PRINCIPLES OF LASER SAFETY

A PART OF LASER SAFETY TRAINING FOR USERS

ON-THE-JOB TRAINING MUST FOLLOW BEFORE AUTHORIZATION TO OPERATE AND ACCESS

CAMPUS LAVAL

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Coherent | Laser Safety Awareness Training

- https://youtu.be/C5brmx5J0-s

12 déc. 2024

By : Coherent Corp.

- https://portail.inrs.ca/moodleinrs/course/view.php?id=7

FUNDAMENTALS OF LASER OPERATION

L ight

A mplification by

S timulated

E mission of

R adiation

STIMULATED
EMISSION OF LIGHT

Laser basic architecture

Gain/Lasing medium

Solid (Crystal)

Gas

Semi-conductor (diode)

Liquid (dye)

Pump

Optical

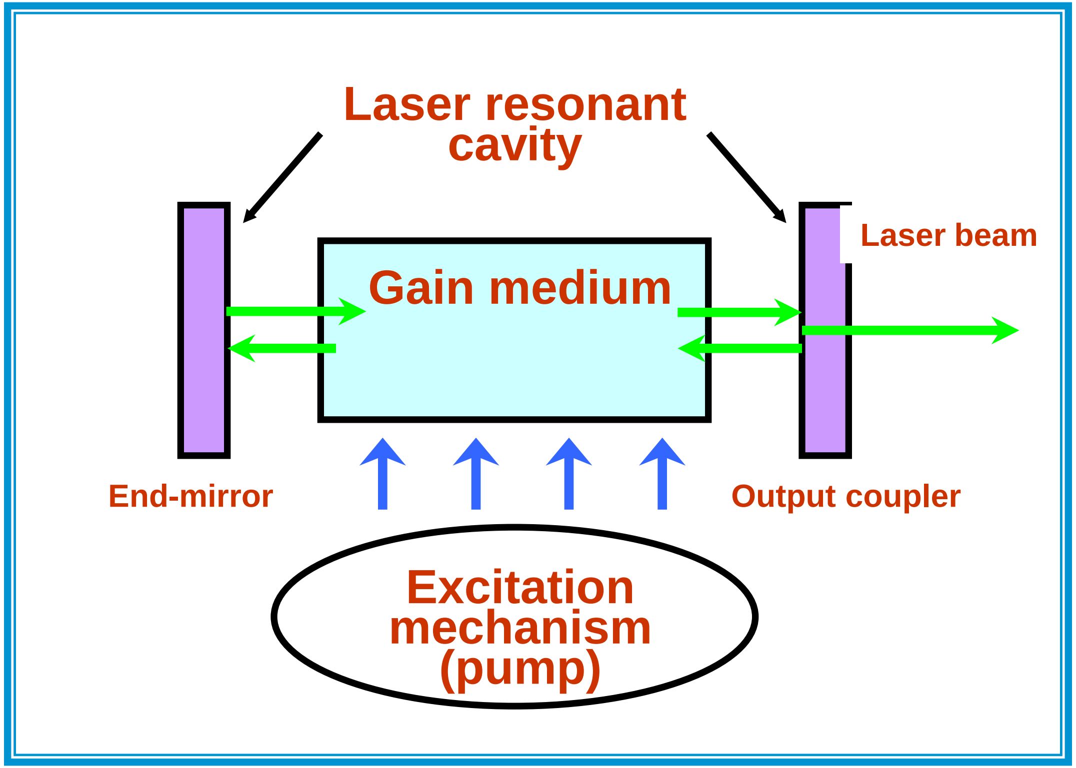
High-voltage discharge

Chemicals

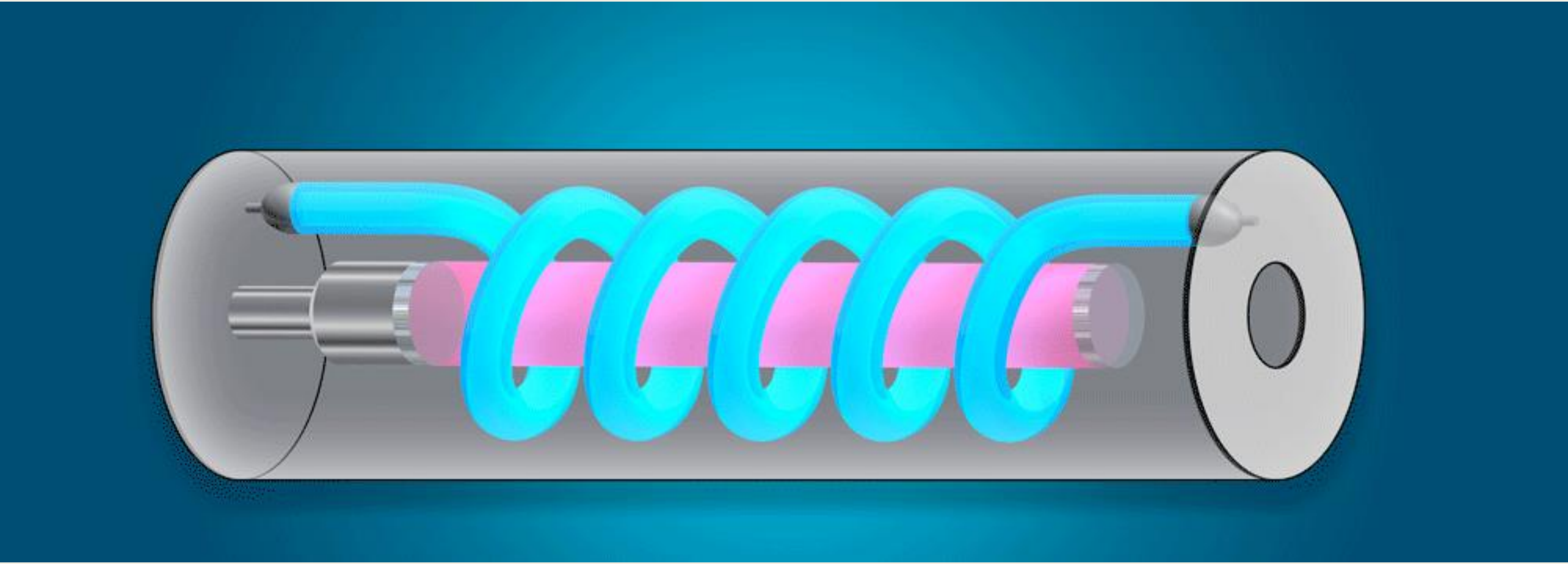
Laser resonant cavity

High-reflective mirror

Output coupler (partially transmissive mirror)



[NIF's Guide to How Lasers Work | National Ignition Facility & Photon Science]

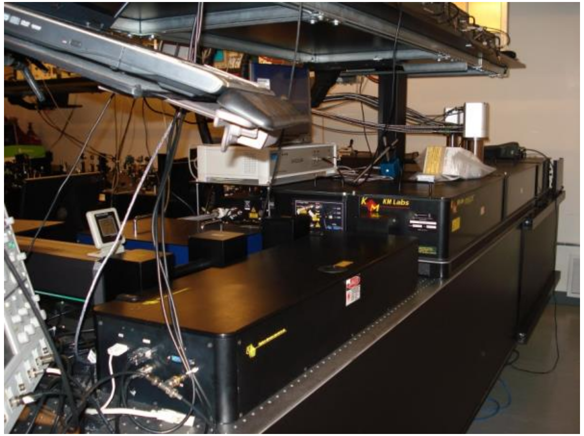


LASERS at INRS-EMT

Kr F **Class 4**
Wavelength: 248 nm
Energy per pulse: 400mJ
Repetition rate: 100hz
Pulse duration: 25 nanosec

Nd-YAG **Class 4**
Wavelength: 1064/532 nm
Energy per pulse: 2J / 1J
Repetition rate: 10hz
Pulse duration: 10 nanosec

LASERS at INRS-EMT



Ti Sa **Class 4**

Wavelength: 780-820 nm
Energy per pulse: 5mj
Repetition rate: 1Khz
Pulse duration: 25 femtosecond

OPA **Class 4**

Wavelength: 400 nm à 20 000 nm
Energy per pulse: few μJ to 2mj
Repetition rate: 100hz
Pulse duration: 40 to 70 femtosec

