Light Sources and the Eye

The wavelength of the light emitted by a source depends on several factors, mainly the material of the source and its atomic or molecular energy. In the visible spectrum, 400nm violet light and 700nm red light border the visible spectrum. As technicians, we usually correlate wavelength to color, however, it is more accurate to correlate frequency to color. Why? When light enters a medium or different index of refraction, the wavelength and speed change. The frequency and color are always constant. When a HeNe (Helium Neon) laser is directed into a tank of water, the wavelength shifts to the low 400nms or violet light, but the color of the light is still the same.

White light is the combination of three or more colors of the spectrum. Red, Green, and Blue are the primary colors for devices that emit their own light. Equal amounts of the three primary colors results in a white color. When white light enters a higher index material, like a prism, the light is split into its component frequencies, or more commonly called color dispersion. The higher frequency or energy photons bend more than the lower energy photons. So in our visible spectrum, violet light bends the most, red light bends the least. This separation also happens in water droplets causing a rainbow to appear in the sky.

Laser light is a pure light. Lasers emit close to a single frequency of light or one color, known as monochromatic. Lasers emit light that has very low divergence, or spreading of the beam. This makes them highly directional and this comes in handy for pointing or aligning in construction applications. If light waves are present at the same place and time, they have the possibility of adding together to form a resultant wave. If the frequencies are different, the resultant wave is mostly noisy or there is not much of a change in the overall intensity. On the other hand, if the light is coherent, the same frequency and in phase, the constructive interference creates an increase in overall intensity.

Regular old light bulbs or more technically, “incandescent lights,” emit mostly infrared light, but most emit many of our useful visible wavelengths. The light comes from a tungsten wire suspended between two small posts, and when current is applied to the wire, it heats to over 400 degrees Fahrenheit and emits light in all directions.

HIDs, or High Intensity Discharge, lamps are used in gyms and large industrial areas because of their intense output. They are typically mercury and can emit hazardous UV light if a borosilicate outer glass is not used to absorb the UV light. These are the lights that take forever to come back on if they are turned off hot.

Extremely bright flashes of light that come from laser cavities are produced by “flashlamps.” Krypton or Xenon are common flashlamp elements. They emit line spectra (wavelengths given off) that closely match the absorption spectra (wavelengths being absorbed) of common solid state laser materials. They operate off of a high voltage supply. They put out enough energy that they usually have to be water cooled.

Semiconductor light sources such as LEDs and OLEDs are gaining popularity as common light sources. Traffic lights, car and trailer stop lights, boat directional lights, and even home lighting are using LEDs because of advances in brightness and lifetime. An LED operates off of around 3 volts and 10s of milliamps. LEDs are made of two different semiconducting materials grown next to each other. One material is positive “P” and has “holes” or a deficiency of electrons. The other material is negative “N” and has an excess of electrons. When a voltage is applied across the device and it is high enough, around 3 volts, electrons begin to jump the gap to fill the holes. When they jump, the gap energy is released in the form of a photon. Even though these light sources are very popular, lasers are way cooler.

We have to use caution when using any of the light sources, as not to damage any part of our own or anyone else’s body. The eye is the most sensitive to light. Therefore, it requires a brief lesson on what effects light can have on different parts of our eye. Basically, light or laser safety comes down to wearing the proper personal protective equipment ALL of the time when possible hazards are near. I have been asked “will it hurt if you look into a laser pointer?” My response is “Will it hurt if you grab the bar and chain of a running chain saw?” I’m positive it will, but I’m not about to find out.

Let’s look at the eye in more detail. The cornea of the eye is the outer layer. It is a transparent protein chemically similar to the white of an egg. When long wavelength CO_2 laser light strikes the cornea, it heats it much like a hot frying pan heats an egg white. Ultraviolet exposure of the cornea produces a photochemical effect called ‘Photokeratitis,’ also known as welder’s flash. This is a painful but temporary condition because the eye, to an extent, can automatically repair the cornea. The lens of the eye absorbs ultraviolet light. The long term effect is the formation of scar tissue on the surface of the lens. This is called a cataract. Reducing UV exposure is important in preventing cataracts later in life. Polycarbonate glasses block the wavelengths most likely to cause cataracts. The Macula-Lutea is the area of the retina with the greatest concentration of cones for color vision and high visual acuity. Damage to the Macula will result in the greatest loss of vision. The Fovea is a dip in the center of the Macula and is the part of the eye that is the image plane or screen for detailed vision.

