures as set down in Section 3.
- Ensure that laser safety googles, appropriate for the lasers systems are available.

1.1.2. Responsibilities of the Laser Users

All laser users have responsibilities to themselves and others working within the laser laboratory. These responsibilities are to ensure:

- that their registration process has been completed
- a risk assessment form has been completed and authorised and that only work described in that risk assessment is to be carried out.
- the control measures outlined in Section 3.3 for the safe use of lasers in the laser laboratory are complied with.
- the appropriate laser safety googles **MUST BE WORN**
- that lasers are not switched on without informing all those present in the laboratory.
- safe work practices are maintained,
- that incidents are reported to the LSO and department safety officer immediately.
- that any issues relating to safety equipment is reported immediately.

Section 2

Laser Hazards

2.1 Laser Radiation Hazards

Hazards associated with Laser systems can be divided into two main categories, *beam hazards* and non-beam hazards. Beam hazards arise from direct exposure to leaser beams; these are mainly concerned with the impact the beam can have on exposed skin or eyes when not protected properly. Non-beam hazards are those associated with the laser system as a whole, these would include the danger of electrical shock etc. Beam hazards can cause serious injury, particularly to the eyes.

2.1.1 Beam Hazards

Laser beams present a hazard to two main areas of the body, the skin and the eyes. The optical properties of the skin are wavelength dependent. The outer layer of the skin, the stratum corneum absorbs UV and with increasing wavelength the penetration depth increases up to the near infra-red. The eye, however, is much more susceptible to injury due to the focusing capability on the retina. As with the skin, the type and location of injuries that can occur with the eye are wavelength dependent. This is discussed in detail in Appendix 10.

Consideration must be given to the cause of injury when biological tissue is subjected to high-powered laser beam. The type of damage may be related to certain physical parameters of the laser, the most important of which are:

- Wavelength
- Pulse Duration
- Beam size
- Irradiance (power) and radiant exposure time.

These interactions with biological tissue can be grouped into thermal, acoustical and photochemical effects.

2.1.1.1 Thermal Effects

Thermal effects occur when sufficient radiant energy from the laser beam has been absorbed by the tissue and the molecules experience an increase in heat energy. This energy can result in burn injury to a confined area extending further around the incident beam site with increased time of exposure. Significant tissue injury can occur with only milliseconds of exposure.

2.1.1.2 Acoustic Effects/Photochemical Effects

These hazards result from exposure to pulse lasers and UV radiation respectively and are not considered here.

2.1.2 Non-Beam Hazards

Non-beam hazards in this context are those where the laser radiation is not directly responsible for the cause of injury. These additional hazards may arise from the particular type of laser in use or the function for which it is being used. Many of these dangers may not be unique to lasers. It is imperative that these hazards are identified and taken into account by all personnel working with or present where lasers are used. No laser setup must be left unattended unless it is deemed perfectly safe to do so. Always ensure that the setup is safe and there are no potential hazards that may cause injury or damage. These hazards can be divided into a number of categories, Electrical, Physical, Chemical, and Fire.

2.1.2.1 Electrical

Most high powered laser systems require high voltages and currents. These lasers have integrated or separate power supplies that have interlocked enclosures which shut down power when removed. Large capacitors are capable of discharging high levels of electrical power. No departmental personnel must access the enclosed electrical components of any laser system unless fully trained and competent.

2.1.2.2 Chemical

No chemical is to be stored or used in the laser laboratory.

2.1.2.3 Fire and Explosion

High powered lasers can provide a fire hazard especially if focusing optics are used. Wherever a component has the potential to be exposed to an incident beam it must be made of flame retardant material, this includes beam stops, enclosures, etc. Never leave any material with the potential to combust in the beam for longer than necessary, for example, florescent cards used for finding the beam location during alignment

2.1.2.4 Good Housekeeping in the laser laboratory

A laser must be set up on an optical bench with adequate access by the user so that they do not need to lean or climb over other equipment to access the area they need to work on. Where practicable, personnel should be able to walk around the optical bench. Awkwardly leaning over other systems or clutter to manipulate components in the beam path may lead to accidental deflection of the beam with the potential for personal injury. The floor area around the optical table and laser setup must be clear of any unnecessary clutter.

2.2 Hazard Classification of Lasers

Due to the great variation in laser systems, having different wavelengths, energy and power, emission type there is a need to have a class system based on the degree of hazard and maximum Accessible Emission Levels (see Appendix 10 and 12). It is important to understand that the power is not just the only criteria used. If a high powered laser is fully enclosed the hazard it presents can be completely reduced so that it is no longer deemed dangerous as in the case for a laser printer. Other relatively low powered lasers if combined with focusing optics may well present a much greater hazard which needs to be considered. The class system for lasers is set by the International Electrotechnical Commission (IEC) document 60825-14 [9]. A laser product can only be assigned to a particular class when it has met all of the requirements for that class for example, engineering controls, labelling. Laser beam exposure conditions are usually broken down into three areas.

- In ***intrabeam*** viewing the eye is directly exposed to a primary laser beam.
- In a ***specular reflection***, the eye/skin is exposed to a mirror-like reflection of a laser beam from a smooth surface. In this type of reflection, the power being delivered can approach that of an intrabeam exposure. Exposure to specular reflections is usually as hazardous as intrabeam exposure.
- With ***diffuse reflections***, the eye is exposed to a laser beam being reflected from a rough surface. As the light is diffused by the rough surface, it rapidly spreads and therefore decreases the beam irradiance, reducing or eliminating the hazard for all but class 4 lasers.

2.2.1 CLASS 1

Class 1 includes all lasers that are deemed safe during normal use and present no significant risk to the user as long as the manufacturer protocols are adhered to. Users of class 1 lasers are exempt from optical radiation hazard controls during normal operation. It must be noted that these systems can embed high powered lasers that are fully enclosed and present no hazard during normal use although if this high powered component is accessed during maintenance or servicing the hazard and class changes also. Other members of class 1 are laser pointers below 1 mw of power and CD and DVD players. A confocal microscope with a class 3B or 4 laser embedded safely into the system and interlocked will also be considered a class 1 system.

2.2.2 CLASS 1M

Class 1M lasers are restricted to 302.5 to 4000 nm and are generally considered safe for the naked eye under reasonable foreseeable conditions of operation but may become hazardous if used with focusing optics such as a lens or a telescope. In fact the M in 1M refers to magnifying optical viewing systems. Class 1M are safe only if optical instruments are not used and must be either collimated with a large beam diameter or contain highly divergent lasers. A laser can be classified as Class 1M if the power that can pass through the pupil of the naked eye is less than the AEL for Class 1, but if magnifying optics are used the power that may enter into the eye is higher than the AEL for Class 1 and lower than the AEL for Class 3B. An example of this class is the laser beam emission from a disconnected fibre optic communication system or audio cable.

2.2.3 CLASS 1C

Class 1C is applicable when the laser radiation is intended to be applied in contact with the intended target and has safeguards that prevent leakage of laser radiation in excess of an equivalent Class 1 laser. Typical Class 1C laser products would include those intended for hair removal, skin wrinkle reduction and acne reduction, including those for home-use. There must be adequate engineering controls to prevent emission into the surrounding space or to the eye that limits the exposure of the intended target tissue to levels that are appropriate for the intended application.

2.2.4 CLASS 2

Class 2 lasers are safe for momentary exposures even when using magnifying optical instruments but can be hazardous for deliberate staring into the beam. It only applies to visible-light lasers (400–700 nm). They are typically less than 1 mW in power. Class 2 Lasers are not inherently safe for the eyes but are assumed to be safe if used correctly. The normal blink reflex should be enough to protect the eyes from accidental exposure. Examples of this class are amusement laser guns, laser pointers and barcode scanners.

2.2.5 CLASS 2M

Class 2M laser systems have the M designation as do class 1M to indicate the potential hazard if optical components are used for focusing of the beam. These systems as with class 2 are safe for normal use. These lasers must be either collimated with large beam diameter or highly divergent. Examples of these systems are level and orientation instruments for civil engineering applications.

2.2.6 CLASS 3R

Class 3R lasers are hazardous for prolonged viewing of the intra- beam. In most cases the risk of injury is low for short unintentional exposure. The R in the 3R is derived from Reduced or relaxed requirements for the manufacturer and the user, i.e. no need for hazard controls such as interlocks and key switches, etc. They are usually of low to medium power in range, 1–5 mW. This class covers only the visible (400 to 700nm) wavelength range and with continuous wave emission. For other wavelengths and for pulsed lasers, other limits apply. Examples of this class are laser pointers and alignment lasers.

2.2.7 CLASS 3B

Class 3B lasers are extremely hazardous if the eye is exposed to the direct beam. This class requires controls to prevent exposure within the nominal ocular hazard distance (NOHD - see Appendix Section A10.3.5). They are of medium power ranging from 5mw up to 500mW. All wavelengths are hazardous for direct beam viewing and specular reflections. Viewing of diffuse reflections is normally considered safe but at a distance of greater than 13 cm and for a duration of less than 10s. Examples of this class are Diode lasers with powers greater than 5mW

2.2.8 CLASS 4

Class 4 lasers systems are the most hazardous, there is no class above this. They range in power from 500mW and up. All wavelengths are hazardous to the exposed eye for both specular and diffuse reflections as well as direct beam viewing. There is also the added danger to exposed skin as well as fire, the beam can cause ignition of combustible material, paper, clothes, and chemicals, etc. Some lasers are classified as Class 4 with <500mW because they are invisible.

2.2.9 Relationship between old and new classification systems

As there are many laser systems still in operation in the university environment that are classed under the old system it is useful to be aware of the differences. If you are unaware of the class of a particular laser due to obscured or damaged labelling always assume it is Class 4 until you are appropriately informed otherwise.

CLASS	Meaning	Old	New	Reason for Change
Class 1	Normally Safe	**1**	**1** **1M** **1C**	1M - diverging/low power density devices that could be hazardous if beam focussed
Class 2	Eye protected by aversion response (visible only)	**2**	**2** **2M**	2M - diverging/low power density devices that could be hazardous if beam focussed
Class 3	Eye hazard	**3A & 3B***	**3R**	Low eye hazard, power density restriction removed
		3B**	**3B**	No significant change
Class 4	Eye and skin hazard	**4**	**4**	No significant change

Section 3

Risk Management Controls for the Use of Lasers

3.1 Risk Assessment

When working with laser radiation a risk assessment must be carried out prior to use. Before engaging in any work with a laser, the hazards must be identified, the risks assessed, and the controls must be implemented. A risk assessment involves the following:

1. Identify all hazards that may cause personal harm or damage
2. Assess the risks from these hazards
3. Determine and implement safety control measures

To assist with the risk assessment, a risk assessment form is provided in Appendix 4 and 5.

Class 3B and 4 laser systems are capable of causing injury by intrabeam viewing or by specular reflections. Even diffuse reflection can cause eye damage.

Electrical and chemical hazards may also need to be considered.

People at risk must be identified as part of the risk assessment. Where servicing or cleaning of the laboratory is required by external staff, this must be scheduled with the LSO.

Appropriate control measures must be implemented and documented in the risk assessment.

3.1.1 Identifying the Laser Radiation Hazards

An important part of a risk assessment is to consider sources of potential injury to the user(s).
It is important to consider the full range of possible hazards and the circumstances under which they might arise, taking into account the type of laser equipment and the task or process being performed, i.e. the laser class, the conditions under which hazardous exposure could occur, and the kind of injury that could result must be considered. Apart from the hazard that exposure to laser radiation poses it is quite often not the only one. Other hazards such as electrical and biological must also be considered. The latter is discussed in a separate document.

3.1.2 Risk assessment

Risk is defined as high, medium or low, see Appendix 4 and 5.

3.2 Engineering Controls in the Laser laboratory for the Safe Use of Lasers

3.2.1 Laboratory Design and Layout

The laboratory is designed so that the risk of laser related hazards to laboratory users is minimised.

3.2.2 Optical Tables

The optical table is positioned to provide safe access to equipment on the table from all sides; a clear passage way around the table perimeter must be maintained at all times. Screens on the table should be used so as to minimise the possibility of stray beams exiting the table area, across a room and towards any entry points, windows or flammable materials.

3.2.3 Electrical Outlets

Cables must not run across the floor from items located on the table. If not properly arranged these cables can present trip hazards.

3.2.4 Windows

The window in the laboratory is blackened out with a shutter system and a suitable laser curtain that is capable of withstanding a direct continuous hit from all of the laser sources in the laboratory.

3.2.5 Workstation Station

Workstations (e.g. computer) are positioned to minimise the risk of any stray laser beams.

3.2.6 Protective Laser safety googles Storage

Laser protective laser safety googles are stored at the entry point to the laboratory so that users entering the room can put them on beforehand. Labelled storage units allow for easy identification.

3.2.7 General Housekeeping

Providing good general storage space in the laboratory can aid in keeping the area around and on top of the optical table and benches clutter free. This helps eliminate the risk of trip hazards and flammable or reflective materials in the vicinity of the exposed beams. Appropriate storage facilities for chemicals are provided externally and not permitted in the laser laboratory.

3.2.8 Laboratory Lighting

The walls in the laser laboratory are painted with a white matt colour, which diffusely reflects the light in the laboratory. Ambient light levels should be maintained where practicable as this will help to restrict the eyes' pupil diameter, thereby reducing retinal exposure. Lighting in the laboratory will provide better visibility where laser safety goggles may make the room appear dark. Some experiments may require low background lighting for duration of the task. Emergency lighting is present to guide people in the case of emergency/fire and in the event of a power cut.

3.2.9 Ventilation and Air-conditioning

Air conditioning is available in the room to maintain a controlled temperature. This can minimise the need to carry out frequent realignments of optical components, which can be hazardous when working with lasers.

3.2.10 Emergency Switch

In the event of a laser emergency, a red emergency push button switch is provided within the laboratory to disable all lasers.

3.2.11 Interlocks

The laboratory door automatically locks, and is fitted with a switch that is interlocked with the electrical circuit on the laser(s). When the laser is operational, a warning light on the outside of the door indicates that the laser may be on and no entry is permitted. This can be overridden by registered authorised users, by the use of the 10 second override key on the entrance and a push button on the exit. Interlocked enclosures can be used to reduce the hazard class of the laser system.

3.2.12 *Screens and Enclosures*

Screens and other enclosure types provide protection from laser beams. They are used in the laser laboratory where they can reduce the risk of the laser beam causing injury outside of the perimeter of the optical bench.

