CNRS UMR 5048 - UM - INSERM U 1054
MONTPELLIER - France

Centre de Biochimie Structurale
Montpellier

Laser Safety Training

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outlook

- Brief introduction to lasers

Definition, Characterization, type.
Definition of MPE-limit and NOHD.

- Laser Classifications

Overview and explanation of what is included in each laser class.

- Main hazards

Eyes injuries
Skin injuries
Associated with combustible materials.

- Safety laser Protections

Global
Individual

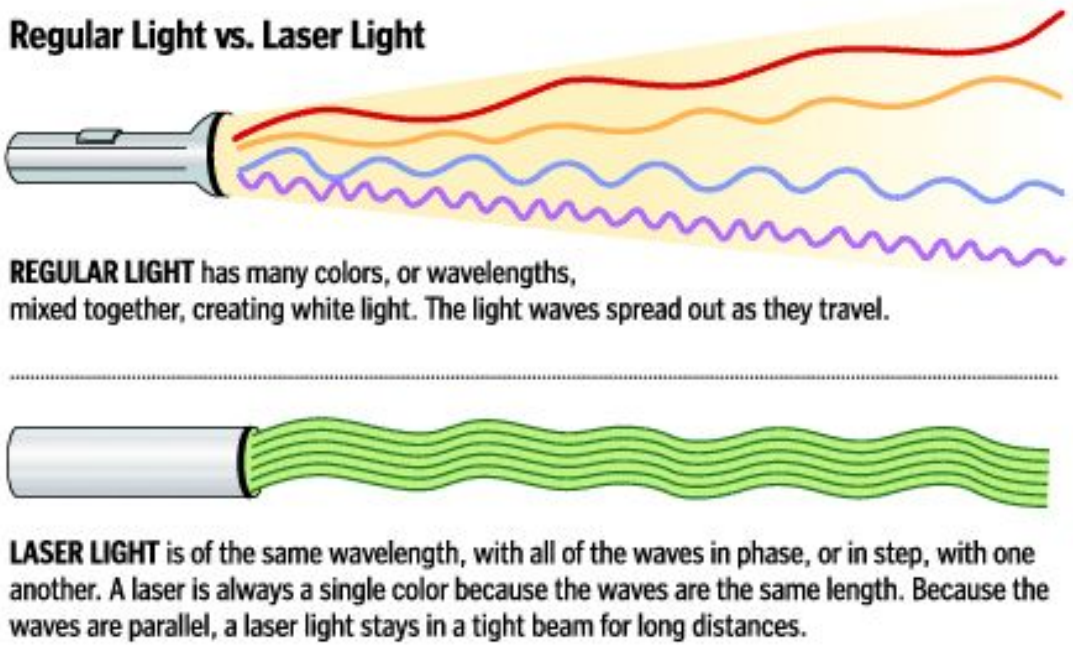
- Good practices in laser laboratory

Introduction

- **<u>Definition</u>**: **Laser** (**L**ight **A**mplification **S**timulated **E**mission **R**adiation)
- **<u>Characteritics:</u>**

- The energy generated by the laser is in ranges from UV (100-400nm), visible(400-750nm) and IR (750nm-1 mm).

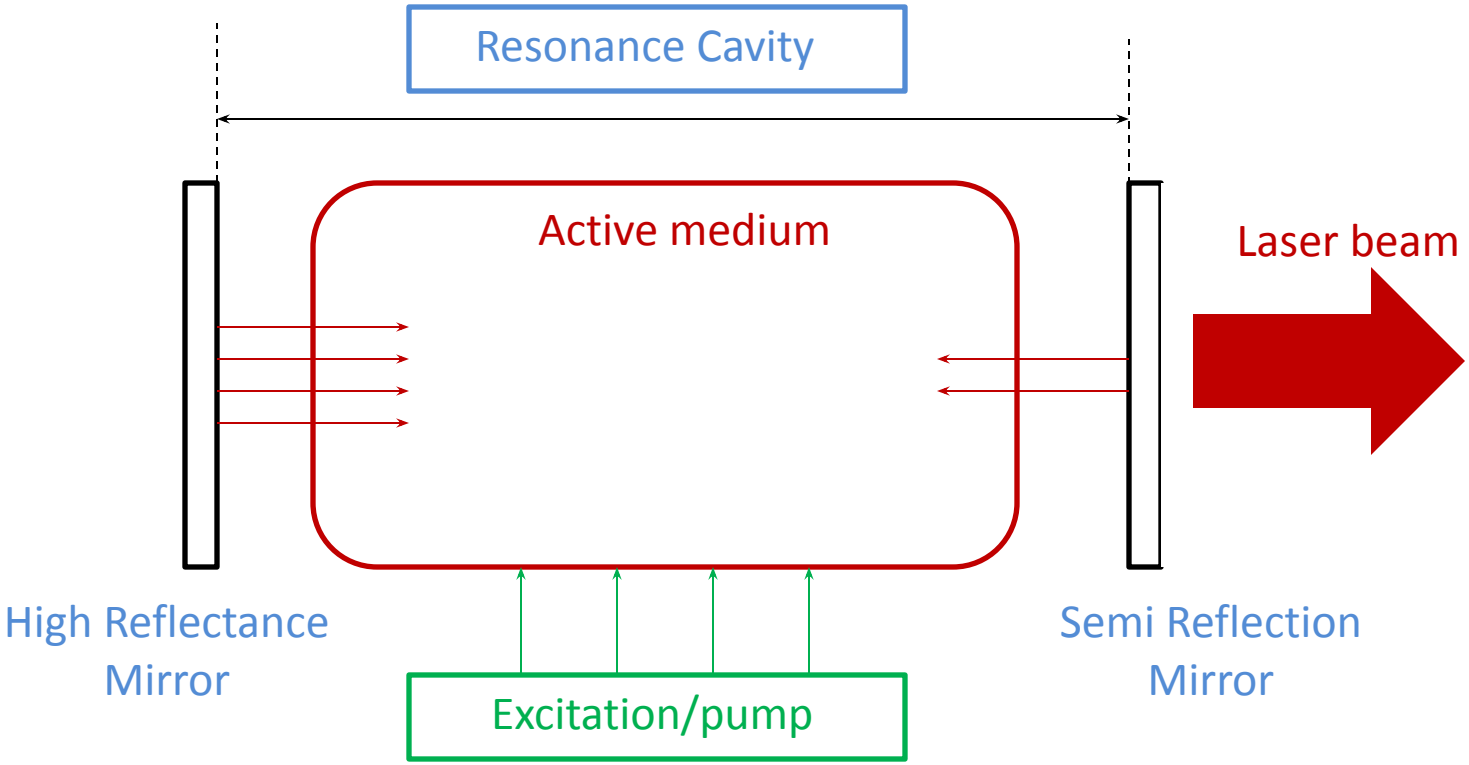
- Monochromatic
- Directional
- Coherent



- Continuous wave (CW) (>0.25s)
- Pulsed Laser (<0.25s)
- Q-switched Laser (pulse 5-25 ns high power) (used in dermato)

Ref: The Washington Post

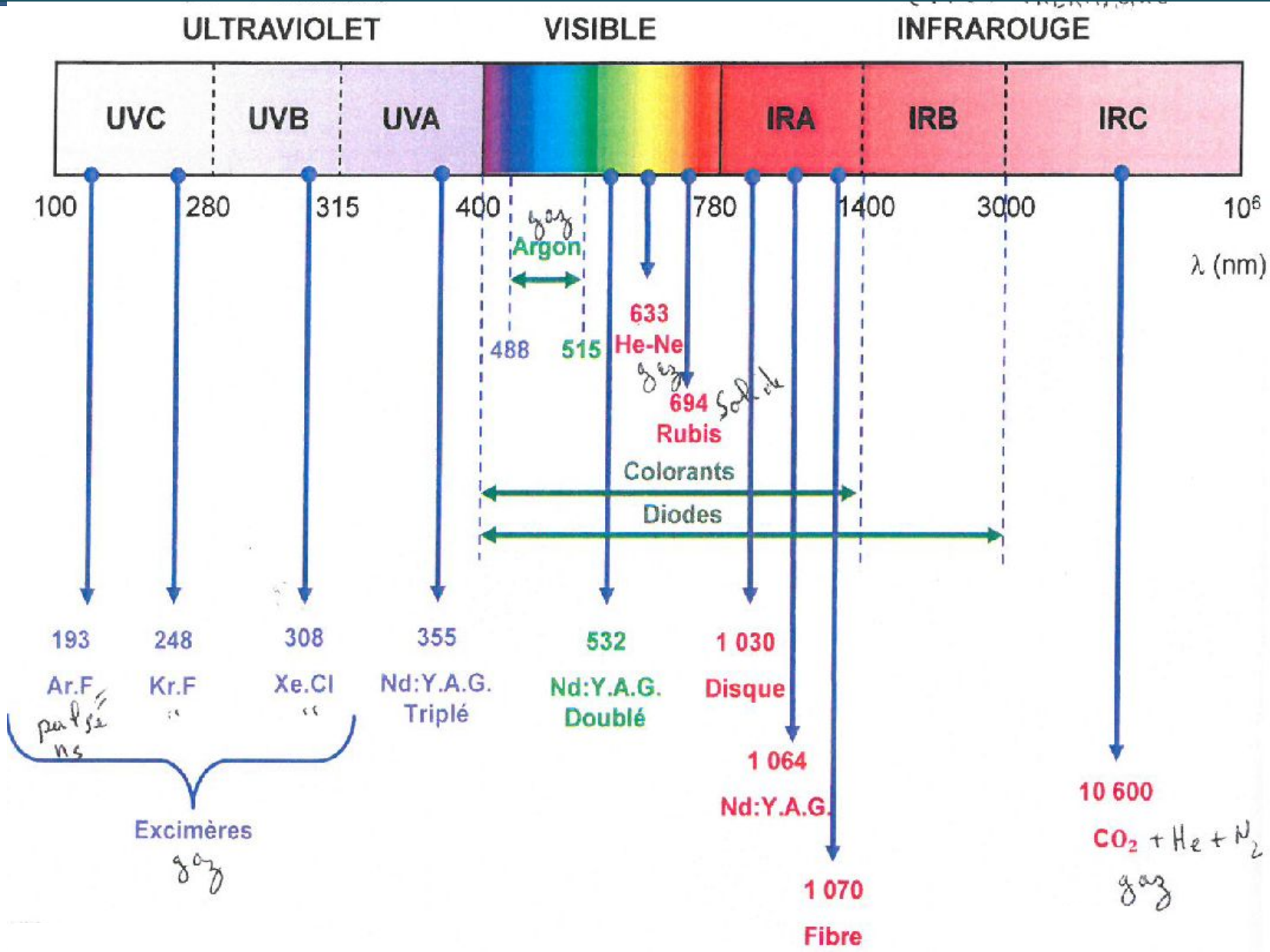
Principle



- Active Medium: - Gaz (Ar; He-Ne; CO_2)
  - Solid (Cristal Nd-YAG; Fiber silice)
  - Liquid (dye solution)
  - Semi conductors or diodes

