Laser Safety
Online training
Welcome to the EPFL Laser safety online training!

This training will help you understand direct and indirect hazards related to the use of lasers and explain safety measures applicable to the use of class 3B and class 4 lasers at the EPFL.

Please, follow the training carefully, as you will be given a test to answer after finishing the training. Passing this test is prerequisite for accessing your laser lab. Passing grade credit is 80% and the test can be attempted three times at maximum.
Terminology and measure units

1. Laser light properties
   - Wavelength: nm or µm (THz, GHz, cm⁻¹)
   - Beam divergence: mRad
   - Beam diameter: mm at aperture

2. Understanding laser hazards

3. Laser classification

3. Laser risk controls

Continuous laser
- Power: Measured in W or mW

Pulsed laser
- Energy: J or mJ
- Pulse length: ms, ns, ps, fs
- Repetition rate: Hz
1. Laser light properties

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Radiation name</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 - 280 nm</td>
<td>UV C</td>
</tr>
<tr>
<td>280 - 315 nm</td>
<td>UV B</td>
</tr>
<tr>
<td>315 - 400 nm</td>
<td>UV A</td>
</tr>
<tr>
<td>400 - 700 nm</td>
<td>Visible</td>
</tr>
<tr>
<td>700 - 1400 nm</td>
<td>IR A</td>
</tr>
<tr>
<td>1400 - 3000 nm</td>
<td>IR B</td>
</tr>
<tr>
<td>3000 - 10^6 nm</td>
<td>IR C</td>
</tr>
</tbody>
</table>

Laser wavelengths

Laser types

Laser wavelengths

Laser types

1. Laser light properties

2. Understanding laser hazards

3. Laser classification

3. Laser risk controls
broadband sources vs. LASER

<table>
<thead>
<tr>
<th>Source</th>
<th>Power (W)</th>
<th>Irradiance (power incident on a surface) (W/m^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>4 \cdot 10^{26}</td>
<td>(at the surface of the Earth) 1400</td>
</tr>
<tr>
<td>Incandescent light bulb</td>
<td>100</td>
<td>(at 1 m from the bulb) 8</td>
</tr>
<tr>
<td>He-Ne Laser</td>
<td>5 \cdot 10^{-3}</td>
<td>1100</td>
</tr>
<tr>
<td>CO_2 Laser</td>
<td>20</td>
<td>4 \cdot 10^6</td>
</tr>
</tbody>
</table>
Wavelengths in the range 400-1400 nm can be focused on the retina (**retinal hazard range**).

700-1400 nm are **invisible**!

**1 mW laser**

100 W light bulb
Retinal damages can cause **instantaneous loss of the fine vision.**

Retinal tissue does not regenerate, the damage is permanent!

**Thermal injuries of the retina**

- Subretinal hemorrhage
- Permanent retinal lesion
- Profuse hemorrhage into the vitreous
- Multiple burn spots

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N. McLin 9th Annual DOE Laser Safety Officer Workshop (2013)

Interactions with the eye, wavelengths ($\lambda$) outside 400-1400 nm range

- **FIR + FUV ($> 1400 \text{ nm, } < 300 \text{ nm}$)**
  - Absorbed by the cornea!

- **Ultraviolet (300–400 nm)**
  - Absorbed by the lens!

**Keratitis** (inflammation of the cornea)

- Thermal damages of the lens @ 300-400 nm
- **Cataract** (clouding of the eye’s lens) @ 300 nm
Variation of pupillary aperture determines the energy that penetrates the eye

- Natural defence mechanism
- Works only with visible light
- Average response time: 0.25 seconds
- So this mechanism can protect us for class 1 and 2 lasers only

Facts on the aversion response (blinking effect):

- Natural defence mechanism
- Works only with visible light
- Average response time: 0.25 seconds
- So this mechanism can protect us for class 1 and 2 lasers only

Variation of pupillary aperture determines the energy that penetrates the eye

- 2 mm day light
- 3 mm interior light
- 7 mm semi-darkness (twilight)
- 8 mm pupil dilated for medical exam.

Human Pupil
2 - 3mm

Bright Conditions

Keep the lights on as much as possible!

Human Pupil
7mm

Low Light Conditions

0.25 s
Specular vs. diffuse reflection

Intrabeam viewing

Specular reflection
Hazard similar to the direct beam—may contain up to 90% of the initial energy!

Diffuse reflection
Hazardous for the class 4 lasers!

Be careful

Bad idea
Thermal skin damage (Infrared + Visible + near UV)

- Conversion of light to heat
- Coagulation of proteins

Burns are a function of time and temperature

10 µs – 5 s
Photochemical skin damage (medium and far UV)

- Destructions, loose of space structure
- Denaturation, and cellular disorganisation.

Consequences not always immediate
Cancers can be provoked on the longer term.
Examples of skin damage

**Hyperpigmentation**
Typical for UVA lasers (315 nm to 400 nm). Here after laser hair removal

**Melanoma**
Risks of carcinogenesis for UVB lasers (280 nm to 315 nm). Damage to the DNA or carcinogenic intracellular viruses.