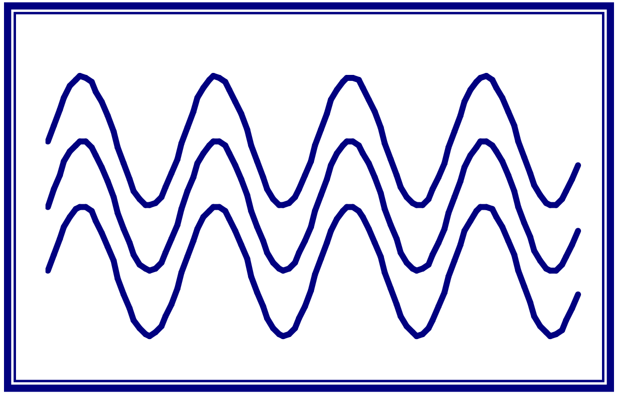
CHARACTERISTICS OF LASER RADIATION

Laser beam properties

Monochromatic *

Directionnal

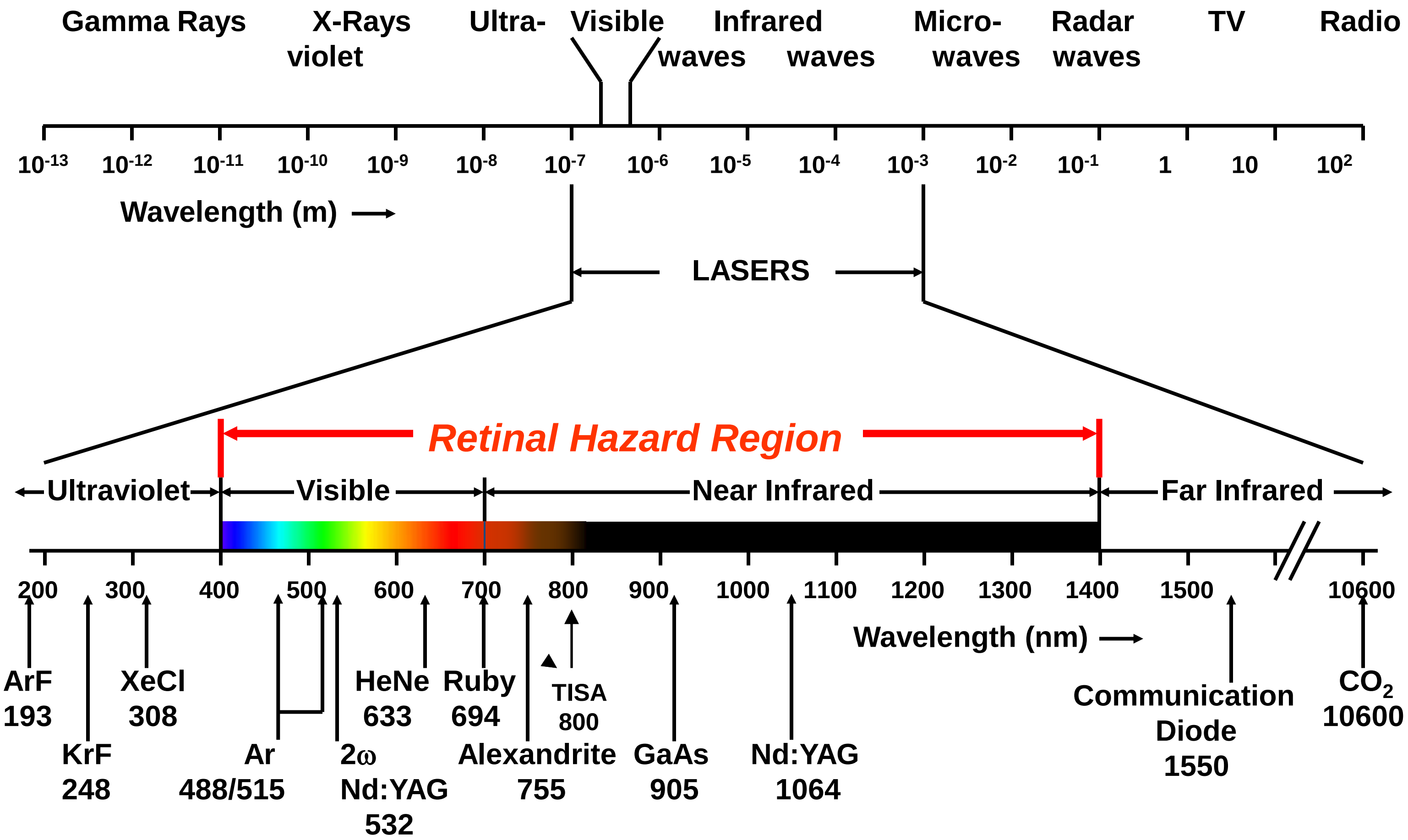
Coherent



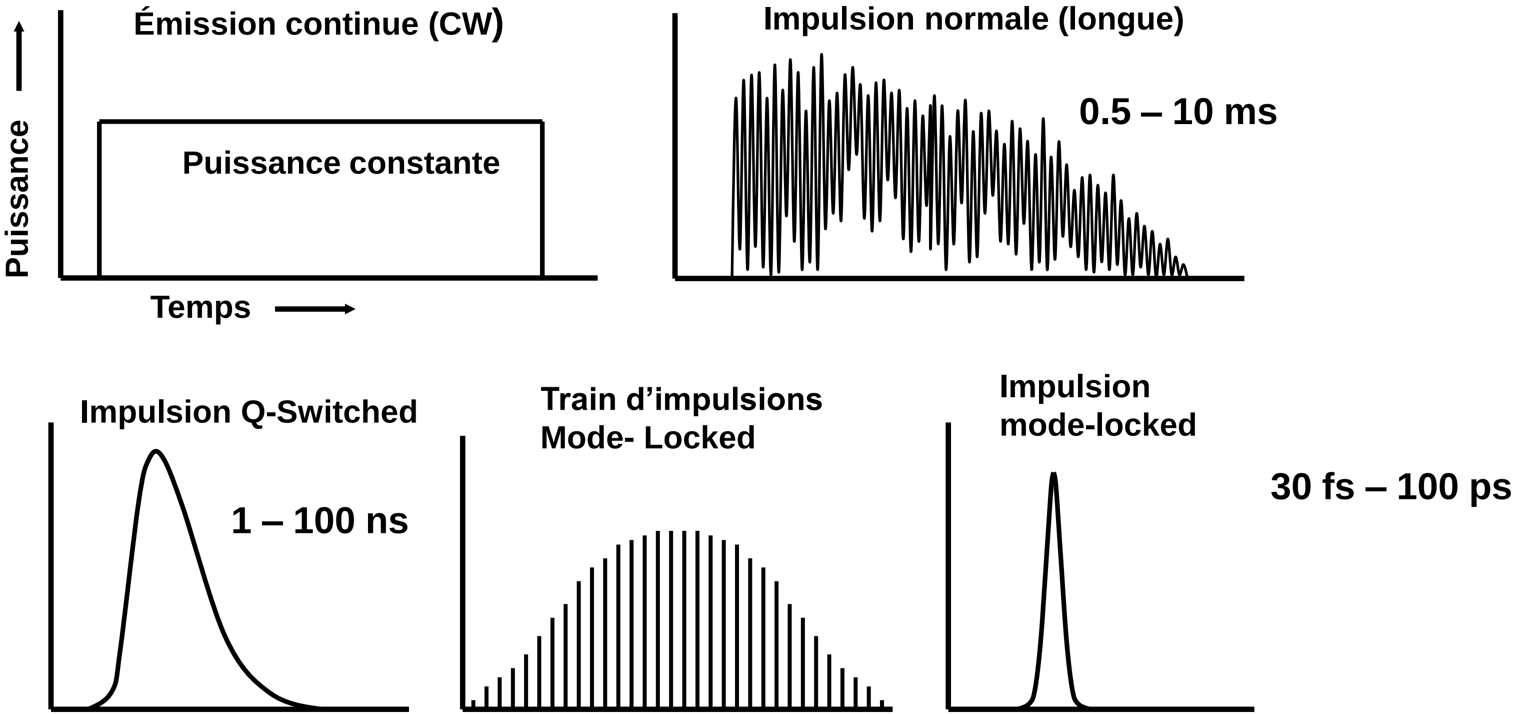
The combination of these properties makes a laser beam to focus on a very small spot size as compared with ambiant sources of light. The high concentration of energy on a small surface results in hazardous intensities

