Laser Safety

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Topics

- Introduction: Why Light?
- Laser Eye Hazards; Photochemical and Photothermal
- Light and the Eye; Focusing on the Retina
- Time Issues; Is it Energy or Power that Matters?
- Laser Safety Standards and Classification
- Protective Eyeware Example
- Summary; Where to Learn More.

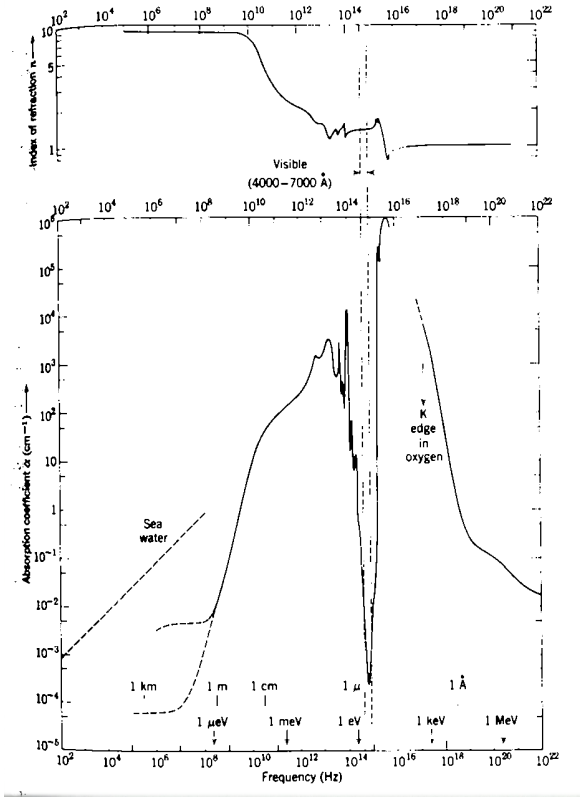
Caveat

This lecture is not to replace mandatory institutional safety training at your institutuion.

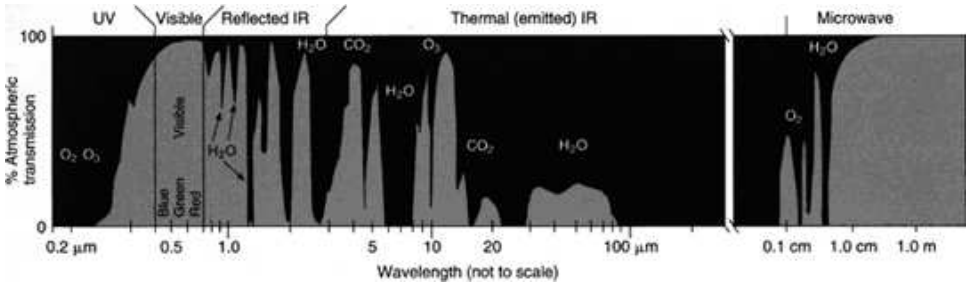
My intent is to provide some insight into the safety issues for engineers and scientists.

It's complicated and what you need to know depends on your role in the research, the lasers you use, and the environment in which you use them.

Why Light?



