Technion Guide to Laser Safety

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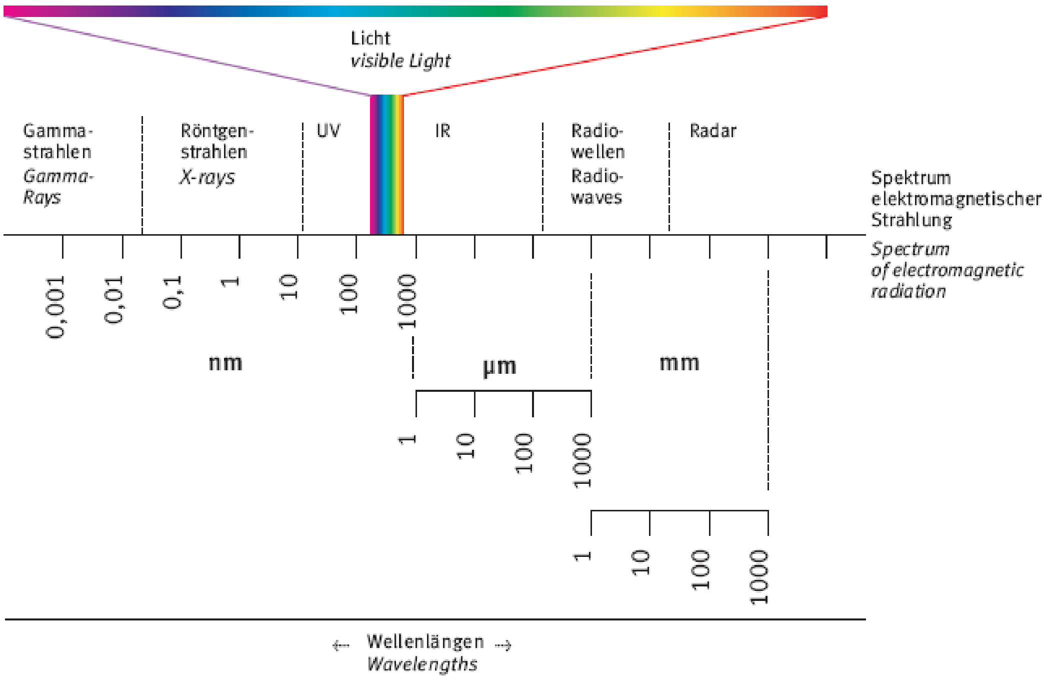
1.1 Electromagnetic radiation

Electromagnetic radiation is a natural phenomenon in almost all areas of daily life. Some examples include thermal radiation (warmth), x-rays and γ-rays emerging from radioactive decomposition. Electromagnetic radiation is also artificially generated by radio-transmitters or mobile phones. It travels in waves like sound and is produced by the movement of charged particles. In contrast to sound, electromagnetic radiation does not need a medium in which to travel.

Electromagnetic radiation within the visible range is commonly called 'light'. In this general sense, light consists of an electromagnetic radiation between 380 nm and 780 nm (nm = nanometer = one billionth of a meter). This range is designated as the visible spectrum. When all wavelengths in the visible spectrum are emitted simultaneously, this is perceived as white light.

When white light falls on an optically dispersive element, such as a prism or bi-refringent filter, the colours of the spectrum can be seen due to refraction. The refraction starts at with the short violet waves, turning to blue, green, than yellow and goes to the long red waves. Beyond the long red waves of the spectrum is the near and far infrared range. Below the blue shortwave range is the ultraviolet range.

Laser radiation – like all light – consists of an electromagnetic radiation as well, but the term ‘laser-light’ refers to a much broader range of the electromagnetic spectrum: between 150 nm up to 11000 nm, i.e. from UV up to the far infrared.



1.2 **LASER radiation**

The word LASER is an acronym for **L**ight **A**mplification by **S**timulated **E**mission **R**adiation.

Lasers emit concentrated beams of light through optical amplification of an electromagnetic radiation. Lasers differ from other sources of electromagnetic radiation in that the source is -

1. extremely coherent (in phase),
2. collimated (narrow beam)
3. usually monochromatic (one wavelength), thus allowing the beam to be focused to a tiny spot, only a few microns in diameter, making a laser beam to be highly dense, many times greater than the sun's irradiance, therefore even relatively small amounts of laser light can lead to permanent eye injuries.

