West Virginia University

Laser Safety

Department of Physics

Thursday, January 27, 2011

Why?

• Picosecond pulses cause bleeding/latent viewing distortion – cause: frequency doubler without AR coatings

• Reflected beam caused vision loss – cause: Professor removed eyewear to "see better" while doing an experiment

• Retinal burn from beam off rear laser mirror of YAG laser - cause: student with INCORRECT EYEWEAR (rated for OD 4 not required OD 6)

• Blurred vision from reflected exposure - Student without eye protection received reflected beam from Ti-Sapphire laser of off plastic tool box lid

• Off-axis beam causes macular burn in left eye - scientist bumped mirror mount

• Backscatter from mirror causes haemorrhage and oveal blindspot - student aligning laser amplifier caught professor in eye

LASER SAFETY INCIDENTS LEAD TO LAB SHUTDOWNS – Los Alamos, U. Manchester

Q: Can This happen in our department?

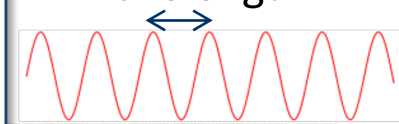
Outline

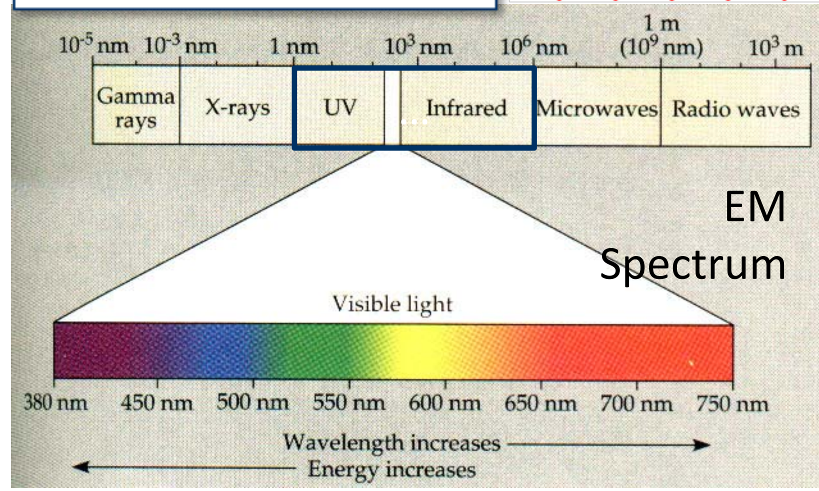
- **What is a LASER?**
- **Summary of laser hazards**
- **Laser classifications**
- **Laser-related hazards**
    - Non-beam hazards
    - Beam hazards
- **Optical protection**
    - Maximum permissible exposure, calculating requirements
    - Laser-protective spectacles
- **Issues in practical laser safety**
    - Particular hazards (Ti:sapphire)
    - Past incidents
    - Minimizing risk: practical rules and tips

What is a LASER?

L	light
A	amplification by
S	stimulated
E	emission of
R	radiation

Laser radiation
UV-VIS-IR
(~1 nm to 100,000 nm)



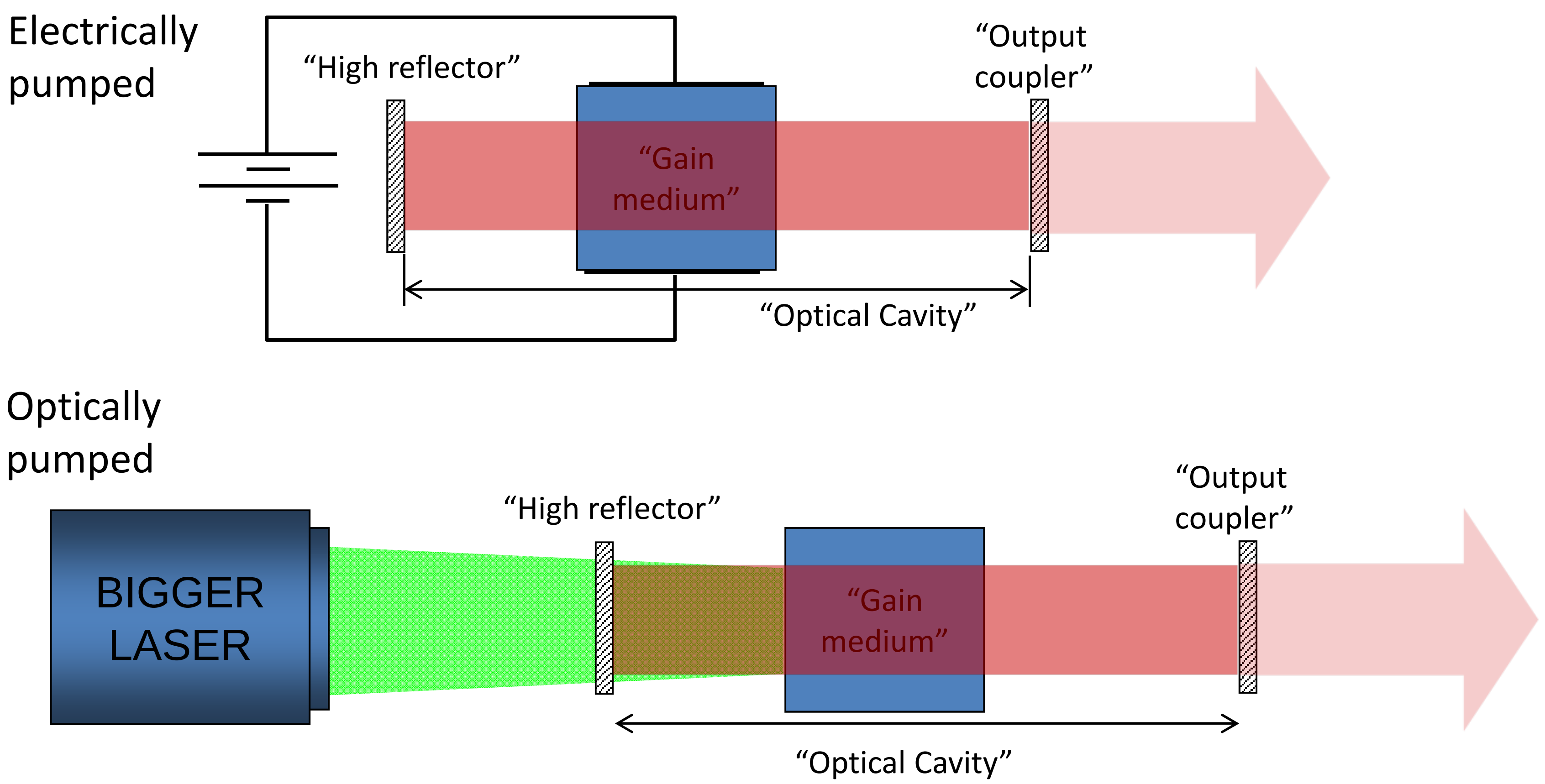


Inside a laser

- the atomic process known as stimulated emission generates electromagnetic (EM) radiation
- this radiation is amplified using feedback in an optical cavity
- lasers used stimulated emission to amplify EM energy
- which becomes very intense
- the intensity of laser light is therefore a hazard

