LEO 103: Photonics Fundamentals Learning Unit 3: Assignment

Study Guide: Light Sources and Laser Safety

1. Define the following properties of laser light:
a. Monochromaticity: Laser light, unlike ordinary light, is unique in that it usually consists of only a single color of light. The wavelengths that make up this single color, while not perfectly equal in length, occur within a very narrow range of wavelengths. **Monochromaticity** is the laser light's property of containing only one pure color and a narrow range of wavelengths.

b. Directionality: The light from an ordinary source like a light bulb radiates away from the source in all directions. This spreading or divergence of ordinary light is what makes it so useful for lighting homes and workplaces. Laser light, however, is very **directional**. By comparison, the light emitted by a laser diverges very little.

c. Coherence: Non-coherent light waves produced by ordinary sources don't form an orderly pattern. Their amplitudes combine in a random fashion and produce a resultant wave that is no larger than any of the multiple single waves. Such light is said to be incoherent. By contrast, the waves produced by a laser travel through space in step with one another. They're said to be "in phase" or **coherent**. Since all the separate waves in the beam remain in step with one another, the resultant wave is much stronger than that of any single wave. A very intense, coherent beam is generated.

2. Distinguish between different types of non-laser light sources & identify their characteristics.
a. Incandescent sources: Introduced in the 19th century, composed of a metal filament encased in a vacuum enclosure filled with a gas to increase the filament's lifetime. Tungsten is normally used and alloyed with thorium or rhenium. The most common gas is halogen. They operate very hot (500°).

b. Fluorescent: Fluorescent light sources are low-pressure discharge lamps with a fluorescent phosphor. Most fluorescent lights consist of mercury discharge lamps that emit 90% of their energy at a wavelength of 253.7 nm. These ultraviolet photons can excite a number of phosphors, producing a range of wavelengths from infrared to ultraviolet. Visible wavelengths are characterized as white, warm white, cool white, etc. The two common types of ballast are the rapid-start and the preheat ballast. Most of today's lamps operate with rapid-start ballasts. Luminous efficiency is a ratio of the visible light energy produced by a light source (measured in lumens) to the electrical energy (in watts) needed to power the light source.

c. High-intensity discharge lamps (HID): Can be made of mercury, sodium, or metal halides. The gas pressures inside the lamps are usually 2–4 atmospheres. HID lamps have two envelopes: the inner quartz discharge tube and an outer glass jacket. The outer jacket absorbs the UV radiation generated by the internal operation of the bulb.

d. Flashlamps and arc lamps: Flash lamps and arc lamps are high-intensity discharge devices commonly used in laser technology. Usually contain gases such as xenon and krypton. The flash or arc is initiated by a high voltage placed across the discharge tube. This action in turn ionizes the gas and produces a high-intensity light with output peaks in both the visible and infrared regions of the electromagnetic spectrum.

e. Light-emitting diodes (LED): Semiconductor devices that are directly modulated by varying input current. They are usually made of aluminum-gallium-arsenide (AlGaAs). However, other dopants maybe added to vary wavelength. LEDs are common in fiber-optic communication, pocket calculators, and other visual displays. These devices can emit light in both the visible and infrared regions of the spectrum. Unlike a semiconductor laser (a laser pointer for example), a light-emitting diode emits light in all directions and has a low irradiance. Power from LEDs generally is in the microwatt range up to maybe a few milliwatts. LEDs are small in size, low temperature, rugged, and inexpensive devices. They operate with pn junctions.

3. Record various non-beam hazards such as electrical and chemical hazards.

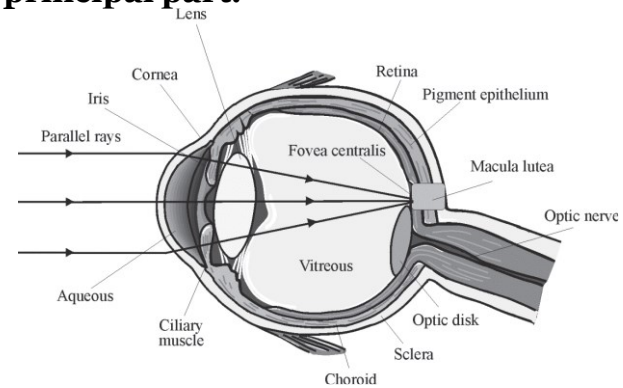
Fire hazard: Class 4 laser systems represent a fire hazard. Enclosure of Class 4 laser beams can result in potential fire hazards if enclosure materials are likely to be exposed to irradiances exceeding 10 W/cm^2 or beam powers exceeding 0.5 W. The use of flame-retardant materials is advisable and necessary.

