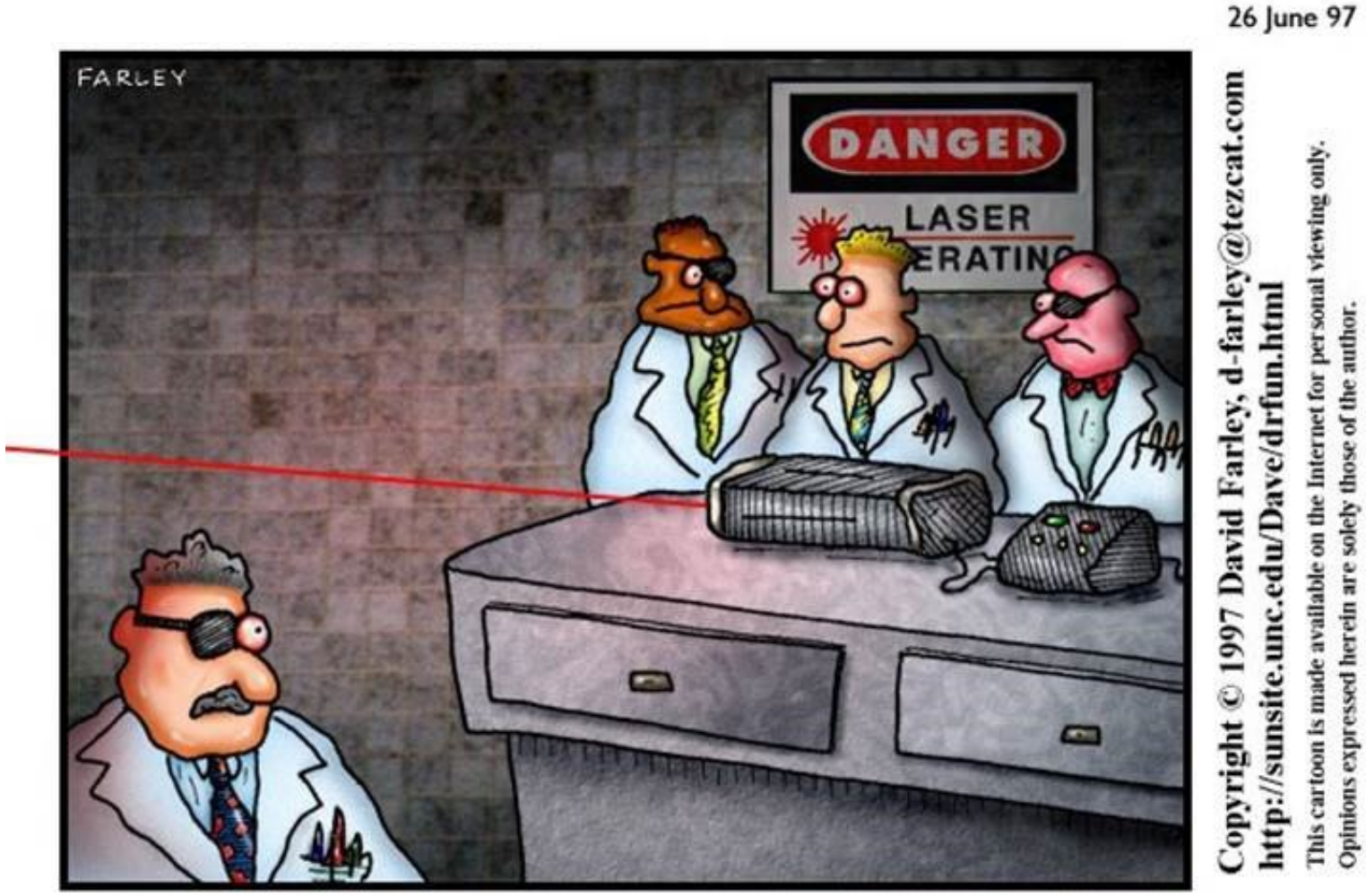
The Basics of Laser Safety in the Workplace

PSES

Product Safety Engineering Society

Talk about pressure!



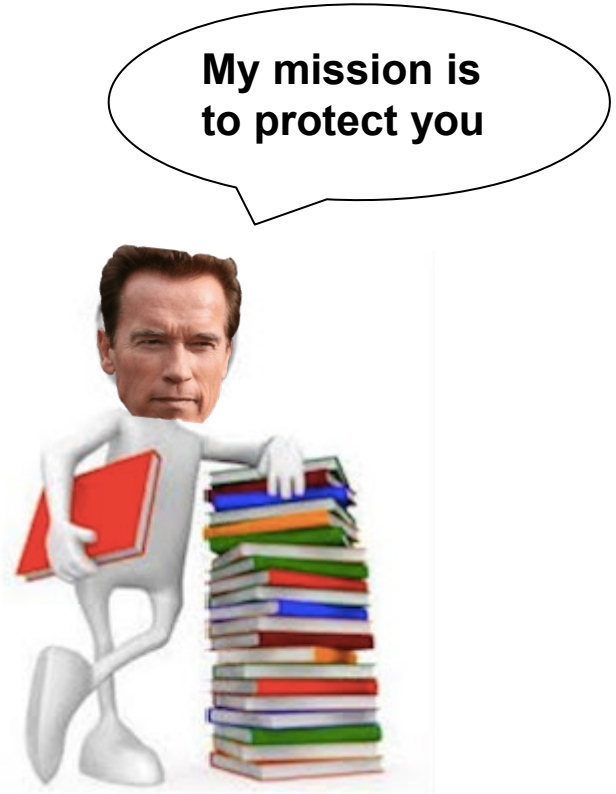
Peer pressure in the laser lab

The Mission:

Agenda

- Basic Laser concepts & definitions
- Laser Bio effects and Hazards
- Laser Classifications & Standards
- Laser Safety Control Measures
- Laser Safety program

- Not included (possible future talk)
  - Laser hazard analysis & calculations



L.A.S.E.R acronym

The correct scientific acronym:

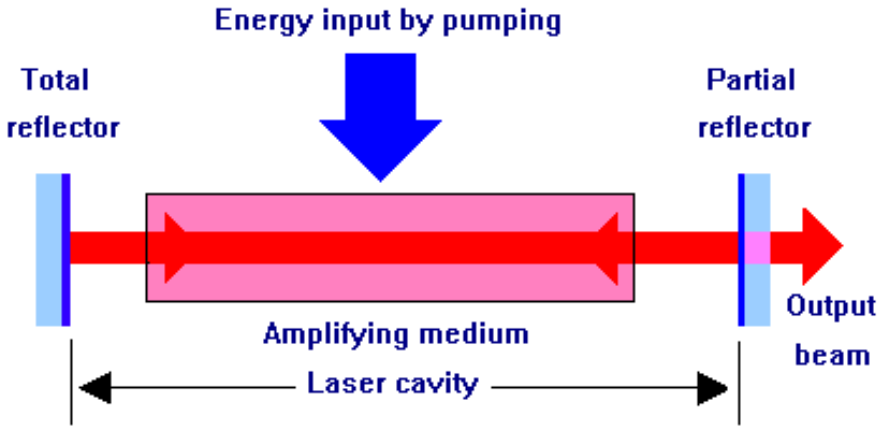
- L Light
- O Oscillation by
- S Stimulated
- E Emission of
- R Radiation

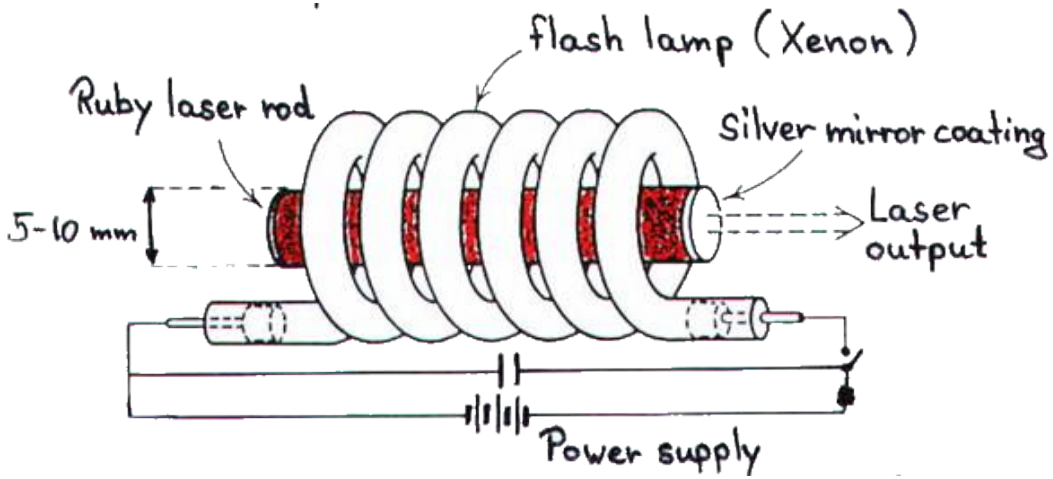
The more publicly accepted acronym:

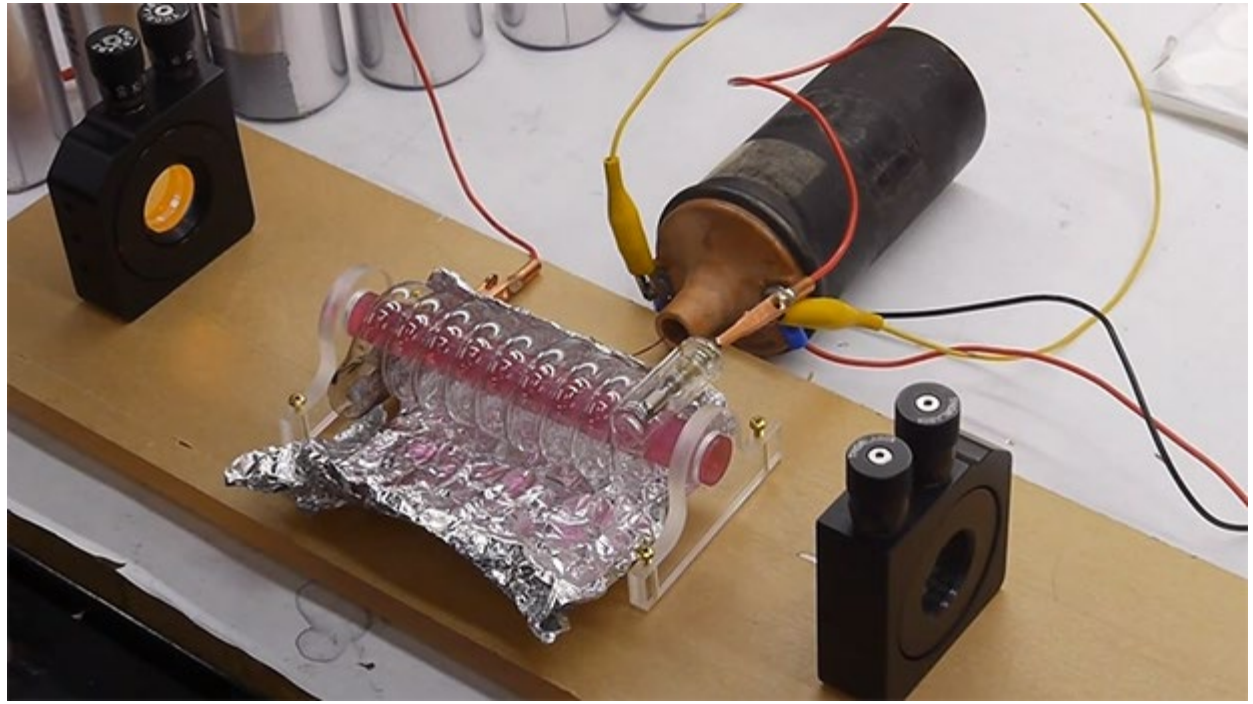
- L Light
- A Amplification by
- S Stimulated
- E Emission of
- R Radiation

In 1918, Einstein developed a general theory of the process by which atoms emit and absorb electromagnetic radiation, which is the basis of lasers (stimulated emission) and shaped the development of modern quantum electrodynamics, the best-validated physical theory at present.

Basic Laser Concepts







Type of Lasers – for example…..

Solid-State Lasers

Nd:YAG, Ruby, Fiber

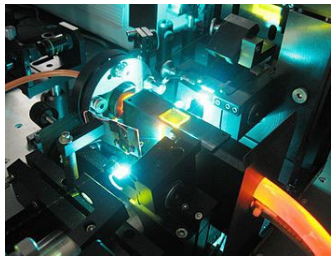
Applications: Spectroscopy, photocoagulation

Semiconductor (Diode) Lasers

GaAs, GaAlAs, InGaAsP, GaN

Applications: CD ROM, laser pointers, etc.

