Introduction to Laser Safety

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Norms and Standards for Laser Safety

- to ensure a safe use of machinery and to protect operators against hazards:
  - EN 60825 (IEC 825): „Safety of Laser Products“
    - describes the effect of laser radiation on the eye/skin
    - defines thresholds
    - definition of safety classes
    - labeling, engineering specifications, safety precautions, maximum permissible exposure (MPE)
    - Lasers and LEDs
  - ANSI Z136 series, EN 207/208: Laser Safety Eyewear

http://en.wikipedia.org/wiki/File:Laser_goggles_en207.jpg

Laser Hazards

Primary hazard potential

Laser radiation

Secondary hazard potential

Direct

Device related
- Electrical components
- Pump radiation
- Laser gases
- Optical components

Indirect

Application related
- Emitted hazardous substances
- Ignition of explosives
- Fire hazard
- Secondary radiation

- primary sites of damage: eye, skin

Laser Basics

- „Light Amplification by the Stimulated Emission of Radiation“

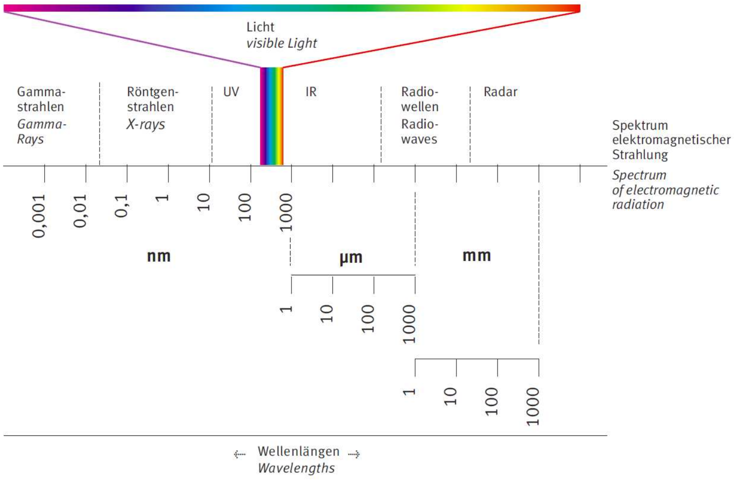
- properties
  - monochromatic
  - coherent
  - small divergence

- modes of operation
  - cw
  - pulsed

- laser medium
  - gas
  - solid
  - dye
  - semiconductor

http://www.nmm.ac.uk/rog/2009/01/

Electromagnetic Radiation Spectrum



- lasers: UV – IR, 180 nm – 1000 µm
  → laser radiation can be partly or completely invisible
  → can pretend false safety

Laser Types

- gas (Helium-Neon Laser)
- solid state (Nd:YAG, Ti:Sapphire)
- dye
- diode

Quantifying Light: Power and Energy

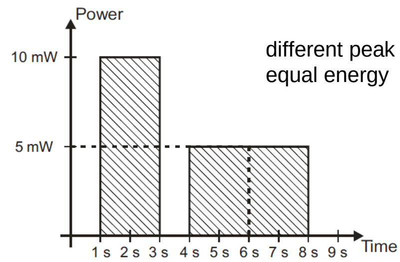
- Watt: unit of radiant power (= rate of flow of energy)
- Joule: unit of radiant energy

$$\text{Power} = \frac{\text{Energy}}{\text{Period of Time}}$$

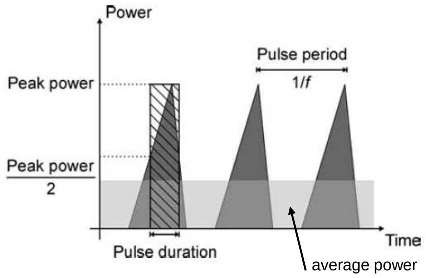
- Example:
  laser beam of 3 Watts, emitted for ten seconds, generates a total energy during this time of 30 Joules

- emission of continuous wave (cw) lasers: power P (Watts)
- emission of pulsed lasers: energy Q (Joule) of each pulse

$$Q = \int_{t_1}^{t_2} P(t)\,\mathrm{d}t$$



Quantifying Light: Pulse Duration and Peak Power



Parameters usually used to characterize pulsed laser radiation.