* Ultrashort laser pulses (femto-sec.) have an extended spectrum.

Electromagnetic spectrum



Laser emission types (temporal)



Ultrashort laser pulses is increasing the intensity by 12-15 orders of magnitude if we compare similar average power

BIOEFFECTS OF LASER RADIATION ON THE EYE AND SKIN

Laser potential hazards

Photo provenant de la revue Photonics Spectra, Mars 2005

(**In Laser Safety, Little Mistakes Can Have Big Consequences)**

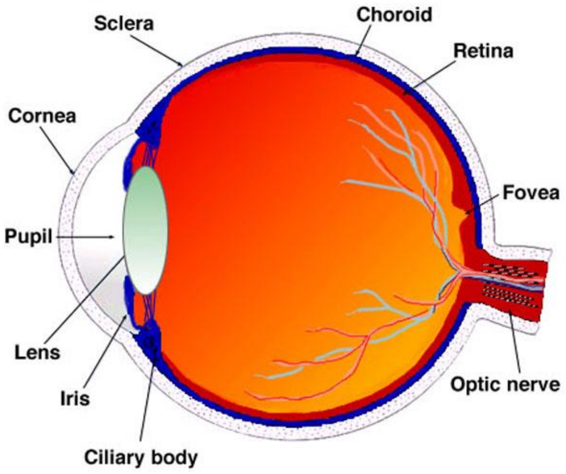


Fig. 6. Vertical sagittal section of the adult human eye.

Risks on personal health

Lasers can cause severe harm to the eyes and result in serious and permanent vision loss

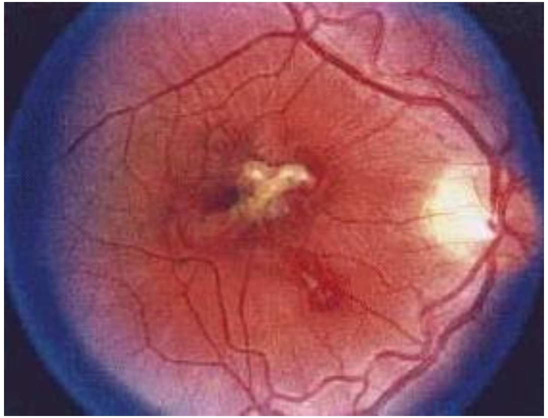


Photo provenant de la revue Photonics Spectra, Mars 2005

(**In Laser Safety, Little Mistakes Can Have Big Consequences)**

Photokeratitis (UV)

Retina damage (400 à1400 nm)

Cataract (1400 nm à 1mm et UV)

Cornea thermal burn

Risks for personal health

Powerful lasers can cause severe wounds and burn the skin

Thermal wounds

Surface burn

Deep burn (1 µm)

Tissue vaporisation(focal)

Photochemical wound

Sun burn (scattered UV)

Risk of cancer

(Extended exposition to UV)

EYE INJURIES AT VARIOUS WAVELENGTHS

Wavelength (μm)	Type of Injury
0.18 – 0.4	UV – Thermal or photochemical injury to cornea or photochemical injury to lens
0.4 – 1.4	RETINAL HAZARD REGION (Explosive retinal effects from short pulses)
0.4 – 0.6	Visible – Thermal or photochemical injury to retina (Greater blue light retinal hazard at shorter wavelengths)
0.6 – 0.7	Visible – Thermal injury to retina
0.7 – 1.4	Near IR – Thermal injury to retina
1.4 – 2.6	Far IR – Thermal injury to cornea or lens
2.6 – 1000	Far IR – Thermal injury to cornea (Mostly surface burns)

