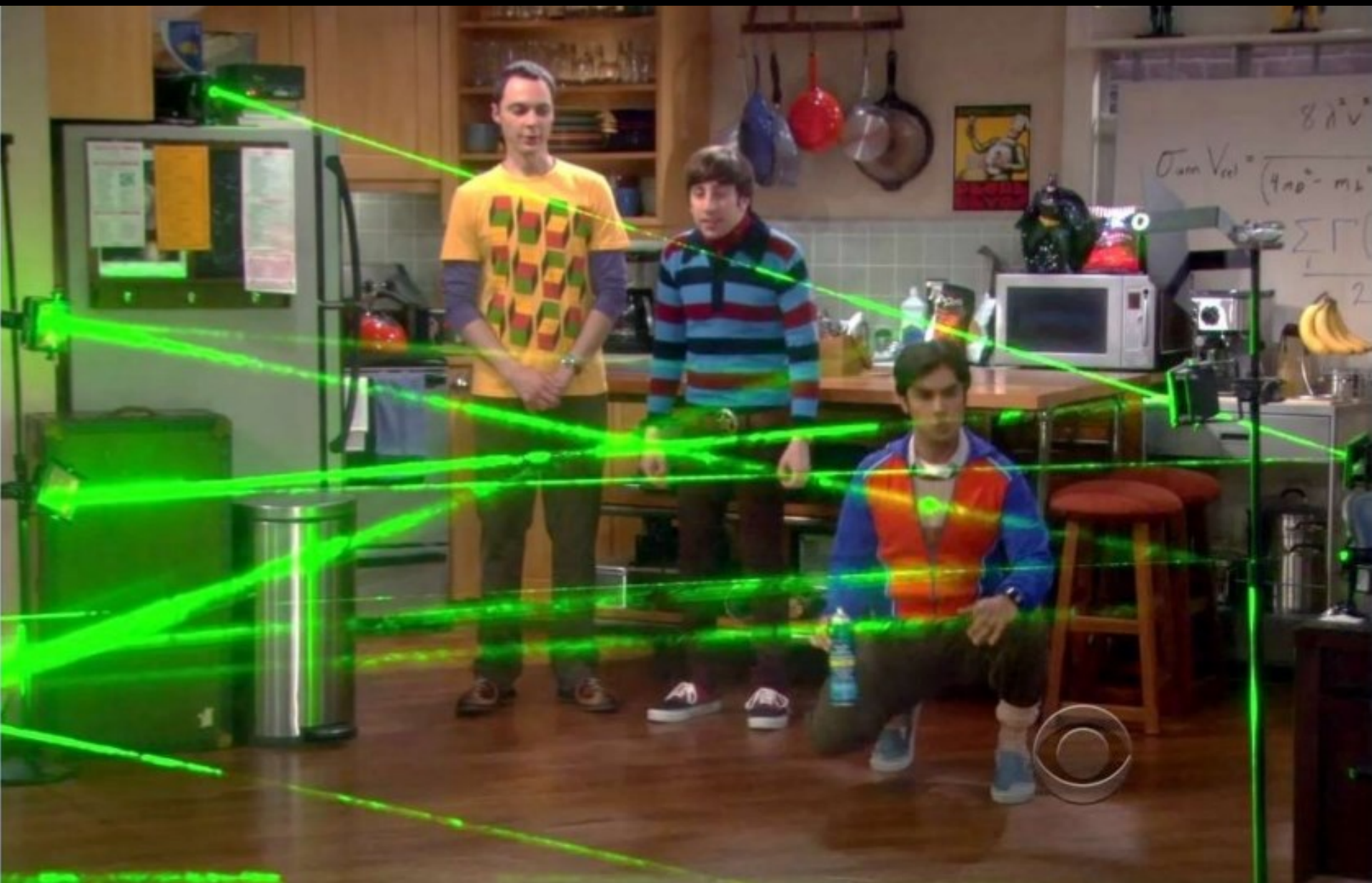
Laser Safety Instructions



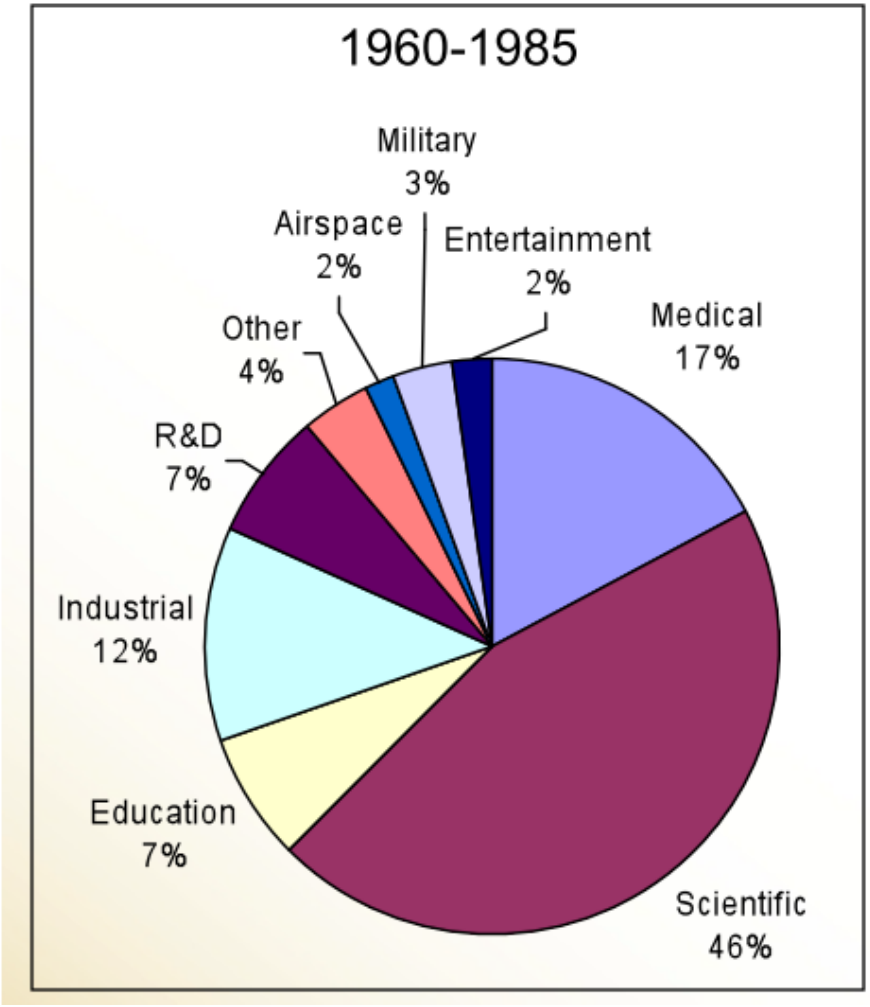
Outline

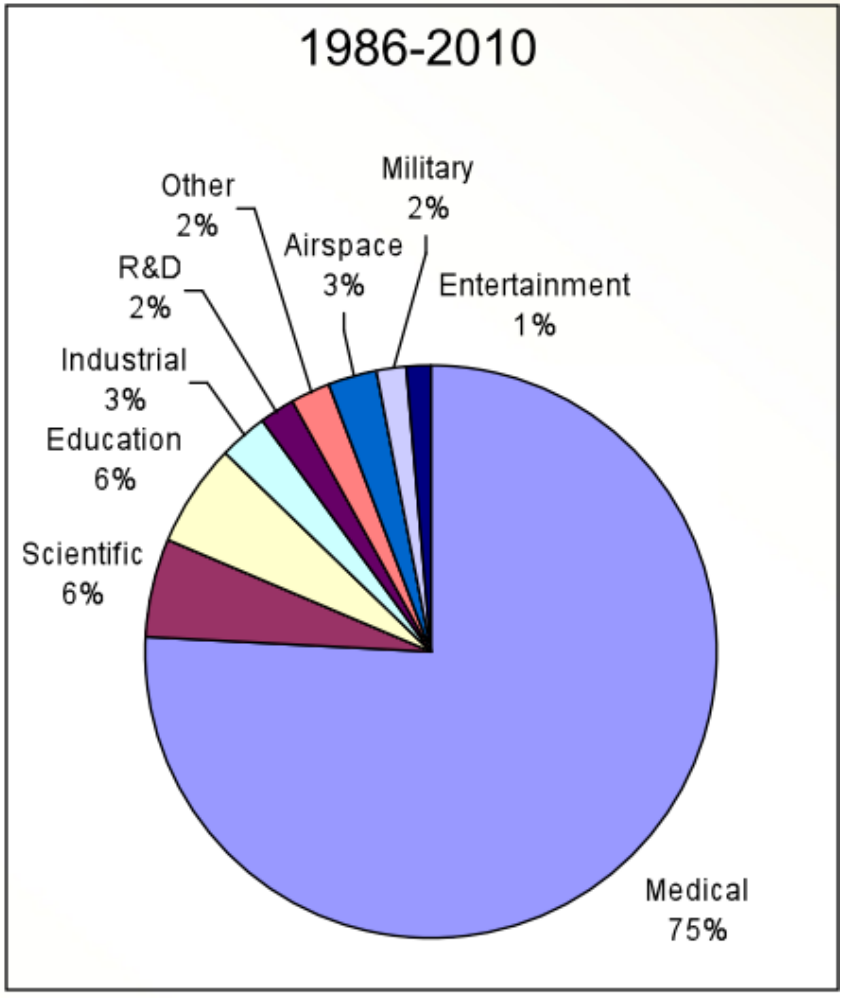
1. Why LASER safety instructions?
2. What is a LASER?
3. Why is LASER light dangerous?
4. Important terms (DIN EN 60825-1):
    - LASER classes
    - Maximum Permissible Exposure
