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International Standard ISO 31/6

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION•МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ•ORGANISATION INTERNATIONALE DE NORMALISATION

Quantities and units of light and related electromagnetic radiations

Grandeurs et unités de lumière et de rayonnements électromagnétiques connexes

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards institutes (ISO member bodies). The work of developing International Standards is carried out through ISO technical committees. Every member body interested in a subject for which a technical committee has been set up has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work.

Draft International Standards adopted by the technical committees are circulated to the member bodies for approval before their acceptance as International Standards by the ISO Council.

International Standard ISO 31/6 was developed by Technical Committee ISO/TC 12, *Quantities, units, symbols, conversion factors and conversion tables*, and was circulated to the member bodies in July 1979.

It has been approved by the member bodies of the following countries :

Australia	France	Poland
Austria	Germany, F.R.	Romania
Belgium	India	Portugal
Brazil	Israel	South Africa, Rep. of
Bulgaria	Italy	Spain
Canada	Japan	Sweden
Cuba	Korea, Dem. P. Rep. of	Switzerland
Czechoslovakia	Mexico	United Kingdom
Denmark	Netherlands	USA
Egypt, Arab Rep. of	New Zealand	USSR
Finland	Norway	

No member body expressed disapproval of the document.

This second edition cancels and replaces the first edition (i.e. ISO 31/6-1973).

INTERNATIONAL STANDARD ISO 31/6-1980 (E)/ERRATUM

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INTERNATIONAL ORGANIZATION FOR STANDARDIZATION • МЕЖДУНАРОДНАЯ ОРГАНИЗАЦИЯ ПО СТАНДАРТИЗАЦИИ • ORGANISATION INTERNATIONALE DE NORMALISATION

Quantities and units of light and related electromagnetic radiations

ERRATUM

Page 4

Quantity No. 6-4.1, column "Remarks" : Insert a tilde over the first nu so as to read :"$\tilde{\nu}$ is also used for ν/c_0".

Page 5

Delete the broken line between unit No. 6-2.a and unit 6-2.b.

Page 10

Quantity No. 6-29.1, column "Definition", line 7 : Insert "energy" between "radiant" and "flux".

Page 12

Quantity No. 6-31.1, column "Symbol" : Add ", μ_l".

Quantities and units of light and related electromagnetic radiations

Introduction

This document, containing a table of *quantities and units of light and related electromagnetic radiations*, is part 6 of ISO 31, which deals with quantities and units in the various fields of science and technology. The complete list of parts of ISO 31 is as follows :

Part 0 : *General principles concerning quantities, units and symbols.*

Part 1 : *Quantities and units of space and time.*

Part 2 : *Quantities and units of periodic and related phenomena.*

Part 3 : *Quantities and units of mechanics.*

Part 4 : *Quantities and units of heat.*

Part 5 : *Quantities and units of electricity and magnetism.*

Part 6 : *Quantities and units of light and related electromagnetic radiations.*

Part 7 : *Quantities and units of acoustics.*

Part 8 : *Quantities and units of physical chemistry and molecular physics.*

Part 9 : *Quantities and units of atomic and nuclear physics.*

Part 10 : *Quantities and units of nuclear reactions and ionizing radiations.*

Part 11 : *Mathematical signs and symbols for use in the physical sciences and technology.*

Part 12 : *Dimensionless parameters.*

Part 13 : *Quantities and units of solid state physics.*

Arrangement of the tables

The tables of quantities and units in ISO 31 are arranged so that the quantities are presented on left-hand pages and the units on corresponding right-hand pages.

All units between two full lines belong to the quantities between the corresponding full lines on the left-hand pages.

Where the numbering of the items has been changed in the revision of a part of ISO 31, the number in the preceding edition is shown in parentheses on the left-hand page under the new number for the quantity; a dash is used to indicate that the item in question did not appear in the preceding edition.

Tables of quantities

The most important quantities within the field of this document are given together with their symbols and, in most cases, definitions. These definitions are given merely for identification; they are not intended to be complete.

The vectorial character of some quantities is pointed out, especially when this is needed for the definitions, but no attempt is made to be complete or consistent.