**Erythema**

**Pigment-darkening effect**
Typical for UVC lasers (200 nm to 280 nm) and UVA. Less harmful to skin since if exposure to small levels
## Summary of effects for different wavelengths of laser beams

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Name</th>
<th>Effects on eyes</th>
<th>Effects on skin</th>
</tr>
</thead>
<tbody>
<tr>
<td>180 - 280 nm</td>
<td>UV C</td>
<td>-Photokeratitis</td>
<td>- Sunburn</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Accelerated skin aging</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Skin cancer</td>
</tr>
<tr>
<td>280 - 315 nm</td>
<td>UV B</td>
<td>-Cataract related to photochemical process</td>
<td>- Increased pigmentation</td>
</tr>
<tr>
<td>315 - 400 nm</td>
<td>UV A</td>
<td>-Thermal damage of the lens</td>
<td>- Pigment darkening</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- Skin burn</td>
</tr>
<tr>
<td>400 - 700 nm</td>
<td>Visible</td>
<td>-Retinal injuries Photochemical and thermal</td>
<td></td>
</tr>
<tr>
<td>700 - 1400 nm</td>
<td>IR A</td>
<td>-IR Cataract</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Retinal burns</td>
<td></td>
</tr>
<tr>
<td>1400 - 3000 nm</td>
<td>IR B</td>
<td>-Burns of cornea</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-Protein level increasing in the cells in aqueous humor.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-IR Cataract</td>
<td></td>
</tr>
<tr>
<td>3000 nm - 10⁶ nm</td>
<td>IR C</td>
<td>Burns of cornea</td>
<td></td>
</tr>
</tbody>
</table>
Associated (collateral) hazards

**Chemical**
Some lasers require hazardous or toxic substances to function.
- Example: dye lasers or Excimers, ZnSe optics for CO$_2$ lasers.

**Electrical**
- Some lasers use high voltages, that can be lethal.
- Discharge lasers like Ar.

**Fire**
- Flammable materials (e.g. acetone, ethanol used in the labs) can be inflamed by the direct beam of specular reflexion of high power CW beams of IR lasers.
- Enclosure of Class 4 laser beams and terminations of some focused Class 3B lasers, can result in potential fire hazards if the enclosure materials are exposed to irradiance exceeding 10 W/cm$^2$.
- Solvents used in dye lasers are flammable. High-voltage pulses or flash lamps may cause inflammation.
International regulation on laser safety: the norm applied in Europe is 60825-1/A2. Some safety terms employed:

- **MPE** is Maximum Permissible Exposure (the maximum level of exposure to a laser without harm).
- **NOHD** is Nominal Ocular Hazard Distance (see image below).
## Laser classes - safety aspects

<table>
<thead>
<tr>
<th>Class</th>
<th>Naked Eye</th>
<th>Magnifying optics</th>
<th>Specular reflection</th>
<th>Diffuse reflection</th>
<th>Skin hazard</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/1C</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>1M</td>
<td>✓</td>
<td>!</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>2M</td>
<td>✓</td>
<td>!</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3R</td>
<td>!</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>3B</td>
<td>!</td>
<td>!</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
<td>!</td>
</tr>
</tbody>
</table>

- **✓**: No risk from exposure
- **!**: Caution required to prevent exposure
- **⚠️**: Maximal protection required
- **🔥**: Can ignite fire
Safety control measures for managing the risk are often divided into **4 groups that are hierarchized (order of priority)** as bellow:

1.) **S trategic control measures**  
e.g. substitution with a lower laser class if possible.

2.) **T echnical (engineering) control measures**  
e.g. enclosures, tubes, interlocks.

3.) **O rganizational (administrative) control measures**  
e.g. confining the hazard zone, controlling access, training, standard operating procedures.

4.) **P ersonal protection measures**  
e.g. goggles, gloves.
Technical control measures (to reduce the access to hazard)

Beam enclosures

- Must be sufficiently robust and stable, and capable of containing the hazard.
- Ex: Beam tubes or other suitable covers.
- Open beam paths should be kept short, localizing the hazard within the smallest possible area.
If the laser beam can not be **enclosed**, the **access** to laser hazard area must be **controlled** and **personal protective equipment** used.
(1) Work with class 3B and 4 lasers @ EPFL, STOP

- Beam paths are enclosed wherever possible. Use plates to enclose lasers, tables etc. (eg: 2-2.5 mm thick aluminium plates with black anodizing)
- Optical bench is free of unnecessary reflective items.
- Beam stops are present at the end of all beam paths and are not combustible.
(2) Work with class 3B and 4 lasers @ EPFL, STOP

- The laser beam must be confined in a plane lower than the eyes of a seated or standing person.
- Persons sitting at the work stations (computers) have to be protected against beam exposure.
(3) Work with class 3B and 4 lasers @ EPFL, STOP