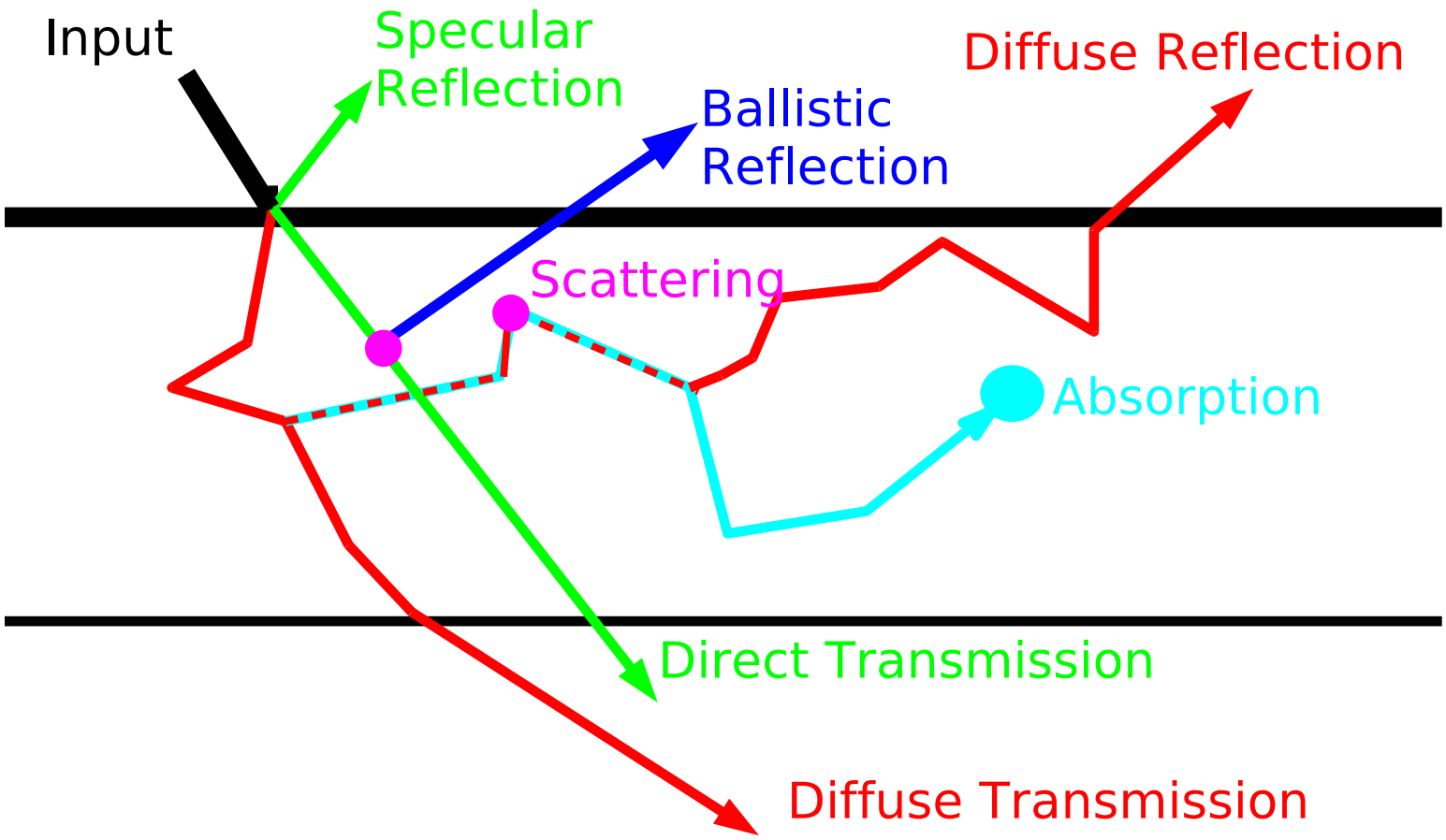
A. Liquid Water



B. Water Vapor

ELECTROMAGNETIC TRANSMISSION. Water strongly absorbs most electromagnetic waves, with the exception of wavelengths near the visible spectrum (A, From Jackson *Classical Electrodynamics*, ©1975). The atmosphere also absorbs most wavelengths, except for very long wavelengths and a few transmission bands (B, NASA's Earth Observatory).

Light Interactions

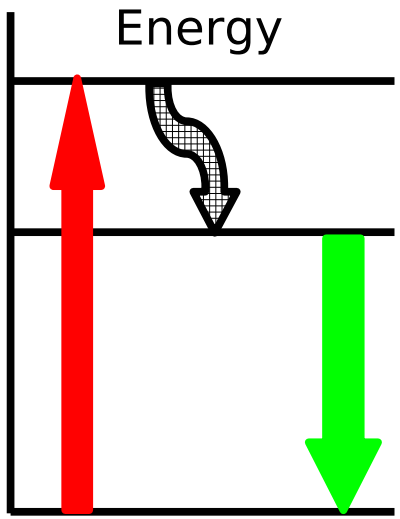


(and of course, emission)

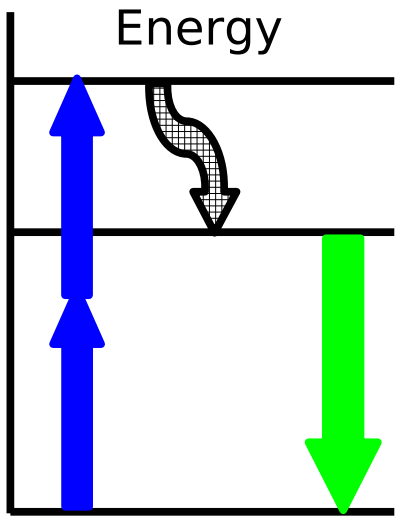
Energy Levels and Transitions

Absorption, ↑ Stimulated Emission, ↓ Spontaneous Emission ↓ nanoseconds?