Explosion hazard: High-pressure arc lamps, filament lamps, and capacitor banks in laser equipment shall be enclosed in housings that can withstand the maximum explosive pressure resulting from component disintegration. The laser target and elements of the optical train that may shatter during laser operation shall also be enclosed or equivalently protected to prevent injury to operators and observers. Explosive reactions of chemical laser reactants or other laser gases may be a concern in some cases.

Electrical hazard: The use of lasers or laser systems can present an electric shock hazard. This may occur from contact with exposed utility power use, device control, and power-supply conductors operating at potentials of 50 volts and above. These exposures can occur during laser
setup or installation, maintenance, and service, where equipment protective covers are often removed to allow access to active components as required.

Chemical hazards: Dye lasers use a complex fluorescent organic compound that, when in solution with certain solvents, forms a lasing medium. Certain dyes are highly toxic or carcinogenic. These dyes have to be frequently changed and therefore, special care must be taken when handling, preparing solutions, and operating dye lasers. Low-permeability gloves should be worn by personnel any time a situation arises where contact with a dye/solvent may occur.

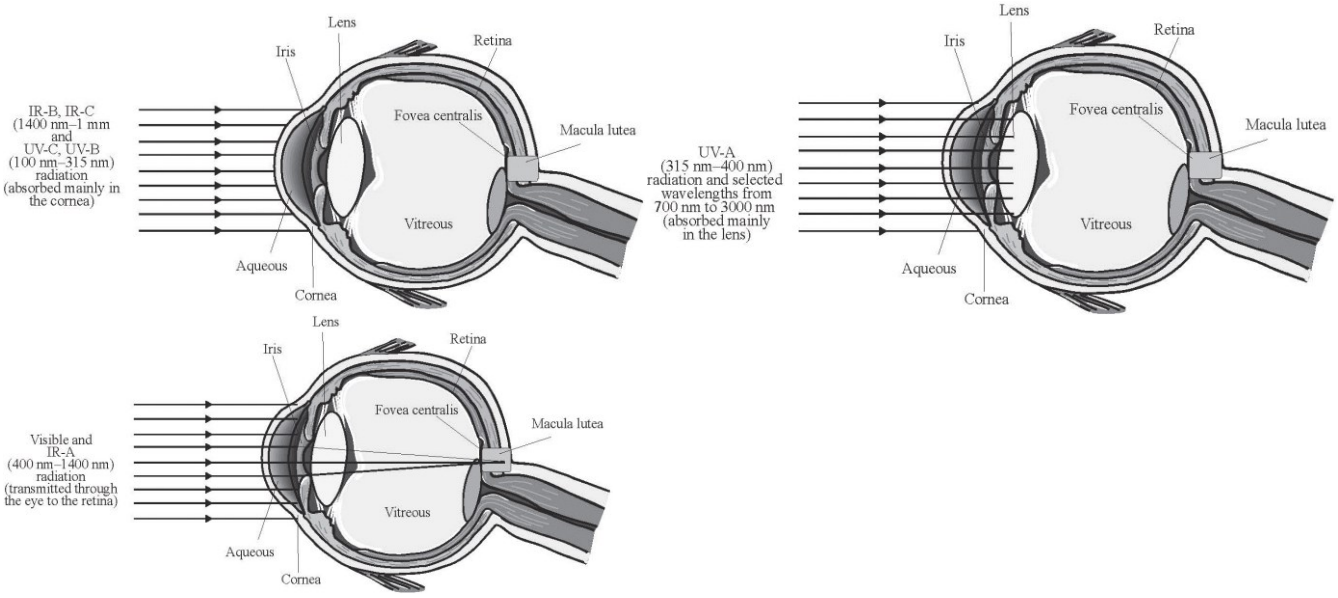
4. Label a diagram of the human eye, showing its principal parts. State the function of each principal part.



The light irradiance (in units of watts/m2) of the image formed on the retina is 100,000 times greater than the light irradiance at the front of the eye. It is this considerable optical gain that creates an eye hazard when stray laser beams enter the eye.