    - Nominal Hazard Zones
5. Safety precautions

1. Why Laser Safety Instructions?

LASER Accident Statistics

Total number of incidents 1345





… approx. 80 % physical injuries (eyes, 70%; skin 10%)

Source: Rockwell Laser Industries Homepage: www.rli.com

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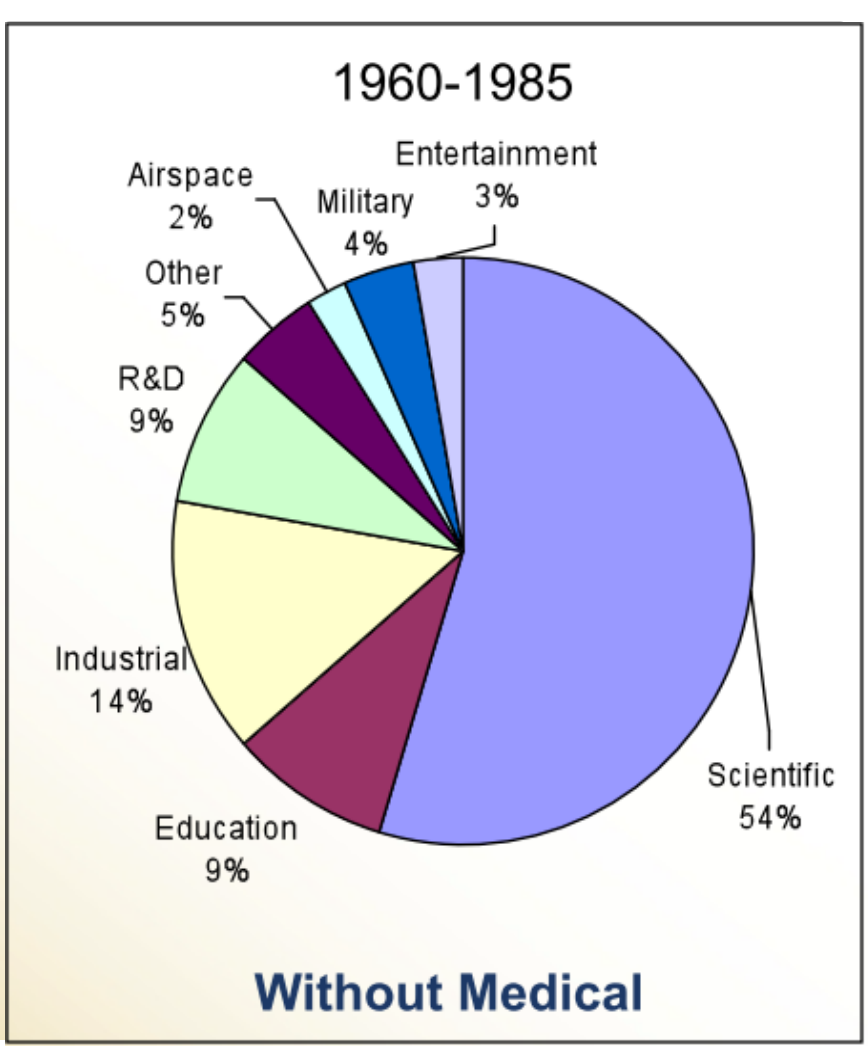