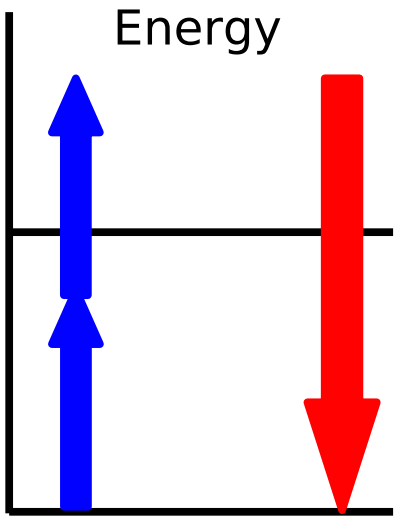
Fluorescence, Harmonic Generation, Mixing, and more



Fluorescence



2–Photon Fluorescence



Second Harmonic

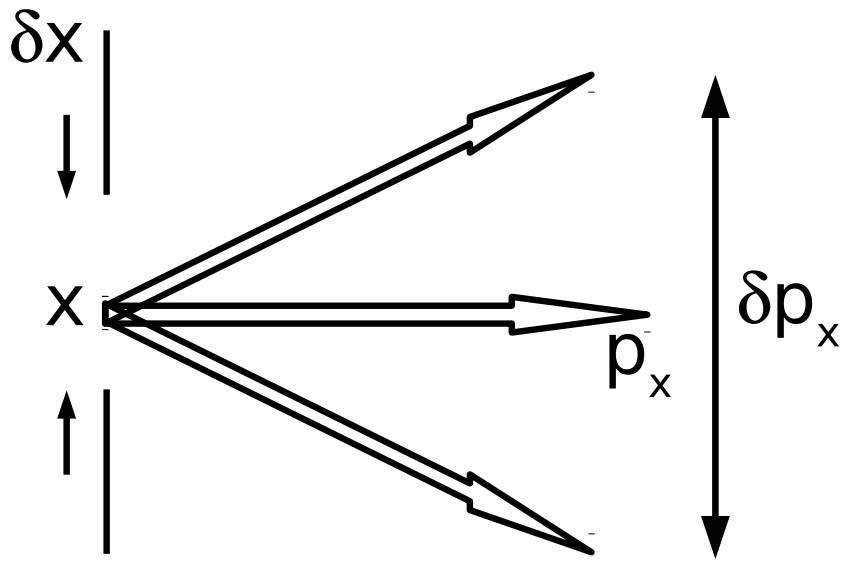
Safety Issues

- Photochemical Issues
  - Primarily at Short Wavelengths (High Photon Energy)

$$Energy = h\nu = \frac{hc}{\lambda}$$

- Photothermal
  - All Wavelengths
- Mitigating Effects
  - Beam Divergence
  - Scattering
  - Thermal Diffusion

What's Special About Lasers?



