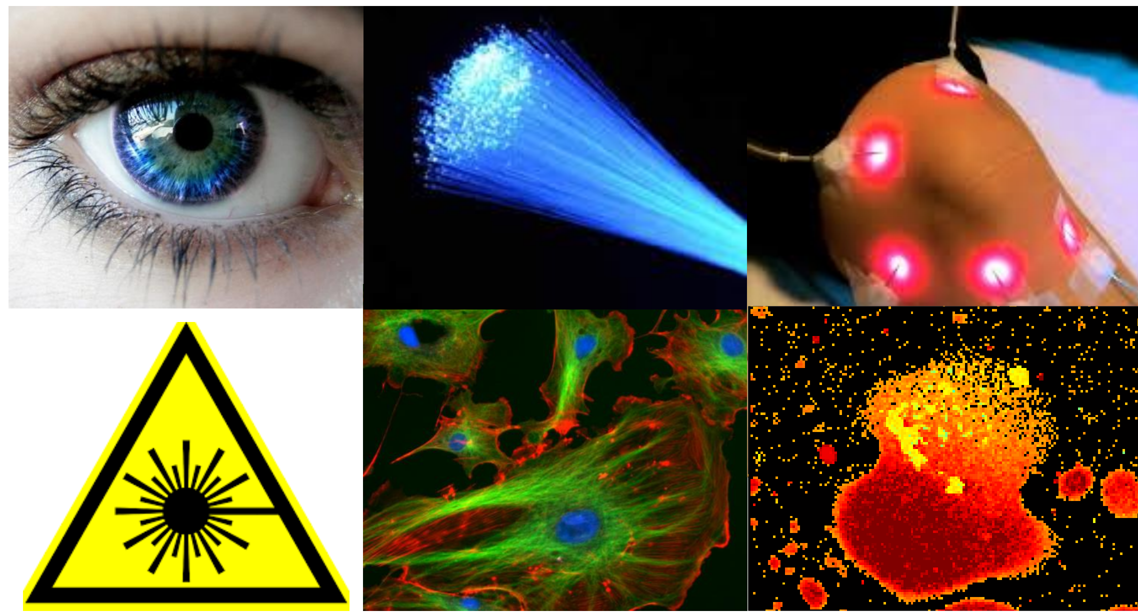
Laser Safety

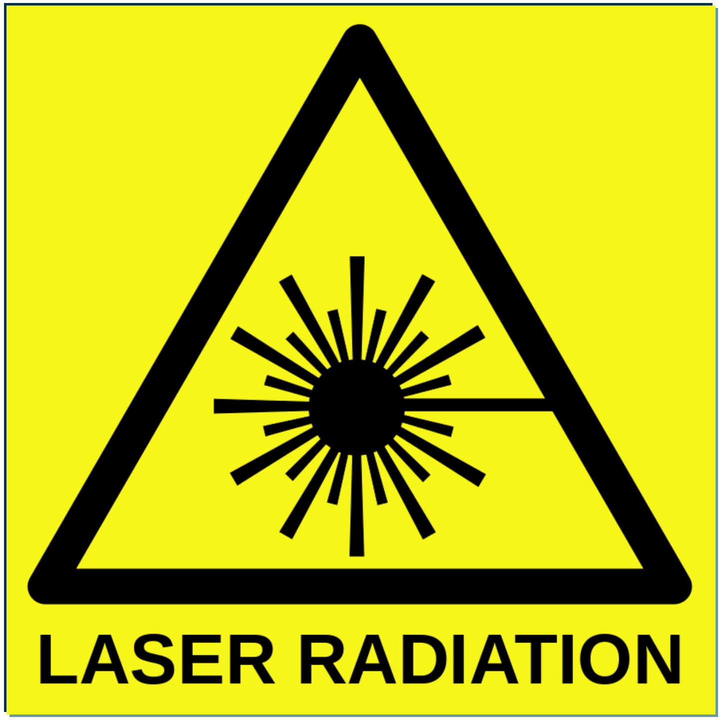


Pedro Jorge

Laser safety

- ligth, non ionizing radiation
- Exposure of patients and professional operators
- Optical power and wavelength dependent

- European standard EN 207.
- US - ANSI Z136 series of standards
  - ANSI Z136.3 – Safe Use of Lasers in Health Care