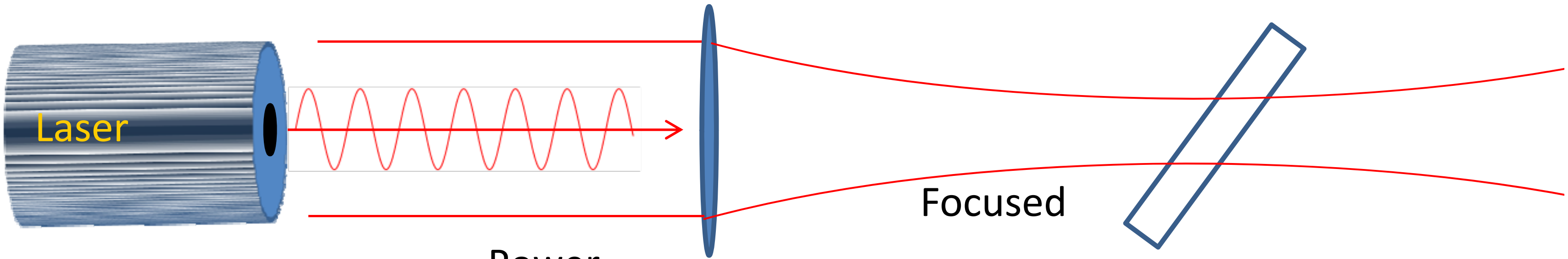
Note that this radiation should not be confused with ionizing radiation or radioactive materials

What is a LASER?

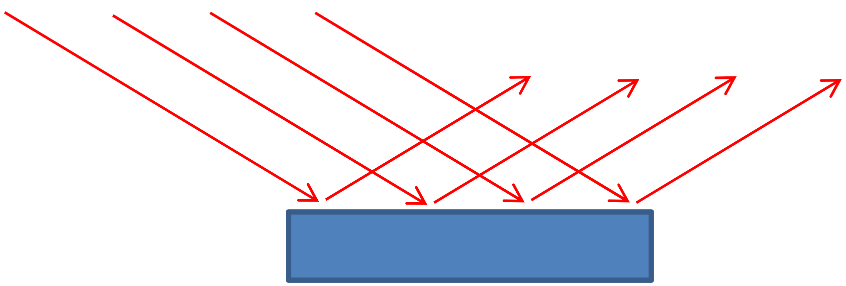


Lasers produces an intense highly directional beam of light

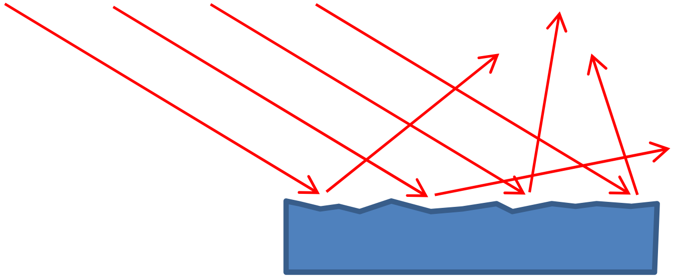
What is a LASER?



$$\text{Intensity} = \frac{\text{Power}}{\text{Area}}$$



Smooth surface – specula reflection



Rough surface – diffuse reflection

- Laser energy can be directed, reflected or focused on an object
- Partially absorbed by materials it comes in contact with
- Laser power is important to consider – this will help us assess the danger

Summary of laser hazards

- **High Voltage, current, power (separate training required)**

- **Chemical Hazards (MSDS – separate training required)**
    - F2 , Cl2 gas
    - Explosion hazards
    - Cryogenic hazards

- **Concentrated light (primary focus of laser safety)**
    - Fire hazard
    - Skin, Clothing EYE HAZARD

Marine labs?

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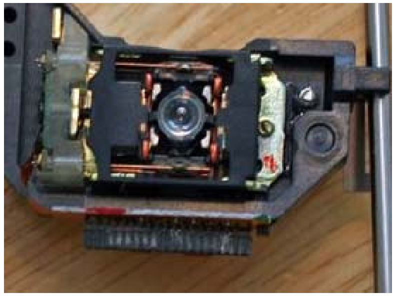
Laser classification

Maximum Permissible Exposure (MPE)

Class 1

- Safe to the eye under all conditions (e.g. at 600 nm emits <0.39 mW)
- Includes high-power lasers that are completely encased
  - Examples: CD-ROM players/drives



Class 1M

- Safe except when passed through focusing optics
(i.e. naturally large area or diverging beams)

Class 2

- Safe within “blink response” time of the eye (e.g 0.25 second or less)
- Intentional extended viewing, however, *is considered hazardous*
- Must also be visible region of EM spectrum (400-700 nm)
- Limited to 1 mW continuous wave – MPE for most lasers
  - Example: supermarket scanners

Class 2M

- Safe except when passed through optics system (i.e. focusing)

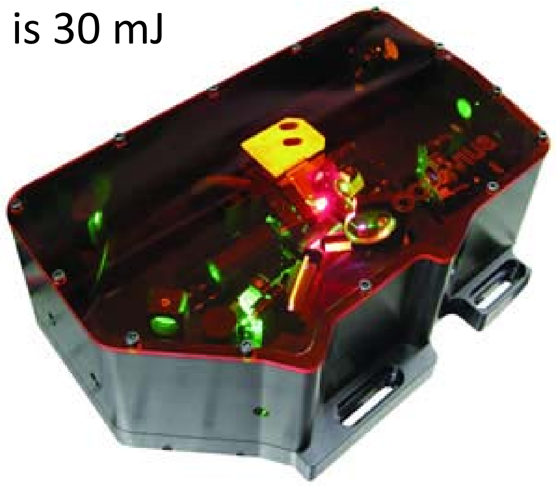
Laser classification

Class 3R

- Considered safe if handled carefully
- Requires restricted beam viewing conditions
- Exceeds MPE, but unlikely to cause serious injury
- Visible continuous lasers in Class 3R are limited to 5 mW
    - Examples: <5 mW Laser pointers

Class 3B

- A Class 3B laser is hazardous if the eye is exposed directly
- Diffuse reflections are not harmful
- Continuous lasers for 315 nm to far infrared wavelength are limited to 0.5 W
- For pulsed lasers between 400 and 700 nm, the limit is 30 mJ
- Protective eyewear is typically required
    - Example CW laser for photoluminescence



