



Coláiste na Tríonóide, Baile Átha Cliath
Trinity College Dublin

Ollscoil Átha Cliath | The University of Dublin

GUIDANCE ON THE SAFE USE OF LASERS

**IN
TRINITY COLLEGE DUBLIN**



Short Course for Laser Users

Ed. 2017

CHRISTOPHER SMITH

Disclaimer

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Emergency Information

For any Laser accident that involves the eyes seek immediate medical attention.

College emergency number **1999**

You may well be suffering from psychological shock seek help from a colleague then go together to the Hospital Immediately.

Accident & Emergency

Royal Victoria Eye and Ear Hospital

Adelaide Road

Dublin 2

Telephone 01 6644600

*Do not use the laboratory or disturb the equipment until after the accident has been investigated
Report all accidents to the: Laser Safety Officer and School/Department General Safety Officer.*

Preface

Conducting research using lasers can be a very exciting and rewarding endeavour but it can also be the cause of a life changing accident if not conducted correctly and safely. This guide is part of the Laser Safety program in Trinity College and is intended to provide a framework for good practice regarding Laser systems and users. It should aid in the identification of the hazards associated with lasers and assist in the assessment of risk and in the implementing of control measures in both teaching and research laboratories. Many of the technical aspects in this guide are explained at a level to accommodate people without a background in lasers or optical physics.

This document is for preliminary guidance only and does not imply that the laser system or the laser user is fully compliant with the registration process within Trinity College. Only through full consultation with the College Laser Safety Officer can the registration process be completed. Intending laser users must attend the Laser Safety Workshop to become fully registered to carry out work with or within the vicinity of active laser systems.

This guide is for Trinity College personnel only and is not to be reproduced or used outside of the college.

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1 RESOURCES

Website <https://www.tcd.ie/Physics/research/facilities/oal/laser-safety/> or just use the web browser to search for Laser Safety Trinity College Dublin. The website provides information and templates.

- [Laser Safety Officer](#)
- [Laser Safety Policy \(pdf\)](#)
- [Training and Registration](#)
- [Risk Assessment](#)
- [Signs and Labels](#)
- [Eye protection](#)
- [Laser Safety Guide](#)
- [Emergency procedure](#)
- [Legislation](#)
- [Online safety course and assessment](#)

A more comprehensive manual useful for reference or those in charge of the safety in laser designated areas can be accessed [Guidance on the Safe Use of Lasers](#) .

This guide covers the following topics; a detailed table of contents is included for ease of reference.

- ✓ [Legislation and Standards](#)
- ✓ [Training and Registration](#)
- ✓ [The Ubiquitous Laser](#)
- ✓ [Laser Radiation Properties](#)
- ✓ [Laser Hazards and Injury](#)
- ✓ [Power and Energy](#)
- ✓ [Maximum Permissible Exposure](#)
- ✓ [Nominal Ocular Hazard Distance](#)
- ✓ [Laser Classification](#)
- ✓ [Controls and Protection](#)
- ✓ [Laser Safety Eyewear](#)
- ✓ [Warning Labels and Signage](#)
- ✓ [Risk Assessment](#)
- ✓ [Scheme of Work](#)
- ✓ [Emergency procedures](#)

2 LEGISLATION AND STANDARDS

European Directives are legal acts which require member states to establish harmonisation in their legislation. It does not dictate the means of achieving that result. It helps member countries to trade in the single market by ensuring standardisation of products and services.

Legislation is a law placed by a governing body which must be complied with, they are general principles that do not require regular updating. May also be referred to as an Act or Statute

Regulations also called Statutory Instruments (S.I.s) are specific requirements within legislation, they are basically the way the legislation is enforced by regulators. In industry, they specify the particular legal requirements that need to be adhered to by organisations, employers and personnel to help ensure compliance. Often regulations address product safety, as well as other factors. Regulations are typically developed through technical specifications or through standards.

Standards are documents that set out the requirements for a specific device, material, system or service. Standards help ensure standardisation and compatibility of products and services. They bring many benefits to the consumer including the improvement of safety. A standard is not law but legislation and regulations may refer to standards and even make compliance with them compulsory. Developed and published by the International Electrotechnical Commission, IEC. The current main Irish standard on laser safety is I.S. EN 60825-1:2014 available from the National Standards Authority of Ireland (NSAI)

2.1.1 Irish Legislation

The main legislation pertaining to the health and safety of people in the work place are the [Safety, Health and Welfare at Work Acts 2005 and 2010](#). Applies to all employers, employees and self-employed people in their workplaces. The Acts set out the rights and obligations of both employers and employees and provides for substantial fines and penalties for breaches of the health and safety legislation.

2.1.2 Irish Regulations

[The Safety, Health and Welfare at Work \(General Application\) Regulations 2007](#).

The purpose of these regulations is to revise and amalgamate a number of existing regulations into one comprehensive set of regulations. They are continuously amended. These operate in conjunction with the 2005 Act. The Regulations give effect to a wide range of EU Directives.

2.1.3 EU Directive 2006/25/EC on Optical Radiation

[On the minimum health and safety requirements regarding the exposure of workers to risks arising from artificial optical radiation](#). The amendment was inserted into the Irish regulations The Safety, Health and Welfare at Work (General Application) (Amendment) Regulations 2010 as part 9 Control of Artificial Optical Radiation at Work. Deals with *Exposure Limits, Risk assessment, controls, training...*

2.1.4 Standard I.S. EN 60825-1

Safety of laser products - Part 1: Equipment Classification and requirements

2.1.5 Technical Report IEC TR 60825-14

Safety of Laser Products – A user guide

2.1.6 Standard EN207 and EN208

Personal eye-protection equipment - Filters and eye-protectors against laser radiation

2.2 Legal requirement and Responsibilities

The Employer has a responsibility to identify the risks and ensure that workers are not exposed to levels of artificial optical radiation in excess of the exposure limit values (ELV). They must take action to eliminate or control these risks.

The Distributors, agents and retailers of laser systems must supply safe and compliant products, with the correct documentation. Many new products come within the scope of one or more EU supply Directives and therefore should be CE marked, Conformité Européenne (European Conformity) come with a Declaration of Conformity, and be supplied with user instructions, written in English.



The College must provide you with suitable information and training and provide you with safe infrastructure and equipment.

You the Laser User must follow College safety procedures and rules and carry out risk assessments related to your work and apply controls to reduce risk to a level that is as low as possible. If you cannot carry out your work safely you must not proceed.

3 TRAINING AND REGISTRATION

In the college it is a requirement to register all the LASER systems, even if they are not in use. To do this the LSO must be provided with the

- ✓ Model and type of laser, wavelengths and power
- ✓ Location
- ✓ Responsible person in charge

If you intend to purchase or dispose of a laser system within the college you should contact the LSO.

All laser users in the college must register with the Safety Office through the LSO. You must provide the following information.

- | | |
|----------------------|-------------------------------------|
| ✓ Position | ✓ School / Department |
| ✓ Name | ✓ e-mail address |
| ✓ Supervisor / Group | ✓ The main laser system worked with |

If you have a medical condition or disability that you feel may impede your ability to work with lasers safely please speak with the Laser Safety Officer about it so that a solution can be reached. It will be dealt with confidentially within the normal [data protection practises of the college](#).

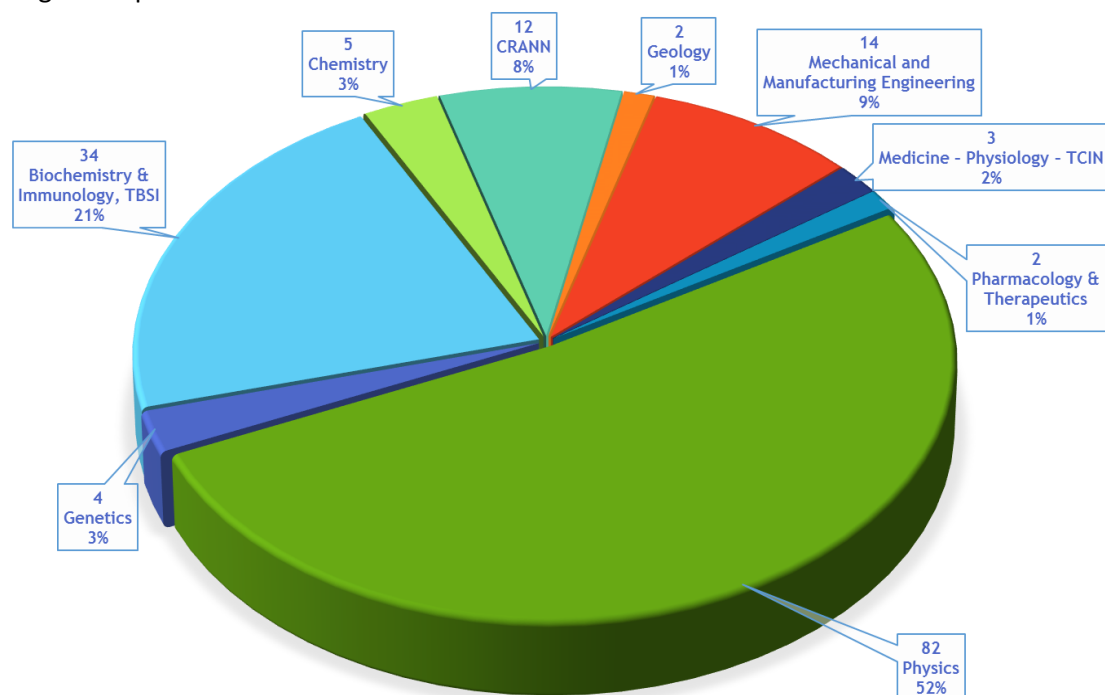
All personnel wishing to work with Lasers or in the vicinity of active Lasers in the college must

- ✓ Attend the course given by the LSO
- ✓ Complete the registration process
- ✓ Be a Registered Laser User
- ✓ Be aware of the hazards
- ✓ Complete a risk assessment before commencing work
- ✓ Take appropriate precautions
- ✓ Take appropriate action in the event of an incident

4 THE UBIQUITOUS LASER

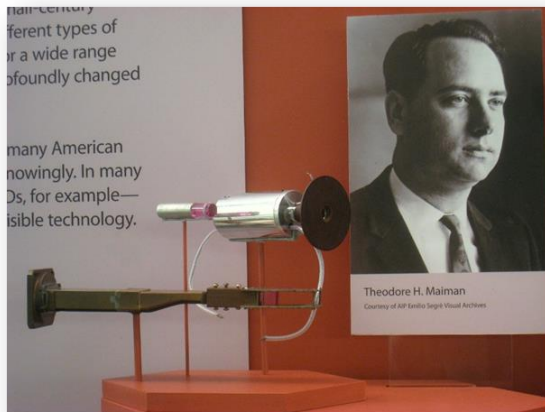


There are lasers everywhere, from DVD players to laser pointers. Most high powered lasers in consumable products are embedded and considered eye safe. Others require a trained competent user, as in laser light displays or medical equipment. Within the teaching and research environment of the University we have many different types of lasers also, but due to the nature of the work these systems are potentially very dangerous and require great care in their use as well as appropriate training for all personnel.



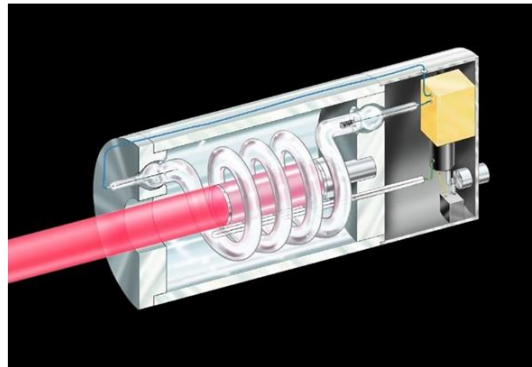
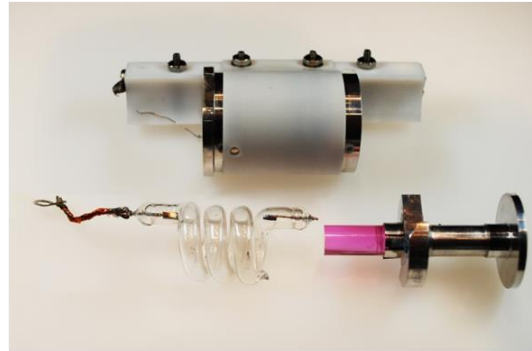
A basic break down of the location and use of lasers within the University shows that physics have the largest number as one might expect but from the pie chart one can see that there are lasers in use across nine disciplines over three faculties. Data was compiled in 2016.

4.1 A Brief History



The world's first laser: a ruby crystal of 1.5cm length, emitting its first laser light on May 16, 1960.

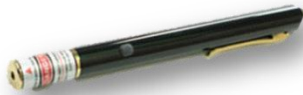
Theodore Maiman, Exhibit in National Museum of American History, Washington, DC, USA.



- **1898:** H. G. Wells' CLASSic science fiction novel *The War of the Worlds* describes a Heat-Ray, essentially a directed-energy weapon.
- **1917:** Einstein proposed the process that makes lasers possible.
- **1954:** Charles Townes demonstrates the first MASER with Zeiger and Gordon.
- **1957:** Graduate student Gordon Gould jots his ideas down for building a laser and coined the name LASER.
- **1960:** Theodore H. Maiman, a physicist at Hughes Research Laboratories in California builds the first laser.
- **1961:** The first medical treatment using an optical ruby laser is used to destroy a retinal tumour.
- **1964:** The carbon dioxide laser is invented by Kumar Patel at Bell Labs, it is now used worldwide as a cutting tool in surgery and industry.
- **1978:** The Laser-Disc hits the home video market, with little impact.
- **1982:** The audio Compact Disc (CD), a spinoff of Laser-Disc video technology, debuts. Billy Joel's album "52nd Street" is the first to be released on CD.

4.2 Relative Power

To help you better understand the range and scale of powers lasers can produce, a number of examples are presented here. The typical laser pointer used for lectures and presentations is considered safe except in the case of intentional prolonged intrabeam viewing. These are CLASS 2 lasers and the power is normally less than 1 milliwatt. Looking at the Industrial lasers used in materials processing the power can be upwards of 20 Kilowatts, typically these lasers are CLASS 4 but are fully enclosed and interlocked. CLASS 4 lasers are the most dangerous not only can they cause severe injury to all the tissues of the body but they can also ignite fires if incident on combustible materials.



Laser pointers
0.001 W



Theodolites
0.005 W



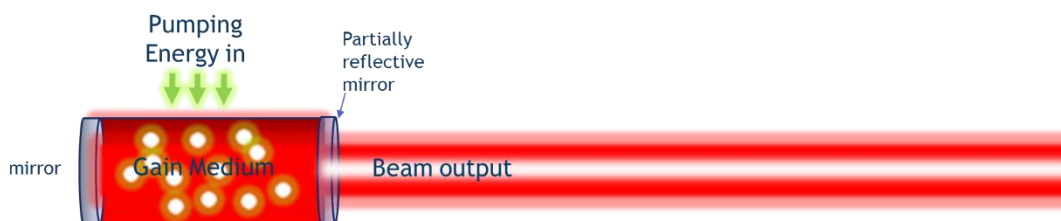
Industrial Lasers 20000.000 W



Research Lasers 1.000 W

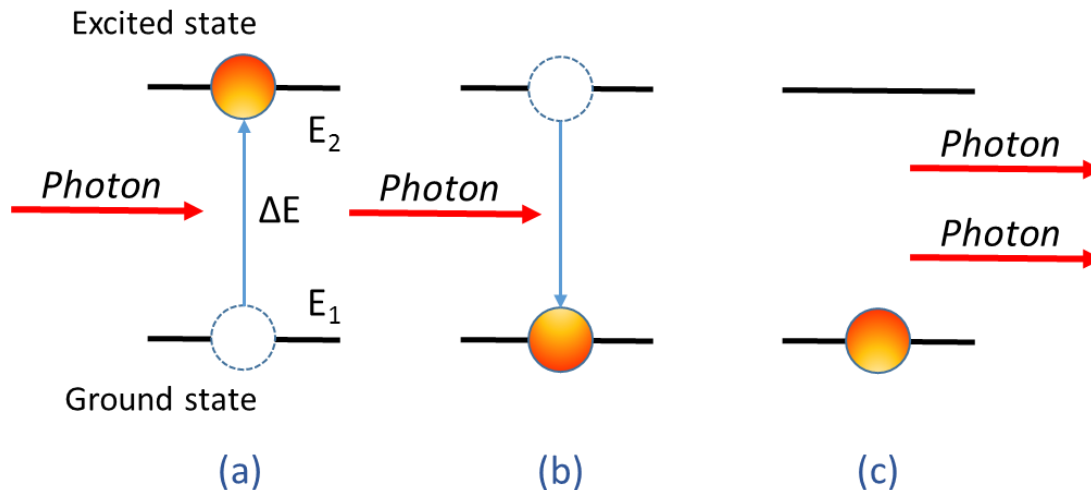
5 LASER RADIATION PROPERTIES

Laser light has specific properties that are different from normal sources of light and it is some of these properties that can make it much more dangerous. Due to the relatively high power concentrated into a small diameter and the low divergence of the beam the power density on the retina of the eye can be as much as 120 times greater for a 1 milliwatt laser pointer than that of direct sunlight. To better appreciate the reasons why lasers are dangerous a brief outline of how a laser works and the main properties of laser light which arise as a consequence will be helpful.



