Radiometric vs. Photometric Units

For many applications, light emitting diodes (LEDs) provide a low cost, reliable alternative to traditional light sources such as the incandescent light bulb, halogen bulbs, or arc lamps. Applications involving these former light sources gave rise to photometric measures for power, brightness, etc. Since Thorlabs typically provides radiometric specifications for our laser diodes, this overview is to serve as the bridge between the two regimes.

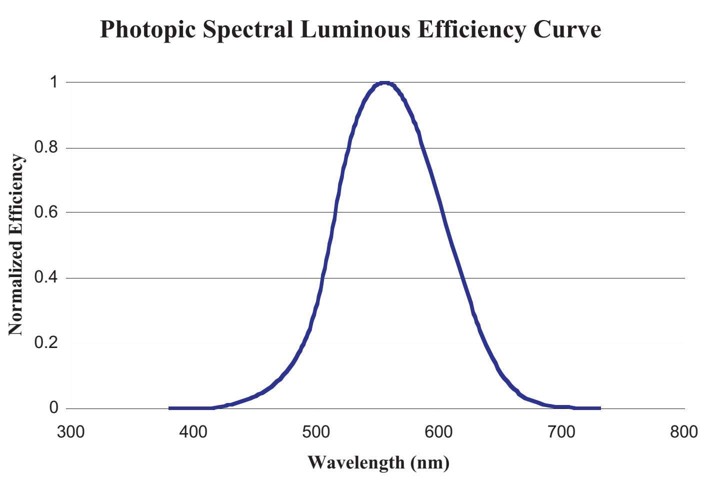
Depending on the LED, the specifications might be given using any of the following radiometric quantities: power (also called radiant flux and measured in watts (W)), irradiance (measured in W/m^2), radiant intensity (measured in watts per steradian (W/sr)), and radiance (measured in $W/m^2 \cdot sr$). The corresponding photometric quantities, which are listed in the table below, are based on the SI unit for luminous intensity, the candela (cd). Values reported in candelas are weighted by a spectral luminous efficiency function, which represents the human eye's sensitivity to the light at a given wavelength. Hence, candelas are a photometric unit, thereby giving information about the perceived brightness of a source; in contrast, power, irradiance, radiant intensity, and radiance are radiometric units, thus providing information about the absolute brightness of a source.

Based on the candela, three other photometric quantities are also commonly used to specify power measurements for LEDs: luminance (measured in cd/m^2, which is also sometimes referred to as a Nit), luminous flux (whose SI unit is the lumen (lm)), and illuminance (whose SI unit is the lux (lx)). Therefore, each radiometric quantity has a photometric counterpart, which is weighted by the spectral response of the human eye.

To convert between radiometric and photometric units, one needs to know the photopic spectral luminous efficiency curve V(λ), which gives the spectral response of the human eye to various wavelengths of light. The original curve, which is shown below, was adopted by the Commission on Illumination (CIE) as the standard in 1924 and is still used today even though modifications have been suggested.

QUANTITY	RADIOMETRIC	PHOTOMETRIC
Power	W	Lumen (lm) = cd·sr
Power Per Unit Area	W/m^2	Lux (lx) = $cd \cdot sr/m^2 = lm/m^2$
Power Per Unit Solid Angle	W/sr	Candela (cd)
Power Per Unit Area Per Unit Solid Angle	$W/m^2 \cdot sr$	$cd/m^2 = lm/m^2 \cdot sr$ = nit

Empirical data shows that the curve has a maximum value of unity at 555nm, which is the wavelength of light at which the human eye is most sensitive, and trails off to levels below 10^{-5} for wavelengths below 370nm and above 780nm.



A non-linear regression fit to the experimental data yields the approximation,

$$V(\lambda) = 1.019e^{-285.4(\lambda - 0.559)^2},$$

where the wavelength is in micrometers.

According to the definition for a candela, there are 683 lumens per watt for 555nm light that is propagating in a vacuum. Hence, for a monochromatic light source, it is fairly simple to convert from watts to lumens; simply multiply the power in watts by the appropriate V(λ) value, and use the conversion factor from the definition for a candela.

For example, the photometric power of a 5mW red (λ = 650nm) laser pointer, which corresponds to V(λ) = 0.096, is 0.096 x 0.005W x 683lm/W = 0.33lm, whereas the value for a 5mW green (λ = 532nm) laser pointer is 0.828 x 0.005W x 683lm/W = 2.83lm. Thus, although both laser pointers have the exact same radiant flux, the green laser pointer will appear approximately 8.5 times brighter than the red one assuming both have the same beam diameter.

Conversion from radiometric to photometric units becomes more complex if the light source is not monochromatic. In this case, the mathematical quantity of interest is

$$\Phi_V = K_m \int_{\lambda=380}^{\lambda=830} \Phi_E(\lambda) V(\lambda) \delta\lambda$$

where Φ_v is the luminous flux in lumens, Km is a scaling factor equal to 683 lumens per watt, $\Phi_E(\lambda)$ is the spectral power in watts per nanometer, and V(λ) is the photopic spectral luminous efficiency function. Note that the integration is only carried out over the wavelengths for which V(λ) is non-zero (i.e. λ = 380 - 830nm). Since V(λ) is given by a table of empirical values, it is best to do the integration numerically.