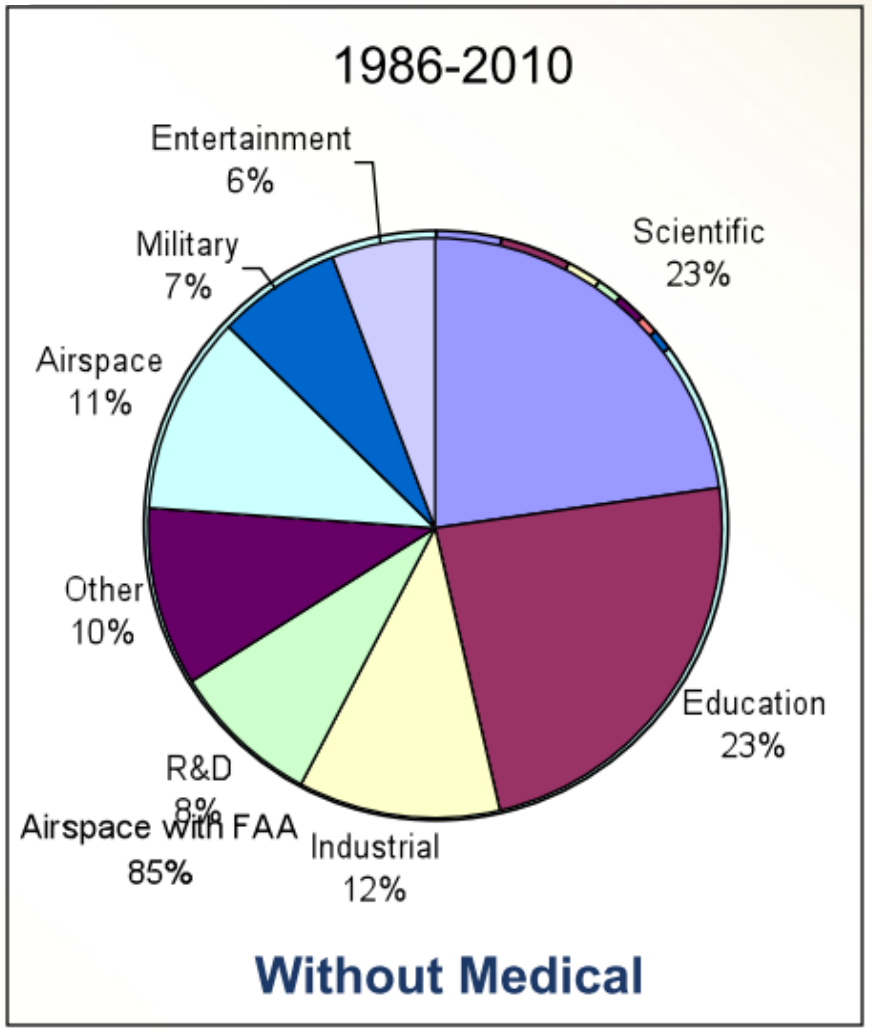

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Top 14 Accidents

Rockwell Laser Industry‘s top 14 Reported Causes of Laser Related Injuries

1. Unanticipated eye exposure during alignment.
2. Misaligned optics and upwardly directed beams.
3. Available laser eye protection was not used.
4. Equipment malfunction.
5. Improper method of handling high voltage.
6. Intentional exposure of unprotected persons.
7. Operators unfamiliar with laser equipment.
8. No protection provided for associated hazards.
9. Improper restoration of equipment following servicing.
10. Incorrect eyewear selection and/or eyewear failure.
11. Accidental eye/skin exposure during normal use.
12. Inhalation of laser generated fume & viewing of secondary radiation (UV, blue light).
13. Laser ignition of fires.
14. Photochemical eye or skin exposure.

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The Teaching and Research Environment

- **100% Protection?**
  - Not possible to have industrial safety levels – fully enclosed systems
  - Risk should be **As Low As Reasonably Achievable** (ALARA principle)

- **Multi user access**
  - There can be more than one laser in use in the lab
  - There can be more than one wavelength in use at one time

- **Versatile Systems**
  - Changing wavelength
  - Re-alignments
  - Repairs

Safety Awareness is CRUCIAL!

2. What is a LASER?

LASER: Working Principle

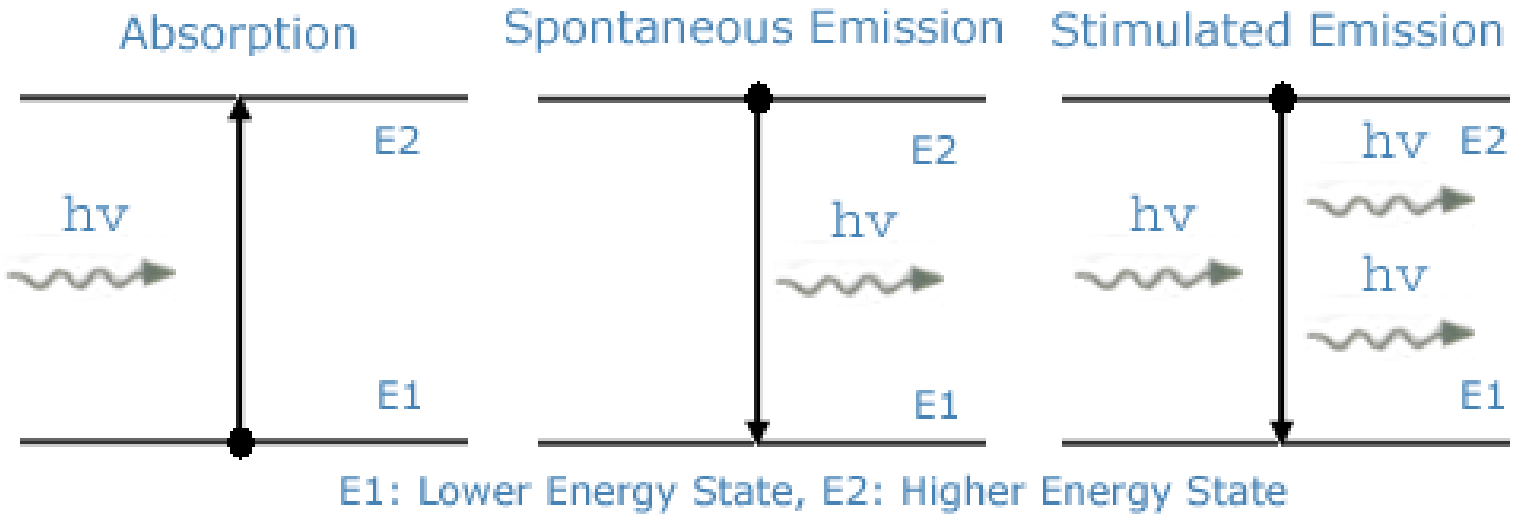
Light
Amplification by
Stimulated
Emission of
Radition