Laser classification

Class 4

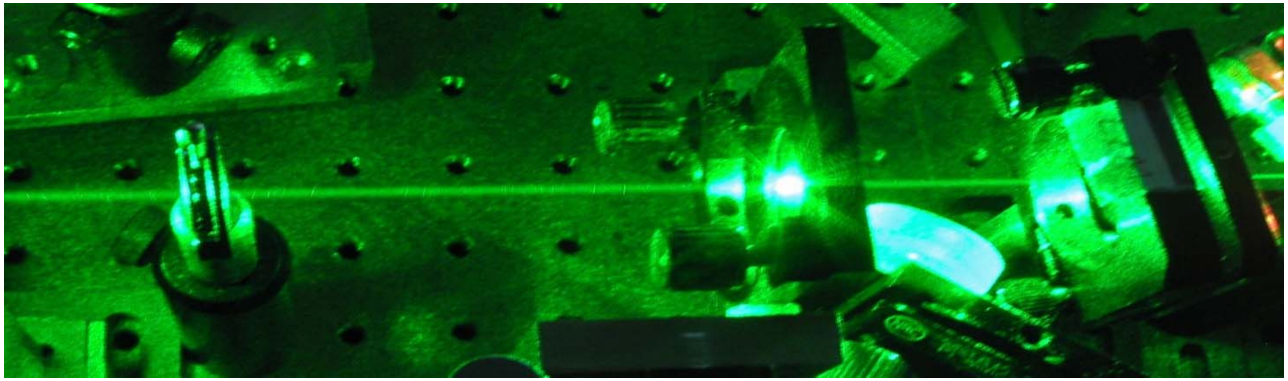
- Very high average beam powers for CW lasers or pulse energies for pulsed and ultrashort lasers
- Can burn skin
- Even diffuse reflections are a hazard to the eye
- Direct viewing will mostly result in devastating and permanent eye damage
- Stringent control measures are required
- Examples:

  Verdi (532 nm, 5W)

  Ti:Sapphire oscillator (modelocked, <100 fs, ~800 nm)

  CW/Q-switched Nd:YAG (1064 nm)

  Amplified Spontaneous Emission .... and many more!



Laser classification: other considerations

- **Other Considerations for continuous wave (CW) lasers**
  - the average power output (Watts)
  - limiting exposure time inherent in the design

- **For pulsed lasers**
  - the total energy per pulse (Joules)
  - pulse duration
  - pulse repetition frequency
  - emergent beam radiant exposure are considered

- **Ultrashort pulsed lasers**
  - <10 fs very short pulses, wide band emission
  - <1 fs or continuum generation – no protection available

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Laser-related hazards: non-beam hazards

High Voltage

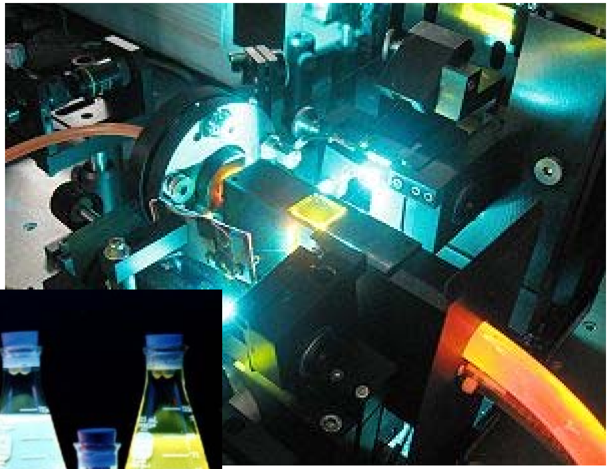
- Capacitor discharges
- High voltage – electrocution
- Sparks – fire hazard

- Only “qualified personnel” should open box
- At least one graduate-student death per year due to laser High Voltage

- Many lasers use high voltage to generate sufficient laser action, but require water cooling to dissipate heat.
- This balance can be <u>lethal</u> to inexperienced people opening laser equipment

Laser-related hazards: non-beam hazards

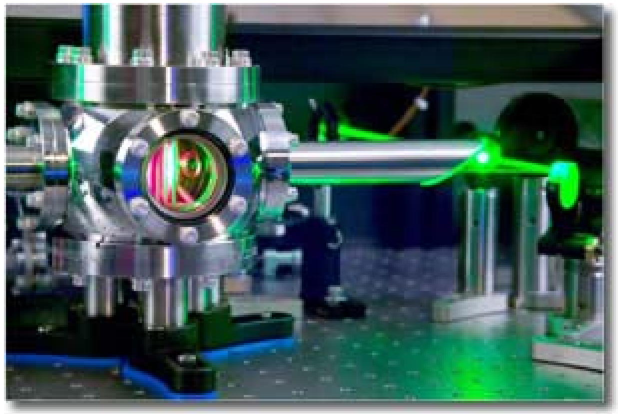
Chemicals and Cryogenics



- Laser dyes can be potentially lethal too
- Toxic, e.g. almost all
- Carcinogenic, e.g. RHODAMINE 6G

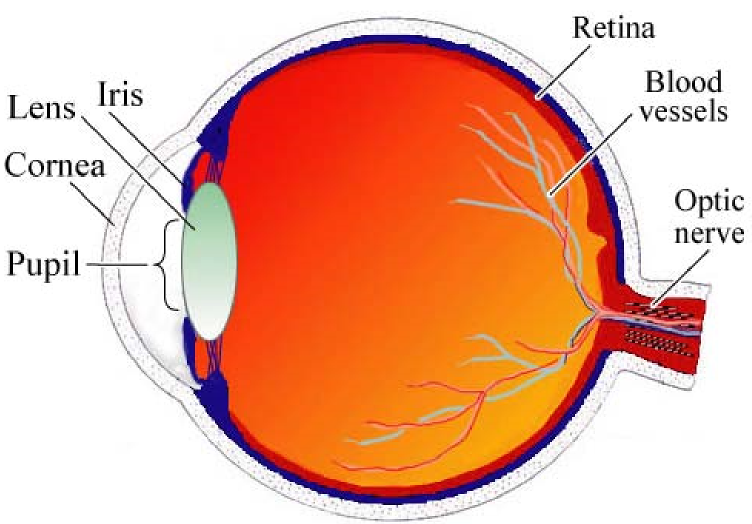
Requires Knowing:

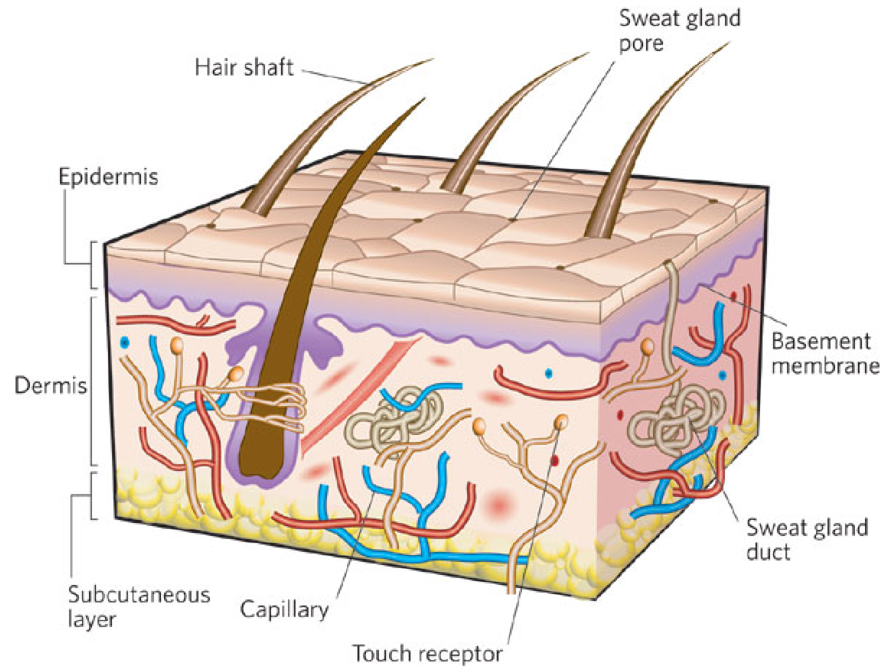
- Materials Safety Datasheets
- Proper storage, handling and waste management
- **Requires additional training**



