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Quantities and units —

Part 7:
Light and radiation

Grandeurs et unités —

Partie 7: Lumière et rayonnements

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www. iso. org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www. iso .org/iso/foreword. html.

This document was prepared by Technical Committee ISO/TC 12, *Quantities and units*, in collaboration with Technical Committee IEC/TC 25, *Quantities and units*.

This second edition cancels and replaces the first edition (ISO 80000-7:2008), which has been technically revised.

The main changes compared to the previous edition are as follows:

- the table giving the quantities and units has been simplified;
- some definitions and the remarks have been stated physically more precisely.

A list of all parts in the ISO 80000 and IEC 80000 series can be found on the ISO and IEC websites.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction — Special remarks

0.1 Quantities

ISO 80000-7 contains a selection of quantities pertaining to light and other electromagnetic radiation. Radiometric quantities relating to radiation in general may be useful for the whole range of electromagnetic radiations, whereas photometric quantities pertain only to visible radiation.

In several cases, the same symbol is used for a trio of corresponding radiant, luminous and photon quantities with the understanding that subscripts "e" for energetics, "v" for visible and "p" for photon will be added whenever confusion among these quantities might otherwise occur.

For ionizing radiation, however, see ISO 80000-10.

Several of the quantities in ISO 80000-7 can be defined for monochromatic radiation, i.e. radiation of a single frequency ν only. They are denoted by their reference quantity as an argument like $q(\nu)$. An example is speed of light in a medium $c(\nu)$, or the refractive index in a medium $n(\nu) = c_0/c(\nu)$ Some of those quantities are derivatives

$$q'(\lambda)=\frac{\mathrm{d}q(\lambda)}{\mathrm{d}\lambda}=\lim_{\Delta\lambda\to 0}\frac{q(\lambda+\Delta\lambda)-q(\lambda)}{\Delta\lambda}$$

of a quantity which are also frequently described as fractions $\Delta q(\lambda)$ of a quantity q corresponding to the radiation with wavelength in the interval $[\lambda,\lambda+\Delta\lambda]$ divided by the range $\Delta\lambda$ of that interval to point to the physical measurement process behind. Such fractions must be additive so that the integral yields the overall quantity, e.g. radiance (item 7-6.1) and spectral radiance (item 7-6.2). These derivatives of quantities are called spectral quantities and are denoted by subscript λ.

On the other hand, some multidimensional quantities like radiant intensity $I_\mathrm{e}(\vartheta,\varphi)$, irradiance $E_\mathrm{e}(x,y)$, radiance $L_\mathrm{e}(x,y,\vartheta,\varphi)$, etc., are quantities that are strictly defined as values of a derivative at a certain point, a certain direction or at a certain point and direction in space. Hence, the most fundamental definition according to ISO 80000-2 would be e.g. in case of the most complex term "radiance" (item 7-6.1):

> "at a given point (x_1,y_1) of a real or imaginary surface, in a given direction (ϑ_1,φ_1),
>
> $$L_\mathrm{e}(x,y,\vartheta,\varphi)=\frac{\partial^2\Phi_\mathrm{e}(x,y,\vartheta,\varphi)}{\partial A(x,y)\cdot\cos\varepsilon\cdot\partial\Omega(\vartheta,\varphi)}=\left(\frac{\partial^2\Phi_\mathrm{e}}{\partial A\cdot\cos\varepsilon\cdot\partial\Omega}\right)_{\substack{x=x_1\\ y=y_1\\ \vartheta=\vartheta_1\\ \varphi=\varphi_1}}$$
>
> where $\Phi_\mathrm{e}(x,y,\vartheta,\varphi)$ represents the radiant flux transmitted through an area $A(x,y)$ at a given point (x_1,y_1) and propagating in a given direction (ϑ_1,φ_1), and ε is the angle between the normal $\overline{A(x_1,y_1)}$ to that area at the given point and the given direction (ϑ_1,φ_1)".

To ease the use of the table in Clause 3, the simplified definitions (like item 7-6.1 in case of radiance) are used which assume that fractions of quantities are always isotropic and uniform and continuous. In this case, the given definitions are equivalent to the fundamental approach given above.

Instead of frequency ν, other reference quantities of light may be used: angular frequency $\omega=2\pi\nu$, wavelength in a medium $\lambda=c_0/(n\nu)$, wavelength in vacuum $\lambda_0=c_0/\nu$, wavenumber in medium $\sigma = 1/\lambda$, wavenumber in vacuum $\tilde{\nu} = \nu / c_0 = \sigma / n = 1/\lambda_0$, etc. As an example, the refractive index may be given as $n(\lambda = 555 \text{ nm}) \approx 1{,}333$.