Cornea: outermost, transparent layer. It covers the front of the eye. The cornea can withstand dust, sand, and other assaults from the environment. That's partly because corneal cells replace themselves in about 48 hours. Thus, mild injuries to the cornea are healed quickly.
Aqueous humor: a liquid (mostly water) between the cornea and the lens. The water in the aqueous humor absorbs heat, so it protects the internal portion of the eye from thermal (heat) radiation. The index of refraction is approximately 1.33, same as water.
Lens: flexible tissue that changes shape. In conjunction with the cornea, the lens focuses light on the back of the eye. When the lens changes shape, its focal length also changes. This enables the eye to focus on both near and far objects.
Iris: controls the amount of light that enters the eye. The iris is the pigmented or colored part of the eye. It responds to light intensity by adjusting its size. The change in iris size adjusts pupil size and controls the amount of light admitted to the eye.
P**upil:** the opening in the center of the iris through which light passes. The size of a pupil changes from about 2 mm to 7 mm, according to the brightness of light in the environment. The darker the environment, the larger the pupil will be. A fully dilated pupil (expanded to admit the greatest amount of light) is considered to be about 7 mm.
Vitreous humor: a colorless gel that fills the large area at the center of the eyeball. The vitreous humor helps to maintain the shape of the eye.
R**etina:** the light-sensitive layer located at the back of the eye. Think of it as a sort of viewing screen on which the cornea and lens focus an image. The retina contains two types of photoreceptor (light-receiving) cells: rods and cones. These cells convert the optical image produced by the lens into electrical signals. The signals then are transmitted to the brain.
F**ovea:** most sensitive, central part of the retina. It's the area responsible for the most detailed vision. A foveal lesion caused by laser radiation is a worst-case scenario for vision.
O**ptic nerve:** carries electrical impulses from the retina to the brain.

5. Match the parts of the eye with the spectral regions to which they are most vulnerable.



6. Given the basic information required, calculate retinal spot size and retinal irradiance.

Example 1 and then Example 2:

A 1-mW HeNe laser beam with a divergence of 0.5 mrad enters the eye. Find the irradiance on the retina if the focal length of the eye, from cornea to retina, is equal to f = 1.7 cm.

Power P = 1 mW
Full-angle divergence (beam spread) θ = 0.5 mrad
f = focal length of eye focusing system (1.7 cm)

Diameter of retinal spot size: d = f θ
Area of the spot: A = $\pi d^2/4$
Retinal Irradiance: E_{Ret} = Power in beam focused on retina/Area of focused spot

7. Describe the following laser classifications based upon the potential hazards to include the representative power levels:

a. Class 1:
may produce visible or invisible laser radiation. Under all normal conditions of operations, Class 1 lasers are considered to be incapable of causing injury from directly viewing the beam. Class 1M adds "unless beam is viewed with an optical instrument, such viewing is prohibited.

b. Class 2:
visible laser power no greater than 1 milliwatt, does not have enough output power to injure a person accidentally. Eye protection is normally afforded by the natural aversion response (blink reflex) time (0.25 s), but eye injury may occur if stared at for a long period. Direct viewing of Class 2 laser radiation is prohibited. A "caution" label must be on the device.

c. Class 3a/R:
CW output power of a visible laser between 1 to 5 mW and the normal aversion response is generally sufficient to prevent injury from inadvertently viewing the output with the unaided eye. Eye exposure to lasers that produce ultraviolet light or infrared emissions may not be perceived by the eye. For such lasers, the Class 3R accessible emission limit does not rely upon the normal aversion response, but rather on the fact that the eye does not fixate on the beam long enough to cause injury. However, the use of collecting optics can produce retinal irradiances that are considered capable of causing injury.

d. Class 3b/B:
visible or invisible light lasers from 5 to 500 mW can produce eye injury when viewed directly or with optics, without eye protection. Normal aversion response does not prevent injury. This class of laser requires a danger label and could have dangerous specular reflections. Class 3B lasers do not usually produce a hazardous diffuse reflection or fire hazard. At the upper end of the Class 3B range, skin burns may be possible. ***Eye protection is required.***

e. Class 4
visible and invisible lasers that have >500 mW and can injure you by directly viewing either the specular or diffuse reflections of the beam. Are capable of causing injury to the eye and skin as well as producing dangerous specular and diffuse reflections. They can also produce a fire hazard. A danger sign will label this laser. ***Eye and skin protection is required.***

8. Define maximum permissible exposure (MPE). State why it's important.
Take into account the output characteristics of the laser which include wavelength, output energy and power, size of the irradiated area, and duration of exposure. If you're using a pulsed laser, you also must consider the pulse repetition rate. Maximum Permissible Exposure limits indicate the greatest exposure that most individuals can tolerate without sustaining injury. The MPE involves both an incident *irradiance* level and an *exposure* time. Thus, an MPE is usually expressed in terms of the allowable exposure time (in seconds) for a given irradiance (in watts/cm2) at a particular wavelength.