- Excitation or pumping : - Optic (laser, flash lamp,…)
  - Electric (HT current), …

Types of lasers



Ref: Laser Conseil

Maximum Permissible Exposure (MPE)

- Lasers output characteristic (Wavelength, Power, Size and Duration of exposure) determine how much exposure to laser is Hazardous.
- **Maximum permissible exposure** (MPE- limit) = greatest exposure that people can tolerate without injury.
- It is expressed in terms of allowable exposure time (s) for a given irradiance (W/cm^2) at a particular wavelength.
- If the calculated value for a specific laser **> MPE** => collective and individual **safety protections** & procedures should be put in place.

Table 3-3. MPE for Selected Lasers and Exposure Times
(Reference: ANSI Z136.1-2000)

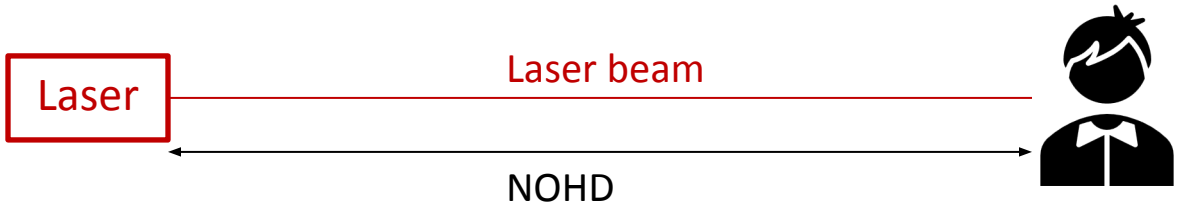
Laser Type	Wavelength (μm)	MPE (average power density—watts/cm^2)			
		Exposure time in seconds			
		0.25 s	10 s	600 s	3×10^4 s
CO_2	10.6	—	0.1 W/cm^2	—	0.1 W/cm^2
Nd:YAG (cw)[a]	1.33	—	5.1×10^{-3}	—	1.6×10^{-3}
Nd:YAG (cw)	1.064	—	5.1×10^{-3}	—	1.6×10^{-3}
Nd:YAG Q-switched[b]	1.064	—	17×10^{-3}	—	2.3×10^{-6}
GaAs (diode)	0.840	—	1.9×10^{-3}	—	610×10^{-6}
InGdAlP (diode)	0.670	2.5×10^{-3}	—	—	—
HeNe	0.633	2.5×10^{-3}	—	293×10^{-6}	17.6×10^{-6}
Krypton	0.647	2.5×10^{-3}	—	364×10^{-6}	28.5×10^{-6}
	0.568	2.5×10^{-3}	—	31×10^{-6}	18.6×10^{-6}
	0.530	2.5×10^{-3}	—	16.7×10^{-6}	1.0×10^{-6}
Argon	0.514	2.5×10^{-3}	—	16.7×10^{-6}	1.0×10^{-6}

In any case, the workers exposure must be minimal and < MPE.

Ref: LASER-TEC

Nominal Ocular Hazard Distance (NOHD)

- The Nominal Occular Hazard Distance (NOHD) is the distance at one should stand away from the laser beam source to be **< MPE-limit**.



- Low power + High diverging beam Small NOHD
- High power + collimated beam Huge NOHD

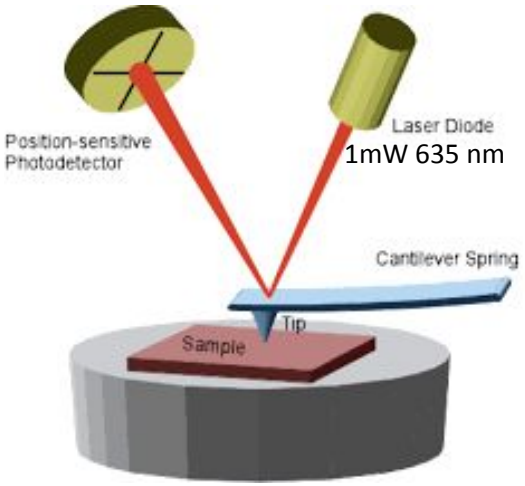
Laser Classification: Class 1

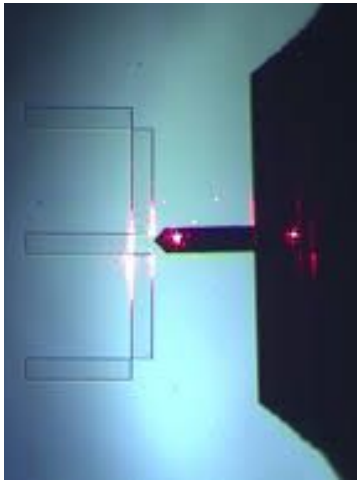
- Completely safe under normal use.
- Output power < 0.4 mW
- Higher power laser fully enclosed and sealed or interlocked can also belong to Class 1
- Below the MPE limit => No protection required

Ref: Web images

Class 2 Lasers

- Only visible light lasers (400-700 nm).
- Output power 0.4 – 1 mW
- Blink reflect (150-200 ms) protect against this class
- Intentional viewing can lead to eye damage.
- Below the MPE limit => No protection required





Ref: Web images

Class 3 Lasers

- 3R : - Output power from **1 to 5 mW** in continuous mode; Safe if handle correctly. Can cause eye injury when the energy is collected and put into the eye with binoculars for example.

- 3B: - Output power from **5 to 500 mW**. Hazardous. Eye protection required and must include safety interlock and key-switch.

- Can be **hazardous** under **direct** and **specular reflection** viewing conditions
- **Not hazardous** for **diffuse reflections**

Ref: Thorlabs.com

Class 4 Lasers

- Dangerous
- **> 500 mW.**
- must include safety interlock and key-switch.
- Hazardous under **direct**, **specular** and **diffuse** reflections conditions for the **skin** and the **eyes**.
- These lasers can also ignite **fire**

MaiTai Fs Pulsed IR laser. 3 W.

Most powerful laser 10PW.

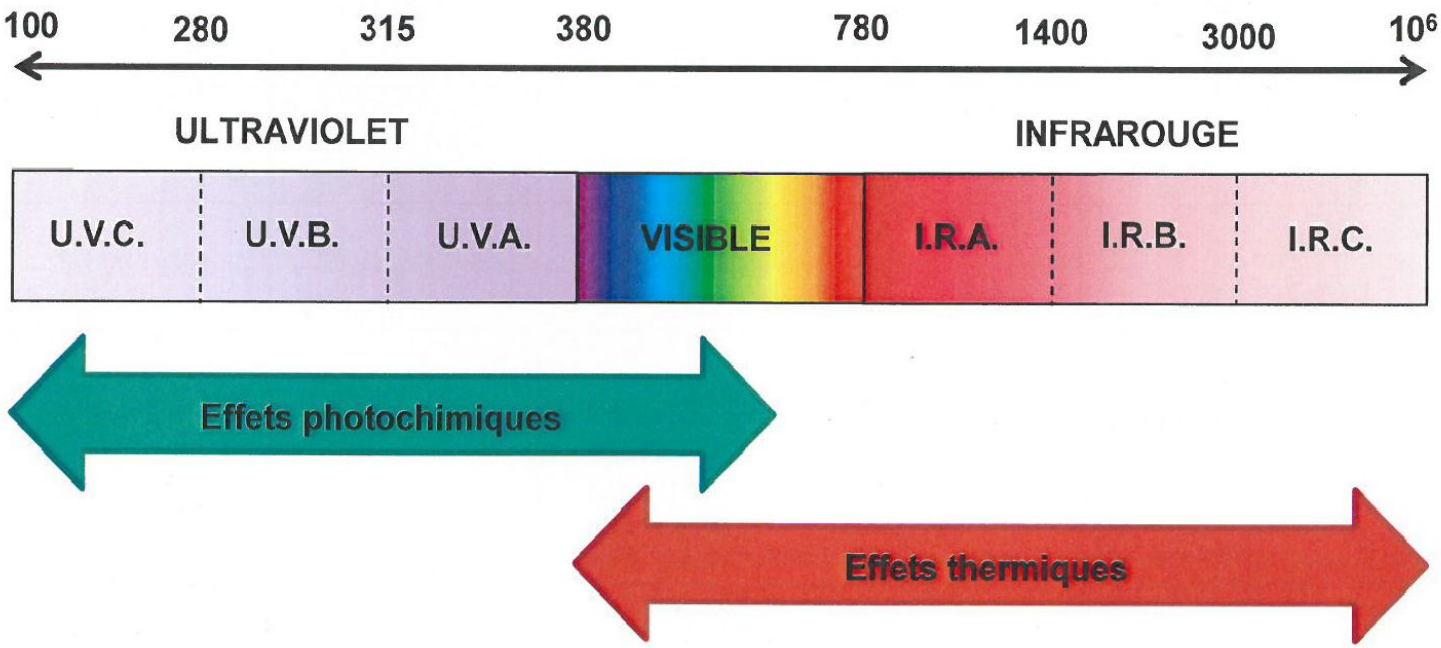
Ref: Spectra-Physics.com; Thalesgroup.com