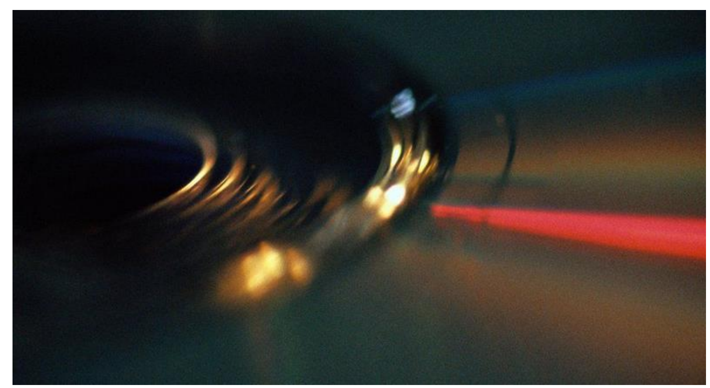
All lasers of class equal or higher than class 2 must have this warning sign.

Classificação Lasers

Class	Description	Warning Label
1	This class of laser is safe under all conditions of normal use, including use with optical instruments for intrabeam viewing. Lasers in this class do not emit radiation at levels that may cause injury during normal operation, and therefore the maximum permissible exposure (MPE) cannot be exceeded. Class 1 lasers can also include enclosed, high-power lasers where exposure to the radiation is not possible without opening or shutting down the laser.	
1M	Class 1M lasers are safe except when used in conjunction with optical components such as telescopes and microscopes. Lasers belonging to this class emit large-diameter or divergent beams, and the MPE cannot normally be exceeded unless focusing or imaging optics are used to narrow the beam. However, if the beam is refocused, the hazard may be increased and the class may be changed accordingly.	

Classe 1
Even when the laser itself has a higher class. The system can be class 1:

- Safety ensured by the design of the laser system
- Completely closed systems



https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=762

Classificação Lasers

2	Class 2 lasers, which are limited to 1 mW of visible continuous-wave radiation, are safe because the blink reflex will limit the exposure in the eye to 0.25 seconds. This category only applies to visible radiation (400 - 700 nm).
2M	Because of the blink reflex, this class of laser is classified as safe as long as the beam is not viewed through optical instruments. This laser class also applies to larger-diameter or diverging laser beams.

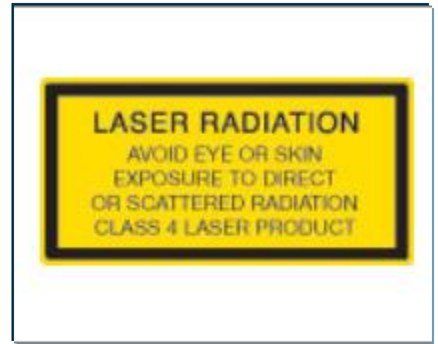
lasers emitting in the visible range (CW,P < 1 mW)!

Classificação Lasers

3R	Lasers in this class are considered safe as long as they are handled with restricted beam viewing. The MPE can be exceeded with this class of laser, however, this presents a low risk level to injury. Visible, continuous-wave lasers are limited to 5 mW of output power in this class.	
3B	Class 3B lasers are hazardous to the eye if exposed directly. However, diffuse reflections are not harmful. Safe handling of devices in this class includes wearing protective eyewear where direct viewing of the laser beam may occur. In addition, laser safety signs lightboxes should be used with lasers that require a safety interlock so that the laser cannot be used without the safety light turning on. Class-3B lasers must be equipped with a key switch and a safety interlock.	

Classificação Lasers

4	This class of laser may cause damage to the skin, and also to the eye, even from the viewing of diffuse reflections. These hazards may also apply to indirect or non-specular reflections of the beam, even from apparently matte surfaces. Great care must be taken when handling these lasers. They also represent a fire risk, because they may ignite combustible material. Class 4 lasers must be equipped with a key switch and a safety interlock.

