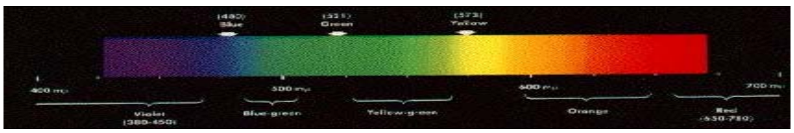
# Radiometry

Radiometry is the measurement of optical radiation, corresponding to wavelengths between 0.01 and 1000 μm, and includes the regions commonly called the ultraviolet, the visible and the infrared.




# Energy & Power

Energy, Q, is measured in joules (J). Think of this as the number of photons in a beam of em radiation since each photon is a discrete packet of energy.

Power, $\Phi$, is the derivative of energy with respect to time, d$Q$/dt, and the unit is the watt (W = J / s).

Energy is the integral over time of power, and is used for pulsed sources.

Power is used for continuous sources

# Radiometric Quantities

Irradiance, E, is measured in $W/m^2$. Irradiance is power per unit area incident from all directions onto a surface.

Radiant exitance, M, which is power per unit area leaving a surface. This also has the units of $W/m^2$.

Radiant intensity, I, is measured in W/sr. Intensity is power per unit solid angle.

Radiance, L, is measured in $W/m^2$-sr. Radiance is power per unit projected area per unit solid angle.

# Laser Classes

| CLASS | Maximum Power | Comment |
|---|---|---|
| I | <0.38 μW | No ocular hazard |
| II | <1 mW | No retinal burns <0.25 sec, aversion |
| IIIa | <5 mW | 1 sec burn threshold |
| IIIb | <500 mW | No skin burns < 1.0 sec |
| IV | >500 mW | Ocular, skin and fire hazard |

# Maximum Permissible Exposure

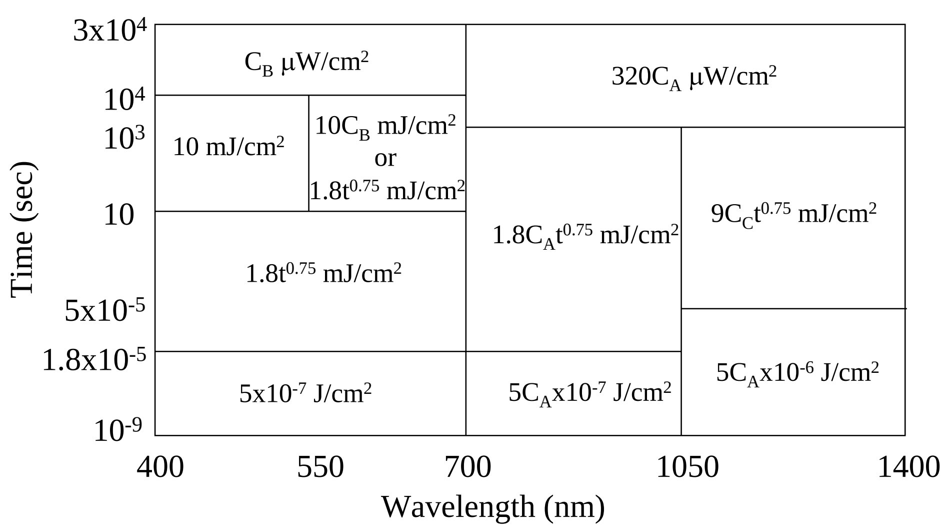
Somewhat self-explanatory. This is the amount of energy or power that can be safely viewed with the eye without damage. It is an order of magnitude below damage threshold.

The following constants are defined for MPE:

$$C_A = \begin{cases} 1 & 0.4 \le \lambda < 0.7\mu m \\ 10^{2(\lambda-0.7)} & 0.7 \le \lambda < 1.05\mu m \\ 5 & 1.05 \le \lambda < 1.4\mu m \end{cases} \qquad C_B = 10^{15(\lambda-0.55)} \quad \text{for } 0.55 \le \lambda \le 0.77$$

$$C_C = \begin{cases} 1 & \lambda < 1.15\mu m \\ 10 & 1.15 \le \lambda < 1.20\mu m \\ 8 & 1.20 \le \lambda < 1.40\mu m \end{cases}$$

# Maximum Permissible Exposure



# Example

MPE levels are given in terms of energy flux (i.e. $J/cm^2$). Power meters usually measure power in W or irradiance in $W/cm^2$. Need to convert units depending on situation.

