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Quantities and units

It is possible to find in different books different symbols, units and other nomenclature used to describe properties of optical radiation as there is still no a single standard recognised by all people working in field of technology. The symbols, units and other nomenclature used in this book generally conform to the mentioned earlier Lighting Vocabulary published by the International Lighting Commission CIE. The terminology used in this standard is entering common practice in a number of fields dealing with optical radiation. If the symbols or units used in this book are not in agreement with the Vocabulary, there is an additional information in a footnote.

There are three types of quantities of optical radiation: radiant quantities, luminous quantities and photon quantities. Radiant quantities are measures of optical radiation properties such as radiated power and its spatial and angular distribution in SI units. Photon quantities are measures of the same properties when number of photons is a unit of radiant energy. A photon quantity can be calculated by dividing the radiant quantity by energy of a single photon. Finally, luminous quantities are modified radiant quantities to indicate human response to them.

Basic symbols are the same for all three types of quantities. However, different indexes are used to identify type of quantity (e-radiant, p-photon, v-luminous. For example ϕ_e, ϕ_p, ϕ_v symbols are used to indicate radiant flux, photon flux and luminous flux.

Photon quantities are only rarely used in literature on electro-optical imaging systems; radiant quantities are typically used in case of infrared imaging systems, luminous quantities – in case of visible imaging systems. Therefore only radiant and luminous quantities will be defined in this website.

Radiant quantities:

Radiant flux (power) Φ_e is the time flow of radiant energy emitted, transferred or received by a surface or region of space (unit: watt, where 1 W= 1 J s^{-1}).

Flux can be considered as the fundamental quantity; the other quantities defined next are geometric or spectral distributions of flux.

Radiant exitance M_e[1] is the radiant flux per unit area in a specified surface that is leaving the specified surface (unit: W m^{-2})

Radiant intensity I_e is the solid angle density of radiant flux, the radiant flux per unit solid angle incident on, passing through, or emerging from a point in space and propagating in a specified direction (unit: W sr^{-1}). The defining equation can be written as

$$I = \frac{d\Phi}{d\omega}$$

where $d\Phi$ is the element of flux incident on or emerging from a point within the element $d\omega$ of solid angle in a specified direction.

Radiance L_e is the area and solid angle density of radiant flux, the radiant flux per unit projected area and per unit solid angle incident on, passing through, or emerging in a specified direction from specified point in a specified surface (unit: W m^{-2} sr^{-1}). The defining equation can be written as

$$L = \frac{d^2\Phi}{dAd\omega} = \frac{d^2\Phi}{d\omega dA_0 \cos\theta}$$

1 The exitance M has been called *emittance* in the past but nowadays this term is generally reserved as a replacement term for *emissivity,* a property of a material surface.

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where $dA = dA_0 \cos\theta$ is the quantity called the projected area, $d\omega$ is the element of solid angle in the specified direction and θ is the angle between this direction and the normal to the surface at the specified point.

Irradiance E_e is the area density of radiant flux , the radiant flux per unit area in a specified surface that is incident on or passing through the specified surface (unit: W m^{-2})

All the presented earlier quantities can be defined also as spectral quantities. For example the spectral radiance L_λ is the spectral concentration of the radiance L (typical unit: W m^{-2} sr^{-1} μm^{-1}) defined as

$$L_\lambda = \frac{dL}{d\lambda}.$$

L_λ for λ=x can be interpreted as radiant flux emitted from the area of area 1 m^2 within the solid angle of 1 steradian in the specified direction and within the spectral band [x-0.5µm, x+0.5µm] if the µm was chosen as a unit of the wavelength λ.

Luminous quantities:

Luminous flux Φ_v (unit: lumen)– quantity calculated as

$$\Phi_v = K_m \int_0^\infty \frac{d\Phi_e(\lambda)}{d\lambda} \cdot V(\lambda) d\lambda$$

where:

$V(\lambda)$ – spectral luminous efficiency

K_m = 683 lm W^{-1} for photopic vision

K_m = 1700 lm W^{-1} for scotopic vision.

Luminous intensity I_v is the solid angle density of luminous flux, the luminous flux per unit solid angle incident on, passing through, or emerging from a point in space and propagating in a specified direction (unit: lm sr^{-1} or cd).

Luminance L_v is the area and solid angle density of luminous flux, the luminous flux per unit projected area and per unit solid angle incident on, passing through, or emerging in a specified direction from specified point in a specified surface (unit: lm m^{-2} sr^{-1}=cd m^2).

Iluminance E_v is the area density of luminous flux , the luminous flux per unit area in a specified surface that is incident on or passing through the specified surface (unit: lm m^{-2}= lux, abbrev. lx)