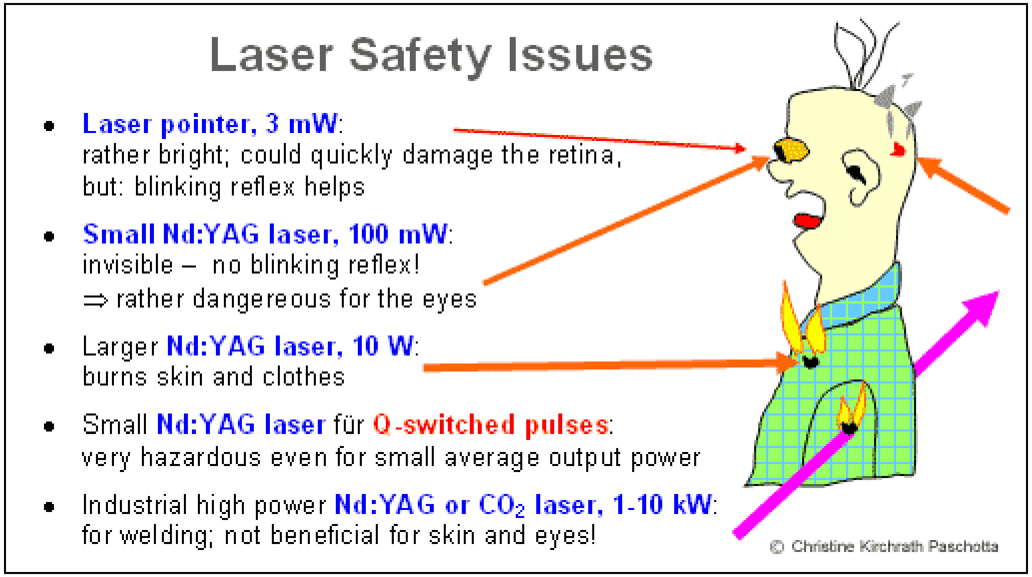


Schematic overview of shutters connected to Interlock® control with safety and warning devices

Associated risks

- Chemical
  - Manipulation of toxic gases or dyes (excimer laser, dye laser)
  - Ligth induced chemical reacitions release of toxic gases
- Electrical
  - High voltage
  - Electric current
  - Cooling systems
- others
  - Criogeninc systems
  - Handling optical fibers

  (burning and infection hazards)
  - noise
  - X ray orignating from defective sources
  - Fire hazard



https://www.rp-photonics.com/laser_safety.html

Protection: Eye exposure hazards

- risk:
  - burning (cornea, retina)
  - Opacity formation (cornea e cristalin)
- damage:
  - Strong absorption at a particular wavelength
  - Wavelength λ and accomulated exposure should be considered
- Organs
  - retina, : 0.4 -1.4 μm
    - Focusing effect leads to increased energy density 10^5
- cornea, radiation outsider the range : 0.4 -1.4 μm
  - Strongly absorbed
- cristaline, λ :UV
  - catarats

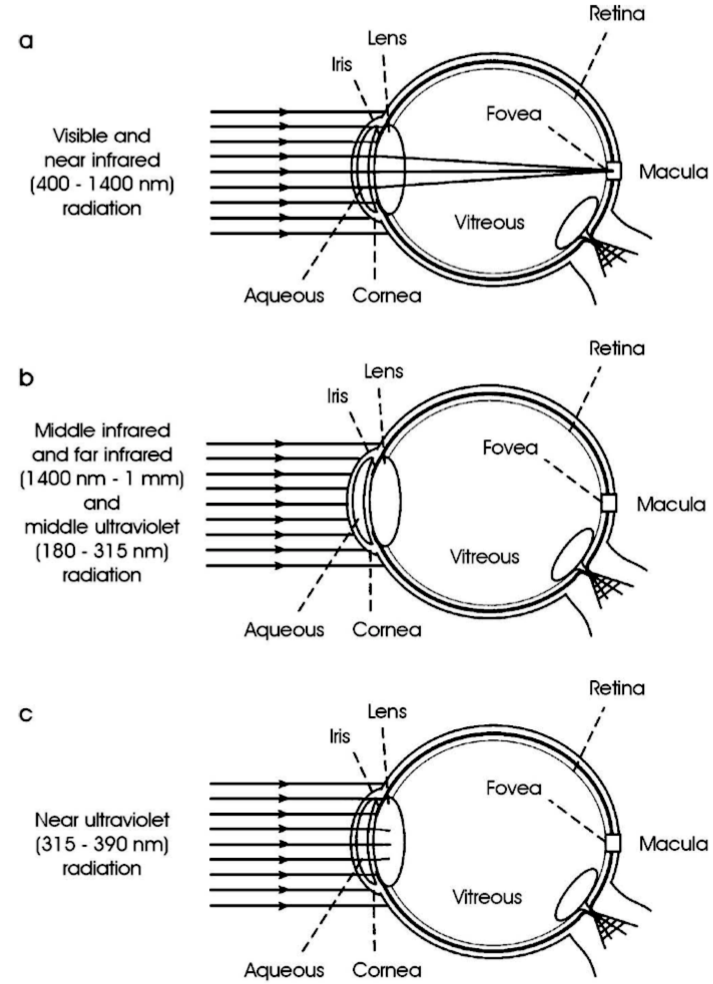


Fig. 5.1. (a) Absorption sites of visible and near infrared radiation. **(b)** Absorption sites of middle infrared, far infrared, and middle ultraviolet radiation. **(c)** Absorption sites of near ultraviolet radiation