Summary Laser Classification

TYPE	INJURY OR RISK	RISK LEVEL
Class 1	Low energy levels, not hazardous to skin or eyes. Safe during normal operation.	Low
Class 1M	Safe during normal operation but may cause eye injury if viewed with an optical instrument.	Low-Medium
Class 2	Visible wavelengths only, natural blink response provides eye safety.	Low-Medium
Class 2M	Visible wavelengths only, blink response provides eye safety for unaided viewing	Medium
Class 3R	Transitional zone between safe and hazardous laser products. Direct viewing of	Medium-High
Class 3B	Direct viewing and specular reflections can cause eye injury. Diffuse reflections are	High
Class 4	Can cause severe skin and eye injury through any direct exposure, specular reflections and/or sometimes from diffuse reflections.	Extreme

Ref: Lund University

Main hazards



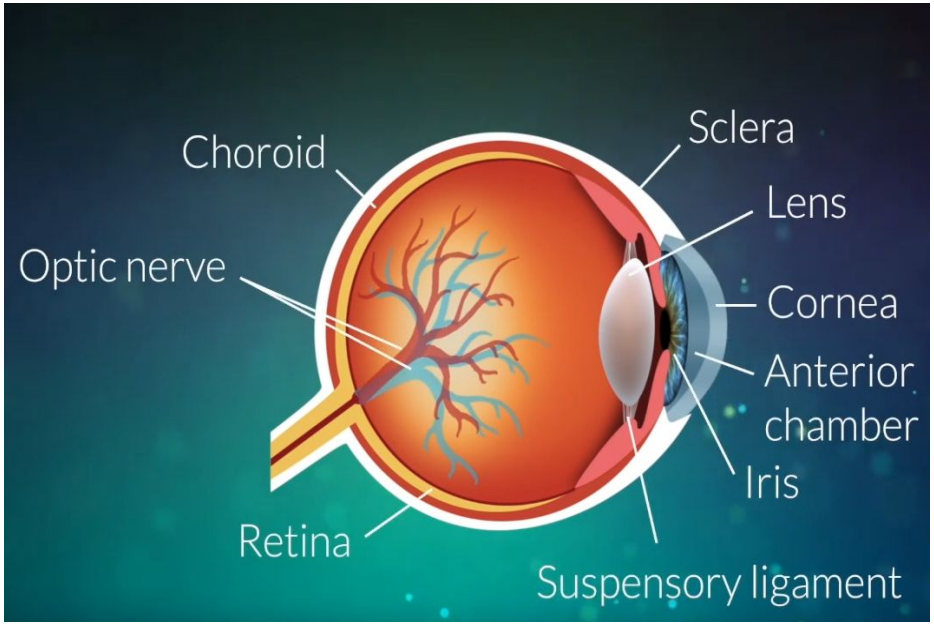
- Damages depend of **Wavelength**, **Power**, Exposure **Duration** and **Type** (Direct, Diffuse reflection or long term low level).

- Eye Injuries
- Skin Injuries

- Explosions and Fire Hazards
- Electrical Hazards
- Chemical Hazards

Ref: Laser Conseil

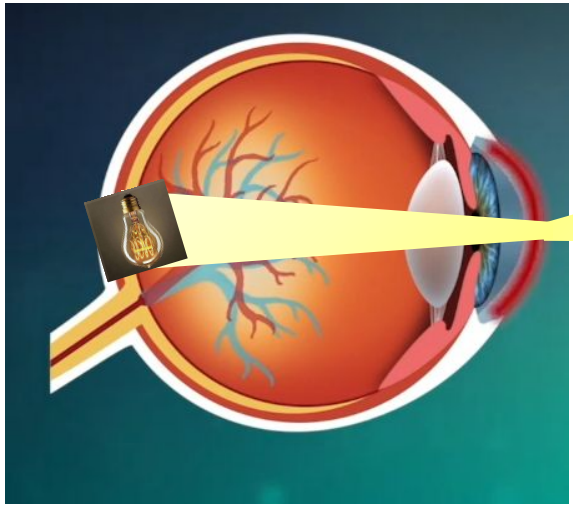
Eye injuries



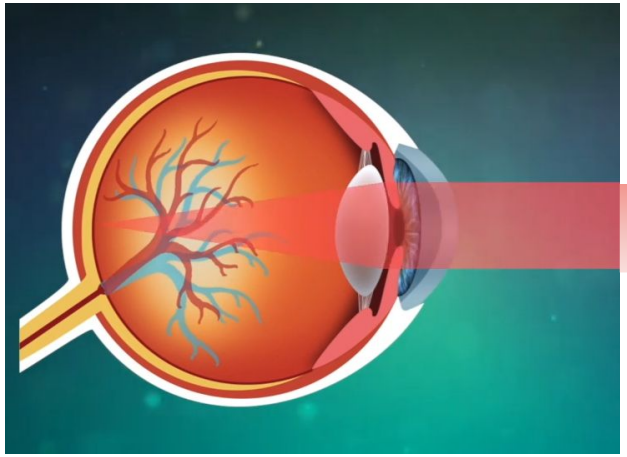
- Photochemical
- Retinal burn

Ref: Lund U.

Eye injuries



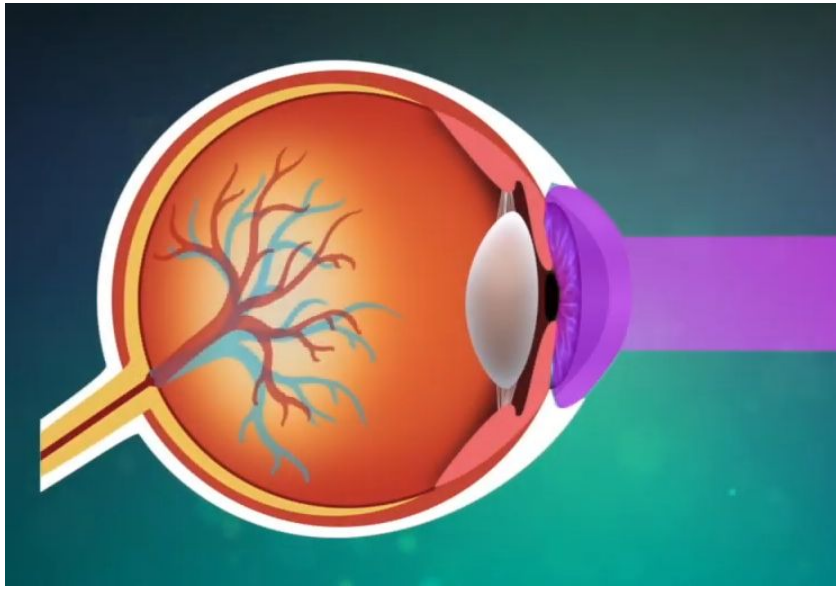
Diffuse light



Laser beam

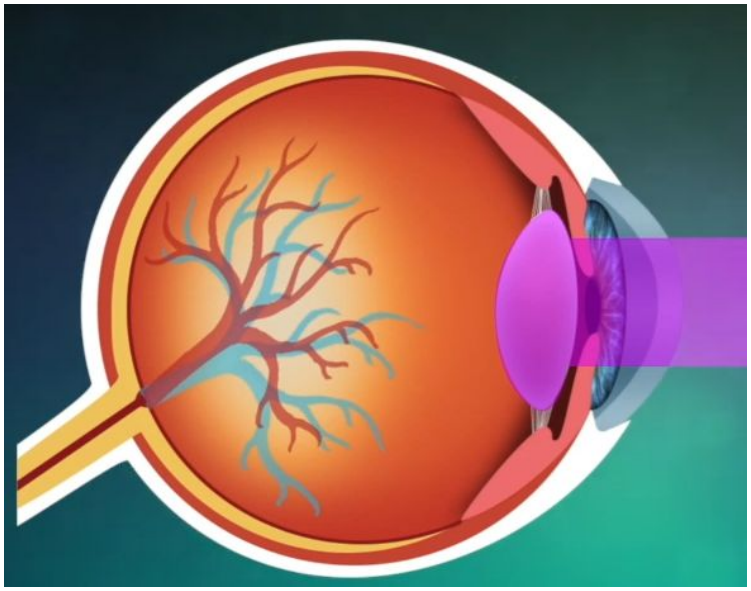
UV light

From 180-315 nm



- Photokeratitis & eye sunburn

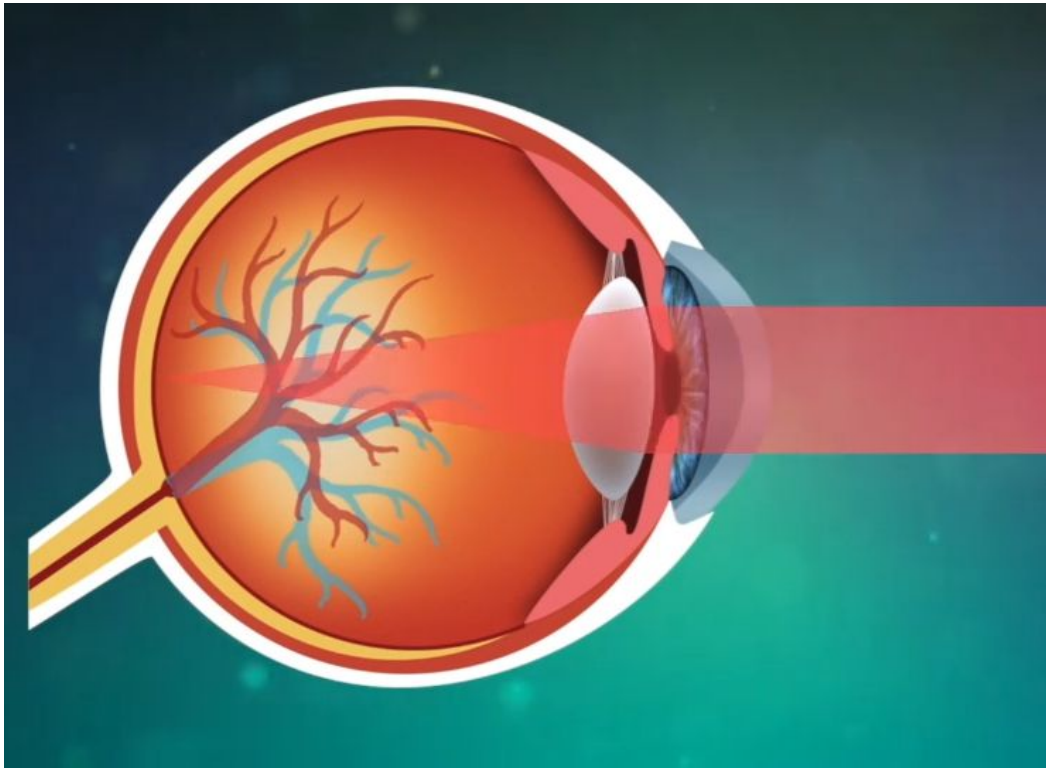
From 315-400 nm



- Photochemical cataract
- Clouding of the eye lens.