What is a safe power level for shining a HeNe laser into the eye for 2 seconds?

$MPE = 1.8t^{0.75}$ $mJ/cm^2$ = 3.027 $mJ/cm^2$ for t = 2 sec

MPE assumes a large pupil of 7 mm as worse case scenario.

$Q = [3.027\ mJ/cm^2][\pi(0.35)^2\ cm^2] = 1.165\ mJ$

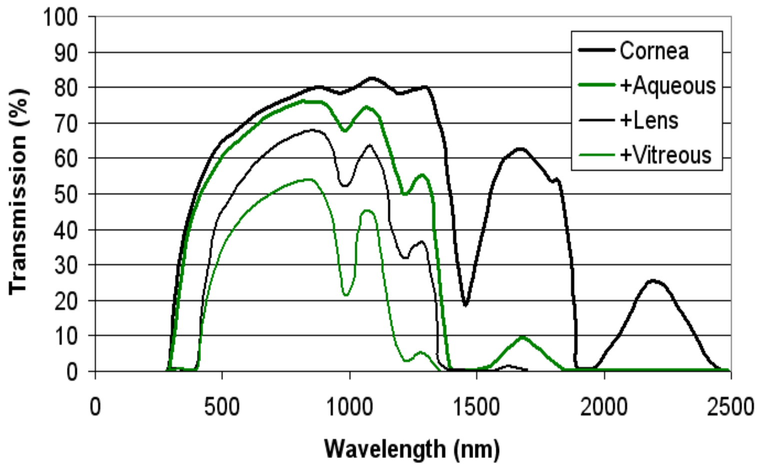
Compute Power

$\Phi = 1.165\ mJ / 2\ sec = 0.5825\ mW$

# Ocular Tissue Absorption

| Wavelength | Absorbing Structure | Effects |
|---|---|---|
| 180 nm - 315 nm | Cornea | Photokeratitis (Welder's Flash) |
| 315 nm - 400 nm | Lens | Cataracts |
| 400 nm -780 nm | Retina | Retinal Lesions |
| 780 nm -1.4 μm | Lens & Retina | Glassblower's Cataracts & Retinal Lesions |
| 1.4 μm - 3.0 μm | Cornea & Lens | Glassblower's & Thermal damage |
| 3.0 μm - 1.0 mm | Cornea | Thermal damage |

# Ocular Transmission




# Ultraviolet Hazards

Different regions of the ultraviolet spectrum have different damage mechanisms.

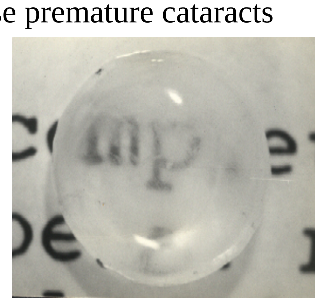
| Label | Wavelength Band (nm) |
|---|---|
| UV-A | 315-400 |
| UV-B | 280-315 |
| UV-C | 100-280 |

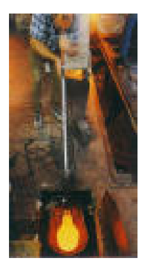
# Photokeratitis

- Also, known as welder's flash and snow blindness.
- Front surface of cornea is covered by thin layer of epithelial cells that regenerate on a weekly basis.
- UV-B damages these cell and pain and poor vision can result.
- Typically, only lasts a couple of days until new epithelial cells resurface the cornea.