- Some high-power lasers are cryogenically cooled
- Frostbite hazards from LN_2 and LHe
- Asphyxiation hazard from LN_2
- **Training required for cryogenics**

Laser-related hazards: beam hazards



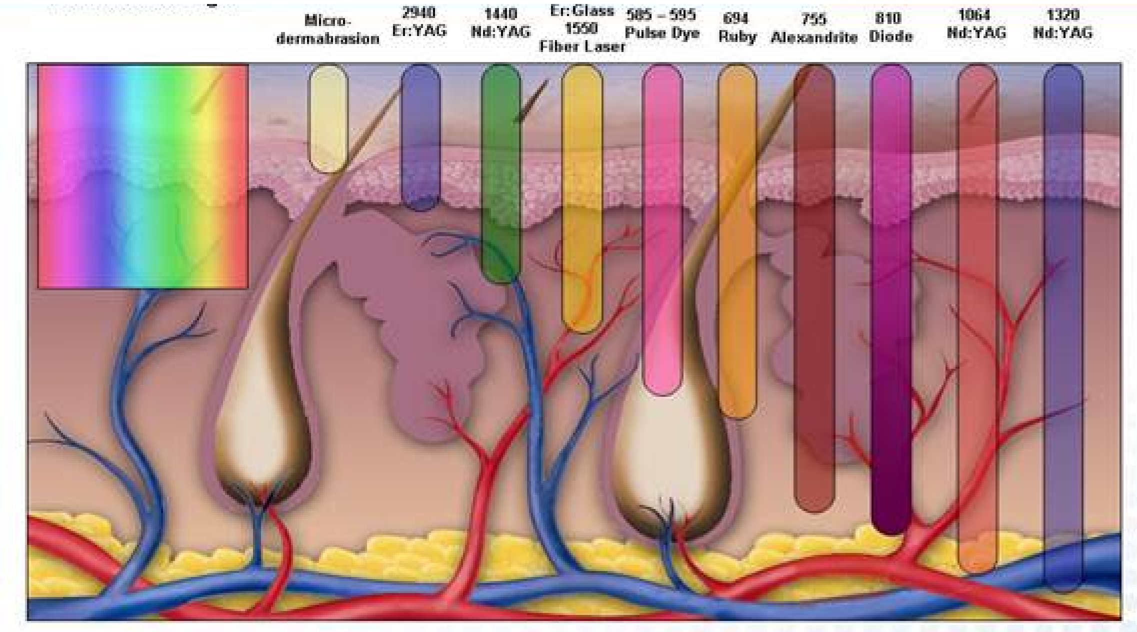


- Radiation absorbed by tissue
- Raising the surface or interior temperature
- Potential alteration or deformation of tissue

  e.g. laser eye surgery
- High intensity $\rightarrow$ Tissue (eye and skin) damage

- Laser pulses can also set fire to flammable lab supplies

Laser-related hazards: beam hazards



Skin has a dead layer that helps protect it against moderate intensity beams

High intensity can oblate the skin e.g. laser welding, cutting tools

Wavelength dependent skin penetration

- UV – short penetration depth
- VIS, NIR and MIR – moderate penetration
- FIR – negligible

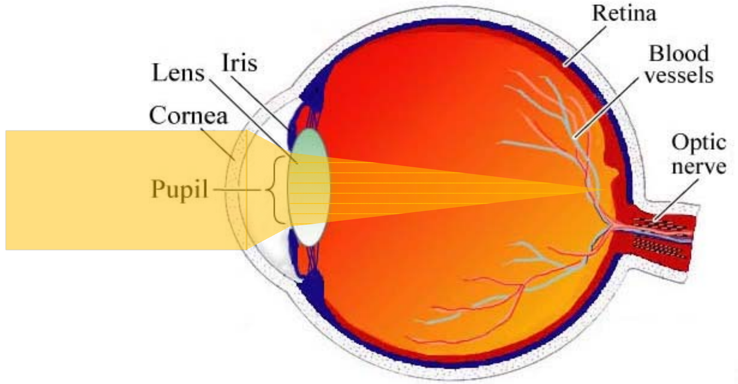
UV risks – skin cancer
(200 to 280 nm)
Photon energy is sufficient to cause photochemistry and therefore cell mutation

Laser-related hazards: beam hazards

Increasing Hazard

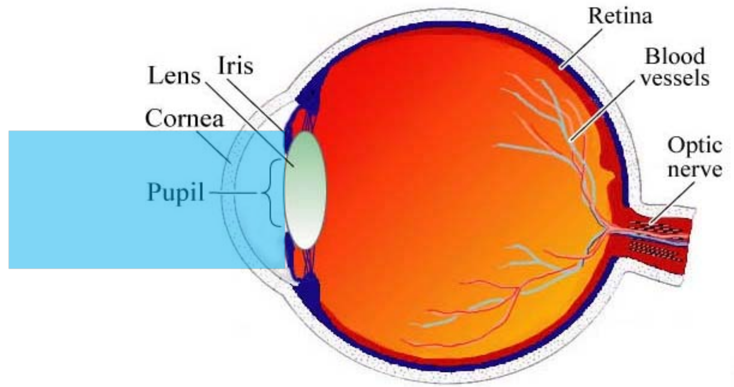
Visible-NIR (400-1400 nm)

- Eye is designed to focus visible light
- An eye focused on the horizon or a far-away object will optimally focus a collimated beam



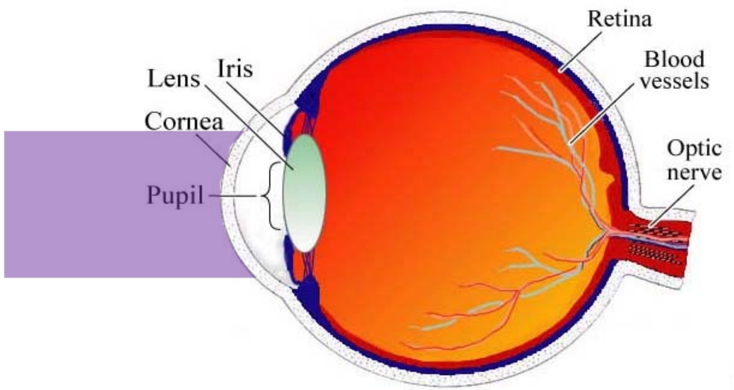
Near UV (315-390 nm)

- Damage to cornea and lens
- light doesn’t penetrate the vitreous humor, so no damage to retina



Mid-infrared (>1400 nm) and middle UV (180-315 nm)