Quantity	Symbol	Unit
Energy per pulse	Q_{pulse}	joule (J)
Peak power	P_{peak}	watt (W)
Pulse duration	t_{pulse}	second (s)
Average power	P_{aver}	watt (W)
Pulse repetition frequency, also called repetition rate	f	hertz (Hz)
Period	t_{period}	second (s)

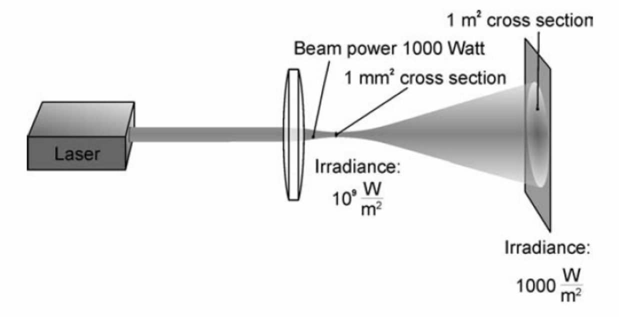
Operation mode		typical pulse length
continuous wave D (cw)	*... is the continuous emission of laser radiation.*	*› 0.2 s*
pulsed mode I	*... is the short-term single or periodically repeated emission of laser radiation.*	*› 1 µs to 0.25 s*
giant pulsed mode R	*... is like pulsed mode, but the pulse 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*

- pulsed lasers can emit peak powers of short times of several TW
- eye: averaging, looks like being low power → considerable hazard

Quantifying Light: Irradiance

- interaction of laser light with material: irradiance

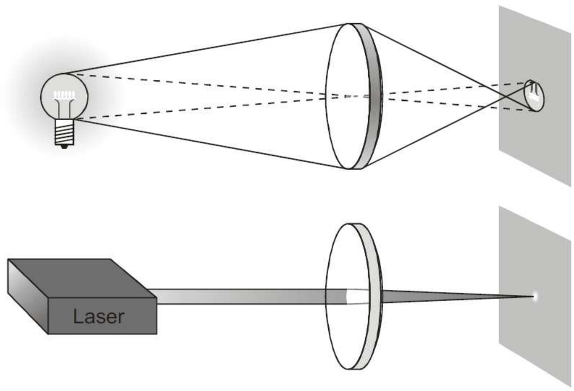
$$\text{Irradiance} = \frac{\text{Power incident on area}}{\text{Area}}$$ unit: W/cm^2



$$\text{Radiant Exposure} = \frac{\text{Energy incident on area}}{\text{Area}}$$ unit: J/cm^2

Lamp vs. Laser

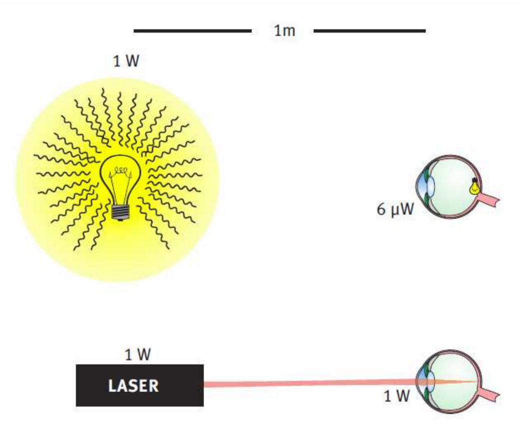
conventional lamp: extended source
smallest patch of light that can be created by focusing is the geometric image of the source



laser: point source
output can be focused by a lens to create a point image

→ low divergence and therefore excellent focusability of laser radiation can cause high irradiances, even in large distances