In most cases only one symbol for the quantity is given[1]; where two or more symbols are given for one quantity and no special distinction is made, they are on an equal footing. When a preferred symbol and a reserve symbol are given, the reserve symbol is in parentheses.

Tables of units

Units for the corresponding quantities are given together with the international symbols and the definitions. For further information, see also ISO 31/0.

(1) When two types of sloping letters exist (for example as with θ; ϑ; φ; ϕ; g; g) only one of these is given; this does not mean that the other is not equally acceptable.

The units are arranged in the following way :

1) The names of the SI units are given in large print (larger than text size). The SI units and their decimal multiples and sub-multiples formed by means of the SI prefixes are particularly recommended. The decimal multiples and sub-multiples are not explicity mentioned.

2) The names of non-SI units which may be used together with SI units because of their practical importance or because of their use in specialized fields are given in normal print (text size).

3) The names of non-SI units which may be used temporarily together with SI units are given in small print (smaller than text size).

The units in classes 2 and 3 are separated by a broken line from the SI units for the quantities concerned.

4) Non-SI units which should not be used together with SI units are given in annexes in some parts of ISO 31. These annexes are not integral parts of the standards. They are arranged in three groups :

a) *Units of the CGS system with special names*

It is generally preferable not to use the special names and symbols of CGS units together with SI units.

b) *Units based on the foot, pound and second and some other units*

c) *Other units*

These are given for information, especially regarding the conversion factor. The use of those units marked with † is deprecated.

Remark on supplementary units

The General Conference of Weights and Measures has classified the SI units radian and steradian as "supplementary units", deliberately leaving open the question of whether they are base units or derived units, and consequently the question of whether plane angle and solid angle are to be considered as base quantities or derived quantities.[1]

In ISO 31, plane angle and solid angle are treated as derived quantities (see also ISO 31/0). In ISO 31, they are defined as ratios of two lengths and of two areas respectively, and consequently they are treated as dimensionless quantities. Although in this treatment the coherent unit for both quantities is the number 1, it is convenient to use the special names radian and steradian instead of the number 1 in many practical cases.

If plane angle and solid angle were treated as base quantities, the units radian and steradian would be base units and could not be considered as special names for the number 1. Such a treatment would require extensive changes in ISO 31.

Number of digits in numerical statements[2]

All numbers in the column "Definition" are exact.

In the column "Conversion factors", the conversion factors on which the calculation of others is based are normally given to seven significant digits. When they are exact and contain seven or fewer digits, and where it is not obvious from the context, the word "exactly" is added, but when they can be terminated after more than seven digits, they may be given in full. When the conversion factors are derived from experiment, they are given with the number of significant digits justified by the accuracy of the experiments. Generally, this means that in such cases the last digit only is in doubt. When, however, experiment justifies more than seven digits, the factor is usually rounded off to seven significant digits.

The other conversion factors are given to not more than six significant digits; when they are exactly known and contain six or fewer digits, and where it is not obvious from the context, the word "exactly" is added.

Numbers in the column "Remarks" are given to a precision appropriate to the particular case.

Special remarks

Quantities

This document contains a selection of quantities pertaining to light, many of which are also useful for the whole range of electromagnetic radiations. For light, mainly photometric quantities are given.

In several cases, the same symbol is used for a pair of corresponding radiant and luminous quantities with the understanding that subscripts e for energetic and v for visible will be added whenever confusion between these quantities might otherwise occur.

(1) However, in October 1980 the International Committee of Weights and Measures decided to interpret the class of supplementary units in the International System as a class of dimensionless derived units for which the General Conference of Weights and Measures leaves open the possibility of using these or not in expressions of derived units of the International System.

(2) The decimal sign is a comma on the line. In documents in the English language, a comma or a dot on the line may be used.

For ionizing radiations, however, see ISO 31/10.