Laser-Professionals.com

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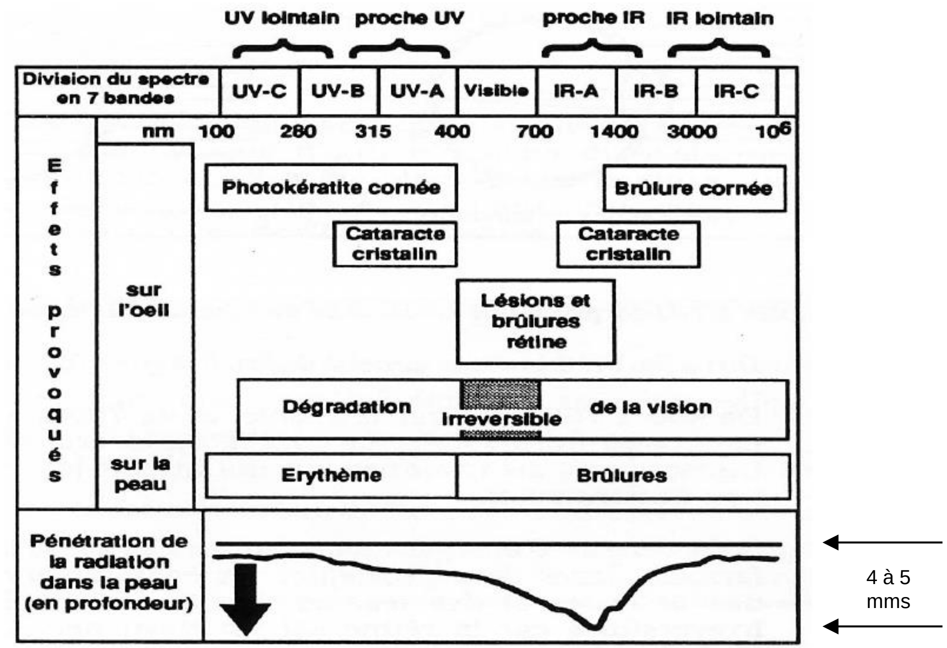
Synthesis


UV lointain
proche UV
proche IR
IR lointain
Division du spectre en 7 bandes
UV-C
UV-B
UV-A
Visible
IR-A
IR-B
IR-C
nm
100
280
315
400
700
1400
3000
10^6
Effets provoqués
sur l'oeil
Photokératite cornée
Brûlure cornée
Cataracte cristallin
Cataracte cristallin
Lésions et brûlures rétine
Dégradation
irreversible
de la vision
sur la peau
Erythème
Brûlures
Pénétration de la radiation dans la peau (en profondeur)
4 à 5 mms

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ACCIDENTS

[Understanding Laser Accidents (CRC 2019)-Ken Barat.pdf]

RADIOMETRIC UNITS

Term	Symbol	Equation	Unit
Radiant Energy	Q	$Q = \Phi \times T$	joule (J)
Radiant Power	Φ	$\Phi = Q/T$	watt (W)
Irradiance	E	$E = \Phi/A$	watts/cm^2
Radiant Exposure	H	$H = Q/A$	joules/cm^2

Laser output is measured in units of energy for pulsed laser and power for CW and repetitive pulsed lasers.

The concentration of the laser light on a target is expressed in units of irradiance or radiant exposure.

Laser-Professionals.com

The energy of a laser pulse is measured in joules.

Power is energy divided by time. If a laser delivers one joule in one second, the average power is one watt.

Irradiance and Radiant Exposure are target functions. Irradiance is a measure of the concentration of the laser power on the target in W/cm^2. Radiant Exposure is the concentration of the light energy in J/cm^2. Both irradiance and radiant exposure are used in laser safety calculations.

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Section 4: Laser Control Measures | Office of Environmental Health and Safety (Princeton U)

Optical Density (OD) (top)

The OD (absorbance) is used in the determination of the appropriate eye protection. OD is a logarithmic function defined by:

$$OD = \log_{10}\left[\frac{H_0}{MPE}\right]$$

Where H_0 is the anticipated worst case exposure conditions (in joules/cm^2 or watts/cm^2) and the MPE is expressed in the same units as H_0. The OD values for various lasers, computed for various appropriate exposure times, are listed below. Keep in mind that these values are for intrabeam viewing (worst case) only. Viewing Class 4 diffuse reflections (such as alignment tasks) requires, in general, less OD. These should be determined for each situation and would be dependent upon the laser parameters and viewing distance.

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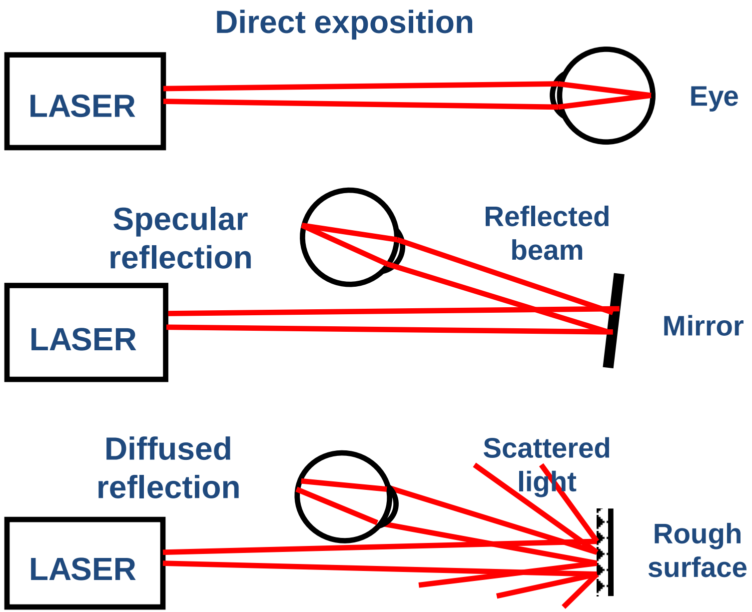
SIGNIFICANCE OF SPECULAR AND DIFFUSE REFLECTIONS

Laser beam exposure sources



LASER AND LASER SYSTEM CLASSIFICATIONS

Standards and Regulations

- CNESST / Loi sur la santé et la sécurité du travail
- ANSI Z136 series
- IEC 60825-1
- Radiation Emitting Devices Regulations (Laser Products)

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Laser classes and hazards

Class 1

Harmless lasers under normal using conditions

Lecteur CD

Class 1M

Lasers for which direct beam observation with optical instruments may be hazardous (302.5 nm to 4000 nm)

Class 2

Lasers emitting visible radiation in the wavelength range from 400 nm to 700 nm. Eye protection is assured by the user palpebral reflex (reflex closing the eye; T=0.25 second).