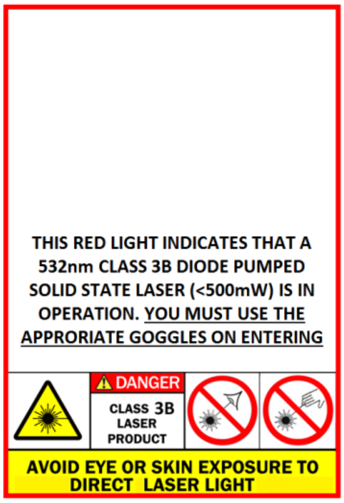
Laser screens and enclosures are useful when more than one laser system and wavelength are in use in the laser laboratory. Screens can be used to partially or fully enclose an optical table. Eye protection must always be worn in the laboratory regardless. All screens need to be appropriately fixed to the optical bench so that they do not become a source of potential danger by falling into a beam and causing a deflection.

Laser curtains are used to create a secondary barrier at the entrance door to the laboratory and also as an additional protection (with the shutter) on the window. Laser certified curtains are used and the installation is inspected biannually by the LSO. The curtains have been selected to meet the requirements imposed by all of the lasers within the laboratory. This takes into account laser power, wavelength, beam size, beam divergence and distance from laser to curtain (see Appendix Section A11.8).

3.2.13 *Signage, Warning Lights and Laser Labelling*

Safety signs are provided that comply with the health and safety regulations. A no entry hazard light is located above the laser laboratory door and is connected to the laser interlock system. On the entrance door of the laboratory the following sign is fixed to the door.

The user must place signage on the door related to the specific laser type in use.

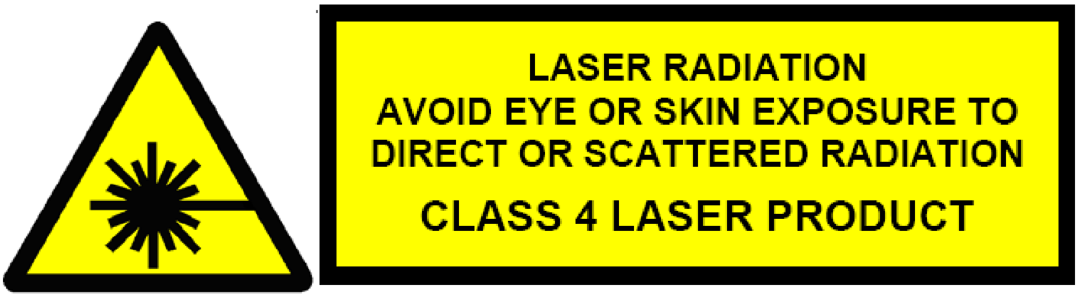


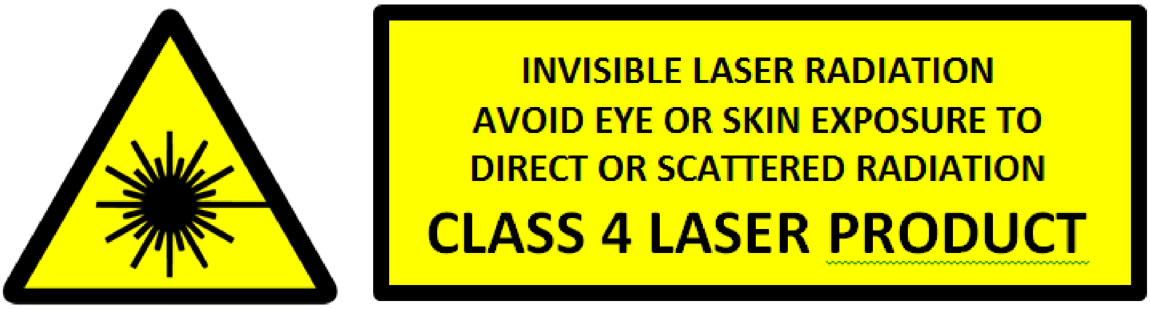
A sign relating to chemicals is posted on the laboratory wall.

NO CHEMICALS
TO BE STORED IN
THIS LAB

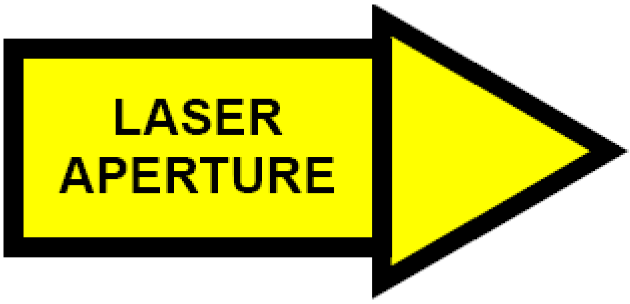
CLASS 4 LASERS CAN
CAUSE
EXPLOSIONS!!

All lasers require labelling hazard signs, except class 1 which are deemed safe within normal operating conditions. Hazards labels must comply with the Health and Safety signs Regulations and where they do not they will need to be relabelled. Example of Hazard safety signs is shown below. All lasers/lasers enclosures must be labelled with the appropriate hazard signs of the following type (with class, wavelength, and power details) as appropriate:

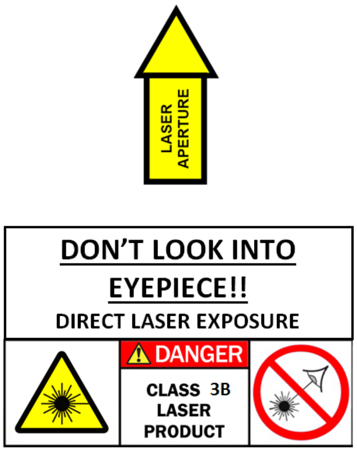




All laser apertures must be marked with the appropriate signage:



All microscope eyepieces must be blocked and must also be marked with the following sign:



The shutter will also have a warning notice:

All laser drives and related electrical instrumentation must be marked with

In addition all administrative control measures listed in this section are posted on the laboratory wall.

3.3 Administrative Controls

Administrative controls cover the laser safety procedures of the laboratory, the implementation of the laser safety risk management measures, which includes the procedures, training, registration and assignment of responsibilities. The delegation of responsibilities in the administrative capacity is outlined in this section.

3.3.1 Laser Safety Documentation

This following documentation will be kept on record by the LSO:

- Guidance document on laser safety
    - Responsibilities
    - Hazards
    - Engineering and administrative controls
- Fire safety and emergency plans (reference departmental safety statement, summary in Appendix 8)
- Copies of the written risk assessments (See Appendix 4 and 5).
- Register of authorised, trained, laser users (see Appendix 2)
- Register of lasers (see Appendix 1)
- Register of inspection for laser control measures. (see Appendix 6)
- Copies of accident-incident reports (see Appendix 9)
- Training records (list of attendees) (see Appendix 7)

3.3.2 Access to the laser laboratory

No unauthorised persons are allowed to enter the laser laboratory when the laser systems are on. and **it is the responsibility of laser users to ensure that this is complied with**. Authorisation requires completion of registration and training, see the following section. Supervised access can be facilitated for visitors. Service engineers/cleaners can avail of scheduled access as agreed with the LSO. Such cases will involve the disablement of all laser sources in the laboratory prior to access.

Working alone is permitted only after a risk assessment of the experiment has been carried out and authorised by the LSO.

3.3.3 Registration of Laser Users

All those working with laser systems must be registered with the LSO. A record of all registered users is maintained, see Appendix 2.

Registration requires:

- Attendance at a laser training course
- Reading of the departments laser safety guidance document
- An eye examination has been completed.
- The user must agree to follow the procedures outlined in this guidance document, including the use of PPE.

3.3.4 Scheduling of an experiment in the laser laboratory

- A risk assessment form must be completed describing the experiment, identifying the hazards, risks, and control measures (see Appendix 4 and 5).
- The risk assessment form must be signed by the LSO.
- The experiment must be scheduled on the online laboratory calendar and authorised by the LSO.
- The experiment is undertaken inside laboratory working hours (9am-5pm) unless authorised by the LSO (note, security may need to be informed).

3.3.5 Training

Training of laser users required to work with 3R, 3B and 4 laser systems must attend the training course provided by the LSO. This will incorporate many of the topics covered by this guide including hazards, risks and their controls. A record of attendance at the training course will be kept, see Appendix 7.

3.3.6 Key control to laser laboratory and Lasers

The laser laboratory has put in place engineering controls to protect users from accidental laser exposure. Three different types of are held by the LSO and provided on a case by case basis following an authorised risk assessment:

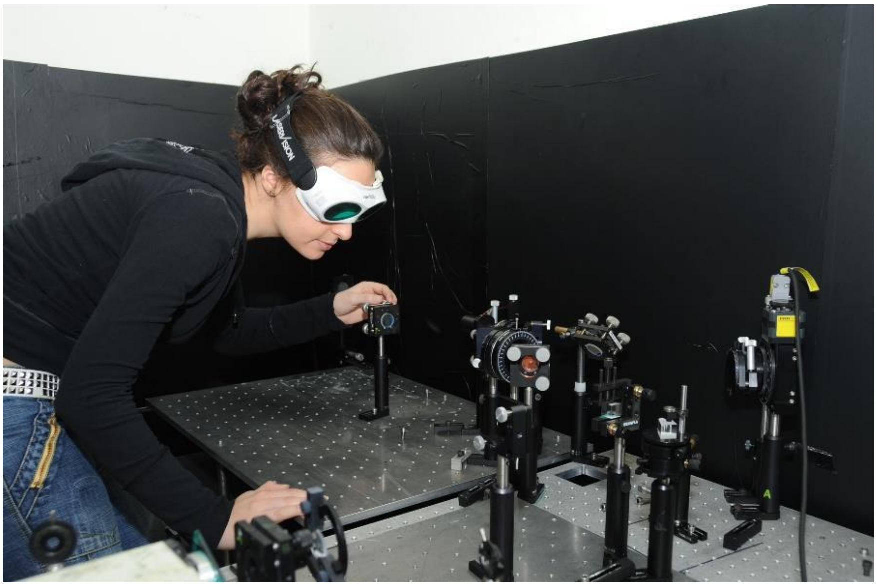
- Laboratory door key
- Key for door interlock override system
- All Class 3B and 4 lasers require control keys in order to be activated. The control keys are held by the LSO.

3.3.7 Identification and Registration of Laser Systems

Within the laboratory, all class 3R, 3B and 4 laser systems must be identified and entered into the laser register, see Appendix 2. When a new laser system is being setup it must be registered by the LSO before use. A laser system is registered only when all of the relevant engineering and administrative controls are in place.

3.3.8 Personal Protection Equipment

Personal protective equipment, (PPE) is required to ensure that in the event of an accidental exposure the laser user is not injured.



A detailed discussion on how to understand the labelling on laser safety goggles and how to select the most appropriate goggles for a particular laser is provided in Appendix 11. All laser safety goggles are accessible to all users entering the laboratory. The safety goggles are stored in marked containers hanging on the back of the door. Care must be taken to replace the laser safety googles back into the correct container and to protect the filters from scratches and mechanical stress

- Laser safety goggles must be worn before turning on laser:
    - The 785nm and 1064nm lasers can only be used together if the appropriate laser safety goggles are used that cover both wavelengths.
    - The 532nm lasers can only be used in isolation as laser safety goggles for these lasers to not protect against the 785nm and 1064nm lasers.
- It is the responsibility of the laser user to ensure that filter band of the laser safety goggles (see label on goggles) is appropriate for the laser power and wavelength.
- Never turn on the laser without making sure everyone in the room is wearing appropriate laser safety goggles (PPE).
- Never remove the laser safety goggles while the laser is switched on.
- **NEVER** look directly into a beam, e.g. for alignment, even if wearing laser safety goggles.
- All jewellery, metallic and reflective objects must be removed before entering the laboratory.
- Do not leave areas of the skin exposed in the region of a laser beam.
- Laboratory coats are also provided and must be worn when operating class 3 or class 4 lasers.
- Laser safety gloves must also be worn when using the NIR and IR lasers to protect hands and wrists, where there is a risk to skin exposure.
- Use latex gloves to protect expensive optics where possible.

3.3.9 Activating a laser

- Ensure that only authorised persons that are included on the risk assessment form are permitted to be present.
- Ensure that engineering controls are in place and functional and all administrative procedures are complied with.
- Ensure that the appropriate sign is on the exterior of the laboratory door indicating which laser(s) is/are in use.
- Only experiments that are approved on the risk assessment form are permissible; do not attempt unscheduled alignments.
- Ensure all laboratory users are wearing PPE, i.e. laser safety goggles.
- Only lasers that are appropriate for the available laser safety googles are used. If multiple lasers are present only lasers appropriate for the PPE are switched on at any given time.
- Ensure the lights in the room are on where practicable, as this reduces the pupil size.
- Make sure the laser is directed away from laboratory entrance where possible.
- Ground yourself to avoid damaging the lasers by placing a hand on the optical table or by wearing the grounding bracelet.

3.3.10 Aligning a laser system

- Your experiment is scheduled on the laboratory calendar and the risk assessment has been completed.
- Keep the lights in the room on, when possible as this reduces the pupil size.
- Do not point the laser at the entry point.
- Laser power must be reduced to a minimum during alignment or the use of a replacement alignment laser must be used for certain cases. Consider using neutral density filters if direct reduction of the power using the control unit is not possible.
- Unnecessary optical reflections must be minimized.
- Antireflective coated components must be used for the given laser wavelength.
- Lasers and optical components must be securely fixed to the table as well as the movable parts locked when not being adjusted.
- Keep beam paths below eye level where possible; if this is not possible use care and consider the use of an enclosure when the laser(s) are operated to minimise risk.
- Keep optical benches free from clutter.
- Be careful of specular and diffuse reflections from surfaces.
- Remove jewellery, wristwatches, chains or ID cards worn on straps, as a matter of procedure when working with lasers as they can possibly reflect the beam.
- Screens must be used where practical and beam paths must be as short as possible.
- Search for stray beams leaving the perimeter of the work area and place a beam block to terminate them where possible. If some beams are leaving the table at an angle or vertically and this is unavoidable then place a clear label to indicate this .
- Beams that are not visible to the human eye can be viewed using IR/UV laser viewing cards or white cards which can fluoresce, which are provided in the laboratory. Beware that these cards may produce reflections and may smoulder and burn. Do not remove safety goggles when using viewing cards.
- Be careful of laser beams when bending down to turn on/off laser control.

3.3.11 Procedures for using enclosures and screens

- The use of non-interlocked enclosures and screens can be used to reduce the risk of beam hazards. However, the class of the laser system remains and the controls in the previous two sections must be applied.

    - Where apertures exist, appropriate signage must be applied, see Section 3.2.13
- Where an enclosure is interlocked with the laser(s) within, this can be treated as a class 1 laser system.
    - Such an enclosure is necessary where multiple laser wavelengths are used simultaneously, which are not protected by a single set of laser safety goggles.