Ref: Lund U.

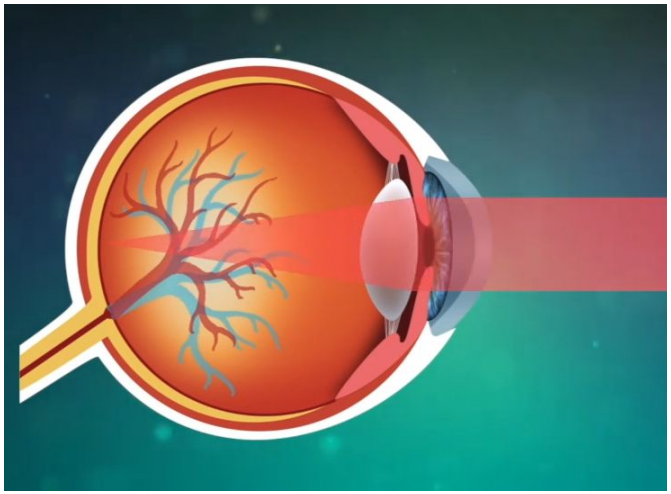
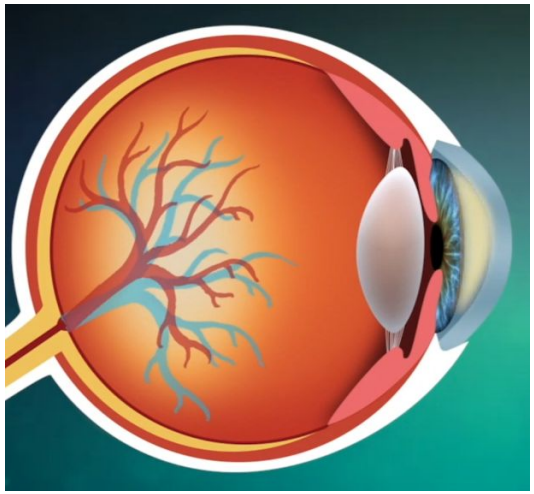
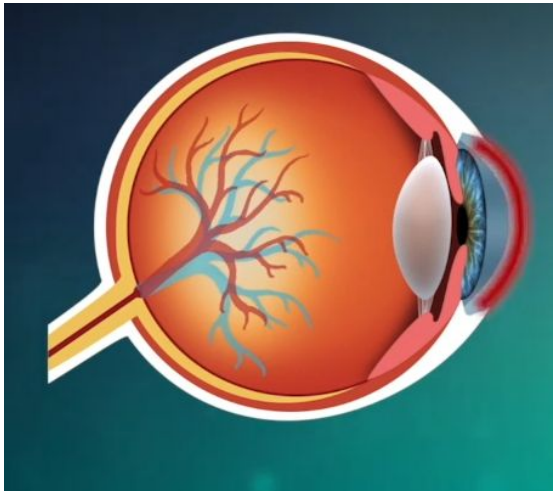
IR (780-1400 nm)



- IR Cannot be seen but will focus on the back of the retina causing **cataract and retinal burn**.

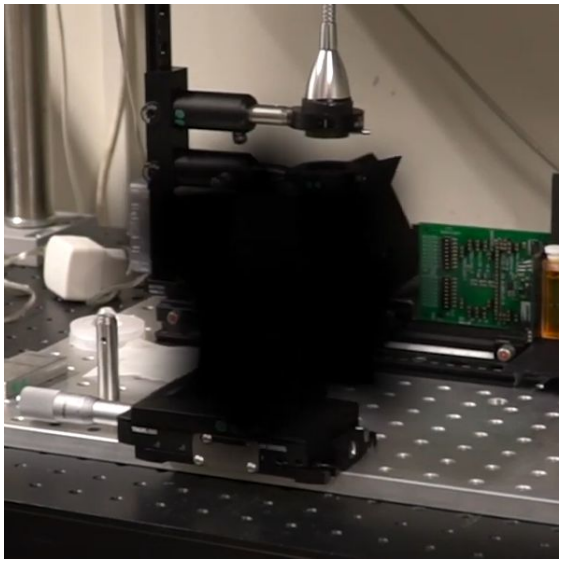
Ref: Lund U.

IR (1.4 µm - 1 mm)

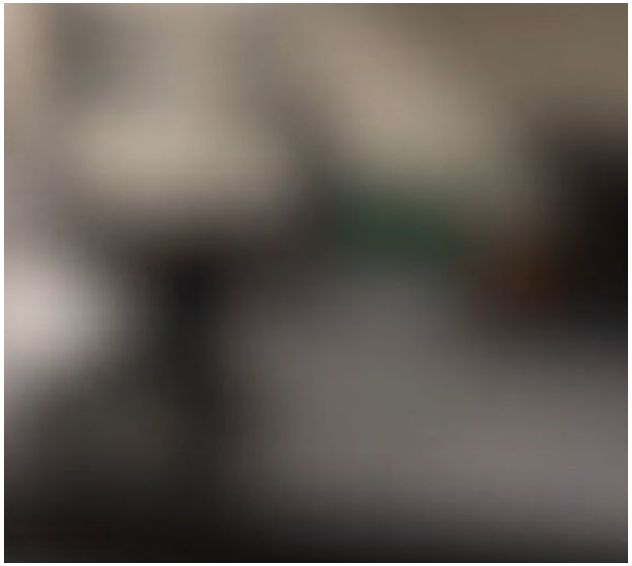




Aqueous flare; cataract and corneal burn.