- Uncertainty Principle

$$\delta x \delta p_x \geq h$$

$$\delta u \geq \frac{\lambda}{D} \qquad u = \sin\theta$$

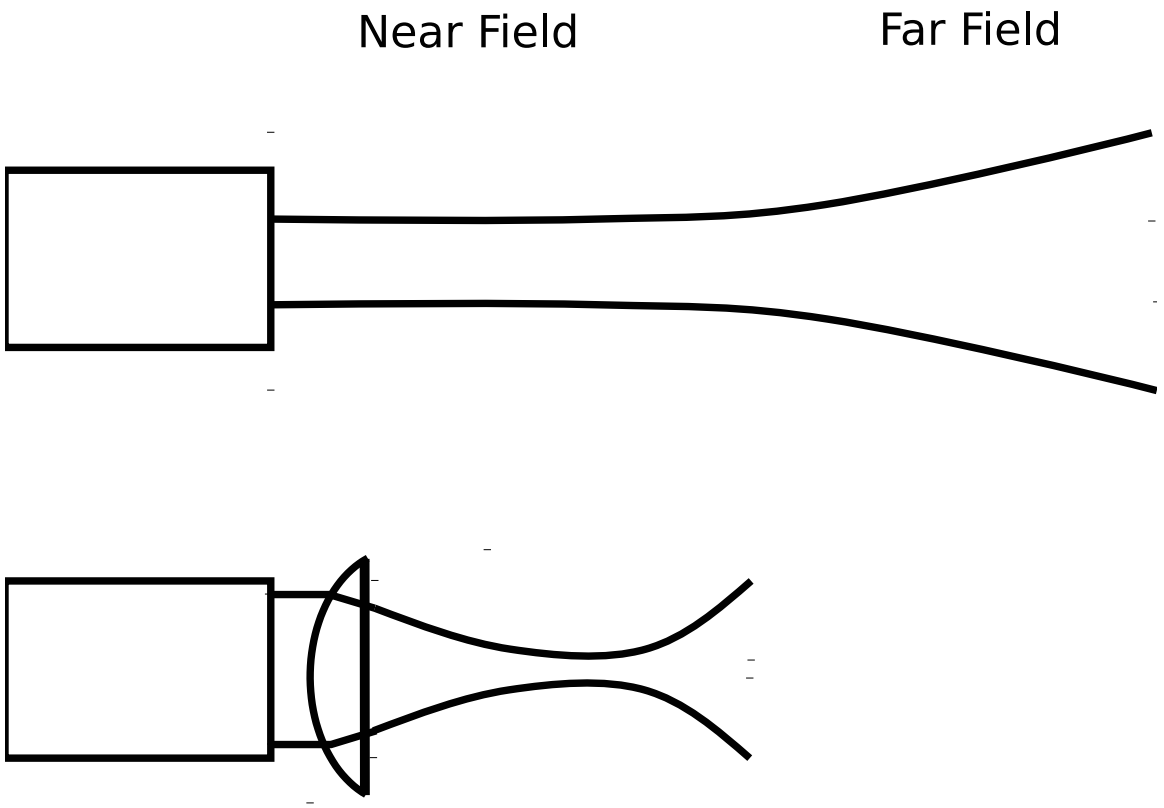
- "Most Light Sources"

$$\sin\theta \gg \frac{\lambda}{D}$$

- Lasers (Gaussian Beam)

$$\sin\theta = \frac{\lambda}{D}$$

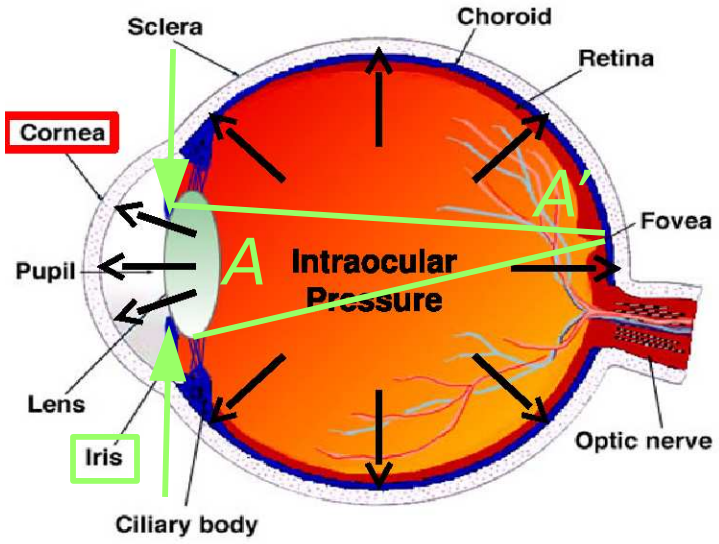
Beam Divergence and Focusing

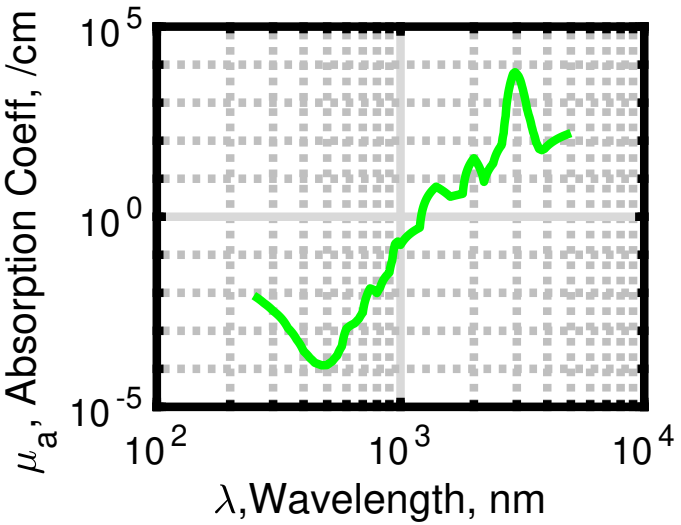


Minimum Spot Size: $\frac{\lambda}{D}z$

A Laser can put a large amount of power or energy onto a very small spot.

