Laser Safety

Jean-Paul Mosnier
School of Physical Sciences
Laser Safety Officer
Chair, Faculty Health & Safety Committee

jean-paul.mosnier@dcu.ie

25th January 2017
Lasers around for almost 60 years

- Laser invented in 1960 (57 years ago)
- Predicted theoretically by Einstein in 1917 (stimulated emission)
- Most famous laser of the 60’s! James Bond movie 
  GOLDFINGER (1964)
- What appears to be scientifically incorrect?
Continuum Powerlite III:
1.25 J at 1064 nm converts to 150 mJ at 266 nm via frequency-quadrupling in 6 ns pulse width every 0.1 s

Laser Selfie!

J.P. MOSNIER LASER
Must wear his protective goggles in the lab!

The red laser safety goggles, red laser protective glasses will protect your eyes from the bright red laser beam. Protection wavelength range: 600nm...

Safety goggles for blue laser is a pair of high quality laser goggle that can block blue laser beam with wavelength 400nm-450nm. Do not look direct...

http://www.armlaser.com/
Coloured filter response

Absorption %

[Diagram showing absorption percentage across different wavelengths (nm)]
Large Laser - Large Cables!
Laser Power Supply
Health and Safety

- Prevent accidents and ill health in work place
- Duty of care to protect people
- Implemented by: Technical experts, Health and Safety Adviser, Optical radiation protection officer
- Ownership: ALL USERS MUST BE INVOLVED
**Legal Documents and Standards**

- **Laser Products Safety:**
  - IEC 60825-1 (2007)
  - BS EN 60825

- **User Safety**
  - IEC 60825-14

- **Lamp Safety Standards:** CIE S 009 (2002); IEC 62471 (2006)

- **EC: Artificial Optical Radiation Directive (AORD) issued 2006 to be implemented by 2010**
Health and Safety

- **Workplace vs Product safety regulations:**
  - Provision of a safe product (manufacturer)
  - Safe ways of working (user)
Health and Safety: Basics

- Hierarchy of risk control: ELIMINATE, REDUCE, PROTECT
- Hazard: Anything that can cause harm
- Risk:
  - Likelihood of hazard causing harm (likely, possible, improbable)
  - Associated severity (major, moderate, minor)
  - Type of injury (acute or chronic)
- **MAIN AIM: MINIMIZE THE RISK**
Peer pressure in the laser lab
Almost all you need to know about laser safety!

- Determine the laser class
- Determine the laser wavelength
- Wear appropriate goggles
- Don’t expose your eyes or skin
- Minimize the number of shiny surfaces
- Beware of electrical safety
- Beware of water leaks
- Use warning signs
- Use interlocks (class 4)
Light Fundamentals

- Optical (Electromagnetic) radiation: Invisible (UV and IR) or Visible (wavelength in nm).
  - Ultraviolet (UV)
    - UV C 200 nm - 280 nm Germicidal/sterilising light
    - UV B 280 nm - 315 nm DNA damage and sunburn
    - UV A 315 nm - 400 nm Sunburn and cataract damage
  - Visible: Violet 400 nm - Red 700 nm
  - Infrared (IR)
    - IR A 700 nm - 1400 nm Retinal hazard
    - IR B 1400 nm - 3000 nm Corneal/skin hazard
    - IR C 3000 nm - 1 mm Corneal/skin hazard
Light Fundamentals

- Wavelength of laser is most important characteristic:
  - Identifies a region of the spectrum
  - Determines which protective eyewear to be used
  - Defines the preponderant type of light-tissue interactions:
    - Penetration depth into skin
    - Retinal or corneal damage, skin damages
    - Resonant absorption within tissue (e.g., 440 nm blue light due to pigment in eye)
Light Fundamentals

- Most common lasers from blue-green (Ar+ laser) to deep IR (10.6 microns CO₂ laser).
- Some lasers produce UV light (excimer, laser diodes)
- Spectral widths of the source is important: broad (diodes), narrow (HeNe)
- Some systems can frequency-double: from visible to UV
Definitions and Units