The word *LASER* is actually an acronym which stands for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A form of energy is pumped into the Gain Medium typically photons which stimulates the

electrons of the atoms or molecules into a higher energy state (a). A photon dropping spontaneously from the excited state to a lower state can stimulate an excited atom or ion to undergo a further transition from the excited state to the ground state hence creating a chain reaction (b). The medium releases this energy as light, some of which is then partially reflected back into the same medium via the mirrors (c). The radiation is amplified and emitted as the laser beam.



This process is known as stimulated emission and typically results in the emission of photons of precisely the same wavelength, phase, and direction. This process gives laser beams their properties which separates them from other sources of light.

The Gain medium in a laser is what normally gives it particular properties and different types of lasers are identified by the gain medium, for example the Nd:YAG laser is named after the neodymium-doped yttrium aluminium garnet; Nd:Y3Al5O12 crystal used as the gain medium. This laser generates beams in the near infrared wavelength range, typically at 1064nm. Gain mediums can consist of different materials and states of matter.

- **Gas** e.g. HeNe lasers using the gas Helium-Neon
- **Liquid** e.g. Dye lasers using Rhodamine
- **Solid** Titanium-Sapphire crystal lasers

The Pumping Mechanism is how energy is fed into the gain medium to make it produce a Laser beam. This energy can be delivered in different ways.

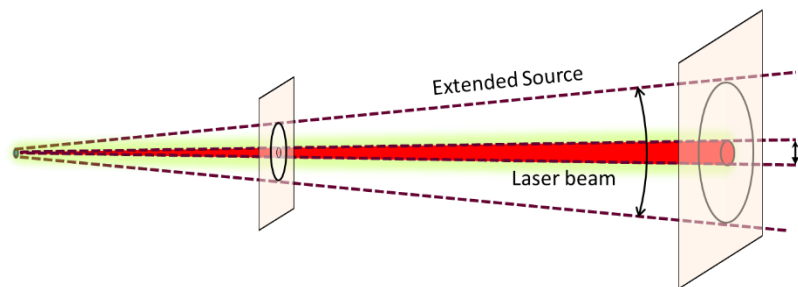
- **Electrical discharge** (gas lasers)
- **Flash-lamps** (Dye laser and solid state)
- **Another Laser** (Solid state Ti:Sapphire)
- **Chemical reaction** (deuterium fluoride (DF) lasers)
- **Current injection** (Diode lasers)
- **Radiofrequency** (electromagnetic radiation kHz to GHz) (gas lasers)

LASER light beams are

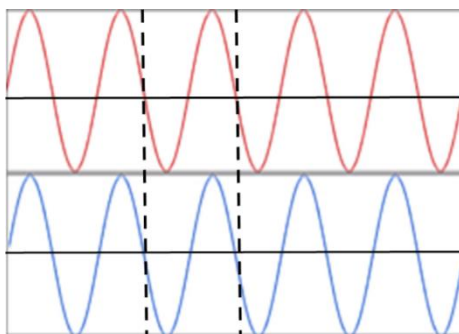
1. Highly Collimated
2. Highly Coherent
3. Usually Monochromatic
4. High Power and Energy density
5. Pulsed or Continuous Emission

5.1 Collimation

Laser light is usually highly collimated, all the rays travel relatively parallel and spread minimally as it propagates through space. Another way to say this is that laser beams are highly directional and the power density is maintained over a relatively great distance when compared to normal light. Even when a person is some distance away, the beam presents a danger. There are documented incidences where pilots have been temporarily blinded by laser pointers being maliciously aimed at aeroplanes and helicopters. Divergences are typically very small and measured in milliradians.



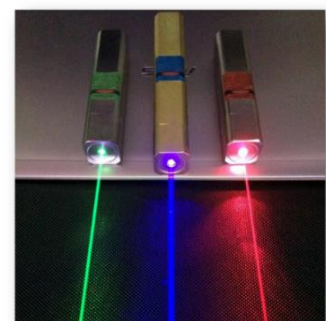
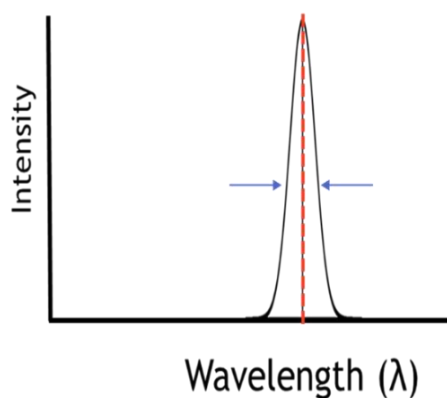
5.2 Coherence



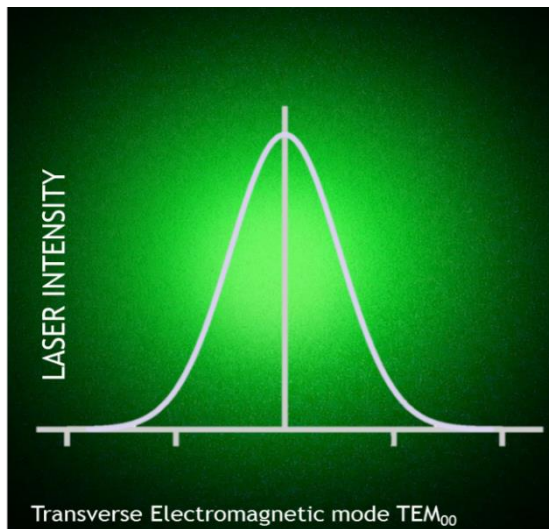
Coherence is one of the unique properties of laser light. It arises from the stimulated emission process. Since a common stimulus triggers the emission events the emitted photons are synchronised and have a phase relation to each other. This coherence is described in terms of temporal coherence and spatial coherence. In this way the light from a laser differs from ordinary light in that it is made up of waves all of the same wavelength which are all in relative phase.

5.3 Monochromatic

Laser light is typically monochromatic, one wavelength with a very narrow spectral bandwidth of just a few nanometres. Various wavelength ranges can present specific dangers to biological tissues of the body, especially the eye.



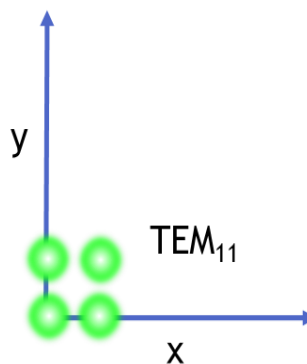
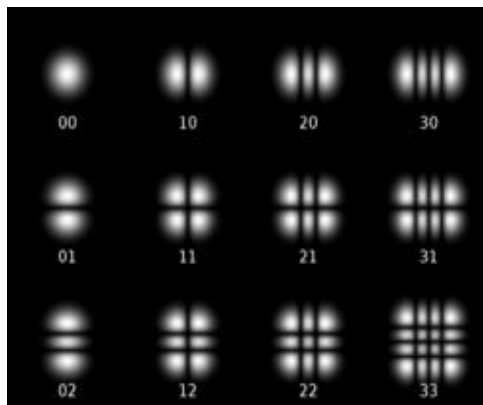
5.4 High Power and Energy density



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.

Looking at the laser beam intensity transversely, typically we will see a Gaussian beam profile. The intensity at the centre of the beam is the highest and drops off away from the centre. Sometimes to simplify laser safety calculations for relatively small diameter beams we use a Top-hat profile approximation, that is, we assume the intensity is constant across the beam and does not drop off

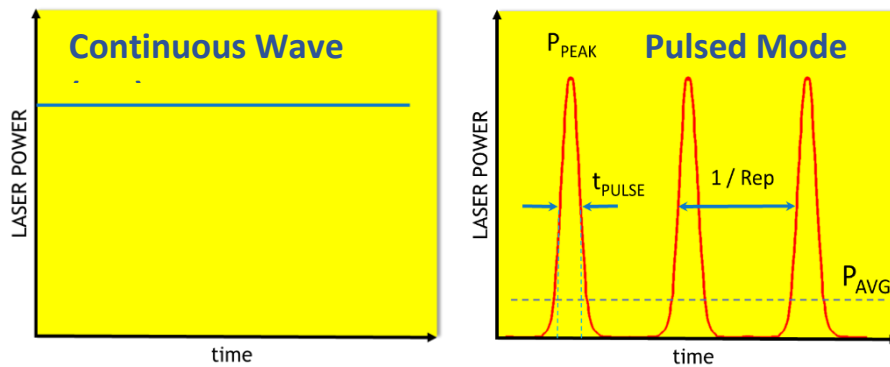
towards the edges. It should be noted that not all lasers produce this kind of profile and that some can have a number of points of high intensity or hot spots.



The beam profiles are identified by the Transverse Electromagnetic Mode number, TEM. The typical Gaussian beam profile is TEM_{00} , but there are others shown in the diagram, these are for rectangular shaped beams but they are also used for circular ones too.

5.5 Pulsed or Continuous Emission

Another property of laser light is the emission mode or temporal mode. Lasers are either Continuous Wave (CW) or Pulsed. "Continuous Wave" or "CW" refers to a laser that produces a continuous output beam, sometimes referred to as "free-running," as opposed to a q-switched, gain-switched or modelocked laser, which has a pulsed output beam.



Pulsed mode lasers can produce extremely high powers in tiny time intervals, from $1\mu s$ down to $< 1ns$. This may be due to the natural operation of the laser or because the application of the laser requires it, for example, material can be evaporated if it is heated in a very short time, while supplying the energy gradually would allow for the heat to be absorbed and emitted over time, never attaining a sufficiently high temperature at a particular point.

5.6 Output Wavelengths of Common Lasers

Laser Type	Wavelength(s) (nm)
Argon Fluoride Excimer (UV)	193
Krypton Chloride Excimer (UV)	222
Krypton Fluoride Excimer (UV)	248
Xenon Chloride Excimer (UV)	308
Xenon Fluoride Excimer (UV)	351
Helium Cadmium (UV, Visible)	325, 442
Nitrogen (UV)	337
Krypton (Visible)	476, 528, 568, 647
Argon (Visible)	488, 514
Copper Vapor (Visible)	510, 578
Nd:YAG Frequency Doubled (Visible)	532
Helium Neon (Visible, Near IR)	543, 594, 612, 633, 1150, 3390
Gold Vapor (Visible)	628
Rhodamine 6G Dye (Visible, Tuneable)	570-650
Ruby (Visible)	694
Diode Semiconductor (Visible, Near IR)	630-1600
Ti:Sapphire (Visible - Near IR)	680-1130
Nd:YAG (Near IR)	1064
Erbium (Near IR)	1540
Hydrogen Fluoride (Near IR)	2600-3000
Carbon Dioxide (Far IR)	9600, 10600

6 LASER HAZARDS AND INJURY



What is a hazard?

A Hazard is a potential source of harm or adverse health effects on a person or it can be damage to property and the environment. An event that is caused by interaction with a hazard is called an incident.



What is a risk?

Risk is the probability or likelihood that a person may be harmed or suffer adverse health effects if an incident occurs because of a hazard. Risk is also increased by the number of times and the number of people exposed to the hazard. Risk takes into account the severity and probability of harm occurring.



What is a control measure?

A control measure is typically an action or actions taken to remove a hazard or reduce the risk of the exposure to that hazard. Can be an administrative control measure, such as signage, or an engineering control measure which can help to reduce or eliminate the hazard, or personal protection equipment which can help protect against the hazard.

6.1 General Categories of Hazards

Physical; electricity, radiation, heat, noise, artificial optical radiation, radiofrequency radiation

Chemical; toxic substances, fumes, fire, carcinogenic substances, irritants

Biological; microbes, bacteria, viruses,

Mechanical; Equipment, cables, pipes, hardware, crush hazards, water supply, heavy items, stability, moving parts, high or low pressure containers, sharp edges

Ergonomic; work environment, seating, workbench, human interface,

Psychosocial; relationship between your mental and emotional wellbeing and the environment this can be effected by people, working hours, expectations, bullying, inadequate training or assistance.

6.2 Hazards Typically Associated with Laser Applications

Hazards associated with Laser systems can be divided into two main categories, beam hazards and non-beam hazards. Beam hazards are of course dangers arising from the laser light directly, these are mainly concerned with the impact the beam can have on exposed tissues, 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 exposure to toxic and cryogenic materials, electrical shock and ionising radiation. One may not consider non-beam hazards as important but these can be much more deadly as they can potentially kill. Normally beam hazards have the potential to cause serious injury only, typically to your eyes.



Laser Optical Radiation

Laser beams present a hazard to two main areas of the human anatomy, the skin and the eyes. Generally, the skin is not so susceptible to serious injury from the laser beam. The human eye however is much more susceptible to injury due to the focusing capability on the retina at the back of the eye.

Eye: corneal and, or retinal burns, lens damage, cataracts

Skin: burns, accelerated aging, cancer



Electrical Hazards

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. One should be aware that there are large capacitors that can retain extremely high and dangerous charges which can be lethal even after the system is powered off. No college personnel should access the enclosed electrical components of any laser system unless fully trained and competent; always seek expert guidance.



Chemical Hazards

Cryogenic fluids such as liquid nitrogen at -196 °C are often used for cooling of lasers and detectors. These fluids can produce severe skin burns and should be handled with great care. Liquid Nitrogen can also evaporate and push the oxygen out of the area resulting in an asphyxiation hazard.

The laser process may result in the production of particulate and gaseous materials (vaporised targets, reaction products), ensure the area is ventilated appropriately. Any chemicals being used must be treated with care in accordance with the Chemical Safety Officer's directives.



Secondary Hazards

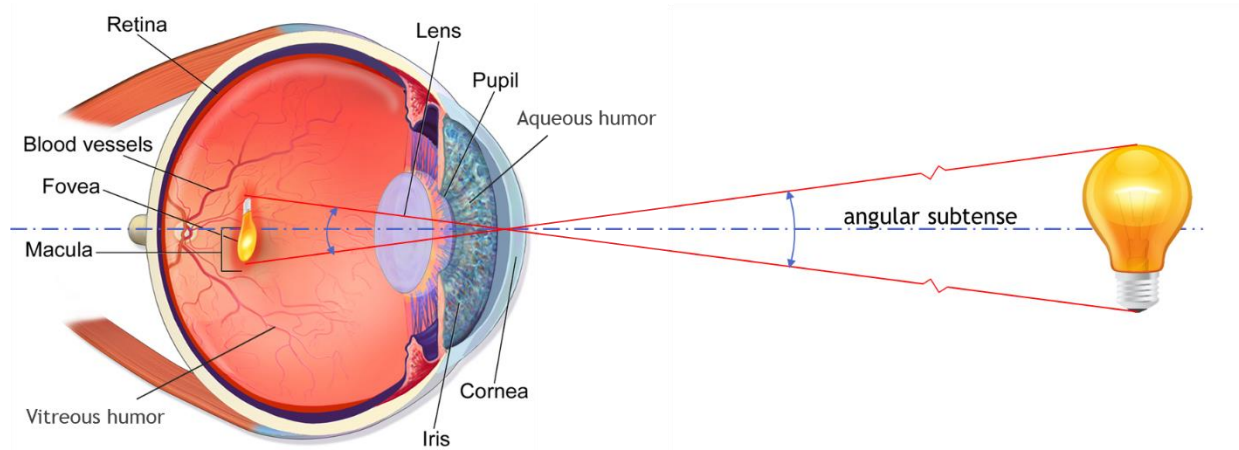
Other sources of dangerous secondary emissions of optical radiation are laser discharge tubes, arc and flash lamps. These lamps may also be a source of explosion hazards as they normally contain gas at a much higher pressure than atmosphere. These lamps should be enclosed in case they are compromised and explode. Wherever a component of a laser facility has the potential to be exposed to an incident beam it should be made of flame retardant material, this includes beam stops, enclosures, screens, etc.

Explosion: high gas pressure arc lamps, gases,

Fire: combustible material in vicinity of beam, volatile chemicals.

This is not a complete list of all the possible hazards associated with lasers and the environment they may be located in. It is just an outline to help you to start considering what hazards are present in your particular situation. You must identify and document them in your risk assessment as well as implement control measures to too eliminate or reduce the risk to as low as possible.