The Eye





- Iris Size

$$D_{max} = 2 \text{ to } 8\text{mm}$$

$$A = \frac{\pi D^2}{4}$$

- Spot on Retina

$$z \approx 25\text{mm}$$

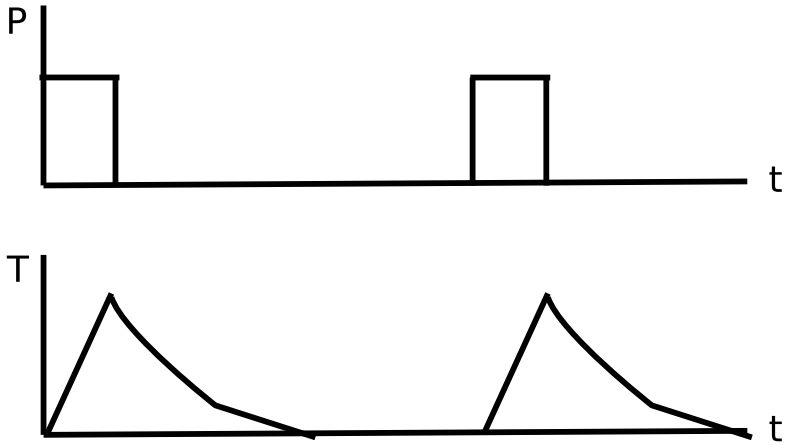
$$d = \text{few } \mu\text{m}$$

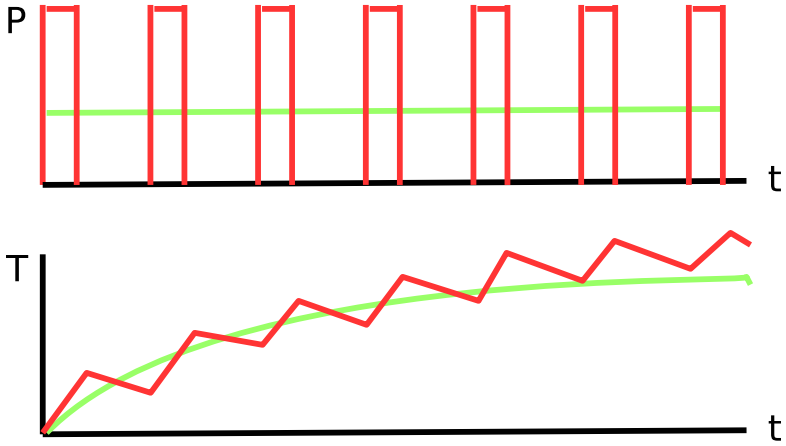
- Hazard:
  - Power/Area increases by ≈ 5 Orders of Magnitude
- The IR Safety Advantage (over 1400nm)

Time Issues

- Short Time
  - Pulsed Lasers (Single Pulse)
  - No Thermal Diffusion
  - Fluence Most Important (Energy/Area)