Irradiance

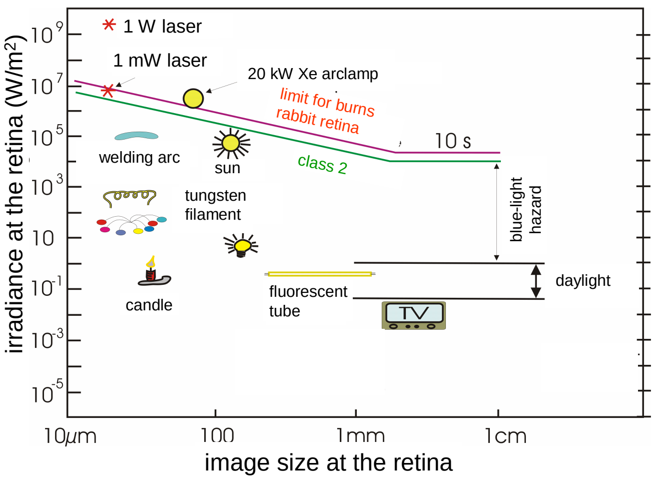


- lamp: 1 W
  at a distance of 1 m: 6 µW
- laser: 1 W
  at a distance of 1 m: 1 W
- lamp, 1 W, at a distance of 1 m
  diameter on retina: 100 µm
  irradiance: 0.1 W/cm^2
- sun:
  diameter on retina: 0.35 mm
  irradiance: 6 – 100 W/cm^2
- laser beam, 1 mW
  diameter on retina :10 µm
  irradiance: > 1 kW/cm^2
- hotplate: 3 W/cm^2

Never stare into a laser beam!

Never stare into a laser beam!

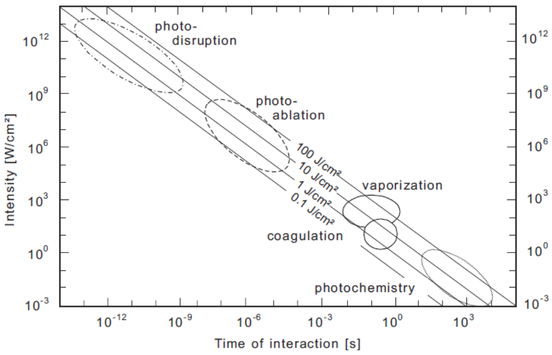
Virtually any laser is more dangerous than any other natural or artificial light source!



Effects of Laser Radiation on Biological Tissue

- effect depends upon the
  - irradiance of light
  - its wavelength
  - interaction time

- five different interaction processes:
  - photochemical reactions
  - thermal interaction: heating → coagulation, vaporization
  - photoablation: spontaneous removal of tissue
  - disruption: ionization of tissue, extremely high temperatures and pressures



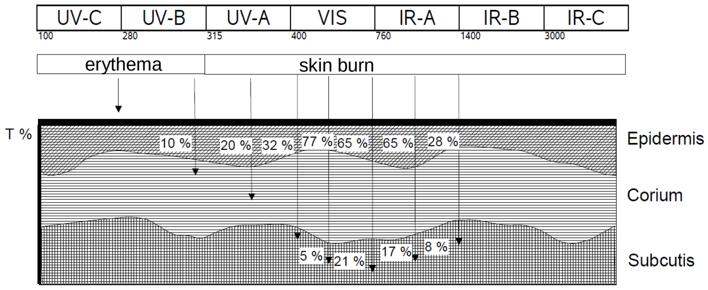
Damage

- absorption of laser radiation and properties of tissue determine
  - penetration depth
  - damage mechanism
  - extend of injury

- damage effects
  - thermal
    - IR region
    - most common damage mechanism
  - opto-acoustic
    - IR region
    - short-duration high intensities:
      heat conduction not fast enough, water explosively vaporized
      → damage of surrounding tissue („popcorn effect“)
  - photochemical
    - UV region
    - chemical properties of the material altered

Hazards: Skin

- UV-C (280 nm – 100 nm): skin aging, skin cancer
- UV-B (280 nm – 315 nm): erythema, enhances the hazard for cancer
- UV-A (315 nm – 400 nm): hyperpigmentation
- photosensitive reactions
- skin burn
- low-intensity IR irradiation: dilate blood capillaries, leading to inflammation



Beware: accumulating effects from long-time exposure!