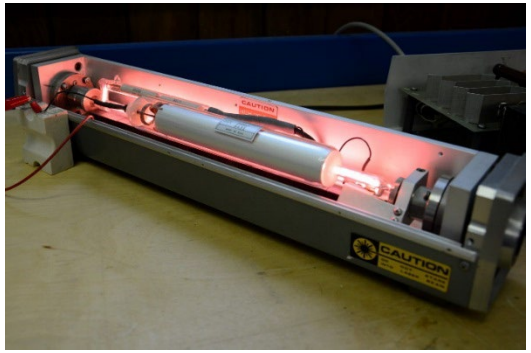
Liquid (Dye) Lasers



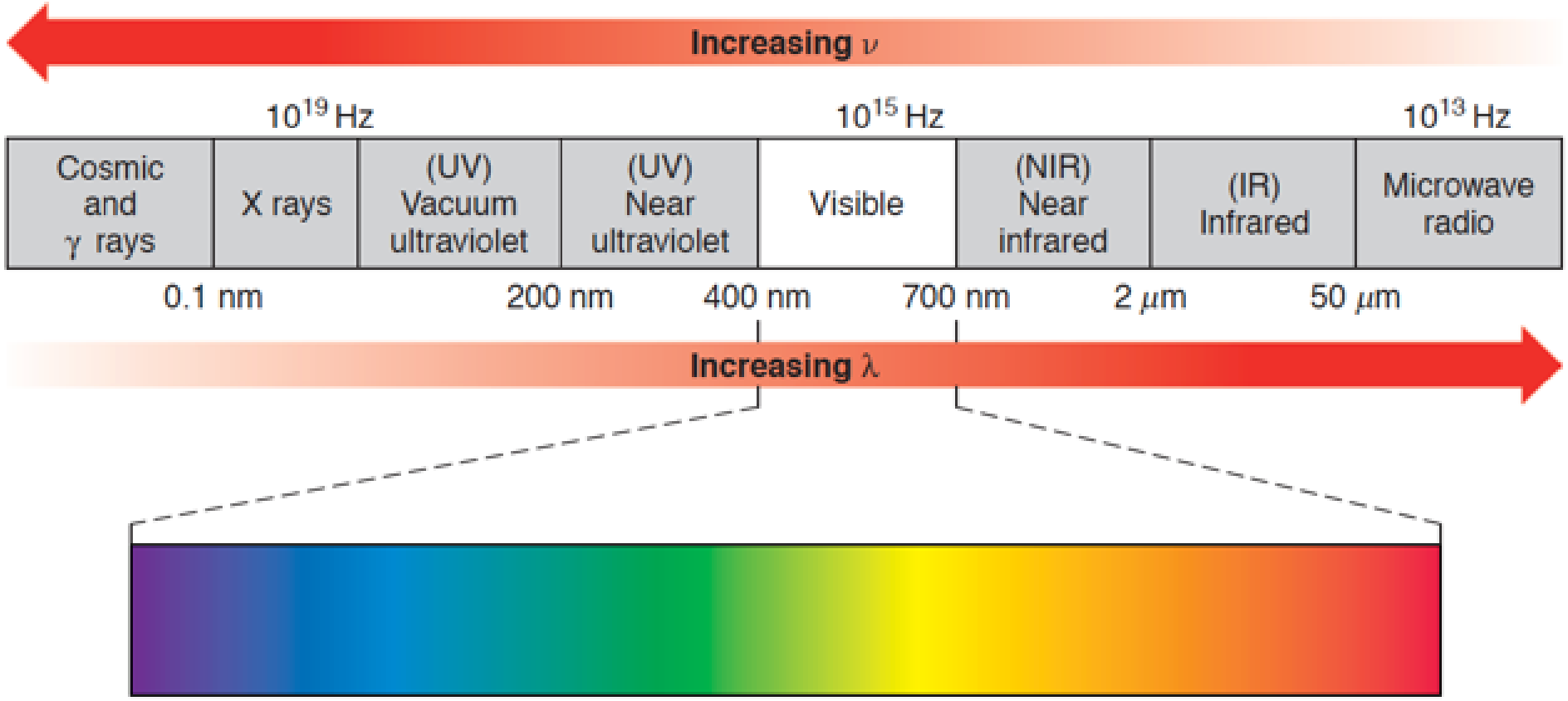
Gas Lasers

(CO2, Argon, Krypton, Excimer, HeNe)

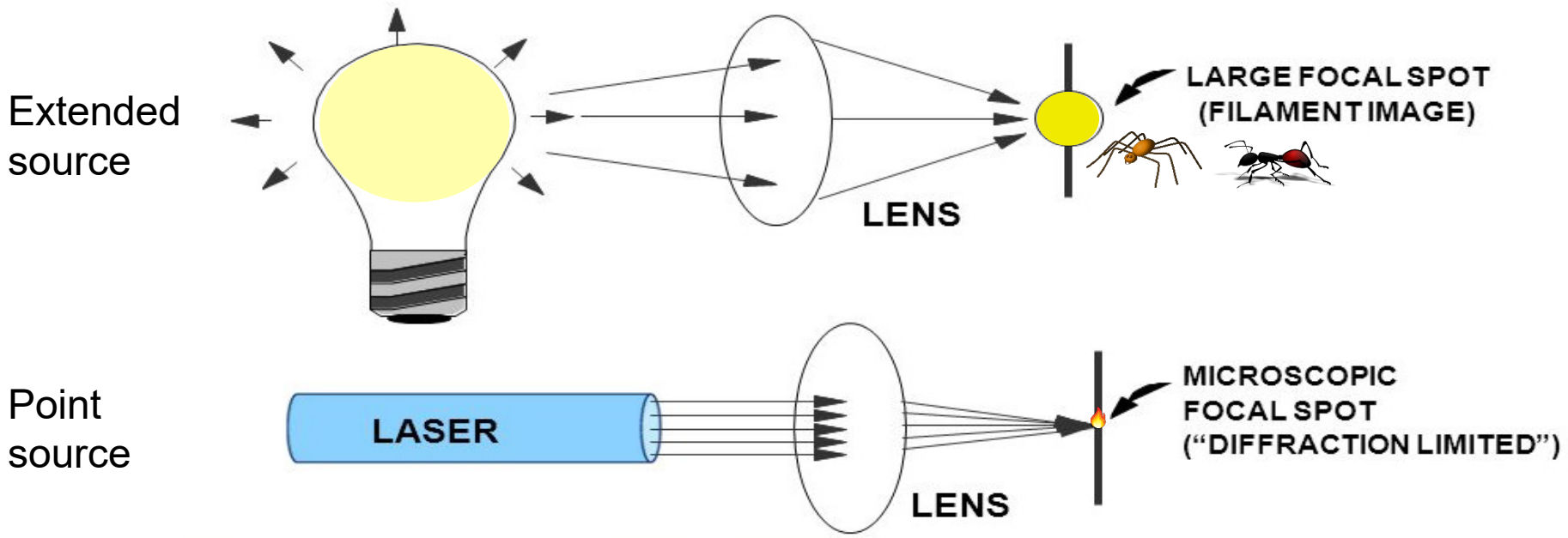
Applications: Welding, marking, cutting, drilling

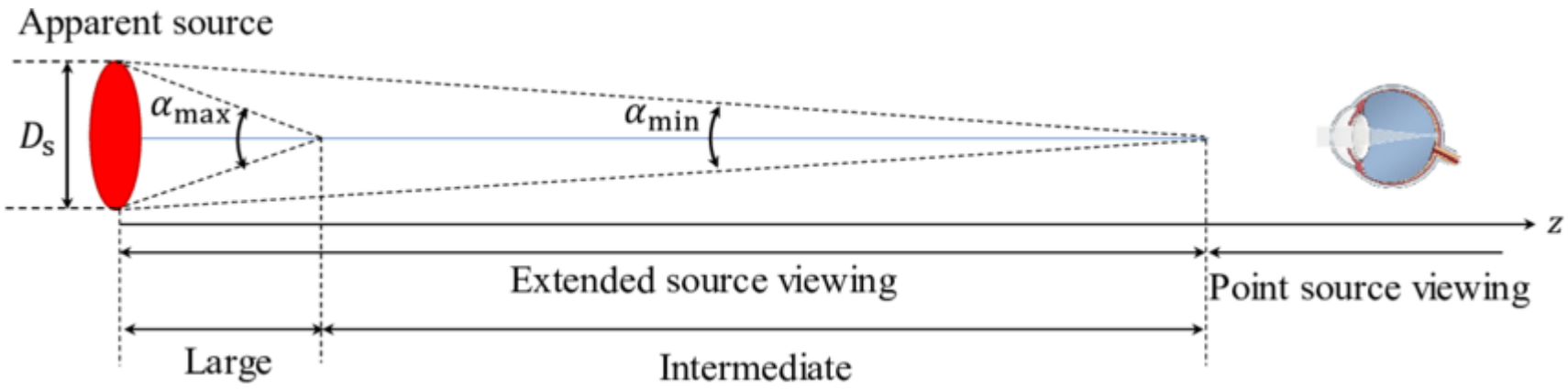


White light, UV & IR frequencies in the Laser spectrum

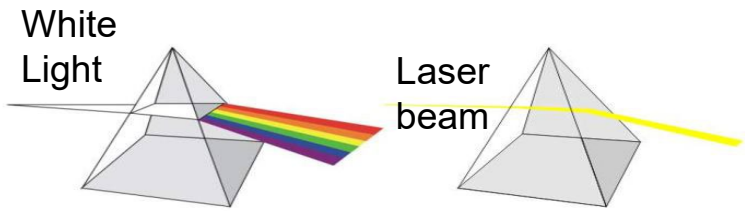


Laser Brightness (Radiance)





Characteristics of Laser Light

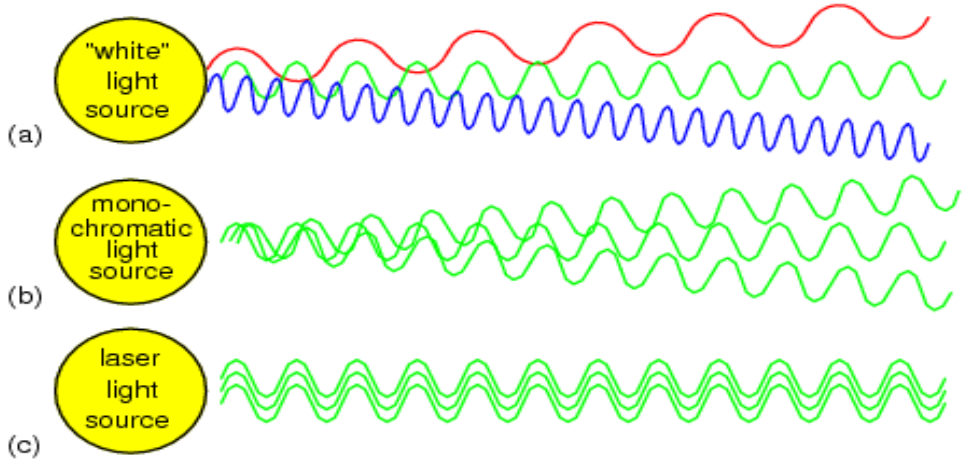


Monochromatic

- all light is one wavelength or color

Directional

- Laser beam does not expand ***"as quickly"*** as other light



Coherent

- all waves of light are generated in phase with each other
- The wave crests and troughs are "locked" together

Disecting the laser beam

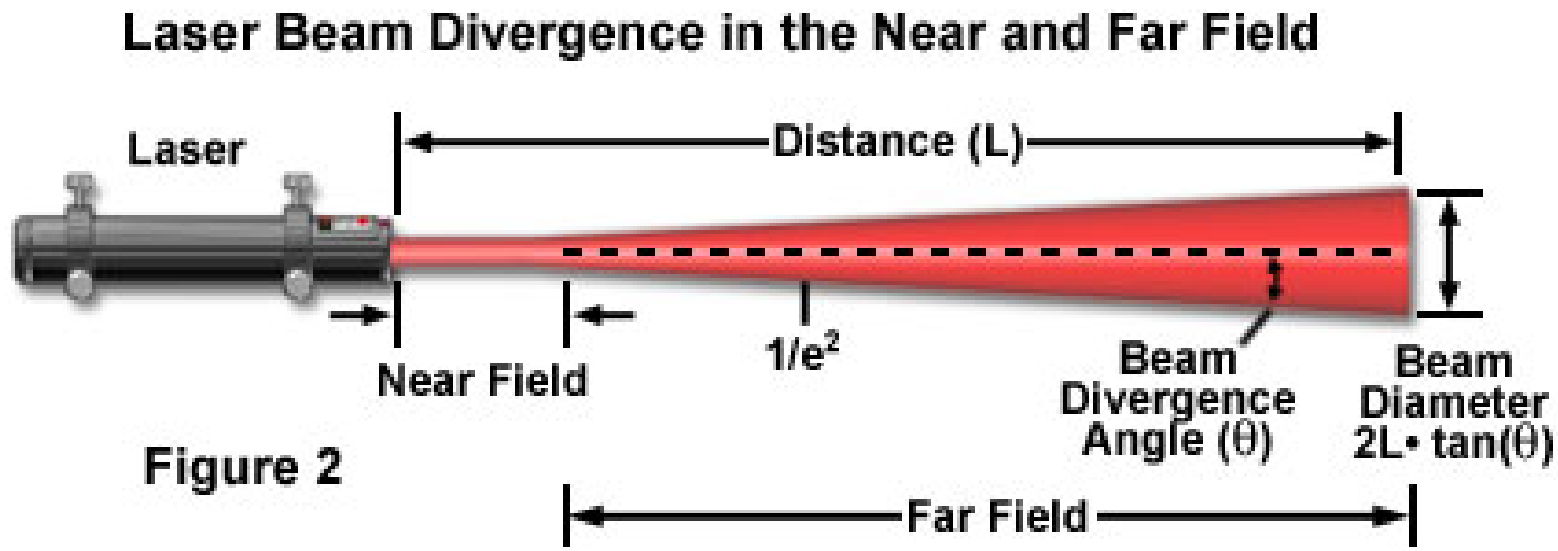
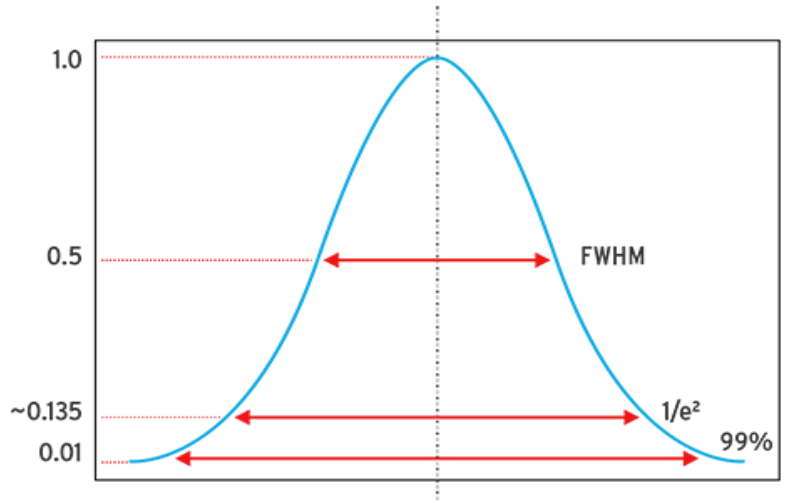