- No penetrate, so no retinal hazard
- Photochemical damage to cornea

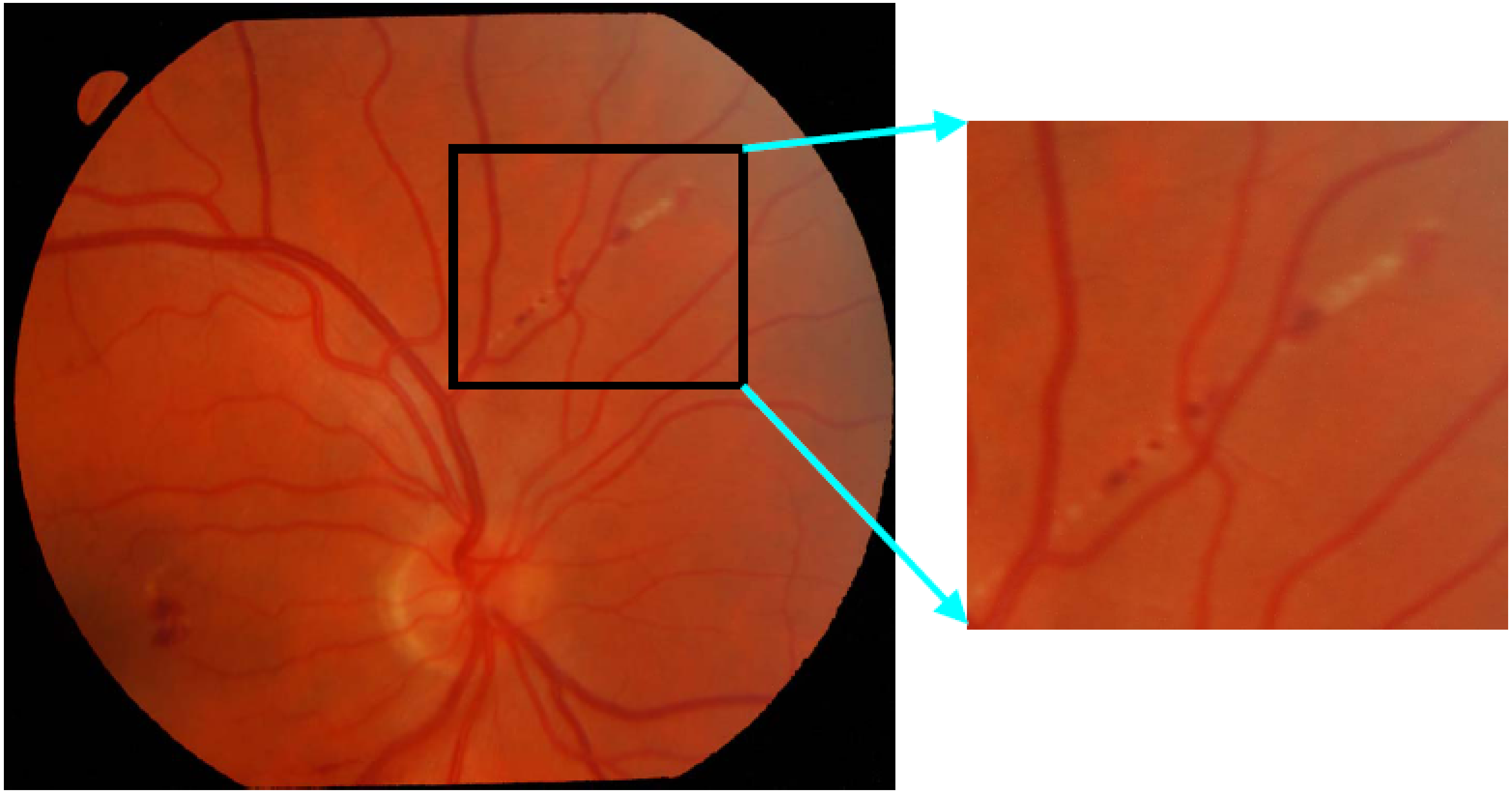


Laser-related hazards: summary of beam hazards

<table>
<tr><th>Spectral region</th><th>Eye</th><th colspan="2">Skin</th></tr>
<tr><td>Ultra-violet C
(180 nm to 280 nm)</td><td rowspan="2">Photokeratitis</td><td rowspan="2">Erythema (sunburn)
Accelerated skin ageing</td><td rowspan="2"></td></tr>
<tr><td>Ultra-violet B
(280 nm to 315 nm)</td></tr>
<tr><td>Ultra-violet A
(315 nm to 400 nm)</td><td>Photochemical cataract</td><td rowspan="2">Pigment darkening
Photosensitive reactions</td><td rowspan="5">Skin burn</td></tr>
<tr><td>Visible
(400 nm to 780 nm)</td><td>Photochemical & thermal retinal injury</td></tr>
<tr><td>Infra-red A
(780 nm to 1400 nm)</td><td>Cataract, retinal burn</td><td></td></tr>
<tr><td>Infra-red B
(1,4 µm to 3,0 µm)</td><td>Aqueous flare, cataract, corneal burn</td><td></td></tr>
<tr><td>Infra-red C
(3,0 µm to 1 mm)</td><td>Corneal burn only</td><td></td></tr>
</table>

Laser-related hazards: beam hazards

Examples of eye damage: ultrafast laser



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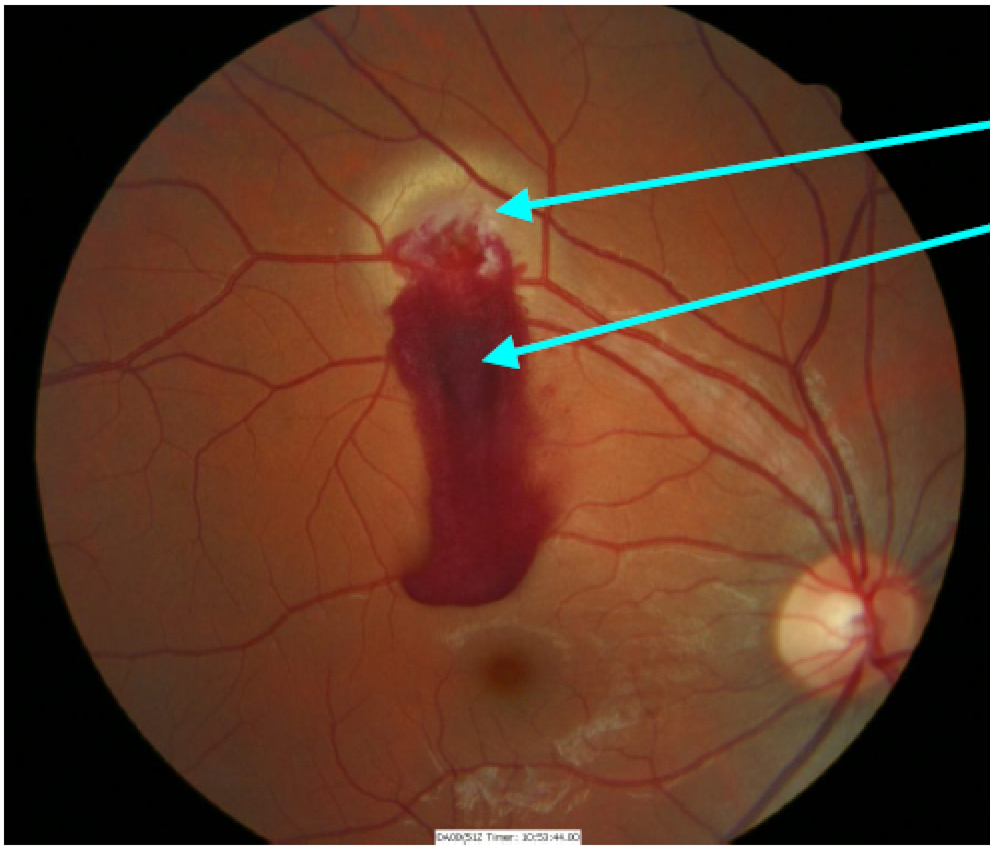


