

Photometric definitions

Radiometry is the measurement of optical radiation, which is electromagnetic radiation within the frequency range between 3×10^{11} and 3×10^{16} Hz (0.01 to 1000 micrometres).

Photometry is the science of measuring visible light in units that are weighted according to the sensitivity of the human eye. It is a quantitative science based on a statistical model of the human visual response to light under carefully controlled conditions.

The subjective impression of seeing can be quantified for “normal” viewing conditions. In 1924, the *Commission Internationale d’Eclairage* (International Commission on Illumination, or CIE) asked over one hundred observers to visually match the “brightness” of monochromatic light sources with different wavelengths under controlled conditions. The statistical result (the so-called CIE photometric curve shown in **Figure 1**) shows the *photopic luminous efficiency* of the human visual system as well as the corresponding *absolute luminosity* as a function of wavelength.

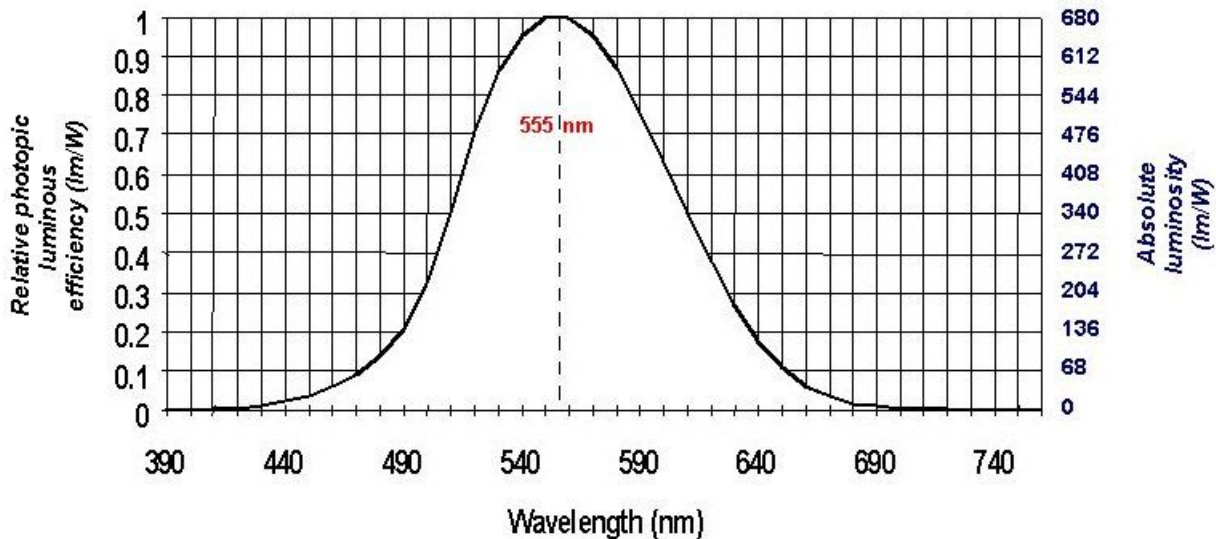


Figure 1. CIE photometric curve

- **Luminous Intensity**

The luminous intensity is the luminous flux emitted in a unit solid angle. It is expressed in lumens per steradian or candelas. The candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540×10^{12} Hz (or approximately 555 nm) and that has a radiant intensity in that direction of 1/683 watt per steradian.

- **Luminous Flux (Luminous Power)**

Luminous flux is photometrically weighted radiant flux (power). Its unit of measurement is the lumen, defined as 1/683 watts of radiant power at a frequency of 540×10^{12} Hertz. A point source having a uniform (isotropic) luminous intensity of one candela in all directions (i.e., a uniform intensity distribution) emits one lumen of luminous flux per unit solid angle (steradian).

- **Luminous Energy**

Luminous energy is photometrically weighted radiant energy. It is measured in lumen-seconds.

- **Luminous Flux Density (Illuminance and Luminous Exitance)**

Luminous flux density is photometrically weighted radiant flux density. Illuminance is the photometric equivalent of irradiance, whereas luminous exitance is the photometric equivalent of radiant exitance. Luminous flux density is measured in lumens per square meter.

- **Luminance**

Luminance is photometrically weighted radiance. In terms of visual perception, we perceive luminance. It is an approximate measure of how “bright” a surface appears when we view it from a given direction. Luminance is measured in lumens per square meter per steradian.

Figure 2 below shows the correspondence between radiometric and photometric quantities.

QUANTITY	RADIOMETRIC	PHOTOMETRIC
power	watt (W)	lumen (lm)
power per unit area	W/m ²	lm/m ² = lux (lx)
power per unit solid angle	W/sr	lm/sr = candela (cd)
power per unit area per unit solid angle	W/m ² -sr	lm/m ² -sr = cd/m ² = nit

Figure 2. Correspondence between radiometric and photometric quantities

Conversion between radiometric and photometric quantities

- **Monochromatic light source**

We know from the definition of the candela that there are 683 lumens per watt at a frequency of 540THz, which is 555 nm (in vacuum or air). This is the wavelength that corresponds to the maximum spectral responsivity of the human eye. At any other wavelength, the conversion between photometric units and radiometric units **for a monochromatic light source** is given by the following formula:

(photometric unit) = (corresponding radiometric unit) × K_m × V(λ)

where: V(λ) = the "luminous efficiency," and is a function of the wavelength of light ; K_m = 683 lm/W, the maximum sensitivity for photopic vision, which occurs at 555nm.