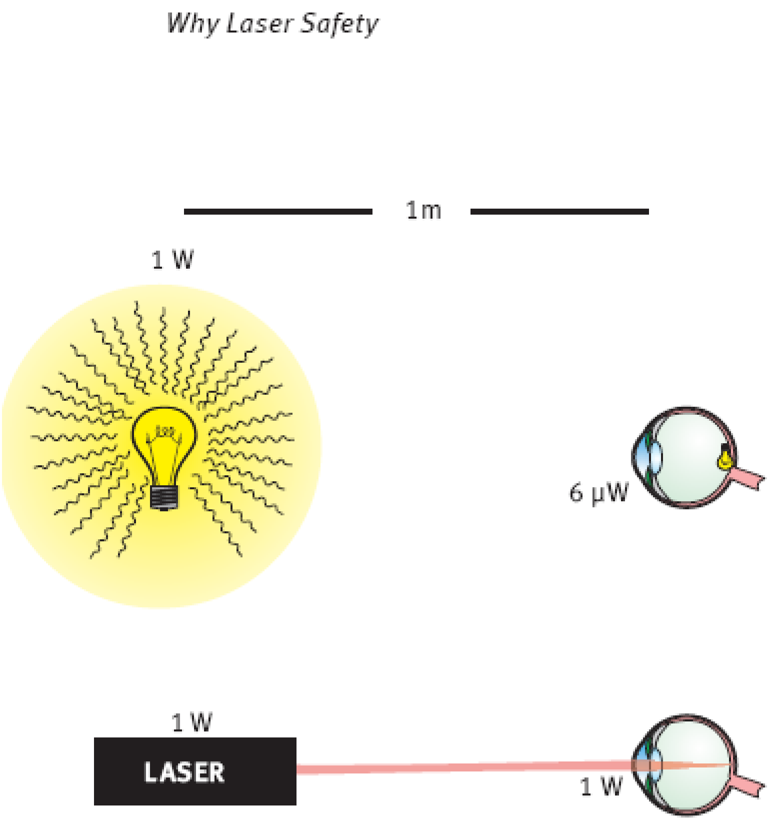
1.3 **Why laser safety?**

The 'light' from powerful lasers can be concentrated to power densities (power per area or watts/cm^2) high enough to evaporate tissue, metal or ceramics. In the medical field laser radiation is used to remove tattoos or to cut human tissue. These examples show a range of applications, which require high power lasers and as such there is a high potential risk of accidental illumination of the user. The eyes are extremely sensitive to light. In fact, it is possible to cause irreversible ocular injury with just one glance into a direct or reflected laser beam even at lower power output levels.

1.4 What makes lasers dangerous compared to conventional light sources?

Wave trains of any given laser radiation have a fixed relation to time and space (co-herent) and are all nearly the same wavelength (monochromatic). Laser light can travel over great distances as a nearly parallel beam (collimated). All of this means that the power that can impact an area, such as the eye, is independent of the distance to the radiation source. Imagine a laser pointer with a beam spot that remains about the same size over great distances.

If you compare a thermal source of radiation, like a light bulb, with a laser - you will observe several differences: the light bulb emits light over a very broad spectrum of wavelengths with no specific dispersion direction.



The power of the bulb that may reach the eye decreases with distance because the bulb radiates in all directions. When comparing a light bulb with a laser beam, both emitting

1 W optical power, if there is a 1 meter distance between our eyes and the light source, then the quantity of light coming from the laser beam would be increased by a factor of 100,000 compared to the light quantity from the bulb (this assumes a normally dilated pupil diameter of 7 mm – i.e. eyes adapted to darkness).

In addition to the quantity of light that can hit the eye, the high focus ability of the coherent laser light is another danger. While the bulb creates an image on the retina of approximately 100 µm, the laser light is reduced to a spot of just a few micrometers (~ 10 µm) in diameter. A physicist would say that the bulb produces incoherent light. Therefore, the light quantity of a laser that hits the eye is concentrated on a much smaller spot. The power density (power per area or watts/cm^2) resulting from this concentration may be sufficiently high, so that any tissue in the focus will be heated up and very quickly destroyed.

Since the fovea - responsible for sharp central vision and located on the retina - also has a size of just a few micrometers, it is possible to lose one's eyesight by one single laser pulse.

2. **How do laser wavelengths affect our eyes?**

2.1 **Injury mechanisms**

There are several tissue damage mechanisms for laser radiation, including thermal, photochemical thermo-acoustic transients and non-linear effects. For suprathreshold exposures, the predominant injury mechanism is determined principally by a combination of laser wavelength and exposure / pulse duration.

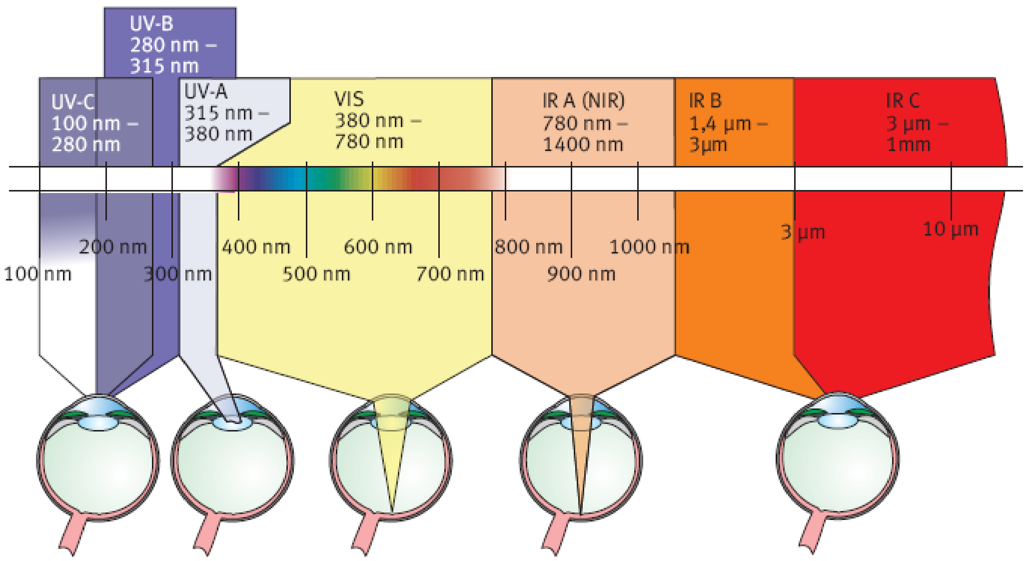
In general, photochemical mechanisms dominate the ultraviolet region, where thresholds for photochemical damage are generally lower than for thermal injury. For wavelengths between 400 nm - 550 nm, both photochemical and thermal mechanisms occur, with the dominant mechanism dependent on the timescale of exposure. At longer wavelengths mechanisms are predominantly thermal. As noted above, the injury mechanism also depends on the exposure duration.