6.3 The Eye

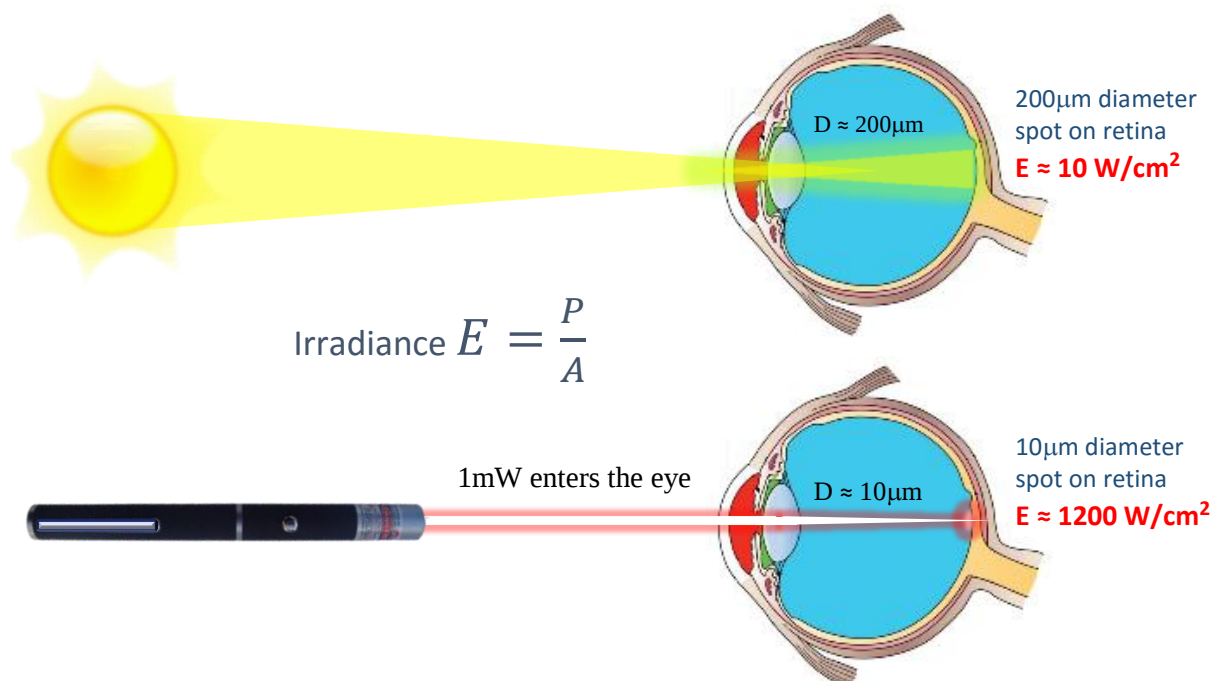


The human eye is an amazing optical apparatus; it is extremely sensitive to light in the visible region. The maximum spectral sensitivity of the human eye under daylight conditions is at **555 nm**, while in the dark, the peak shifts to 507 nm. The wavelength 555nm is perceived as the colour green and. If we take two laser beams one green and one red, both with the same optical power, the green will appear much brighter than the red. It is important to understand that although a red beam towards the near infrared may not seem very bright it could still be of extremely high power and dangerous.

6.3.1 Irradiance Comparison

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.

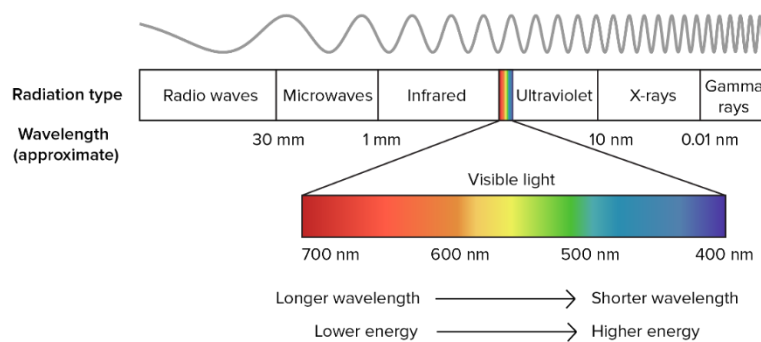
Irradiance (E) is the incident electromagnetic power per unit area. The sun irradiates the earth at approximately $1\text{KW}/\text{m}^2$ or $0.1\text{ W}/\text{cm}^2$. Let's take a 1mw laser pointer emitting a beam of wavelength 633nm and diameter of 2mm . Let's assume a *top hat* profile to the beam i.e. power density is consistent across the area of the beam. 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 200 μ m in diameter whereas the collimated laser with low divergence will produce a much smaller image of approximately 10 μ m. From these values we can work out the irradiance at the retina to be approximately 10 W/cm² for the sun and 1200 W/cm² for the laser. The laser light incident on the retina is 120 times more intense than the sun. It is never recommended to stare at the sun continuously 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.

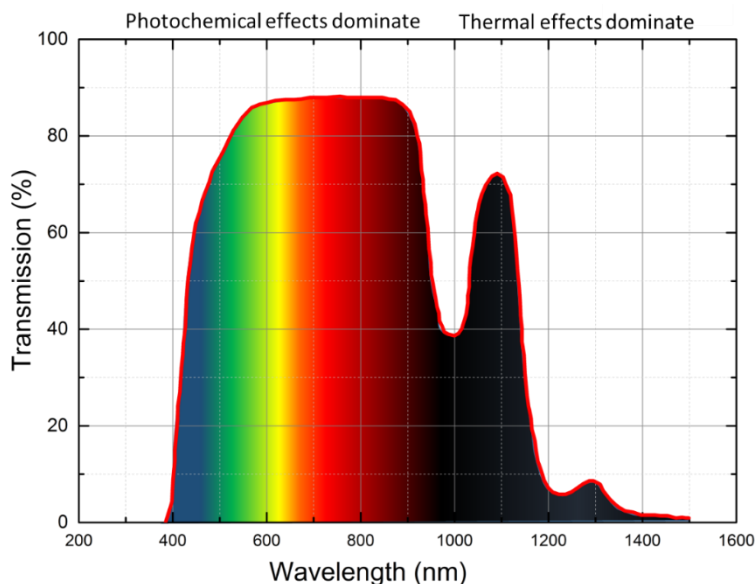
6.3.2 Wavelength Transmission through the Eye

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.



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 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 to cause injury.

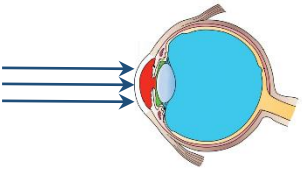
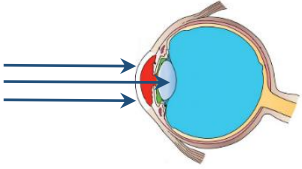
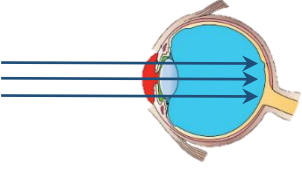
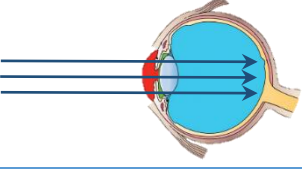
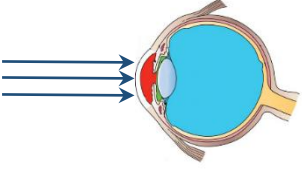


We can see the spectrally transmittance dependence of the human eye in relation wavelength in the graph. In regards to damage caused by laser irradiance photochemical effects dominate towards the shorter wavelengths, while towards the longer wavelengths thermal effects dominate. Different parts of the eye are more susceptible to injury from laser radiation at particular wavelengths than others.

The cornea can absorb all UV ranges from the mid-UV to the near-UV which can induce photokeratitis, sunburn of the cornea and sclera. This is a photochemical effect where a denaturation of the proteins occurs. It is a painful eye condition but your 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 grit 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 can result in cataracts causing a 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 very dangerous because 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 light sensitive retina. The blink reflex typically 0.25 seconds, can offer some protection in this range but only at relatively low irradiances. The most dangerous has to be the near infra-red range 700 – 1400 nm which can also reach the retina but because it is invisible to the eye there is no blink reflex to offer any protection. The exposure duration may be prolonged increasing the injury to the retina.

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	

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 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.

6.4 Mechanism of Injury and Symptoms

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

6.4.1 Photo-Thermal Effects

Thermal effects occur when sufficient electromagnetic radiant energy from the laser beam has been absorbed by the biological 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.

6.4.2 Photo-Mechanical Effects

Photo-mechanical or sometimes referred to as acoustical effects occur when a laser beam is incident on the tissue which is heated very rapidly in only nanoseconds or less, inducing a mechanical shockwave. Typically associated with very short pulses, less than nanoseconds, the liquid component of the tissues may evaporate into a hot gas with extremely high temperatures. The phase changes are so rapid that they are explosive and the cells rupture.

6.4.3 Photo-Chemical Effects

Photochemical effects can be the direct result of specific wavelength absorption resulting in chemical changes in exposed biological tissues, typically in the UV range. This photochemical reaction is believed to be responsible for damage at relatively low levels of exposure where duration of exposure is more significant. The skin, the cornea and the lens of the eye, may experience irreversible changes induced by prolonged exposure to moderate levels of UV radiation. Such photochemical induced changes may result in injury if the duration of irradiation is excessive, or if shorter exposures are repeated over prolonged periods.

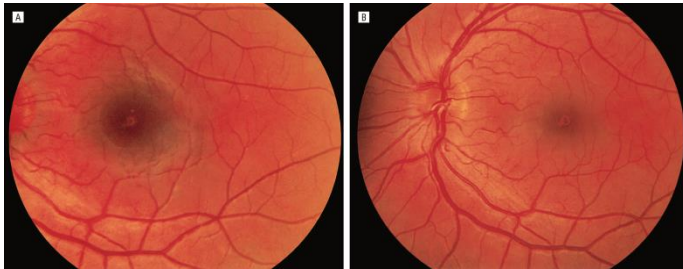
6.4.4 Symptoms of Laser Induced Injury to the Eye

We have been discussing the mechanism of injury to the various parts of the eye but it is useful at this stage to list the main symptoms you may experience if you are unfortunate enough to have a laser beam induced injury to your eyes. Please note, it is important to understand that the apparent absence of immediate symptoms does not mean that serious damage has not been done. You should seek medical attention and report the incident.

- Headache shortly after exposure, excessive watering of the eyes, sudden appearance of floaters.
- Minor corneal burns cause a gritty feeling, like sand in the eye
- The exposure to a visible laser beam can be detected by a bright colour flash of the emitted wavelength and an after-image of its complementary colour (e.g., a green 532 nm laser light would produce a green flash followed by a red after-image).
- Exposure to near Infra-red beams are especially hazardous and it may initially go undetected because the beam is invisible and the retina lacks pain sensory nerves.
- Photo-Mechanical 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.

6.5 Case Studies

6.5.1 A mild accidental laser injury



A 21-year-old female technician accidentally looked into the exit aperture of a repetitively pulsed infrared Nd:YAG 1064-nm target designation laser. The technician reported seeing 2 or 3 yellowish flashes at the time of the laser exposure. Visual acuity in her left eye was 20/50 a few hours after the accident and

20/200 two days later; visual acuity returned to 20/15 two months after the injury. **A**, Four days after the accident, there is foveal edema, surrounding sub-retinal hemorrhage, and several small, hypopigmented retinal pigment epithelium lesions. **B**, One month after the accident, foveal edema and sub-retinal hemorrhage have resolved, and a small area of foveal retinal pigment epithelium degeneration has developed.

6.5.2 Retinal injury from a recreational handheld laser



Images of the right and left eyes immediately after exposure to laser showing bilateral pre-retinal hemorrhages and the laser burn site in the left eye (arrow).

Images of the right and left eyes 2 months after laser exposure, showing improvement of pre-retinal hemorrhages.

A 9-year old boy with bilateral vision loss after playing with an adult who directed a handheld laser into both of his eyes. Known as the Spyder III Pro Arctic, the device was a CLASS 4, high-powered 1250mW laser that is manufactured from the 445 nm blue diode of a dismantled home theatre projector and that is commercially available for online purchase from overseas

6.5.3 Injury from a Nd:YAG laser in a research laboratory

A postgraduate student sustained a serious eye injury from an Nd:YAG laser. He had worn his protective eyewear in the afternoon when he set up the experiment, but when he returned to take some data after a break, he did not bother putting the eyewear back on because, *he felt, there were no exposed beams that posed any danger*. As he made a slight adjustment to a power-meter, he saw a flash and heard a loud popping sound. He had sustained a serious injury to his left eye. The student experienced some vision impairment months after the accident. Moreover the incident led to a prolonged investigation and a significant decline in funding for the research group.

6.6 Statistics of Laser Injuries

This data is maintained by Rockwell Laser Industries, <https://www.rli.com/>, it is based on reported cases and shows you that most are due to work typically carried out in a research environment. Reported Causes of Laser Related Injuries. Visible and near-infrared laser injuries account for more than 80% of all the reported incidents. Technical and Research staff are involved in almost 39% of all the reported incidents. Be cautious with alignment procedures and always wear protective eyewear!

6.6.1 Reported Causes of Laser Related Injuries

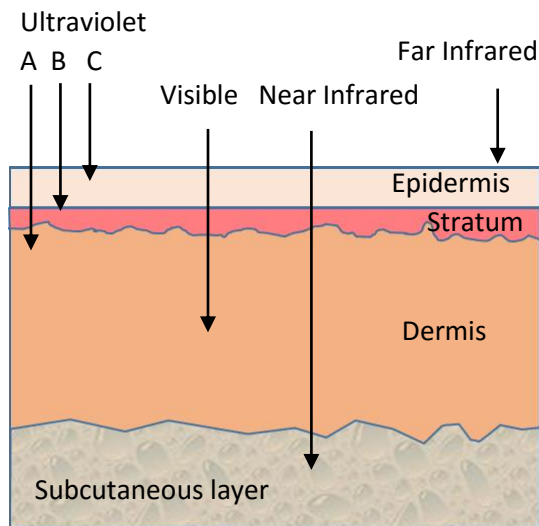
1. Unanticipated eye exposure during alignment.
2. Misaligned optics and upwardly directed beams.
3. Available laser eye protection was not used.
4. Equipment malfunction.
5. Improper method of handling high voltage.
6. Intentional exposure of unprotected persons.
7. Operators unfamiliar with laser equipment.
8. No protection provided for associated hazards.
9. Improper restoration of equipment following servicing.
10. Incorrect eyewear selection and/or eyewear failure.
11. Accidental eye / skin exposure during normal use.
12. Inhalation of laser-generated fume & viewing of secondary radiation (UV, blue light).
13. Laser ignition of fires.
14. Photochemical eye or skin exposure.

6.6.2 Occupations of Persons Involved in Incidents

1. Technical Staff	21.3%
2. Research Staff	17.6%
3. Patients	12.9%
4. Plant Workers	10.7%
5. Medical Staff	9.2%
6. Undergraduates	8.4%
7. Spectators	4.8%
8. Laser Show Operators	4.0%
9. Pilot / Military	3.3%
10. Equipment	3.3%
11. Field Service	2.6%
12. Office Staff	1.8%

6.7 The Skin

- Skin injuries are generally considered secondary to the risk of eye injury
- Skin is considered less vulnerable and can heal better than the eye from a serious trauma. Generally the injury would not be life changing.
- Skin injury is usually from photo-thermal or photo-chemical effects
- The skin also has Maximum Permissible Exposure values as for the eye and need to be calculated in a similar way.



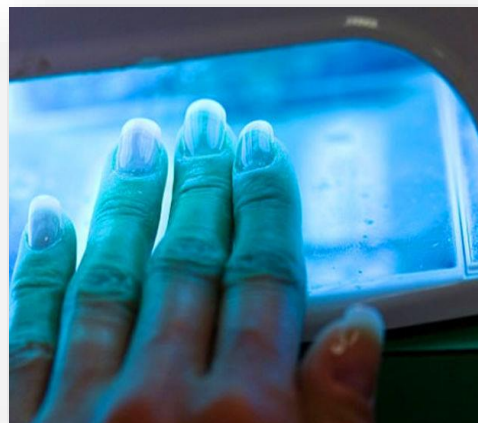
The optical properties of the skin are strongly wavelength dependent, in the far UV the radiation is mainly absorbed by the top layer the stratum corneum. As the wavelength increases the penetration depth also increases up to the near infrared, where at 800nm a maximum is reached. With longer wavelengths 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. When lasers with the potential to cause injury to the skin are being used, adequate precautions must be taken. To

help protect the skin as well as the eyes ensure that the lowest optical power setting on the laser is being used during alignment. Wear long sleeves and fire-resistant gloves if available to help protect the skin but one should never intentionally place any part of your body in the beam path. Where dexterity for the manipulation of components is needed thin nitrile gloves will offer limited protection against laser burns.

Ultra Violet radiation (UV): is a particular source of danger even at low power as the effects are cumulative.

Ultra Violet Sources in the college: include Lasers, e.g. optical parametric amplifier (OPA). Extended sources UV lamps e.g. xenon and mercury lamps. Arc welding, and the sun, put your suntan lotion on!

- UV C (180-280 nm) Absorbed in Ozone layer
- UV B (280-315 nm) Deep strata of skin at risk
- UV A (315-400 nm) Tanning, Skin at risk



The skin is usually much less sensitive to laser light than the eye, but excessive exposure to ultraviolet light from any source (laser or non-laser) can cause short- and long-term effects similar to sun exposure, while visible and infrared wavelengths may cause thermal damage.

7 LASER SAFETY PARAMETERS AND CALCULATIONS

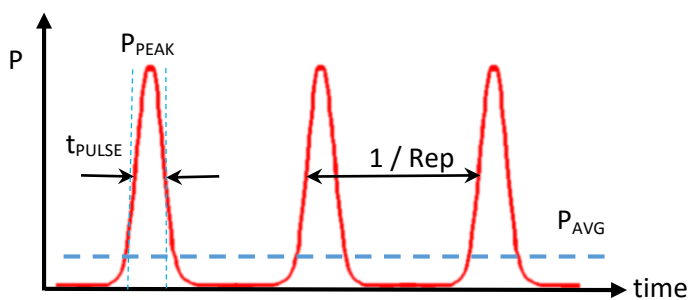
To understand the potential hazard presented by the beam of a laser system you need to be able to understand the significance of power and energy values based on the laser emission type.

Power is the amount of energy transferred per unit time. The unit is Joules per second called the Watt (W), named after the Scottish engineer James Watt.