Protection: skin hazards

- Risks:
  - Burning
  - carcinome
- damage:
  - λ : 230 - 380 nm
    - eriteme (solar burn) (mainly in UV-B)
    - Skin cancer
    - Precoce aging
  - λ : 280 - 480 nm : Pigmentation
  - λ : 310 - 400 nm e λ : 400 - 600 nm: fotosensitive reactions
  - λ : 700 - 1000 nm: burns and skin dehydration

Protection: risks of high power lasers

Risks:

- respiratory:
  - Vapor and gas release
- electrocution:
  - Manipulartion of laser systems
- Fire:
  - for $P_{optical}(CW) > 0:5$ W
- criogenic:
  - Skin contact, leaks, explosions, poor ventilation
- Acoustic:
  - Operation noise

Protection: safety norms application

parameters:

- Limiar aperture: maximum circular área over which irradiance is measured.
- Exposure duration, t_{max}
  - Maximum exposure time (cannot exceed 8h/day)
- MPE value (maximum permissible exposure)
  - Calculated value, dependente on exoposure type and laser characteristics.
  - Function of wavelength, pulse duration, exposure duration and type of tissue exposed (skin or eyes)

LASER SOURCES	TEMPORAL MODE	EYE M.P.E.	SKIN M.P.E.
Excimers	Pulsed	30 J/m^2	30 J/m^2
He-Ne	Continuous (t=2,25 s)	25 W/m^2	3.10^4 J/m^2
Nd:YAG	Pulsed (t=1ms)	0,5 J/m^2	9780 J/m^2
CO_2	Continuous (t>10s)	1000 W/m^2	1000 W/m^2