3.3.12 Leaving the lab

When leaving the laboratory make sure that

- All equipment (not just the lasers!) have been fully switched off and powered down
- Laser keys are returned to laser safety officer/admin office.
- All laser enclosures are fully closed.
- All laboratory waste has been disposed of safely
- All surfaces that have been exposed to biological samples are cleaned with alcohol wipes.
- It is good practice to ensure personal hygiene when leaving the laboratory, e.g. hand washing etc.
- The work space is left clean and tidy.
- Ensure the laboratory door is locked and the key is returned t the LSO/admin office

3.3.13 Inspections

A biannual inspection will be carried by the LSO to:

- Ensure engineering controls are in place and functioning
- Ensure compliance with the administrative controls.

Reports of each inspection will be maintained by the LSO and copied to the departmental safety officer/head of department, See Appendix 6.

Section 4

Appendices

APPENDIX 1

Contact Information

Head of Department of Electronic Engineering
NAME: Ronan Farrell
CONTACT DETAILS Room 3.05 Ext 6197

Department of Electronic Engineering Laser Safety Officer
NAME: Bryan Hennelly
CONTACT DETAILS Room 3.11 Ext 3338

Department of Electronic Engineering Safety Officer
NAME John Maloco
CONTACT DETAILS Room 3.10 Ext. 6056

Maynooth University Safety Officer
NAME Brendan Ashe
CONTACT DETAILS Ext 4720

APPENDIX 2

Laser Register

LOCATION	LASER MODEL/SYSTEM	CLASS	TYPE	MAX POWER	WAVELENGTH
Laser laboratory Room 1.03	Laser Quantum Torus 532 http://www.laserquantum.com/products/detail.cfm?id=19	3B	CW	<150mW	532nm
Laser laboratory Room 1.03	Laser Quantum GEM 532 http://www.laserquantum.com/products/category.cfm?id=11	4	CW	>500mW	532nm
Laser laboratory Room 1.03	CNI MGL-III-532-400mW http://www.cnilaser.com/PDF/MGL-III-532.pdf	3B	CW	400mW	532
Laser laboratory Room 1.03	CNI MIL-III-1064-500mW http://www.cnilaser.com/PDF/MIL-III-1064.pdf	4	CW	500mW	1064
Laser laboratory Room 1.03	Sacher Laser TEC-520 0780-100 http://data.sacher-laser.com/lion/li0780100.pdf	3B	CW	<150mW	775-795 Tunable
Laser laboratory Room 1.03	CNI MSL-III-532-10mW http://www.cnilaser.com/PDF/MGL-III-532.pdf	3B	CW	10mW	532
Laser laboratory Room 1.03	NIRS OPTIX CW6 System http://nirsoptix.com/CW6.php (32 lasers, fiber connected)	3B	CW		785,850

Do not include office based Class 1 laser such as CD /DVD players or laser printers etc.
School / Department: ____
Laboratory Supervisor or expert user: ____
Signed: ________________________ Date ____/____/_______

APPENDIX 3

Laser User Register

Department	Name	Date of Registration	Date of completed Training

Department: ____
Laboratory Supervisor or expert user: ____
Signed: ________________________ Date ____/____/_______

APPENDIX 4

Use of Class 1M, 2/2M, and 3R Lasers Hazard and Risk Assessment

Assessor Name	**Email**	**Assessment Number**	
School / Department / Room	**Tel:**	**Date of Assessment**	

NOTE: Without the use of magnifying optics 1M devices do not pose an eye hazard, neither do 2M or Class 2 devices as long as the user does not stare into the beam (eye protection is normally afforded by the aversion responses). An eye injury is possible if there are exposure times in excess of more than 0.25 seconds from Class 2/2M lasers, exposure to Class 1M/2M; or if Class 3R lasers are viewed directly. Risk of eye injury is low. There is no skin or fire hazard.

BRIEF DESCRIPTION OF THE WORK ACTIVITY INVOLVING THE LASER

LASER SPECIFICATIONS:	
Manufacturer	
Model	
Maximum Power (mW)	
Wavelength Range	

OPTICAL AND NON OPTICAL HAZARDS		
Hazards	**Risk**	**Control Measure**

CONTROLS MEASURES	
Do!	✓ Follow the manufacturer’s safety instructions ✓ Take care when operating the laser system ✓ Leave the laser on only when necessary ✓ Restrict unauthorised use ✓ Terminate the beam at the end of its useful path
Do Not!	✗ Do not point towards anyone deliberately ✗ Do not point towards mirrored surfaces that may cause unintended reflections ✗ Never look directly into the laser aperture or the beam when on ✗ Do not use optical components to focus the beam unintentionally ✗ Never allow unauthorised use of the laser

APPENDIX 5

Risk Assessment Form for Class 3B and 4 Lasers

Class 3B and Class 4 lasers can cause serious eye injury if the beam is accidently viewed either directly or by specular reflections. Diffuse reflections of a high-powered CLASS 4 laser beam can cause permanent eye damage. High-powered laser beams, CLASS 4, can burn exposed skin and ignite flammable materials. Laser equipment can pose hazards associated with high voltage. Proposed experiments must be risk assessed to determine the hazards and risks involved. Based on the risk assessment the safety measures and risk management must be adhered to as set out in the laser guidance document.

S1	**Assessor Name**	**Email:**	**Assessment Number**
Department/Room		**Tel:**	**Date of Assessment**

S2	**DESCRIPTION OF THE EXPERIMENT INVOLVING LASER(S)** Please provide a brief description of the experiment

S3	**LASER SPECIFICATIONS:**			
		Laser 1	**Laser 2**	**Laser 3**
LASER CLASS 3B or 4				
Manufacturer				
Model				
Type of Emission CW or Pulsed				
Maximum Power (mW)				
Wavelength Range (nm or µm)				
Wavelength in Use (nm or µm)				
Beam shape (circular, square, ellipse)				
Diameter or dimensions (mm)				
Beam Divergence (milli-radians)				

S4	Hazards, Risk, and Control Measures	
Hazards	**Risk**	**Controls**
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	
	☐HIGH ☐MED ☐LOW	

S5	PERSONS WHO MAY BE AT RISK	
	Name	Registered Laser User YES/NO
1		☐YES ☐NO ☐N/A
2		☐YES ☐NO ☐N/A
3		☐YES ☐NO ☐N/A
4		☐YES ☐NO ☐N/A
5		☐YES ☐NO ☐N/A

S8	LASER SAFETY		
List the laser safety googles intended to be used for, the type of emission D I R M, and the scale number stating the code LB for full or R for alignment protection.			
Manufacturer	Wavelength	DIRM	Scale No.

9	EMERGENCY ACTION
In event of an emergency it is important to understand the control measures listed below.	
Fire	✓ Switch off the power supply to the laser if it is safe to do so ✓ Do not put yourself in danger ✓ Activate the fire alarm ✓ As long as it does not compromise your safety you can attempt to extinguish the fire with the appropriate equipment provided ✓ Evacuate to an assembly point
Laser Eye Injury	✓ If an accident occurs seek help from a colleague/LSO. ✓ Press the emergency button to disable laser systems ✓ Call 3929, to request the emergency services ✓ Even if you think your injury is very minor you should go to the Accident & Emergency, Royal Victoria Eye and Ear Hospital, Adelaide Road Dublin 2. Telephone (+353) 1 6644600
ALL ACCIDENTS/INCIDENTS MUST BE REPORTED TO THE LASER SAFETY OFFICER, AND THE UNIVERSITY SAFETY OFFICER! **A list of trained first aiders is posted in the laboratory.** **A list of emergency exits, fire extinguisher locations, eye wash location and assembly points are listed I the laboratory.**	

SIGNATURES

Responsible Person Signature	**Date**
Signature of Authorising Officer (Laser Safety Officer)	**Date**

Sample Risk Assessment Form

Risk Assessment Form for Class 3B and 4 Lasers

Class 3B and Class 4 lasers can cause serious eye injury if the beam is accidently viewed either directly or by specular reflections. Diffuse reflections of a high-powered CLASS 4 laser beam can cause permanent eye damage. High-powered laser beams, CLASS 4, can burn exposed skin and ignite flammable materials. Laser equipment can pose hazards associated with high voltage. Proposed experiments must be risk assessed to determine the hazards and risks involved. Based on the risk assessment the safety measures and risk management must be adhered to as set out in the laser guidance document.

S1	**Assessor Name** Joe Bloggs	**Email:** **Joe.bloggs@nuim.ie**	**Assessment Number** **123**
Department/Room **3.11**		**Tel:** **Ext 1234**	**Date of Assessment** **1st Jan 2050**

S2	**DESCRIPTION OF THE EXPERIMENT INVOLVING LASER(S)** Please provide a brief description of the experiment

Performing laser alignment of Raman micro-spectroscopy system.

Enclosure will be removed in order to access optical components. Positon of various lenses, dichroic beam splitters, long pass filter, and confocal aperture will be adjusted to arrange optimal alignment of laser spot sample and with spectrograph slit.

Alignment will be tested by monitoring laser spot on the microscope camera system and silicon spectrum on the cooled CCD.

S3 **LASER SPECIFICATIONS:**

	Laser 1	**Laser 2**	**Laser 3**
LASER CLASS 3B or 4	3B		
Manufacturer	Laser Quantum		
Model	Torus		
Type of Emission CW or Pulsed	CW		
Maximum Power (mW)	150mW		
Wavelength Range (nm or µm)	1e-9nm		
Wavelength in Use (nm or µm)	532nm		
Beam shape (circular, square, ellipse)	TEM00		
Diameter or dimensions (mm)	1mm		
Beam Divergence (milli-radians)	<0.4millirad		

S4	Hazards, Risk, and Control Measures	
Hazards	**Risk**	**Controls**
Eye Injury from direct beam exposure	☐HIGH ☐MED ☒LOW	Use correct PPE (laser sfatey goggles). Use lowest laser power possible for experiment. Use beam blocks/screens to avoid stray beams. Do not view beam directly even with PPE. Do not remove PPE for any reason, even when looking at PC. Use viewing card for alignment purposes where necessary. Keep beam below eye level. Take care when bending down.
Skin injury from direct beam exposure	☐HIGH ☐MED ☒LOW	Use correct PPE (lab coat/gloves). Use lowest laser power possible for experiment. Use beam blocks/screens to avoid stray beams.
Specular Reflection from optical component	☐HIGH ☐MED ☒LOW	Use correct PPE. Use lowest possible laser power. Use components with anti-reflective coating. Securely fix laser and components to optical table.
Eye injury from diffuse reflection	☐HIGH ☐MED ☒LOW	Not applicable for laser class 3B. NOTE Class 4 lasers would require the use of a suitable beam stop to prevent diffuse reflection.
Fire	☐HIGH ☐MED ☒LOW	Do not direct beam towards flammable material. Be aware of fire extinguishers and emergency exit.
Electrical shock	☐HIGH ☐MED ☐LOW	Do not tamper with electrical equipment
Trips/falls	☐HIGH ☐MED ☐LOW	Ensure clear passage around table Avoid trailing cables

S5	PERSONS WHO MAY BE AT RISK	
	Name	Registered Laser User YES/NO
1	Joe Bloggs	☒YES ☐NO ☐N/A
2	Bryan Hennelly (LSO)	☒YES ☐NO ☐N/A
3		☐YES ☐NO ☐N/A
4		☐YES ☐NO ☐N/A
5		☐YES ☐NO ☐N/A

S8	LASER SAFETY		
List the laser safety googles intended to be used for, the type of emission D I R M, and the scale number stating the code LB for full or R for alignment protection.			
Manufacturer	Wavelength	DIRM	Scale No.
Laservision GmBh	532nm	D	LB5

9	EMERGENCY ACTION
In event of an emergency it is important to understand the control measures listed below.	
Fire	✓ Switch off the power supply to the laser if it is safe to do so ✓ Do not put yourself in danger ✓ Activate the fire alarm ✓ As long as it does not compromise your safety you can attempt to extinguish the fire with the appropriate equipment provided ✓ Evacuate to an assembly point
Laser Eye Injury	✓ If an accident occurs seek help from a colleague/LSO. ✓ Press the emergency button to disable laser systems ✓ Call 3929, to request the emergency services ✓ Even if you think your injury is very minor you should go to the Accident & Emergency, Royal Victoria Eye and Ear Hospital, Adelaide Road Dublin 2. Telephone (+353) 1 6644600
ALL ACCIDENTS/INCIDENTS MUST BE REPORTED TO THE LASER SAFETY OFFICER, AND THE UNIVERSITY SAFETY OFFICER! **A list of trained first aiders is posted in the laboratory.** **A list of emergency exits, fire extinguisher locations, eye wash location and assembly points are listed I the laboratory.**	

SIGNATURES

Responsible Person Signature	Date
Signature of Authorising Officer (Laser Safety Officer)	Date

APPENDIX 6

Laser Laboratory Inspection Form

Inspected By	
Location	Engineering and Bioscience Building, Room 3.2
Date	

Engineering Controls

Hazard light operational	☐YES ☐NO ☐N/A
Interlock functioning	☐YES ☐NO ☐N/A
Interlock override system functioning correctly	☐YES ☐NO ☐N/A
Correct signage on door	☐YES ☐NO ☐N/A
Automatic door lock operational	☐YES ☐NO ☐N/A
Door safety curtain in place	☐YES ☐NO ☐N/A
PPE in good condition	☐YES ☐NO ☐N/A
PPE stored correctly at entry point	☐YES ☐NO ☐N/A
Emergency switch operational	☐YES ☐NO ☐N/A
Optical Table	☐YES ☐NO ☐N/A
Availability if screens/beam stops	☐YES ☐NO ☐N/A
Safe use of cables	☐YES ☐NO ☐N/A
Window blacked out	☐YES ☐NO ☐N/A
Safe positioning of workstations	☐YES ☐NO ☐N/A
Appropriate ambient lighting	☐YES ☐NO ☐N/A
Air conditioning functioning	☐YES ☐NO ☐N/A
Correct use of signage throughout laboratory	☐YES ☐NO ☐N/A
Viewing cards available for IR/NIR	☐YES ☐NO ☐N/A
Interlocked enclosures operational	☐YES ☐NO ☐N/A
Emergency light/LED	☐YES ☐NO ☐N/A

Good Housekeeping

Clear bench/table space	☐YES ☐NO ☐N/A
Clear passage around table	☐YES ☐NO ☐N/A
Clean/clear floor space	☐YES ☐NO ☐N/A
Safe use of cables	☐YES ☐NO ☐N/A

Comments/Actions

ACTIONS	RESPONSIBILITY	DATE

Administrative Controls

Laser register up to date	☐YES ☐NO ☐N/A
Laser user register up to date	☐YES ☐NO ☐N/A
Lab key present	☐YES ☐NO ☐N/A
Override key available	☐YES ☐NO ☐N/A
All laser control keys accounted for	☐YES ☐NO ☐N/A
Only authorised persons present (training completed)	☐YES ☐NO ☐N/A
Laser safety documentation available	☐YES ☐NO ☐N/A
Experiment is compliant with authorised risk assessment form	☐YES ☐NO ☐N/A
Experiment has been scheduled correctly	☐YES ☐NO ☐N/A

Procedures for activating/aligning the laser (compliance)

Appropriate sign on door for specific laser system(s)	☐YES ☐NO ☐N/A
Correct PPE is in use	☐YES ☐NO ☐N/A
Correct use of enclosures/screens	☐YES ☐NO ☐N/A
No stray laser beams detected	☐YES ☐NO ☐N/A
Laser power reduced	☐YES ☐NO ☐N/A
Antireflective elements in use	☐YES ☐NO ☐N/A
Lasers and optical components fixed to table	☐YES ☐NO ☐N/A
Safe use of any beam paths above eye level	☐YES ☐NO ☐N/A
Hazardous diffuse or specular reflections	☐YES ☐NO ☐N/A
Removal of reflective jewellery etc	☐YES ☐NO ☐N/A

Comments/Actions

ACTIONS	RESPONSIBILITY	DATE

APPENDIX 7

Laser Safety Training Register

Maynooth University
National University of Ireland Maynooth

Training Course given by	
Location	
Date	

Attendees

NAME (BLOCK CAPITALS)	Signature

Signature of Trainer

Laser Safety Goggles Declaration form.