Energy may exist in different forms potential, kinetic, thermal, electrical, chemical, electromagnetic, etc. The unit is the Joule (J) named after the English physicist James Prescott Joule.

$$Power = \frac{Energy}{time}$$

7.1 Optical Power and Energy



This section will help you understand basic calculations and values necessary for choosing the correct safety eyewear. It is also the information you will be asked for by a supplier if purchasing new eyewear.

Lasers emit beams in either continuous or pulsed mode, depending on whether the power output is essentially continuous

over time, termed continuous wave (CW) or whether its output takes the form of pulses of light modulated over time with durations in the millisecond to femtosecond range.

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). The optical output of a pulsed laser is typically reported in terms of energy and is related to the power output, where the pulse energy (Q) is the laser's peak power (P_{PEAK}) multiplied by the laser pulse duration (t_{PULSE}).

$$Q = P_{PEAK} \times t_{PULSE}$$

Each pulsed laser system will generate a fixed number of pulses per time interval, this frequency is termed the repetition rate of the laser and it is measured in pulses per second (Hertz). The time of one period $T = 1/Rep$.

The average power of a pulsed laser (P_{AVG}) is all the energy delivered over a second. We know that the repetition rate (Rep) tells us the number of pulses in a second so we simply multiply the pulse energy (Q) by the laser repetition rate (Rep).

$$P_{AVG} = Q \times Rep$$

The repetition rate is normally variable and can be changed by the user thus the average power can be changed. The average power can typically be measured using a laser power meter. The repetition rate can be read from the laser control panel or by observing the output train with a suitable detector

and an oscilloscope and determining the number of pulses per second. Pulse duration, t_{PULSE} can be determined by viewing the laser output on an oscilloscope screen or where necessary, determined from an autocorrelator at the full-width-half-max part of the pulse.

7.1.1 Duty Cycle

The *Duty Cycle* of the laser is the fraction of time the pulsed laser is actually on. If you don't know the energy per pulse then you can calculate the P_{PEAK} or the P_{AVG} using the *Duty Cycle*, Dc of the pulsed laser with the following relationship.

$$P_{\text{AVG}} = P_{\text{PEAK}} \times Dc$$

$$Dc = t_{\text{PULSE}} \times \text{Rep}$$

7.1.2 Example Calculation 1

An Excimer laser might have a 10 ns pulse width, energy of 10 mJ per pulse, and operates at a repetition rate of 10 pulses per second. This laser has a peak power of:

$$P_{\text{PEAK}} = 10 \text{ mJ} / 10 \text{ ns} = 1 \text{ MW}$$

and an average power of:

$$P_{\text{AVG}} = 10 \text{ mJ} \times 10 \text{ hertz} = 100 \text{ mW}$$

We can see that the peak power here is huge compared to the average power. The pulse length can be very short (i.e. picoseconds or femtoseconds) resulting in very high peak powers with relatively low pulse energy, or it can be very long (i.e. milliseconds) resulting in low peak power and high pulse energy, while each of these conditions might produce similar average power levels.

7.1.3 Example Calculation 2

Consider a HeNe CW laser with a constant output of 10mW, what is the energy of the output beam over a duration of quarter of a second? So we know that power is the rate of change of energy so we only need to multiply the power by time to find the energy.

$$Q = 10 \text{ mW} \times 0.25 \text{ s} = 2.5 \text{ mJ}$$

Let's consider a pulsed laser system with the equivalent energy per pulse but with a pulse duration of just 10ns. What is the peak power per pulse?

$$P_{\text{PEAK}} = 2.5 \text{ mJ} / 10 \text{ ns} = 2.5 \times 10^5 \text{ W}$$

We can see clearly that the peak power per pulse is huge for the pulsed laser system.

7.1.4 Example Calculation 3

This time let us look at a Ti:sapphire Regenerative Amplifier used to generate short but high energy pulses of laser light. The repetition rate is 200kHz, read from the display panel on the controller. The average power at the output is 900mW measured using a standard power meter. What is the peak energy and the peak power per pulse? The measured output power is the average power so we can calculate the Energy per pulse by taking the repetition rate and dividing it into this value.

$$Q = 900 \text{ mW} / 200 \text{ kHz} = 4.5 \text{ } \mu\text{J}$$

so we get an energy of 4.5 μJ per pulse.

Using a standard autocorrelator we can see the pulse width, t_{PULSE} is 130 femtoseconds (fs). We can now calculate the pulse Peak Power, P_{PEAK} .

$$P_{\text{PEAK}} = 4.5 \text{ } \mu\text{J} / 130 \text{ fs} = 35 \text{ MW}$$

Once again we can see the peak power is huge compared to the average power of 900mW.

NB: The repetition rate of a laser can be changed by the user resulting in a corresponding change in average power.

7.2 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 critically important. When a laser beam's power is focused down 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 by per unit area contained in the beam profile than if the beam is spread over a greater area.

Irradiance (E) is the Power (P) received by a surface per unit area (A) measured in Watts per square meter, W/m^2 .

$$E = \frac{P}{A}$$

Radiant Exposure (H) is the radiant Energy (Q) received by a surface per unit area (A), measured in Joules per square meter, J/m^2 .

$$H = \frac{Q}{A}$$

It is important to recognise that E is not used for energy in laser calculations and always represents Irradiance.

Radiant exposure is typically used for pulsed laser systems which cannot be fully characterised using only irradiance as it does not take the frequency, temporal width and energy of the pulses into consideration.

Calculating the irradiance and radiant exposure is especially important when choosing safety eyewear 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 yourself and to do this you will need to comply with standard conventions. If you need to make these measurements you should consult with your Laser Safety Officer.

7.3 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. They are calculated for both the eyes and skin. You may see the term Exposure Limit Values (ELV) used instead of MPE generally the only significant difference is that ELVs are often used as mandatory levels, and to exceed them is to commit a regulatory offence. The MPE values are set by the *International Commission on Non-Ionizing Radiation Protection* (ICNIRP). MPEs are also used as the basis for Laser Classification.

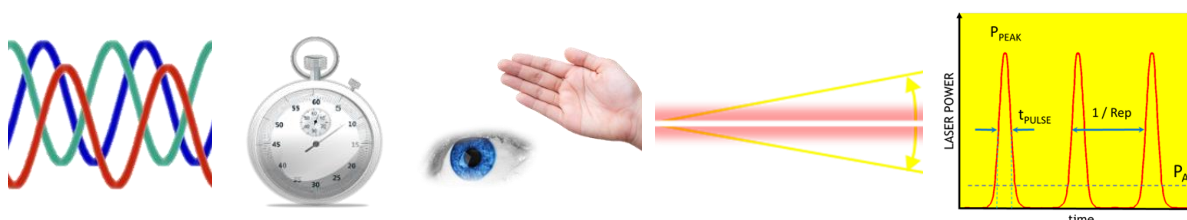
MPEs are based on studies of the “Exposure Dose 50” or “ED50.” For visible laser light, this is the irradiance at which a given laser exposure has a 50/50 chance of causing the smallest detectable change.

The Maximum Permissible Exposure has been set to be 1/10 of the ED50 limit; this can be considered to be a “10-times safety factor.” Usually 10% of the dose that has 50% chance of doing damage.

The MPE is measured in irradiance (W/cm^2) and radiant exposure (J/cm^2).

The MPE depends on

1. Wavelength
2. exposure time
3. tissue at risk, ocular or skin
4. spatial distribution of the beam
5. Emission mode, CW or Pulsed



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.

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.

7.3.1 Example Calculation of an MPE

This example will show you how MPEs are calculated using the tables in standard 60825-1:2014. A normal laser user will not typically be required to make such calculations but it is useful for your understanding to see how these calculations are made and how they relate to laser CLASS.

What is the MPE for a continuous wave visible laser? i.e. What is the safe level of power for a visible laser if incident on an unprotected, fully dilated pupil?

1. For MPE calculations a fully dilated pupil is assumed to be 7mm in diameter
2. We look up the formula for the MPE from the tables in the EN 60825-1:2014 standard and we find it is

$$\text{MPE} = 18t^{0.75} \text{ Jm}^{-2}$$

3. We are told to use the value 0.25s for t as this is the time it takes for the eye to react to an uncomfortable stimulus (blink reflex).
4. putting in $t = 0.25\text{s}$ we find the

$$\text{MPE} = 6.36 \text{ Jm}^{-2}$$

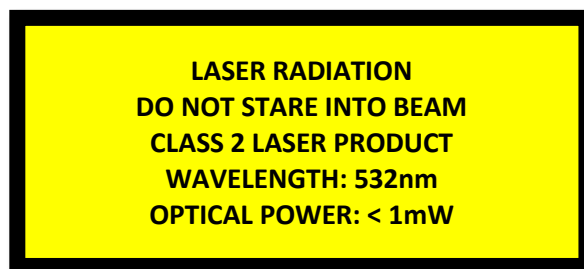
5. Remember that power = energy/time so to convert this value to irradiance (Wm^{-2}), we divide 6.36 Jm^{-2} by the time 0.25s, which gives us a value of 25.4 Wm^{-2} . So we now know that the safe irradiance is 25.4 Wm^{-2} for a visible laser.

$$\text{MPE is } 25.4 \text{ Wm}^{-2}$$

6. How does this equate to the power level which can enter the eye and not cause damage?
The area for the pupil of diameter 7mm using πr^2 is $3.85 \times 10^{-5} \text{ m}^2$, we can now calculate how much power enters the eye.

$$25.4 \text{ Wm}^{-2} \times 3.85 \times 10^{-5} \text{ m}^2 \approx 1 \text{ mW}$$

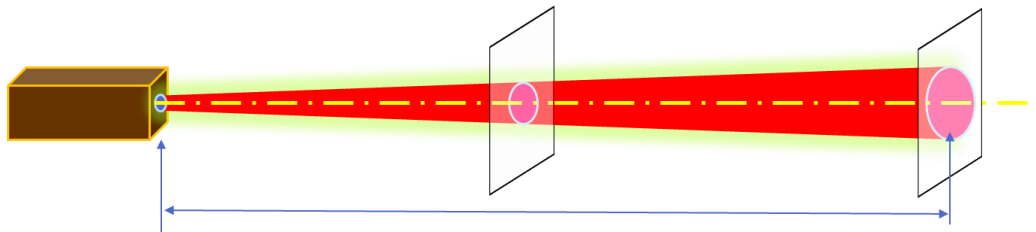
Hence all CLASS 2 lasers must be 1mW or less so that the blink reflex can help to protect the eye from accidental intra-beam viewing.



7.3.2 Summary

- MPEs are set below the damage threshold
- MPEs are reviewed by the International Commission on Non Ionising Radiation (ICNIRP).
- MPEs are used in the EN 60825-1 standard.
- MPEs are also used as a basis for Laser Classification.

7.4 Nominal Ocular Hazard Distance (NOHD)



In the university environment where lasers are in operation it is better to assume the entire laboratory is in the Hazard Zone, for both intra-beam viewing as well as specular and diffuse beam reflections.

Where lasers are in open space or where focusing optics are introduced to a beam the irradiance may be increased or decreased and thus increase or reduce the hazard at a particular distance from the beam. Even if optical components are not used the beam diverges as it propagates through free space, it is therefore possible at some distance the irradiance may equal the MPE. Within this distance there is a danger of receiving an eye or skin injury directly or from reflection thus it is termed the Nominal Ocular Hazard Distance and Zone respectively. The lower the divergence the greater the distance.

As already stated within the college any high powered laser above CLASS 3R should be treated as if the hazard distance is effectively infinite. Specular and diffuse reflections must also be treated as a serious hazard. Diffuse reflections from CLASS 4 lasers especially from near infra-red beams are particularly dangerous as prolonged viewing can lead to substantial injury to the retina of the eye.

Using the beam diameter at the aperture of the laser and the divergence value (from specifications for laser) in radians the NOHD can be calculated.

$$NOHD = \frac{\sqrt{\frac{4 \times Power}{\pi \times MPE} - Diameter}}{Divergence}$$

7.4.1 Summary

- The divergence of the laser should be available from the specifications for the system
- If there are no optics affecting the irradiance significantly along the beam it is best to assume that the laser beam is fully collimated with distance.
- If the beam is being focused the irradiance is also increased.
- Diffuse reflections may exceed the MPE within the hazard Zone
- Even relatively low powered lasers may have their CLASS effectively changed to a higher one if focusing optics are placed in the beam path.

7.5 Measuring the Power of a Laser Beam

Whether it is for laser safety or for your own research work it will probably be necessary to measure the power output of your laser. You may need to measure the diameter of the beam also if optical components have been used that focus the beam or collimate it. You may need to speak with your laser safety officer or another laser expert user if you are not familiar with the procedures to do so. Wide beams may require a limiting aperture to be placed in front to help measure the irradiance for laser safety protocols.

There are various power meters on the market which can be purchased but depending on your situation it may be sufficient to borrow one.



- Be careful, each power meter will have a power and wavelength range, check the manual.
- You may inadvertently damage the meter with high power or measure wrong values if it is not appropriate for your laser application.
- For pulsed laser systems the meters measure the average power not the peak power.
- Energy and peak power per pulse is calculated from the average power and repetition rate.

8 LASER CLASSIFICATION

Classification indicates the level of laser beam hazard presented by a particular laser system, typically it is the responsibility of the manufacturer to state the correct CLASS but if the system is changed by the end user or the product comes from outside the EU it may be necessary to redefine the CLASS.

8.1 Accessible Emission Limit (AEL)

AEL is the maximum accessible Emission limit of laser radiation permitted within a particular laser CLASS. Once the AEL for a particular CLASS is exceeded then the next higher CLASS must be considered.

The Accessible Emission Limit (AEL) defines the maximum emitted laser radiation permitted within a particular CLASS.

1. in a specified wavelength range
 2. In a specified exposure time
 3. through a specified aperture stop
 4. at a specified distance
- AELs are not applicable to CLASS 4 lasers as there is no upper limit for this CLASS.
 - The AEL values are determined using the MPE values



8.2 LASER CLASSES

There are 8 Laser CLASSES in total specified in the EN 60825-1:2014 standard.

8.2.1 CLASS 1

- Lasers that are *eye-safe* during normal use, including long-term direct intrabeam viewing, even with the use of focusing optics are categorised as CLASS 1 Lasers.
- The term '*eye-safe*' can only be used for CLASS 1 lasers.
- CLASS 1 lasers may have embedded high powered lasers of a higher CLASS inaccessible to the normal user.



Examples: DVD players, laser printers, confocal microscopes

8.2.2 CLASS 1C

- The C in this CLASS stands for contact and these lasers are specifically designed for contact application to the skin or non-ocular tissue.
- Typically applied to skin or internal body tissues for medical, diagnostic, therapeutic or cosmetic procedures.
- CLASS 1C may use higher CLASS lasers but the danger of accidental exposure is prevented by one or more engineering controls.



Examples: medical lasers, lasers used for hair removal, acne reduction, tattoo removal

8.2.3 CLASS 1M

- Lasers that are safe during normal use, including long-term direct intrabeam viewing with the unaided naked eye.
- The MPE could be exceeded with the use of focusing optics such as binoculars or telescopes.
- CLASS 1M lasers are restricted to the spectral region of 300nm to 4000nm where glass can transmit. The 'M' stands for magnification.



Examples: Fibre communication systems

8.2.4 CLASS 2

- Safe within normal use. Low power, only applies to visible lasers 400-700nm.
- A CLASS 2 laser is considered safe because the blink reflex (0.25s) will limit the exposure.
- Can be dangerous for intentional prolonged exposure.
- CLASS 2 lasers typically have an AEL of 1 mW for Continuous Wave.
- Can be pulsed or Continuous Wave.



Examples: laser pointers, bar scanners, alignment lasers

8.2.5 CLASS 2M

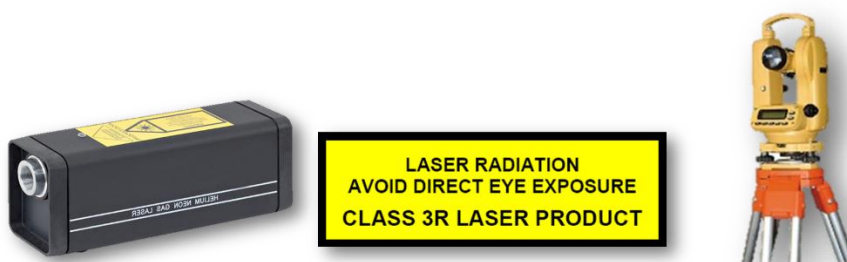
- Lasers that are safe during normal use, including unintentional short-term direct intrabeam viewing with the unaided naked eye.
- As with CLASS 1M this CLASS will have a relatively low irradiance but the MPE could be exceeded with the use of focusing optics such as binoculars or telescopes.
- As with CLASS 2 lasers they are restricted to the visible region of the spectrum.