In this document spectral concentrations in terms of wavelength correspond to several quantities. The definition is given explicitly in 6-8.1 and the relation to 6-7.1 is shown in the remarks column. Other spectral concentrations are indicated by equations in the remarks column. The subscript λ is used as part of the symbol to indicate that the quantity has the dimension of a derivative with respect to λ. Spectral concentrations in terms of frequency or wave number are defined and denoted similarly, the subscript λ being replaced by ν or σ respectively. Spectral concentrations are also called distribution functions, for example wavelength distribution function, frequency distribution function. The name of a quantity which is a spectral concentration may be shortened by replacing the words "spectral concentration of" by the adjective "spectral", for example spectral concentration of radiant energy density may be called spectral radiant energy density.

The adjective "spectral" is also used to designate quantities which are functions of wavelength (or frequency or wave number), but which are not spectral concentrations, for example spectral emissivity, see 6-18.2. The functional dependence is usually indicated by including λ (or ν or σ) in parentheses as part of the symbol, for example $\varepsilon(\lambda)$.

Units

In photometry, the supplementary unit steradian is used for convenience.

Quantities
6-1.1 . . . 6-11.1

6. Light and related electromagnetic radiations

Item No.	Quantity	Symbol	Definition	Remarks
6-1.1	frequency	f, ν	Number of cycles divided by time.	
6-2.1	circular frequency	ω	$\omega = 2 \pi \nu$	
6-3.1	wavelength	λ	Distance in the direction of propagation of a periodic wave between two successive points at which the phase is the same (at the same time).	The wavelength in a medium is equal to the wavelength *in vacuo* divided by the refractive index of the medium, see 6-33.1.
6-4.1 6-4.2	wavenumber, repetency circular wavenumber, circular repetency	σ k	$\sigma = 1/\lambda$ $k = 2 \pi \sigma$	In molecular spectroscopy ν is also used for ν / c_0.
6-5.1	velocity (speed) of propagation of electromagnetic waves *in vacuo*	c, c_0		$c = (2{,}997\ 924\ 58 \pm 0{,}000\ 000\ 012) \times 10^8$ m/s[1] Sometimes c is used for the phase velocity in a medium, in which case c_0 is used for the velocity *in vacuo*.
6-6.1	radiant energy	$Q, W,$ (U, Q_e)	Energy emitted, transferred or received as radiation.	
6-7.1	radiant energy density	$w, (u)$	Radiant energy in an element of volume, divided by that element.	For non-polarized black body (full) radiation $w_\lambda = 8 \pi hc \cdot f(\lambda, T)$ and $w = \frac{4 \sigma}{c} T^4$. For $f(\lambda, T)$ and σ, see 6-16.1, 6-17.1 and 6-15.1, respectively $w = \int w_\lambda \, d\lambda$ See also the introduction, special remarks.
6-8.1	spectral concentration of radiant energy density (in terms of wavelength), spectral radiant energy density (in terms of wavelength)	w_λ	The radiant energy density in an infinitesimal wavelength interval, divided by the range of that interval.	
6-9.1	radiant power, radiant energy flux	$P, \Phi, (\Phi_e)$	Power emitted, transferred or received as radiation.	$\Phi = \int \Phi_\lambda \, d\lambda$
6-10.1	radiant energy fluence rate	φ, ψ	At a given point in space, the radiant energy flux incident on a small sphere, divided by the cross-sectional area of that sphere.	$\varphi = \int \varphi_\lambda \, d\lambda$ In an isotropic homogeneous radiation field, φ / c is the energy density, and the irradiance of a surface is $\varphi/4$.
6-11.1	radiant intensity	$I, (I_e)$	In a given direction from a source, the radiant energy flux leaving the source, or an element of the source, in an element of solid angle containing the given direction, divided by that element of solid angle.	$I = \int I_\lambda \, d\lambda$

(1) CODATA Bulletin 11 (1973). Recommended for universal use by the 15th CGPM (1975).