Figure 2

Gaussian Distribution



FWHM = Full width, Half max

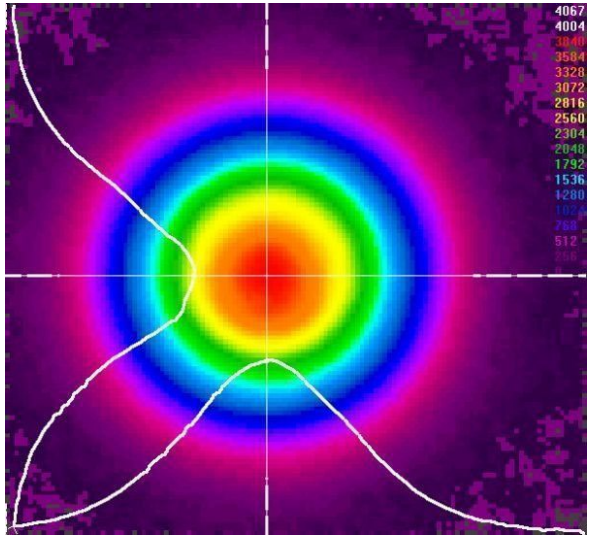
86% of the laser power is contained within the $1/e^2$ width

beam diameter at

$$\frac{1}{e^2} = 2 \times FWHM \times 0.849$$

beam diameter at

$$\frac{1}{e^2} = 99\%/1.5$$



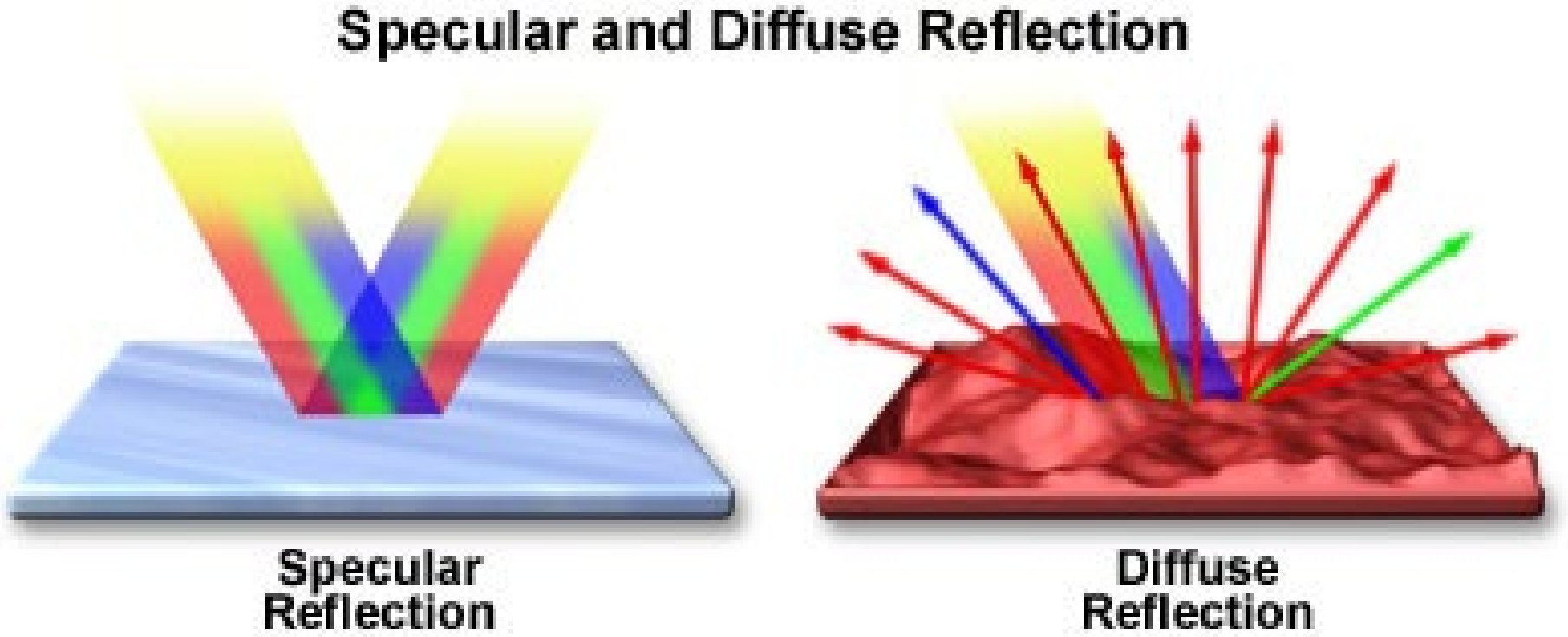
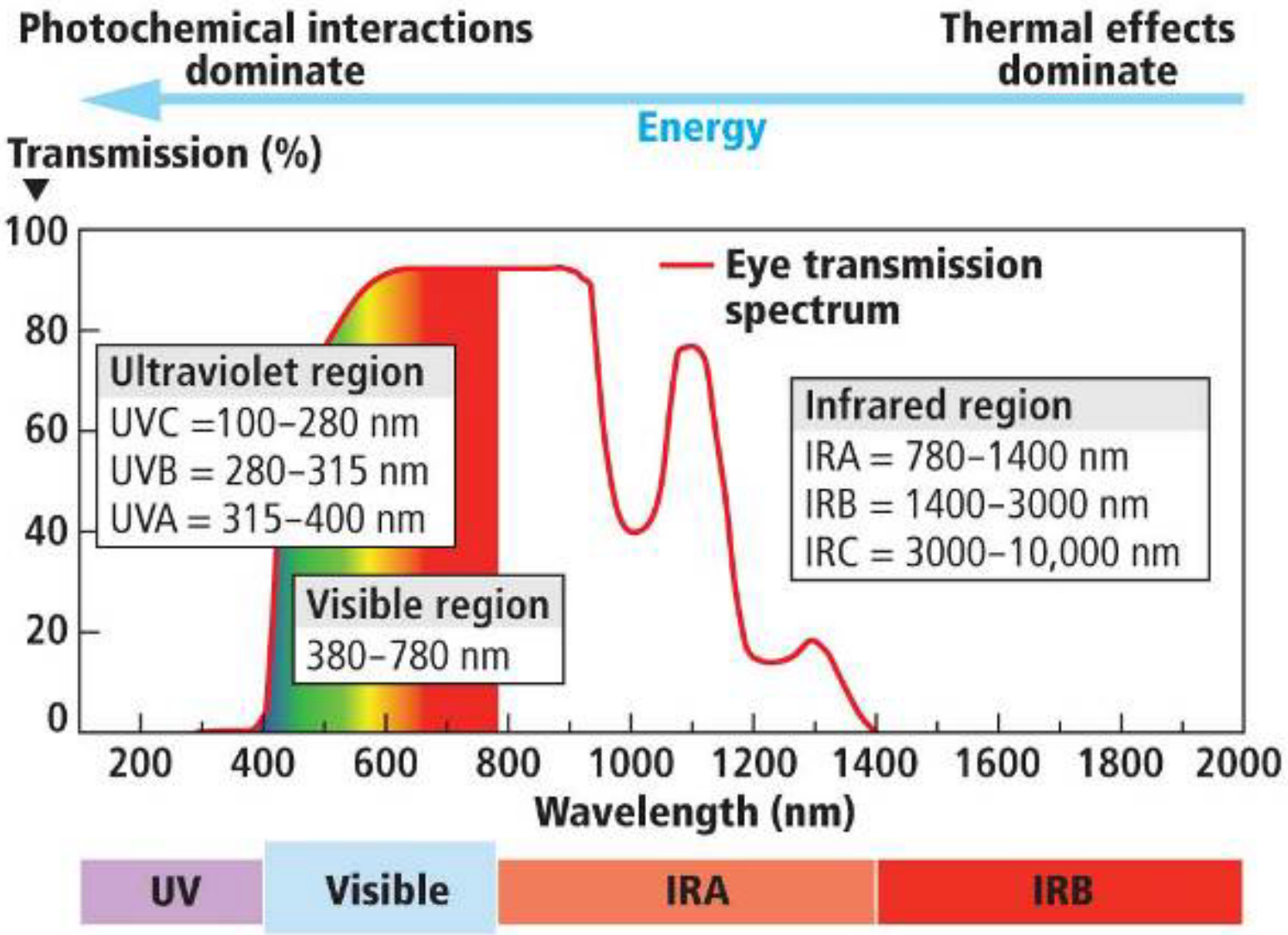
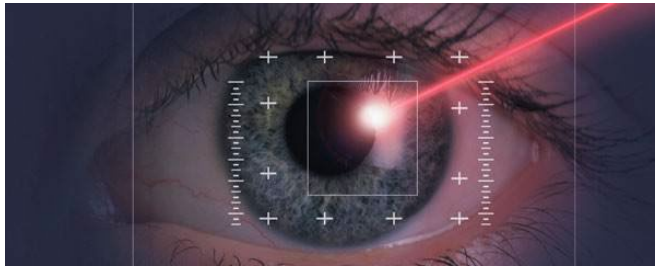