Examples: alignment lasers, entertainment laser light projectors

8.2.6 CLASS 3R

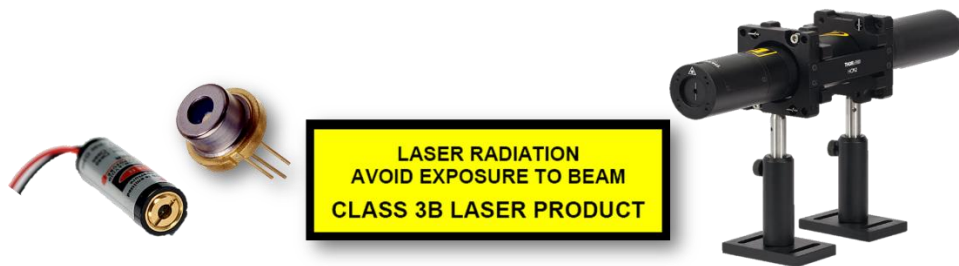
- Laser products that can exceed the MPE under direct intrabeam viewing, but the risk of injury in most cases is relatively low. The R stands for Relaxed/Reduced criteria.
- CLASS 3R lasers are generally < 5mW in the visible region, for other wavelengths and pulsed lasers other limits apply
- They are considered low risk in normal use because of the safety margin accounted for in the MPE.



Examples: research lasers < 5mW, theodolites used in surveying

8.2.7 CLASS 3B

- CLASS 3B Lasers are normally hazardous when intrabeam ocular exposure occurs including accidental short time exposure.
- Viewing diffuse reflections is normally safe but not specular reflections.
- CLASS 3B lasers may produce minor skin injuries or even pose a risk of igniting flammable materials if focusing occurs.
- They are typically in the power range of 5mW to 500mW.



Examples: Diode lasers, HeNe lasers

8.2.8 CLASS 4

- CLASS 4 lasers are high powered, generally greater than 500 mW.
- Viewing of the direct beam, specular reflections or diffuse reflections is dangerous and will most likely result in injury.
- CLASS 4 lasers present a significant fire and skin hazard: beam can cause ignition of combustible material, paper, clothes, plastic, and chemicals.
- There is no upper AEL for CLASS 4 lasers



Examples: industrial material processing lasers, research based lasers

8.2.9 Old and New Classification System

You may still come across lasers using the older system for Classification and it is important to recognise and understand it. Also you may see laser CLASSES marked in Roman numerals; IIIB, IV (ANSI Z136.1).

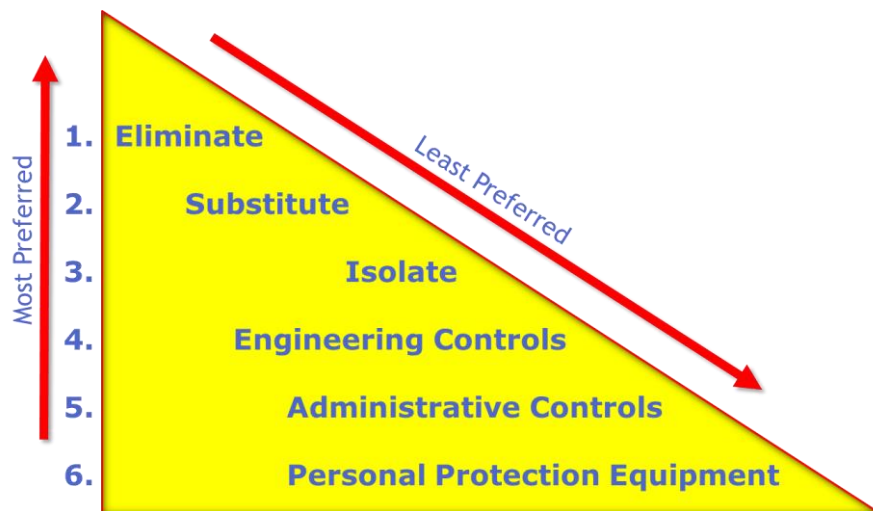
OLD	NEW	HAZARD LEVEL
1	1	Eye Safe because of enclosure or low irradiance but may have embedded high powered lasers.
	1C	Safe when used only as intended on target tissue
	1M	Safe to the unaided eye provided focusing optics not used to view Avoid using magnifying lenses, telescopes, microscopes etc
2	2	Visible lasers. Safe for accidental exposure (< 0.25s) Avoid staring into the beam
	2M	Visible lasers. Safe for accidental exposure (< 0.25s) as long as no focusing optics are used. Avoid staring into the beam
3A & 3B*	3R	Not safe but low risk of injury if used correctly Prevent direct eye exposure
3B**	3B	Hazardous. Viewing of diffuse reflection may be safe. Prevent eye and skin exposure
4	4	Hazardous. Viewing of diffuse reflection also hazardous. Fire risk. Prevent eye and skin exposure

The main difference is in the lower CLASSES but CLASS 3B and 4 are still basically the same and should still be treated the same. The American standard *ANSI Z136.1 (2014) - Safe Use of Lasers* uses the Old CLASS system and you may need to be aware of this when purchasing. In all cases you should only purchase system that comply to the European standard EN 60825-1:2014.

9 CONTROLS AND PROTECTION

Wherever a risk of personal injury or possible damage to a working environment exists through the use of lasers, control measures must be implemented. The degree of these measures may be determined through an accurate risk assessment or directives from the LSO and recommendations from the manufacturer. Risk should be completely removed or reduced to the absolute minimum possible.

9.1 Hierarchy



The hierarchy for control measures shows the most preferable first with the least preferable at the bottom. An example is given for each measure below.

- **Elimination:** remove the hazard completely, if you do not need a laser then remove it from the lab.
- **Substitution:** If you do not need the power of a CLASS 3B laser replace it with a CLASS 2 or 3R
- **Isolate:** completely enclose the laser system so that no beam is accessible
- **Engineering control:** use interlocks on the enclosure or the entrance to the laser designated area
- **Administrative control:** Put appropriate signs on the door to alert people to the hazards and risks
- **Personal protective equipment:** Use the appropriate protective eyewear for the laser in use

This hierarchy is common for all risk management and can be applied to other secondary non-beam dangers associated with laser systems. The first two on this list should be well considered before commencing with a particular experimental setup. The last three will be dealt with here in a little more detail as they deal with hazards that cannot be completely removed.

9.2 Engineering

Engineering controls and measures are recognised as being far superior to administrative ones as they help remove the human element and do not require a degree of compliance by the individual. Micro switches and interlocks that shut the laser off when covers are removed or doors opened are much more reliable than trusting people to follow procedure. In the R&D environment there are challenges to implementing effective engineering controls that do not inhibit the functionality or the progress of work. Very often decisions need to be made in conjunction with the LSO to reduce the risk as far as possible using engineering controls and then augment with added administrative ones to help better protect the users. For example, this could happen where there are multiple wavelengths in a laser laboratory coming from the same or other laser systems. It may not be possible to interlock all enclosures and screens around a particular system but by defining what eye protection must be worn and where people are prohibited from in the room the risk can further reduce the risk.

- **Use beam enclosures and place beam blocks and screens where possible.**
- **Block stray beams with beam blocks**
- **Reduce the power of the beam to as low as possible.**
- **Reduce the power of the beam during alignment procedures.**
- **Ensure all optical components and mounts are securely fixed**
- **Keep the beam below eye level and parallel with the surface of the optical bench.**
- **Use a Laser Designated Area (LDA) with interlocks.**
- **Provide good ventilation and extraction if required.**
- **Ensure there is no possibility of the beam escaping the LDA.**



Screens can be used to surround an experimental setup to stop stray beams from exiting the optical bench area. Tubes can be used in the experimental setup to enclose beams so that items cannot fall into the beam path and accidentally deflect the beam towards a person's eyes. Beam blocks / dumps may be needed where an optical component inadvertently splits the beam, e.g. cube polarisers, diffraction gratings.

It is important to use non-flammable material when setting up screens and other enclosures. They can be purchased commercially.

If it is possible, it is always ideal to enclose the laser system completely with a fully interlocked light tight enclosure effectively reducing it to CLASS 1. It may also help to assist your experimental work by blocking out the ambient light and help stabilise environmental effects such as temperature.

9.3 Administrative

Administrative controls are next on the list in the hierarchy of control measures. They depend on the people acting correctly on information and following work procedures. Their implementation and effectiveness depends on the compliance of the laser users and others working in the vicinity. Administrative controls cover the laser safety policies of the university, the implementation of the laser safety management program, work procedures, training, registration and assignment of responsibilities.



Administrative controls will consist mainly of the following

- **Laser Safety Training and Registration.**
- **Laser Designated Areas with Warning Lights!**
- **Logging use of the laser**
- **Removal and return of the power supply keys to a designated point**
- **Good signage both the Lasers and entry points**
- **Risk assessment and Scheme of Work**

As a laser user or if you work in the vicinity of active lasers you will be expected to comply with all administrative controls put in place by your lab supervisor and LSO and to complete a risk assessment appropriate for your laser system.

9.4 Personal Protection Equipment

The nature of the work involving Laser systems in the university environment means that it is not always practical to reduce the danger of exposure to levels of artificial optical radiation to zero by engineering control measures alone. Access to the beam for the servicing of the laser or setting up of optical components and samples for analysis is often necessary as a matter of routine. Personal protective equipment, (PPE) is required to ensure that in the event of an accidental exposure the laser user is not injured.

- **Safety Eyewear**
- **Protective Clothing**
- **Face mask**



In general, the risk of injury to the skin is minimal and can normally be avoided by good practices. Exposure of the skin to direct beams should always be avoided but in the case of the UV wavelengths the use of gloves, long sleeves and a face shield is recommended. If you need to work with high pressure lamps a full protective face shield is required along with eye protection in case of explosion.

An injury to the eye can be life changing and is the most common injury that occurs with lasers in the research environment. Personal eye protection is the last line of defence and is the one unfortunately that is very often absent when an incident occurs even when available and appropriate to the laser in use. 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.

If there is a danger of particulate matter being ablated due to the laser process, adequate extraction and ventilation should be used and if necessary a facemask.

10 SELECTING LASER SAFETY EYEWEAR

Ultimately Laser Safety Eyewear is your last line of protection, it is the least preferable as it implies that the hazard has not been completely removed or reduced to a safe level and you are therefore potentially exposed and at risk of injury. Very often safety laser windows use the same filter materials as do eyewear so the process of selecting the filter material is the same; both must comply with the same European standards, EN207 and EN208.

Choosing the correct Laser Safety Eyewear to wear is not trivial and you must ensure that you are competent enough to be able to select the correct eyewear for the laser beam you are working with.

Always check the eyewear you are using; do not assume just because it was handed to you or because it was beside a laser that it is correct. Many laser systems are tuneable and can have their output changed, power, wavelength, emission mode, repetition rate and pulse energy can be changed by the user.

All laser safety eyewear must be cleaned and stored appropriately to help keep them in good condition, do not use non-recommended solvents as they may affect the filters. Speak with the manufacturer / supplier for details. Safety Eyewear should be placed in storage near the entry point to the LDA so that they can be put on before entering.

Laser safety eyewear works by simply absorbing the laser light so that it does not reach your eyes. The filter material and frame must be able to absorb the energy of a laser beam strike without losing integrity.



10.1 Optical Density (OD)

Protective eyewear is made possible with the use of filters which can 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.

Attenuation (H / 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

$$OD = \text{Log}_{10} \left[\frac{AE}{MPE} \right]$$

The formula above gives you the attenuation factor required for a particular MPE (safe level) when you know the highest AE (accessible emission) of the laser. The units can be irradiance (E) or radiant exposure (H) measured in W/m² or J/m² respectively. The value is logarithmic so the OD will tell you the attenuation factor the filter material theoretically has on the

beam. It does not however tell you the damage threshold of the filter material! The material may not be able to withstand the power of a particular laser and may fail instantaneously and result in serious eye injury.

In Europe two standards have been developed for materials used as filters and frames in laser protective eyewear and windows. EN207 and EN208 both account for the damage threshold of the material being used.

EN207 is used for full attenuation filters where they fully block the wavelength they are specified for. They are not limited to a particular wavelength range.

EN208 is used for partial attenuation, these filters are used only in the visible range 380-700nm where they reduce the beam intensity down to the MPE (safe level). They are particularly useful for alignment where seeing the beam is necessary.

We will refer to just the filters used in protective eyewear in this guide but it should be understood that the material used to support the filters is also tested and included in the standard.

It should be also noted that any laser protection filters that are scratched or damaged or have received a laser strike are no longer safe to use.

10.2 EN207 Full Attenuation

With CLASS 3B or 4 lasers where there is a danger of exposure to limits above the MPE full attenuation eye protection must be worn in the UV and in the NIR, Mid to Far IR wavelength ranges as there is no advantage to wearing partial transmitting alignment eyewear where the light is invisible to the human eye.

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

*D63 diameter is when 63.2% (1/e cut-off) of the total power is contained in a variable aperture

In 2010 the testing criteria was changed therefore protective eyewear was relabelled to indicate this. The older 1998 eyewear will use *L* beside the attenuation factor and the newer will have *LB*. The Optical Density is still stated on the eyewear and you will be shown how to interpret the labelling on eyewear correctly in this guide.

The LB rating of the filter material

- Specifies the damage threshold at a maximum power or energy density.
- Must be able to withstand a direct hit for a period of > 5 seconds in Continuous Wave mode or for 50 pulses.
- This Scale number should give reasonable comparability of similar laser safety products.
- We do not need to worry about calculating the MPEs because these have already been accounted for in the maximum power / energy densities specified for each LB number.

10.3 EN208 Partial Attenuation

With CLASS 3B or 4 laser systems in the visible wavelength range, 380-700nm where there may be a need to see the beam for alignment purposes, filters complying to EN208 will effectively reduce the laser irradiance down to the safe MPE level.

EN208	Beam Diameter D63*	Exposure time	Labelling
1998	2mm	10s or 100 pulses	R
2010	1mm	5s or 50 pulses	RB

*D63 diameter is when 63.2% (1/e cut-off) of the total power is contained in a variable aperture

The RB rating of a filter material

- EN208 applies to Visible lasers only (i.e. 380 - 700 nm wavelength range)
- Standard used for alignment eyewear where sometimes it is necessary to be able to see where the beam is.
- The hazard is reduced to below CLASS 2 AEL limit.

10.4 Labelling on Protective Eyewear

All laser protection eyewear 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.

1	2	3	4	5	6	7
Wavelength (nm)	Laser Type (DIRM)	Protection level	Manufacturing code	Compliance	EC type approval	Mechanical robustness
900-1100	D	LB 10	LV	DIN	CE	S
1	The wavelength range that the eye protection is specified for.					
2	The code letter here is for the different laser emission pulse lengths that the eyewear protects against in this wavelength range, it can be D, I, R or M see below.					
3	LB as discussed previously is the protection rating of the filter material for full attenuation, EN207. RB if seen here is used for partial attenuation, EN208. The number 10 implies the Optical density is 10 or greater.					
4	LV is the manufacturing code, Laser Vision in this case					
5	DIN is a compliance code you may or may not see "Deutsches Institut für Normung", meaning "German institute for standardisation."					
6	The CE mark is very important and must be displayed on the eyewear to indicate compliance with the European standards. Abbreviation of French phrase "Conformité Européene" which literally means "European Conformity"					
7	The letter S may also be present to indicate "Increased robustness" of both the frame and filters.					

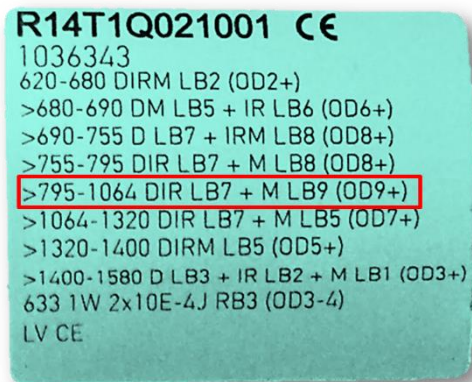
10.5 Temporal mode

The laser protective eyewear must be appropriate for the temporal mode of the laser. It must take

CODE	Emission Mode
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)

into account the radiant exposure, (H) as well as the irradiance, (E) that the filters can withstand within the testing criteria set by EN207 and EN208. Letter [R] for short pulses must not be confused with the older 1998 EN208 alignment filter code R.

- Letter [D] is used for continuous wave, CW pulses greater than 0.25 seconds in duration.
- Letter [I] indicates the pulse range from the 0.25 seconds to 1 microsecond in length.
- Letter [R] is for lasers with pulses in the microsecond to the 1 nanosecond range.
- Letter [M] indicates a pulse duration of less than a nanosecond down to the femtosecond.



The label shown here is typical of those found on protection eyewear 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 right. We can see that for different wavelength ranges and pulse widths the eyewear has different protection levels.

Taking the sample line **>795-1064 DIR LB7 + M LB9 (OD9+)**

- We see all values on this line are relevant to the wavelength range greater than but not including 795nm and up to and including 1064nm.
- For lasers with long pulses > 0.25s (D) and for pulses greater than 1ns in length (IR) it will offer protection of LB7.
- For pulses less than a 1ns (M) the protection level is LB9.
- The highest optical density of 9 (OD9+) in this range is also indicated in brackets for completeness.
- The last line on this label shows that the eyewear can be used to provide alignment protection of RB3 for the wavelength 633nm up to 1 Watt of power or 2×10^{-4} Joules.

10.6 Choosing the Correct Eyewear

When 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 RB number. Once we know the wavelength(s), emission mode and the power or energy of the laser we can calculate which protection level is required using the EN207 and EN 208 charts.

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. If in doubt speak with your Laser Safety officer.

We have discussed the protection level indicated by the scale numbers found on eyewear and its meaning, but how do you know what level of protection is appropriate for the system you are using?

Before calculating the correct protection level required there are some fundamental parameters of the laser you will be required to know. These may be provided in the specifications but they can be variable or effected by the configuration of the system.