LASER media:

Solids such as Nd:YAG, Ti:Sapphire, Diodes

Liquids such as organic dyes

Gases such as He-Ne, Ar-Kr, Excimer



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LASER media:

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Gases such as He-Ne, Ar-Kr, Excimer

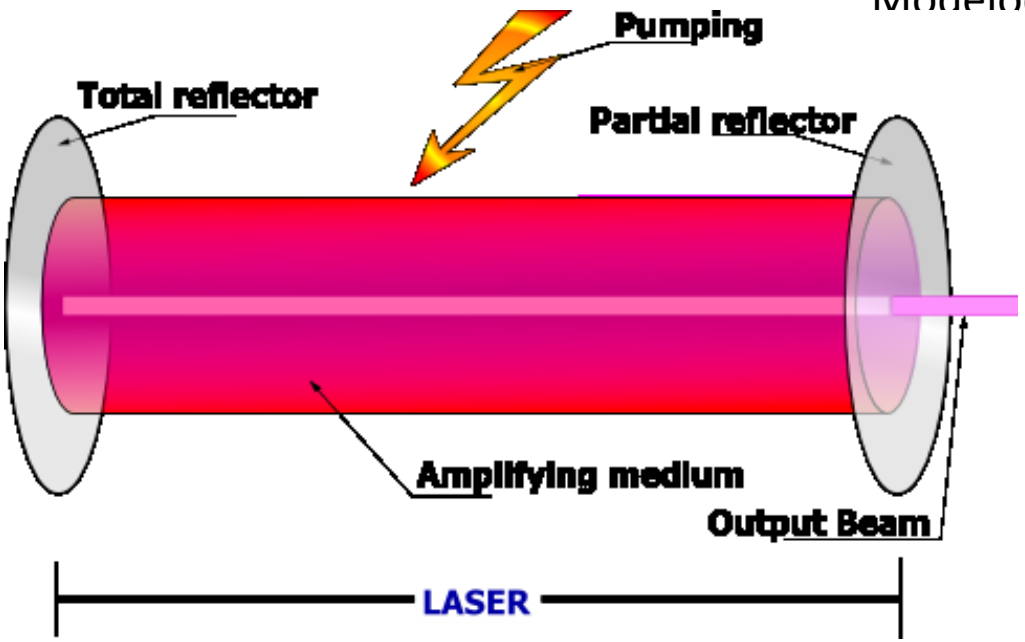
LASER modes:

Continuous Wave (> 0.25 s)

Pulsed (> 1 µs to 0,25 s)

Giant pulsed (1 µs to 1 ns)

Modelocked (< 1 ns)