The predominant injury mechanisms for different exposure / pulse durations are summarized below.

Timescale	Mechanism
>10 s	Photochemical
10 µs – 10 s	Thermal
1 ns – 10µ s	Shock waves resulting from localized self focussing
< 1 ns	Non-linear effects, particularly low density plasma generation

The risk of eyesight loss because of an accidental exposure to laser radiation is due to the special optical properties of the human eye: when looking at the different depths of penetration in relation to the wavelengths, the eye is transparent only in the wavelength range between 370 nm - 1400nm. UV-light below 350nm either penetrates the lens or is absorbed at the surface of the eye (cornea). A consequence of exposure to high power light at these wavelengths is an injury to the cornea by ablation or a cat-aract.

Light in the visible wavelength region (380 – 780nm) penetrates the retina. The eye is sensitive to radiation and humans have developed natural protective mechanisms. When the light appears too bright, which means the power density exceeds the damage threshold of the eye, we automatically turn away and close our eyes (i.e. aversion response or a blink reflex).



This automatic reaction is effective for radiation up to 1mW power. With higher power levels, too much energy reaches the eye before the blink reflex can respond, which can result in irreversible damage.

The near infrared wavelengths (780 nm– 1400 nm) are a specifically dangerous radiation type to the human eye because there is no natural protection against it. The radiation again penetrates the retina, but the exposure is only noticed after the damage has occurred. Infrared radiation (1400 nm – 11000 nm) is absorbed at the surface of the eye (cornea). It leads to overheating of the tissue and burning or ablation of the cornea.

2.2 Symptoms of a laser-induced injury to the eye

The main symptoms you may experience in case of a laser beam injury to the eyes:

* 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).

The apparent absence of immediate symptoms does not mean that serious damage has not occurred. **Always seek medical attention and report the incident**.

- ♣ Exposure to the Q-switched Nd:YAG laser beam (1064 nm) is especially hazardous and may initially go undetected because the beam is invisible and the retina lacks pain sensory nerves.
- ♣ Photoacoustic retinal damage may be associated with an audible "pop" at the time of exposure. Visual disorientation due to retinal damage may not be apparent to the operator until considerable thermal damage has occurred.
- ♣ Blurred vision
- ♣ A floating black spot

3. Laser Safety Regulations

3.1 Laser categories according to EN 60825-1

Lasers have been categorized into four (4) hazard classes based on their Accessible Emission Limits (AELs). These limits indicate the class of the laser and are listed in EN 60825-1 and the American National Standards ANSI Z136.1 for the safe use of lasers.

3.2 Maximum Accessible Emission Limit (AEL)

AEL is the maximum Accessible Emission Limit of the laser radiation permitted at each laser class. It is the primary measurement of a laser's hazard potential. For a particular class of laser, the AEL is quoted as the maximum irradiance (W/cm2) or radiant exposure (J/cm2) that can be emitted in a specified wavelength range and exposure time at a specified distance known to cause biological implications.

3.3 Maximum Permissible Exposure (MPE)

A Maximum Permissible Exposure (MPE) is the level of laser radiation to which, under normal circumstances, people may be exposed to without suffering adverse effects. MPE is equivalent to the Exposure Limit Value (ELV).

The Maximum Permissible Exposure values (MPEs) are the values of the highest level of laser radiation which are considered safe, i.e., the laser power that a person may be exposed to for a given exposure time without suffering immediate or long-term adverse effects. The MPE is usually 10% of the dose that has a 50% chance to cause damage.

Although for laser safety assessments the MPEs are generally used as a strict limit between safe and hazardous exposures, the MPEs are based on current knowledge derived from experiments, and therefore cannot be considered an exact line between 'safe' and 'hazardous'.

The MPE is measured at the cornea of the human eye or at the upper surface of the skin for a given wavelength and exposure time. The MPE for ocular exposure considers the various ways a laser beam can affect the various parts of the eye. For example, UV can cause cumulative damage, even at very low powers. IR, on the other hand, with wave lengths 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 those for visible or near-IR light.

In addition to the wavelength and exposure time, the MPE considers the spatial distribution of the light. Collimated laser beams of visible and near-IR light are especially dangerous at relatively low powers because the focusing capability of the eye will create a tiny spot in the order of microns on the retina, dramatically increasing the power density.

3.4 Nominal Hazard Zone (NHZ)

The Nominal Hazard Zone is the distance within which the irradiance or radiant exposure of the beam is greater than the maximum permissible exposure (MPE), i.e., the area around your laser system that is considered dangerous. The laboratory in which a laser system is operating is considered the Nominal Hazard Zone.