-Power limitation to 1mW. Bar code reader, laser pointer, alignment

Class 2M

Lasers emitting visible radiation in the wavelength range from 400 nm to 700 nm for which direct beam observation with optical instruments may be hazardous.

Laser classes and hazards

Class 3R (Class 3A)

Lasers emitting radiation in the wavelength range from 300 nm to 10 µm. Direct observation of the beam may be harmful.

-Power limitation to 5 mW. Alignement laser, laser pointer,

Eye protection is strongly advised.

Class 3B

Direct observation of the beam is hazardous. Observation of scattered or diffused radiation is usually not hazardous.

-Power limitation to 500 mW Processing laser(YAG),machining

Eye protection is mandatory.

Class 4

Direct observation of the beam is hazardous. Observation of scattered or diffused radiation is also hazardous. These lasers can also cause skin damage and burns.

-Lasers exceeding 500 mW of continuous emission High power lasers

Eye protection is mandatory.

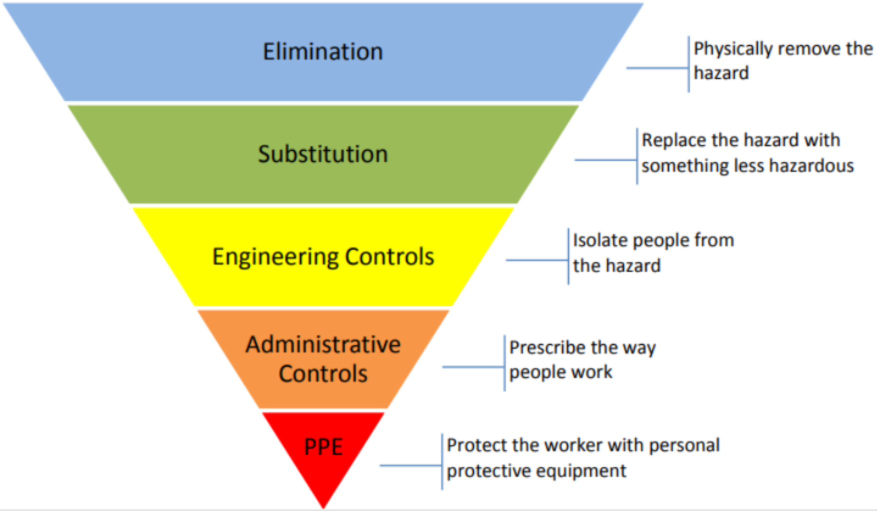
normes *EN 60825-1:2007 Ed.2.0* et *ANSIZ136.1-2007*

CONTROL MEASURES AND
PROTECTIVE EYEWEAR
(PERSONAL PROTECTIVE EQUIPMENT)

Laser Safety Program Requirements for DOE Facilities (efcog)

3.2. Hazard Control Hierarchy

Once a hazard is identified, a hazard control hierarchy *shall* be applied to determine how to mitigate the hazard. One *should* first try to eliminate the hazard or make a substitution to reduce the hazard level. When elimination and substitution are not practical, then a selection of engineering, administrative, and PPE controls *shall* be implemented to reduce risk to an acceptable level. Engineering controls are prioritized over administrative and PPE controls because they are the most reliable. Where practical, they can be used to minimize the laser hazard by fully enclosing the laser beam. To ensure engineering controls are effective, they must have good integrity, be reliable, and be implemented in accordance with good engineering practices. When engineering controls cannot fully mitigate the laser hazards, then additional administrative and PPE controls *shall* be employed. The prioritization for controls implementation is illustrated in Figure 3-1.



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[Program Requirements/Procedures | Office of Environment, Health & Safety](https://ehs.berkeley.edu/laser-safety-manual/program-requirementsprocedures)

https://ehs.berkeley.edu/laser-safety-manual/program-requirementsprocedures

Laser Safety Program Requirements for DOE Facilities

3.4. Engineering Controls

3.4.1. LCA Warning Device

3.4.2. Emergency Stop Device

3.4.3. Remote Interlock Connector

3.4.4. Master Key

3.4.5. Beam Stop/Attenuator

3.4.6. Enclosures (Protective Housings, Class 1 Enclosures, Beam Conduits and Fiber Transport)

[Laser Safety Program Requirements for DOE Facilities]