damaged area

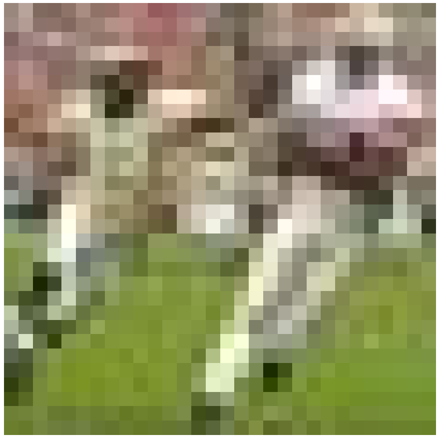
hemorrhaging

Caused by 3mJ, 20ns infrared laser and failure to use protective eyewear

Laser-related hazards: beam hazards

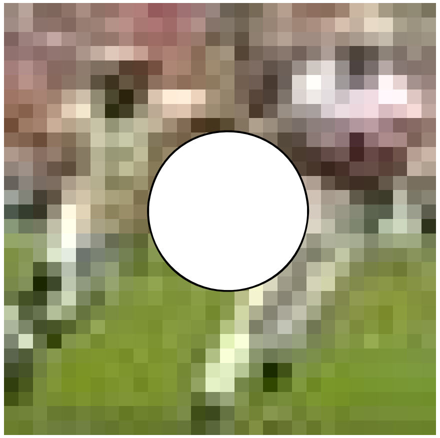
Examples of eye damage

Good vision



Cornea Damage

BAD

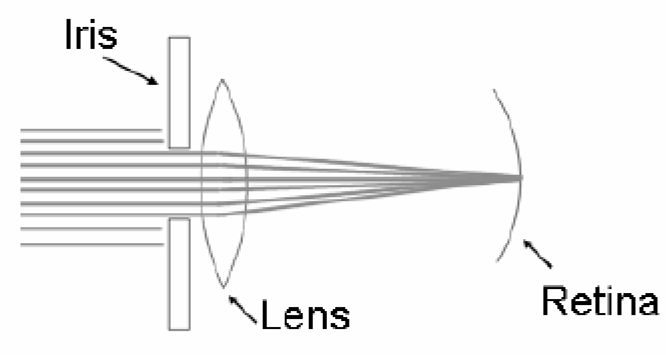


Retina Damage

WORSE

Laser-related hazards: beam hazards

Eye Hazards – “natural”



Eye basic parameters:

- Focal length ~25 mm
- Maximum size of iris 7 mm

Staring at the sun:

- 100 mW cm^{-2}, 10 mrad angle subtended
- Iris in full sun ~2 mm diameter
- Diameter of image on retina:

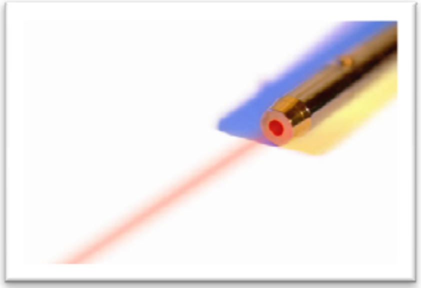
  $d_{retina} = 10 \times 10^{-3}$ radians $\times$ 25 mm = 0.25 mm
- Power into iris:

  $P_{iris} = 100\ mW\ cm^{-2} \times \pi\ (1\ mm)^2 = 3\ mW$
- Fluence:

  $F_{retina} = 3\ mW / \pi(.0125cm)^2 = 6\ W\ cm^{-2}$

Laser-related hazards: beam hazards

Eye Hazards – 1mW HeNe laser



Collimated, diffraction-limited spot, beam 2 mm diameter

- Eye is nearly diffraction-limited for $d \leq 2$ mm

$$d_{retina} = 2\lambda f / \pi r = 2 \times (633 \times 10^{-7}\ \text{cm}) \times 2.5\ \text{cm} / \pi\ 0.1\ \text{cm} = 10\ \mu\text{m}$$

- Fluence on retina:

$$F_{retina} = 1\ \text{mW} / (\pi\ 5 \times 10^{-4}\ \text{cm})^2 = 1300\ \text{W cm}^{-2}$$

So staring into a 1mW He-Ne laser can result in about 200 times more fluence on your retina than staring at the sun

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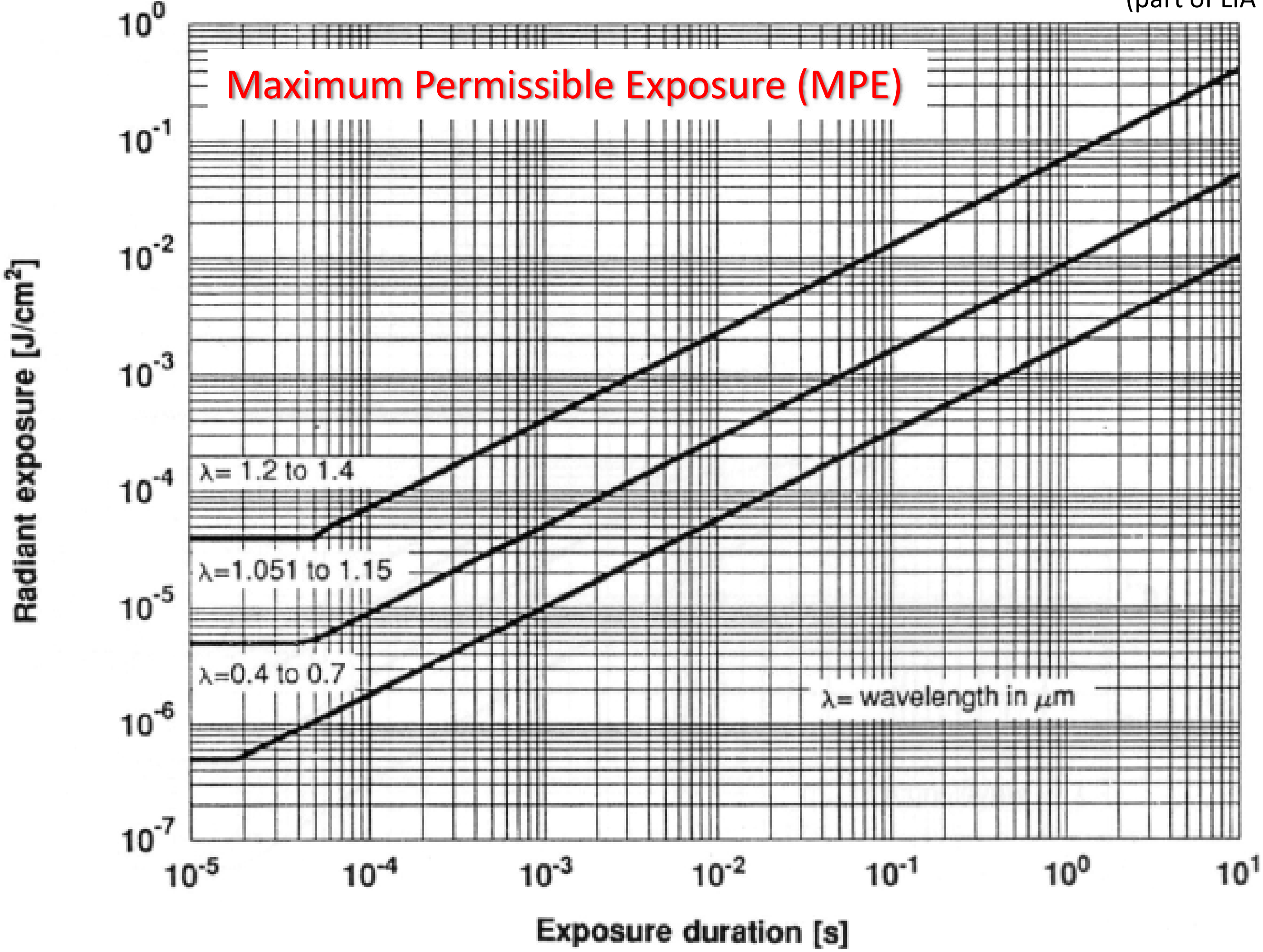
Optical protection: maximum permissible exposure