Maynooth University
National University of Ireland Maynooth

This form must be completed by all students and staff, as part of laser safety training, prior to commencing work with lasers.

It is the policy of the university to eliminate all hazards where reasonable practicable and to assess what PPE is required. Within the Department of Electronic Engineering, it is the policy that all staff/students/visitors must wear appropriate laser safety goggles in the laser laboratory for the duration of all laser experiments.

Staff members will inform any person in the laboratory observed not wearing protective equipment as required and such persons will be instructed not to continue working until PPE is obtained and used. Inspections will be performed by the members of the Safety Committee on a regular basis.

(Please refer to Department of Electronic Engineering Laser Safety Guidance Document for further information)

I have read and understand the health and safety requirement as stated above and I agree to comply with them.

Signed:____

Date:_______________________

Name (IN BLOCK CAPITAL LETTERS):__________________________

Laser Safety Declaration form.

Maynooth University
National University of Ireland Maynooth

This form, to be completed by all undergraduate and postgraduate students, postdoctoral researchers, and visiting academics must be completed before any laser experiments commence.

Name of research project supervisor ____

Name of research worker* ____
*Status: Undergraduate, postgraduate, postdoctoral or visitor (delete as appropriate)

For the research worker:

- I have read the Department of Electronic Engineering Laser Safety Guidance Document and attended the Laser Safety Training course, and I fully understand the safety recommendations.
- I have read and fully understand the risk assessment forms. and will carry out continuous RISK ASSESSMENTS as required during the course of my work.
- where appropriate I will seek advice/information from my project supervisor, if I am in doubt about any safety matter relating to my work.

Signature of the research worker...

Date...........................

Name (IN BLOCK CAPITAL LETTERS):___________________________

APPENDIX 8

Medical Supervision and Emergency Information

Eye examinations for laser users are required for laser users on an annual basis, and will be organised by the LSO. In the event of an apparent or suspected eye injury a medical examination by a qualified specialist needs to be carried out immediately.

The most appropriate Accident and Emergency Department that deals with eye injuries is in the Royal Victoria Eye and Ear Hospital, details listed below.

Following an incident/accident, a university incident report must be provided to the department safety officer and made available to the university safety office.

Laser eye injury requires immediate medical attention

EMERGENCY INFORMATION

Emergency Services	**01 708 3333**	**999 or 112**
Fire	**01 708 3929**	**999 or 112**
First Aid		
John Maloco – EENG	**01 708 6056**	**Automatic External Defibrillator Trained – nearest AED is located in the Sports Centre or the Arts building**
James Kinsella - Eolas	**01 708 6935**	
Paul Davis – Sports Officer	**01 708 6406 /6407**	
Medical Centre	**01 708 3878**	
If you cannot contact anybody listed call Security 3929		
Eye & Ear Hospital	**01 664 4600**	
Security	**01 708 3929**	

If you suffer an eye injury you may well be in shock seek help from a colleague then go together to the Hospital Immediately. Get a taxi if necessary.

Accident & Emergency
Royal Victoria Eye
Ear Hospital Adelaide Road
Dublin 2

Report all accidents to the: Department of Electronic Engineering Laser Safety Officer, the Department of Electronic Engineering Safety Officer and the University Safety Officer. More details on emergency procedure are given in the Appendix 7 at the end of this guidance. Do not use the laboratory or disturb the equipment until after the accident has been investigated.

APPENDIX 9

Incident/Accident Report Form

ACCIDENT - INCIDENT REPORT

All incidents resulting in personal injury, a dangerous occurrence, damage to property or a near miss which could have resulted in injury must be reported within 24 hours, by completing this form and returning it to the University Safety Office.

Report Completed by: ____________________ Date: ___________

Date of incident	Time	Campus	Exact Location

Name of Injured Party. ________________________

Occupation________________________________

Address ___________________________________

____

____

Staff/Student/Other

Details___________________________________

Facility___________________________________

Describe the nature and extent of injuries suffered.

____

____

____

First Aid Treatment Y/N? ☐

____

____

Referred to Doctor Y/N? ☐

Describe the circumstances and nature of the accident/incident.

____

____

____

Doctors Name & Address

____

____

____

What was the person doing at the time of the incident Work/ Other Activity, Describe: _____________________________

____

____

____

Taken to Hospital Y/N? ☐

By_______________________________________

Hospital__________________________________

Admitted or Discharged after Treatment. Specify

____

What protective clothing was worn at the time of the incident?

____

Was any machinery or vehicle involved? Give Details:

____

Comments or additional information

____

____

Witness to incident? Y/N ☐

Name____________________________________

Phone No.________________________________

Address: ________________________________

Reported By: _____________________________

Phone No. _______________________________

Department/Address_______________________

____

Office Use only

Classification	Action	Reported Ins./ HSA	Acknowledged	Date Recorded
F/A T/L Other				

APPENDIX 10

Background to Laser Technology

A10.1 Basic Properties of Lasers

The word *LASER* is an acronym for ***L**ight **A**mplification* by ***S**timulated **E**mission **R**adiation*. Lasers emit concentrated beams of light through this process of optical amplification of electromagnetic radiation. Lasers differ from other sources of electromagnetic radiation in that the source is extremely coherent (in phase), collimated (narrow beam) and usually monochromatic (one wavelength) thus allowing the beam to be focused to a tiny spot only a few microns in diameter. This means that there is also a very large power density, which typically can be many times greater than the sun's irradiance, therefore even relatively small amounts of laser light can lead to permanent eye injuries.

Laser light has specific properties that make it different from other sources of light; it is some of these properties that can make it more dangerous. Due the relatively high power concentrated in a small diameter, and the low divergence of the beam, the power density on the retina of the eye can be 120 times greater for a focused 1-milliwatt laser than that of direct sunlight. To better appreciate the reasons why lasers are dangerous a brief outline of the main properties of laser light are explained below.

A10.1.1 Collimation

Laser light is usually highly collimated, all the rays travel approximately parallel and spread minimally as it propagates. Laser beams are highly directional and the power density is maintained over a relatively great distance when compared to normal light sources. Divergence angles are typically very small and measured in milliradians. When a person is some distance away, the beam can present a danger if incorrectly applied.

A10.1.2 Coherent

The light from a laser differs from ordinary light in that it is made up of waves, all of the same wavelength which are in phase. This means that all the electromagnetic waves are synchronised as they propagate.

A10.1.3 Monochromatic Light

Laser light is typically monochromatic, one wavelength with a very narrow spectral bandwidth of just a few nanometres. The wavelength range of lasers can extend the electromagnetic spectrum from as low as 100nm, ultraviolet, through the visible 400nm to 700nm and into the near and far infrared out to 1mm. various wavelength ranges can present specific dangers to biological tissues of the body, especially the eye.

A10.1.4 High Power and Energy Density

Laser light appears much brighter than normal light because the power is concentrated in a much smaller area. The optical power density of a laser is termed *irradiance* and is the average power per unit area. The energy density is termed *radiant exposure* and is the energy in joules per unit area.

A10.1.5 Emission Type

Another property of laser light is the beam emission type. Lasers are either Continuous Wave (CW) or Pulsed. CW lasers emit at a constant power while pulsed lasers emit pulses of finite temporal width, usually with huge peak powers. Only CW lasers are currently in use in the laser laboratory.

A10.1.6 Comparison of Irradiance

It is useful to compare the irradiance of a laser on the retina with a non-collimated source like the sun to better understand the potential of relatively low powered lasers to cause serious injury. Irradiance (E) is the incident electromagnetic power per unit area. The sun irradiates the earth at approximately 1KW/m^2 or 0.1 W/cm^2. Let's take a 1mw laser pointer emitting a beam of wavelength 633nm and diameter of 2mm. Let's assume a *top hat* profile to the beam that is the power density is consistent across the area of the beam (see Section A10.2.2.2 below). For convenience let's also assume a pupil diameter of 2mm, we can then approximate the area to be 3mm^2. This means the full milliwatt of power from the laser can enter the eye. Ignoring aberrations and other possible defects of the eye, the image of the sun when focused on the retina will produce a spot of approximately 200µm in diameter whereas the collimated laser with low divergence will produce a much smaller image of approximately 10µm. From these values we can work out the irradiance at the retina to be approximately 10 W/cm^2 for the sun and 1200 W/cm^2 for the laser.

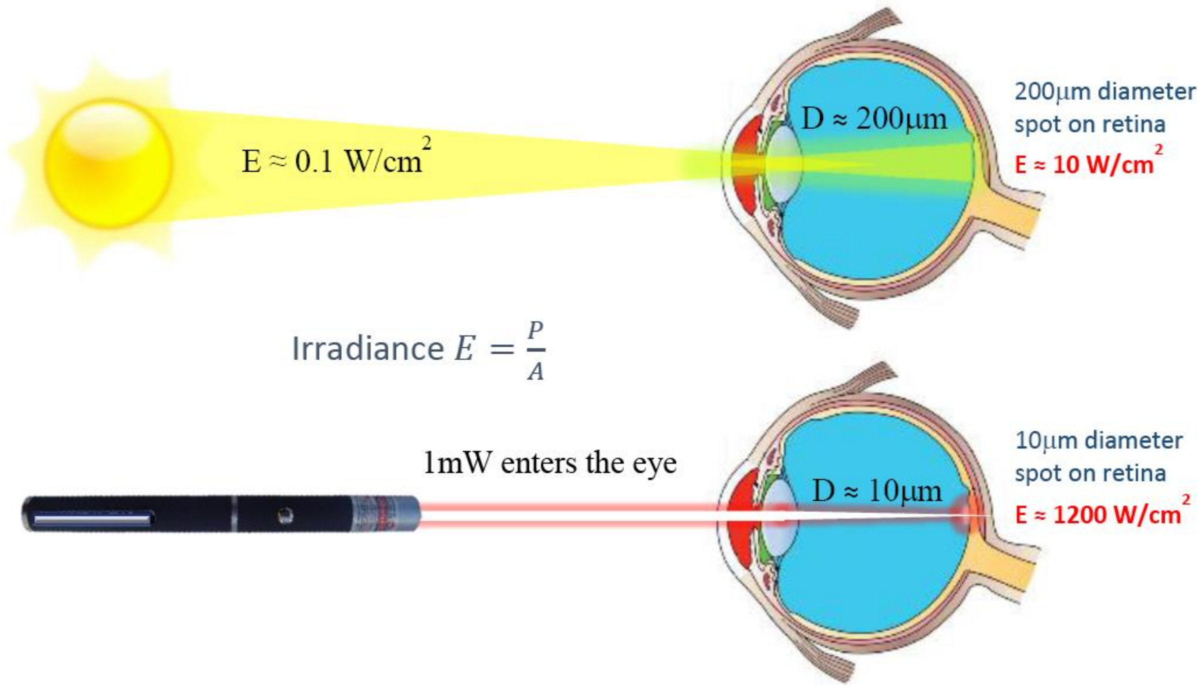


Fig. A10.1 Comparison of irradiance of the sun and a 1mW laser on the retina

The laser light incident on the retina is 120 times more intense than the sun. It is never recommended to stare at the sun as it can cause damage to your eyes but we are all familiar with how bright it is, therefore you can imagine how uncomfortable and dangerous it would be to stare at something 120 times brighter.

A10.2 Understanding Laser Power

A10.2.1 Power for Continuous Wave Lasers

Although detailed safety calculations will not typically be necessary by the normal laser user within the laser laboratory, an understanding of these calculations and relevant values will aid in a better assessment of the optical safety of a given situation. It will also be of benefit to understand the significance of power and energy values based on the laser emission type and manufacturing data provided. This section will assist in the calculating the values necessary for choosing the correct safety laser safety googles. It is also the information that may be asked by a supplier if purchasing new laser safety googles. Lasers emit beams in either continuous or pulsed mode, depending on whether the power output is continuous over time, termed continuous wave (CW), or whether its output takes the form of pulses of light with durations in the millisecond to femtosecond range. All of the lasers in the Department of Electronic Engineering are continuous wave lasers and the discussion below deals primarily with these types of lasers.

Power is the rate of change of energy per unit time, the unit of power is *joules per second* (J/s), known as the *Watt.* The optical output of a pulsed-laser is stated as the average power (P_{AVG}) and for a CW laser it is constant power (P) which typically ranges from several milliwatts (mW) to Watts (W).

Consider a HeNe CW laser with a constant output of 10mW; the energy of the output beam over a duration of quarter of a second can be calculated as follow. Power is the rate of change of energy so we only need to multiply the power by time to find the energy. $Q = 10mW \times 0.25s = 2.5mJ$

A10.2.2 Irradiance and Radiant Exposure

The previous section dealt with the basic quantities of power and energy, and their relationship in regards to laser systems. When considering the interaction of this power and energy with materials, especially in regards to biological tissues, and safety, the surface area over which the radiation is distributed is important. When a laser beam's power is focused to a relatively small spot this will increase the optical power density incident on a material surface, which will lead to more energy being absorbed per unit area within the beam profile than if the beam is spread over a greater area.

We have already discussed *Irradiance* which is the radiant power per unit area, (W/cm^2) and normally used for continuous wave lasers but it is also important to understand *radiant exposure,* energy per unit area, (J/cm^2).

Calculating irradiance and radiant exposure is important when choosing safety laser safety googles and to do so you will need to know, the smallest accessible beam diameter and divergence. These values may well be stated by the laser manufacturer but if this data is not available, or the beam is altered by optical components, it may be necessary to make the measurement in compliance with standard conventions.

A10.2.2.1 Beam Divergence

To calculate irradiance and radiant exposure at a point we need to know the radius of the laser at that point. Although laser beams can be highly collimated there is always some divergence which will affect the radius of the laser over distance, and thus change the optical power density. As the beam propagates through free space it will spread out by a constant amount if it does not pass through any optical components.