The Nominal Ocular Hazard Distance (NOHD) is the distance from the output aperture of the laser at which the beam irradiance or radiant exposure equals the appropriate MPE. If the NOHD includes the possibility of viewing through optical aids, this is termed the "extended NOHD (ENOHD)".

3.6 Summary of the laser safety classification:

Laser classes are defined as:

Class	Type of laser	Potential hazard	App. CW power
Class 1	Very low power	Generally safe for long-term direct viewing, even with a magnifying instrument like telescope	40µW blue and 400µW red, measured via aperture
Class 1M	* Very low power * Collimated large beam diameter / highly divergent	Generally safe for long-term direct viewing but potentially hazardous with a magnifying instrument like a telescope	Same as class 1 but measured through a 7mm aperture, representing an unaided eye
Class 2	Low power visible wavelength	Generally safe for brief viewing as normal blink reflex will limit	1mW

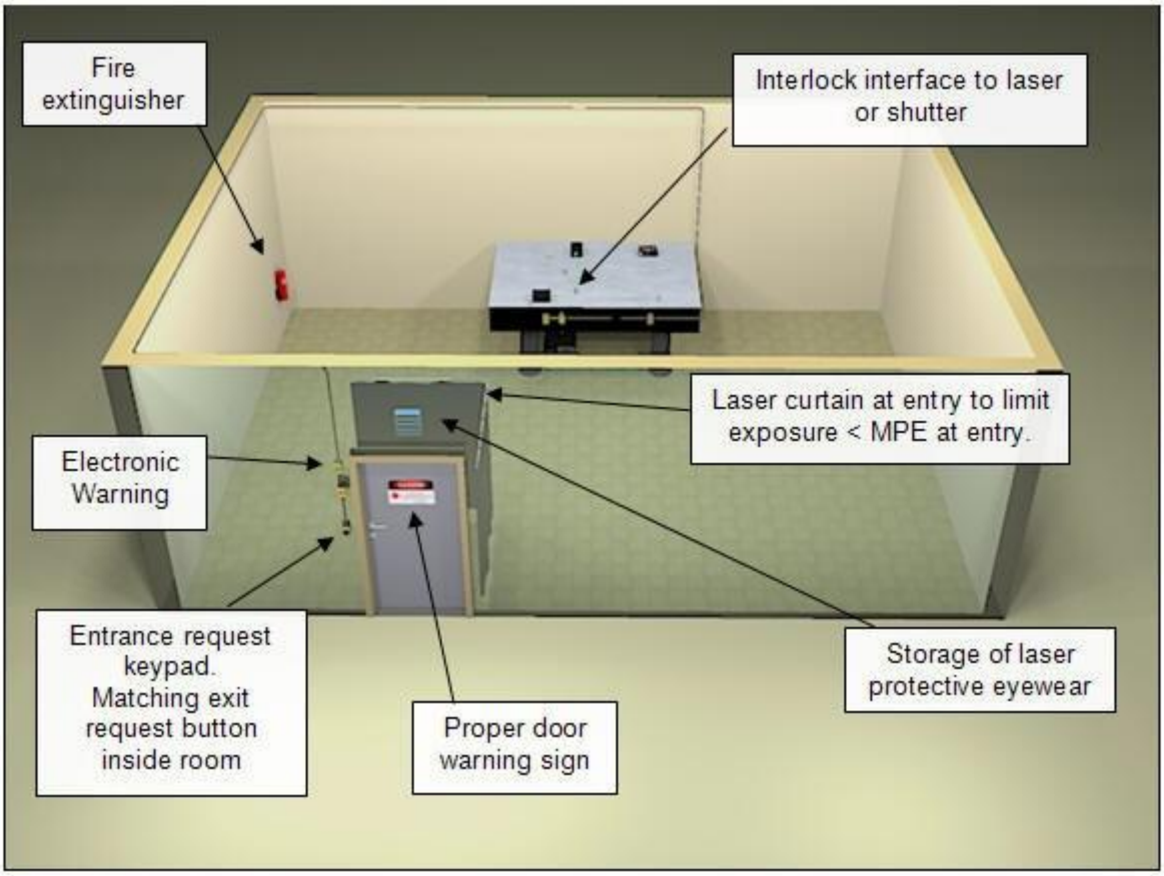
		exposure; avoid extended viewing	
Class 2M	* Very low power * Collimated large beam diameter / highly divergent	Same as class 2 but potentially hazardous with a magnifying instrument like a telescope	1mW via 7mm aperture representing unaided eye
Class 3R (visible)	Low power e.g. alignment laser	* Accidental brief exposure * Generally safe but eye injury possible with intentional long-term intra-beam viewing	5mW
Class3R (non-visible)	Low power	* Accidental brief exposure * Generally safe but eye injury possible with long-term intra-beam viewing, which may be undetected	5 x class 1 levels wavelength dependent
Class3B	Medium power	* Can cause serious eye injury even for a brief exposure * Unlikely to cause skin burns; optional slight skin injury for beam powers near upper limit * Diffuse reflections, normally safe	500mW
Class 4	High power	* Serious eye injury likely even to diffuse reflections viewed close-up * Serious skin injury likely * A fire hazard	No limit
Embedded laser	A Class 1 device containing a higher-class laser: formerly 1E embedded laser system	* Totally enclosed systems, inherently safe because of engineering design, restricting exposure to Class 1 AEL * Typically applies to scientific instruments, such as cell counters. * Authorized personnel only	* Ideally, maintenance and adjustment operations performed only by the service engineer * Staff should not be present if the system is operated without guards * In case maintenance is performed by university staff - the system must be reclassified by over-riding of interlocks * The system must be designed on a fail-safe basis * Lasers within the enclosure must be clearly identified and labelled * A clear-sited and labelled electrical isolation switch must