LASER light …

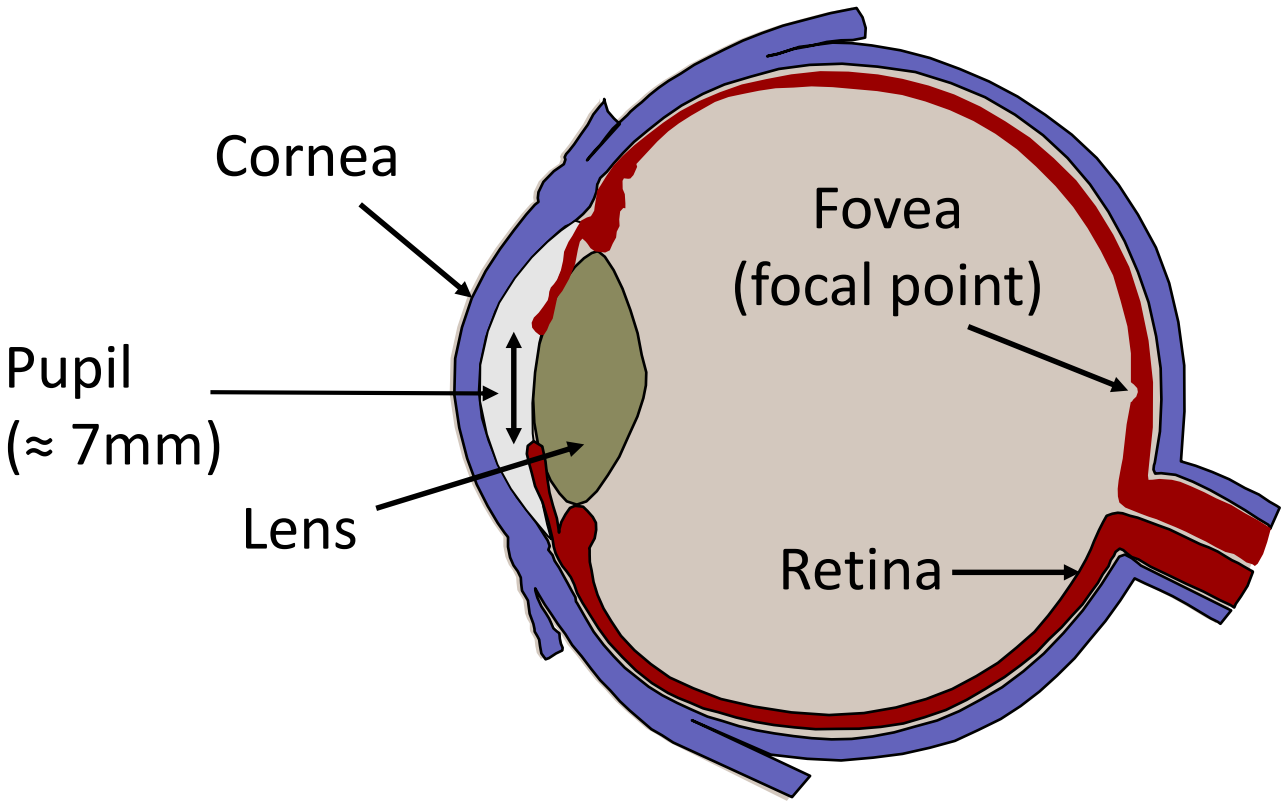
… is almost monochromatic

… is highly collimated

… extremely intense

3. Why is LASER Light Dangerous?

Anatomy of the Eye



Hazard: Light Bulb vs. LASER

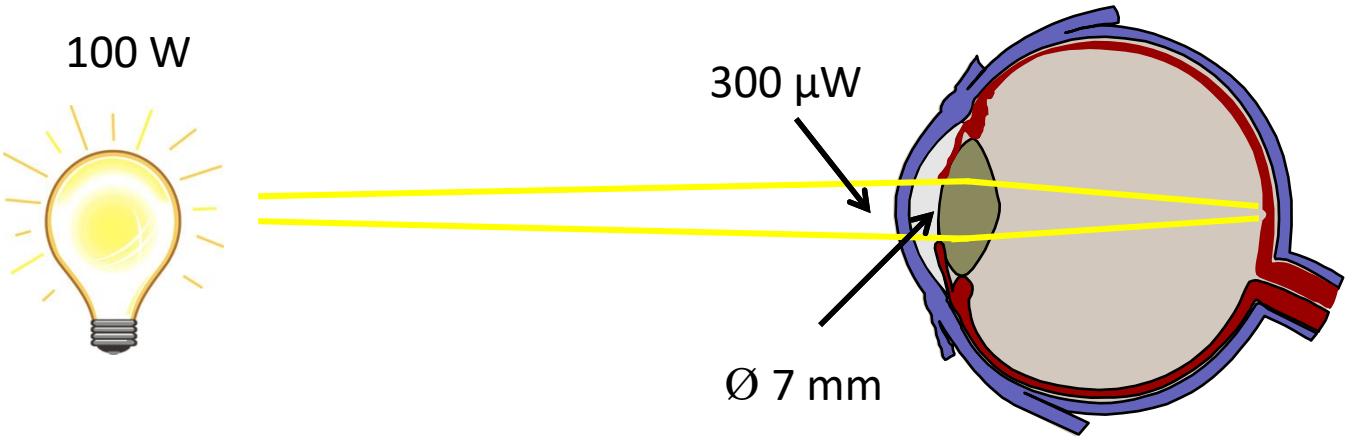


Image size:
b = 800 µm
Intensity:
I = 610 W/m^2

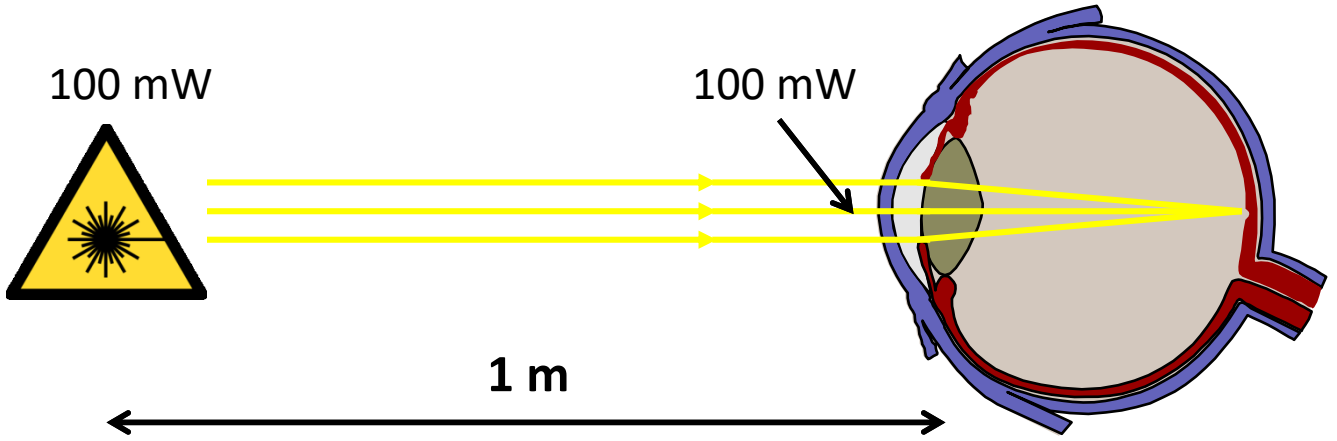
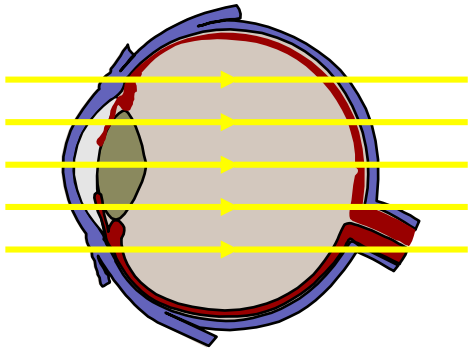


Image size:
b = 10 µm
Intensity:
I = 1,3 x 10^9 W/m^2

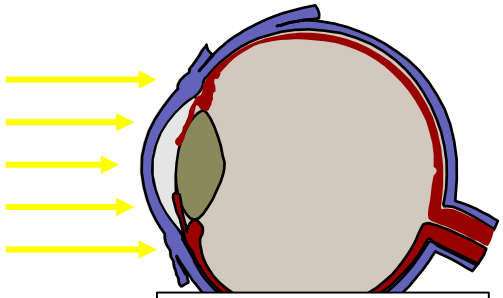
Intensity ratio at retina: $\frac{I_{\text{Laser}}}{I_{\text{Bulb}}} = 2{,}1 \cdot 10^6$