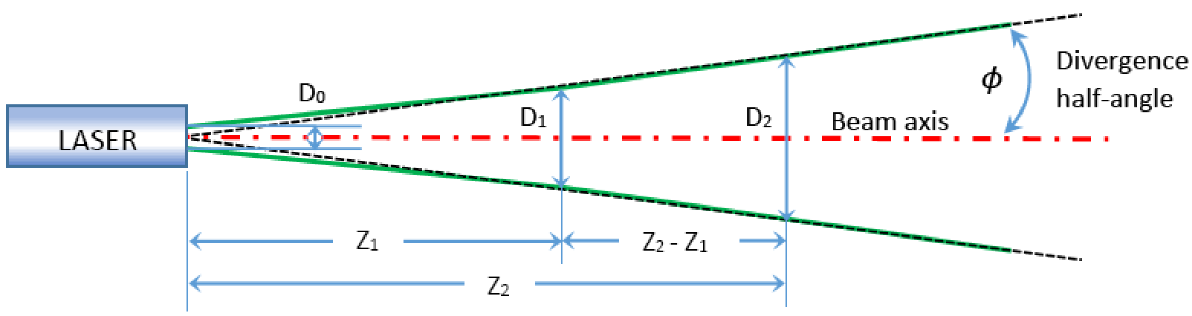


Fig. A10.2 Illustration of laser beam divergence.

Laser beam divergence is normally measured in milliradians (mrad). If the divergence is not stated by the manufacturer, or if it has changed due to the introduction of optical components, it can be measured by evaluating the diameter of the beam at two different points along the beam axis. Divergence is the half angle from the beam axis to the outer edge of the beam. The full divergence, angle (2ϕ) of the beam can be calculated using the simple trigonometric small angle approximation.

$$2\phi = \frac{D_2 - D_1}{z_2 - z_1}$$

Typically the divergence half-angle is what is quoted, and this can be calculated using the above formula, and replacing D_1 and D_2 with the equivalent radii respectively. If the beam divergence is being measured where an optical component such as a focusing lens is being used then the radius should be measured from the focus of the component where the beam is at its narrowest, this point is also termed the *beam waste*. For elliptical and rectangular beams the measurement should be made using the average of the two axes.

A10.2.2.2 Profile of the Beam

To simplify safety calculations a *Top Hat* profile for the beam is often used which assumes that the irradiance is constant across the beam profile. This is not always true and typically the most common profile for irradiance is Gaussian (sometimes called a TEM00 spatial mode), where the irradiance decreases gradually towards the edge of the beam, as shown the figure below.

There are two cut off points typically used to define the diameter or the radius of a laser beam. The first is the distance from the beam axis where the intensity would drop to $1/e^2$ (≈ 13.5%) of the maximum. This means an aperture of this equivalent diameter placed in the beam would pass approximately 86.5% of the maximum intensity. This value is typically used by the laser industry where an accurate power density value needs to be calculated for Gaussian beams and is defined as the D_{86} diameter.

For laser safety assessments the more commonly used criteria is that of the 1/e diameter. This is defined as the distance where approximately 36.8 % of the intensity is cut off, thus an aperture here would pass 63.2% of the total intensity and therefore is known as the D_{63} diameter. This criteria is used for testing filters for laser protection laser safety googles and windows, see European Standard for Laser Eye Protection.

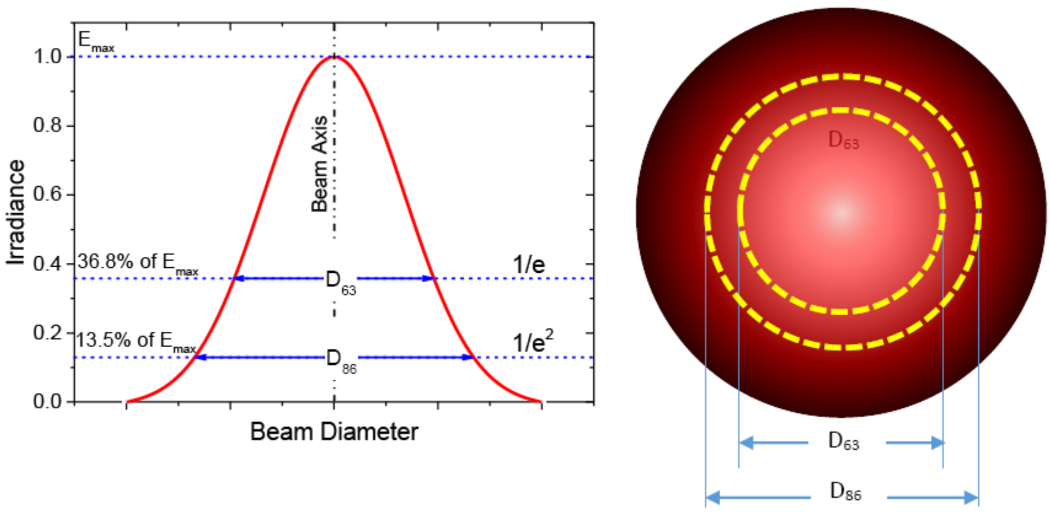


Figure A10.3 Normalised intensity profile of a laser beam showing the cut off points used to define the diameter.

It is important to note that not all lasers produce beams which fall into the above descriptions some are complex and are non-Gaussian, they are difficult to define as the profile can change with distance from the source. In these cases a generalised statistical approach is taken to assess the beam profile. Since no such lasers are present in the laser laboratory there is no further discussion.

To measure the physical parameters of the beam profile, there are a number of techniques available, these include, the use of a variable aperture or iris, a moving knife-edge or moving slit. Ideally a purpose built CCD camera with image analysis software is the most accurate system that can be employed for this purpose.

A10.3 Bioeffects of exposure to Laser Radiation

A10.3.1 The Anatomy of the Eye

The eye is the organ that is most sensitive to light and therefore the most susceptible to damage from laser light. The focusing mechanism of the eye, the cornea and lens combination produces an image on the light sensitive retina. The fovea is an area rich in light receptors (cones and rods) where an individual focuses with high resolution and produces the sharpest image typically used for perceiving detail, as in reading or object recognition. Approximately half of the nerve fibres in the optic nerve carry image information from the fovea.

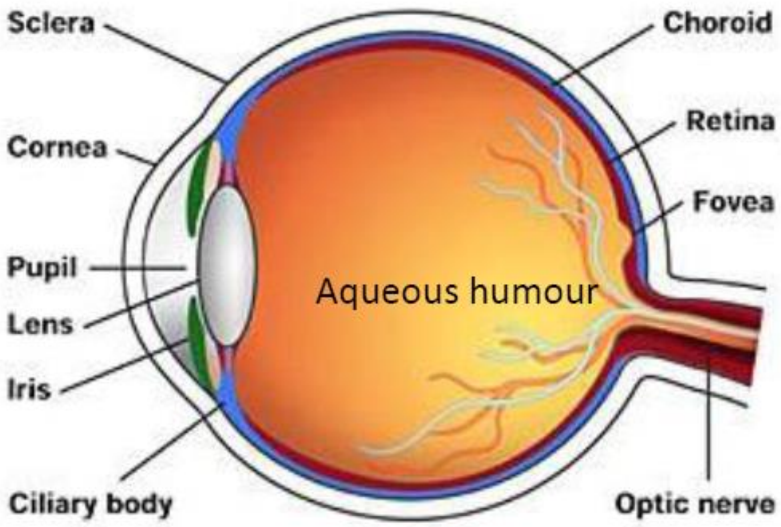


Fig. A10.4. Anatomy of the eye

Due to the focusing effect of the eye even a very low powered laser is a potential hazard. The eye can focus a beam in the wavelength range of 400-1400nm to a very small spot, approximately 10 to 20 micrometres in diameter. For example a 1-milliwatt beam produces a retinal irradiance value on the order of 1200 W/cm2. Direct viewing of the sun produces an irradiance at the retina of approximately 10 W/cm2 in comparison. If a laser burn is received to the fovea, a serious loss of vision may occur leading to an inability to see detail, effectively causing blindness. If a laser burn occurs in the rest of the retina it may cause damage, and an increase in the blind spot. The degree and location of damage in the eye caused is dependent on a number of factors of the beam including irradiance and wavelength.

A10.3.2 Wavelength Dependence

How and where the eye is damaged is dependent on the spectral transmission properties of the eye. The human eye only perceives a relatively narrow group of wavelengths, the *visual spectrum,* which ranges from about 390 to 700 nm. It is important to realise though that the eye can still transmit up to 1400nm. The significance of this is that laser light that is completely invisible to the human eye can still reach the retina.

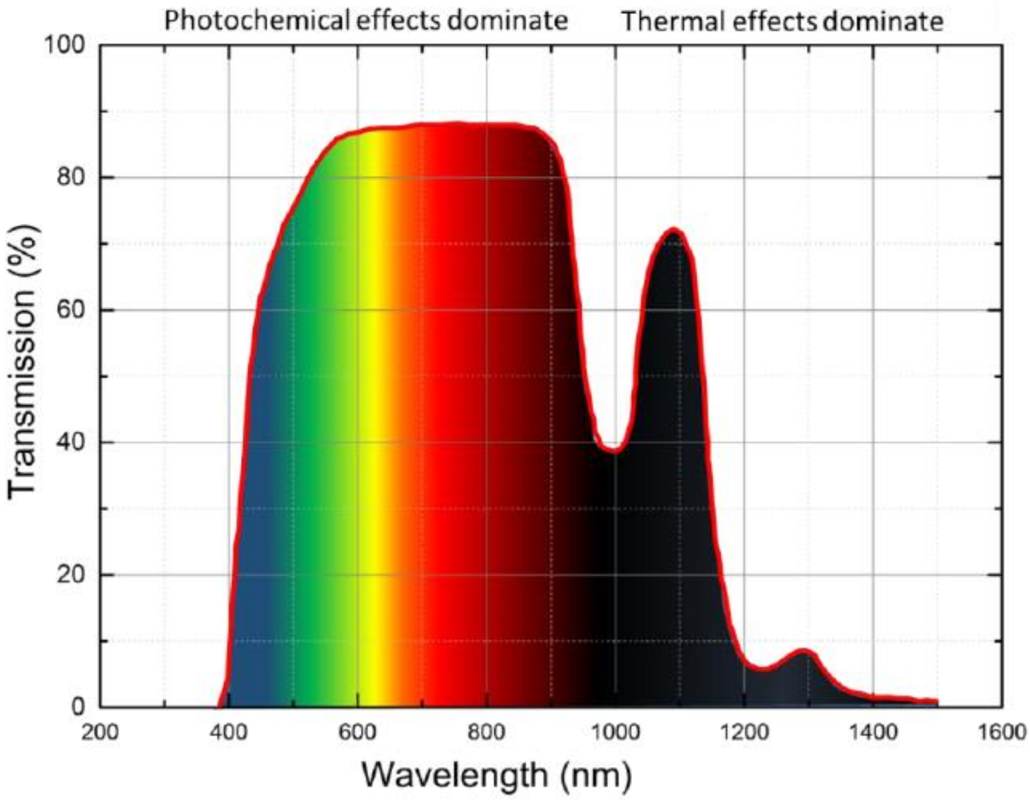


Fig. A10.5 Spectral transmission properties of the ocular media in front of retina

The above figure demonstrates the spectral transmittance dependence of the human eye in relation wavelength. In regards to damage caused by laser irradiance photochemical effects dominate towards the shorter wavelengths (higher frequencies), while towards the longer wavelengths thermal effects dominate. Different parts of the eye are more susceptible to injury from laser radiation at particular wavelengths than others, see Table A10.1.

The cornea can absorb all UV ranges from the mid-UV to the near-UV which can induce photokeratitis, also known as *welders flash.* This is a photochemical effect where a denaturisation of the proteins occurs. It is a painful eye condition but the cornea can repair itself over time without permanent damage. Medical care is necessary because if it is not treated an infection may occur. The symptoms include watering of the eyes, pain and discomfort likened to having sand in the eyes similar to conjunctivitis.

The near-UV range is also transmitted through the cornea to the lens, where induced photochemical effects in the lens that can result in cataracts, clouding of the lens, which leads to a decrease in vision. Normally this needs to be treated by surgery where the lens is removed and replaced with an artificial one.

The visible range is dangerous as the human eye has evolved to transmit this part of the electromagnetic spectrum, 400 nm to 700nm, through all the ocular parts as efficiently as possible on to the retina. **The blink reflex typically 0.25 seconds, can offer some protection in this range but**

only at relatively low irradiances. The focusing effects of the cornea and lens can lead to an increase in the irradiance by up to 100,000 times on the retina. Damage occurs to the retinal tissue by absorption of the light, and the induced photochemical on the receptors leading to long-term poor colour vision and night blindness. If the damage is at the fovea then the severe permanent visual impairment can occur.

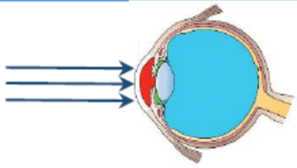
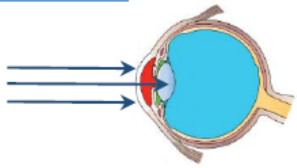
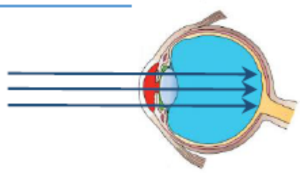
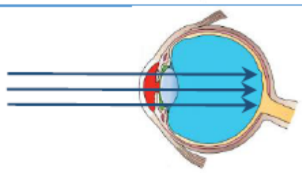
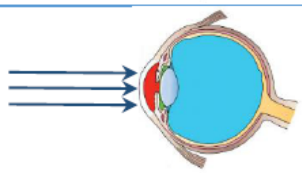
Wavelength Range		Area at Risk	
Mid UV UV B and UV C	180 – 315 nm	Cornea	
Near UV UV A	315 – 400 nm	Cornea - Lens	
Visible	400 – 700 nm	Retina	
Near IR	700 – 1400 nm	Retina	
Mid - Far IR	1400 nm – 1 mm	Cornea	

Table A10.1 Transmission through the eye and area at risk by wavelength range

The near IR can be particularly dangerous as the transmission properties of the eye result in the beam reaching the retina but as the light is not perceivable the natural blink reflex is not activated. As injuries to the retina are always serious the wavelength range 380nm to 1400nm is termed the *Retinal Hazard Region*. Wavelengths in the far infrared region, 1400nm to 1mm are still dangerous to the eyes, mainly the cornea where the natural moisture can absorb the energy resulting in injury through thermal effects. Excessive exposure to infrared radiation can result in a loss of transparency of the cornea.