			be provided * A separate RA will be needed for maintenance

3.6 Summary of 60825-1 for manufacturer and user

1	Remote interlock	* Connection provided by the manufacturer for door / enclosure interlock * 3B, 4
2	Safety interlocks	* For access panels * 3R, 3B, 4
3	Key control	* A key / similar device to control unauthorized operation * 3B, 4
4	Emission indicator	* An audible / visible indicator provided by manufacturer * 3R (except wavelengths 400-700nm), 3B, 4
5	Beam stop / attenuator/shutter	* Provided by manufacturer * 3B, 4
6	Beam termination	* User must ensure all beam paths are terminated at the end of their useful path * Does not apply to Class 1 devices
7	Beam level	Avoid eye level
8	Beam enclosure	* Used to guard against specular reflections: from screening the experimental area / piping the beam up to a total enclosure. * 3R, 3B, 4
9	Eye protection	* For work with an open invisible beam * 3R, 3B, 4
10	Protective clothing	* mainly Class 4; Class 3B UV lasers * may need fire-resistant material
11	Eye examinations	* Only required following an accident * Vital for people with poor eyesight working with Class 3B or Class 4
12	Training	3, 4, modified Class 1M or Class 2M devices
13	Laser labels	Required for all lasers except low power Class 1

14	Door/area signs	* 3B, 4 indoors * 1M, 2M, 3R outdoors



Summary of control measures for normal laser operation

Risk →	NO RISK	LOW RISK				HIGH RISK	
Class →	1		2	3R	1M and 2M	Class 3B	Class 4
Requirement ↓	Intrinsic	Embedded					
LRO needs to be appointed						√	√
Registration	-	√	-	√	√	√	√
Standing Orders	-	-	-	√	-	√	√
Generic (MHSW 99) risk assessment		√	√		√		
Optical radiation-specific risk assessment	-	-	-	√	-	√	√
Training for normal use	-	-	-	√	√	√	√
Restricted use of viewing aids	-	-	-	-	√	-	-
Conform to basic beam path design principles	-	-	-	√	√	√	√
Conform to restricted beam path design principles	-	-	-	-	-	√	√
Control of specular reflections	-	-	√*	√	√*	√	√
Use of key control	-	√	-	-	-	√	√
Service and maintenance restrictions	-	√	-	-	-	√	√
Restricted to interlocked Designated Laser Area	-	-	-	-	-	√	√
Isolation of non-laser activities in normal operation	-	-	-	-	-	√	√
Restricted multiple wavelength operation	-	-	-	-	-	√	√
Medical examination required in the event of accidental exposure	-	-	-	√	-	√	√
Laser Safety Eyewear to be provided (if identified in risk assessment)	-	-	-	-	-	√	√
Protective clothing to be provided (if identified in risk assessment)	-	-	-	-	-	-	√

* visible beam lasers only

3.7 Summary of Warnings & Protective Measures

CLASS	Control Measures
1	* None under normal use * May be needed for service
1M	* Prevent direct viewing with magnifying optics * Warning signage

2	* Do not stare into beam * Do not direct towards people * Should not be used in public areas * Warning signage re risk assessment * Local induction and training
2M	* Do not stare into beam * Do not direct towards people * Should not be used in public areas * Warning signage re risk assessment * Local induction and training
3R	* Do not stare into beam * Do not direct towards people * Should not be used in public areas * Warning signage re risk assessment * Local induction and training: safe work with laser devices
3B & 4	* Risk assessment * Fully enclosure laser beam path / beam enclosure only * Standard operating procedure (SOP) for alignment * Emission indicators * Access to laser area controlled via an interlock / key control * Training completion: 'Safe use of laser devices' * Local induction training * Appointing a laser safety officer * Designate a laser area * Warning signage at all access points * Personal protective equipment
Class 1 containing higher-class laser – formerly 1E embedded laser system	* Totally enclosed systems, inherently safe because of engineering design, restricting exposure to Class 1 AEL * Typically applies to scientific instruments, such as cell counters. * Must be registered with the laser safety officer

4. Technion laser safety: code of practices

4.1 Training

1. All users of Class 3B and 4 lasers MUST attend one of the safety unit's laser safety training sessions. **No unsupervised work can take place until laser users have completed their training.**
2. All laser users must be informed by their principle investigator or lab engineer regarding the systems' risk assessments of their working area.

4.2 Risk Assessment

Class 3B and Class 4 laser products emit laser radiation that could exceed exposure limit values, therefore any experiment which involves the use of these lasers must be subjected to a thorough risk assessment. However, under some circumstances, lower hazard class lasers may also need assessment.