Specular and Diffuse Reflection
Specular Reflection
Diffuse Reflection

Figure 1

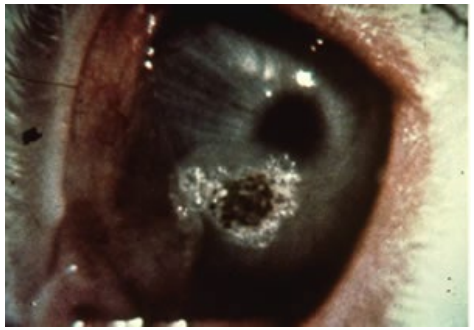
CIE PHOTOBIOLOGICAL SPECTRAL BANDS



** CIE – Commission Internationale de l'Eclairage or International Commission on Illumination*

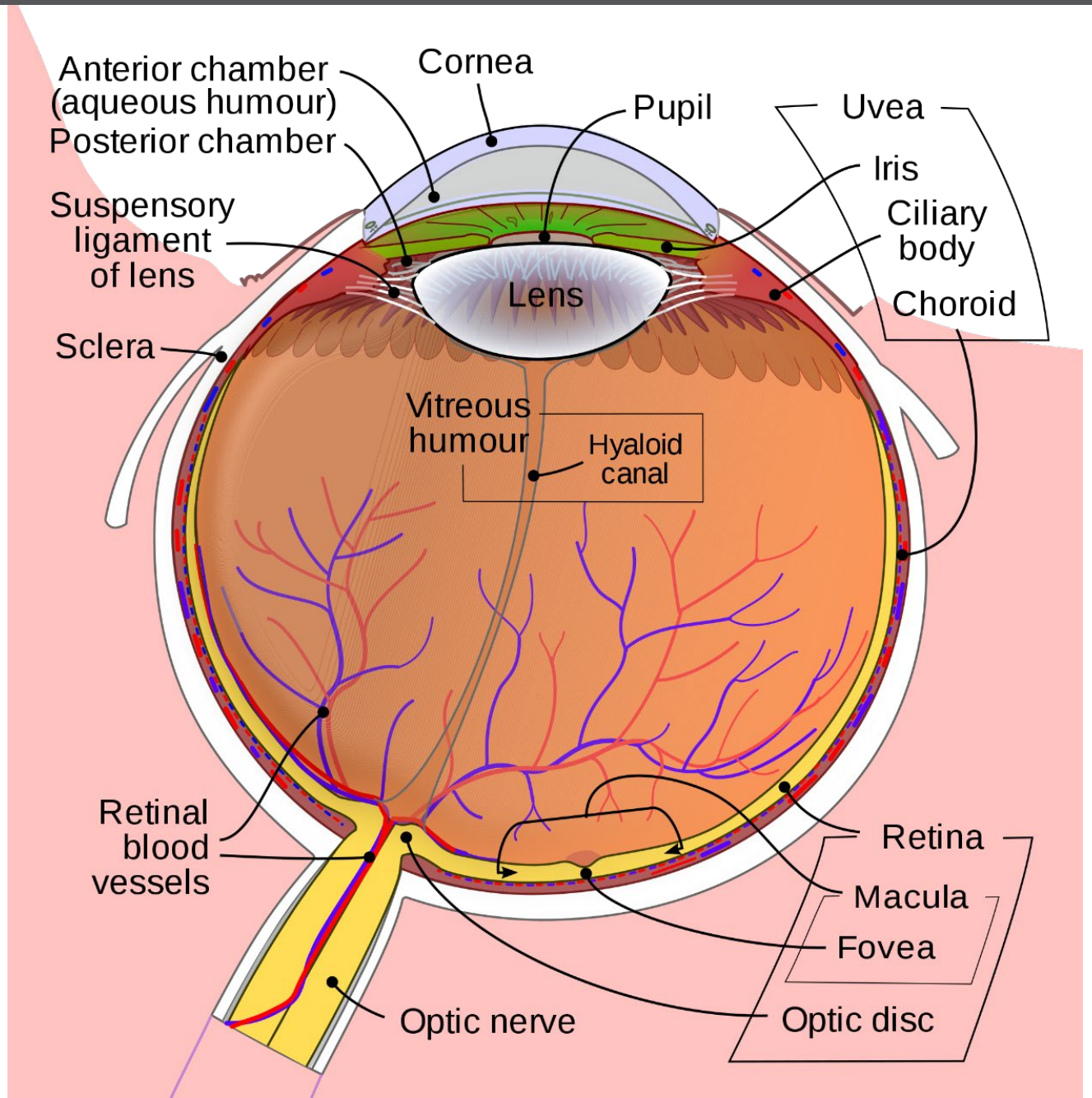


Laser Bioeffects and Hazards



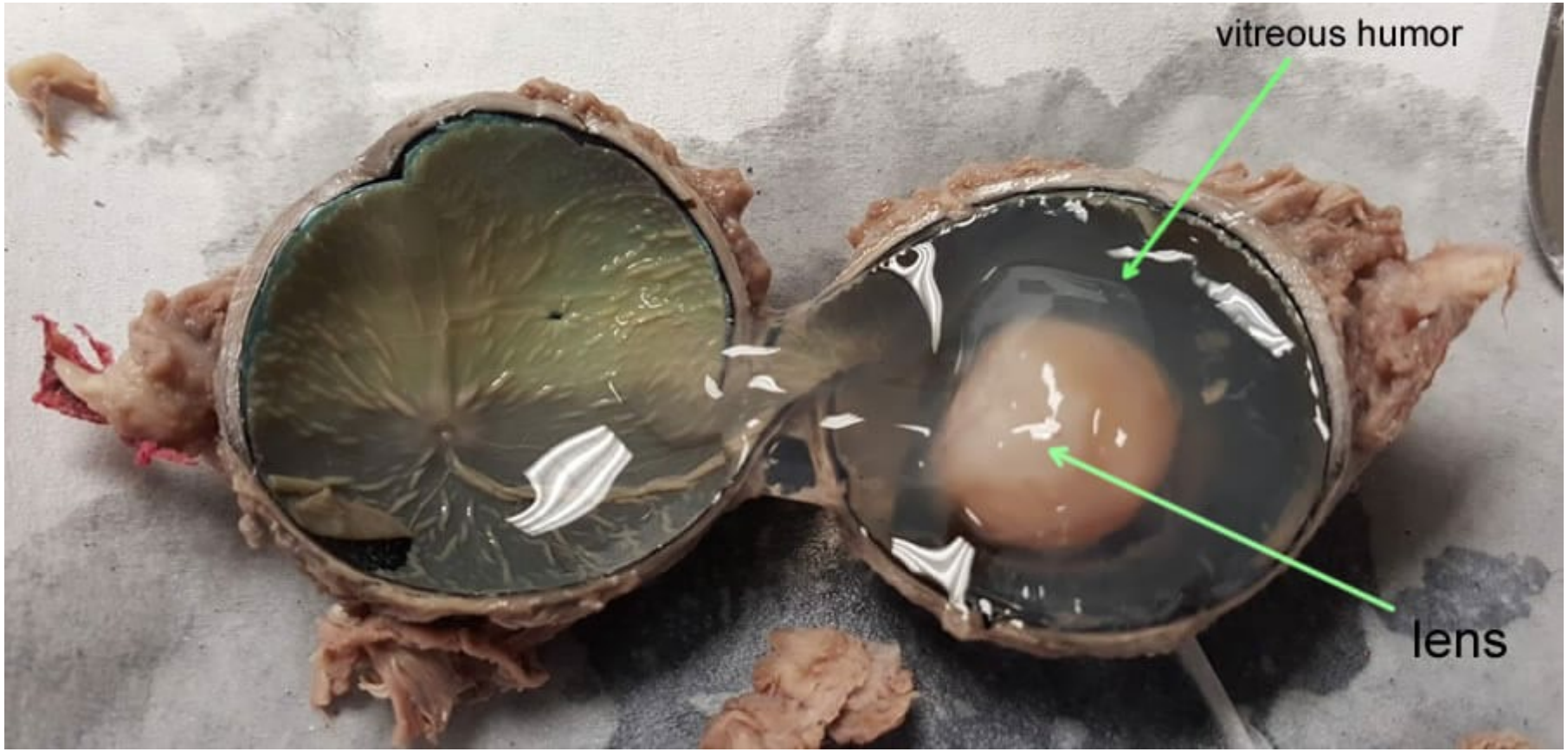
Scientific term for ‘Gross me out’

The Human eye

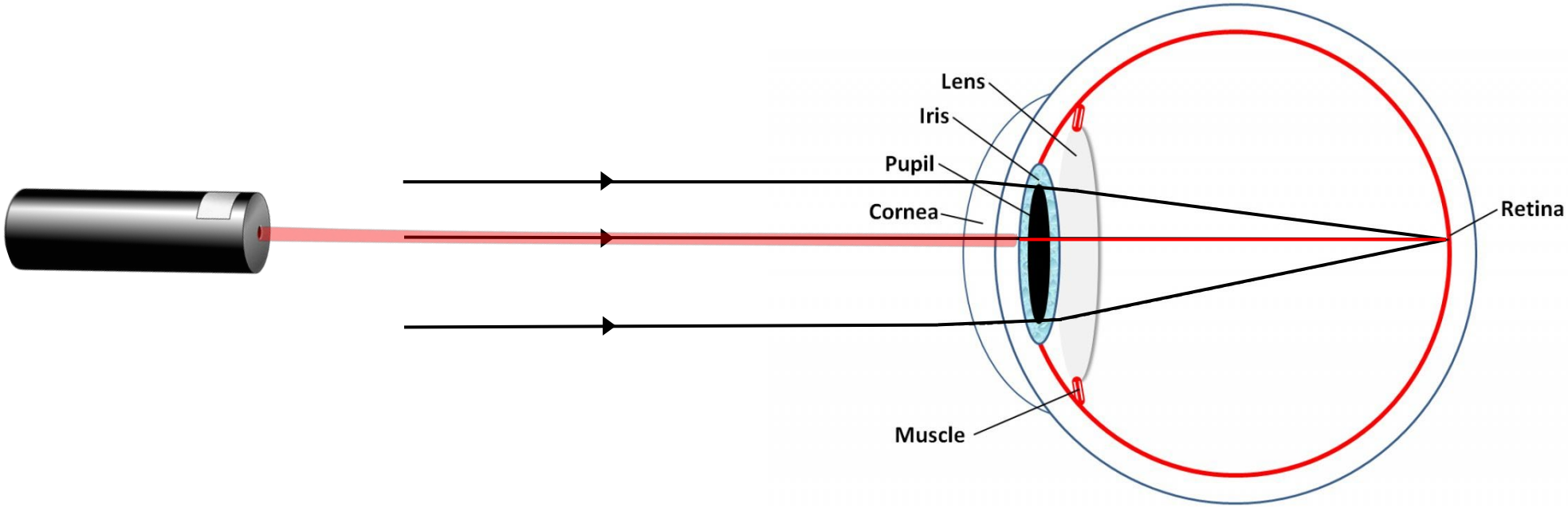


The Lens & Cornea

Vitreous humor



Optical Concentration by the Eye



- Wavelength that focus on retina (400 – 1400 nm), optical concentration is **100,000 X !**
- If irradiance entering is 1 mW/cm2, at retina will be 100 W/cm2

Spectral Absorption Properties of the Human Eye

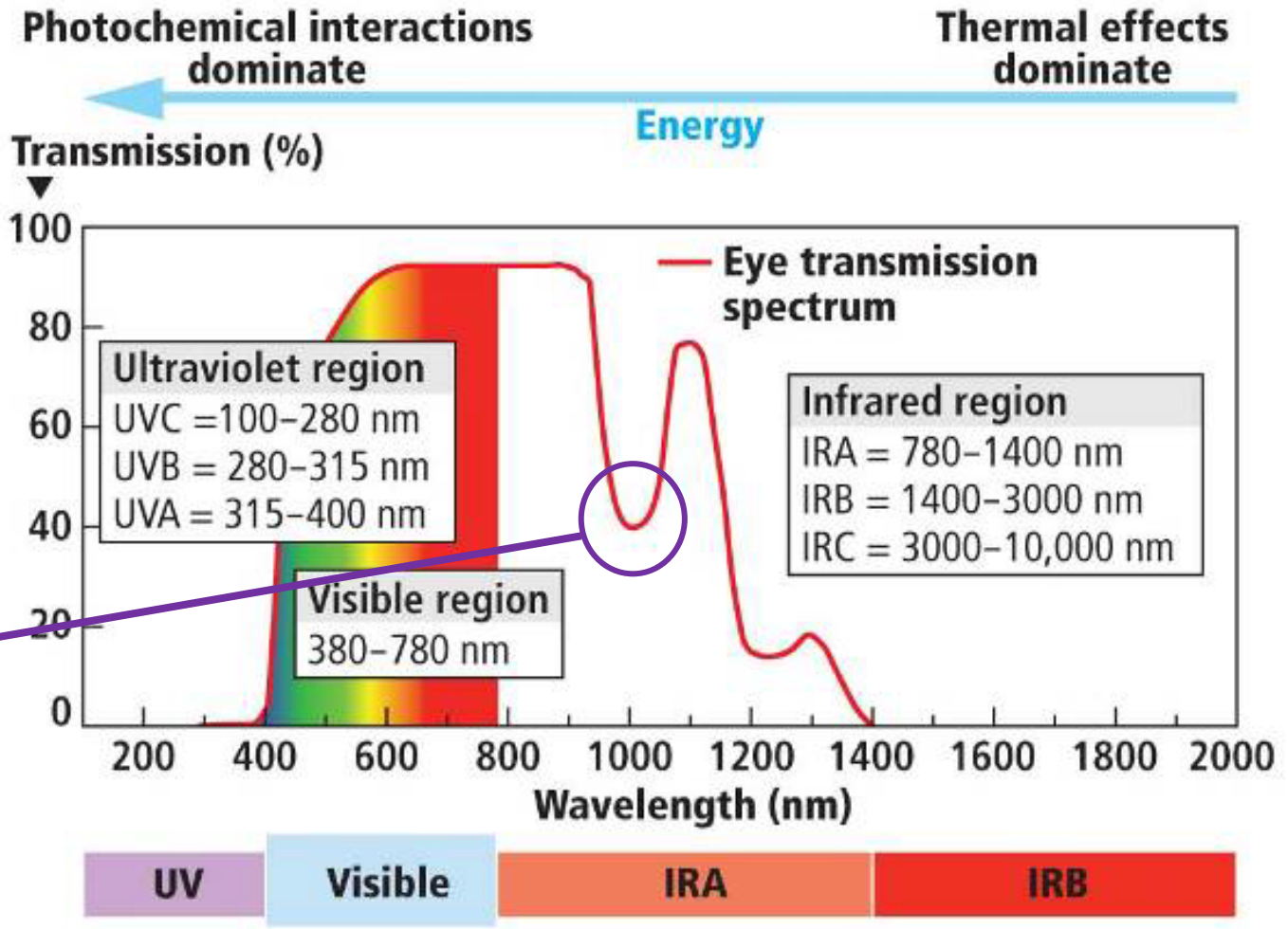
Cornea principally absorbs:
UV-C, UV-B, IR-B, IR-C

Lens principally absorbs:
UV-A

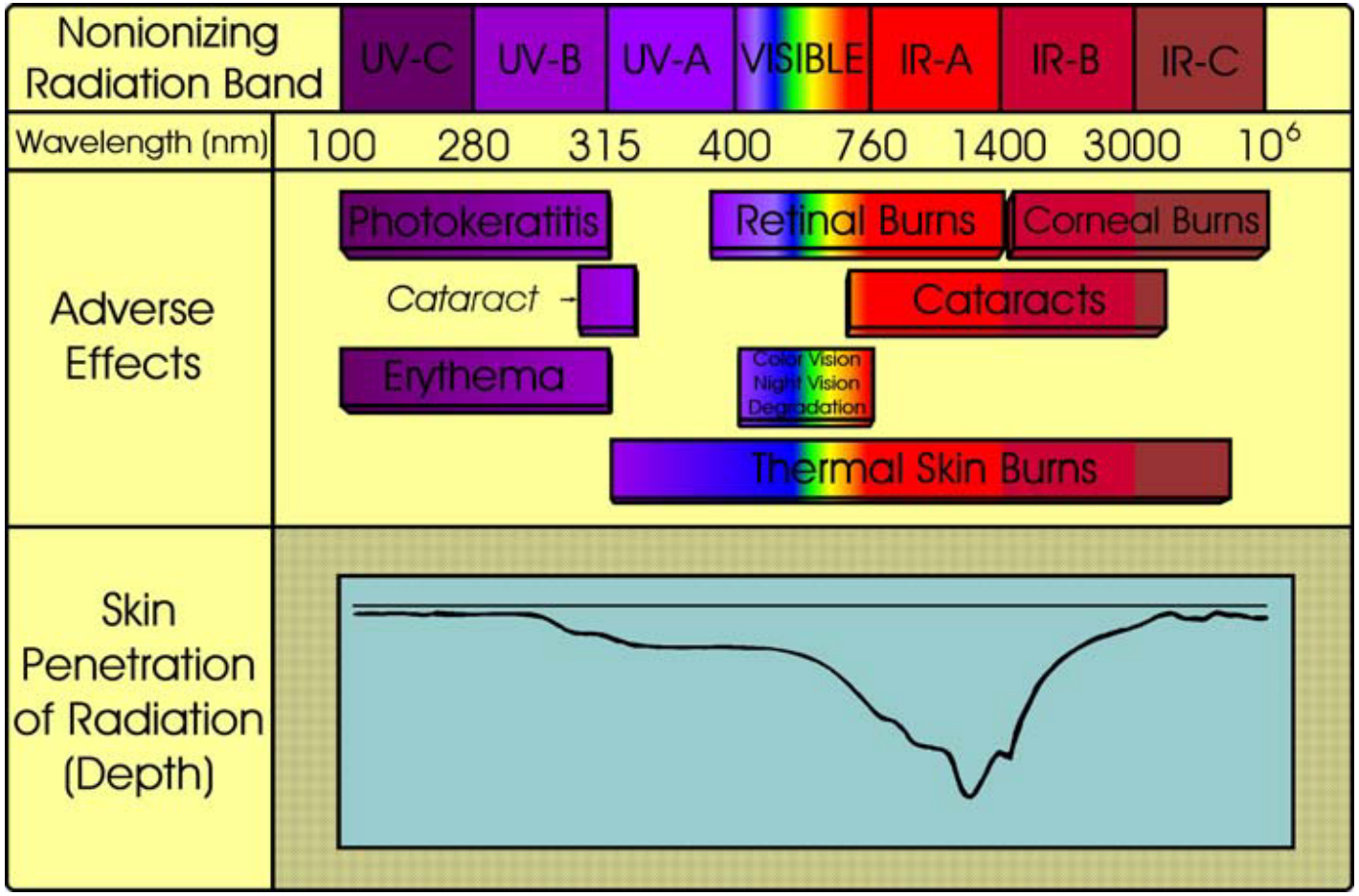
Retina principally absorbs:
Visible and IR-A

Paper

The absorption in that part of the spectrum is mainly driven by the vitreous humor - and to a lesser extent the aqueous humor - and is attributed to the absorption of light by water in the eye at 980nm and 1200nm.