Laser Hazards of the Eye

x-rays and γ-rays < 100 nm

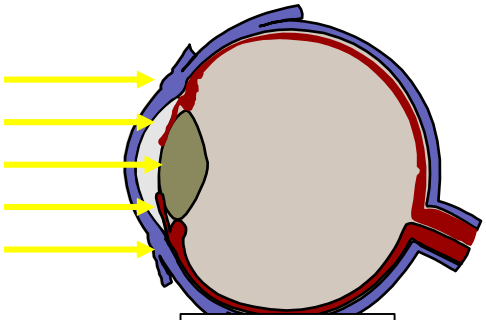


UV-B / UB-C: 100 - 315 nm



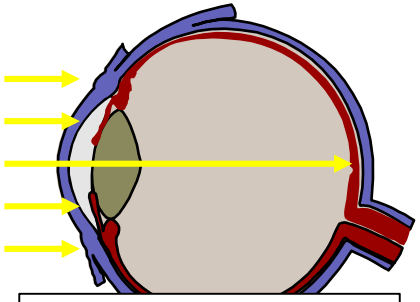
Conjunctivitis, Keratitis

UV-A: 315 - 400 nm



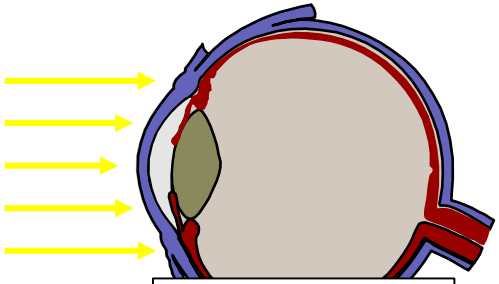
Cataract

Vis / IR-A: 400 - 1400 nm



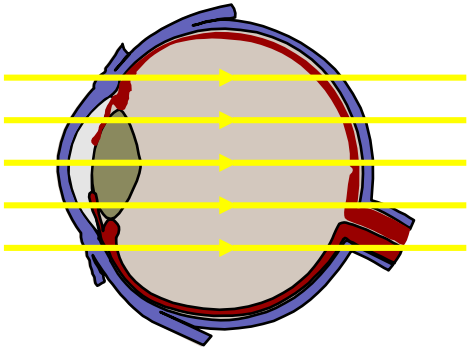
Photothermal damage / burns

IR-B / IR-C: 1400 - 3 mm



Burn of lens and cornea

Micro / Radio: > 3 mm



Laser Hazards of the Skin

All high power lasers can cause skin burns!

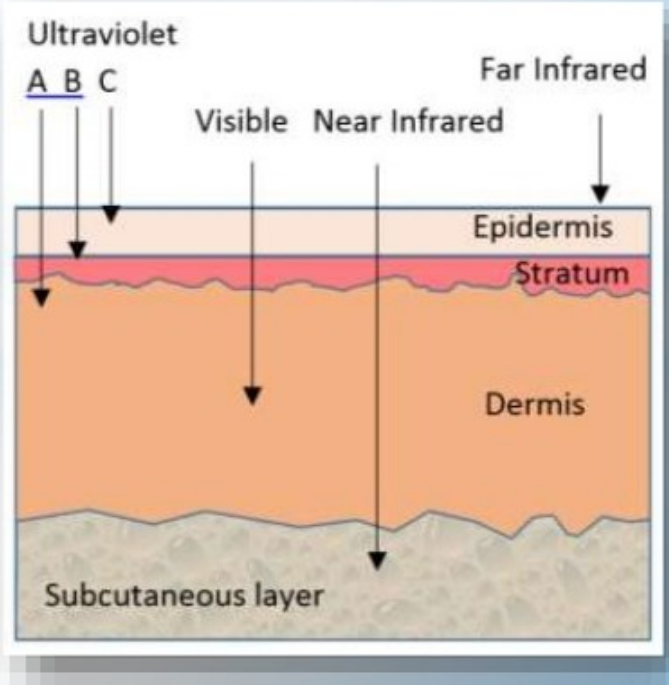
Ultra Violet radiation (UV): is a particular source of danger even at low power

Ultra Violet Sources in the Lab: include Lasers, e.g. optical parametric amplifier (OPA) and UV lamps e.g. xenon Lamps

Effects of exposure on skin

- mild erythema (sunburn)
- accelerated skin ageing
- skin cancer.

- UV C (180-280 nm) Absorbed in Ozone layer
- UV B (280-315 nm) Deep strata of skin at risk
- UV A (315-400 nm) Tanning, Skin at risk



4. Important Terms

Laser Classes

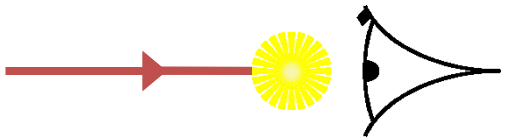
Maximum Permissible Exposure

Nominal Hazard Zones

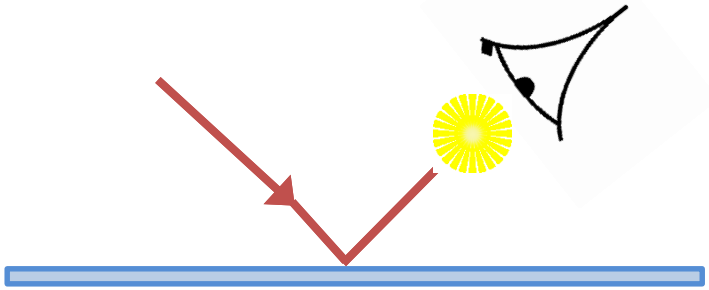
Laser Classes

$$1 \rightarrow 1M \rightarrow 2 \rightarrow 2M \rightarrow 3R \rightarrow 3B \rightarrow 4$$

Increasing Hazard



Direct exposure hazardous (2, 2M, 3R, 3B, 4)



Specular viewing hazardous
(2, 2M, 3R, 3B, 4)

Diffusive reflections hazardous
(3R, 3B, 4)

cp.: **DIN EN 60825-1 / VDE 0837-1**

Laser Class 1 & 1M (Eye-Safe)

$P < 0{,}4\ \mathrm{mW}$
$\emptyset < 7{,}0\ \mathrm{mm}$

$P < 0{,}4\ \mathrm{mW}$
$\emptyset > 7{,}0\ \mathrm{mm}$

$$302{,}5\ \mathrm{nm} \leq \lambda \leq 4000\ \mathrm{nm}$$

- Incapable of producing damaging radiation levels
- No precautions required
- No labeling obligation
- Laser of any class having been **completely enclosed** so that no hazardous radiation can escape and cause injury
- Pupil of the eye reduces potential intensity
- There is the potential for hazardous exposure if optical viewing aids are used

cp.: **DIN EN 60825-1 / VDE 0837-1**

Laser Class 2 & 2M

$P < 1{,}0\ \mathrm{mW}$
$\emptyset < 7{,}0\ \mathrm{mm}$

$P < 1{,}0\ \mathrm{mW}$
$\emptyset > 7{,}0\ \mathrm{mm}$

$$400\ \mathrm{nm} \leq \lambda \leq 700\ \mathrm{nm}$$

- Only hazardous if one stare directly into the beam ($> 0{,}25\ \mathrm{s}$)
- No Precaution required: Aversion reaction / eyelid closure reflex
- Safety instructions required

- Pupil of the eye reduces potential intensity
- There is the potential for hazardous exposure if optical viewing aids are used

cp.: **DIN EN 60825-1 / VDE 0837-1**

Laser Class 3R & 3B

$P_{\mathrm{Vis}} < 5{,}0\ \mathrm{mW}$

$P < 500{,}0\ \mathrm{mW}$

$$302{,}5\ \mathrm{nm} \leq \lambda \leq 1\ \mathrm{mm}$$

- Direct look into beam is hazardous
- Direct beam exposure should be very unlikely
- Precaution: Adequate eye protection
- Safety instructions required