Spectral quantities corresponding to different reference quantities are related, e.g.

$$dq = q_\nu(\nu)d\nu = q_\omega(\omega)d\omega = q_{\tilde{\nu}}(\tilde{\nu})d\tilde{\nu} = q_\lambda(\lambda)d\lambda = q_\sigma(\sigma)d\sigma$$

thus

$$q_\nu(\nu) = 2\pi \cdot q_\omega(\omega) = q_{\tilde{\nu}}(\tilde{\nu})/c_0 = q_\lambda(\lambda) \cdot c_0/n = q_\sigma(\sigma) \cdot n/c_0$$

From the theoretical point of view, the frequency ν is the more fundamental reference quantity, keeping its value when a light beam passes through media with different refractive index, n. For historical reasons, the wavelength, λ, is still mostly used as a reference quantity as it had been the most accurately measured quantity in the past. In this respect, spectral quantities, as the spectral radiance (item 7-6.2), $L_{\mathrm{e},\lambda}(\lambda)$, have the meaning of spectral “densities” corresponding to the respective integrated quantities – i.e. in the case of radiance, $L_{\mathrm{e}}(\lambda)$ (item 7-6.1),

$$L_{\mathrm{e},\lambda} = \frac{\partial L_{\mathrm{e}}}{\partial \lambda}$$

0.2 Units

In photometry and radiometry, the unit steradian is retained for convenience.

0.3 Photopic quantities

In the great majority of instances, photopic vision (provided by the cones in the human visual system and used for vision in daylight) is dealt with. Standard values of the spectral luminous efficiency function $V(\lambda)$ for photopic vision were originally adopted by the International Commission on Illumination (CIE) in 1924. These values were adopted by the International Committee for Weights and Measures (CIPM) (see BIPM Monograph in Reference [11]).

0.4 Scotopic quantities

For scotopic vision (provided by the rods and used for vision at night), corresponding quantities are defined in the same manner as the photopic ones (items 7-10 to 7-18), using symbols with a prime.

For the term “spectral luminous efficiency” (item 7-10.2), the remarks would read:

> “Standard values of luminous efficiency function $V'(\lambda)$ for scotopic vision were originally adopted by CIE in 1951. They were later adopted by the CIPM[11].”

For the term “maximum luminous efficacy” (item 7-11.3), the definition would read:

> “<for scotopic vision> maximum value of the spectral luminous efficacy for scotopic vision”

In the Remark it would read:

"The value is calculated by

$$K'_{\mathrm{m}} = \frac{683\ \mathrm{lm\ W^{-1}}}{V'(\lambda_{\mathrm{cd}})} \approx 1\,700\ \mathrm{lm\ W^{-1}}$$

where $V'(\lambda)$ is the spectral luminous efficiency in terms of wavelength λ for scotopic vision and λ_{cd} is the wavelength in air corresponding to the frequency $540 \cdot 10^{12}$ Hz given in the definition of the SI unit candela."

0.5 Mesopic quantities

For mesopic vision (provided by the rods and cones and used for vision intermediate between photopic and scotopic vision), corresponding quantities are defined in the same manner as the photopic ones (items 7-10 to 7-18), using symbols with the subscript "mes".

For the term "spectral luminous efficiency" (item 7-10.2), the remarks would read:

"Standard values of spectral luminous efficiency functions $V_{\mathrm{mes}}(\lambda)$ for mesopic vision depend on the used adaptation level *m* and were originally recommended by CIE in 2010[12]. They are adopted by the CIPM[11]."

For the term "maximum luminous efficacy" (item 7-11.3), the definition would read:

"<for mesopic vision> adaptation level *m* dependent maximum value of the spectral luminous efficacy for mesopic vision"

In the Remark it would read:

"The value is calculated by

$$K_{\mathrm{m,mes};m} = \frac{683\ \mathrm{lm\ W^{-1}}}{V_{\mathrm{mes};m}(\lambda_{\mathrm{cd}})}$$

where $V_{\mathrm{mes};m}(\lambda)$ is the spectral luminous efficiency for mesopic vision at an adaptation level *m* and λ_{cd} is the wavelength in air corresponding to the frequency $540 \cdot 10^{12}$ Hz given in the definition of the SI unit candela."

Quantities and units —

Part 7:
Light and radiation

1 Scope

This document gives names, symbols, definitions and units for quantities used for light and optical radiation in the wavelength range of approximately 1 nm to 1 mm. Where appropriate, conversion factors are also given.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

Names, symbols, definitions and units for quantities used in light and optical radiation in the wavelength range of approximately 1 nm to 1 mm are given in Table 1.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

In the field of light, the CIE maintains the Electronic international lighting vocabulary, available at http://eilv.cie.co.at/.