Light is transmitted to the retina in the wavelength range of 400 to 1400nm. The ANSI Standard considers 400 to 700nm to be visible. In this wavelength range, a hazardous eye exposure to a CW laser will result in an aversion response that protects the eye within 0.25 seconds. Light in the range of 700 to 800nm becomes progressively less visible. The aversion response and visual estimates of power are not reliable for wavelengths longer than 700nm. Even though there is some visual response, these wavelengths are considered to be infrared for purposes of hazard analysis. The factor that limits transmission at the blue end of the curve is absorption in the lens of the eye. The factor that limits transmission at the IR end is absorption by water. The dip at 1000nm is also due to water absorption. The ANSI correction factor CC adjusts the MPE for pre-retinal absorption for wavelengths longer than 1150nm. If we look at the entire electromagnetic spectrum, our visible portion is quite small, and the Laser portion runs from 50nm to 1mm. If a laser beam is viewed directly, it could burn light spots on the macula of the retina. 0.25 second (quarter of a second) exposures from a green laser beam with a power of 10 mW will heat the retinal tissue to the point that the protein cooks, producing a “white burn.”

This is the most common type of laser eye injury in humans. It is likely that thousands of people have received these small retinal burns. They are permanent blind spots. If the burn is outside the Macula, the effect on vision is small. If the burn is inside the Macula, the effect is much greater. One such burn in the center of the Macula will mean that you cannot thread a needle using that eye. A slightly larger spot or multiple spots will make reading difficult. This type of injury can be prevented by wearing laser safety eyewear.

Working with Infrared pulsed lasers without laser safety eyewear creates another problem. Cases where the retina of a human who experienced an eye injury from a repetitive pulse near infrared laser have been documented. The beam was invisible. In such cases, people do not usually realize they are being exposed until their vision has been severely affected. The person's eye was moving during this exposure. This resulted in a line of laser burns on the retina. The laser safety eyewear would have prevented this injury.

In a case of an eye that received a single short pulse laser pulse, the laser energy was absorbed in a small volume of the retina. Most of the energy was absorbed in a thin layer at the back of the retina called the pigment epithelium. This is a layer pigmented by melanin, the substance that colors skin. It absorbs most of the light entering the eye. This prevents light scattering in the eye that would blur vision. When a short laser pulse is absorbed in this layer, the energy heats the melanin grains. This thermal energy is transferred to the surrounding water, resulting in a microscopic steam explosion. The shockwave from this explosion ruptures blood vessels in the surrounding tissue. This causes hemorrhaging in the ocular medium and inside the retinal layers. This can be seen as the darkened area surrounding the lesion. This part of the retina will die. The resulting blind spot will destroy the central vision of this eye. Hundreds of humans have lost significant vision because of such injuries. Wearing appropriate laser safety eyewear would have prevented these injuries.

Short pulse lasers produce the greatest eye hazards. Each short pulse results in a tiny explosion in the retina. The resulting shockwave causes severe damage to the retinal tissue. Permanent destruction of the macular region is possible. Visual acuity in the eye could reach approximately 20/400 and will not improve. Once again, these injuries could be prevented if the individuals would wear the appropriate laser safety eyewear.

Irradiance is the key to many laser applications and to understanding possible hazards. Irradiance is the power density of a beam or how much optical power is squeezed into a small area. The smaller the diameter of the beam, the larger the irradiance. Irradiance is high enough in many industrial applications to heat a metal surface to vaporization temperatures.

If your eye is illuminated with a laser beam, let's say 2 mW, and it covers your 7mm iris, the focused light will have an irradiance of 1000 W/cm^2. In humans, the eye is one organ that can be exposed to laser light. The other is skin. Skin is made of two main layers, the epidermis or outermost layer, and the dermis or inner layer. The epidermis absorbs IR-B&C and UV-B&C wavelengths. It transmits or reflects visible and IR-A wavelengths. There are two effects light has on skin. One is thermal effects, or heating. The other is photochemical effects, like suntans. The thermal effects are temporary or the heat is

transferred eventually. Photochemical effects are actinic, or continue to build after each exposure, like the darkening of skin after many days in the sunlight.