Impact

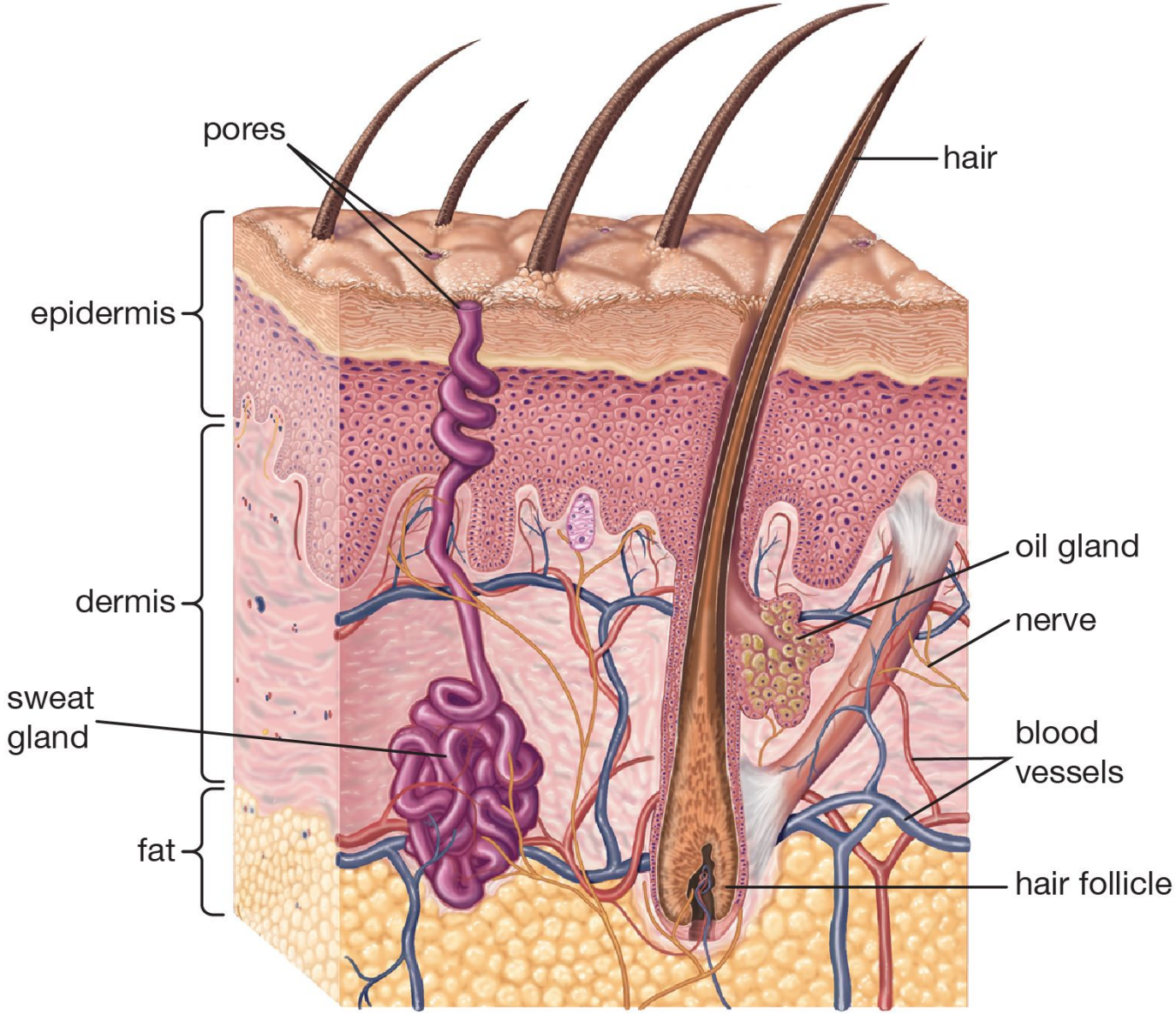


cataract

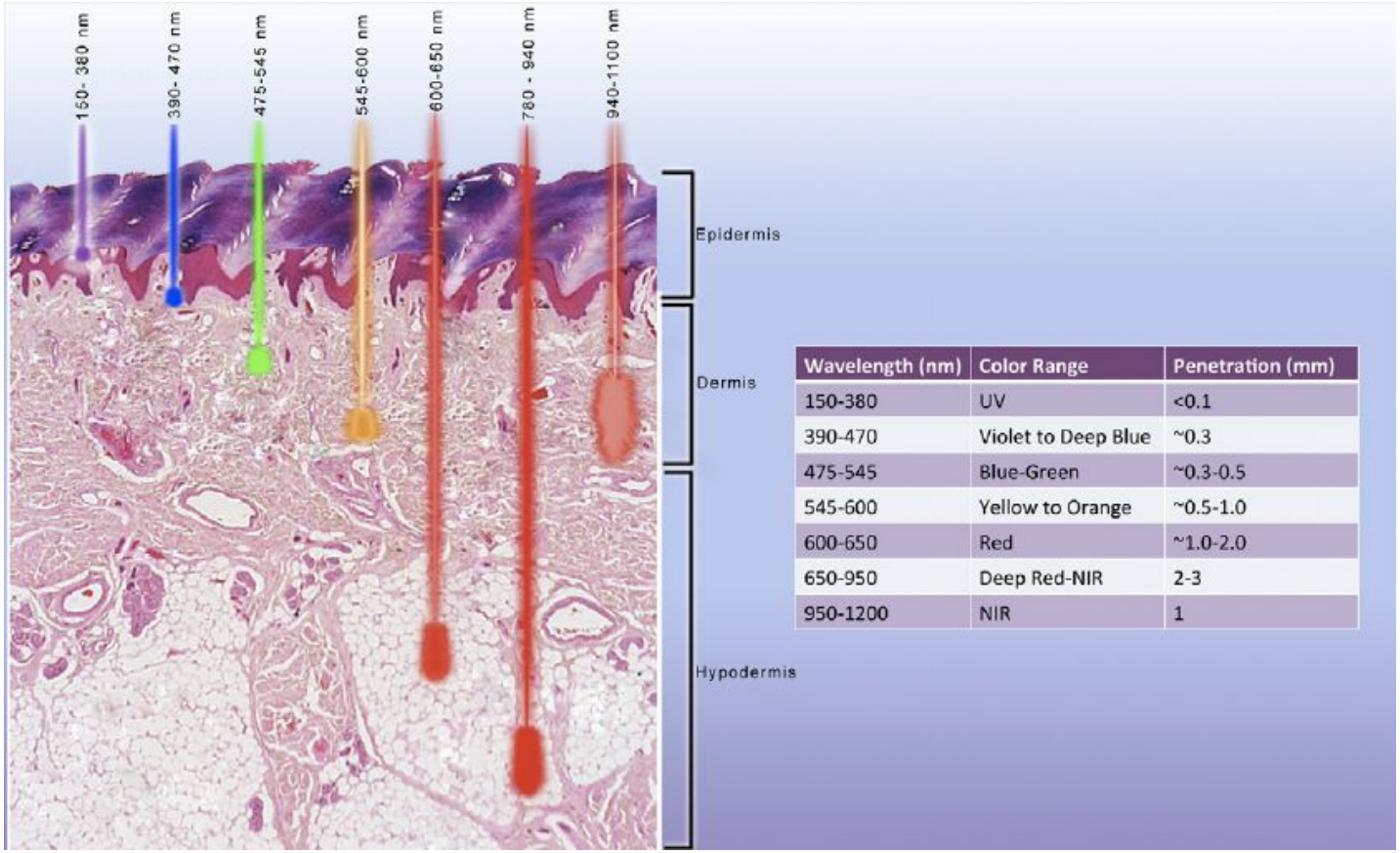


Ref: Lund U.

Skin injuries



Skin injuries

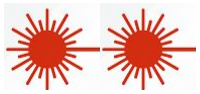
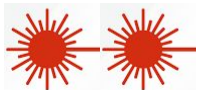


Wavelength (nm)	Color Range	Penetration (mm)
150-380	UV	<0.1
390-470	Violet to Deep Blue	~0.3
475-545	Blue-Green	~0.3-0.5
545-600	Yellow to Orange	~0.5-1.0
600-650	Red	~1.0-2.0
650-950	Deep Red-NIR	2-3
950-1200	NIR	1

- Damage can range from surface or dermis **skin burn, sunburn, increased of skin aging, or increase of risk of skin cancer** (UV)
- **Photosensitive reactions** can occur (VIS range)

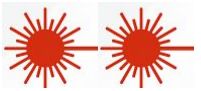
Ref: Lund U.

Summary

Risk / Class	Eye Direct laser beam vision	Eye Direct laser beam vision with optics	Eye diffuse beam vision	Skin	Fire
1					
1M					
2					
2M					
3R					
3B					
4					

 Hazardous if t>0.25 s

 Could be Hazardous

 Hazardous

 Fire ignition Hazardous

Safety controls

- **Engineering controls** involved design features applied to laser, laser beam or laser environment that restrict exposure. (eg: beam shutter, beam attenuator, protective housing, interlocks)

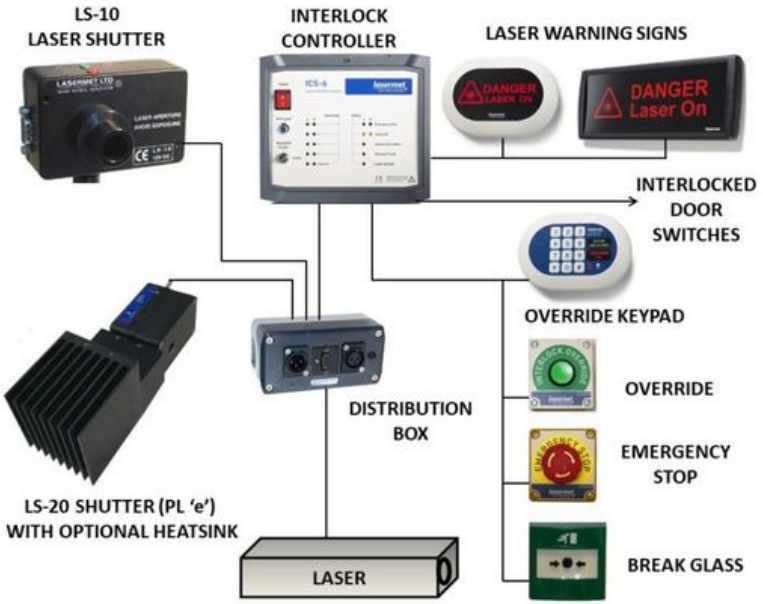
- **Administrative control measures** involve procedures and information (eg: Laser Safety Training, Posting warning signs and labels, Nomination of a Laser safety officer, publishing operating procedures, entry limitations)

- **Environment protective equipment** : Laser lab should be equipped with controlled access, safety signs, safety protections (cover, curtains,…) and safety notices.

- **Personal protective equipment:** is worn by personnel using or being in vicinity of lasers. This control includes protective eyewear, gloves and clothing.

Environment safety

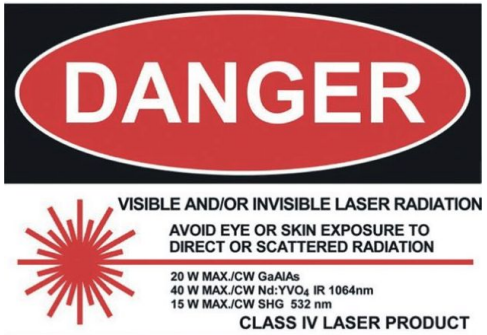
- **Laser room**: controlled access, Non reflecting floor, Matt & light paint on the walls, 500 Lux lights, protective curtains, protective covers.
- **Control units:** Key command for laser ON, Emergency stop button, Laser safety signs light on when laser is on, Interlocked keys.