Spectrum band and skin penetration



Photochemical versus Thermal Effects on the Eye

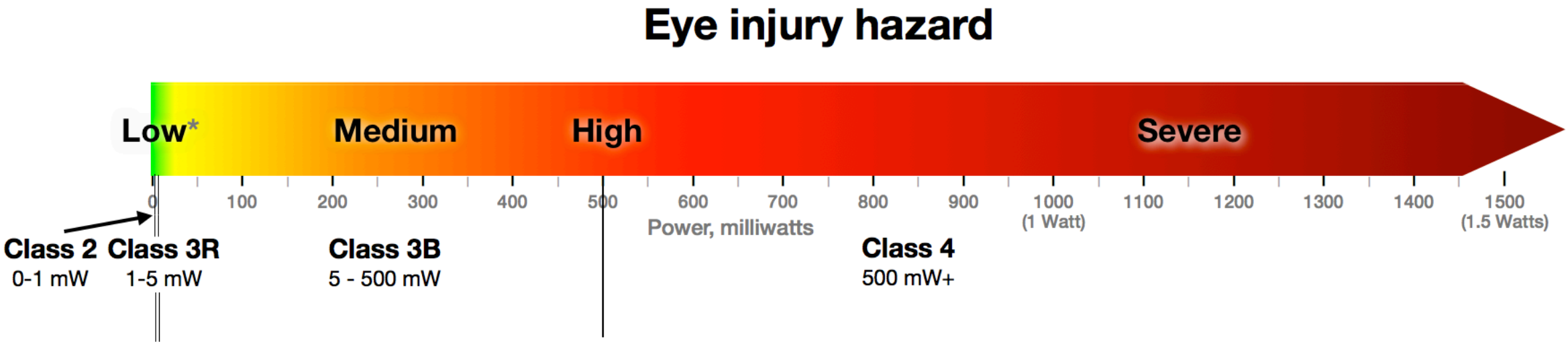
Photochemical

- Reciprocity: Irradiance vs Time
- Action spectrum: narrow, limited wavelength region
- Individual photon interacts with molecule

Thermal

- Rate-process
- Heat dissipation with time
- Not limited by photon energy

Eye Injury Hazard



*Eye injury hazard descriptions above are valid for for exposures relatively close to the laser. Because the beam spreads, less light will enter the pupil at greater distances. The hazard decreases the farther a person is from the laser, and the shorter the exposure time (e.g., do not deliberately look or stare into the beam). For example, a 1mW Class 2 laser beam is eye safe for unintentional exposures after about 2 ft (7 m), a 5mW Class 3R beam is eye safe after about 52 ft (16 m), a 500 mW Class 3B beam is eye safe after about 520 ft (160 m), and a 1500 mW Class 4 beam is eye safe after about 900 ft (275 m).

(Calculations are for visible light, a 1 milliradian beam, and a 1/4 second Maximum Permissible Exposure limit.)

Laser Incidents and benefits

Most notable injuries

- Holes through fingers
- 3rd degree burns

In general, non-debilitating

- Although scars can have an impact…..

Permanent injury

- Hearing loss
- Peripheral nervous system damage
  - Back of hand

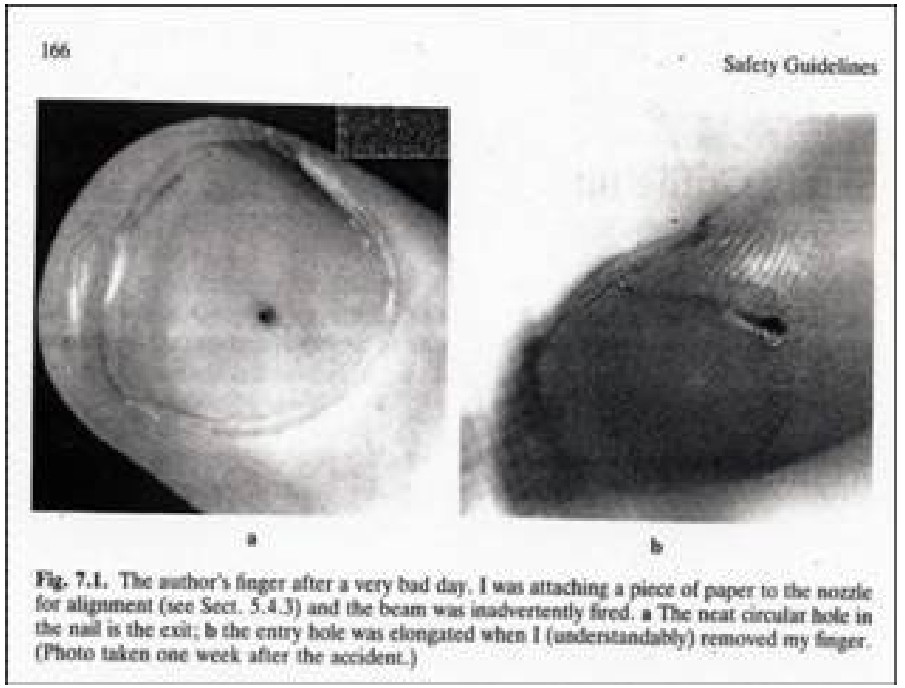


Fig. 7.1. The author's finger after a very bad day. I was attaching a piece of paper to the nozzle for alignment (see Sect. 5.4.3) and the beam was inadvertently fired. a The neat circular hole in the nail is the exit; b the entry hole was elongated when I (understandably) removed my finger. (Photo taken one week after the accident.)

Laser Incidents: Fire

Figure 2. Demonstration of rocket-like flames shooting from a tracheal tube caused by laser ignition of the tube with 100% oxygen flowing. Image provided courtesy of ECRI Institute.

Laser Classifications & Standards

ANSI Z136.1 and IEC 60825-1 standards

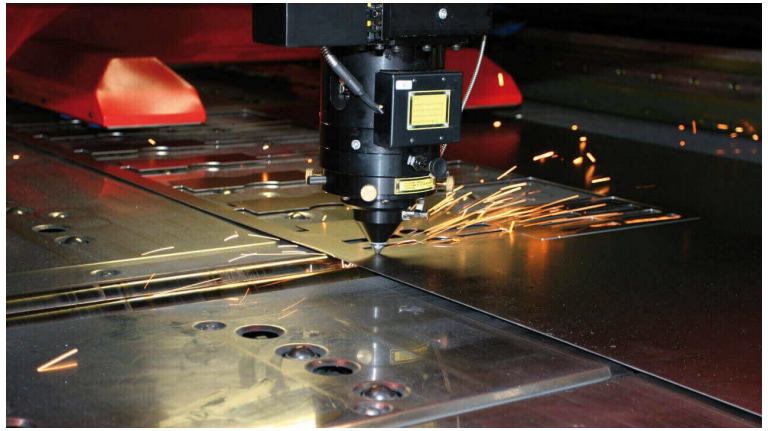
MPE & AEL

MPE: Maximum **P**ermissible **E**xposure

is the maximum radiation level one can be exposed to before undergoing immediate or long term injuries. They were obtained by extrapolating to mankind the experimental M.P.E. measured on animals. (i.e. rabbits)

- applies to laser product user standards
- used to determine **N**ominal **O**cular **H**azard **D**istance (NOHD) and **O**ptical **D**ensity (OD)….*more on this in Part 2.*

AEL: Accessible **E**mission **L**imit

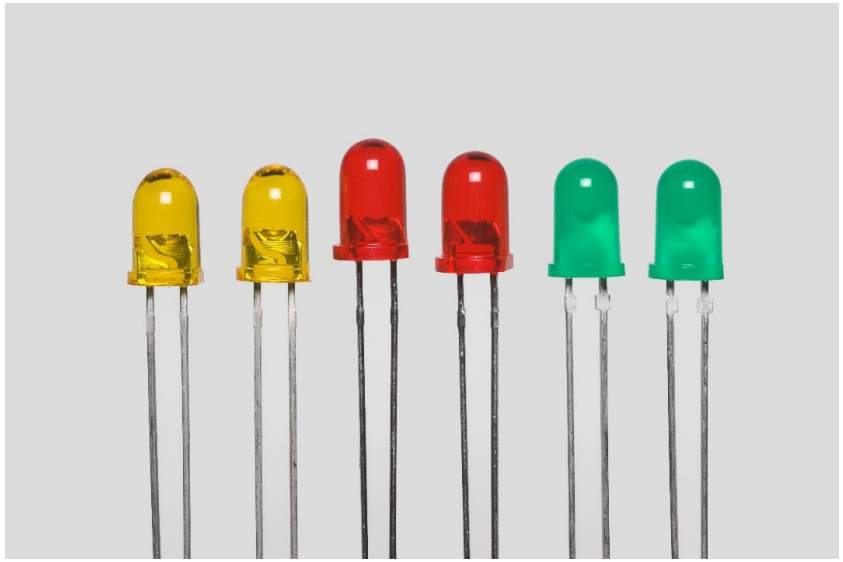


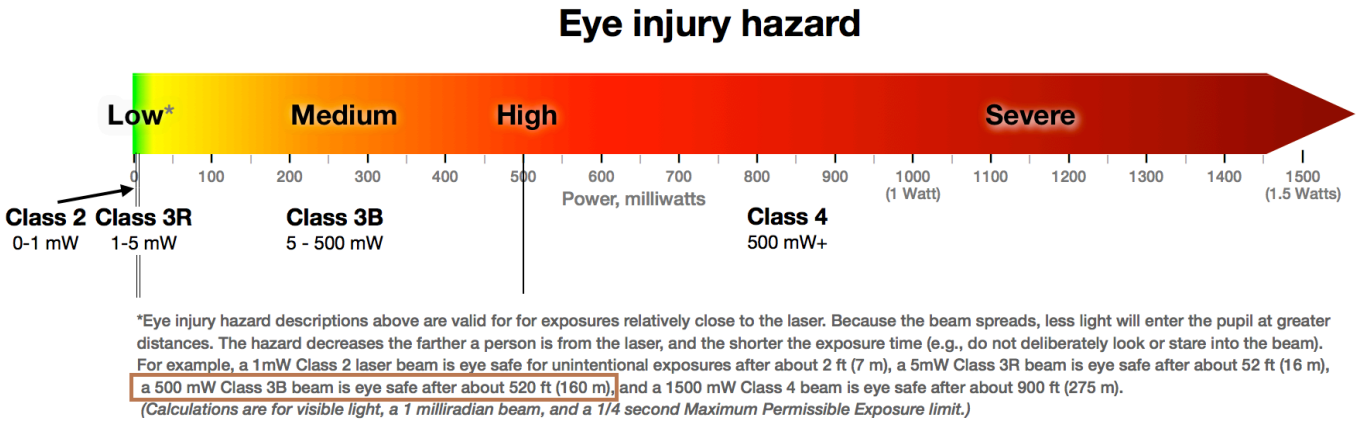
applies to laser product manufacturing regulations used to determine laser product hazard classification according to the related hazard, depending on their characteristics. The limits were defined on the powers and energies emitted by the laser and accessible to the user – this explains the acronym **A.E.L.** Each laser class is labeled by a maximum accessible emission that must not be exceeded.

Class 1 (includes LED's – used to be exempt)

Each laser class is based on these AEL thresholds:

Class 1 lasers or systems cannot emit accessible laser radiation in excess of the applicable Class 1 AEL for any exposure times within the maximum duration inherent in the design or intended use of the laser.





Class 1C products – i.e. home hair removal machines

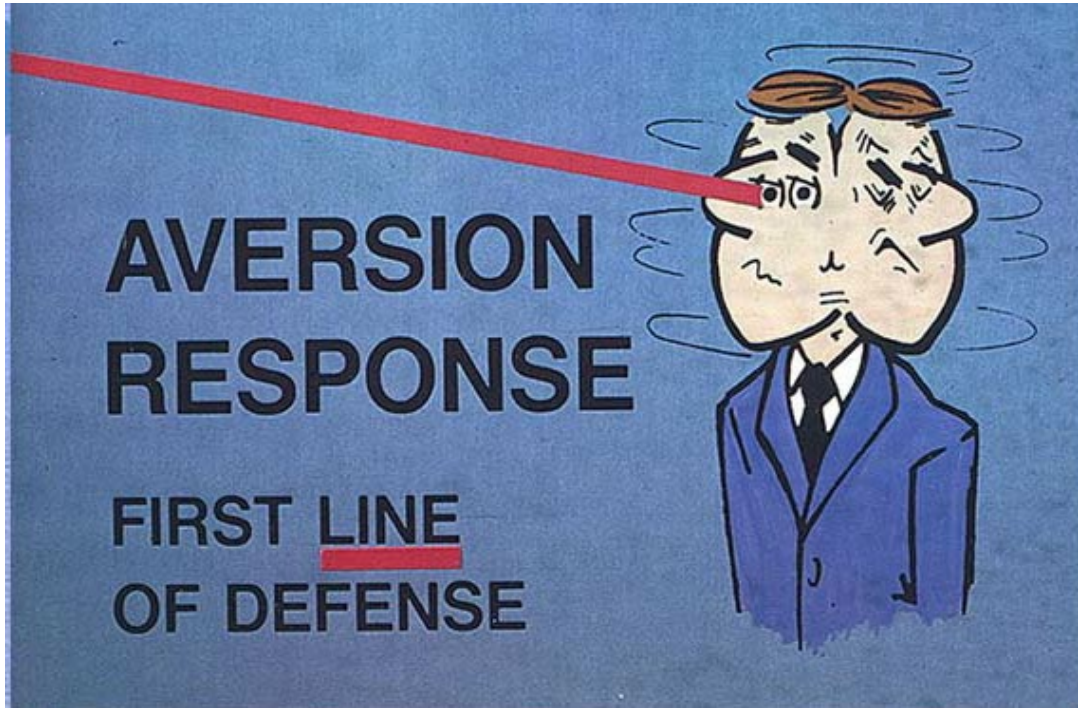
Laser Class 1C

- Laser class 1C has been newly established in IEC 60825 version 07-2015 and covers laser systems that are designed for direct contact with the "objective", like e.g. the skin. This can be laser systems for hair removal, reduction of wrinkles, tattoo removal and treatment of acne. Included are laser systems for home use as well.
- Protection measures for these laser systems must ensure to not allow any emission of radiation that exceeds the level of laser class 1. Usually the laser class 1C units have special contact sensors that prevent laser emission if the laser is not used in a safe way. The electrical conductivity of human skin is often used for these kind of safety measures.