10.6.1 Continuous Wave

For Continuous wave, CW lasers you will need to know the

- wavelength in nanometres (nm)
- laser power in Watts (W)
- the smallest beam diameter in meters (m)

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 the table of 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.

10.6.2 Pulsed Lasers

Choosing the right laser protection eyewear for a pulsed laser is a little more complicated as we will need to calculate the irradiance (E) and radiant exposure (H), to do so we will need to know

- laser wavelength (nm),
- average laser power in Watts (W)
- energy per pulse in Joules (J)
- pulse repetition rate in Hertz (Hz)
- temporal width of the pulse in seconds (s)
- smallest beam diameter in meters (m)

We must ensure that the eyewear offers the correct protection level for both the equivalent CW (D long pulse) and pulsed (IRM short to ultra-short pulse) emission types according to EN207 for full attenuation. For the alignment standard, EN208, we only need to consider the energy of the laser.

There are two steps required to calculate the LB and RB scale number for a Pulsed Laser. The first is based on the average power and the second is based on the radiant exposure.

Average power of a pulsed laser

1. Calculate the cross-sectional area of the laser beam.
2. Now calculate the average power of the beam. This is the energy per pulse multiplied by the pulse repetition frequency, see section 7.1. It can also be measured directly using a suitable power meter.
3. Next, calculate the average power density of the beam by dividing the average power by the area of the beam.
4. Next, refer to the table of protection levels in EN 207.
5. Select the column corresponding to the wavelength range of your laser, either 180-315nm, >315-1400nm or >1400-10000nm.
6. Initially we need to select the column in that wavelength range for the equivalent CW laser, temporal mode type D.
7. Now choose the first scale number, LB, under the D column which is equal to or higher than the average power density of your laser.

Corrected radiant exposure of a pulsed laser

1. For the second part of the calculation, take the beam area you calculated in step 1 above and calculate the energy density of the beam by dividing the pulse energy by the area of the beam.
2. If your laser wavelength falls between 400 to 1400nm, the range which can be transmitted to the retina, you need to calculate a corrected energy density by multiplying the energy density from the previous step by the factor $N^{0.25}$ where N is the total number of pulses emitted in 5 seconds. To calculate the number of pulses in 5 seconds just multiply the pulse repetition rate in Hertz (Hz) by 5.
3. Again refer to the table of protection levels in 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 laser type corresponding to the pulse duration of your laser, either I for long pulsed, R for Q-switched and M for modelocked.
6. Finally, choose the scale number, LB, which is equal to or higher than the energy density of your laser.

If the average power scale number is higher than the radiant exposure, then that value must be used.

Pulsed laser safety calculations are particularly complicated and if you require assistance you should contact your laser safety officer.

10.6.3 Example

To help you better understand we will work through a relatively simple scenario.

We need protective eyewear for a 10W, CW laser of wavelength 1064nm the circular beam diameter is 4 mm.

To simplify the calculations without compromising safety we assume no divergence, full collimation, and a flat beam profile, not Gaussian. The beam is invisible so we must use eye protection which fully attenuates the beam according to standard EN207.

Using $A = \pi r^2$ we can take half the diameter, convert to meters, and the area of the beam is $12.5 \times 10^{-6} \text{ m}^2$.

We can divide the power of 10W by the area to get an irradiance of $8 \times 10^5 \text{ Wm}^{-2}$.

Now we refer to the chart for EN207, next page

- The wavelength is 1064nm so we go to the column spanning the wavelength range 315 -1400 nm, outlined in red.
- The emission mode of the laser is CW so we look at the column under this mode D.
- Looking at the exponent value of the irradiance, $8 \times 10^5 \text{ Wm}^{-2}$ we can go to that value in the column.
- But we can see that the coefficient is 8, but we can round up to 10, so we can move to the next higher value of 1×10^6 . Always round up to be safe, the higher the LB number the higher the protection.
- We can then read off the protection level from the side and in this case it is LB5.

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
S	T	$\geq 3 \times 10^{-4}$	10^{-9} to 3×10^{-4}	$< 10^{-9}$	$\geq 5 \times 10^{-4}$	10^{-9} to 5×10^{-4}	$< 10^{-9}$	≥ 0.1	10^{-9} to 0.1	$< 10^{-9}$
LB1	10^{-1}	0.01	3×10^2	3×10^{11}	10^2	0.05	1.5×10^{-3}	10^4	10^3	10^{12}
LB2	10^{-2}	0.1	3×10^3	3×10^{12}	10^3	0.5	1.5×10^{-2}	10^5	10^4	10^{13}
LB3	10^{-3}	1	3×10^4	3×10^{13}	10^4	5	0.15	10^6	10^5	10^{14}
LB4	10^{-4}	10	3×10^5	3×10^{14}	10^5	50	1.5	10^7	10^6	10^{15}
LB5	10^{-5}	10^2	3×10^6	3×10^{15}	10^6	5×10^2	15	10^8	10^7	10^{16}
LB6	10^{-6}	10^3	3×10^7	3×10^{16}	10^7	5×10^3	1.5×10^2	10^9	10^8	10^{17}
LB7	10^{-7}	10^4	3×10^8	3×10^{17}	10^8	5×10^4	1.5×10^3	10^{10}	10^9	10^{18}
LB8	10^{-8}	10^5	3×10^9	3×10^{18}	10^9	5×10^5	1.5×10^4	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^6	3×10^{10}	3×10^{19}	10^{10}	5×10^6	1.5×10^5	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^7	3×10^{11}	3×10^{20}	10^{11}	5×10^7	1.5×10^6	10^{13}	10^{12}	10^{21}

Check carefully whether the marking on the laser safety eyewear gives you the appropriate protection required for the laser you are using.

- Appropriate wavelength(s)?
- Appropriate for the power and energy density?
- Appropriate Emission type? Pulsed or Continuous Wave?
- Appropriate protection level?

10.7 Purchasing Protective Eyewear



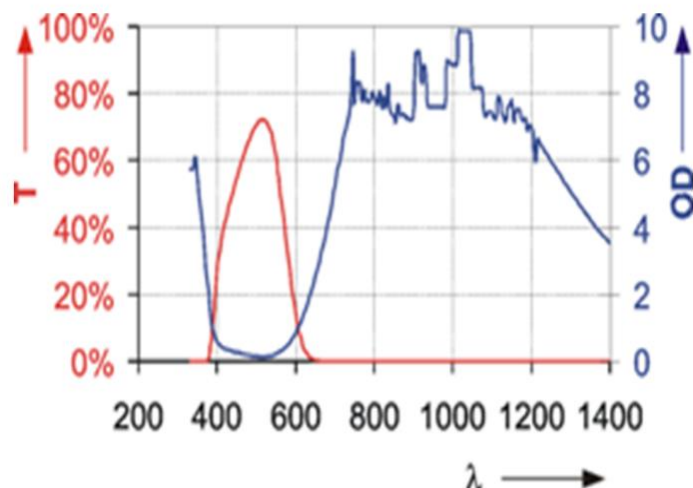
If you need to purchase protective eyewear from a supplier, you will need to give them some basic information about the laser beam you are working with.

They will request details on

- Laser wavelength
- Average power
- Smallest beam diameter
- Beam divergence
- Repetition rate for pulsed lasers
- pulse energy
- Pulse duration / temporal width

You should also consider the following

- How comfortable the frame is, will it fit over prescription glasses, if the eyewear does not fit well people will be less likely to wear it.
- The visible light transmission VLT and perceived brightness, the higher the better, if too many wavelengths are blocked in the visible spectrum you may be in more danger as your ability to see is diminished. If it is unavoidable then the ambient illumination of the room must be increased.
- Speak with your laser safety officer if you need assistance with purchases.



10.8 Maintaining and Storing Protective Eyewear

All laser protective eyewear pertaining to a particular laser hazard zone should be accessible to all users entering the area. The eyewear should be stored in designated, clean draws or containers, in an area outside the hazard zone close to the entry point. These containers should be well labelled with the details of the eyewear on the outside. Care should be taken to replace the eyewear back to the correct container. Eyewear, filters, or laser protection windows damaged or scratched and filters that have changed colour should not be used. Do not expose the eyewear permanently to daylight or UV-lamps. Protect all the filters and eyewear from scratches and mechanical stress. Avoid contact with chemicals, or reactive fumes. Never leave glasses with filters facing down. Glasses should not be stored near heaters or hot equipment. Store in dry, sturdy boxes. Only clean the filters according to the manufactures instruction.

It is your personal responsibility to ensure you have the correct laser protection eyewear, do not assume because the eyewear is in a particular location or it is handed to you that it is correct for the laser you are working with.

10.9 Multiple wavelength Environment

Not all designated laser areas are used for just one single laser system and wavelength, although this would be the ideal situation. You may well find yourself working in an area with two or more systems producing multiple wavelengths. You need to be mindful that other personnel may be aligning or manipulating the direction of the beam and can accidentally send it across the room towards you. There should always be enclosures, screens and beam blocks used where possible to minimise accidental exposure. But if you are in a hazard area then you need to wear eye protection to cover all the laser wavelengths that you may be exposed to. The eyewear must provide you with protection but you must also be able to see adequately. The more wavelengths the eyewear protects you from in the visible region of the spectrum the lower the brightness will be. The LDA must be managed to minimise accidental exposure, ensure adequate administrative controls on the wavelengths of the laser beams in use at the same time.

There can also be laser systems where there are more than one wavelength emitted and the beams are superimposed. The conservative approach of adding the exposures should always be taken. Exposures in this case from several wavelengths should be assumed to have an additive effect especially where both wavelengths affect the same tissue. For example, exposure to 532 nm and 1064 nm Q-switched radiation will be treated as additive, as both affect the retina.

11 WARNING LABELS AND SIGNAGE

Safety signs should be used only where appropriate and should be clear and unambiguous otherwise they are often ignored. Warning signs should indicate the equipment in use and the appropriate action or actions to protect one self. Signs should be placed at the entrance to and within a controlled area at eye level. All safety signs should comply with European standard EN 60825-1 [9].

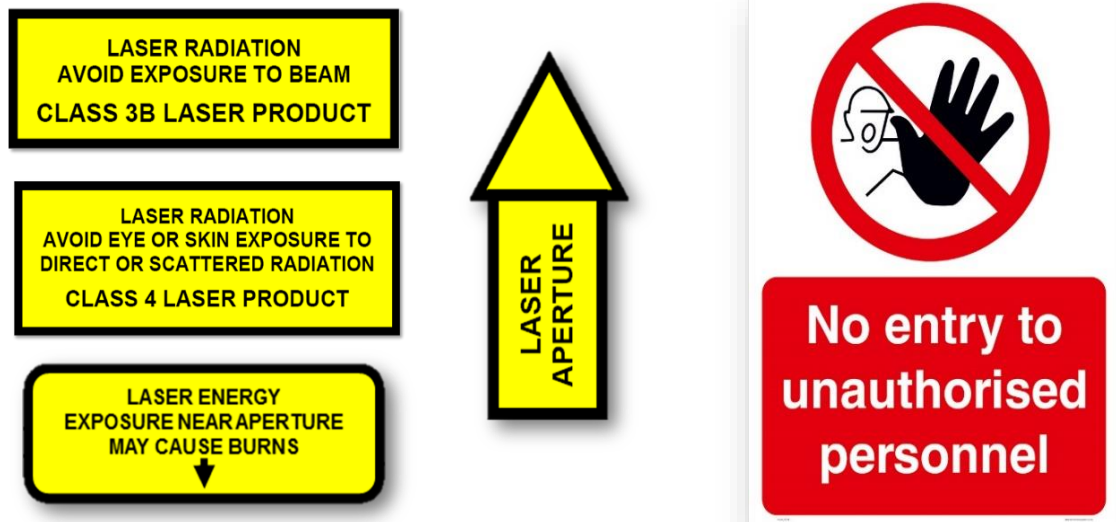
The following signs and labels are required where a laser is in use and a potential hazard could be present.

- **Warning triangles;**
The star burst label is required on all lasers above CLASS 1
- **Aperture labels;**
These are required on all CLASS 3R, CLASS 3B and CLASS 4 lasers. You may also need to place them on different parts of your experimental set up where the laser is exiting an optical component.
- **Classification labels;**
Any laser exceeding CLASS 1 requires a Classification label, if the size of the laser does not permit the affixing of a reasonably sized label, a sign should be displayed in close proximity to the laser with all appropriate information.



- **Safe CLASS 1 Lasers Labels;**

In the University all material processing and research based CLASS 1 laser systems containing lasers of a higher CLASS must be a labelled specifying CLASS 1 on the exterior, and ideally a label specifying the details of the embedded lasers contained in the system. These embedded lasers are often required to be accessed for service and maintenance.



- **Protective housing labels;**

These are required on all panels or connections which when removed, opened or displaced will give access to radiation in excess of CLASS 1. The CLASS of this label is determined by the CLASS of the laser radiation accessible once the panel is opened (e.g. a panel on a CLASS 1 laser product, which when removed gives access to CLASS 3B laser radiation will require a Protective Housing CLASS 3B label).

- **Interlocked housing labels;**

These are required on all interlocked panels which when opened will give access to radiation in excess of CLASS 1 when the interlock is overridden. The label should be fixed in close proximity to the opening and must be visible prior to and during interlock override. The CLASS of this label is determined by the CLASS of the laser radiation accessed once the panel is opened and the interlock overridden (e.g. an interlocked panel on a CLASS 1 laser product, which when opened and the interlock overridden gives access to CLASS 4 laser radiation will require an Interlocked Housing CLASS 4 label).

- **Warning lights;**

These are an administrative control used to tell personnel that a laser is on and possibly emitting. A flashing red light connected to the interlock system on the laser is typically mounted near the entry point to the controlled area. There should also be a sign on all entry points to the area stating that there is a laser system and the access is restricted.

11.1 University Sign Template

Too many signs spread out over a door to a laser designated area tend to make people blind to them, they don't take in the information presented to them as it requires time to scan the whole door. For the University there are designed templates for the various laser CLASSES with the relevant information based on the standard EN 60825-1:2014. It is all contained in one A4 page which can be printed and laminated. The label must be adhered securely to the access point. These templates are available on the laser safety website but you can also contact the college LSO for a copy if you cannot access it.



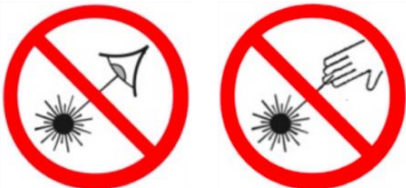
DANGER



Warning
Laser beam

LASER

4



AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED BEAM

Model	Emission	wavelength	Average Power	Rep rate	CLASS
Coherent Verdi 10	CW	532nm	10W		4
Coherent Mira	Pulsed	700-980nm	2W	80MHz	4
Coherent Mira OPO	Pulsed	550-740nm / 1100-1600nm / 1600-2600nm	5mW - 300mW	80MHz	4
Coherent Micra	CW/Pulsed	532nm (CW) / 800nm (pulsed)	18W (CW) / 500mW	80MHz	4
Coherent Legend Elite	Pulsed	800nm	1W	1KHz	4
Coherent Evolution-15	CW	527nm	12W		4
Coherent Verdi12	CW	532nm	12W		4
Coherent RegA	Pulsed	800nm	700mW	100KHz	3B
Coherent OPA9400	Pulsed	550-700nm / 933-1460nm	20mW	100KHz	3B
Coherent OPA9800	Pulsed	1200-1600nm / 1600-2400nm	10mW	100KHz	3B
Coherent Sapphire SF 488-100	CW	488nm	100mW		3B
Renishaw He-Ne	CW	633nm	20mW		3B



**LASER EYE PROTECTION
MUST BE WORN**

Contact: Jing Jing Wang **Email:** jjwang@tcd.ie **Ext:** 4633
College Laser Safety Officer: Christopher Smith **Email:** chris.smith@tcd.ie **Ext:** 3649

The template presents the user with

- the appropriate CLASS of the highest powered laser within the area
- the appropriate hazard warnings
- Directives on control measures such as Eye Protection
- the details of the laser systems within the area, wavelength, power, etc
- Relevant contact information

If there are lasers of various CLASSES present, then the highest CLASS should be displayed on the top of the template. The details of all the lasers present in the LDA must be displayed in the table also.

11.2 High Intensity Lamps

Many lamps used as light sources in the university may produce hazardous levels of UV, an appropriate label should be placed on or near the housing of the lamp warning personnel of the hazard.



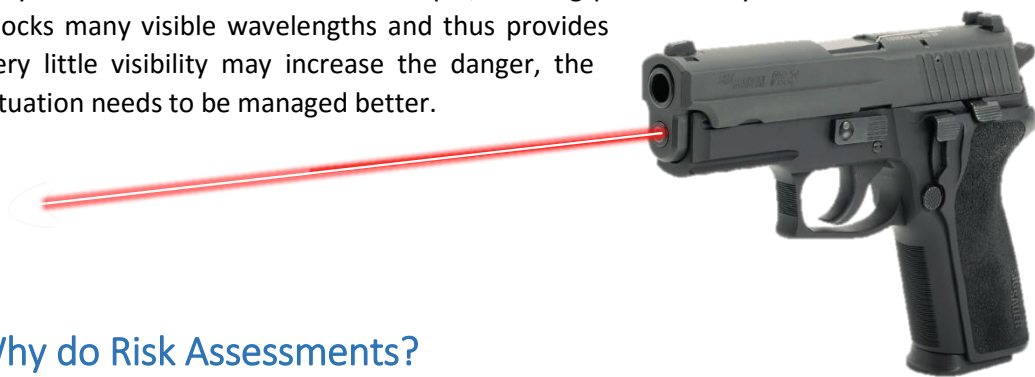
CAUTION

UV radiation hazard.
Use only with shielding in place.
Protect eyes & skin from exposure to UV light.