Table 02 : Typical M.P.E for common laser sources

Type of exposure

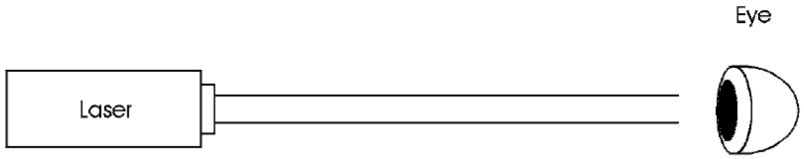


Fig. 5.3. Intrabeam viewing of a direct beam

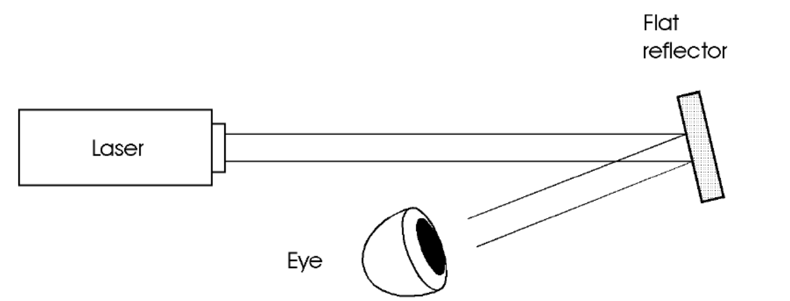


Fig. 5.4. Intrabeam viewing of a specularly reflected beam from a flat surface

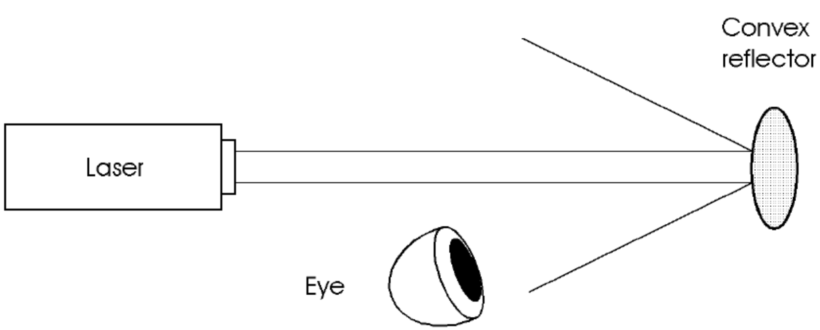


Fig. 5.5. Intrabeam viewing of a specularly reflected beam from a curved surface

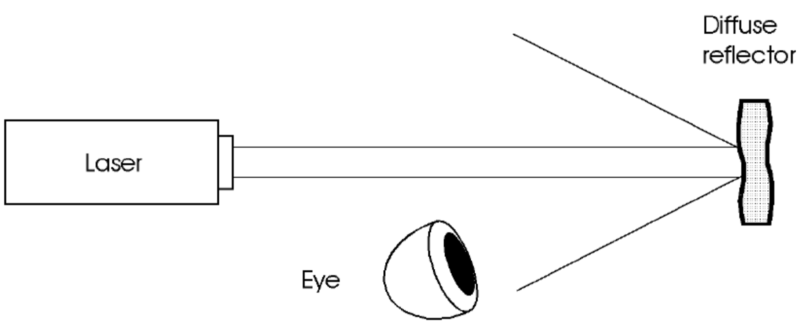


Fig. 5.6. Extended source viewing of a diffuse reflection

Ocular MPE

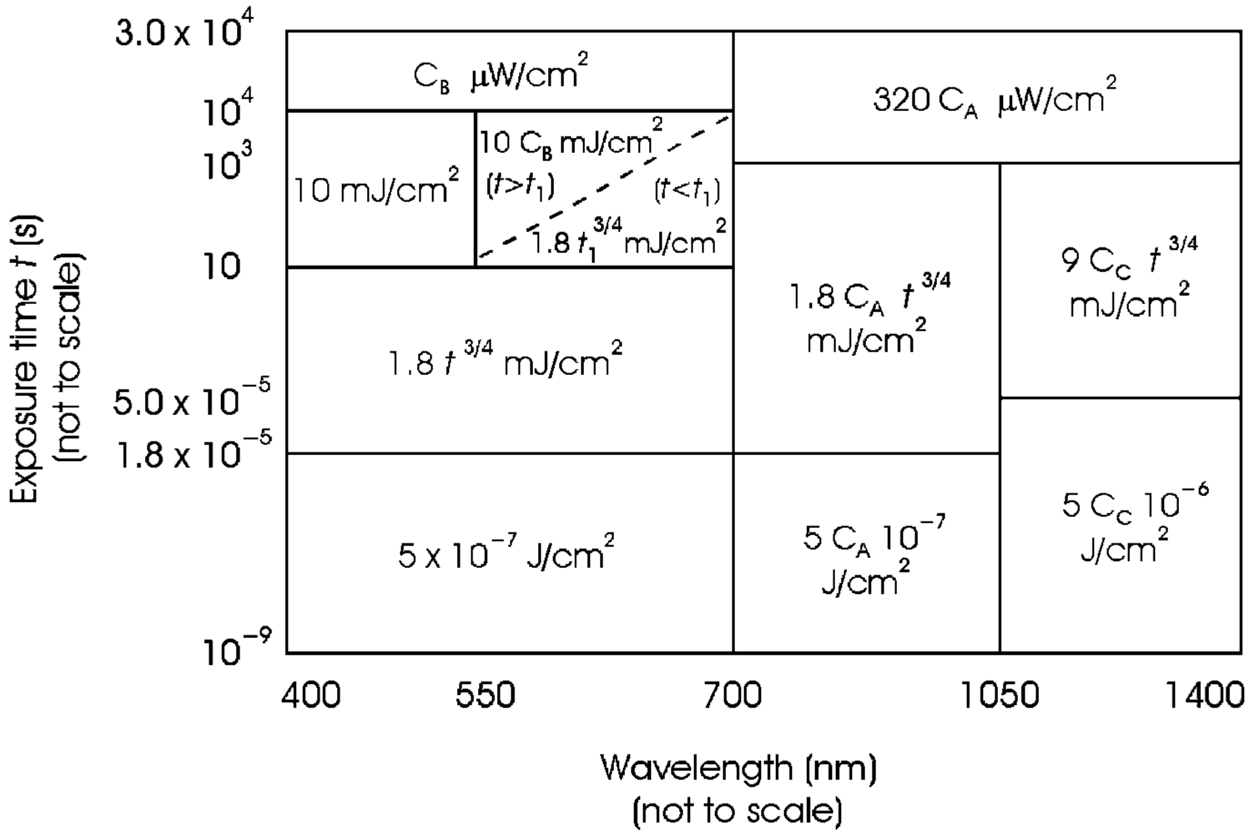


Fig. 5.2. Visible and near-IR MPE values for direct ocular exposure. Note that the correction factors (C) vary by wavelength. $C_A = 10^{2(\lambda-0.700)}$ for 0.700–1.050 μm. $C_A = 5$ for 1.050–1.400 μm. $C_B = 1$ for 0.400–0.550 μm. $C_B = 10^{15(\lambda-0.550)}$ for 0.550–0.700 μm. $t_1 = 10 \times 10^{20(\lambda-0.550)}$ for 0.550–0.700 μm. $C_C = 1$ for 1.050–1.150 μm. $C_C = 10^{18(\lambda-1.150)}$ for 1.150–1.200 μm. $C_C = 8$ for 1.200–1.400 μm