A10.3.3 Symptoms of Laser Eye Injuries

- The exposure to a laser beam can sometimes be detected by a bright colour flash
- Photoacoustic retinal damage may be associated with an audible "pop" at the time of exposure. Visual disorientation due to retinal damage may not be apparent to the operator until considerable thermal damage has occurred.
- Minor corneal burns cause a gritty feeling, like sand, in the eye
- Obvious impairment to the vision

A10.3.4 The Skin

The outer layers of the skin, the epidermis and dermis are the most prone to laser beam injury of various wavelengths, see figure A10.6 below. The optical properties of the skin are strongly wavelength dependent, in the far UV the radiation is mainly absorbed by the top layer the stratum corneum. As the wavelength increases the penetration depth also increases up to the near infrared, where at 800nm a maximum is reached. With longer wavelengths the depth decreases with a wavelength dependence close to that of water. It is important to realise that at high power densities no matter the wavelength the penetration depth can be much greater. The damage mechanism may be acoustical as well as thermal causing serious injury. If lasers having the potential of causing injury to the skin are being used, adequate precautions must be taken.

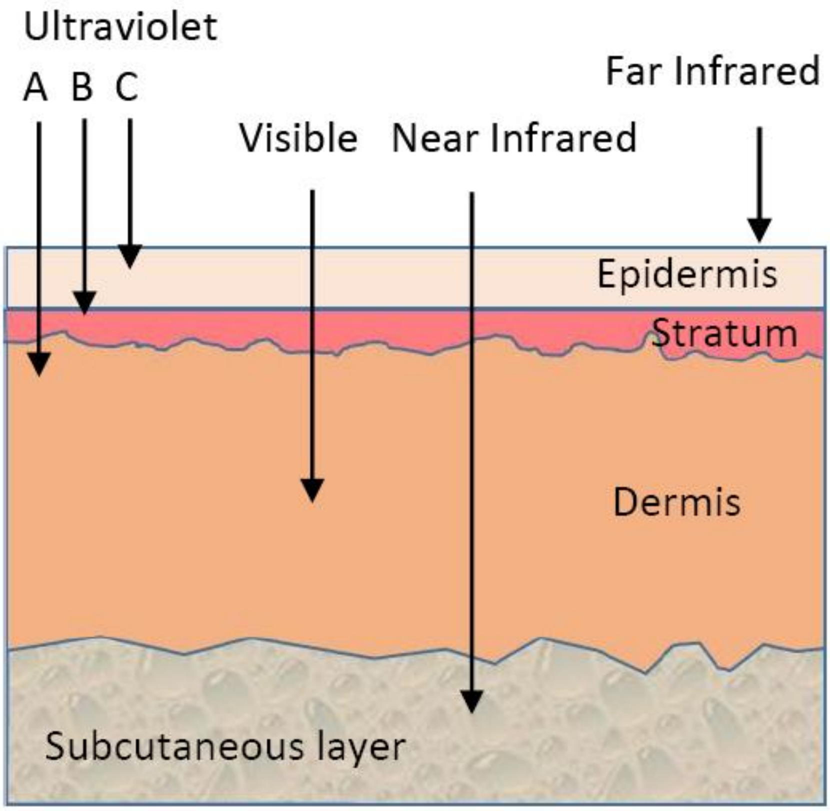


Fig. A10.6 Penetration depth dependence of the skin to different wavelengths

A10.3.3 Maximum Accessible Emission Limit (AEL)

AEL is the maximum accessible Emission limit of laser radiation permitted within a particular laser class. It is the primary measurement of a laser's hazard potential. For a particular class of laser the AEL is quoted as the *maximum irradiance* (W/cm^2) or *radiant exposure* (J/cm^2) that can be emitted in a *specified wavelength range,* and *exposure time,* at a *specified distance,* and known to cause a biological effect in a *target tissue*. It is not applicable to Class 4 lasers as no upper limit is set for this class. AELs are typically used for classifying lasers, which in most cases will be already specified by the manufacturer. The AELS are based on guidelines set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and are presented in Annex II of the European Directive 2006/25/EC. An example of an AEL value is that of a Class 2 laser device, if the average power is below 1 mW then the beam is not deemed hazardous under the Class 2 laser criteria. AELs are normally determined from the Maximum Permissible Exposure (MPE) and duration of exposure.

A10.3.4 Maximum Permissible Exposure (MPE)

Maximum Permissible Exposure is that level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE values as with the AELS are set by the ICNIRP. The Maximum Permissible Exposure values, MPEs are the values of the highest level of laser radiation which are considered safe, that is the laser power that a person may be exposed for a given exposure time without suffering immediate or long term adverse effects; usually 10% of the dose that has 50% chance of doing damage. The MPE is related to the AEL by the limiting aperture of the eye, see Appendix 9 for more details. The MPE is measured in irradiance (W/cm_2) and radiant exposure (J/cm_2). It depends on factors such as the:

- Wavelength
- Exposure time
- CW or pulsed laser
- Tissue at risk (or just eyes)
- Spatial distribution of the skin

The MPE is measured at the cornea of the human eye or at the skin, for a given wavelength and exposure time. The MPE for ocular exposure takes into account the various ways laser light can affect the various parts of the eye. For example, ultraviolet light can cause cumulative damage, even at very low powers. Infrared light on the other hand with wavelengths longer than 1400 nm is not transmitted through the eye to the retina, which means that the MPE for these wavelengths can be higher than for visible or near infra-red light. In addition to the wavelength and exposure time, the MPE takes into account the spatial distribution of the light. Collimated laser beams of visible and near-infrared light are especially dangerous at relatively low powers because the focusing capability of the eye will create a tiny spot in the order of microns on the retina, increasing the power density dramatically.

When a laser emits radiation at several widely different wavelengths, or where pulses are superimposed upon a CW background, calculations of the MPE may be complex. Exposures from several wavelengths should be assumed to have an additive effect.

For completeness tables that assist in the calculation of MPEs are provided in Appendix 12.

A10.3.5 Nominal Hazard Zone (NHZ)

The *Nominal Hazard Zone* is the distance within which the irradiance, or radiant exposure, of the beam is greater than the maximum permissible exposure (MPE), i.e. the area around your laser system that is considered dangerous. It is also useful to understand the term *Nominal Ocular Hazard Distance* (NOHD) which is the distance from the output aperture of the laser at which the beam irradiance or radiant exposure equals the appropriate MPE. If the NOHD includes the possibility of viewing through optical aids, this is termed the "extended NOHD (ENOHD)".

APPENDIX 11

How to Select Laser Safety Goggles

Whenever complete beam containment is not an option and there is a risk of exposure to levels above the MPE, personal eye protection must be worn. Laser eye protection comes in two types, full attenuation and alignment. The full attenuation type is completely opaque to the beam while the alignment allows a small percentage of the beam in the visible wavelength region to be transmitted so that it can be seen for alignment purposes. Typically the beam is visible at its termination point or where it scatters off dust particles in the ambient air.

A11.1 Full Attenuation

With Class 3B or 4 laser systems, where there is a danger of exposure to limits above the MPE, full attenuation eye protection must be worn in the UV wavelength region of 190 to 380 nm and in the NIR region of 700 to 1400nm. It should be worn also in the mid to far IR also. All these regions are in the nonvisible wavelengths therefore there is no advantage to wearing the alignment eyewear. If viewing of the beam is not required in the visible region, 400 to 700 nm, then full attenuation eyewear should also be worn. Risk should always be minimised to the lowest possible.

A11.2 Visual Light Transmission and Fit

VLT is the percentage of visible light transmitted through a filter, calculated against the spectral sensitivity of the eye to daylight. A high VLT is preferred. A VLT of 35% is recommended and any VLT below 20% should always be used in a well-illuminated environment. Comfort and fit should be considered but also the eyewear should be comfortably wearable with prescription glasses underneath without compromising the level of protection.

A11.3 Optical Density

Protective laser safety googles is made possible with the use of filters that can transmit or attenuate a particular wavelength of light, partially or completely. The *Optical Density* (OD) of a filter is a measure of this attenuation. It is a logarithmic ratio of the light incident upon the filter, to the light transmitted through the filter. The required OD for a particular laser can be chosen, using the following equation, when the Maximum Permissible Exposure (*MPE*) is known as well as the anticipated worst case radiant exposure that the living tissue could be exposed to without protection (H_0) from the laser.

$$OD = log_{10}[H_0/MPE]$$

The units are in J/cm^2 for pulsed laser systems and in W/cm^2 for CW systems for both parameters. See Annex 9 for more details on both MPE and AEL. The potential maximum exposure H_0 can be calculated directly from the laser beam itself and the full power value must be used even if beam attenuators are applied. Simply put, the OD scale factor of the eye protection must be based on the maximum output power or energy density from the laser that a user could be exposed to. The OD scale represents the attenuation factor or inversely the transmission, of the filters, see Table 8-1, but it only indicates how much or how little light is transmitted through a filter at a particular wavelength. It does not account for the damage threshold of the filter material.

Attenuation (H_0 / MPE)	T	Scale factor OD
10	10^{-1}	1
100	10^{-2}	2
1000	10^{-3}	3
10000	10^{-4}	4
100000	10^{-5}	5
1000000	10^{-6}	6
10000000	10^{-7}	7

Table A11.1 Attenuation factor and OD scale

Consider an ocular MPE ≈ 1mW and a filter OD = 6 it may be wrongly assumed that the laser safety googles protects against 1mW x10^6 = 1kW, but the material may be easily destroyed when placed in the beam, and offer little or no protection. The frame in which the filters are mounted must also be considered if this material may has a low damage threshold. The European standard EN207:2010 takes into account the damage threshold of the filter material and the frame. Both should be able to withstand a direct hit of laser radiation of specified power/energy and duration.

A11.4 European Standard for Laser Eye Protection

All products sold in the European Union must be CE marked, (Conformité Européenne) where a relevant European Directive exists. The European standard for full attenuation laser safety laser safety googles is EN207 and for alignment is EN208. This was first issued in 1998 and then modified in 2010. Table A11.2 demonstrates the main differences after the modification.

EN207	Beam Diameter D63*	Exposure time	Labelling
1998	2mm	10s or 100 pulses	L
2010	1mm	5s or 50 pulses	LB

Table A11.2 European standard EN207, *D63 diameter is when 63.2% of the total power is contained in a variable aperture, see section A10.2.2.2.

Ultra short pulse laser radiation can induce nonlinear processes in the filter material used to protect the eye. This interaction of the light with the material can lead to a momentary increase of the transmission when the material is irradiated with short, high-energy laser pulses. If improper eye protection, with inappropriate filters, is worn transmitted radiation may cause serious injury to the eyes.

The LB rating specifies damage threshold of the filter material at maximum power or energy density. The filter material and frame must be able to withstand a direct hit for a period of > 5 seconds in CW mode or for 50 pulses. This LB scale number should give reasonable comparability between similar laser safety products from different manufacturers also. Testing shall always be done at least for 5 s, but in the case of pulsed operation never with less than 50 pulses.

The other standard EN208 applies to visible lasers only, in the 400 - 700 nm wavelength range and is used for alignment laser safety googles only where it is necessary to be able to see the beam for purposes of setting up and aligning. It effectively reduces the AEL, maximum accessible emission limit of the laser to that of CLASS 2. Alignment glasses are not intended for direct intrabeam viewing of the laser, rather for diffuse, indirect viewing. When using this level of protection the hazard is reduced to below the Class 2 safety limit. If the diameter of the laser is considerably large, then the selection can be based on the fraction of the power that would pass through a 7mm aperture. It uses the R rating under the 1998 standard but now uses the RB rating, B showing the difference in the same way as LB.

After testing to EN 207 or EN208 standards the laser protective laser safety googles are labelled to specify the maximum power and energy densities which the laser safety googles can protect against at different wavelengths.

A11.5 Labelling

All laser protection laser safety googles must be appropriately labelled so that the user can identify that the protection level provided is appropriate for the laser they intend to use. Being able to read the labels and making that decision is imperative to protecting your eyes.

Wavelength (nm)	Laser Type (DIRM)	Protection level	Manufacturing code	Compliance	EC type approval	Mechanical robustness
900-1100	D	LB 10	LV	DIN	CE	S

Table A11.3 Typical labelling components of EN207 compliant laser eye protection.

The first part of a label is normally the wavelength range that the eye protection is functioning for. The second part displays the code letter for different laser emission pulse lengths that the laser safety googles protects against in this wavelength range, see table A11.4.

CODE	Emission type
D	Continuous wave (>0.25s)
I	Long Pulse (1µs to 0.25s)
R	Q-switched Short Pulse (1ns to 1µs)
M	Mode locked Ultra short pulse (< 1ns)

Table A11.4 Codes used for laser emission pulse length

The letter D is used for continuous outputs, CW, where the emission length is greater than 0.25 seconds in duration. The Letter I indicates the pulse range from the 0.25 seconds to 1 microsecond and *R* is for lasers with pulses in the microsecond to the 1 nanosecond range. The last letter M indicates a pulse duration of less than a nanosecond down to the femtosecond and potentially the attosecond range.

Next on the label we can see the LB scale number, in this case 10. This indicates that the laser laser safety googles will offer a protection level with the attenuation factor of x1010 for the wavelength range stated. The Optical Density of the filter material is implicit in the code LB10 and is equal to the numerical value. The LB part, as stated before is the European standard, EN207, for testing the damage threshold. LV is the manufacturing code, DIN is a compliance code you may or may not see "Deutsches Institut für Normung", meaning "German institute for standardisation. The CE mark must be displayed on the laser safety googles to indicate compliance with the European standards. The letter S may also be present to indicate "Increased robustness" of both the frame and filters.

The label shown in figure below is typical of those found on protection laser safety googles compliant with EN207.

The R14T1Q021001 is a manufacturing code that includes the type of frame as well as the filter. The frame has to be able to tolerate the beam power as well as the filter. The CE mark is visible in the top left.

We can see that for different wavelength ranges and pulse widths the laser safety googles has different protection levels. Taking a sample range in the visible region, 690-755 D LB7 +IRM LB8 (OD8+). We know that in the wavelength range 690 to 755nm the laser safety googles will offer protection of LB7 for lasers with pulses greater than 0.25 seconds, (D), and for pulses shorter than this (IRM) it will offer protection of LB8. The highest optical density (OD) of 8 in this range is also indicated in brackets for completeness. The last line on this label shows that the laser safety googles can be used to provide alignment protection of RB3 for the wavelength 633nm up to 1 Watt of power or 2 x 10-4 Joules.