Class 2 lasers

Class 2 lasers are CW and repetitively pulsed lasers with wavelengths between 400 nm and 700 nm that can emit energy in excess of the Class 1 AEL, but do not exceed the Class 1 AEL for an emission duration ***less than 0.25 seconds*** and have an average radiant power of 1mW or less.

Now that's FAST!



Class 3a lasers

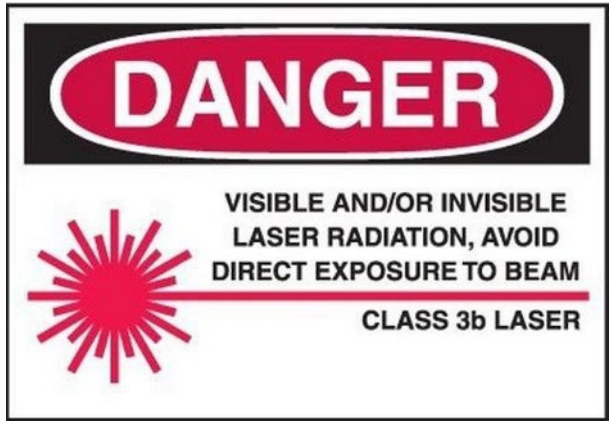
Class 3a lasers have an accessible output between 1 and 5 times the Class 1 AEL for wavelengths shorter than 400 nm or longer than 700 nm, or less than 5 times the Class 2 AEL for wavelengths between 400 nm and 700 nm.

1 – 5 mW

Class 3b lasers

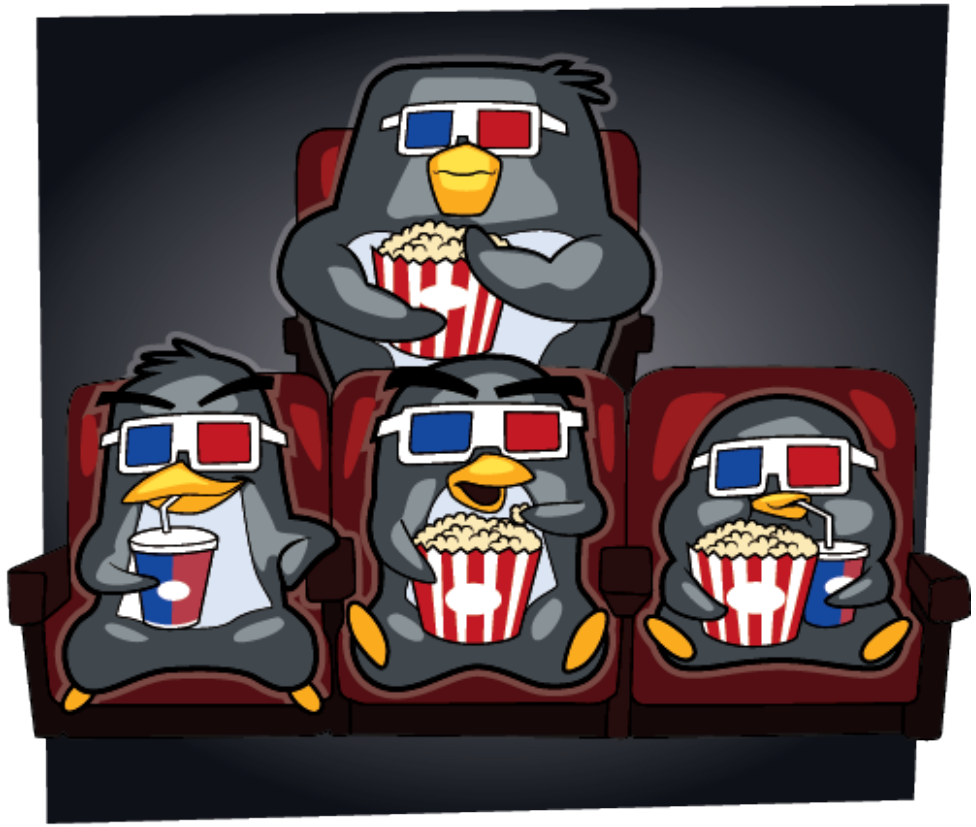
Class 3b lasers cannot emit an average radiant power greater than 0.5 Watts for an exposure time equal to or greater than 0.25 seconds or 0.125 Joules for an exposure time less than 0.25 seconds for wavelengths between 180 nm and 400 nm, or between 1400 nm and 1 mm.

In addition, lasers between 400 nm and 1400 nm exceeding the Class 3a AEL cannot emit an average radiant power greater than 0.5 Watts for exposures equal to or greater than 0.25 seconds.



5 – 500 mW

Class 4 lasers



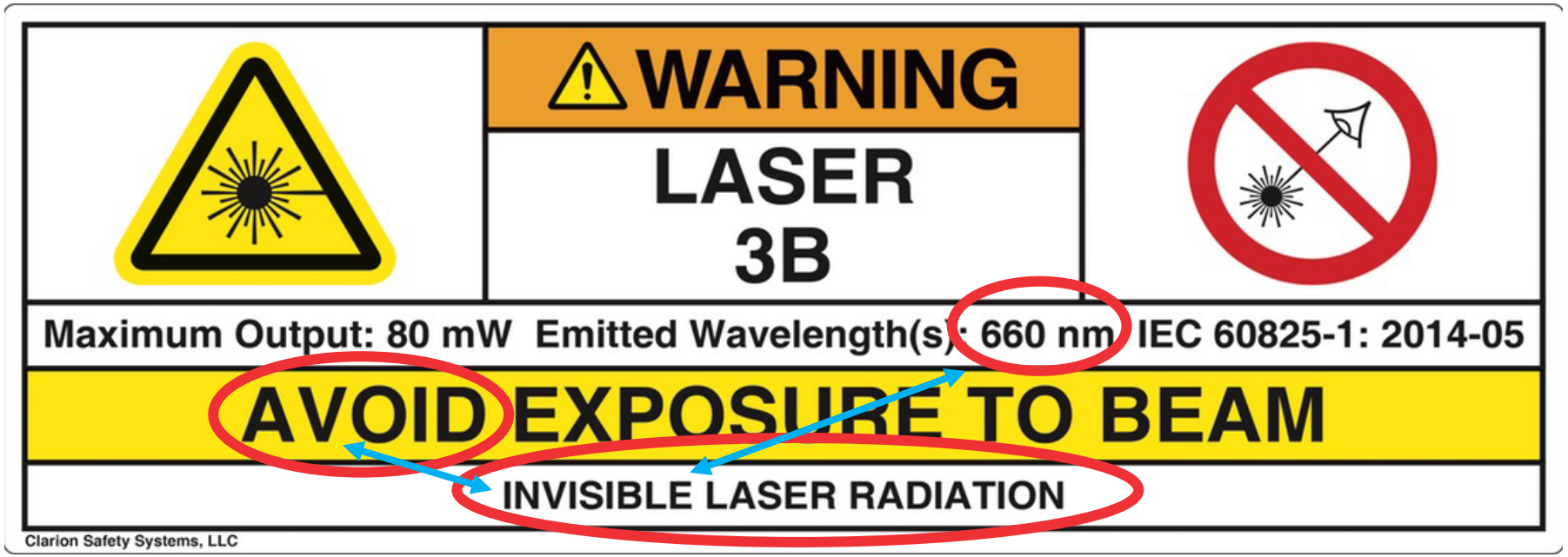
https://www.youtube.com/watch?v=RNLRTzt3MvQ

https://www.facebook.com/JamesBond007/videos/goldfinger-laser-scene/2021094724572095/

Laser Equipment Labels

Conspicuously displayed where they will best serve to warn

- Class of laser
- Emitted wavelength, pulse duration, maximum output power
- Precautionary statement
- Formatted similar to signs or IEC
- Don’t confuse the reader



Comparison of Classifications

Class	IEC 60825 (Amend. 2)	U.S. FDA/CDRH	ANSI-Z136.1 (2000)
Class 1	Any laser or laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injury during normal operation. This does not apply to service periods requiring access to Class 1 enclosures containing higher class lasers.		
Class 1M	Not known to cause eye or skin damage unless collecting optics are used.	N/A	N/A
Class 2a	N/A	Visible lasers that are not intended for viewing and cannot produce any known eye or skin injury during operation based on a maximum exposure time of 1000 seconds.	N/A
Class 2	Visible lasers considered incapable of emitting laser radiation at levels that are known to cause skin or eye injury within the time period of the human eye aversion response (0.25 seconds).		
Class 2M	Not known to cause eye or skin damage within the aversion response time unless collecting optics are used.	N/A	N/A
Class 3a	N/A	Lasers similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam Visible Only	Lasers similar to Class 2 with the exception that collecting optics cannot be used to directly view the beam
Class 3R	Replaces Class 3a and has different limits. Up to 5 times the Class 2 limit for visible and 5 times the Class 1 limits for some invisible.	N/A	N/A
Class 3b	Medium powered lasers (visible or invisible regions) that present a potential eye hazard for intrabeam (direct) or specular (mirror-like) conditions. Class 3b lasers do not present a diffuse (scatter) hazard or significant skin hazard except for higher powered 3b lasers operating at certain wavelength regions.		
Class 4	High powered lasers (visible or invisible) considered to present potential acute hazard to the eye and skin for both direct (intrabeam) and scatter (diffused) conditions. Also have potential hazard considerations for fire (ignition) and byproduct emissions from target or process materials.		

Laser Safety Control Measures

Control measures are based upon classification and hazard evaluation

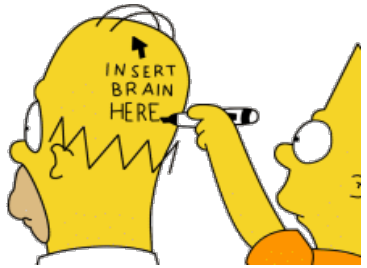
3 aspects of laser application influence hazard evaluation

1. **The laser** or **laser system's capability** of injuring personnel or interfering with task performance

2. **The environment** in which the laser is used, including access to the beam path (considering enclosures, baffle, beam, etc.)

Classroom, R&D lab, production line, space?

3. **The personnel** who may use or be exposed to laser radiation



Three User Functions with Laser or Laser System

Operation

- Intended use – full range of intended tasks

Maintenance

- Tasks for assuring routine performance
- Cleaning and replenishment of expendable materials
- Typically, does not require beam access

Service

- Infrequent tasks (i.e. repairing faulty components)
- Usually requires beam access

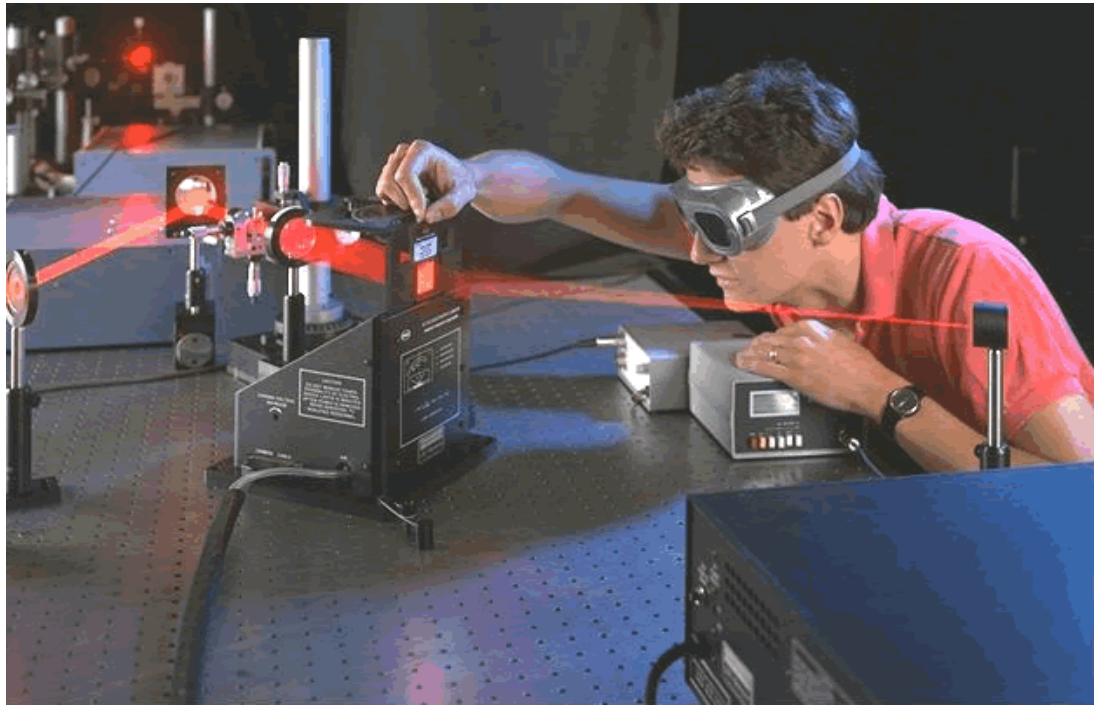
Control Measures: (ANSI Z136.1 – 2014)

Three types of controls

- Engineering (EC)
- Administrative & Procedural (A&P)
- Personal protective equipment (PPE)

Priority of controls allows latitude (Section 4.1)

- Priority given to engineering controls
- Enclosure of equipment or beam path is the preferred control
- If impractical or inadequate, A&P and PPE shall be used
- PPE is considered “the last line of defense….”