- Exposure of eye and skin is hazardous
- Can cause fire
- Precaution: Laser goggles and safety gloves

cp.: **DIN EN 60825-1 / VDE 0837-1**

Laser Class 4

$P > 500{,}0\ \mathrm{mW}$

- Will cause *severe* eye damage and burn the skin.
- Even diffuse reflections can cause retinal injuries.
- Can cause fire and explosions
- Direct beam exposure should be very unlikely
- Precaution: Laser alignment googles only for $P < 100\ \mathrm{W}$, else always safety goggles
- Safety instructions required

cp.: **DIN EN 60825-1 / VDE 0837-1**

Maximum Permissible Exposure (MPE)

- The MPE is the highest level of radiation to which a person can be exposed without hazardous effects.
- The MPE is specified in W/m^2 for CW lasers and in J/m^2 for pulsed lasers. The value depends on wavelength, exposure duration and pulse repetition frequency.
- Exposure to radiation levels in excess of the MPE may result in adverse biological effects, such as injury to the skin and/or eyes.

Example: CW laser, $400\ \mathrm{nm} \leq \lambda \leq 700\ \mathrm{mm}$, duration $0{,}25\ \mathrm{s}$:

$$\mathrm{MPE} = 25{,}6\,\frac{\mathrm{W}}{\mathrm{m}^2} = 3{,}9\ \mathrm{mW/pupil\ area}$$

cp.: guideline 2006/25/EG

Nominal Hazard Zone (NHZ)

- The NHZ is the location around the laser within which a person can be exposed to radiation in excess of the MPE.
- When Class 3b and 4 lasers are unenclosed, the Laser Safety Officer must establish a NHZ.
- People may be injured if they are within the perimeter of this zone while the laser is in operation.

5. Safety Precautions

Three Lines of Defence

1. Engineering Controls

- Design the experiment/lab in such a way that dangerous exposure cannot happen. Reduce power during alignment
- Use beam enclosures and place beam blocks where possible
- Ensure all optics and mounts are securely fixed to optical table. Many incidents happen with an accidentally deflected beam
- Use a designated area with interlocks and warning lights on the entrances

2. Administrative Controls

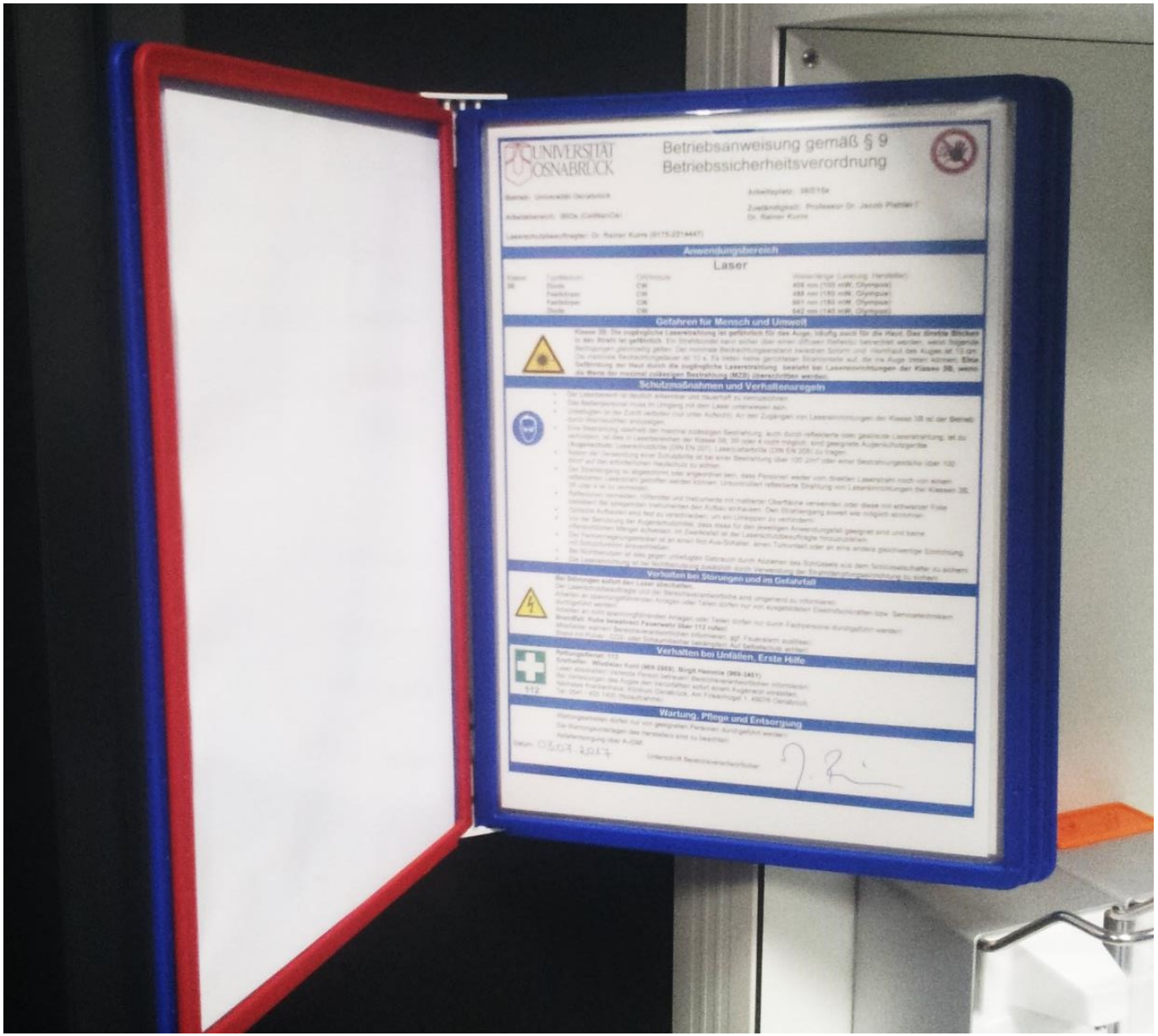
- Laser Safety Training
- Designated Areas
- Good Signage

3. Personal Protection

- Safety Eye wear, Protective clothing
- Awareness and good sense
  - do I need to be here?
  - what are others in the laboratory doing?