Example from ANSI Z136.1-1993: American National Standard for Safe Use of Lasers
(part of LIA Laser Hazard Evaluator Manual)



- Single pulse laser beam
- Exposure duration is FWHM
- Aversion response time ~ 0.25s
- Check reference for multiple pulse exposure

$$Cp = n^{-1/4}$$

Correction factor for multiple pulse exposure for visible and NIR laser

Optical protection: maximum permissible exposure

From graph, ~0.5×10^{-6} J cm^{-2} @ 10^{-5} sec

- 7 mm iris diameter = 0.385 cm^2
- Pulse energy limit ~0.2 μJ

  = 2 μW @ 10 Hz

  = 0.2 mW @ 1 kHz

  ~ 10^{-4} to 10^{-6} of full-beam energy

Modelocked ti:sapphire laser ~ 5 nJ = 0.005 μJ /pulse

- Treat as CW laser ~ 0.5 W output power
- 1 sec exposure ~ 1.5×10^{-3} J cm^{-2}; 1.5×10^{-3} W cm^{-2}
- 2 mm beam diameter -> 0.6 mW beam

Single pulse of an attenuated ps/fs laser is enough to cause damage

Optical protection: optical density

"Optical density" refers to transmission on log scale

e.g. OD 3 means 10^{-3} transmission

Required OD:

$$OD_{req} = \log_{10} \{ \text{laser energy (power)} / \text{MPE} \}$$

Example: CW Ti:sapphire laser

$$OD_{req} = \log_{10} \{ 500 \text{ mW} / 0.6 \text{ mW} \} = 3$$

100 mJ Ti:sapphire

$$OD_{req} = \log_{10} \{ 0.1 \text{ J} / 0.2 \ \mu\text{W} \} = 5.7$$

2J ti:sapphire

$$OD_{req} = \log_{10} \{ 2 \text{ J} / 0.2 \ \mu\text{W} \} = 7$$

If beam is larger than 7 mm dia, effective pulse energy can be reduced

Optical protection: suitable eyewear

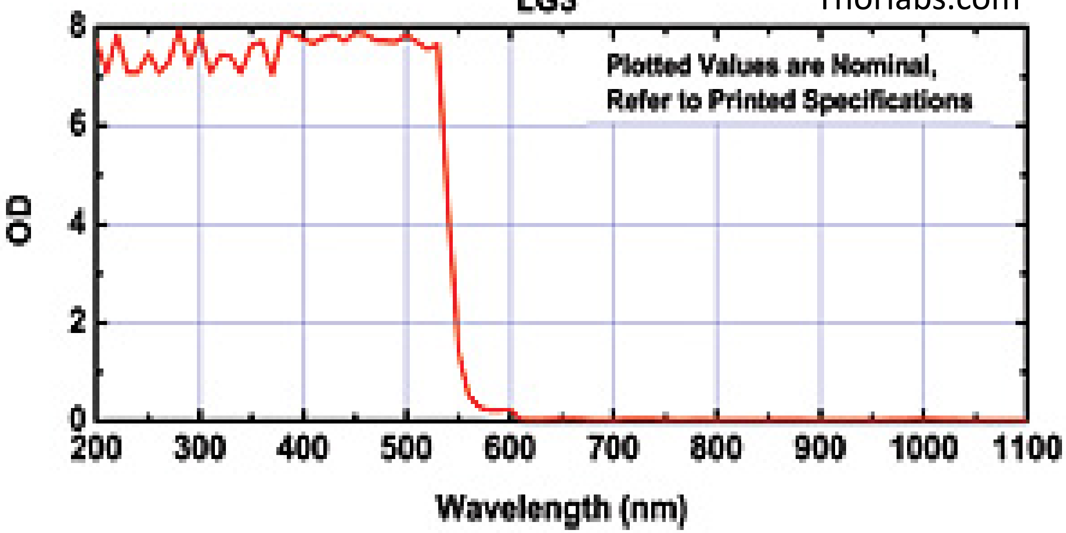
Example 1

Orange Glasses (OD 7)

- 5-18 W Verdi (532 nm)
- ~10W Argon laser (488 nm)
- pulsed frequency doubled Nd:YAG (532 nm)

•Note:

- usable
- fit over glasses
- OD range written on side



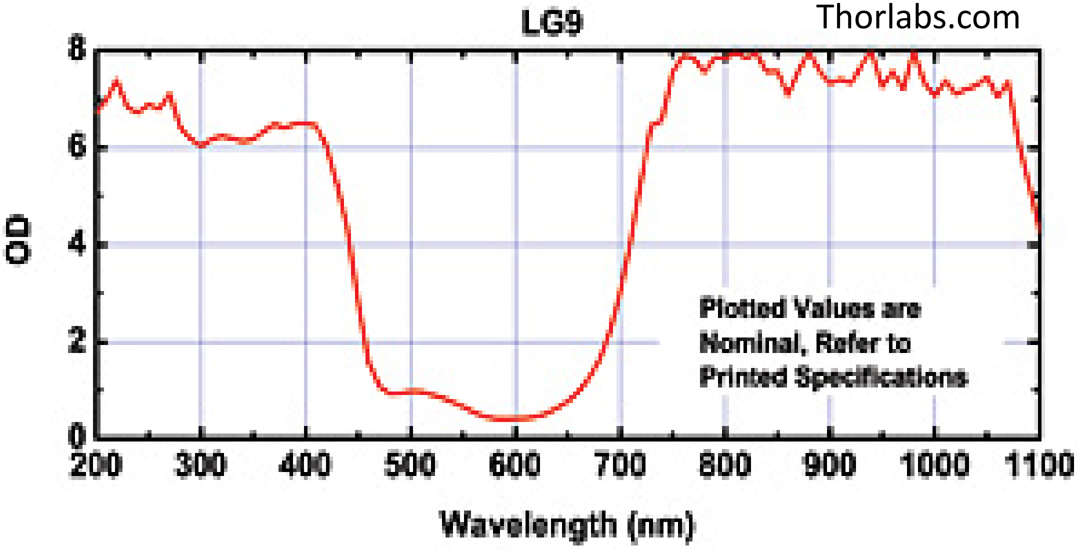
Optical protection: suitable eyewear

Example 2

Amber Glasses

- Ti:sapphire (750-980 nm) = **(OD 7)**
- Eximer lasers (190-400) = **(OD 6)**

OTHER EYE PROTECTION AVAILABLE – FIND THE APPROPRIATE TYPE FOR YOUR LASER



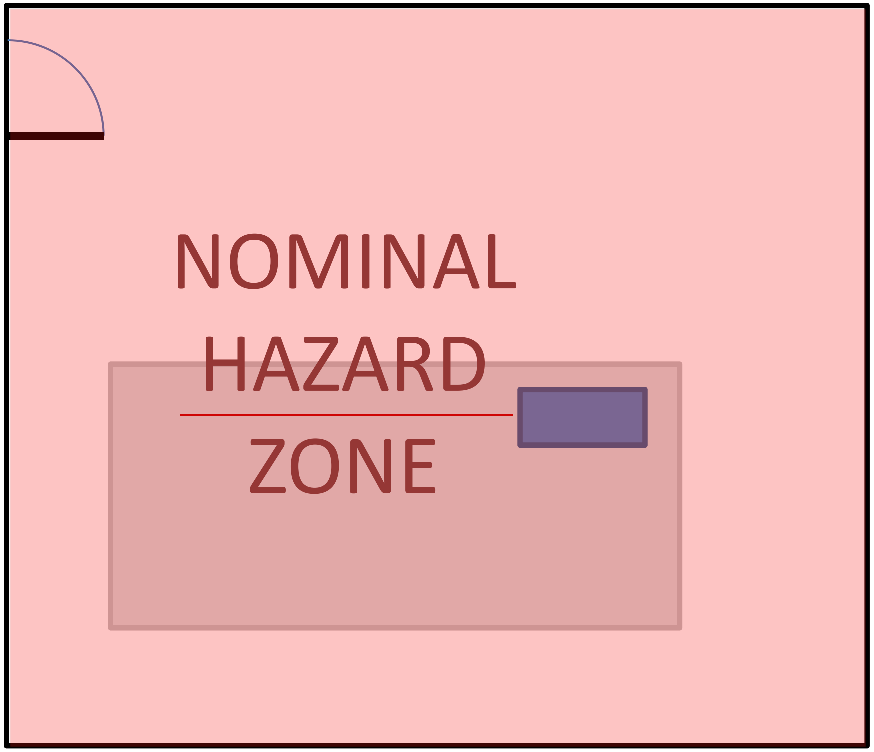
Optical protection: hazard evaluation and nominal hazard zone

• EVERY laser operator (from supervisor to new students) should understand the risk of working with high-power and ultrashort laser pulses

• Evaluate the dangers in your lab – reflecting surfaces, exposed beams

Nominal Hazard Zone:
• area where caution is required
• can be entire lab

• ideal: all lasers are class 1, because they are encapsulated
• reality: unlikely in experimental physics labs



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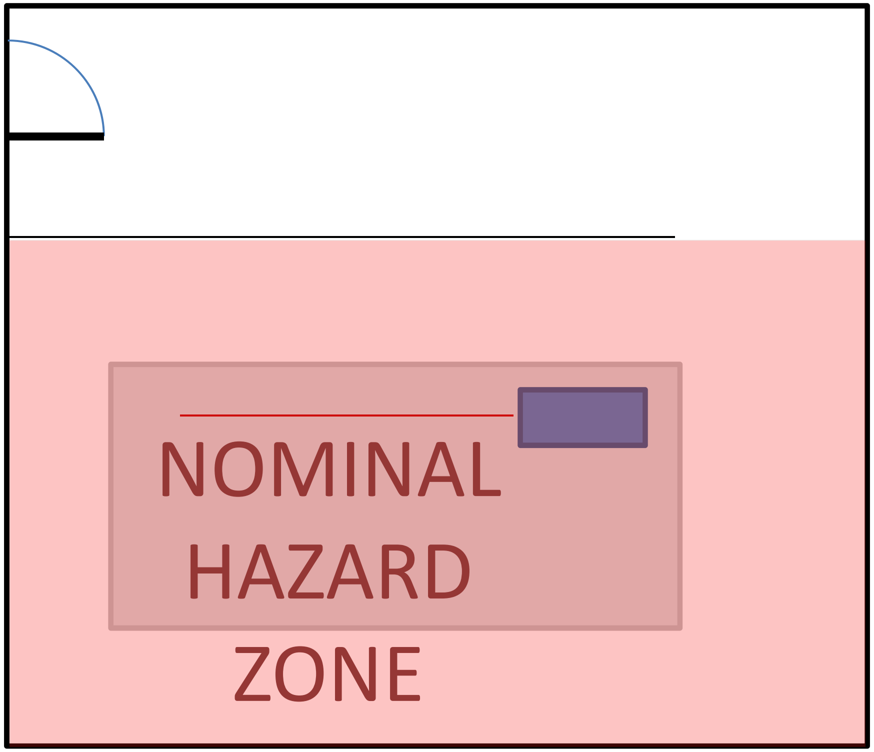

Optical protection: interlocks and warning signs

- Interlocks are automatic mechanism to shut down the laser when the nominal hazard zone is invaded
- Interlocks are often simply shutters – so as not to disturb the lasing action
- Ensure all interlocks are working correctly
- Do not override interlocks
- The best practice for avoiding interlocks is to

Each laser lab needs a sign, which is

- clearly posted outside all lab entrances
- especially if the entire lab is the NHZ
- warning signs must specify the laser type, operation characteristics and class

Optical protection: practical tips for laser operators

- REMOVE jewelry, especially watches and rings
- REMOVE any other reflective surfaces from body
    - (you don't need to be naked though!)

- Avoid using reflective tools in alignment
– **most incidents occur during alignment**

- Monitor every reflections from optics in the setup

- Close eyes when bowing through plane of laser table
 – i.e. picking up a dropped tool

- **Communicate** with other lab operators, when performing high-risk tasks

- No one will think less of you for insisting that laser safety goggles are warn at all times – they will however hold a grudge if you blind them

Summary

- Lasers can be hazardous
- Know the safety guidelines for the equipment you are using
- If you don’t know, don’t guess
- Use common sense, but exercise caution
- **Be safe!**
  - don’t exposure yourself, others or flammable object to the beam
  - wear eye protection
  - make sure sufficient warning/notification is in place
  - mind out for the non-beam hazards too

Q: Do the benefits of unsafe practices outweigh the risks?