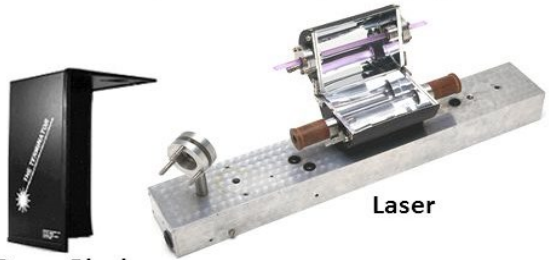


Engineering Controls

Engineering Controls

Interlock

Warning Light



Beam Block

Laser

Eliminate Exposure

Use physical structures as your first line of defense

1. Protective housing
2. Interlocks
3. Aperture beam blocks
4. Warning lights

A laser or laser system may be developed or modified by a user for internal use only. User-developed or user-modified laser products shall have their engineering controls reviewed and approved by the LSO (Laser Safety Officer) to determine the adequacy of their protection.

The use of engineering controls are preferred over administrative controls.

Protective housing, Laser Barriers and Curtains

Applications

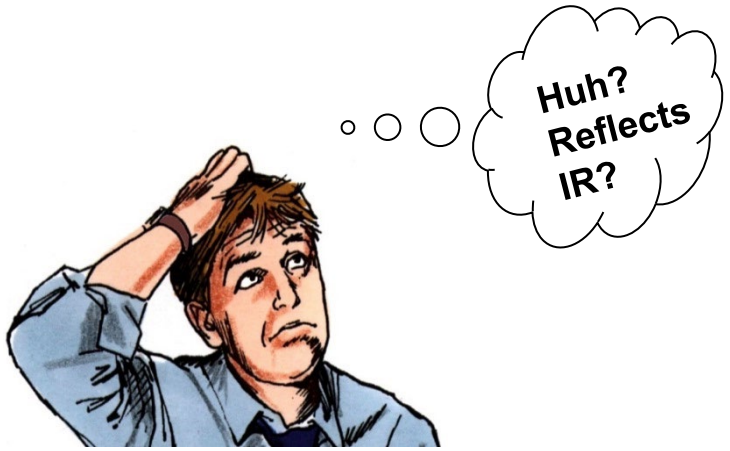
- Used at entryway
- Temporary laser controlled area

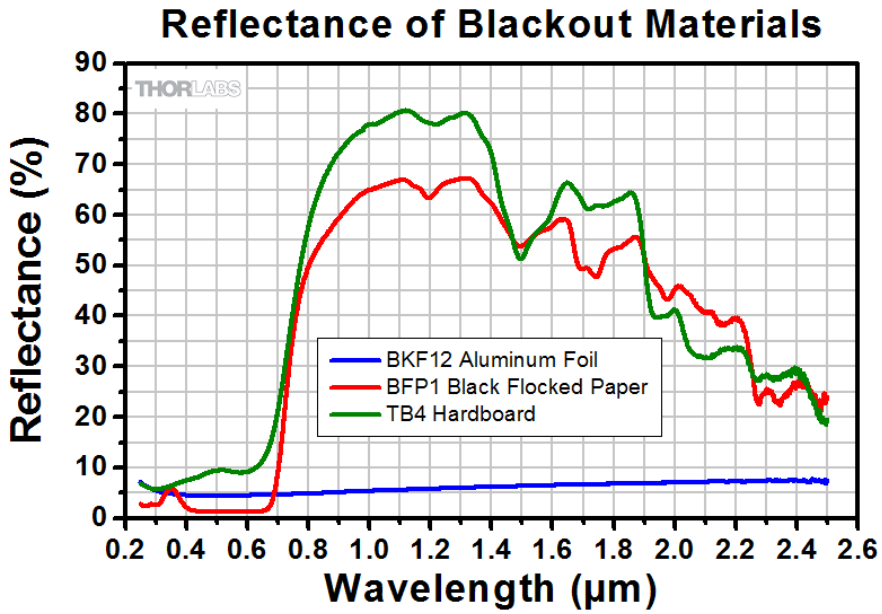
Should not be flammable or emit toxic by-products

If barrier does not extend floor-to-ceiling, LSO should evaluate potential exposure (i.e. NHZ) outside barrier

www.kenteklaserstore.com/laser-barriers-curtains.aspx

Laser Barriers and Curtains





NOTE: SOME BLACKOUT MATERIAL CAN REFLECT INFRARED!

Few materials have been tested & reported in scientific literature

- Contact manufacturer for information
- Link to RLI testing (rli.com/products/barriers.aspx)+

Area Warning Device (visible or audible or both)

Visible warning device required for Class 4 lasers during startup and operation

- Recommended for Class 3B
- Visible warning device is most common

<u>Warns prior to entering the laser area</u>

May be mechanical or electrical

- Single lamp or lighted warning sign

Must be visible through laser protective eyewear

Audible warning devices used outside immediate laser area (optional)

LCA (Laser Controlled Area)

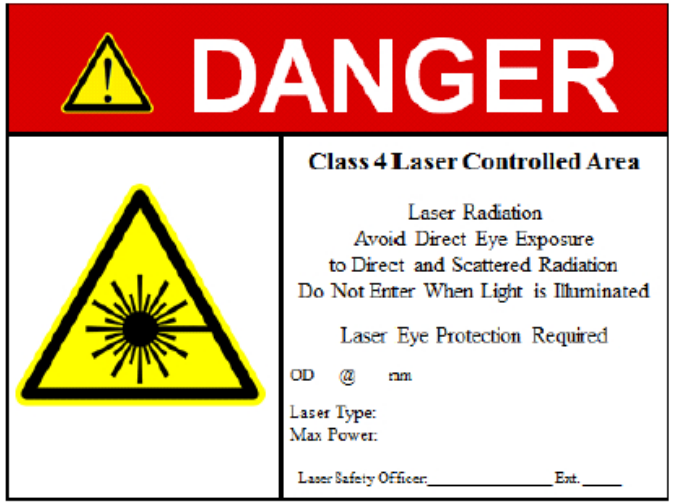


Figure 1a

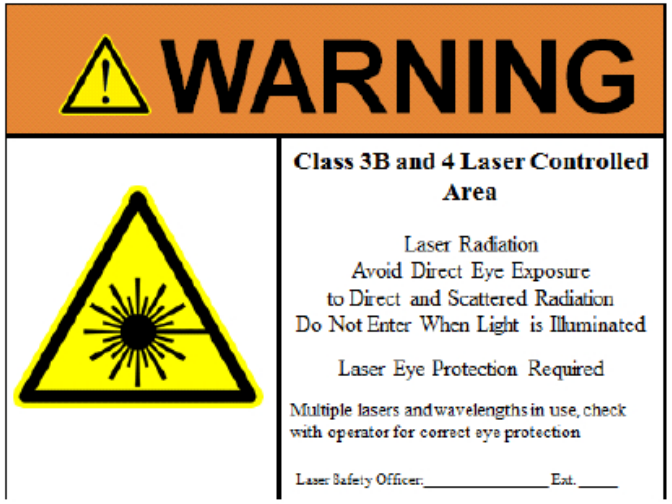


Figure 1b

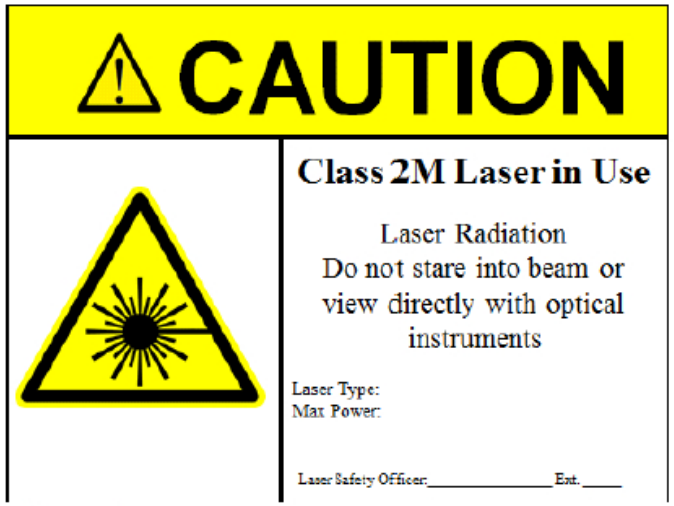


Figure 1c

Figure 1d

Alignment Practices

Exclude unnecessary personnel

Turn down power or use low power visible beam for path simulation

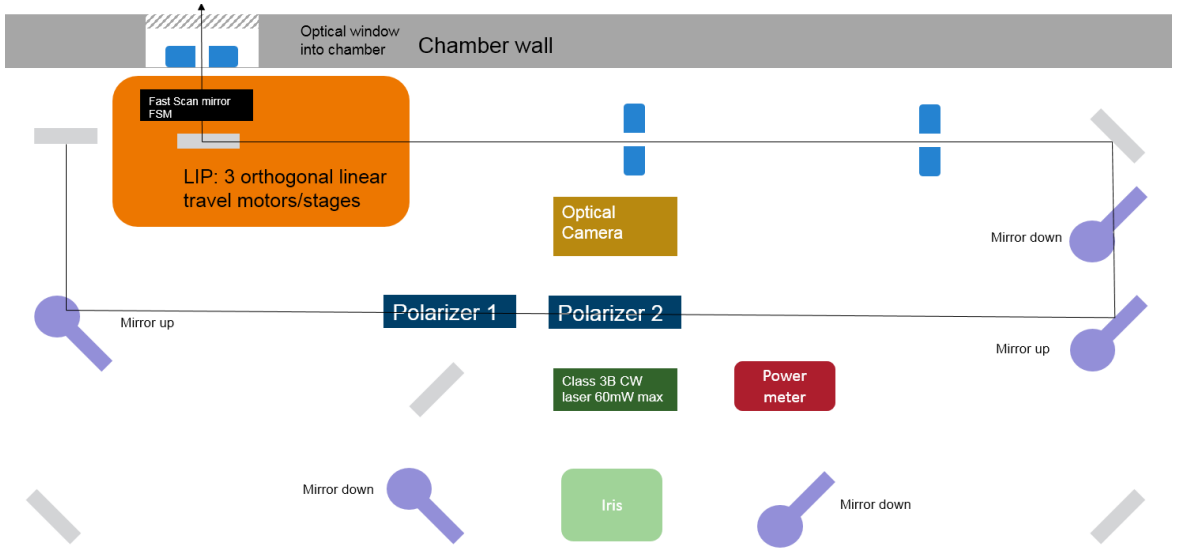
PPE for eyes and skin, as applicable

- Ensure OD is appropriate for beam power

Tools, targets, curtains, signs, caution tape, etc.

Beam stops/blocks

- Beam not needed
- Down range
- Mirrors



Use of Viewing Cards

- Invisible/visible laser radiation converted to visible wavelength
- Spot of light is visible but still must use laser eye protection

The View-It® Infrared Detector Pocket Card features a target aperture of 38mm square. The aperture converts invisible 800-1700nm light to a visible green with a minimum sensitivity of 1mJ/cm² and a maximum damage threshold of 20J/cm².

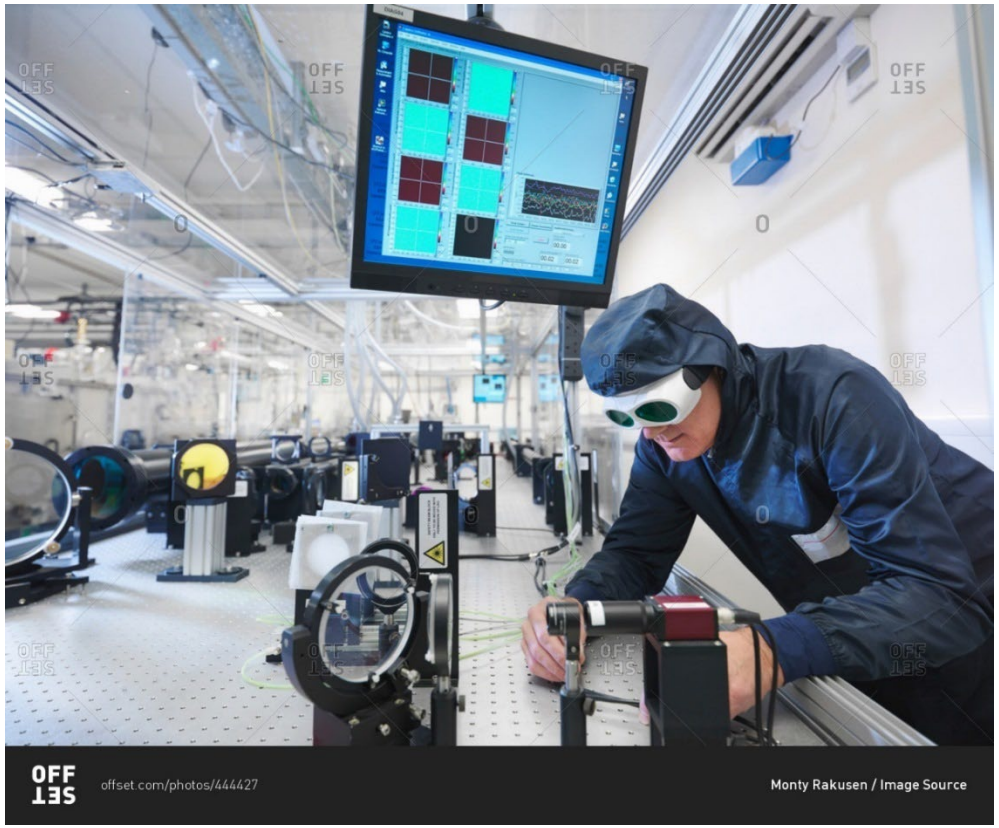
Personal Protective Equipment

When other controls measure are not practicable, PPE shall be used…..