9. Describe three general types of laser hazard controls.
Engineering controls involve design features or devices applied to the laser, laser beam, or laser
environment that restrict exposure or reduce irradiance. Such controls include beam shutters, beam attenuators, remote firing and monitoring systems, and the protective housing placed entirely around some laser systems.
Administrative control measures involve procedures and information rather than devices or mechanical systems. Some important administrative controls are posting of warning signs and labels, establishment of standard operating procedures (SOP), and safety training.
Personal protective equipment is worn by personnel using the laser or being in the vicinity of the laser. This control includes protective eyewear, gloves, and special clothing. Table 3-2 lists some of the more commonly used control measures for Class 3b, Class 3B, and Class 4 lasers and laser systems.

10. Describe laser-hazard warning signs.
Signs used for lasers and laser systems are the DANGER, CAUTION, and NOTICE signs.
Caution used for a Class 2 laser and some Class 3a lasers, depending on their irradiance.
Danger used on some Class 3a, Class 3b, and Class 4 lasers and laser systems.
Notice used in a temporary laser controlled area while service or repair is being done.

11. Describe the most frequent causes of laser accidents.
Most laser accidents occur because adequate control measures are not in place: for example, doing alignment procedures without laser safety eyewear or wearing the wrong eyewear for the laser used

12. List five laser safety precautions that are applicable to all types of lasers.
1. Avoid looking directly into any laser beam or at its reflection.
2. Remove all unnecessary specular (shiny) reflecting surfaces from the work area.
3. Operate lasers in well-defined areas to which access can be controlled. The area should be posted with appropriate signs to alert persons passing by the area that a potential hazard exists.
4. The laser system should be operated only by or under the direct supervision of a person knowledgeable of the hazards and control methods for both beam and nonbeam conditions. This individual is usually the laser safety officer (LSO) who is designated by the administration of the company, hospital, or educational institution. The LSO shall have the authority and the responsibility to effect monitoring and enforce the control of laser hazards and to achieve the knowledgeable control of laser hazards.
5. Any accident should be reported immediately to the responsible medical authority. If there is an accidental exposure to the eye, the services of an ophthalmologist should be sought

13. Explain the difference between incandescent and fluorescent light sources.
a. Incandescent sources: composed of a metal filament encased in a vacuum enclosure filled with a gas to increase the filament's lifetime.
b. Fluorescent sources: are low-pressure discharge lamps with a fluorescent phosphor. Most fluorescent lights consist of mercury discharge lamps that emit 90% of their energy at a wavelength of 253.7 nm.

14. Calculate the irradiance of a laser beam in watts/cm² if the power of the laser beam is 500 milliwatts and the diameter of laser beam is 2 mm.
P = 500 mW which is .5W
D = 2 mm which is .2 cm

Irradiance: E = P/A
Area of the spot: A = $\pi d^2/4$
3.1416 x (.2 cm)²/4
3.1416 x .04cm² = .125664cm²
.125664cm² / 4 = **.031416cm²**

Irradiance: E = P/A ∴ .5W / 0.031416cm² = **<u>15.9W/cm²</u>**

15. Explain when to use a:
a. Caution signs are used for a Class 2 laser and some Class 3a lasers, depending on their irradiance.
b. Danger signs are used on some Class 3a, Class 3b, and Class 4 lasers and laser systems.
c. Notice signs are used in a temporary laser controlled area while service or repair is being done.

16. Calculate the transmission through filters with the following optical densities:
$T = 10^{-OD}$
a. OD = 2
$T = 10^{-OD}$ = .01
b. OD = 5
0.00001
c. OD = 6
0.000001
d. OD = 8
0.00000001

17. Explain the difference between engineering controls, administrative controls, and personal protective equipment in regard to control measures.
Engineering controls involve design features or devices applied to the laser.
Administrative controls involve procedures and information such as standard operating procedures (SOP)
PPE's are worn by the personnel operating, maintaining or in the vicinity of the laser.

18. Explain the role of the laser safety officer (LSO) in an industrial environment.
The laser system should be operated only by or under the direct supervision of a person knowledgeable of the hazards and control methods for both beam and nonbeam conditions. This individual is usually the laser safety officer (LSO) who is designated by the administration of the company, hospital, or educational institution. The LSO shall have the authority and the responsibility to effect monitoring and enforce the control of laser hazards and to achieve the knowledgeable control of laser hazards

19. Identify the maximum intrabeam permissible exposure (MPE) for the eye:
a. CO_2 laser for 10 seconds
.1 W/cm^2 from Table 3-3
b. HeNe laser for 0.25 second
2.5×10^{-3} W/cm^2 from Table 3-3
c. Argon laser for 600 seconds
16.7×10^{-6} W/cm^2 from Table 3-3
d. XeCl laser for 30,000 seconds
1.3×10^{-6} W/cm^2 from Table 3-3

20. Discuss the nonbeam hazards described in this module and suggest procedures and controls to reduce or eliminate them.
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