Table 1 — Quantities and units used in light and optical radiation in the wavelength range of approximately 1 nm to 1 mm

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
7-1.1	speed of light in a medium	c	phase speed of an electromagnetic wave at a given point in a medium	m s^{-1}	See also ISO 80000-3. The value of the speed of light in a medium can depend on the frequency, polarization, and direction. For the definition of the speed of electromagnetic waves in vacuum, c_0, see ISO 80000-1.
7-1.2	refractive index	n	quotient of speed of light in vacuum (ISO 80000-1) and speed of light in a medium (item 7-1.1)	1	The value of the refractive index can depend on the frequency, polarization, and direction. The refractive index is expressed by $n = c_0/c$, where c_0 is the speed of light in vacuum and c is the speed of light in the medium. For a medium with absorption, the complex refractive index $\underline{n}$ is defined by $\underline{n} = n + \mathrm{i}k$ where k is spectral absorption index (IEC 60050-845) and i is imaginary unit. The refractivity is expressed by $n - 1$, where n is refractive index.
7-2.1	radiant energy <electromagnetism>	Q_e, W, U (Q)	energy (ISO 80000-5) emitted, transferred or received in form of electromagnetic waves	J kg $\mathrm{m}^2\,\mathrm{s}^{-2}$	Radiant energy can be expressed by the time integral of radiant flux (item 7-4.1), Φ_e, over a given duration (ISO 80000-3), Δt $Q_\mathrm{e} = \int_{\Delta t} \Phi_\mathrm{e} \mathrm{d}t$ Radiant energy is expressed either as a function of wavelength (ISO 80000-3), λ, as a function of frequency (ISO 80000-3), ν, or as a function of wavenumber, σ. (See also 0.1.) The corresponding photometric quantity is “luminous energy” (item 7-12). The corresponding quantity for photons is “photon energy” (item 7-19.2).

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
7-2.2	spectral radiant energy	$Q_{e,\lambda}$, W_λ, U_λ (Q_λ)	spectral density of radiant energy, expressed by $Q_{e,\lambda} = \frac{dQ_e}{d\lambda}$ where Q_e is radiant energy (item 7-2.1) in terms of wavelength λ (ISO 80000-3)	J/nm kg m s^{-2}	The integral of (total) radiant energy is determined by the wavelength interval (λ_1, λ_2) under consideration: $Q_e = \int_{\lambda_1}^{\lambda_2} Q_{e,\lambda} d\lambda$
7-3.1	radiant energy density	w (ρ_e)	volumetric density of radiant energy, expressed by $w = \frac{dQ_e}{dV}$ where Q_e is radiant energy (item 7-2.1) in an elementary three-dimensional domain and V is the volume (ISO 80000-3) of that domain	J/m^3 kg m^{-1} s^{-2}	Radiant energy density within a Planckian radiator is given by $w = \frac{4\sigma}{c_0} T^4$ where σ is the Stefan-Boltzmann constant (ISO 80000-1), c_0 is speed of light in vacuum (ISO 80000-1) and T is thermodynamic temperature (ISO 80000-5).
7-3.2	spectral radiant energy density in terms of wavelength	w_λ	change of radiant energy density with wavelength, expressed by $w_\lambda = \frac{dw}{d\lambda}$ where w is radiant energy density (item 7-3.1) as a function of wavelength λ (ISO 80000-3)	J/(m^3 nm) kg m^{-2} s^{-2}	Spectral radiant energy density within a Planckian radiator is given by $w_\lambda = 8\pi h c_0 \cdot f(\lambda, T)$, where h is the Planck constant (ISO 80000-1), c_0 is speed of light in vacuum (ISO 80000-1), T is thermodynamic temperature (ISO 80000-5) and $f(\lambda, T) = \frac{\lambda^{-5}}{\exp(c_2 \lambda^{-1} T^{-1}) - 1}$ For the radiation constant c_2 in $f(\lambda, T)$, see ISO 80000-1.
7-3.3	spectral radiant energy density in terms of wavenumber	$w_{\tilde{\nu}}$, $\rho_{\tilde{\nu}}$	change of radiant energy density with wavenumber, expressed by $w_{\tilde{\nu}} = \frac{dw}{d\tilde{\nu}}$ where w is radiant energy density (item 7-3.1) as a function of wavenumber $\tilde{\nu}$ (ISO 80000-3)	J/m^2 kg s^{-2}	