Hazards: Eye

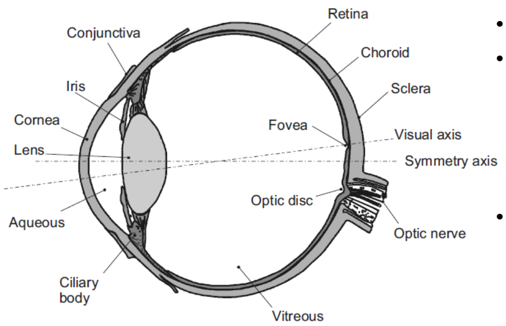
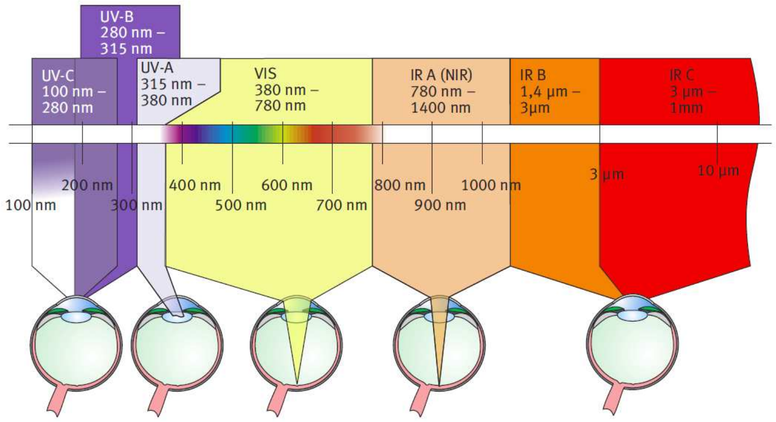


Figure 3.2. Schematic horizontal cross section of a human eye. Central sharp vision is only possible in the central part of the retina, the fovea, an area with densely packed cones. It is also interesting to note that the main refractive power of the eye is provided by the cornea, while the lens is mainly needed to adapt between distant and close objects.

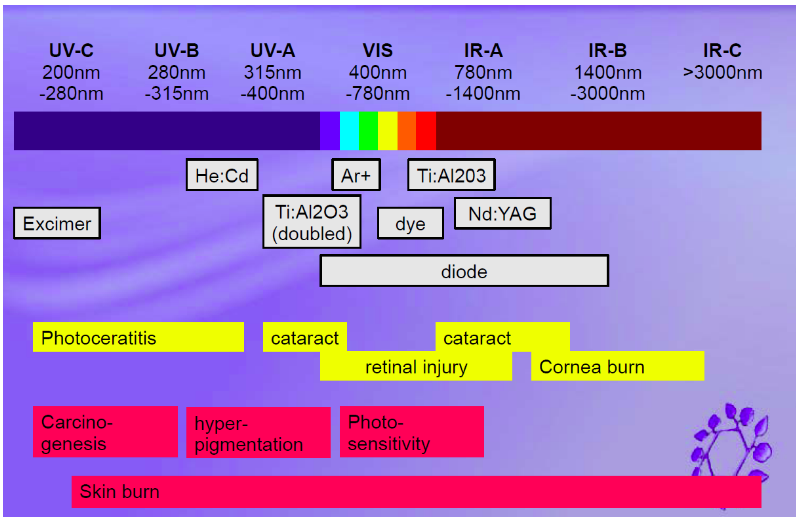
- laser beam damage can be
  - thermal burns
  - acoustic shock
    - high-intensity short-pulse lasers: sudden vaporization of tissue which then causes a shock wave to spread, tearing other tissues in the eye
  - photochemical reactions
    - cause cloudiness in the eye tissue
    - result in a loss of light sensitivity

Hazards: Eye



- visible and IR A: focusing of light onto the retina, amplification by a factor of $5x10^5$
- less than 400 nm: absorption by the cornea
- above 1400 nm: absorption by water inside the eye, burns of the cornea

Hazards Overview

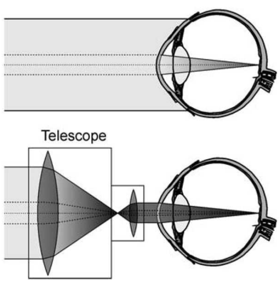


Remember:
You only have 2 eyes!