Ocular MPE by type of laser

Table 5.2. Ocular and skin exposure limits of some representative lasers. Repetitive pulses at rates less than one pulse per second were assumed for any repetitive exposures. Higher repetition rates require more adjustment of the exposure limits. τ: pulse duration

Laser type	Wavelength (nm)	Ocular exposure limit[a] (MPE value)
Argon ion	488/514	0.5 μJ/cm^2 for 1 ns to 18 μs
		$1.8\,\tau^{3/4}$ mJ/cm^2 for 18 μs to 10 s
		10 mJ/cm^2 for 10 s to 10 000 s
		1 μW/cm^2 for greater durations
He-Ne	632.8	0.5 μJ/cm^2 for 1 ns to 18 μs
		$1.8\,\tau^{3/4}$ mJ/cm^2 for 18 μs to 430 s
		170 mJ/cm^2 for 430 s to 10 000 s
		17 μW/cm^2 for greater durations
Nd:YAG	1064	5 μJ/cm^2 for 1 ns to 50 μs
		$9\,\tau^{3/4}$ mJ/cm^2 for 50 μs to 1 000 s
		1.6 mW/cm^2 for greater durations
Diode	910	1.3 μJ/cm^2 for 1 ns to 18 μs
		$4.5\,\tau^{3/4}$ mJ/cm^2 for 18 μs to 1 000 s
		0.8 mW/cm^2 for greater durations
CO_2	10600	10 mJ/cm^2 for 1 ns to 100 ns
		$0.56\,\tau^{1/4}$ J/cm^2 for 100 ns to 10 s
		0.1 W/cm^2 for greater durations

Skin MPE by type of laser

Laser type	Wavelength (nm)	Skin exposure limit[b] (MPE value)
Argon ion	488/514	$0.02\,\mathrm{J/cm^2}$ for 1 ns to 100 ns
		$1.1\,\tau^{1/4}\,\mathrm{J/cm^2}$ for 100 ns to 10 s
		$0.2\,\mathrm{W/cm^2}$ for greater durations
He-Ne	632.8	$0.02\,\mathrm{J/cm^2}$ for 1 ns to 100 ns
		$1.1\,\tau^{1/4}\,\mathrm{J/cm^2}$ for 100 ns to 10 s
		$0.2\,\mathrm{W/cm^2}$ for greater durations
Nd:YAG	1064	$0.1\,\mathrm{J/cm^2}$ for 1 ns to 100 ns
		$5.5\,\tau^{1/4}\,\mathrm{J/cm^2}$ for 100 ns to 10 s
		$1.0\,\mathrm{W/cm^2}$ for greater durations
Diode	910	$0.05\,\mathrm{J/cm^2}$ for 1 ns to 100 ns
		$2.8\,\tau^{1/4}\,\mathrm{J/cm^2}$ for 100 ns to 10 s
		$0.5\,\mathrm{W/cm^2}$ for greater durations
CO_2	10600	$10\,\mathrm{mJ/cm^2}$ for 1 ns to 100 ns
		$0.56\,\tau^{1/4}\,\mathrm{J/cm^2}$ for 100 ns to 10 s
		$0.1\,\mathrm{W/cm^2}$ for greater durations

[a] The exposure limit is averaged over a 7 mm aperture for wavelengths between 400 nm and 1400 nm, and over 1.0 mm for the CO_2 laser wavelength at 10.6 µm.

[b] The exposure limit is defined for a 3.5 mm measuring aperture.