4.3 Risk Controls

A risk control hierarchy must be applied to remove or reduce risk. The hierarchy is:

4.3.1 Elimination/substitution

It is unlikely that the laser can be removed entirely but the substitution of a laser with one from a less hazardous class must be considered, e.g. change the use of a Class 3B laser to a Class 2 laser.

4.3.2 Engineering controls

The most effective methods of control for a given laser, therefore should always be considered first: guarding and signage.

4.3.3 Management controls

Change behaviour so people do not inadvertently / deliberately put themselves at risk.

Examples:

- Training
- Designating laser controlled areas where exposure can exceed the ELV for the particular wavelength of laser radiation
- Signage and warning lights
- Preventing unauthorized access
- Controlling access to keys
- Keeping beam paths as short as possible
- Containing the beam in fibers, flight tubes or other forms of containment

 Written safe operating procedures for high-risk activities, including maintenance and alignment of the beam

 Maintenance of equipment that may cause specular reflections

 Local system's rules

 Alignment aids during routine maintenance to realign the beam path, e.g. use of a lower power sighting laser / mask / target

 Emergency plan protocol signage near entrance

4.3.4 **Personal Protective Equipment (PPE)**

An eye injury can be life changing and is the most common research-laser-labs' injury. PPE are the items worn by an individual to protect against residual risks. PPE is the last form of control that should be considered as a safety measure and it should only be provided if it is not possible to guarantee that laser exposure will be less than the ELV under all circumstances. PPE also needs to be maintained and replaced when necessary.

 PPE should be provided in case, despite using other control means, eyes can still be exposed to laser radiation above ELV.

 PPE has been deemed compulsory by the laser safety officer

 Laser eyewear must be carefully selected to ensure that the proper wavelength of is selectively blocked by the PPE's filter

 In case different wavelength lasers are in use, colour coding or other means must be used to match the laser with the appropriate eyewear.

 Eyewear must be permanently marked to show –

a) the operating wavelength

b) the optical density at the operating wavelength

 Eyewear must be replaced if it is exposed to a single incident of accidental exposure to high-level radiation or if the filter has degraded following prolonged or accumulative exposure

In most Technion labs the nature of work involving laser systems make it impractical to reduce exposure to levels of zero artificial radiation only by engineering controls, since access to the beam for the setting up of optical components and samples for analysis is often routinely necessary. PPE is therefore required to ensure that in the event of an accidental exposure the laser – the user is not injured. Whenever complete beam containment is not an option and potential above MPE exposure, PPE is compulsory.

There are two (2) types of eye laser protection: full attenuation and alignment. The full attenuation type is completely opaque to the beam while the alignment allows a small percentage of the beam in the visible wavelength region to be transmitted so that it can be seen for alignment purposes. Typically, the beam is visible at its termination point or where it scatters off-dust particles in ambient air.

4.3.3.1 Optical Density

Protective eyewear uses filters, which can partially or completely transmit or attenuate a particular wavelength of light. The Optical Density (OD) of a filter is a measure of this attenuation. It is a logarithmic ratio between the light incident upon the filter and the transmitted the light going through the filter.

The required OD for a particular laser can be chosen, given the Maximum Permissible Exposure (MPE) and the anticipated worst-case exposure a living tissue can withstand without protection (H_0): $OD = log_{10}\,[\,H_0\,/MPE]$. The units are in J/cm^2 for pulsed laser systems and in W/cm^2 for CW systems for both parameters.

The potential maximum exposure H_0 can be calculated directly from the laser beam itself. If the laser system, for example, has neutral density filters or the beam has a large divergence then H_0 may well be reduced, but since full access is primarily required to Class 4 laser beams in research labs it is best practice to assume it is always equal to the AEL. Simply put, the OD scale factor of eye protection equipment must be based on the maximum output power or energy density the user could potentially be exposed to.

5 European (Israeli) Standard for Laser Eye Protection:

5.1 EN207 (IS 4041/10) Full Attenuation

Class 3B or 4 laser systems pose an exposure risk to limits above the MPE, therefore full attenuation eye protection must be worn in the UV wavelength region of 190 to 380 nm and in the NIR region of 700 to 1400nm. Eye protection should also be worn in the mid- to far-IR, which all reside in the nonvisible wavelengths, thus there is no advantage to wearing the alignment eyewear. If viewing of the beam is not required in the visible region, 400 to 700 nm, then full attenuation eyewear should also be worn.

All products sold in Israel must be CE-marked. To sell non-CE-marked products is illegal. The European standard for full attenuation laser safety eyewear is EN207 and for alignment is EN208 (issued in 1998, modified in 2010).

EN 207	Beam Diameter D63	Exposure time	Labelling
1998	2mm	10s or 100 pulses	L
2010	1mm	5s or 50 pulses	LB

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

The LB rating specifies damage threshold of the filter material at maximum power or energy density. The filter material and frame must be able to withstand a direct hit for a period of more than 5 seconds in CW mode or for 50 pulses. This LB scale number should give reasonable comparability between similar attenuations.

5.1.1 Labelling

All laser protection eyewear must be appropriately labelled for simplicity of protection choice by the user.