15.12.2010 14:24

Classification

- class 1
  - safe under all conditions of normal use
  - includes high-power lasers within an enclosure that prevents exposure
- class 1M
  - safe under normal conditions of operation
  - unsafe in combination with optical instruments (magnifying glass, microscope, etc …)



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Classification

- class 2
  - laser damages to the retina are prevented by the blink reflex (0.25 seconds exposure time)
  - only applies to visible light (400 nm – 700 nm)
  - limited to 1 mW
  - forced suppression of blink reflex can cause retina damages
- class 2M
  - same criteria as in class 2, but use of magnifying optics can cause eye damage

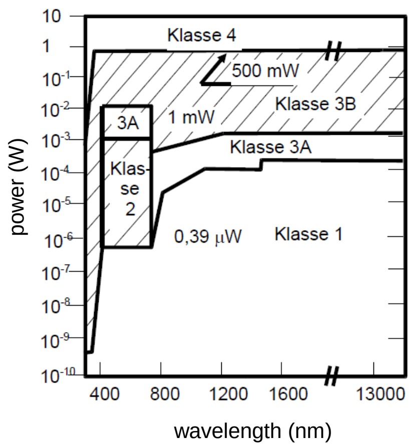
Classification

- class 3R
  - „safe if handled carefully“, low risk
  - max 5 mW visible cw (limits differ for other wavelengths or fs-pulses)
  - may be hazardous under direct and specular reflection viewing conditions, normally not a diffuse reflection hazard
- class 3B
  - up to 500 mW visible cw (limits differ for other wavelengths or fs pulses)
  - must have key switch and safety interlock
  - may be hazardous under direct and specular reflection viewing conditions, normally not a diffuse reflection hazard
- class 4
  - potentially dangerous laser
  - hazard to the eye or skin from the direct beam
  - diffuse reflections can be harmful
  - may pose fire hazard
  - must be equipped with key switch and safety interlock

Classification, Safety Equipment

Class	Concept	Comment
1	*The radiation emitted by this laser is not dangerous*	*No need for protection equipment*
1M	*Eye safe when used without optical instruments, may not be safe when optical instruments are used*	*No need for protection equipment, if used without optical instruments*
2	*Eye safe by aversion responses including the blink reflex.*	*No need for protection equipment*
2M	*The light that can hit the eye has the values of a class 2 laser, depending on a divergent or widened beam, it may not be safe when optical instruments are used*	*No need for protection equipment, if used without optical instruments*
3R	*The radiation from this laser exceeds the MPE values (MPE: maximum permissible exposure). The radiation is max. 5 x AELs of class 1 (invisible) or 5 x of class 2 (visible). The risk is slightly lower than that of class 3B*	*Dangerous to the eyes, safety glasses are recommended*
3B	*Old class 3B without 3R. The view into the laser is dangerous. Diffuse reflections are not considered as dangerous.*	*Dangerous to the eyes, safety glasses are obligatory*
4	*Old class 4 Even scattered radiation can be dangerous, also danger of fire and danger to the skin*	*Personal safety equipment is necessary (glasses, screens)*

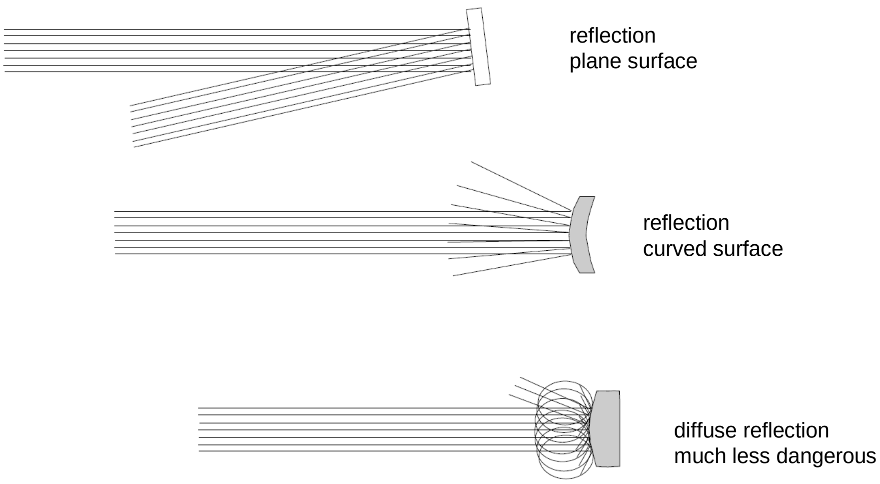
Classification (old)