Ocular Protection

- Filters and protection googles

$$OD = \log_{10}\left(\frac{1}{T}\right), \text{ or } \ T = 10^{-OD}$$

H_0 is the maximum expected exposure

- CW: W/cm^2
- Pulsed: J/cm^2

Optical density

$$OD(\lambda) = \log \frac{H_0}{MPE}$$

Ocular protection: Calculations

- Intensity of laser beam
  - Beam waist or diameter to consider:
    - 90% energy (pulsed regime)
    - 87% power (CW regime, gaussian)
- Limiar aperture
  - Diffraction limited lens: $$2w_o = 2.44\lambda\left(\frac{f}{\#}\right)$$

λ (nm)	Limiar aperture (mm)
< 400	1
$400 - 1400$	7
> 1400	3.5
$0.1 - 1$ mm	10

  - Beam divergence $$\Phi = \frac{2\Delta w}{\Delta z}\ [rad] \qquad w^2 = w_0^2 + \left(\frac{\Phi z}{2}\right)^2$$

Ocular protection: Calculations

- Intensity at the centre of the optical beam I_0

$$I_0 = \frac{P}{\pi w_{1/e}^2}$$

- Where $w_{1/e}$ corresponds to the beam waist where the power is 63% of its maximum (gaussian beam

- Fluence

$$E_0 = \frac{Q}{\pi w_{1/e}^2}$$

Ocular protection: Calculations

- Example

  - laser Nd:YAG (1064 nm),
  - $d_{feixe} = 2$ mm,
  - $\Phi = 1.0$ mrad,
  - TEM_{00}, 80 mJ,
  - 15 ns
    - qual a MPE=?
    - H_0=?
    - H=?
    - OD?

Laser Mode Designation

Laser Mode	Engraved Symbol	Pulse Duration
Continuous Wave (CW)	D	>0.25 s
Pulsed Mode	I	>1 μs - 0.25 s
Giant Pulsed Mode	R	1 ns - 1 μs
Mode Locked	M	< 1ns
Please refer to the official EN 207 standard that can be purchased from BSI.		

European Norm for the Selection of Laser Safety Glasses

Wavelength Range	Laser Mode	Maximum Power Density (P) or Maximum Energy Density (E)	Minimum Scale Number (LBn)
180 - 315 nm	D	$1 \times 10^{n-3}$ W/m^2 ($1 \times 10^{n-7}$ W/cm^2)	$\log_{10}(P)+3$
	I and R	$3 \times 10^{n+1}$ J/m^2 ($3 \times 10^{n-3}$ J/cm^2)	$\log_{10}(E/3)-1$
	M	$3 \times 10^{n+10}$ W/m^2 ($3 \times 10^{n+6}$ W/cm^2)	$\log_{10}(P)-10$
>315 - 1400 nm	D	$1 \times 10^{n+1}$ W/m^2 ($1 \times 10^{n-3}$ W/cm^2)	$\log_{10}(P)-1$
	I and R	$5 \times 10^{n-3}$ J/m^2 ($5 \times 10^{n-7}$ J/cm^2)	$\log_{10}(E/5)+3$
	M	$1.5 \times 10^{n-4}$ J/m^2 ($1.5 \times 10^{n-8}$ J/cm^2)	$\log_{10}(E/1.5)+4$
>1400 - 1000000 nm	D	$1 \times 10^{n+3}$ W/m^2 ($1 \times 10^{n-1}$ W/cm^2)	$\log_{10}(P)-3$
	I and R	$1 \times 10^{n+2}$ J/m^2 ($1 \times 10^{n-2}$ J/cm^2)	$\log_{10}(E)-2$
	M	$1 \times 10^{n+11}$ W/m^2 ($1 \times 10^{n+7}$ W/cm^2)	$\log_{10}(P)-11$
Please refer to the official EN 207 standard that can be purchased from BSI.			

dBm to mW Power Conversions

dBm	mW	dBm	mW
0.0	1.0000	10.0	10.0000
2.0	1.5849	20.0	100.0000
4.0	2.5119	30.0	1,000.0000 (1 W)
6.0	3.9811	40.0	10,000.0000 (10 W)
8.0	6.3096	50.0	100,000.0000 (100 W)

$$dBm = 10\log_{10}\frac{P\,(mW)}{1\;mW}$$

$$P(mW) = 10^{(dBm/10)}$$

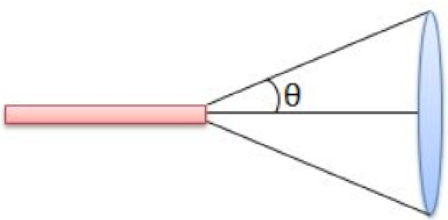
P(mW) = Power in mW

Light Exiting a Fiber

NA	Divergence Half Angle, Θ	Beam Area @ 25.4 mm (1") From Fiber
0.10	5.7°	20 mm^2
0.15	8.6°	46 mm^2
0.20	11.5°	83 mm^2
0.25	14.4°	133 mm^2
0.30	17.4°	199 mm^2
0.35	20.4°	280 mm^2
0.40	23.5°	383 mm^2
0.45	26.7°	512 mm^2
0.50	30.0°	675 mm^2

Note: The values in this table are rounded down to provide conservative beam areas.