12 RISK ASSESSMENT

Before conducting any work with laser systems within the laboratories of the University you must complete an appropriate Risk Assessment.

- It is a methodology to help you consider what potential sources of hazard exist and how severe they may be to you and others. A well thought out concise Risk Assessment has greater value than pages and pages of cut and paste generic information.
- It helps you to determine the level of exposure to a potential hazard to you and others.
- It will help you to determine the control measures required to eliminate or minimise the risk and the residual risk once the control measures are implemented.
- Use common sense, being pedantic about one thing and ignoring the greater source of danger may well increase the risk. For example, wearing protective eyewear which blocks many visible wavelengths and thus provides very little visibility may increase the danger, the situation needs to be managed better.



12.1 Why do Risk Assessments?

- There are **legal obligations** under the 2005 Safety, Health and Welfare at Work act.
- You have a **moral obligation** to ensure the safety of everyone in your work environment.
- You also have an **economic obligation**, accidents cost money, productivity, and damage.
- Risk Assessments help you **to protect you!** The probability is that if you are working with a high powered laser it is your eye which will be injured if you get it wrong.

In the process of doing a complete Risk assessment the following stages should be followed

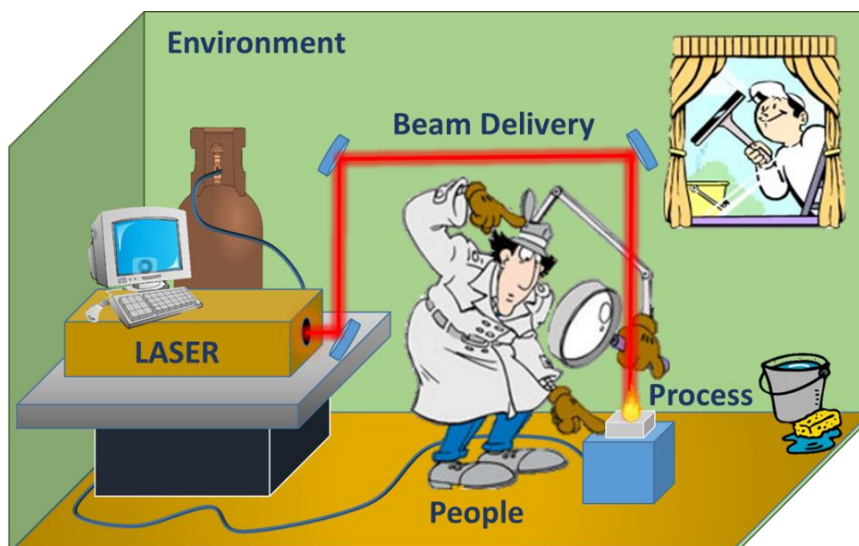
1. Identify hazards (potential for harm)
2. Decide who may be harmed and how
3. Assess the risks including the level. (Probability of harm)
4. Determine the control measures required.
5. Record your assessment in writing.
6. Review your assessment and refine the control measures if necessary.

12.2 Laser Application – 5 point model

To aid you better in completing a valid Risk Assessment we can break the whole laser application down to 5 main stages which need to be considered. Risk Assessments should always be reviewed and augmented as necessary.

1. **Laser**
2. **Beam Delivery**
3. **Laser Process**
4. **Environment**
5. **People**

We can look at these stages and then consider the hazards and risks associated with each and then implement the control measures required to eliminate or reduce the risk.



The most important part of a risk assessment is to consider every reasonably foreseeable situation that could result in injury to the person. This injury could arise from use of the laser equipment, including installation, normal operation, maintenance, service, and even misuse or failure.

When we refer to the LASER often people consider the laser beam in isolation but we must look at where this beam is coming from, where it is going to and what it is doing as well as the area where it is located and who may be affected.

12.2.1 Laser

Typically, the box where the laser beam comes out is called the laser head. It may have an associated power supply, cooling unit and control unit. There may also be other components requiring consideration, gas lines, cables, chemicals and there may even be more than one laser head to consider as one may be used for pumping the other. All the hazards and risks must be considered and the appropriate control measures must be implemented.

12.2.2 Beam Delivery

Beam delivery is basically how the beam is delivered to the process which it is being used for. The beam may travel through or be reflected off many components outside of the laser head. Optical mirrors, polarisers, diffraction gratings, lenses, photo-detectors, power meters, etc. Any device which can focus, deflect, reflect or scatter the beam must be considered in regards to hazard and risk. Appropriate control measures must then be implemented. Protective eyewear must always be worn where there is a danger of exposure to the beam.

12.2.3 Laser Process

It is assumed that the laser has a function otherwise it is not required. It may be used to process materials, to do optical analysis, or carry out medical procedures. Whatever the process is, the hazards need to be considered and dealt with. The ablated materials may need to be extracted, reflections both diffuse and specular may need to be considered if the process is not fully enclosed. Even biological material from organic sources may need to be extracted. Face masks may be a requirement.

12.2.4 Environment

If you consider the factors associated with the environment and address them before a laser system is installed, you will potentially save a lot of time rectifying the issues afterwards.

The laser environment covers

- the location of the laser equipment: e.g., will it be placed inside a building within an enclosed and dedicated laser designated area? does it need to be placed in a more-widely accessible or open-plan working area? is it used outside?
- the state of the working area from an equipment viewpoint: e.g., the influence on equipment of temperature, humidity, vibration, dust etc. and the possibility of disturbances or damage by collisions with persons or moving equipment;
- the state of the working area from a personnel or ergonomic viewpoint: e.g., spacious or cluttered; clean or dirty; well-lit or dark; ease of use and ease of operation of the laser and associated equipment; the simplicity or complexity of the task being performed;
- The level of access: e.g., localised restricted area within premises having no public access; unrestricted area within premises having no public access; public access areas.

The area in which the laser is used should be appropriate for the CLASS of the laser. In the University the laser system typically will be located in a laboratory. If the laser is CLASS 3B or 4 the room will need to be defined as a Laser Designated Area (LDA), light tight with restricted access and interlocked. Some CLASS 1 lasers may require temporary LDAs for servicing and maintenance where Administrative Controls at the entry point must be used during this time to restrict access. Inside the LDA hazards and the associated risks need to be considered. Trip hazards, clutter, flooding, other equipment, luminance, ventilation, and ergonomic factors should be considered and the control measures necessary to address them. Keeping an area organised and tidy will help to maintain a good working environment and thus help to decrease the potential for accidents.

12.2.5 People

Issues relating to persons at risk include the number of those at risk and their level of awareness, protection and training. The people at risk can include skilled and trained operators, service personnel, employees who may be unaware of the hazards, contractors, visitors, and others who may not fully understand warning signs or appreciate the dangers involved, you may need to consider cleaning staff for example. Unfortunately, you may even need to consider the lack of awareness and consideration of your supervisor or other persons in position of authority. You may be using a lab where other research staff are working, if there is a requirement for them to be present, then they must complete the laser safety training also even if they do not work directly with the laser systems. You may be present when someone is using a laser, if you are not required to be there then leave. Be aware of what is going on in the laboratory. Another group of people who may need to access the laser systems but are not members of the college are service engineers. They may not give the level of consideration to the safety issues arising from the service visit that may be necessary. In the course of their work they may override interlocks on enclosures without notifying other personnel in the area. A competent expert user of the system should be present to assist and implement all the safety protocols required.

12.3 Making a Laser Risk Assessment

To aid you in the making of your risk assessment there are a number of templates that can be used to systematically go through all the necessary stages from identifying the hazards and risks to implementing control measures. All the templates here are available from the laser safety website or you can request a copy. They are templates, not forms, you can modify them as necessary to suit your particular application as long as they still serve the purpose of a logical and adequate risk assessment.

12.3.1 Background information

You will need to identify the laser system you are completing a risk assessment for, and the relevant parts of the laser application. This information will also be required by the LSO.

LASER Risk Assessment		Name: _____ date: ____/____/____	
Background Information, give details and tick as appropriate ☒		student / staff No. _____ Email: _____	
Location:	Building: _____	Facility / Group: _____	Room: 1.6
Describe the system and application:	What is the system doing, what is the experiment? You can draw a schematic if it helps here or attach one:		
Describe the Laser: Give all relevant details	Laser Class:	Wavelength(s) nm:	
	Manufacturer:	If pulsed what is the Repetition Rate (Hz):	
	Model:	Beam shape: circular ☐ square ☐ ellipse ☐ other ☐ describe:	
	Type of Emission CW ☐ or Pulsed ☐	Beam Diameter or Dimensions:	
	Power (mW):	Beam Divergence (milliradians):	
	Maximum Pulse Energy (Joules):	Is the Laser Portable, easily moved? Yes ☐ No ☐	
	Type of laser and other relevant information: gas, solid state, dye, semiconductor		
Describe the beam delivery system:	Any components that are placed in the beam path to direct, focus, polarise, attenuate etc., must be listed or tick the boxes as appropriate		
	Open Beams ☐ Enclosed Beams ☐ Mirrors ☐ Fibre ☐ Polarisers ☐ Prisms ☐ Half / Quarter Waveplates ☐ Other ☐ _____		
Describe the laser process:	Examples Absorption, reflection, transduction, SHG, Z-scan, plasma, etching, excitation, welding, ablation.		
Describe the Environment:	Where is the laser?, what type of room, teaching, research laboratory etc.		
Personnel using the system	People using the system: undergrads ☐ postgrads ☐ staff ☒ service engineers ☐		
Life Cycle	The Laser may be at a certain stage of its life please indicate by ticking the boxes, using the following: Planning ☐ ; Design ☐ ; Manufacturing ☐ ; testing ☐ ; transport ☐ ; Installation ☐ ; Commissioning ☐ ; Normal operation ☐ ; Maintenance ☐ ; servicing ☐ ; Modification ☐ ; Decommissioning ☐ ; Disposal ☐ ;		

12.3.2 Risk Assessment

A template to help identify risk and level is also provided for each of the 5 parts of the Laser application. The example shown here is for the laser but almost all the fields in each template are identical. In the template the hazards are listed, the personnel at risk, the activities being carried out and the control measures in place. There is also a chart below to aid you in the identification of hazards, it should not be assumed to be complete, you may well identify more and it is your responsibility to deal with them accordingly. You may well need to speak with your supervisor or the LSO to help you deal with the issues. The level of risk is then given a value based on severity and probability. A chart is provided to help you make the simple calculation. Numbers are not critical in a risk assessment but they do provide you with a measure of risk that is useful for understanding and communicating.

Risk Assessment									
Identification of associated hazards and the implemented control measures; tick as appropriate ☒									
Assessment No. :	Assessment Date: ___/___/___			Building: _____ Room: _____					
	Review Date: ___/___/___			Facility: research ☐ teaching ☐ Other, (give details): _____					
Assessed by:	Position:			Area Supervisor:					
THE LASER									
List significant Hazards View hazards sheet to aid you.	Who is at Risk: <i>undergrads, postgrads, staff, service engineers</i>	Activity / Exposure <i>See Life Cycle list for options</i>	Control measures: <i>Engineering, Administrative, PPE. Give details</i>	Assess the level of Risk Look at the Hazard Assessment calculation to aid you			further actions necessary: <i>describe the control measures needed</i>	Completed	
				Severity	Probability	Risk		Yes	No
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐
				Major ☐ Serious ☐ Minor ☐	High ☐ Medium ☐ Low ☐	High ☐ Medium ☐ Low ☐		☐	☐

Potential Hazards from Laser Systems				
Hazard Category	Specific hazards This is an aid and is not a complete list, you may need to add more hazards relevant to your situation			
	Laser	Beam Delivery	Process	Environment and People
Physical	Noise Vibration Optical radiation from beam Optical radiation from process Electricity Fire	Optical radiation from beam Optical radiation from process, Specular reflections Diffuse reflections Fire Electrical, (active optics) Stability of components	Optical radiation from inside the cavity Secondary beams from optical components Optical radiation from flash lamps Radio frequency Radiation Electricity Fire	Secondary radiation, e.g. X-rays High Temperatures Low Temperatures Electricity Fire
Chemical	Gases used in the laser Toxic Substances Carcinogenic substances Fire	Gases used in the laser Toxic Substances Carcinogenic substances Fire	Gases Toxic Substances Carcinogenic substances Irritants Dust and particulate	Gases Toxic Substances Carcinogenic substances Irritants Dust and particulate
Biological			Microbiological Organisms Bacteria Viruses	Bacteria Microbiological Organisms Viruses
Mechanical	Trip hazards from trailing cables, pipes Water slipping electrical hazards from water, mechanical damage to electrical cables high pressure lamps (explosive) Stability of optical components	Trip hazards from trailing cables Heavy items Stability of components	Sharp Edges, glass, metal Electrical connections Mechanically moving parts Heavy items	Sharp Edges, glass, metal Connections Equipment, boxes etc. Heavy items Stability of items Gas Bottles at high pressure
Ergonomic	Access to laser and experimental setup Badly fitting PPE	Access to the experimental setup Badly fitting PPE	Ease of operation Workstation setup Person machine interface Badly fitting PPE	Environmental Lighting Air-conditioning and room temperature manual handling of equipment Workstation setup Person machine interface
Other	damaged inadequate PPE	damaged inadequate PPE	damaged inadequate PPE	People, bullying, bad work practices, Bad training, competency, shift patterns, supervision, lone working.

To make a risk analysis of a particular hazard it can be useful to use numeric values to scale the risks. A simple calculation can be made using the chart below. If we consider a plugged in open laser power supply in the laboratory, then the severity will be MAJOR and given a value of 3. Now assess the PROBABILITY of harm occurring, well depending on the situation and the personnel involved this may change, but we will give it a medium level of 2. So we multiply these values to ascertain the RISK, which is 6, this is considered high and control measures are required immediately. If the power supply is unplugged and the enclosure is fitted and secured, then the PROBABILITY is reduced to 1 and therefore the RISK is reduced to medium which can be acceptable if no further control measures can be implemented. At any stage of the risk assessment if you need assistance or clarification please contact your LSO.

Hazard Assessment			
To help you better identify the level of risk you can identify the associated hazards and then assign an appropriate risk level to them based on the Risk Calculation below			
Severity	x	Probability	= Risk
MAJOR = 3 Death, Major Injury, Irreversible health damage,		High = 3 Certain or near certain harm will occur	High = 6 , 9
Serious = 2 Absence or reversible health damage		Medium = 2 Where harm will frequently occur	Medium = 2 , 3 , 4
Minor = 1 Only requires, first aid, possible lost time due to the incident		Low = 1 Where harm will seldom occur	Low = 1

13 SCHEME OF WORK

Typically, if we work in a teaching / research laboratory or a workshop, we document the standard procedures we need to carry out for experimental work or the use of equipment so that we can reproduce the procedure or communicate to others how things need to be done correctly. Very often this is carried out to help protect equipment as well as to carry out good quality work and retrieve valid data. So if we incorporate safety into these working procedures then we are also protecting personnel and not just equipment. A simple non-over complicated scheme of work will outline the procedures required to be followed by personnel working in the LDA and with the laser systems in the area. They should be devised, documented and made available to all personnel working in the LDA. They should also so be reviewed and augmented as necessary. You will find a *Scheme of Work* template on the laser safety website which will help.

Safe protocols and procedures should be established and documented for the various aspects associated with the laser application.

- **General safety procedures;** such as those discussed here should be put into a general document for current and new personnel wishing to conduct work in your laboratory. Conducting a risk assessment, following safety procedures, logging activity, returning and maintaining laser safety eyewear should all have a set procedure for consistency and ensuring PPE is well cared for.
- **Setting up;** applies to the initial installation of a new experiment, and to major changes such as the addition of a new type of laser system, or, for example, a complete change of beam paths.
- **Adding new elements;** applies to the introduction of any new optic into the beam path of a CLASS 4 laser such as a lens or filter.
- **Sample / process;** as with new elements the changing and setting up of a new sample for analysis or process should have an established procedure to ensure it is done so safely
- **Servicing and maintenance;** is the performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the product's performance. It can include activities such as the removal and reinstallation of optics for cleaning, the changing of laser dyes, the changing of flash lamps, and the installation of new optics inside the laser cavity. It may be conducted by a competent expert user in the laboratory or by an external engineer.
- **Other;** there may well be other procedures which require a documented scheme of work unique to your situation such as medical procedures etc.

14 MEDICAL SUPERVISION, EMERGENCY PROCEDURES

Eye examinations for laser users are not recommended as a part of a safety programme. The value of routine examinations for CLASS 3B/4 laser users has been reviewed and it is generally accepted that routine examinations are of little value and that the only reason for these may be for medical legal reasons.

What is of more importance is having procedures in place if there has been an apparent or suspected ocular exposure. A medical examination by a qualified specialist needs to be carried out as soon as possible.

In the event of an accident or incident involving suspected injury to the eye(s), an emergency examination should be carried out as soon as possible.