# Glassblower's Cataract

- Intensely heated glass gives off lots of infrared radiation (think of blackbody sources).
- Chronic exposure to these wavelengths (10-15 years) can cause premature cataracts

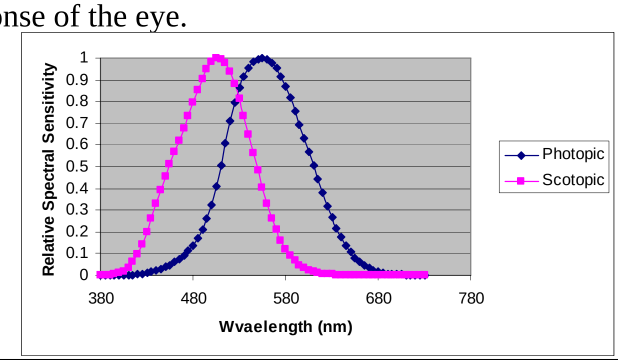




# Photometry

Photometry is the measurement of light, which is defined as electromagnetic radiation which is detectable by the human eye. It is thus restricted to the wavelength range from about 360 to 830 nanometers.

Photometry is just like radiometry except that everything is weighted by the spectral response of the eye.

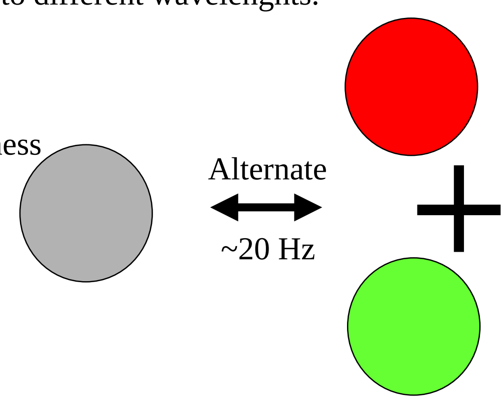



# Measuring Response Curves

Heterochromic flicker photometry is a technique for measuring the sensitivity of the eye to different wavelenghts.

At this frequency, the spot will appear to flicker. The observer adjusts the brightness of the red spot until flicker is gone.

Brightness of red spot to brightness of green spot is the relative sensitivity.



# Radiometric vs. Photometric Units

| Radiometric | Photometric |
|---|---|
| Watt(W) | Lumen(lm) |
| $W/m^2$ | $lm/m^2$ = lux |
| W/sr | lm/sr = candela (cd) |
| $W/m^2$-sr | $lm/m^2$-sr = $cd/m^2$ |

# Luminous Flux

Luminous Flux (think Power), $\Phi_v$, is in units of Lumens (lm) and is given by

$$\Phi_v = 683\int \Phi(\lambda)V(\lambda)d\lambda$$

for photopic vision, where V(λ) is the photopic response curve. There are 683 lm per W at a wavelength of 555 nm. For scoptic vision

$$\Phi_v = 1700\int \Phi(\lambda)V'(\lambda)d\lambda$$

where V'(λ) is the scotopic response curve.

# Photometric Quantities

Illuminance, $E_v$, is measured in $lm/m^2$ (aka lux). Irradiance is the photopically weighted power per unit area incident from all directions onto a surface. Most light meters measure this quantity.

Luminous intensity, $I_v$, is measured in lm/sr (aka candela, cd). Intensity is spectrally weighted power per unit solid angle. Typically, only for small sources.

Luminance, $L_v$, is measured in $lm/m^2$-sr (aka $cd/m^2$). Luminance is the spectrally weighted power per unit projected area per unit solid angle. It gives the “brightness” of an source.

# Luminance

| Scene | Luminance ($cd/m^2$) |
|---|---|
| Clear Day | $10^4$ |
| Overcast Day | $10^3$ |
| Heavily Overcast Day | $10^2$ |
| Sunset Overcast Day | 10 |
| 15 Minutes After Sunset, Clear | 1 |
| 30 Minutes After Sunset, Clear | $10^{-1}$ |
| Bright Moonlight | $10^{-2}$ |
| Moonless Clear Night | $10^{-3}$ |
| Moonless Overcast Night | $10^{-4}$ |

# Retinal Illuminance

A common unit for measuring Retinal Illuminance is the Troland, instead of lux.

Troland = (Luminance in $cd/m^2$)x(Pupil Area in $mm^2$)

Retinal Illuminance (Trolands) = 278 $E_v$ (lux)

Example: A piece of paper in sunlight has a luminance of about 10000 $cd/m^2$. Typical pupil sizes in bright sum are 2 mm

$(10000\ cd/m^2)(\pi 1^2) = 31400$ Trolands