When working with fiber optics, light emitted directly from the endface of a fiber is diverging. Thus, the power density is decreasing as the beam spreads and the danger of damage to the eye decreases. The table to the left lists the beam area created by light exiting a fiber for fibers with numerical apertures (NA) between 0.10 and 0.50. If you know the total power emitted from the fiber, you can calculate the power density at 25.4 mm (1") from the fiber tip. This power density will allow you to determine the safe fiber-tip viewing distances.



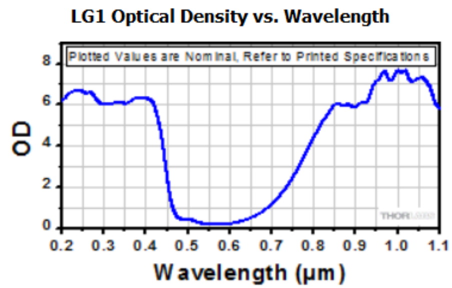
Laser Safety Glasses: 59% Visible Light Transmission

Zoom

OD Specs (ANSI Z136)
190 to 400 nm, OD = 5+
808 to 840 nm, OD = 4+
>840 to 950 nm, OD = 5+
>950 to 1080 nm, OD = 7+
>1080 to 1090 nm, OD = 5+

LB-Rating Specs (EN 207)[a]
190 to 315 nm (D LB8 + IR LB4 + M LB6Y)
>315 to 425 nm (DIRM LB5)
790 to <808 nm (DIRM LB3)
808 to 840 nm (DIRM LB4)
>840 to 950 nm (DIRM LB5)
>950 to 1080 nm (D LB6 + IRM LB7[b])
>1080 to 1090 nm (DIRM LB5)

a. Refer to the *Specs Tutorial* tab above for a full explanation of the EN 207 markings.
b. For the M rating of LB7 in the wavelength range of >950 to 1064 nm, the glasses were tested at pulses between 12 ps and 170 fs.



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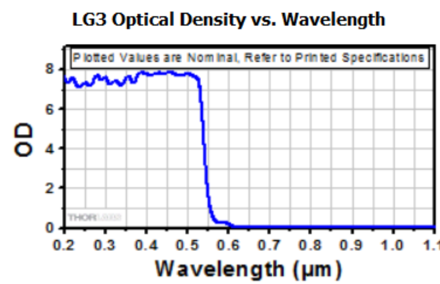
Laser Safety Glasses: 48% Visible Light Transmission

Zoom

OD Specs (ANSI Z136)
180 to 532 nm, OD = 7+

LB-Rating Specs (EN 207)[a]
180 to 315 nm (D LB7 + IR LB4)
>315 to 532 nm (DIRM LB6)

a. Refer to the *Specs Tutorial* tab above for a full explanation of the EN 207 markings.



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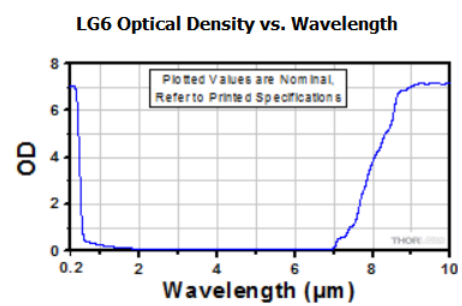
Laser Safety Glasses: 93% Visible Light Transmission

Zoom

OD Specs (ANSI Z136)
190 to 398 nm, OD = 7+
9,000 to 11,000 nm, OD = 7+

LB-Rating Specs (EN 207)[a]
190 to 315 nm (D LB7 + IR LB4)
>315 to 398 nm (DIRM LB5)
9,000 to 11,000 nm (DI LB3)

a. Refer to the *Specs Tutorial* tab above for a full explanation of the EN 207 markings.



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http://www.optique-ingenieur.org/en/courses/OPI_ang_M01_C02/co/Contenu_08.html

https://www.lasermet.com/laser-beam-shutters.php

http://www.bbc.co.uk/newsbeat/article/34908500/everything-you-need-to-know-about-lasers-because-people-are-pointing-them-at-planes

https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=762

Laser safety Video

https://www.youtube.com/watch?v=lV6s7NoFsSU&t=205s

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24/2		Resolution of problems: beam propagation and manipulation. Laser Safety and protection LASER: safety norms and risk classification.		chapter 5	