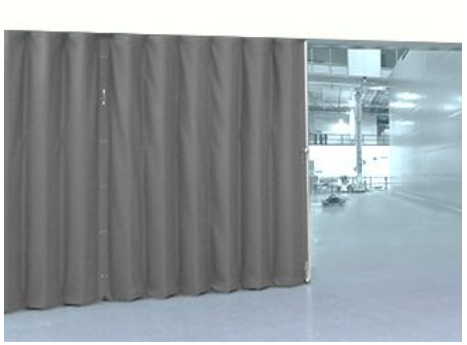


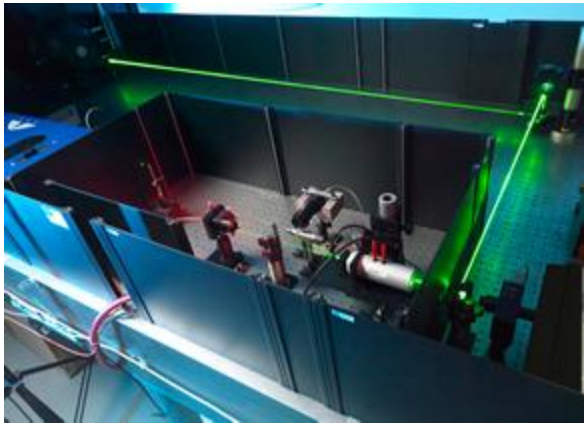
Ref: Lasermet.com

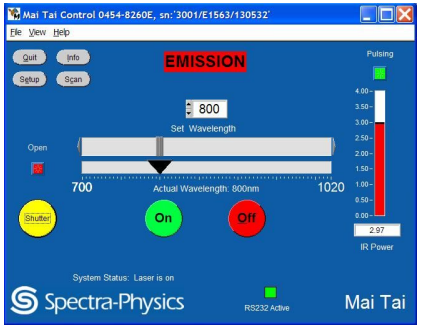
Environment safety

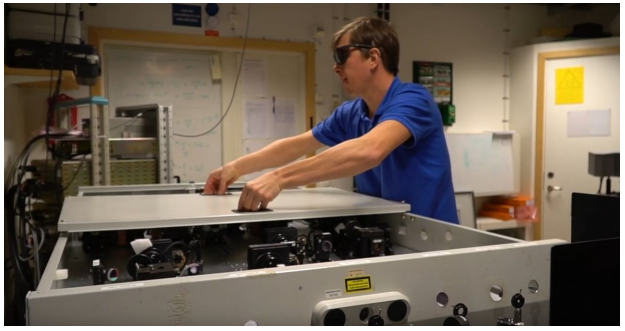
- **Security unit:** Emission alarm, protective cover, shutters, laser power meter, class identification, danger symbol





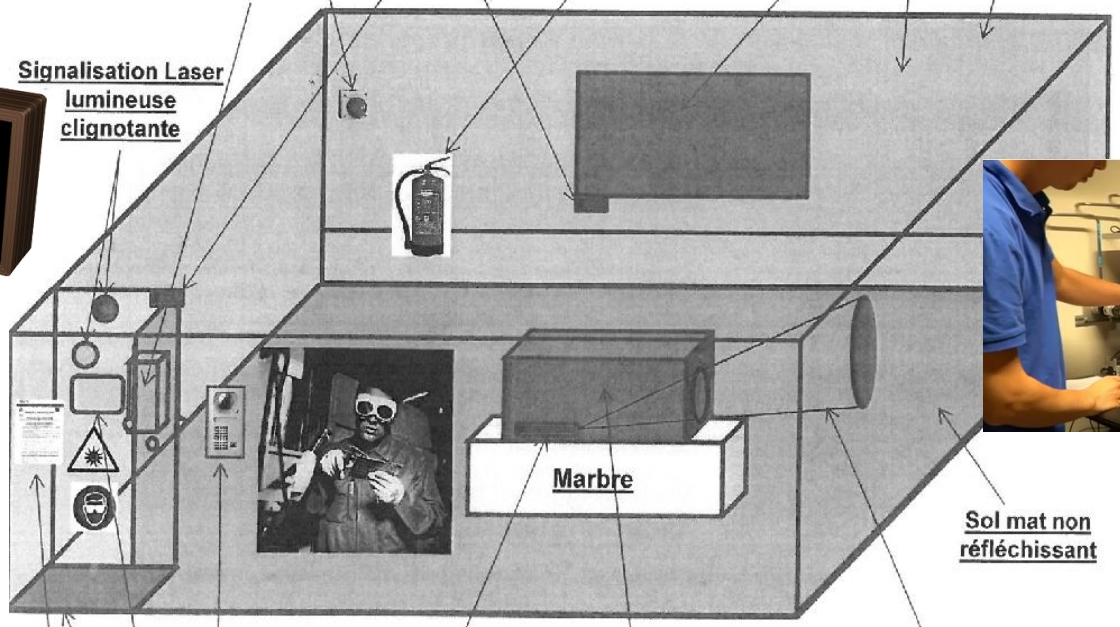


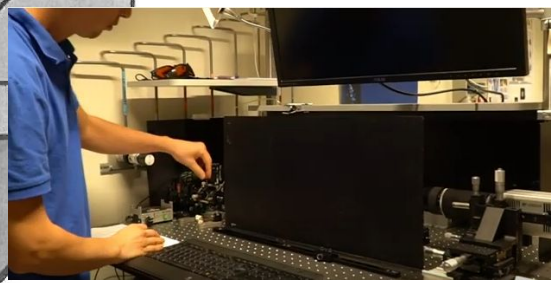




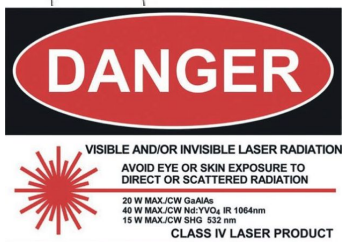
Ref: Lasermet.com

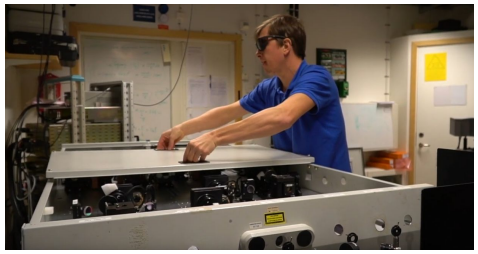
Laser room safely equiped



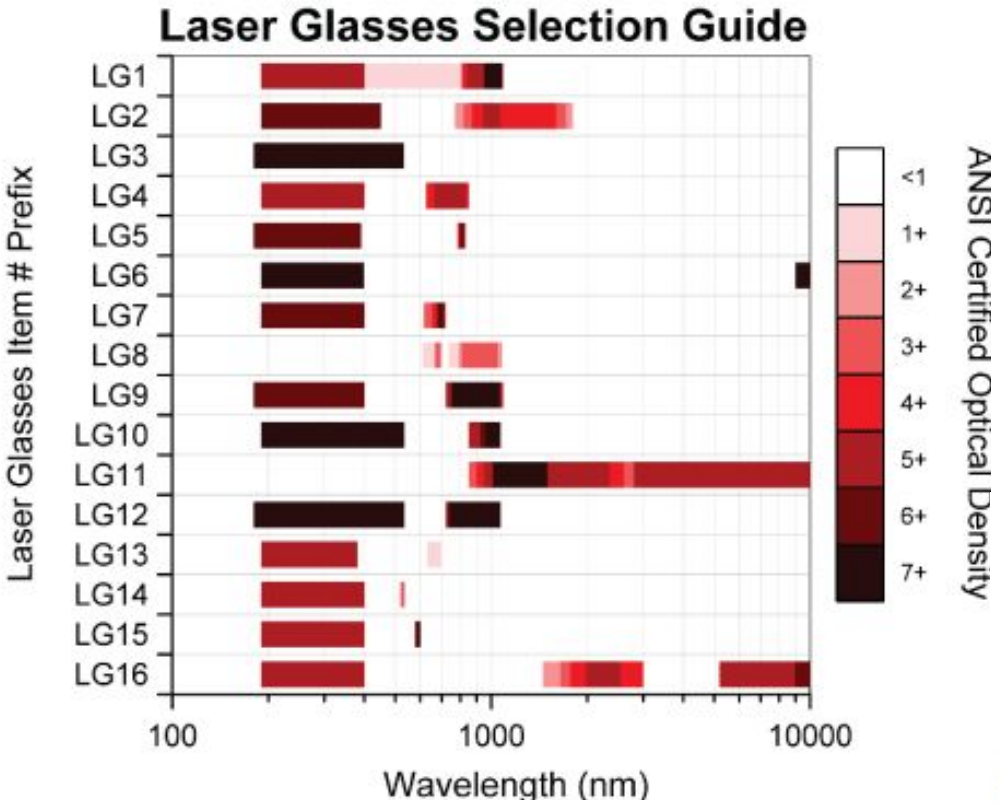


Security

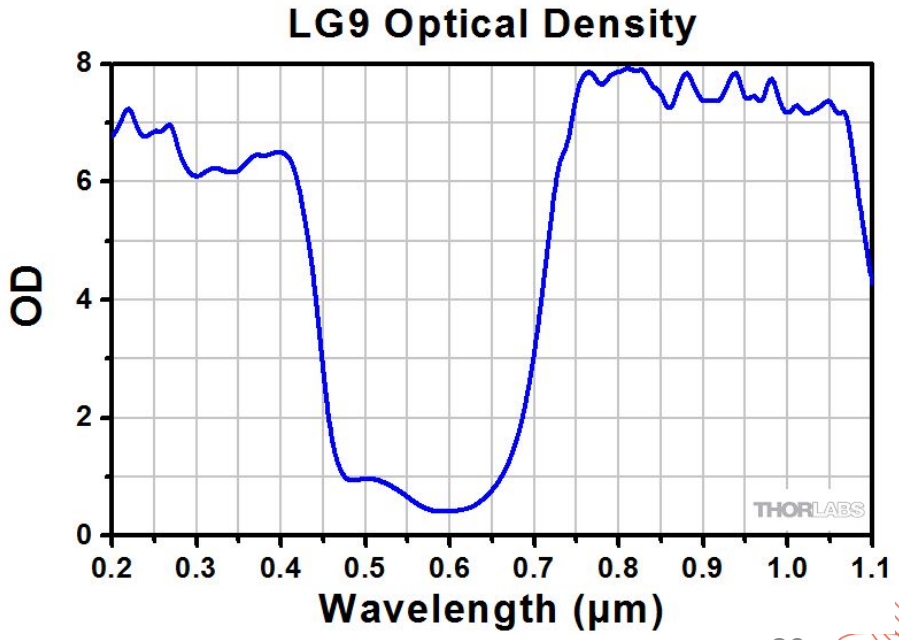




Laser safety Glasses



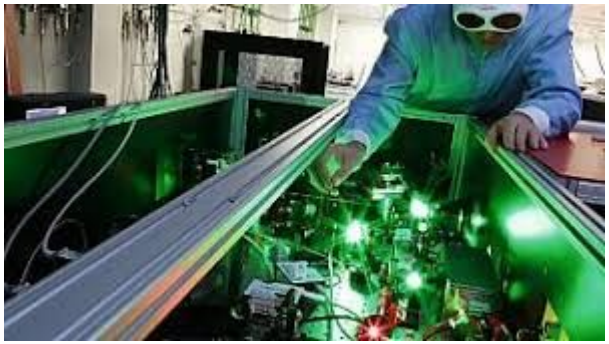
OD Specs (ANSI Z136)
180 to 400 nm, OD = 6+
720 to 1090 nm, OD = 5+
750 to 1064 nm, OD = 7+