- Stick to SI units! (physicists like to mix!)
- Radiant energy in Joules (J) (specified)
- Radiant power in Watts (W) (specified)
- Energy DOSE (J): Power x exposure time
- Beam cross-sectional area is important:
  - Radiant exposure, energy per unit area J/m$^2$ (fluence)
  - Irradiance: power per unit area W/cm$^2$ or W/m$^2$.
  - 0.4 mW in 7 mm beam diameter = 10 W/m$^2$
Continuous Wave (CW) and Pulsed Beams

- CW Radiant energy = Radiant Power (in watts) x emission time (seconds)
- Single Pulse emission: Peak Power = (Pulse Energy / Pulse duration): 1 Joule in 1 ns is $10^9$ W (Gigawatts).
- Repetitively pulsed laser: Repetition rate or frequency in Hz (eg 10 Hz, 1 MHz)
- Peak power vs average power is important
Duty Cycle %

$T = \text{period (s)}$

$\Delta \tau = \text{pulse width (s)}$

Duty cycle $= \frac{\text{Time on (pulse width)}}{\text{Period}} \times 100\%$

Peak Power (Watts): $P_i = \frac{\text{Pulse energy}}{\text{Pulse width}} = \frac{\varepsilon}{\Delta \tau}$

Average Power (Watts): $\bar{P} = \frac{\text{Pulse energy}}{\text{Period}} = \frac{\varepsilon}{T}$

Average Power $\frac{\bar{P}}{P_i} = \frac{\Delta \tau}{T} \equiv \text{Duty cycle}$
100 mJ Nd:YAG laser, 10 ns pulse width, rep rate 50 kHz.

Peak Power (Watts):

\[ P_i = \frac{0.1}{10 \times 10^{-9}} = 10 \text{ MW} \]

Average Power (Watts):

\[ \bar{P} = \frac{0.1}{20 \times 10^{-6}} = 5 \text{ kW} \]

\[
\frac{\text{Average Power}}{\text{Peak Power}} = \frac{\bar{P}}{P_i} = \frac{5 \text{ kW}}{10 \text{ MW}} = \frac{10 \times 10^{-9}}{20 \times 10^{-6}} \equiv 5 \times 10^{-4}
\]

Duty cycle = \[5 \times 10^{-4} \times 100 \equiv 0.05\%\]
Beam Properties

- Laser beams diverge naturally (Gaussian beam). Typically small (milliradians)
- Typically a few mm diameter
- Lenses can be used to collimate (laser pointer)
- Lenses can be used to expand the beam
- Beams emitted through optical fibres are highly divergent
Laser Fundamentals

- Light amplification by stimulated emission of radiation (LASER)
- Highly directional and monochromatic: Coherent radiation
- Light bulbs are based on spontaneous emission of radiation: Incoherent radiation
Physiology of the eye

- **Aversion response (blink reflex):**
  - Response to visible only
  - Eyelid closes in 100 ms
  - Head turn away in 0.25 s
  - Linked to laser classes 2, 2M and 3R (vis)

- **Optical radiation hazard spectrum:**
  - UV to 400 nm: Front of eye (corneal)
  - 400 nm to 1400 nm: Back of eye (retina)
  - 1400 nm up: Front of eye
Exposure Limits

- Determined by risk to the eye and risk to the skin
- **Maximum Permissible Exposure Limit (MPEL):** Depends on wavelength, exposure duration, irradiance and whether eye or skin
- **Nominal Ocular Hazard Distance (NOHD):**
  - Distance to MPEL (in m)
  - Personnel not allowed within this zone
- Exposure limit values for coherent and non-coherent optical radiation are given in Standards (see refs above)
More data become available
More data become available
What is it based on?