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
7-4.1	radiant flux, radiant power	Φ_e, P_e (Φ, P)	change in radiant energy with time, expressed by $\Phi_e = \frac{dQ_e}{dt}$ where Q_e is the radiant energy (item 7-2.1) emitted, transferred or received and t is time (ISO 80000-3)	W kg m^2 s^{-3}	The corresponding photometric quantity is “luminous flux” (item 7-13). The corresponding quantity for photons is “photon flux” (item 7-20).
7-4.2	spectral radiant flux, spectral radiant power	$\Phi_{e,\lambda}$, $P_{e,\lambda}$ $(\Phi_\lambda, P_\lambda)$	spectral density of radiant flux, expressed by $\Phi_{e,\lambda} = \frac{d\Phi_e}{d\lambda}$ where Φ_e is radiant flux (item 7-4.1) in terms of wavelength λ (ISO 80000-3)	W/nm kg m s^{-3}	The integral of (total) radiant flux is determined by the wavelength interval (λ_1, λ_2) under consideration: $\Phi_e = \int_{\lambda_1}^{\lambda_2} \Phi_{e,\lambda} d\lambda$
7-5.1	radiant intensity	I_e (I)	density of radiant flux with respect to solid angle in a specified direction, expressed by $I_e = \frac{d\Phi_e}{d\Omega}$ where Φ_e is the radiant flux (item 7-4.1) emitted in a specified direction, and Ω is the solid angle (ISO 80000-3) containing that direction	W/sr kg m^2 s^{-3} sr^{-1}	The definition holds strictly only for a point source. The distribution of the radiant intensities as a function of the direction of emission, e.g. given by the polar angles (ϑ, φ), is used to determine the radiant flux (item 7-4.1) within a certain solid angle (ISO 80000-3), Ω, of a source: $\Phi_e = \iint_{\Omega} I_e(\vartheta, \varphi) \sin\vartheta d\varphi d\vartheta$ The corresponding photometric quantity is “luminous intensity” (item 7-14). The corresponding quantity for photons is “photon intensity” (item 7-21).
7-5.2	spectral radiant intensity	$I_{e,\lambda}$ (I_λ)	spectral density of radiant intensity, expressed by $I_{e,\lambda} = \frac{dI_e}{d\lambda}$ where I_e is radiant intensity (item 7-5.1) in terms of wavelength λ (ISO 80000-3)	W/(sr nm) kg m s^{-3} sr^{-1}	The integral of (total) radiant intensity is determined by the wavelength interval (λ_1, λ_2) under consideration: $I_e = \int_{\lambda_1}^{\lambda_2} I_{e,\lambda} d\lambda$

Table 1 *(continued)*

Item No.	Quantity			Unit	Remarks
	Name	Symbol	Definition		
7-6.1	radiance	L_e (L)	density of radiant intensity with respect to projected area in a specified direction at a specified point on a real or imaginary surface, expressed by $L_e = \frac{dI_e}{dA} \frac{1}{\cos\alpha}$ where I_e is radiant intensity (item 7-5.1), A is area (ISO 80000-3), and α is the angle between the normal to the surface at the specified point and the specified direction	W/(sr m^2) kg s^{-3} sr^{-1}	See also 0.1. For Planckian radiation, $L_e = \frac{\sigma}{\pi} T^4$ where T is thermodynamic temperature (ISO 80000-5) and σ is the Stefan-Boltzmann constant (ISO 80000-1). The corresponding photometric quantity is “luminance” (item 7-15). The corresponding quantity for photons is “photon radiance” (item 7-22).
7-6.2	spectral radiance	$L_{e,\lambda}$ (L_λ)	density of radiance with respect to wavelength, expressed by $L_{e,\lambda} = \frac{dL_e}{d\lambda}$ where L_e is radiance (item 7-6.1) in terms of wavelength λ (ISO 80000-3)	W/(sr m^2 nm) kg m^{-1} s^{-3} sr^{-1}	For Planckian radiation, $L_{e,\lambda}(\lambda) = \frac{c(\lambda)}{4\pi} \omega_\lambda(\lambda) = hc_0^2 \cdot f(\lambda,T)$ where $c(\lambda)$ is phase speed (ISO 80000-3) of electromagnetic radiation of a wavelength (ISO 80000-3) λ in a given medium, $\omega_\lambda(\lambda)$ is spectral radiant energy density in terms of wavelength, c_0 is speed of light in vacuum (ISO 80000-1), h is the Planck constant (ISO 80000-1), and $f(\lambda,T) = \frac{\lambda^{-5}}{\exp\left(c_2 \lambda^{-1} T^{-1}\right) - 1}$ where the radiation constant $c_2 = hc/k$. The integral of (total) radiance is determined by the wavelength interval (λ_1, λ_2) under consideration: $L_e = \int_{\lambda_1}^{\lambda_2} L_{e,\lambda} d\lambda$