- Seek assistance immediately you may be suffering from psychological shock which will compromise your ability to think clearly.
- Do not attempt to drive yourself to the hospital
- Power the laser down if you are able to do so safely or ask another competent person familiar with the system to help.
- Write down or ask your colleague to write down the type of laser, power and wavelength for the hospital.
- Do not use the laboratory or disturb the equipment until after the accident has been investigated.
- Report all accidents to the Laser Safety Officer and the School/Department Safety Officer

For Immediate medical attention

College Emergency Number

DIAL 1999

or

01 896 1999

if you need to use your Mobile



1999 is called so that college security can coordinate the emergency services and get them to your location. They will also send assistance to you if required.

Be prepared to state the:

1. Type of assistance required (ambulance, fire brigade, police etc.)
2. Type of emergency (fire, injury, etc.)
3. Name, extension number and location. (also mobile number if needed)

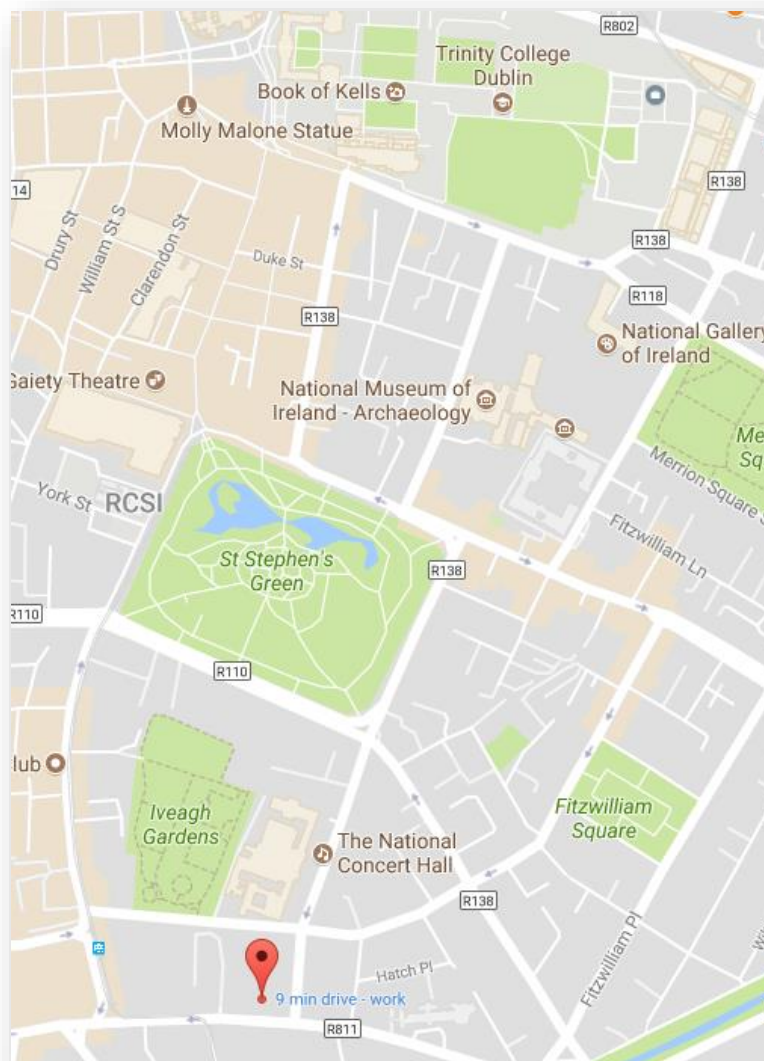
If possible and if it is safe to do so, keep close to the telephone, in order to give further information should it be required by the emergency services.

If your injury is not so severe you will still need medical attention.

The most appropriate Accident and Emergency Department that deals with eye injuries is

Royal Victoria Eye and Ear Hospital
Adelaide Road
Dublin 2
Tel: (+353) 1 6644600

In the event of a skin injury, i.e. thermal burn, this can be treated as would any other burn. There should be a registered occupational first aider in your area, contact them if you need assistance. All first aid kits in the university should have Burns Gel which can be liberally applied to the burn, a clean burns dressing should be applied after and seek appropriate medical attention if required. Running a gentle stream of cool clean water over a burn for ten minutes will also help.



If possible bring details about the laser beam that caused the injury, wavelength, power, emission type, beam diameter.

All accidents and incidents, whether involving an emergency examination or not, must be reported promptly to the Laser Safety Officer and the local Safety Officer where they will carry out a detailed investigation of the accident/incident.

ANNEX 1 EN207

Full attenuation protection levels according to EN 207

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	H	E	E	H	H	E	H	E
		W/m ²	J/m ²	W/m ²	W/m ²	J/m ²	J/m ²	W/m ²	J/m ²	W/m ²
		Pulse duration in seconds								
		D	I,R	M	D	I,R	M	D	I,R	M
S	T	$\geq 3 \times 10^{-4}$	10^{-9} to 3×10^{-4}	$< 10^{-9}$	$\geq 5 \times 10^{-4}$	10^{-9} to 5×10^{-4}	$< 10^{-9}$	≥ 0.1	10^{-9} to 0.1	$< 10^{-9}$
LB1	10^{-1}	0.01	3×10^2	3×10^{11}	10^2	0.05	1.5×10^{-3}	10^4	10^3	10^{12}
LB2	10^{-2}	0.1	3×10^3	3×10^{12}	10^3	0.5	1.5×10^{-2}	10^5	10^4	10^{13}
LB3	10^{-3}	1	3×10^4	3×10^{13}	10^4	5	0.15	10^6	10^5	10^{14}
LB4	10^{-4}	10	3×10^5	3×10^{14}	10^5	50	1.5	10^7	10^6	10^{15}
LB5	10^{-5}	10^2	3×10^6	3×10^{15}	10^6	5×10^2	15	10^8	10^7	10^{16}
LB6	10^{-6}	10^3	3×10^7	3×10^{16}	10^7	5×10^3	1.5×10^2	10^9	10^8	10^{17}
LB7	10^{-7}	10^4	3×10^8	3×10^{17}	10^8	5×10^4	1.5×10^3	10^{10}	10^9	10^{18}
LB8	10^{-8}	10^5	3×10^9	3×10^{18}	10^9	5×10^5	1.5×10^4	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^6	3×10^{10}	3×10^{19}	10^{10}	5×10^6	1.5×10^5	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^7	3×10^{11}	3×10^{20}	10^{11}	5×10^7	1.5×10^6	10^{13}	10^{12}	10^{21}

ANNEX 2 EN208

Alignment protection for visible wavelength levels according to EN 208

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 $\geq 2 \times 10^{-4} \text{ s}$	Pulsed lasers with a pulse duration of $>10^{-9} \text{ s}$ to $2 \times 10^{-4} \text{ s}$
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}

ANNEX 3 MAXIMUM POWER VALUES

This table is for information only. Any calculations based on it should be conducted with the assistance of the LSO. MPEs can be expressed as the *Maximum Power* through a limiting aperture as a function of time. If the value of the power of the beam is greater than the values listed below then the MPE has been exceeded and the beam may cause injury. It is imperative to wear eye protection always. The exposure durations are based on the light being visible and invisible, the Maximum power values will change if these duration values change. The aperture size is based on the transmission characteristics of the particular wavelength through the components of the human eye.

Exposure duration is based on accidental exposures of 0.25s for visible and 10s for invisible.

Wavelength range (nm)	Limiting aperture (mm)	Exposure duration (s)	MPE (W m^{-2})	Maximum power through aperture (W)	Maximum power through aperture (mW)
180 to 302.5	1	10	3.0	0.0000024	0.0024
≥ 302.5 to 315	1	10	3.16 to 1,000	0.0000025 to 0.00079	0.0025 to 0.79
305	1	10	10	0.0000079	0.0079
308	1	10	39.81	0.000031	0.031
310	1	10	100	0.000079	0.079
312	1	10	251.19	0.00020	0.20
≥ 315 to 400	1	10	1,000	0.00079	0.79
≥ 400 to 450	7	0.25	25.44	0.00098	0.98
≥ 450 to 500	7	0.25	25.44	0.00098	0.98
≥ 500 to 700	7	0.25	25.44	0.00098	0.98
≥ 700 to 1050	7	10	10 to 50	0.00039 to 0.0019	0.39 to 1.9
750	7	10	12.59	0.00049	0.49
800	7	10	15.85	0.00061	0.61
850	7	10	19.95	0.00077	0.77
900	7	10	25.12	0.00097	0.97
950	7	10	31.62	0.0012	1.2
1000	7	10	39.81	0.0015	1.5
≥ 1050 to 1400	7	10	50 to 400	0.0019 to 0.015	1.9 to 15
≥ 1050 to 1150	7	10	50	0.0019	1.9
1170	7	10	114.54	0.0044	4.4
1190	7	10	262.40	0.010	10
≥ 1200 to 1400	7	10	400	0.015	15
≥ 1400 to 1500	3.5	10	1000	0.0096	9.6
≥ 1500 to 1800	3.5	10	1000	0.0096	9.6
≥ 1800 to 2600	3.5	10	1000	0.0096	9.6
≥ 2600 to 10^5	3.5	10	1000	0.0096	9.6
$\geq 10^5$ to 10^6	11	10	1000	0.095	95

ANNEX 4 GLOSSARY OF TERMS

Taken from IEC TR 60825-14 with modifications for this document

Aperture any opening in the protective housing or other enclosure of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation

Aperture stop opening serving to define the area over which radiation is measured

Beam laser radiation that may be characterized by direction, divergence, diameter or scan specifications NOTE scattered radiation from a non-specular reflection is not considered to be a beam.

Beam attenuator device which reduces the laser radiation to or below a specified level

Beam divergence far field plane angle of the cone defined by the beam diameter

Beam stop device which terminates a laser beam path

CLASS 1 laser product any laser product which does not permit human access to laser radiation in excess of the accessible emission limits of CLASS 1 for applicable wavelengths and emission durations

CLASS 1M laser product any laser product in the wavelength range from 302,5 nm to 4 000 nm which does not permit human access to laser radiation in excess of the accessible emission limits of CLASS 1 for applicable wavelengths and emission durations, where the level of radiation is measured but is evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for CLASS 1 laser products. NOTE the output of a CLASS 1M product is therefore potentially hazardous when viewed using an optical instrument.

CLASS 2 laser product any laser product, which does not permit human access to laser radiation in excess of the accessible emission limits of CLASS 2 for applicable wavelengths and emission durations

CLASS 2M laser product any laser product in the wavelength range from 400 nm to 700 nm which does not permit human access to laser radiation in excess of the accessible emission limits of CLASS 2 for applicable wavelengths and emission durations, where the level of radiation is measured but is evaluated with smaller measurement apertures or at a greater distance from the apparent source than those used for CLASS 2 laser products. NOTE the output of a CLASS 2M product is therefore potentially hazardous when viewed using an optical instrument.

CLASS 3R and CLASS 3B laser products any laser product which permits human access to laser radiation in excess of the accessible emission limits of CLASS 1 and CLASS 2 as applicable, but which does not permit human access to laser radiation in excess of the accessible emission limits of CLASSes 3R and 3B (respectively) for any emission duration and wavelength

CLASS 4 laser product any laser product which permits human access to laser radiation in excess of the accessible emission limits of CLASS 3B

Collimated beam "parallel" beam of radiation with very small angular divergence or convergence

Continuous wave CW output of a laser which is operated in a continuous rather than pulsed mode. In this part of IEC 60825, a laser operating with a continuous output for a period equal to or greater than 0.25 s is regarded as a CW laser

Defined beam path an intended path of a laser beam within the laser product

Diffuse reflection changes of the spatial distribution of a beam of radiation by scattering in many directions by a surface or medium.

NOTE 1 A perfect diffuser destroys all correlation between the directions of the incident and emergent radiation.

Embedded laser product laser product which, because of engineering features limiting the accessible emissions, has been assigned a CLASS number lower than the inherent capability of the laser incorporated NOTE the laser which is incorporated in the embedded laser product is called the embedded laser.

Emission duration temporal duration of a pulse, of a train or series of pulses, or of continuous operation, during which human access to laser radiation could occur as a result of operation, maintenance or servicing of a laser product. For a train of pulses, this is the duration between the first halfpeak power point of the leading pulse and the last half-peak power point of the trailing pulse

Exposure time duration of a pulse, or series, or train of pulses or of continuous emission of laser radiation incident upon the human body. For a train of pulses, this is the duration between the first halfpeak power point of the leading pulse and the last half-peak power point of the trailing pulse

Extended source viewing, viewing conditions whereby the apparent source at a distance of 100 mm or more subtends an angle at the eye greater than the limiting angular subtense ($\square$ min)

NOTE Two extended source conditions are considered in this standard when considering retinal thermal injury hazards: intermediate source and large source, which are used to distinguish sources with angular subtenses, $\square$, between $\square$ min and $\square$ max (intermediate sources), and greater than $\square$ max (large sources). Examples are viewing of some diffuse reflections and of some laser diode arrays.

Fail safe design consideration in which failure of a component does not increase the hazard. In the failure mode the system is rendered inoperative or non-hazardous

Intrabeam viewing all viewing conditions whereby the eye is exposed to the direct or specularly reflected laser beam in contrast, for example, to viewing of diffuse reflections

Irradiance E measure of the optical power per unit area, units W/m^2 - that is Watts per square meter

Laser any device which can be made to produce or amplify electromagnetic radiation in the wavelength range from 180 nm to 1 mm primarily by the process of controlled stimulated emission.

NOTE This definition is different from IEV 845-04-39.

Laser controlled area or Laser Designated Area LDA, area where the occupancy and activity of those within is subject to control and supervision for the purpose of protection from radiation hazards

Laser product any product or assembly of components which constitutes, incorporates or is intended to incorporate a laser or laser system, and which is not sold to another manufacturer for use as a component (or replacement for such component) of an electronic product

Laser radiation all electromagnetic radiation emitted by a laser product between 180 nm and 1 mm which is produced as a result of controlled stimulated emission

Laser safety officer one who is knowledgeable in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards

Laser system laser in combination with an appropriate laser energy source with or without additional incorporated components

Limiting aperture circular area over which irradiance and radiant exposure are averaged

Maintenance performance of those adjustments or procedures specified in user information provided by the manufacturer with the laser product, which are to be performed by the user for the purpose of assuring the intended performance of the product. It does not include operation or service

Maximum Permissible Exposure MPE that level of laser radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. The MPE levels represent the maximum level to which the eye or skin can be exposed without consequential injury immediately or after a long time and are related to the wavelength of the radiation, the pulse duration or exposure time, the tissue at risk and, for visible and near infra-red radiation in the range 400 nm to 1 400 nm, the size of the retinal image

NOTE 1 The values for maximum permissible exposure used in this document are those recommended by the International Commission on Non-Ionizing Radiation Protection, and are based on the current state of knowledge of threshold levels for laser injury.

Nominal Ocular Hazard Area NOHA, also termed NOHZ (z for zone), area within which the beam irradiance or radiant exposure exceeds the appropriate corneal maximum permissible exposure (MPE), including the possibility of accidental misdirection of the laser beam

NOTE If the NOHA includes the possibility of viewing through optical aids, this is termed the "extended NOHA".

Nominal Ocular Hazard Distance NOHD distance at which the beam irradiance or radiant exposure equals the appropriate corneal maximum permissible exposure (MPE) **NOTE** If the NOHD includes the possibility of optically-aided viewing, this is termed the "extended NOHD".

Optical Density OD logarithm to base ten of the reciprocal of the transmittance □

Photochemical hazard limit MPE that was derived to protect persons against adverse photochemical effects **NOTE** An example of such adverse effects is photoreinitis, a photochemical retinal injury from exposure to radiation in the wavelength range from 400 nm to 600 nm.

Protective enclosure physical means for preventing human exposure to laser radiation unless such access is necessary for the intended functions of the installation

Protective housing those portions of a laser product (including a product incorporating an embedded laser), which are designed to prevent human access to laser radiation in excess of the level required by the laser product's prescribed Classification (generally installed by a manufacturer)

Pulse duration time increment measured between the half peak power points at the leading and trailing edges of a pulse

Pulsed laser laser which delivers its energy in the form of a single pulse or a train of pulses. In this part of IEC 60825, the duration of a pulse is less than 0.25 s

Radiant energy Q energy in the form of electromagnetic waves measured in Joules (J).

Radiant exposure H at a point on a surface, the radiant energy incident on an element of a surface divided by the area of that element. Measured in joules per meter squared, (J/m²).

Remote interlock connector, connector which permits the connection of external controls placed apart from other components of the laser product

Safety interlock automatic device associated with the protective housing of a laser product to prevent human access to CLASS 3 or CLASS 4 laser radiation when that portion of the housing is removed

Service performance of those procedures or adjustments described in the manufacturer's service instructions which may affect any aspect of the product's performance. It does not include maintenance or operation

Specular reflection, reflection from a surface which maintains angular correlation between incident and reflected beams of radiation, as with reflections from a mirror

Thermal hazard limit MPE that was derived to protect persons against adverse thermal effects, as opposed to photochemical injury

Time base emission duration to be considered for Classification

Transmittance ratio of the transmitted radiant flux to the incident flux in the given conditions

Visible radiation (light) any optical radiation capable of causing a visual sensation directly

NOTE In this part of IEC 60825, this is taken to mean electromagnetic radiation for which the wavelength of the monochromatic components lies between 400 nm and 700 nm.