Laser Areas and Operation Instructions at iBiOs

Laser Areas and Operation Instructions at iBiOs



Personal Protective Equipment for Eyes

- PPE is not required for class 2 or 3R lasers unless intentional direct viewing > 0.25 seconds is necessary.
- PPE for eyes exposed to Class 3B or 4 lasers is mandatory. Eyewear with side protection is best. Consider these factors when selecting eyewear:
  - Optical Density (OD) of the eyewear
  - Laser Power and/or pulse energy
  - Laser Wavelength(s)
  - Exposure time criteria
  - Maximum Permissible Exposure (MPE)
  - Safety or alignment goggles

Choosing the Right Safety Goggles

Schutz-stufe *Scale number*	Maximaler spektraler Trans-missionsgrad bei den Laser-wellenlängen *Maximum spectral trans-mittance for laser wavelength* $\tau(\lambda)$	Maximale Leistungs- (E) und/oder Energiedichte (H) im Wellenlängenbereich *Maximum power (E) and energy (H) density in the wavelength range*								
		180 nm ⇢ 315 nm			› 315 nm ⇢ 1400 nm			› 1400 nm ⇢ 1000 µm		
		Für Prüfbedingung *For test condition* / Impulsdauer in s								
		D › $3 \cdot 10^4$ E_D W/m²	I,R 10^{-9} bis $3 \cdot 10^4$ $H_{I,R}$ J/m²	M ‹ 10^{-9} E_M W/m²	D › $5 \cdot 10^{-4}$ E_D W/m²	I,R 10^{-9} bis $5 \cdot 10^{-4}$ $H_{I,R}$ J/m²	M ‹ 10^{-9} H_M J/m²	D › 0,1 E_D W/m²	I,R 10^{-9} bis 0,1 $H_{I,R}$ J/m²	M ‹ 10^{-9} E_M W/m²
L1	10^{-1}	0,01	$3 \cdot 10^2$	$3 \cdot 10^{11}$	10^2	0,05	$1{,}5 \cdot 10^{-3}$	10^4	10^3	10^{12}
L2	10^{-2}	0,1	$3 \cdot 10^3$	$3 \cdot 10^{12}$	10^3	0,5	$1{,}5 \cdot 10^{-2}$	10^5	10^4	10^{13}
L3	10^{-3}	1	$3 \cdot 10^4$	$3 \cdot 10^{13}$	10^4	5	0,15	10^6	10^5	10^{14}
L4	10^{-4}	10	$3 \cdot 10^5$	$3 \cdot 10^{14}$	10^5	50	1,5	10^7	10^6	10^{15}
L5	10^{-5}	100	$3 \cdot 10^6$	$3 \cdot 10^{15}$	10^6	$5 \cdot 10^2$	15	10^8	10^7	10^{16}
L6	10^{-6}	10^3	$3 \cdot 10^7$	$3 \cdot 10^{16}$	10^7	$5 \cdot 10^3$	$1{,}5 \cdot 10^2$	10^9	10^8	10^{17}
L7	10^{-7}	10^4	$3 \cdot 10^8$	$3 \cdot 10^{17}$	10^8	$5 \cdot 10^4$	$1{,}5 \cdot 10^3$	10^{10}	10^9	10^{18}
L8	10^{-8}	10^5	$3 \cdot 10^9$	$3 \cdot 10^{18}$	10^9	$5 \cdot 10^5$	$1{,}5 \cdot 10^4$	10^{11}	10^{10}	10^{19}
L9	10^{-9}	10^6	$3 \cdot 10^{10}$	$3 \cdot 10^{19}$	10^{10}	$5 \cdot 10^6$	$1{,}5 \cdot 10^5$	10^{12}	10^{11}	10^{20}
L10	10^{-10}	10^7	$3 \cdot 10^{11}$	$3 \cdot 10^{20}$	10^{11}	$5 \cdot 10^7$	$1{,}5 \cdot 10^6$	10^{13}	10^{12}	10^{21}

Reference: EN 207 Tab. B.1.

Source: „Guide to Laser Safety“, LaserVision GmbH

Choosing the Right Alignment Goggles

Schutzstufe nach DIN EN 208 *Scale number acc. to EN 208*	Dauerstrichlaser und Impulslaser mit einer Impulslänge › $2 \cdot 10^{-4}$ s Maximale Laserleistung in W *CW lasers and pulsed lasers with a pulse length of › $2 \cdot 10^{-4}$ s Max. laser power in W*	gepulste Laser mit einer Impulslänge › 10^{-9} – 10^{-4} s Maximale Impulsenergie in J *Pulsed lasers with a pulse length › 10^{-9} – 10^{-4} s Max. pulse energy in J*
R1	0,01 W	$2 \cdot 10^{-6}$
R2	0,1 W	$2 \cdot 10^{-5}$
R3	1 W	$2 \cdot 10^{-4}$
R4	10 W	$2 \cdot 10^{-3}$
R5	100 W	$2 \cdot 10^{-2}$

Quelle: EN 208 *Reference: EN 208*

Source: „Guide to Laser Safety“, LaserVision GmbH

Dos & Don‘ts for Laser Work

Don‘ts (or little mistakes with BIG consequences)

- Do not directly look into beam
- Do not expose your skin to beam (use e.g. indicator cards)
- Do not open apertures/covers of microscope/system if laser emission is possible
- Do not touch laser optics or try to realign a laser if you are not authorized.
- Do not avoid safety devices (goggles, indicator cards)
- Do not wear rings, bracelets or any other reflecting materials
- Do not leave laser switched on if not necessary (long term experiments)
- Do not allow non-authorized people usage of laser systems or leave them alone with lasers switched on

Dos

- Mount laser to optical breadboard or bench before usage
- Close lab doors & laser safety curtains to protect other people
- Knock before entering a lab with flashing laser warn lamp
- Reduce laser power as much as possible for aligment procedures
- In case of any malfunction, immediately inform supervisor and laser safety officer

In Case of an Accident

- Switch off lasers if possible
- Contact first aider
- Call emergency: 112
- Turn to a doctor (eye specialist or dermatologist)
- Inform supervisor and laser safety officer

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Complacency is your Enemy!

If you are in doubt or you do not feel you are working with safe practices or equipment:

Contact your supervisor and laser safety officer!

It is your right to work safely no matter the cost or inconvenience!

Rainer Kurre
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Email: rainer.kurre@uos.de
Web: www.ibios.uos.de
Instructions online: https://www.ibios.uos.de/Service/Safety%20Instructions.html

Thank you for your attention!!