European Norm: **EN 207** & **CE-mark**

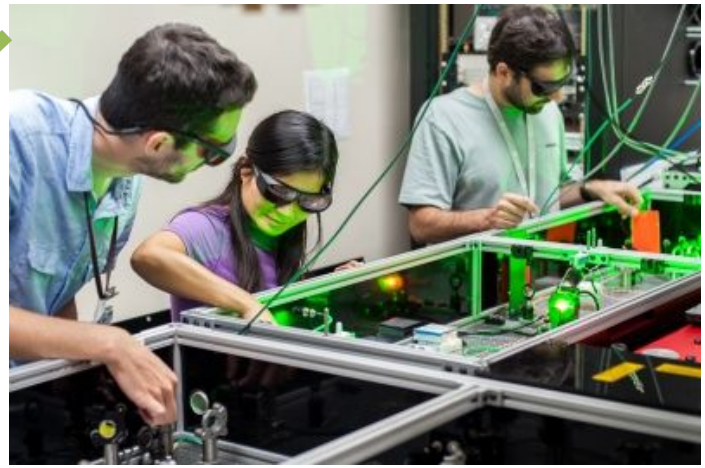
Ref: Thorlabs.com

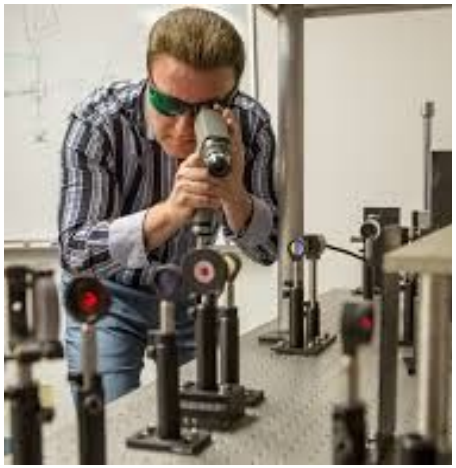
Entering Laser Room Good practices



- ✔ Remove **all reflective objects** and jewelry
- ✔ If the **Laser sign** is ON, **knock on the door and wait for a response**
- ✔ Wear appropriate individual protections (**safety glasses, labcoat**)
- ✔ **Do not turn on the light** if you don't know if an experiment is ongoing.

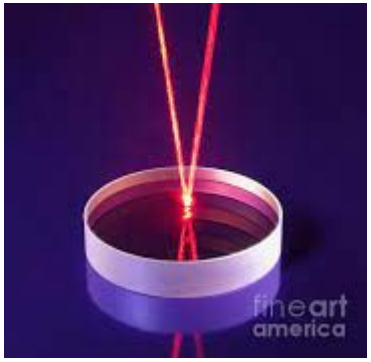
Buildup & Alignment Good practices

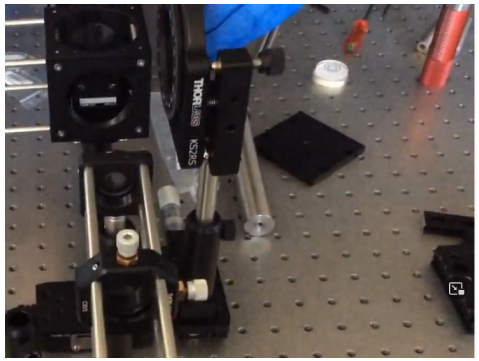


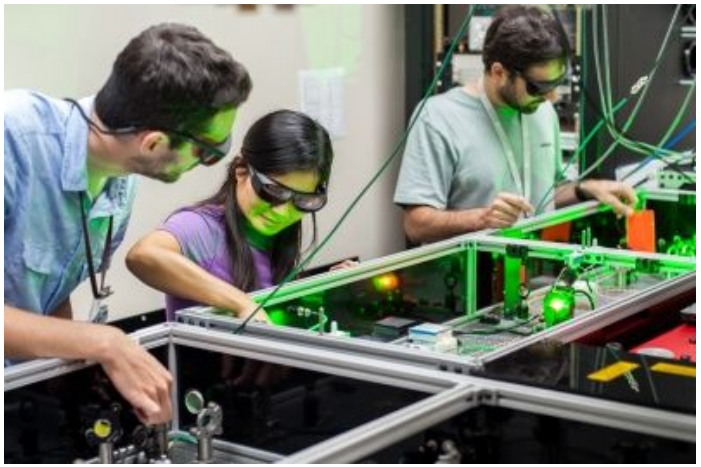


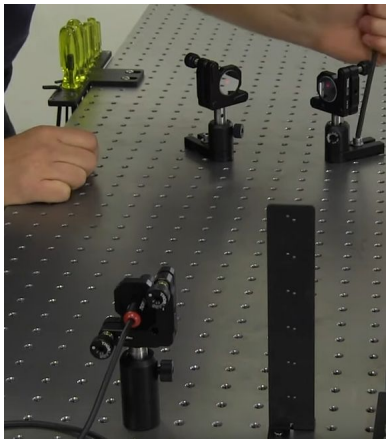
- ✔ Use appropriate laser **safety glasses**.
- ✔ Work with good **light** in room to minimize pupil size.
- ✔ Work with **lowest laser power** as possible.
- ✔ **NEVER** look at the laser **directly**.
- ✔ Use **card** or **camera** to Follow and align the laser beam.

Buildup & Alignment Good practices









- ✔ **Control the propagation** of laser beam (Laser Guarding)
- ✔ Keep the laser beam path in **horizontal plan below eye level**.
- ✔ Always **Fix optic components on optical table**.
- ✔ **Avoid all specular and diffuse reflections**.

Lasers sources @ CBS29

ROOM	Wavelengths	Power mW	**Class**	Which setup
1A14	LSM800 : 405/488/561/640	CW UV-visible 100	**1**	Airy scan
	Lumencor Celesta	1000 mW	**4**	Airy scan
1A14	CW - UV 405 nm	150	**3b**	MFM Antoine
	CW- visible 488 nm	50	**3b**	MFM Antoine
	CW- visible 561 nm	150	**3b**	MFM Antoine
	CW - visible 642 nm	110	**3b**	MFM Antoine
	CW - IR 785 nm	100	**4**	MFM Antoine
1A10	CW - IR 850 nm	CW IR 100 mW at 850 nm	**Class 4**	AFM Super resolution PEM
				AFM Super resolution PEM
	CW-UV-Visible 405;488;568;634 nm	CW 100 mW	**Class 3b**	AFM Super resolution PEM
				AFM Super resolution PEM
	CW - IR 635 nm	CW laser diode 2 mW	**Class 3b**	AFM Super resolution PEM
1A11	CW laser diode 6 mW 660nm (51nanoFI-S Shafter + Kirchhoff)	CW laser diode 6 mW	**Class 3b**	AFM Super resolution PEM
	CW laser diode 30 mW 630 nm (48FI-5-630 Shafter + Kirchhoff)	CW laser diode 30 mW	**Class 3b**	AFM Super resolution PEM

- 8 lasers class 3B
- 3 lasers class 4

Lasers sources @ CBS60

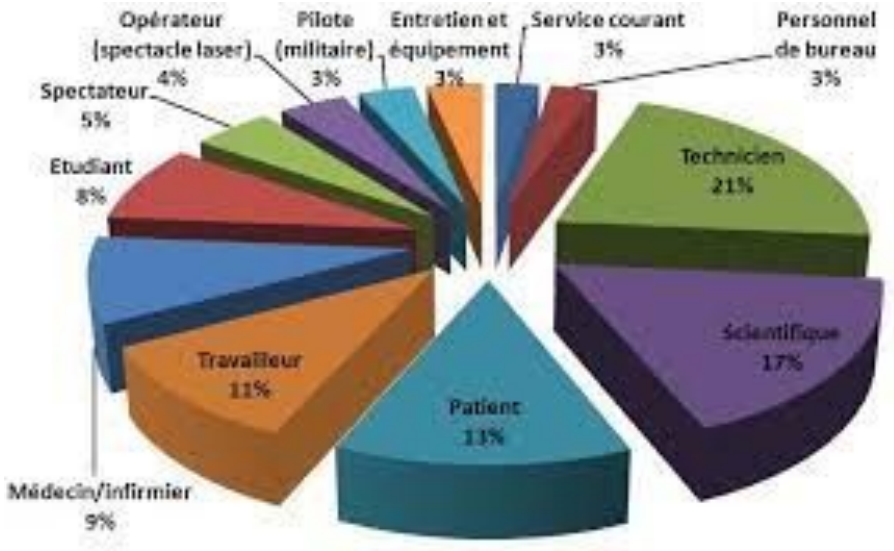
ROOM	Wavelengths	Power mW	Class	Which setup
0B06	CW - UV 405 nm	100	**3b**	RAMM
	CW- visible 488	100	**3b**	RAMM
	CW- visible 561	50	**3b**	RAMM
	CW- visible 642	100	**3b**	RAMM
	CW - IR 785	100	**4**	RAMM
0B08	CW - UV 405	100	**3b**	PALM
	CW- visible 488	100	**3b**	PALM
	CW- visible 561	100	**3b**	PALM
	CW- visible 642	100	**3b**	PALM
	CW - IR 785	100	**4**	PALM
	Pulsed IR - 700-1020 nm	3 W à 800nm	**4**	2PE FCS
	Pulsed and CW 405 nm	50	**3b**	STED-FCS
	Pulsed and CW 485 nm	50	**3b**	STED-FCS
	Pulsed and CW 595 nm	5	**3b**	STED-FCS
	Pulsed and CW 640 nm	50	**3b**	STED-FCS
0B10	CW- visible 450	>100	**3b**	MFM+Single Mol Manu
	CW- visible 488	>100	**3b**	MFM+Single Mol Manu
	CW- visible 514	>100	**3b**	MFM+Single Mol Manu
	CW- visible 532	500	**4**	MFM+Single Mol Manu
	CW- visible 640	100	**3b**	MFM+Single Mol Manu
	CW - IR 785	100	**4**	MFM+Single Mol Manu
	CW- visible 633	17	**3b**	2 spots FCS Manouk
OB13	CW- visible 660	100	**3b**	AFM-Lucas
0B02	Pulsed IR 690-1300 nm	1,46 W à 900 nm	**4**	2-photon IPAM
0B02	Pulsed IR 680-1080 nm	3 W à 800 nm	**4**	2-photon IPAM