Potentially Hazardous Exposure Conditions

	Long-term eye exposure		Short-term (accidental) eye exposure			
	Optical viewing instruments	Naked eye	Optical viewing instruments	Naked eye	Diffuse reflections	Skin exposure
Class 1	Safe	Safe	Safe	Safe	Safe	Safe
Class 1M	!	Safe	!	Safe	Safe	Safe
Class 2	!	!	Safe	Safe	Safe	Safe
Class 2M	!	!	!	Safe	Safe	Safe
Class 3R	!	!	Low risk	Low risk	Safe	Safe
Class 3B	!	!	!	!	Low risk	Low risk
Class 4	!	!	!	!	!	!

Reflections



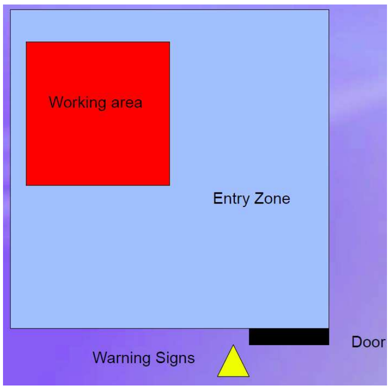
Laser beams are almost invisible, until they hit your eye!

Usage

- only trained users allowed to operate class 3 and class 4 lasers
- laser safety goggles required for lasers higher or equally rated than class 3B (recommended for class 3R)
- workplace must fulfill requirements necessary for lasers higher or equally rated class 3B

Laser Area

- security of operation has to be verified before turning on the laser
- every person in the laser area (during operation) has to have a laser education or otherwise leave the area
- laser operation has to be signaled at the entrance to the laser area (signs on)
- access control for class 3B and for class 4 lasers required to prevent unauthorized personell from entering the area



Laser Signs

Active Laser Safety

- act responsibly
- use interlocks, remove keys when the laser is not operated
- keep open beam paths to a minimum, using shieldings, guards, screens, curtains
- use beam enclosures whenever possible
- use beam blocks and traps

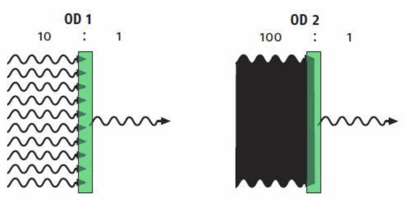
- use appropriate eye protection, i.e. safety glasses

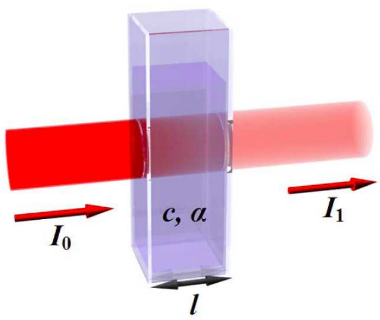
- ensure that the maximum permissible exposure (MPE) is never exceeded

Optical Density

- attenuation of light by a material
- optical density

$$\mathrm{OD}(\lambda) = \log_{10}\left(\frac{I_1}{I_0}\right)$$





Laser Safety Glasses

- depend on
  - wavelength
  - operational mode
  - minimum beam diameter

- declaration has to be written on the glasses
  - optical density (OD) for wavelength
  - sometimes L6@1024 R2@488

Never use goggles for the wrong laser!

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Declaration of Laser Goggles

- full protection glasses
  - attenuated to a level of class 1 lasers
  - withhold power for 10 seconds or 100 pulses
  - scale numbers L + optical density

- alignment filters
  - attenuation to a level of class 2
  - only visible light
  - scale numbers R + optical density