Power (E) and Energy Density (H) in specified wavelength Range and for Pulse duration										
EN207		180 -315 nm			315 -1400 nm			1400 nm -1000 µm		
		E W/m^2	H J/m^2	E W/m^2	E W/m^2	H J/m^2	H J/m^2	E W/m^2	H J/m^2	E W/m^2
		Pulse duration in seconds								
		D	**I,R**	**M**	**D**	**I,R**	**M**	**D**	**I,R**	**M**
		$\geq 3x10^{-4}$	10^{-9} to $3x10^{-4}$	$< 10^{-9}$	$\geq 5x10^{-4}$	10^{-9} to $5x10^{-4}$	$< 10^{-9}$	≥ 0.1	10^{-9} to 0.1	$< 10^{-9}$
LB1	10^{-1}	0.01	$3x10^{2}$	$3x10^{11}$	10^{2}	0.05	$1.5x10^{-3}$	10^{4}	10^{3}	10^{12}
LB2	10^{-2}	0.1	$3x10^{3}$	$3x10^{12}$	10^{3}	0.5	$1.5x10^{-2}$	10^{5}	10^{4}	10^{13}
LB3	10^{-3}	1	$3x10^{4}$	$3x10^{13}$	10^{4}	5	0.15	10^{6}	10^{5}	10^{14}
LB4	10^{-4}	10	$3x10^{5}$	$3x10^{14}$	10^{5}	50	1.5	10^{7}	10^{6}	10^{15}
LB5	10^{-5}	10^{2}	$3x10^{6}$	$3x10^{15}$	10^{6}	$5x10^{2}$	15	10^{8}	10^{7}	10^{16}
LB6	10^{-6}	10^{3}	$3x10^{7}$	$3x10^{16}$	10^{7}	$5x10^{3}$	$1.5x10^{2}$	10^{9}	10^{8}	10^{17}
LB7	10^{-7}	10^{4}	$3x10^{8}$	$3x10^{17}$	10^{8}	$5x10^{4}$	$1.5x10^{3}$	10^{10}	10^{9}	10^{18}
LB8	10^{-8}	10^{5}	$3x10^{9}$	$3x10^{18}$	10^{9}	$5x10^{5}$	$1.5x10^{4}$	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^{6}	$3x10^{10}$	$3x10^{19}$	10^{10}	$5x10^{6}$	$1.5x10^{5}$	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^{7}	$3x10^{11}$	$3x10^{20}$	10^{11}	$5x10^{7}$	$1.5x10^{6}$	10^{13}	10^{12}	10^{21}

Table A11.5 Full attenuation protection levels according to EN 207

Power (E) and Energy Density (H) Continuous Wave and for Pulse duration				
EN208	Spectral Transmission T		CW and Pulsed lasers with a pulse duration of $\geq 2 \times 10^{-4}$ s	Pulsed lasers with a pulse duration of $>10^{-9}$ s to 2×10^{-4} s
Scale	**Filter**	**Frame Structure**	**Maximum Power in W**	**Maximum Energy in J**
RB1	10^{-1}	10^{-1}	0.01	2×10^{-6}
RB2	10^{-2}	10^{-2}	0.1	2×10^{-5}
RB3	10^{-3}	10^{-3}	1	2×10^{-4}
RB4	10^{-4}	10^{-4}	10	2×10^{-3}
RB5	10^{-5}	10^{-5}	100	2×10^{-2}

Table A11.6 Alignment protection for visible wavelength levels according to EN 208

A11.6 Choosing Protection Laser safety googles for a CW Laser

Using EN207 and EN208 in most cases we do not need to worry about calculating the MPEs because this has already been taken account of in the maximum power / energy densities specified for each LB or R number. Once we know the emission type and the power or energy for which the person(s) could be exposed to we can calculate which protection level is required from the EN207 and EN 208 charts above.

It is important that you know how to choose and check the laser eye protection you are required to wear for the laser system you are using. Do not rely on your colleagues to provide you with the correct information you must be proficient in calculating and choosing the correct protection level for yourself.

We have discussed the protection level indicated by the scale numbers found on laser safety googles and its meaning but how do you decide what level of protection is appropriate for the system you are using? The simplest way to do this is to go through a number of examples using the charts provided for the EN207 and EN208 standards.

Before calculating the correct laser safety googles there are some fundamental parameters of the laser you will be required to know. For Continuous wave lasers you will need to know the wavelength in nanometres (nm), the laser power in Watts (W); and the smallest beam diameter in meters (m) that you may be exposed to. The steps required to calculate the LB and RB scale number for a CW laser are as follows:

1. Calculate the cross-sectional area of the laser beam.
2. Calculate the power density of the beam by dividing the power by the area of the beam.

3. Refer to table 8-5 Full attenuation protection levels according to EN 207.
4. Select the column corresponding to the wavelength range of your laser, either 180-315nm, >315-1400nm or >1400-10000nm.
5. Then select the column in that wavelength range for the type of laser, Continuous Wave (CW), denoted with the code D for long pulse.
6. Finally, choose the first scale number which is equal to or higher than the power density of your laser, always round up not down for the protection levels.
7. For alignment protection according to EN208 there is a further requirement when calculating the alignment protection level if the beam diameter is greater than 7mm then a 7mm aperture is required to calculate the proportion of the beam power that will pass through.

A11.6.1 Example 1 Full attenuation

In the first example let us consider a 10 Watt continuous wave (CW) laser, with a single wavelength of 1064nm and a beam diameter of 4mm. The wavelength is not in the visible region so we will use full attenuation protection according to EN207 standards.

We assume in this case that the beam divergence is not significant and the power density will be consistent along the beam to final termination. The beam will typically have a *Gaussian profile,* for safety calculations we would use the 1/e diameter. For these calculations we assume a *Top-hat* profile for the beam where the energy and power density is constant across the transverse beam profile.

We can calculate the area of the beam using the area of a circle formula, πr^2. We need to remember that the power density is quoted in Watts per meter squared in the EN207 chart, so we must convert our lengths to meters to calculate the right power density value. The beam area is thus calculated to be approximately 1.3×10^{-5} m^2.

Dividing the power of 10W now by this value gives us the power density of approximately $8 \times 10_5$ W/m_2. Looking at the EN207 chart shown in Table 8-5 we can see that the wavelength of our laser, 1064nm falls in the range of 315 -1400 nm. Our laser is continuous wave which implies a pulse duration of greater than 0.25 seconds so it comes under the D code. The power density we calculated is 8×10^5 W/m^2, so we round up to the higher order of 10^6 to be sure we have the protection required. From here we can read across to the right and see that the level of protection required is LB5.

Now let’s check the label of the sample laser safety googles in figure 9-7. We can see that this laser safety googles will afford a level of protection of LB7 greater than the LB5 required, for a CW laser (D) with the wavelength of 1062nm thus we can use this set for this laser and know our eyes are well protected.

A11.6.2 Example 2 Alignment protection

Here we need to set up an experiment using a laser that produces a CW power of 5 Watts at 532nm (green) with a beam diameter of 2mm. We need to align optical components and need to see the beam for this purpose. We are unable to reduce the power effectively below a class 2 system so we decide to use alignment protection laser safety googles adhering to standard EN208. With reference to the Table A11.6 of scale numbers given in EN 208, 5W falls between R3 and R4, so you must choose R4 as the lowest scale number that provides the required protection level for the power of this laser. An OD, optical density of 4 is implicit in the scale number, which in turn means that if the full 5W from this laser hit the alignment protection laser safety googles, the power that would be transmitted through the filter would be 5 x 1/10,000 which equals 5 x 10^{-4} Watts or 0.5mW. This power is below the maximum permissible exposure (MPE) level for a class 2 laser which means that the eye would be protected by its inherent blink reflex while the beam remains visible.

A11.7 Purchasing Laser safety googles

You may find yourself in a position where you are either involved in the setup of a new laser system where there is no laser safety googles currently available in your laboratory or that you have found that the laser safety googles is not compliant for the system in use. If this is the case you will need to purchase the laser safety googles required for the laser system and the one or more wavelengths that will present the risk to personnel.

Typically if when you contact a supplier they will require some detailed information about you laser set up so that they can choose the correct laser safety googles to comply with EN207 and EN208. It is important that you use a company that works with these European standards and supply certified laser safety googles with the CE marking.

They will request details on:

- Laser Wavelength
- Max average power
- Smallest beam diameter
- Beam Divergence
- Pulse energy, duration and repetition rate for pulsed lasers

Some of this information you can get from the laser specifications given in the corresponding manual. They may also ask for the laser make and model to further help your decision. If you are choosing a pair for a single wavelength the process is relatively trivial but if there are multiple wavelengths to consider then your decision will be more complex as you have to decide on the range of wavelengths which will be covered and the visibility. This will inferably affect price and quantity.

In addition to its optical protection level it is vital that safety laser safety googles is comfortable to wear, the laser safety googles should therefore fit properly. It should also be able to fit over spectacles if necessary and not unduly restrict normal vision. Poorly fitting laser safety googles not only performs badly but the likelihood of it being used is also diminished.

A company may present you with more than one choice for your application therefore it is important to understand the different aspects of a set of eye protection to consider. In Table 8-7 an example of the information you would be faced with if you are looking through a catalogue, source http://www.uvex-laservision.de/

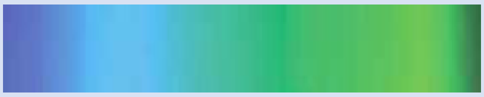
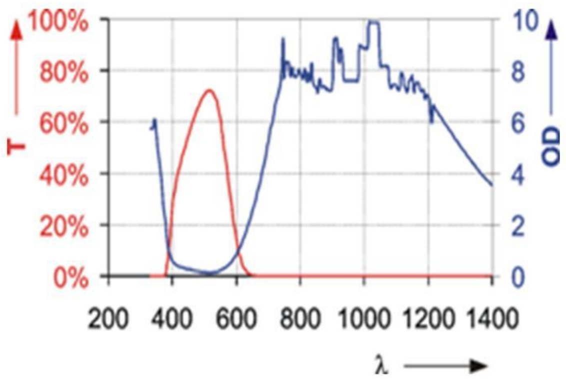
Filter	T1Q03
Type	Alignment & Full Protection
Colour	light green
Filter Material	Mineral glass
Filter Technology	Absorption Filter
Certification	CE
Visible Light Transmission	Approx. 45 %
Visual Brightness	good
Colour View	good
Filter Thickness	approx. 4 mm*
spectrum through the filter 	spectrum without filter 

Table A11.7: typical data presented when purchasing eye protection

The data presented here shows that the filter colour is green, the filters are certified and the visual brightness is good with approximately 45% transmission of the visual spectrum. This is quite good but you will find if one pair of glasses covers a large range of wavelengths especially in the visible range the visibility can decrease to the point where the user may find it difficult to work with them. Here a second pair to cover a narrower range should be considered as it will help to increase the visibility and thus the user will be able to work more safely. If the visibility is reduced to below 20% the user should ensure that there is additional illumination in the working environment to compensate. The information presented in Table A11.7 does not give you specific values for the transmission of the eye protection filter. For these specifications for the filter may be represented graphically as transmission and optical density as in the figure to the left.



We can see that the OD is approximately 8 over the wavelength range of 700nm to 1100nm without significant fall off. We can also see that the transmission is good across 400nm to 600nm, the visible region with a peak at approximately 500nm. Depending on our requirements we can see at a glance the ability of this filter to absorb light of a particular wavelength. To better help us to choose the correct European standard LB or alignment RB scale number for the wavelengths we require protection for specific information will be available. Below in Table A11.8 the specifications for each wavelength range the eye protection is intended to be used for is presented.

	ANSI Standard Frame			Reinforced Frame	
Frame	**OD**	**PROTECTOR**	**ECO**	**PROTECTOR**	**ALL STAR**
Part Number		F14.T1Q03	R01.T1Q03	R14.T1Q03	R17.T1Q03
750 - 800	8+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IRM LB8	D LB6 + IRM LB8
>800 - 1000	9+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IR LB8 + M LB9Y	D LB6 + IR LB8 + M LB9Y
>1000 - 1064	9+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IR LB8 + M LB9	D LB6 + IR LB8 + M LB9
>1064 - 1100	8+	D LB5 + I LB7 + R LB6	D LB6 + IRM LB8	D LB6 + IRM LB8	D LB6 + IRM LB8
10600	4+	DI LB2	D LB3 + I LB4	D LB3 + I LB4	D LB3 + I LB4
633	1-2	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1	0,01W 2x10E-6J RB1

Table A11.8 specifications for eye protection adhering to En207 and EN208

Taking an example, on the 3rd row and 5th column we can find that theses filters when fitted to the protector frame that at 750nm to 800nm the protection level provided is D LB6 and IRM LB8. You can see that the protection level is not consistent across all frame types, this is due to the material and the design. Some glasses are like normal glasses but for higher powered systems the laser safety googles is more goggle like covering the peripheral sides of the eyes also.

A11.8 Curtains

APPENDIX 12

Maximum Permissible Exposure Limits (MPE)

Using EN207 and EN208 in most cases we do not need to worry about calculating the MPEs because this has already been taken account of in the maximum power / energy densities specified for each LB or R number. Once we know the emission type and the power or energy for which the person(s) could be exposed to we can calculate which protection level is required from the EN207 and EN 208 charts below respectively. This Appendix on MPE is provided for reference.

Accessible emission limits (AELs) are generally derived from the maximum permissible exposures (MPEs). MPEs have been included in this informative annex to provide manufacturers with additional information that can assist in evaluating the safety aspects related to the intended use of their product (such as the determination of the Nominal Ocular Hazard Distance, NOHD).
NOTE: Simplified calculations may significantly underestimate the NOHD. For example, when the laser aperture is inside of a large Raleigh range, when there is an external beam waist, or when the beam profile is such that the power that passes through an aperture is underestimated when a Gaussian beam profile is assumed. In such cases, it is usually advantageous to determine the NOHD by measurements.

Maximum permissible exposure values as contained in this part of IEC 60825 are adopted from exposure limit values published by International Commission on Non-Ionizing Radiation Protection. MPE values are set below known hazard levels and are based on the best available information from experimental studies. The MPE values should be used as guides in the control of exposures, for the safe design of a product and as basis for providing user information, and should not be regarded as precisely defined dividing lines between safe and dangerous levels. In any case, exposure to laser radiation should be as low as possible. The MPEs that are given in this informative annex are informative, and should not be interpreted as legally-binding limits for the exposure of employees at the workplace or of the general public. Exposure limits for the eye and the skin of employees at the workplace and the general public are in many countries specified in national laws. These exposure limits might be different to the MPEs given in this annex. Exposures from several wavelengths should be assumed to have an additive effect on a proportional basis of spectral effectiveness according to the MPEs of Tables A.1, A.2, A.3, A.4, and A.5 provided that the spectral regions are shown as additive by the symbols (o) for ocular and (s) for skin exposure in the matrix of Table 1. Where the wavelengths radiated are not shown as additive, the hazards should be assessed separately

An appropriate aperture should be used for all measurements and calculations of exposure values. This is the limiting aperture and is defined in terms of the diameter of a circular area over which the irradiance or radiant exposure is to be averaged. Values for the limiting apertures are shown in Table A.6. When the MPE values for the retinal hazard region expressed as power or energy are used (Table A.3 or Table A.4) the exposure value is to be expressed as power or energy and determined as power or energy passing through an aperture with a diameter of 7 mm. For repetitively pulsed laser exposures within the spectral range between 1 400 nm and 105 nm, the 1 mm aperture is used for evaluating the hazard from an individual pulse; whereas the 3,5 mm aperture is applied for evaluating the MPE applicable for exposures greater than 10 s. The values of ocular exposures in the wavelength range 400 nm to 1 400 nm are measured over a 7 mm diameter aperture (pupil). The MPE shall not be adjusted to take into account smaller pupil diameters.