3.5. Administrative and Procedural Control

3.5.1. Standard Operating Procedures (SOPs)

3.5.2. Alignment Procedures

3.6. Personal Protective Equipment (PPE)

3.7. Signs and Labels

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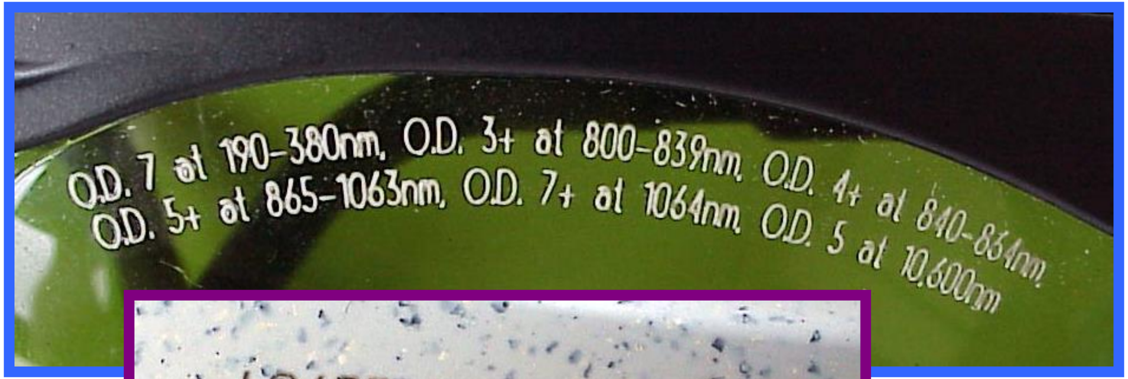
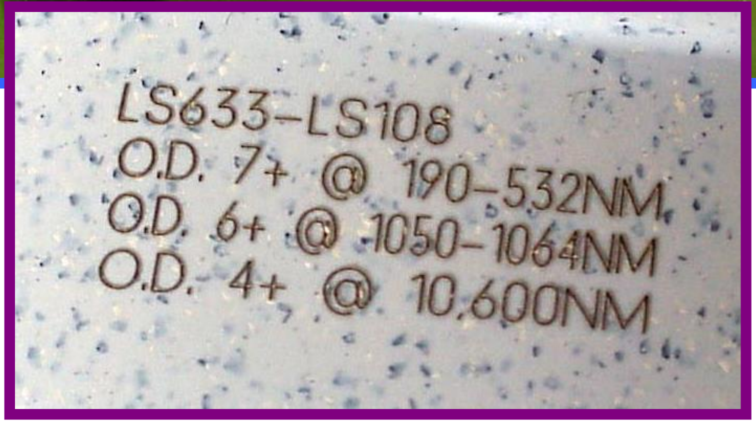
Engineering Control Measures	Classification						
	1	1M	2	2M	3R	3B	4
Protective Housings (4.4.2.1)	X	X	X	X	X	X	X
Without Protective Housing - LSO Hazard Analysis (4.4.2.1.1)	—	—	—	—	—	X	X
Interlocks on Removable Protective Housings (4.4.2.1.3)	▿	▿	▿	▿	▿	X	X
Service Access Panels (4.4.2.1.4)	▿	▿	▿	▿	▿	X	X
Key Control (4.4.2.2)	—	—	—	—	—	•	•
Viewing Windows, Display Screens and Diffuse Display Screens (4.4.2.3)	Ensure viewing limited < MPE						
Facility Window Protection (4.4.2.4)	—	—	—	—	—	X	X
Laser Protective Barriers and Curtains (4.4.2.5)	—	—	—	—	—	X	X
Collecting Optics (4.4.2.6)	X	X	X	X	X	X	X
Fully Open Beam Path (4.4.2.7.1)	—	—	—	—	—	X NHZ	X NHZ
Limited Open Beam Path (4.4.2.7.2)	—	—	—	—	—	X NHZ	X NHZ
Enclosed Beam Path (4.4.2.7.3)	Further controls not required if 4.4.2.1 and 4.4.2.1.3 fulfilled						
Area Warning Device (4.4.2.8)	—	—	—	—	—	•	X
Laser Radiation Emission Warning (4.4.2.9)	—	—	—	—	—	•	X
Class 4 Laser Controlled Area (4.4.2.10 and 4.4.3.5)	—	—	—	—	—	—	X
Entryway Controls (4.4.2.10.3)	—	—	—	—	—	—	X

Safety googles, IR viewer and alignement cards

Filters value (Eye protection)





DANGER

VISIBLE and/ or INVISIBLE LASER RADIATION-
AVOID EYE OR SKIN EXPOSURE TO DIRECT OR
SCATTERED RADIATION.

ND:YAG 1064 nm
100 Watts Max. Average Power

CLASS 4 LASER

Safety rules in a laser lab

- It is mandatory to wear eye protection in laboratories with a operational class 3 or 4 laser.

- Make sure that your eye protection corresponds to the laser in use (wavelength range and optical density (O.D.))

- Any piece of jewelery must be removed prior to entering the lab. This includes the watch which is the most important not to forget.

- It is recommended to wear a labcoat, although not mandatory (class 3 and 4, especially with UV lasers)

- The instructions given by the person responsible of the lab must be followed.

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Instructions for safe beam manipulations

- Clean up your eye protection periodically and make sure it is in good condition. For example, if you need a new cord, or glass, replace it.
- Don't stare into the beam with your eye naked or with an optical instrument
- Never send the laser beam onto another person
- Make sure that the beam is not pointing on a door
- Always keep the beam and optical setup at a reasonnable level lower than the eyes (lower is better) (Most of the accidents)
- If you drop something on the floor, make sure to block the laser beam before passing the head through the beam level. Block or close your eyes and do not face the optical table. This situation may occur several times each day and is very important to take into account.
- In order to align invisible beams, use an IR viewer, fluorescent cards, CCD cameras and cardboard (white or fluorescent).
- Attenuate the laser beam for the alignement procedures

Instructions for safe beam manipulations

- If possible, use an alignement laser when building an optical setup from scratch. (HeNe or a laser diode with similar wavelength).
- Be careful when changing the beam level. Periscope represents a high risk when sending a beam upward. The periscope should be covered to prevent accidents.
- When introducing a new optical component, block the beam, make sure the piece is well positionned and block the beam the nearest distance after to control the new beam position. Fix the optics on the table.
- Oscilloscopes and equipment with a display (reflective screen) must be used on a shelf at a level such that no beam could be deflected from it.
- Working areas (personal computer, lab book) must be organized such that your eyes will no reach a low level. It is highly recommended that such areas are isolated with panels, curtains or barriers.