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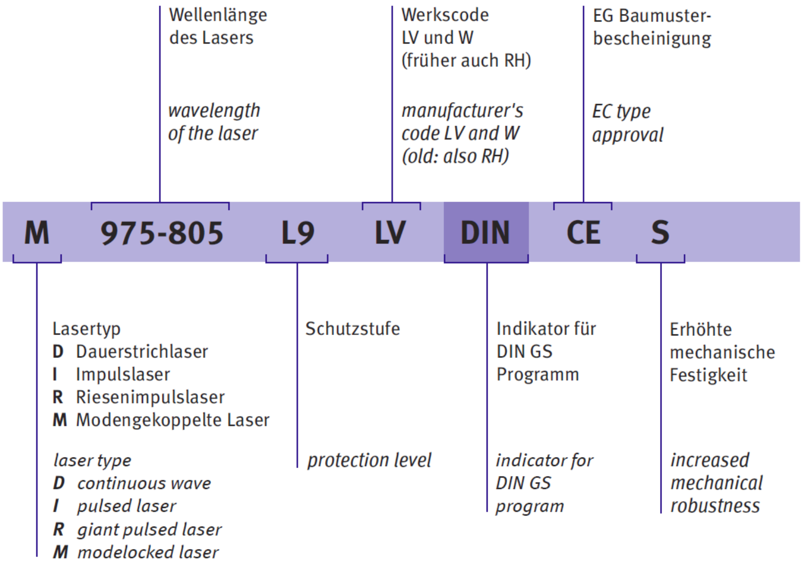
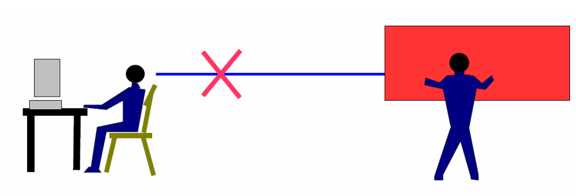
Declaration of Laser Goggles



Good Practice

- never look directly into the laser beam, never into the beam path
- work with the minimum power necessary
- know where your laser is
- take care of reflections and higher refraction orders
- work in one horizontal plane
- avoid a set-up in eye height



Good Practice

- block the beam while working on the beam path
- don‘t work alone
- work in bright ambient conditions
- don‘t wear jewelry, rings or watches while working on a laser
- ues blackened/non reflecting components in the beam path
- take extra care for
  - invisible laser
  - out-of-plane beam paths
- inform your colleagues
- do not direct any laser light towards windows or doors

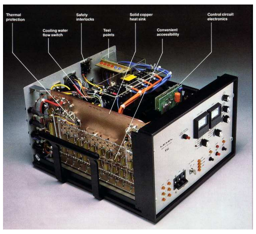
- if in doubt: ask

Common Causes of Accidents

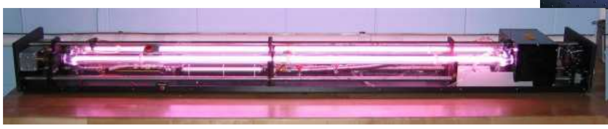
- altering beam path (e.g. adding optical components without regard to beam path)
- inserting reflective objects into beam path
- bypassing interlocks (particulary during alignment)
- accidentally turning on power supply
- accidentally firing of laser
- improper handling of high voltage

Other Hazards

- electrical shocks:
  high voltage, large currents



- mechanical (water / gas)
- chemical (gas / dye)
- temperature (fire)
- explosion
- secondary radiation
  (UV radiation from
  flash lamps for pumping, pump lasers)



Other Hazards: Chemical

- laser media
  - organic dyes are major source of chemical hazards
  - mutagenic, carcinogenic, toxic, and/or highly reactive chemicals
  - gases from laser or interaction of laser with target (e.g. ozone)
  - Beryllium oxide (Ar^+ laser)
- thermochemical decomposition of organic material: pyrolysis
  - PCCH
  - nitrosamines
- plastics (e.g. PMMA)
  - HCN
  - HCl
- laser generated air contaminants

Other Hazards: Electrical

- most common non-beam hazard
- high voltage from power supplies, capacitor banks

The optical beam can blind you,
the high voltage can kill you!

Other Hazards: Fire

- electrical circuits
- improper beam enclosures
- ignition of gases / fumes
- flammable dyes

- use flame-resistant beam enclosures and check electrical circuits for safety to prevent injury

In Case of Emergency

- stay calm!
- shut down laser
- take care about treatment of injuries, visit hospital / ophthalmologist immediately (first 24 to 48 hours most critical), do not hesitate
- inform supervisor / safety officer about
  - time of injury
  - kind of injury
  - how it happened
  - measurements taken

Please sign the attendance list!

Literature

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