- An area where laser is used should be delimited, and access to the area restricted (Camipro, key).
- A doorbell must be installed at the entrance of the laboratory. When the laser is in use, visitors must ring the bell and wait for permission before entering the laboratory.
- The lab door must close automatically and be equipped with a knob handle on the outside.
- To avoid that visitors are exposed to the beams, an entry way control (e.g. laser curtains) must be installed at the lab entrance, and must be kept closed when laser is in use.
- A signal lamp indicating laser in use must be placed above the door outside the laboratory. The bulb must be a white diode and the light must blink.
Video sequence: a visitor during laser alignment

If the embedded video doesn’t function, please use the web link:
https://video.epfl.ch/1113/1/10
STOP: Personal Protection:

Applicable safety standard EN 207: Laser protection eyewear

- Defines the optical density required to protect the eye from a laser with a certain wavelength and power output.
- Objective: reduce the laser power below the MPE.
- The eyewear and its frame must resist 5 seconds or 50 pulses.
- Do not look directly in the beam even with laser protection eyewear!
Optical Density

- All EN 207 rated eyewear will have an LB number for each operational mode for which it is rated.
- The LB number gives the minimum required optical density

<table>
<thead>
<tr>
<th>Scale number</th>
<th>Minimum Optical Density</th>
<th>Ratio $I_0/I$ for a given $\lambda$</th>
</tr>
</thead>
<tbody>
<tr>
<td>LB1</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>LB2</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>LB3</td>
<td>3</td>
<td>1000</td>
</tr>
<tr>
<td>LB4</td>
<td>4</td>
<td>10000</td>
</tr>
<tr>
<td>LB$n$</td>
<td>$n$</td>
<td>$10^n$</td>
</tr>
</tbody>
</table>
Laser protection eyewear markings

<table>
<thead>
<tr>
<th>Operational mode</th>
<th>MARKING Letter</th>
<th>Pulse length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous</td>
<td>D</td>
<td>&gt; 0.25 s</td>
</tr>
<tr>
<td>Pulsed</td>
<td>I</td>
<td>1 μs – 0.25 s</td>
</tr>
<tr>
<td>Pulsed (Q-switched)</td>
<td>R</td>
<td>1 ns – 1 μs</td>
</tr>
<tr>
<td>Pulsed (mode-coupled)</td>
<td>M</td>
<td>&lt; 1 ns</td>
</tr>
</tbody>
</table>

**Example**

1064 D LB5 + IR LB7 GPT CE

1064  Wavelength in nm

D LB5  LB number 5 according to EN 207 for continuous mode lasers @ 1064 nm: Maximum 1MW/m²

IR LB7  LB number 7 according to EN 207 for pulsed and short-pulsed lasers @ 1064 nm: 50kJ/m²

GPT  Manufacturer

CE  CE Marking:89/686/EEC
(4) Work with class 3B and 4 lasers @ EPFL,

STOP

- Compulsory: Lab head makes sure that personnel is trained for work with lasers and has a written evidence of that training (equipment specific training).

- All laser users must follow the present training and pass the quiz.

- Laser protective eyewear (free of damage) is to be worn by all personnel working with laser. Ideally the goggles should be marked with the name of the corresponding laser (photo above)

- The research group is in charge of purchasing laser protective eyewear. It is specific to lasers used and certified EN207.

- Either the vendor or SCC (scc@epfl.ch) can help to choose the goggles.

- If no ocular protection is available for a particular setup, only persons duly trained for this situation are authorized to enter the laboratory. The written orders are given to everyone by the laboratory head.
95% of laser accidents are...

- Unanticipated eye exposure during alignment
- Available laser eye protection not used
- Misaligned optics and upwardly directed beams

5% = Others
What can I do when I have to align my visible laser?

Never remove your laser safety glasses when working with lasers above class 2!

There are so called alignment glasses available for this purpose

**EN 208 for 400 – 700 nm only**

- Suitable for aligning VIS lasers only.
- Do not absorb or reflect the laser radiation completely, the radiation is only reduced to values below
Golden rules of laser safety - (1)

- Do not look into a laser beam (or specular reflections)
- Keep the room lighting the brightest possible
- Locate and terminate all stray laser beams. Make sure they are terminated with a matt, diffusing beam dump which is capable of handling the power of the beam.
- Secure all optical components.
- Remove the watch, jewellery …
Golden rules of laser safety - (2)

- Keep the beams horizontal.
- Do not look below the beam height.
- Use the adequate tools (non-reflecting).
- Maintain records of functions interruptions.
- Users must pass information to each other of any modification in the set-up (change of mirrors, ...) and the experimental conditions (change in wavelengths, ...)
- Do not forget the non optical risks (electrical, liquid nitrogen, chemical… )
What to do in case of accident with laser?

- Turn the laser off (the fastest way is to press emergency stop button if there is one).
- Sit the injured person (do not lie).
- Call 115.
- Place a dry and sterile gauze on both eyes.
- Note the characteristics of the laser (wavelength and power) so they can be given to the first aid staff.
- First aid staff will normally take injured person to ophthalmic hospital.