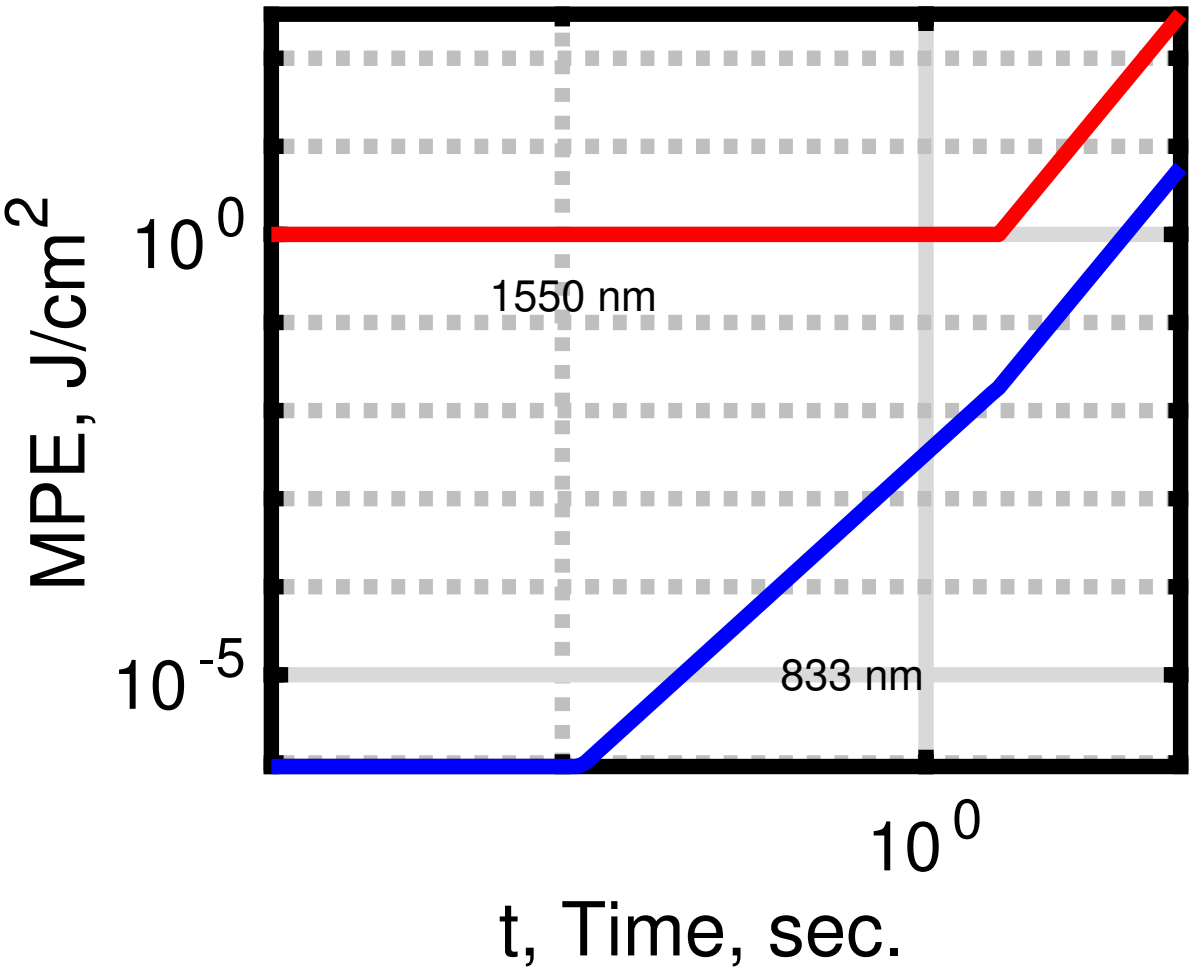
- Long Time
  - Continuous Wave or Repeated Pulses
  - Thermal Diffusion to Equilibrium
  - Irradiance Most Important (Power/Area)





Maximum Permissable Exposure

$\lambda = [0.833, 1.550]\mu$m [Blue, Red]



The Rules

- ANSI Standard Z–136
  - Well–Researched and Comprehensive
  - Many Nearly Identical Standards
- Your Lab Laser Safety Officer
- Your Institutional Occupational Safety Office
  - Training and Registration of Workers
  - Registration of Some Lasers
  - Requirements for Safety
  - Periodic Inspections
  - Much More
- State and Other Laws (*e.g.* Registration)

Classification

Class	Simplified Description	Variations
1	Normally not Hazardous	1, 1M
2	Aversion Response is Protective (Visible Light Only)	2,2M
3	Potential Direct–Beam Eye Hazard	3R,3B,(3A)
4	Diffuse–Light Hazard, Fire Hazard, Air Contamination, Plasma	

Different controls measures are required for different classes.

Protective Eyeware

- Reduce the Beam Power to Class 1.

- Consider the Optical Density, $T = 10^{-OD}$

Example: $\lambda = 640$nm
$P = 100\mu$W, Class 1 Upper Limit from Z–136
My Laser: $P = 100$mW, Class 3b
Protective Eyeware: $OD > 3$ at 640nm
But be sure to check the OD at this wavelength

Use more than you need but maybe not too much more; you may want to be able to see the beam if you are doing alignment.

It's Complicated

- Example
  - Outdoor Laser Use
  - Scanning, Repeated–Pulse Laser
  - Nominal Hazard Zone, Barriers, Signs, Interlocks, *etc.*
  - Protection from Scan Failures, *etc.*
- Non–Beam Hazards
  - Electrical
  - Chemical
  - Many More

But There's Help

- Ask the Laser Operator
- Ask the Lab Laser Safety Officer
- Ask your Institutional Occupational Safety Office
- Study ANSI Z–136
- Comply with All Training and Registration Requirements

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