The first part of a label normally signifies the wavelength range he eye protection is intended for.

The second part of a label displays the code letter for different laser emission pulse lengths the eyewear protects against.

Operation mode		typical pulse length
continuous wave D (cw)	... is the continuous emission of laser radiation.	› 0.2 s
pulsed mode I	... is the short-term single or periodically repeated emission of laser radiation.	› 1 μs to 0.25 s
giant pulsed mode R	... is like pulsed mode, but the pulse length is very short.	1 μs to 1 ns
modelocked M	... is the emission of laser radiation with all the energy stored in the laser medium released within the shortest possible time.	‹ 1 ns

Lasers can work in one or more of the above modes.
**) cw: continuous wave*

The letter **D** indicates continuous outputs, CW, where the emission length is above 0.25 seconds.

The letter **I** indicates the pulse range between 0.25 seconds to 1 microsecond.

The letter **R** indicates pulse lasers in the microsecond-nanosecond range.

The letter **M** indicates a pulse duration of less than a nanosecond down to the femtosecond and potentially to the attosecond range.

The **LB** scale number, (for example: LB 10), indicates that the laser eyewear will offer an attenuation factor of $x10^{10}$ for the wavelength range stated. The CODE Emission type D Continuous wave (>0.25s) I Long Pulse (1µs to 0.25s) R Q-switched Short Pulse (1ns to 1µs) M Mode locked Ultra short pulse (< 1ns).

Optical Density (OD) of the filter material is implicit in the code LB10 and is equal to the numerical value.

The CE mark must be displayed to indicate compliance with the European standards.

The letter S may also be present to indicate "Increased Robustness" of both the frame and filters.

Additionally, it is possible to purchase combination glasses, which include an additional alignment function for working with lasers generating visible light for longer periods of time.

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
		≥3x10^{-4}	10^{-9} to 3x10^{-4}	< 10^{-9}	≥5x10^{-4}	10^{-9} to 5x10^{-4}	< 10^{-9}	≥ 0.1	10^{-9} to 0.1	< 10^{-9}
LB1	10^{-1}	0.01	3x10^{2}	3x10^{11}	10^{2}	0.05	1.5x10^{-3}	10^{4}	10^{3}	10^{12}
LB2	10^{-2}	0.1	3x10^{3}	3x10^{12}	10^{3}	0.5	1.5x10^{-2}	10^{5}	10^{4}	10^{13}
LB3	10^{-3}	1	3x10^{4}	3x10^{13}	10^{4}	5	0.15	10^{6}	10^{5}	10^{14}
LB4	10^{-4}	10	3x10^{5}	3x10^{14}	10^{5}	50	1.5	10^{7}	10^{6}	10^{15}
LB5	10^{-5}	10^{2}	3x10^{6}	3x10^{15}	10^{6}	5x10^{2}	15	10^{8}	10^{7}	10^{16}
LB6	10^{-6}	10^{3}	3x10^{7}	3x10^{16}	10^{7}	5x10^{3}	1.5x10^{2}	10^{9}	10^{8}	10^{17}
LB7	10^{-7}	10^{4}	3x10^{8}	3x10^{17}	10^{8}	5x10^{4}	1.5x10^{3}	10^{10}	10^{9}	10^{18}
LB8	10^{-8}	10^{5}	3x10^{9}	3x10^{18}	10^{9}	5x10^{5}	1.5x10^{4}	10^{11}	10^{10}	10^{19}
LB9	10^{-9}	10^{6}	3x10^{10}	3x10^{19}	10^{10}	5x10^{6}	1.5x10^{5}	10^{12}	10^{11}	10^{20}
LB10	10^{-10}	10^{7}	3x10^{11}	3x10^{20}	10^{11}	5x10^{7}	1.5x10^{6}	10^{13}	10^{12}	10^{21}

Full attenuation protection levels according to EN 207

5.1.2 EN 207 Markings explained

Following compliance according to EN 207 the laser protective eyewear is awarded various markings which are printed on the eyewear and specify the maximum power and energy densities at different wavelengths. For instance:

DI 750 - 1200 LB5

R 750 - 1200 LB6

M 750 - 1200 LB4

This means that over the wavelength range of 750 - 1200 nm the eyewear has the following ratings: D LB5 I LB5 R LB6 M LB4

The D, I, R and M refer to CW or different pulse lengths as follows:

D - Continuous Wave (CW)

I - A pulse length > 100 ns, 'Long Pulse'

R - A pulse length > 1 ns and < 100 ns, 'Q-switched'

M - A pulse length < 1 ns, 'Femtosecond'

The 'L numbers' (LB5, LB6, LB4, etc.) refer to the maximum power or energy density the eyewear is specified for. The actual values must be looked up from Table B1 in EN 207 (which for copyright reasons we cannot reproduce here). For the eyewear markings given above, the values are:

CW	-	1 MW/m2 D LB5
Long Pulse	-	500 J/m2 I LB5
Q Switched	-	5 kJ/m2 R LB6
Femtosecond	-	1.5 J/m2 M LB4

An increase in the LB number by 1 will increase the power and energy density values by one order of magnitude. However, EN 207 breaks down the LB number table into three wavelength ranges: 180 - 315 nm, 315 - 1400 nm and 1400 - 1,000,000 nm. The relationship between the L numbers and power / energy densities shown above holds only for the 315 -1400 nm wavelength region.