- 18 lasers class 3B
- 7 lasers class 4

Main causes of Laser injuries

- **80%** of Eye injuries are due to **specular reflections**.
- **Inadequate Eye protection**: 60% due to Laser safety glasses not worn.
- 80% accidents take place during **alignment**.
- **Bad Control** the **propagation** of laser beam.
- 75% injured person have **>5 years expertise**.
- **Bad training, no information or sensibilization**.
- **No respect of safety procedures**.

Victims Laser Accidents



Laser accident Statistic-professional activity

Actions when accident occur

1) Injured person should be take care of **immediately**.
   - **Lay down the victim on the floor.**

2) Contact **Hospital ophtalmologist emergency**. 04 67 33 77 90
Address: **Hospital Gui de Chauliac**, 80 avenue Augustin Fliche Montpellier.

   - Ophtalmologic control the very day and 10-15 days after.

3) **Report** any accident on the register book.

There is no second chance!!

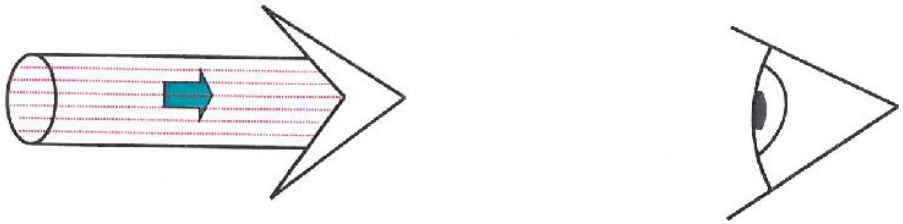
Peer pressure in the laser lab

Ref: Thorlabs.com

Optional slides

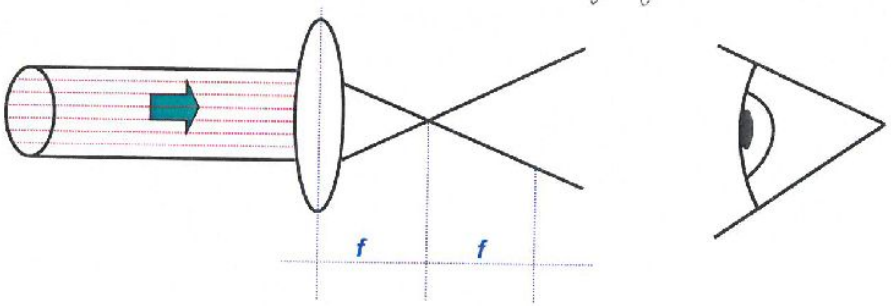
EXPOSITION DIRECTE

FAISCEAU DIRECT



FAISCEAU FOCALISÉ

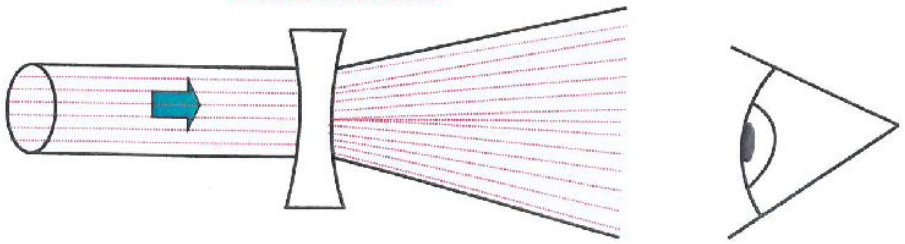
Lentille biconvexe : cas de l'objectif



f = distance focale

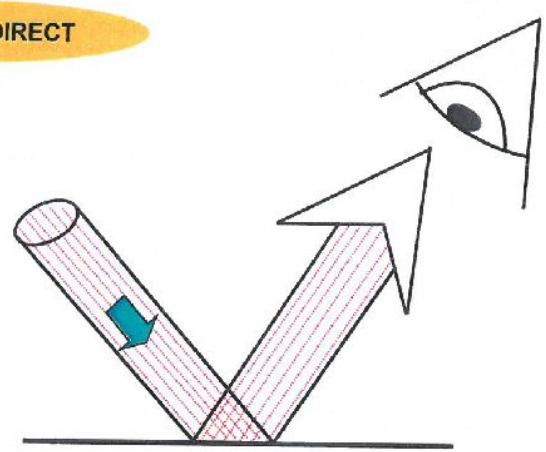
FAISCEAU DIVERGENT

Lentille biconcave



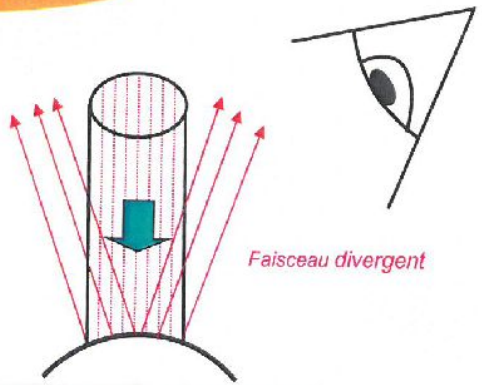
EXPOSITION À UNE RÉFLEXION SPÉCULAIRE

FAISCEAU DIRECT



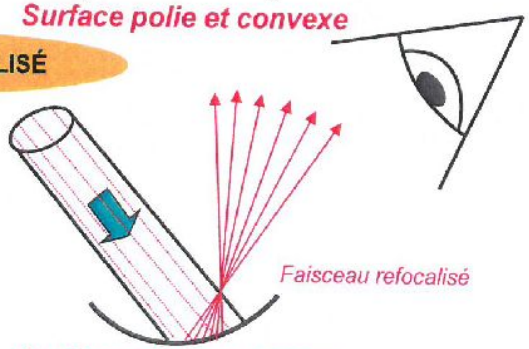
Surface polie et plane

FAISCEAU DIVERGENT



Surface polie et convexe

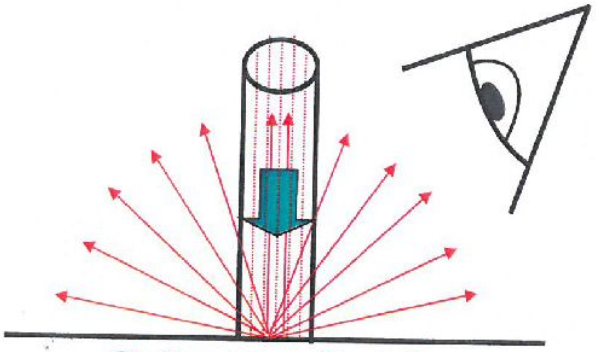
FAISCEAU FOCALISÉ



Surface polie et concave

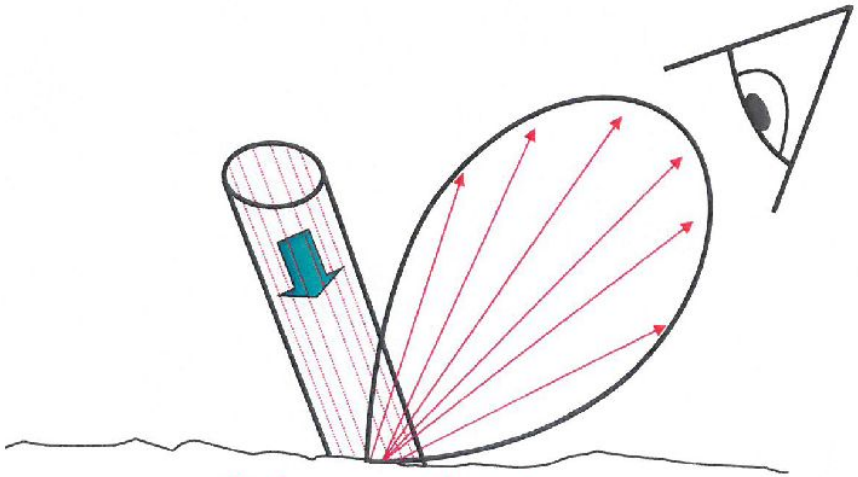
EXPOSITION À UNE RÉFLEXION DIFFUSE

DIFFUSION UNIFORME (Diffuseur parfait)



Surface non polie et plane

DIFFUSION NON UNIFORME (En pratique)



Surface non polie et plane

Optical Density and Transmission

$$E_x = E_0 10^{-OD} \rightarrow T = 10^{-OD}$$

- **Transmission** is defined as the ration of E_x / E_0
- If OD of the laser safety eyewear is = 3, the transmission will be of 10^{-3} or 0.1%

Table 3-6. Transmission at Various OD Values

OD	Transmission		%Transmission
0	1	1.0	100%
1	10^{-1}	0.1	10%
2	10^{-2}	0.01	1%
3	10^{-3}	0.001	0.1%
4	10^{-4}	0.0001	0.01%
5	10^{-5}	0.00001	0.001%
6	10^{-6}	0.000001	0.0001%
7	10^{-7}	0.0000001	0.00001%