Example:

As an example, we can compare laser pointers at 670 nm and 635 nm. At 670 nm, V(λ) is 0.032 and a 5 mW laser has 0.005W×0.032×683 lm/W = 0.11 lumens. At 635 nm, V(λ) is 0.217 and a 5 mW laser has 0.005W×0.217×683lm/W = 0.74 lumens. Therefore, the shorter wavelength (635 nm) laser pointer will create a spot that is almost 7 times as bright as the longer wavelength (670 nm) laser (assuming the same beam diameter).

- **Non-monochromatic light source**

The conversion technique for non-monochromatic light sources is more complicated. It requires multiplying the spectral distribution curve by the photopic response curve, integrating the product curve and multiplying the result by a conversion factor of 683. This is illustrated in the following formula:

$$\Phi_v = K_m \int_{380}^{770} V(\lambda) \cdot \Phi_\lambda(\lambda) \cdot d\lambda$$

where: Φ_v = Photopic Luminous Flux (lm) ; K_m = 683 lm/W ; V(λ) = the "luminous efficiency" ; Φ_λ = Spectral Radiant Flux (W).

Spectral sensitivity of 4 Picos/4 Quik E ICCD cameras

The graphs below demonstrate the stupendous spectral sensitivity (in lux and in W/m^2 units) of our 4 Picos/4 Quik ICCD cameras equipped with two different types of photocathode (S25 Wideband and S20 Enhanced). Here, the electron gain of the image intensifier was set to 1000, the integration time τ to 1s, and calculations were made in such a way to obtain a unity SNR¹.

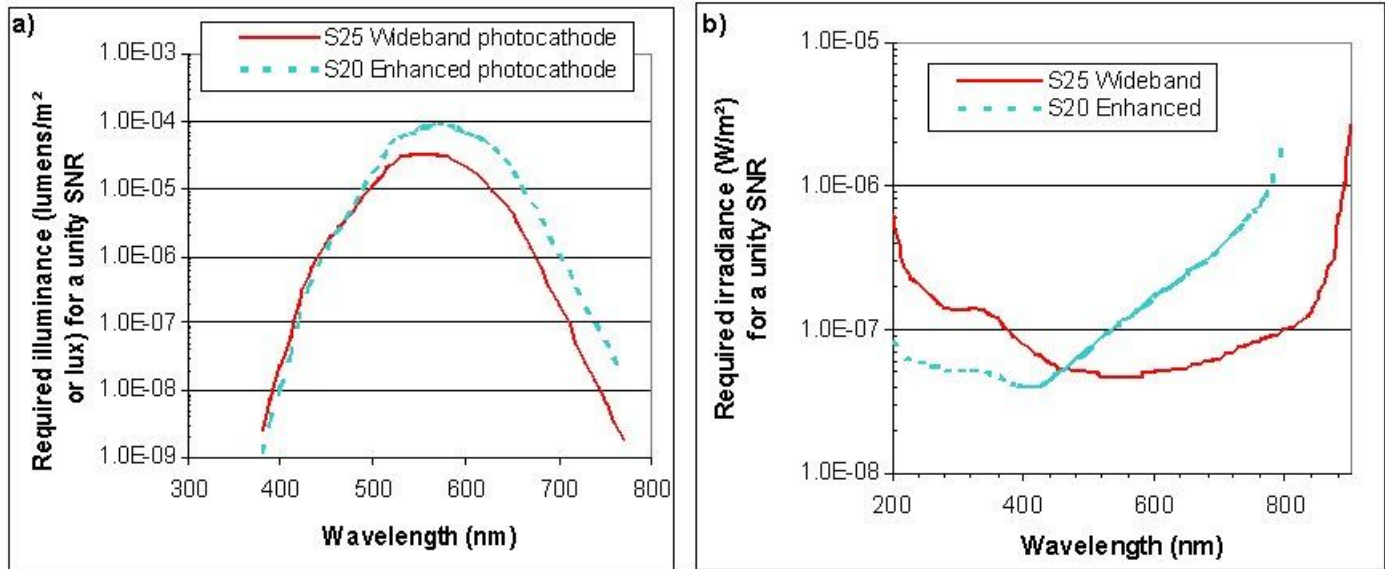


Figure 3. a) Input illuminance required to get a SNR of 1 (electron gain $G = 1000$, integration time $\tau = 1s$); **b)** Input irradiance required to get a SNR of 1 (electron gain $G = 1000$, integration time $\tau = 1s$)

¹ Excel spread sheets used to plot the graphs of **Figure 3** are available on our web site or via email.