For other wavelengths refer to EN 207.

5.2 EN208 Alignment goggles

Alignment glasses will reduce the actual incident to a class 2 laser (< 1 mW for continuous wave lasers). Lasers denoted as class 2 are regarded as eye-safe if the blink reflex is working normally.

Alignment glasses allow the user to see the beam spot while aligning the laser. This is only possible for visible lasers, ranging at 400nm to 700nm. Alignment goggles must also withstand a direct hit from the specified laser for at least 5 seconds (cw) or 50 pulses (pulsed mode) under standardized conditions.

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

Alignment protection for visible wavelength levels according to EN 208

5.3 Good Practice

All laser protective eyewear pertaining to a particular laser hazard zone should be accessible to all users entering the laser area.

* The eyewear should be stored in a designated, clean drawers or containers, outside the hazard zone close and close to the entrance.
* These containers should be labelled with the eyewear details.
* Eyewear should always go back to its correct container.
* Protect all the filters and eyewear from scratches and mechanical stress; never leave glasses with filters facing down; never store goggles ear heaters or hot equipment.
* Avoid contact with chemicals or reactive fumes.
* Damaged or scratched eyewear, filters, or laser protection windows and filters that have changed colour should not be used.
* Do not expose eyewear to daylight or UV lamps.
* Clean according to the manufacturer's instructions.

Always ensure the eye protection carries -

1. The appropriate wavelengths in the hazard area
2. Is suitable or the emission type: pulsed or continuous wave (DIRM)
3. Supplies full protection (LB) or alignment (RB)

It is your personal responsibility to ensure you have the correct laser protection eyewear. Do not assume the eyewear is correct for the laser system you're supposed tyo work with just because of the eyewear's location

6. DO& DO NOT DO

6.1 Ten Golden Rules for Laser Safety

a. Never stare at a laser beam.

* Never look down specular reflections (e.g.: from mirrors or other reflective surfaces).

* Never stare at diffuse reflections.

* Never look back along the optical path through an experiment with an 'ON' energized beam.

Rule-of-Thumb: If it looks bright - don't stare at it.

b. Keep bright lights in the lab, if possible.

The brighter the ambient lighting level - the narrower the eye's pupil will become, thereby reducing the probability of a laser beam hitting one's eye.

c. Remove personal jewelry.

Watches, rings, etc. act as reflectors. When entering a laser lab, remove anything which may reflect the beam.

d. Locate and terminate all laser beams

* Make sure that all beams are terminated with a suitable beam dump capable of handling the power of the laser beam. Remember all transmitting components also back-reflect, thus causing stray beams.

* IR or UV laser beams will not be visible!

* Stainless steel vacuum chambers and VDU screens serve as reflectors of stray beams.

e. Secure all optical components

Only use good quality optical mounts, firmly clamped to the table top, etc.. This will prevent misalignment, reduces the chances of component shuttling.

Blu-Tak is definitely NOT a good way to mount optics!

f. Keep beams in a horizontal plane below eye level, preferably at waist height

* Horizontal beams are easier to work with and are predictable. Avoid vertical and skew beams if possible.
* Change beam height only if unavoidable. Use a periscope; be careful upon alignment.

g. Never bend below beam height

* If you drop something, block the laser beam <u>before</u> retrieving the object. If you cannot stop the beam (for instance, if you are in the middle of an experimental run), kick the object out of the way so that you don't trip over it.
* If you must sit in a lab, ensure the chair places your eyes above beam height.

h. Optical components reflect, transmit and absorb light

Often, a transmitting component will also reflect light. This can lead to stray beams. Components' reflectivity may vary in different spectral regions or upon different light polarizations.

Optical components may change their characteristics when used with high power lasers: neutral density filters can bleach, crack or even explode.

i. Non-optical hazards.

Refrain from tripping over, electrocution, spill solvents, cryogenic burns, etc..

Laser dyes and solvents are nasty chemicals

j. Laser personal protective equipment

* Ensure suitable laser eye protection.
* Protect skin as well as eyes: never enter bare hands into a laser beam's path.

If in doubt, FIND OUT

6.2 UNSAFE PRACTICES, DO NOT DO

Some common unsafe practices which lie at the core of perfectly preventable laser accidents are:

- Lack of pre-planning and failure to follow safety protocols
- Misaligned optics: upwardly directed beams, specifically periscopes, reflections from windows and beam splitters/combiners.
- Available eye protection not used during alignment.
- Wearing the wrong eyewear.
- Bypassing door interlocks and laser housing interlocks.
- Insertion of reflective materials into beam paths.
- Lack of protection from non-beam hazards.
- Improper methods of handling high voltage.
- Operating unfamiliar equipment.

7 Accident Reporting

An eye examination should always be carried out if it is so much as suspected or when someone has been exposed to artificial optical radiation in excess of the optical exposure limit value.

Please contact the SU unit:

tel +972 4 829 2146 Go directly to a hospital or KUPAT CHOLIM for an eye examination

Accidental exposure to laser radiation above the EXPOSURE LIMIT VALUE must be reported to the Technion safety office

Emergency Contact: 2222

IN CASE OF Emergency CALL 2222