Instructions for safe beam manipulations

- Always confine the beam with tubes, enclosures, or barriers. It also involves controlling leaks from mirrors which are never 100% reflectives and also reflections from refractive elements such as windows or lenses or crystals.
- Use an exhaust system in the case of processing materials with a laser in order to avoid exposure to particules.
- When manipulating gas cylinders, use a cart for transportation and fix the bottle in a vertical position prior to using.
- Only qualified personnel should open and work inside a laser
- Consider any optical fiber tip as a laser source
- Keep the passage clear of different objects
- The momentary visitors should be given a permission to access a laser lab and there safety taken into account

NONBEAM HAZARDS OF LASERS

Non-beam hazards

Electrical risks:

Most of the laser sytems operate with high-voltage components. Furthermore, some lab equipment and devices are working with HV.

Chemicals:

Laser ablation of certain materials could produce toxic particles (e.g.: plastics).

Some lasers are working with toxic gas (KrF lasers), carcinogenic dyes, solvents or asphyxiating gas.

UV lasers generate ozone (O_3) as the interact with ambiant air.

Non-beam hazards

- **Fire or explosion:**

Pieces of different materials such as paper, tissues, plastic, wood, etc can take fire after being exposed to a laser beam. This can take a seconds to a few minutes so never block a laser beam with such materials and leave the room. Solvents can also take fire or explose if exposed to a powerful laser beam.

- **Gas bottles:**

Gas cylinders must be attached and kept vertical in order to avoid seal break up and high pressure leak (flying cylinder)

(High pressure is hazardous).

[Non-Beam / Ancillary Hazards | Office of Environment, Health & Safety]

https://ehs.berkeley.edu/laser-safety-manual/non-beam-ancillary-hazards

RADIATION EMITTING DEVICES REGULATIONS (LASER PRODUCTS)

Health Canada: October 9, 2024

Changes have been made to the Radiation Emitting Devices Regulations (Laser Products)

Changes concern laser products that are imported, sold or leased in Canada.

- extend the regulatory oversight to a broader range of laser products
- identify types of laser products that are exempt from the regulations
- align the laser radiation safety requirements with an international standard for laser products by adopting certain sections of IEC 60825-1:2014
- introduce the IEC classification system for laser products that ranks devices according to their degree of hazard
- establish testing methods and rules to determine accessible emission levels and assign laser products to a particular hazard class
- require built-in engineering safety features that are appropriate for the laser class to manage exposure to hazardous levels of radiation

The changes also establish labelling requirements and accompanying information to:

- support compliance monitoring, verification and enforcement activities
  - such as requiring specific details to uniquely identify laser products and their manufacturing origins
- help people who purchase, operate and service laser products to make more informed decisions and take appropriate safety precautions

For more information, consult:

Guidance for laser products
https://www.canada.ca/en/health-canada/services/health-risks-safety/radiation/everyday-things-emit-radiation/laser-products/guidance.html

Radiation Emitting Devices Regulations (Laser Products)

OVERALL RESPONSIBILITIES OF MANAGEMENT AND WORKERS

Professeur / Supervisor

Professors are directly responsible for implementing the laser safety program. This includes the implementation of specified hazard controls, oversight and management of non-laser hazards, and informing the LSO of any changes that affect the laser users.

Laser safety officer (LSO INRS)

- Review and approve laser Standard Operating Procedures (SOPs)
- Perform hazard evaluations of laser use areas
- Verify laser classifications
- Specify control measures
- Perform and document audit, surveys and inspections
- Recommend and approve protective equipment
- Investigate laser incidents

Laser user

All users must meet the laser safety training requirement. All laser users are responsible for following hazard controls and notification requirements. Responsibilities include but are not limited to:

- Attend safety trainings.
- Receive appropriate hands on/on the job training.
- Read, understand, sign and follow lab specific laser standard operating procedures (SOPs).
- Wear appropriate Personal Protective Equipment (PPE) in accordance with the campus laser safety program requirements.
- Immediately report any suspected eye exposures to Professor or Authorized User, LSO, or Health and Safety (Santé et Sécurité du Travail)
- Follow any other campus or lab specific safety procedures, requirements, or policies.
- Report any safety concerns to the Professor (or designated Lab Contact) or LSO.

LISTE DES CONTACTS

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Biosécurité

Mireille Cartier 4226

Risques de rayonnements

Susan Yeung 4330

Matières dangereuses

Daniel Pagé 4292

Comité institutionnel de sécurité laser (CISL)

INRS-AFSB Campus Laval
https://www.campus-laval.com/ss_services.php

Questions sur la sécurité lasers

Institut national de la recherche scientifique

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susan.yeung@inrs.ca
http://www.campus-laval.com/ss_services.php

References and Credits

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