- Maximum Permissible Exposure (MPE)
  - 10% of dose that has 50% chance of doing damage
  - Depends on wavelength, body part, cw or pulsed
  - Visible-IR range, cornea, cw: \( \sim 1 \text{ mW}/\text{cm}^2 \)

- Example: class 1 or class I laser limit
  - Fully dilated pupil: diameter 7 mm, area \( 0.39 \text{ cm}^2 \)
  - Maximum permissible power: 0.39 mW

Note: some lasers have narrower beams
Laser classification: Class 1

- Generally safe and low power (0.3 mW for red laser)
- MPE cannot be exceeded
- Class 1 can be due to total enclosure (e.g., high power UV laser can become Class 4)
Laser classification:
Class 1 M

- M: Aided viewing or Magnification
- Safe for naked eye viewing
- Can be visible or invisible
- Hazardous with Viewing aid
Laser classification: 
Class 2

- Visible lasers only
- Reasonably low power up to 1 mW
- DO NOT STARE INTO THE BEAM
- Blink Reflex must be deployed
- Viewing aids do not increase the beam hazard
Laser classification: Class 2 M

- Same as Class 2
- M: You must NOT use viewing aid under any circumstances
Laser classification: Class 3 R

- Moderate power less than 5 mW
- Prevent direct exposure to beam
- Visible or invisible
- Beam diameter is small
Laser classification: 
Class 3 B

- Hazardous laser beam/Can be any wavelength
- In range 5 mW to 500 mW
- Requires a risk assessment
- Upper limit can be harmful to skin
- Requires eye (+ skin) protective equipment
Laser classification:
Class 4

- Hazardous laser beam/Can be any wavelength
- No upper power limit
- Visible Class 4 exceeds 0.5 W
- Harmful to eye and skin
- Possible scattered light hazard
- Possible fire and fume hazard
Laser Ablation

Atoms, Ions, Molecules
Clusters, Particles

Pulsed Laser Beam
UV lasers

- **Excimer lasers:** gas premix typically contains 0.1 percent of fluorine/chlorine
- **ArF, KrCl, KrF:** UV-C radiation
  - **Eye:** snowblindness
  - **Skin:** sunburn, skin cancer
- **XeCl:** UV-B radiation
  - **Eye:** snowblindness
  - **Skin:** skin aging, increased pigmentation
- **XeF, Nd:YAG tripled:** UV-A radiation
  - **Eye:** cataracts (chemical reactions cloud your vision)
  - **Skin:** skin burn, pigment darkening
Visible/IR lasers

• **CW/pulsed:**
  - protect your eyes (lens focuses by $10^5$!)
  - don’t shoot at your skin
  - visible: burnt retina
  - IR <1400 nm: cataract + burnt retina
  - 1.4-3 µm: makes aqueous humor turbid, cataract, burns cornea

• **Dye lasers:** dyes are carcinogens

• **CO$_2$ lasers:** fire hazard
Good lab design

- Often a competition between hazards:
  - Water
  - Electrical
  - Trip
  - Laser radiation
    - Scatter
    - Direct exposure
- Good management is mostly common sense
  - e.g., don’t forget to remove your watch!
A laser lab (1)

- **Data:**
  - Vacuum chamber
  - Pulsed IR class IV laser
  - Target 10 cm behind glass
  - Target 1.5 m above floor
  - Lens: F.L. 20 cm
  - Lens holder: aluminium

- Can you do better?
A laser lab (2)

- **Beam height:**
  - Unsafe for people >5 ft
  - If you can’t adjust target, move beam out of the way

- **Door:**
  - Don’t shoot laser in that direction!
  - Make sure the system is interlocked – door open, laser off
A laser lab (3)

- **Lens:**
  - Beware of scatter
  - Each surface reflects 4% as a mirror (back into laser!)
    - AR coating
    - Turn lens around
  - You may hit lens holder
    - Spray paint black

- **Window:**
  - 4% reflection focused on lens
A laser lab (4)

- **Adaptability**
  - Can’t easily adjust beam

- **Tripping:**
  - Water/electrical leads all over the floor

- **Invisibility**
  - Can you mount a collinear visible alignment laser?
A laser lab (5)

- **Possible solution:**
  - Co-linear weak visible laser
  - Shorter FL lens
  - Turn lens or beam dump
  - Piped beam
  - Mirrors allow manipulation
  - Laser against wall
  - Beware of pushing against piping
  - Curtain/screen near door