Laser eye protection (LEP) shall be used for Class 3B & 4 lasers

Clothing and gloves specifically selected for suitable protection against laser radiation should be considered for Class 3B & 4 lasers

http://laser.vigosystems.com/project/laser-safety-clothes/?lang=en



Laser Safety Eye Protection – Example of Wavelength Compatibility

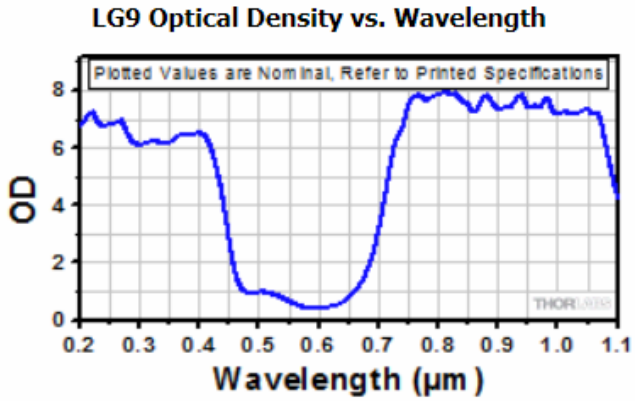
Laser Safety Glasses: 25% Visible Light Transmission

Zoom

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

L-Rating Specs (EN 207)[a]
180 to 315 nm (D LB6 + R LB4)
>315 to 400 nm (DR LB4)
720 to 725 nm (DM LB5)
720 to 750 nm (IR LB5)
>1064 to 1075 nm (IR LB5)
>725 to 1075 nm (DM LB6)
>750 to 1064 nm (IRM LB7)[b]

a. Refer to the *Specs Tutorial* tab above for a full explanation of the EN 207 markings.
b. For the M rating of LB7 in the corresponding wavelength range, the glasses were tested at pulses between 12 ps and 170 fs.



Click to Enlarge
Click Here for Raw Data

Based on your currency / country selection, your order will ship from Newton, New Jersey

+1	Qty	Docs	Part Number - Universal		Price	Available / Ships	
+1			LG9	Laser Safety Glasses, Amber Lenses, 25% Visible Light Transmission, Universal Style	$200.00	√	Today
+1			LG9A	Laser Safety Glasses, Amber Lenses, 25% Visible Light Transmission, Comfort Style	$200.00	√	Today
+1			LG9B	Laser Safety Glasses, Amber Lenses, 25% Visible Light Transmission, Sport Style	$200.00	√	Today

Add To Cart

Laser glasses example

Color	Wavelength	Frequency	Photon energy
violet	380–450 nm	668–789 THz	2.75–3.26 eV
blue	450–495 nm	606–668 THz	2.50–2.75 eV
green	495–570 nm	526–606 THz	2.17–2.50 eV
yellow	570–590 nm	508–526 THz	2.10–2.17 eV
orange	590–620 nm	484–508 THz	2.00–2.10 eV
red	620–750 nm	400–484 THz	1.65–2.00 eV

Eyewear Cleaning & Inspection

Z136.1 recommended inspection frequency: annual for audit purposes

Inspect EVERY TIME:

- Lens: pitting, crazing, cracking, discoloration
- Frame: mechanical integrity
- Goggles: band, ventilation ports, gasket
- Additional: light leaks and coating damage

Eyewear Care & Storage

Eyewear should be cleaned following manufacturer's directions

- Store away from potential contaminants
- Store goggles so they are not stressed (deformed)
  - Keep in original container

Laser Safety Program General Considerations

Basic needs for implementation:

- Recognized need: lasers are a known hazard
- Management buy-in and support
- Laser Safety Officer (LSO) named
- Program funding (expense items, training, etc.)

General considerations: Program basis

Reasons for implementation

- Prevent injuries
  - Moral & ethical considerations
- Meet regulatory requirements
  - OSHA, state radiation requirements
- Reduce liability & potential for negative publicity
- Control insurance costs

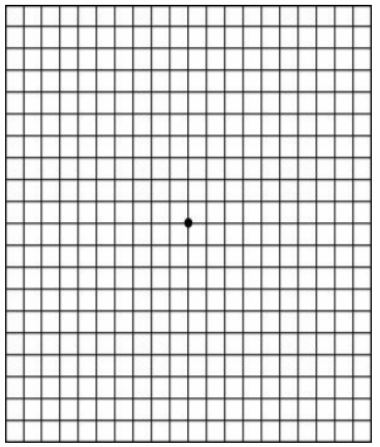
Required Program Elements for Class 3B & 4

Medical surveillance

- Required following suspected injury
  - Ocular history
  - Visual acuity (Snellen)
  - Macular function (Amsler)
  - Color vision (Ishahara)
- Pre-placement for Class 3B/4 users, termination (optional)
  - Laser personnel (users, maintenance workers?)
  - Incident personnel (visual acuity only)
- Users of UV lasers
  - Skin exam
  - Potential for photosensitization

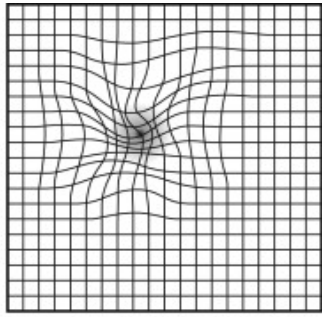
Amsler Chart to Test Your Sight

The Amsler grid is used to check whether lines look wavy or distorted, or whether areas of the visual field are missing.



Download Amsler Chart

1. Tape this page at eye level where light is consistent and without glare.
2. Put on your reading glasses and cover one eye.
3. Fix your gaze on the center black dot.
4. Keeping your gaze fixed, try to see if any lines are distorted or missing.
5. Mark the defect on the chart.
6. TEST EACH EYE SEPARATELY.
7. If the distortion is new or has worsened, arrange to see your eye doctor at once.
8. Always keep the Amsler's Chart the same distance from your eyes each time you test.



B

Required Program Elements for Class 3B & 4

Records

- Written program, history of changes
- Training
- Medical
- Audits, assessments, inspections
- Maintenance history
- Hazard evaluations
- Inventory history
- M&TE calibration
- Purchasing
- Committee minutes, rosters

Required Program Elements for Class 3B & 4

Inspections

- Who does these? LSO, operating group, internal, independent?
- What do they address?
  - General program/procedural requirements
  - Individual laser inspections
  - Hazard identification, QA, concerns

- PPE/protective equipment inspections
- What is the frequency? Daily, weekly, monthly, annually?
- How are the results documented?
- How are the issues resolved?

Required Program Elements for Class 3B & 4

Accident investigations

- Who is included in investigation?
- Graded approach based on incident?

Approval of laser system operations

- When you bring a new system online, do you…..
  - Review layout?
  - Ensure testing is complete and all is properly functional?
  - Approve operational/maintenance procedures?
  - Ensure punch list items are complete?

Laser Safety Committee

Membership

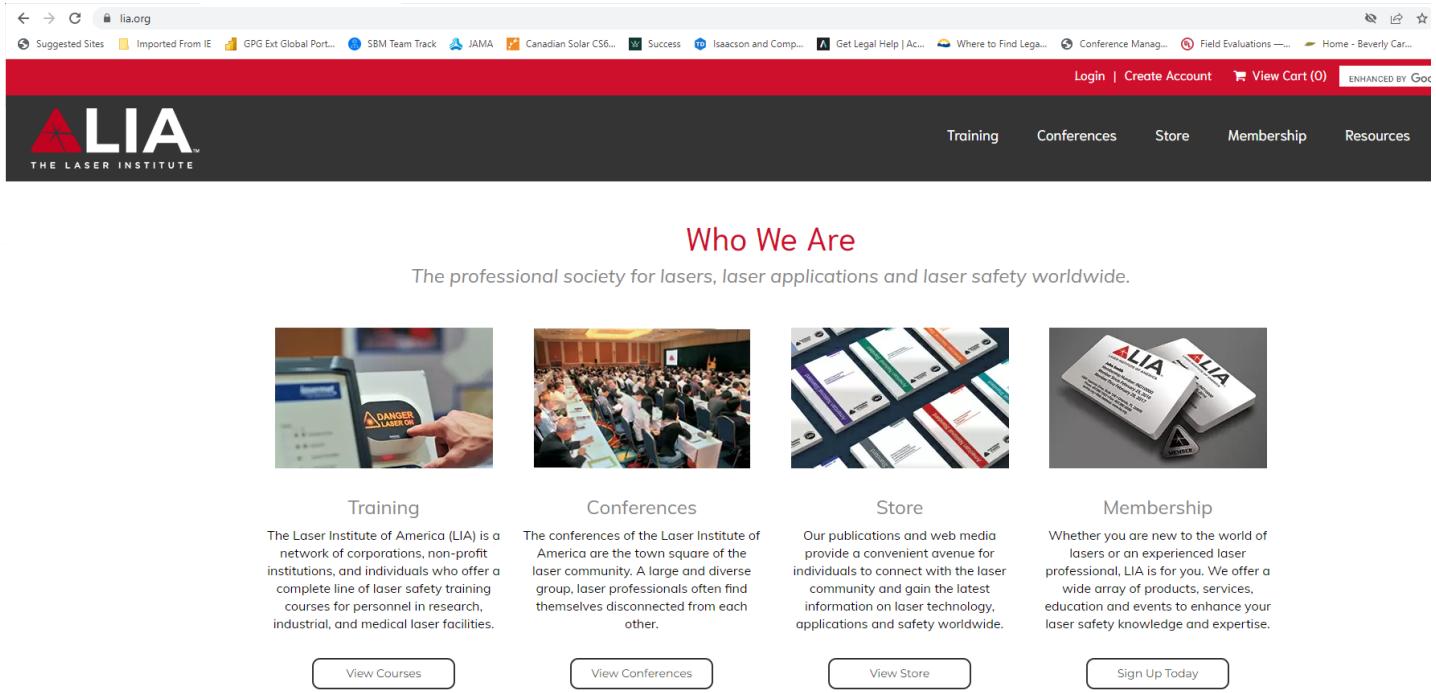
- LSOs
- Other ES&H professionals
- Medical
- Training
- Engineers/Scientists
- Users
- Management

Charter

May assist with establishment of policies, practices, controls, training, equipment, etc.

Shall maintain awareness of industry practices/policies

LIA (Laser Institute of America)

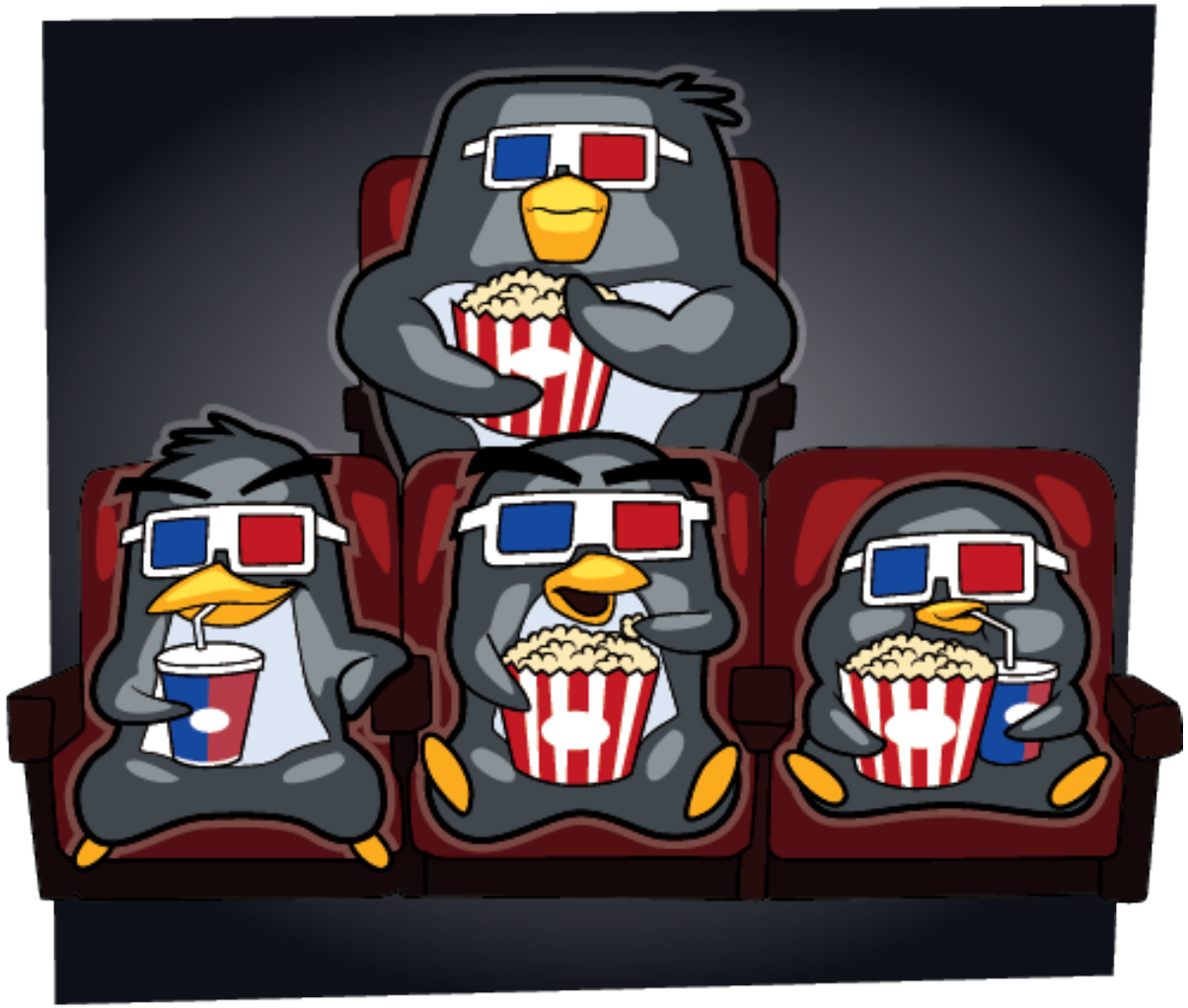


Use code **LSGRA20** which is good for 20% off and is valid through next Saturday, May 21. Reg $25.00

Thank you!

Question period

Movie time!



https://www.youtube.com/watch?v=-wXApAAh8xA