These graphs require addional information available in the references mentioned above.

Table A.1 – Maximum permissible exposure (MPE) for $C_6 = 1$ at the cornea expressed as irradiance or radiant exposure [a, b]

Wavelength λ nm	Exposure time t s								
	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 5×10^{-6}	5×10^{-6} to 13×10^{-6}	13×10^{-6} to 1×10^{-3}	1×10^{-3} to 10	10 to 10^2	10^2 to 3×10^4
180 to 302,5	3×10^{10} W·m^{-2}		30 J·m^{-2}						
302,5 to 315			Thermal hazard [d] ($t \le T_1$) C_1 J·m^{-2} / Photochemical hazard [d] ($t > T_1$) C_2 J·m^{-2}					C_2 J·m^{-2}	
315 to 400			C_1 J·m^{-2}					10^4 J m^{-2}	
400 to 450	1×10^{-3} J·m^{-2}	2×10^{-3} J·m^{-2}			18 $t^{0,75}$ J·m^{-2}			100 J·m^{-2}	C_3 W·m^{-2}
450 to 500								100 C_3 J·m^{-2} and [c] 10 W·m^{-2}	
500 to 700								10 W·m^{-2}	
700 to 1 050	1×10^{-3} J·m^{-2}	2×10^{-3} C_4 J·m^{-2}			18 $t^{0,75}$ C_4 J·m^{-2}			10 C_4 C_7 W·m^{-2}	
1 050 to 1 400[e]	1×10^{-3} C_7 J·m^{-2}	2×10^{-2} C_7 J·m^{-2}				90 $t^{0,75}$ C_7 J·m^{-2}			
1 400 to 1 500	10^{12} W·m^{-2}		10^3 J·m^{-2}				5 600 $t^{0,25}$ J·m^{-2}	1 000 W·m^{-2}	
1 500 to 1 800	10^{13} W·m^{-2}		10^4 J·m^{-2}						
1 800 to 2 600	10^{12} W·m^{-2}		10^3 J·m^{-2}				5 600 $t^{0,25}$ J·m^{-2}		
2 600 to 10^6	10^{11} W·m^{-2}		100 J·m^{-2}	5 600 $t^{0,25}$ J·m^{-2}					

[a] For correction factors and units, see Table 9; the exposure level that is compared with the MPE values is to be averaged over the appropriate aperture (Table A.6).

[b] The MPEs for exposure durations below 10^{-9} s and for wavelengths less than 400 nm and greater than 1 400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure shall not exceed either limit applicable.

[d] For repetitively pulsed UV lasers neither limit should be exceeded.

[e] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

Table A.2 – Maximum permissible exposure (MPE) at the cornea for extended sources in the wavelength range from 400 nm to 1 400 nm (retinal hazard region) expressed as irradiance or radiant exposure[d]

Wavelength λ nm	Exposure time t s						
	10^{-13} to 10^{-11}	10^{-11} to $5,0 \times 10^{-6}$	$5,0 \times 10^{-6}$ to $1,3 \times 10^{-5}$	$1,3 \times 10^{-5}$ to 10	10 to 10^2	10^2 to 10^4	10^4 to 3×10^4
400 to 700	1×10^{-3} C_6 J·m^{-2}	2×10^{-3} C_6 J·m^{-2}	18 $t^{0,75}$ C_6 J·m^{-2}		400 nm to 600 nm – Retinal photochemical hazard [a]		
					100 C_3 J·m^{-2} using γ_{ph} = 11 mrad	1 C_3 W·m^{-2} using γ_{ph} = 1,1 $t^{0,5}$ mrad	1 C_3 W·m^{-2} using γ_{ph} = 110 mrad
					AND [b]		
					400 nm to 700 nm – Retinal thermal hazard		
					($t \le T_2$) 18 $t^{0,75}$ C_6 J·m^{-2} / 18 C_6 $T_2^{-0,25}$ W·m^{-2} ($t > T_2$)		
700 to 1 050	1×10^{-3} C_6 J·m^{-2}	2×10^{-3} C_4 C_6 J·m^{-2}	18 $t^{0,75}$ C_4 C_6 J·m^{-2}		($t \le T_2$) 18 $t^{0,75}$ C_4 C_6 J·m^{-2} / 18 C_4 C_6 $T_2^{-0,25}$ W·m^{-2} ($t > T_2$)		
1 050 to 1 400[c]	1×10^{-3} C_6 C_7 J·m^{-2}	2×10^{-2} C_6 C_7 J·m^{-2}		90 $t^{0,75}$ C_6 C_7 J·m^{-2}	($t \le T_2$) 90 $t^{0,75}$ C_6 C_7 J·m^{-2} / 90 C_6 C_7 $T_2^{-0,25}$ W·m^{-2} ($t > T_2$)		

NOTE Exposure limits for some ocular tissues may be different for ophthalmic instruments – see ISO 15004-2.

[a] The angle γ_{ph} is the limiting measurement angle of acceptance.

[b] In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally, photochemical hazard limits only apply for exposure durations greater than 10 s; however, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of 100 C_3 J·m^{-2} should be applied for exposures greater than or equal to 1 s.

[c] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

[d] For exposure durations less than 0,25 s, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.

Table A.3 – Maximum permissible exposure (MPE) of Table A.1 ($C_6 = 1$) for the wavelength range from 400 nm to 1 400 nm expressed as power or energy [a, b]

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="6">Emission duration t
s</th></tr>
<tr><th>10^{-13} to
10^{-11}</th><th>10^{-11} to
5×10^{-6}</th><th>5×10^{-6} to
13×10^{-6}</th><th>13×10^{-6} to
10</th><th>10 to
10^{2}</th><th>10^{2} to
3×10^{4}</th></tr>
<tr><td>400 to 450</td><td rowspan="3">$3{,}8 \times 10^{-8}$ J</td><td rowspan="3">$7{,}7 \times 10^{-8}$ J</td><td colspan="2" rowspan="3">$7 \times 10^{-4}\ t^{0{,}75}$ J</td><td>$3{,}9 \times 10^{-3}$ J</td><td rowspan="2">$3{,}9 \times 10^{-5}\ C_3$ W</td></tr>
<tr><td>450 to 500</td><td>$3{,}9 \times 10^{-3}\ C_3$ J
and [c]
$3{,}9 \times 10^{-4}$ W</td></tr>
<tr><td>500 to 700</td><td colspan="2">$3{,}9 \times 10^{-4}$ W</td></tr>
<tr><td>700 to 1 050</td><td>$3{,}8 \times 10^{-8}$ J</td><td>$7{,}7 \times 10^{-8}\ C_4$ J</td><td colspan="2">$7 \times 10^{-4}\ t^{0{,}75}\ C_4$ J</td><td colspan="2" rowspan="2">$3{,}9 \times 10^{-4}\ C_4\ C_7$ W</td></tr>
<tr><td>1 050 to 1 400 [d]</td><td>$3{,}8 \times 10^{-8}\ C_7$ J</td><td colspan="2">$7{,}7 \times 10^{-7}\ C_7$ J</td><td>$3{,}5 \times 10^{-3}\ t^{0{,}75}\ C_7$ J</td></tr>
<tr><td colspan="7">NOTE The exposure level to be compared with the MPE expressed as power or energy is to be determined as power or energy that passes through an aperture with a diameter of 7 mm (the MPE values expressed in this table are obtained from the values of Table A.1 by multiplication with the area of an aperture with 7 mm diameter)</td></tr>
<tr><td colspan="7">[a] For correction factors and units, see Table 9
[b] The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent power values of the MPEs at 10^{-13} s.
[c] In the wavelength range between 450 nm and 500 nm, dual limits apply and the exposure must not exceed either limit applicable.
[d] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table, may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.</td></tr>
</table>

Table A.4 – Maximum permissible exposure (MPE) of Table A.2 (extended sources) for the wavelength range from 400 nm to 1 400 nm expressed as power or energy [a, b, c, d, e, f, g]

<table>
<tr><th rowspan="2">Wavelength
λ
nm</th><th colspan="7">Emission duration t
s</th></tr>
<tr><th>10^{-13} to
10^{-11}</th><th>10^{-11} to
5×10^{-6}</th><th>5×10^{-6} to
13×10^{-6}</th><th>13×10^{-6} to
10</th><th>10 to
10^{2}</th><th>10^{2} to
10^{4}</th><th>10^{4} to
3×10^{4}</th></tr>
<tr><td rowspan="5">400 to 700</td><td rowspan="5">$3{,}8 \times 10^{-8}\ C_6$ J</td><td rowspan="5">$7{,}7 \times 10^{-8}\ C_6$ J</td><td colspan="2" rowspan="5">$7 \times 10^{-4}\ t^{0{,}75}\ C_6$ J</td><td colspan="3">400 nm to 600 nm – Retinal photochemical hazard [d, e]</td></tr>
<tr><td>$3{,}9 \times 10^{-3}\ C_3$ J
using
$\gamma_{ph} = 11$ mrad</td><td>$3{,}9 \times 10^{-5}\ C_3$ W
using
$\gamma_{ph} = 1{,}1\ t^{0{,}5}$ mrad</td><td>$3{,}9 \times 10^{-5}\ C_3$ W
using
$\gamma_{ph} = 110$ mrad</td></tr>
<tr><td colspan="3">*AND* [c]</td></tr>
<tr><td colspan="3">400 nm to 700 nm – Retinal thermal hazard</td></tr>
<tr><td colspan="3">$7 \times 10^{-4}\ C_6\ T_2^{-0{,}25}$ W ($t > T_2$)
($t \le T_2$) $7 \times 10^{-4}\ t^{0{,}75}\ C_6$ J</td></tr>
<tr><td>700 to 1 050</td><td>$3{,}8 \times 10^{-8}\ C_6$ J</td><td>$7{,}7 \times 10^{-8}\ C_4\ C_6$ J</td><td colspan="2">$7 \times 10^{-4}\ t^{0{,}75}\ C_4\ C_6$ J</td><td colspan="3">$7 \times 10^{-4}\ C_4\ C_6\ T_2^{-0{,}25}$ W ($t > T_2$)
($t \le T_2$) $7 \times 10^{-4}\ t^{0{,}75}\ C_4\ C_6$ J</td></tr>
<tr><td>1 050 to 1 400 [f]</td><td>$3{,}8 \times 10^{-8}\ C_6\ C_7$ J</td><td colspan="2">$7{,}7 \times 10^{-7}\ C_6\ C_7$ J</td><td>$3{,}5 \times 10^{-3}\ t^{0{,}75}\ C_6\ C_7$ J</td><td colspan="3">$3{,}5 \times 10^{-3}\ C_6\ C_7\ T_2^{-0{,}25}$ W ($t > T_2$)
($t \le T_2$) $3{,}5 \times 10^{-3}\ t^{0{,}75}\ C_6\ C_7$ J</td></tr>
<tr><td colspan="8">NOTE 1 Exposure limits for some ocular tissues may be different for ophthalmic instruments – see ISO 15004-2.
NOTE 2 The exposure level to be compared with the MPE expressed as power or energy is to be determined as power or energy that passes through an aperture with a diameter of 7 mm (the MPE values expressed in this table are obtained from the values of Table A.2 by multiplication with the area of an aperture with 7 mm diameter).</td></tr>
<tr><td colspan="8">[a] For correction factors and units, see Table 9.
[b] The MPEs for exposure durations below 10^{-13} s are set to be equal to the equivalent power values of the MPEs at 10^{-13} s.
[c] In the wavelength range between 450 nm and 600 nm, dual limits apply and the exposure shall not exceed either limit applicable.
[d] The angle γ_{ph} is the limiting measurement angle of acceptance.
[e] If exposure times between 1 s and 10 s are used, for wavelengths between 400 nm and 484 nm and for apparent source sizes between 1,5 mrad and 82 mrad, the dual photochemical hazard limit of $3{,}9 \times 10^{-3}\ C_3$ J is extended to 1 s.
[f] In the wavelength range between 1 250 nm and 1 400 nm, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.
[g] For exposure durations less than 0,25 s, the limits to protect the retina given in this table may not adequately protect the anterior parts of the eye (cornea, iris) and caution needs to be exercised. There is no concern for the anterior parts of the eye if the exposure does not exceed the skin MPE values.</td></tr>
</table>

Table A.5 – Maximum permissible exposure (MPE) of the skin to laser radiation [a, b]

Wavelength λ nm	Exposure time t s					
	$<10^{-9}$	10^{-9} to 10^{-7}	10^{-7} to 10^{-3}	10^{-3} to 10	10 to 10^{3}	10^{3} to 3×10^{4}
180 to 302,5	3×10^{10} W·m^{-2}	30 J·m^{-2}				
302,5 to 315		C_1 J·m^{-2} ($t \leq T_1$) / C_2 J·m^{-2} ($t > T_1$)			C_2 J·m^{-2}	
315 to 400		C_1 J·m^{-2}			10^4 J·m^{-2}	10 W·m^{-2}
400 to 700	2×10^{11} W·m^{-2}	200 J·m^{-2}	$1{,}1 \times 10^4\ t^{0{,}25}$ J·m^{-2}		2 000 W·m^{-2}	
700 to 1 400	$2 \times 10^{11}\ C_4$ W·m^{-2}	200 C_4 J·m^{-2}	$1{,}1 \times 10^4\ C_4\ t^{0{,}25}$ J·m^{-2}		2 000 C_4 W·m^{-2}	
1 400 to 1 500	10^{12} W·m^{-2}	10^3 J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}	1 000 W·m^{-2} [c]	
1 500 to 1 800	10^{13} W·m^{-2}	10^4 J·m^{-2}				
1 800 to 2 600	10^{12} W·m^{-2}	10^3 J·m^{-2}		5 600 $t^{0{,}25}$ J·m^{-2}		
2 600 to 10^6	10^{11} W·m^{-2}	100 J·m^{-2}	5 600 $t^{0{,}25}$ J·m^{-2}			

[a] For correction factors and units, see Table 9.

[b] There is only limited evidence about effects for exposures of less than 10^{-9} s. The MPEs for these exposure durations have been derived by maintaining the irradiance applying at 10^{-9} s.

[c] For exposed skin areas greater than 0,1 m^2, the MPE is reduced to 100 W·m^{-2}. Between 0,01 m^2 and 0,1 m^2, the MPE varies inversely proportional to the irradiated skin area.