6. Light and related electromagnetic radiations

Units
6-1.a . . . 6-11.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
6-1.a	hertz	Hz	1 Hz = 1 s^{-1}		
6-2.a	reciprocal second, second to the power minus one	s^{-1}			
6-2.b	radian per second	rad/s			
6-3.a	metre	m			
6-3.b	ångström	Å	1 Å = 10^{-10} m	1 Å = 10^{-10} m (exactly)	10 Å = 1 nm
6-4.a	reciprocal metre, metre to the power minus one	m^{-1}			The multiple cm^{-1} is often used.
6-5.a	metre per second	m/s			
6-6.a	joule	J	1 J = 1 kg·m^2/s^2		
6-7.a	joule per cubic metre	J/m^3			
6-8.a	joule per metre to the fourth power	J/m^4			
6-9.a	watt	W	1 W = 1 J/s		
6-10.a	watt per square metre	W/m^2			
6-11.a	watt per steradian	W/sr			For steradian, see the introduction.

Quantities
6-12.1 . . . 6-17.1

6. **Light and related electromagnetic radiations** (continued)

Item No.	Quantity	Symbol	Definition	Remarks
6-12.1	radiance	L, (L_e)	At a point of a surface and in a given direction, the radiant intensity of an element of the surface, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction.	$L = \int L_\lambda \, d\lambda$ For non-polarized black body (full) radiation $L_\lambda = \frac{c}{4\pi} w_\lambda = 2hc^2 \cdot f(\lambda, T)$ and $L = \frac{\sigma}{\pi} T^4$. For $f(\lambda, T)$ and σ, see 6-16.1, 6-17.1 and 6-15.1 respectively.
6-13.1	radiant exitance	M, (M_e)	At a point of a surface, the radiant energy flux leaving an element of the surface, divided by the area of that element.	Formerly called radiant emittance. $M = \int M_\lambda \, d\lambda$ For non-polarized black body (full) radiation $M_\lambda = \frac{c}{4} w_\lambda = 2\pi hc^2 \cdot f(\lambda, T)$ and $M = \sigma \cdot T^4$. For $f(\lambda, T)$ and σ, see 6-16.1, 6-17.1 and 6-15.1 respectively.
6-14.1	irradiance	E, (E_e)	At a point of a surface, the radiant energy flux incident on an element of the surface, divided by the area of that element.	$E = \int E_\lambda \, d\lambda$
6-15.1	Stefan-Boltzmann constant	σ	The constant σ in the expression for the radiant exitance of a full radiator (black body) at the thermodynamic temperature T: $M = \sigma \cdot T^4$	$\sigma = \frac{2\pi^5 k^4}{15 h^3 c^2}$ $= (5{,}670\,32 \pm 0{,}000\,71) \times 10^{-8}$ W/(m².K⁴) (1) For k and h, see ISO 31/8 and ISO 31/9 respectively.
6-16.1	first radiation constant	c_1	The constants c_1 and c_2 in the expression for the spectral concentration of the radiant exitance of a full radiator (black body) at the thermodynamic temperature T: $M_\lambda = c_1 f(\lambda, T)$ $= c_1 \frac{\lambda^{-5}}{\exp(c_2/\lambda T) - 1}$	$c_1 = 2\pi hc^2$ $= (3{,}741\,832 \pm 0{,}000\,020) \times 10^{-16}$ W.m² (1) The name first radiation constant has also been used for the factors $8\pi hc$ and hc^2 in the corresponding expressions for w_λ and L_λ (see also remark 6-8.1 and 6-12.1).
6-17.1	second radiation constant	c_2		$c_2 = \frac{hc}{k}$ $= (1{,}438\,786 \pm 0{,}000\,045) \times 10^{-2}$ m.K (1) For expressing temperatures in the "International Practical Temperature Scale of 1968", as adopted by the Comité International des Poids et Mesures, the numerical value $1{,}438\,8 \times 10^{-2}$ should be used.

(1) CODATA Bulletin 11 (1973).

6. Light and related electromagnetic radiations (continued)

Units
6-12.a . . . 6-17.a

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
6-12.a	watt per steradian square metre	$W/(sr \cdot m^2)$			
6.13.a	watt per square metre	W/m^2			
6.14.a	watt per square metre	W/m^2			
6.15.a	watt per square metre kelvin to the fourth power	$W/(m^2 \cdot K^4)$			
6-16.a	watt square metre	$W \cdot m^2$			
6.17.a	metre kelvin	$m \cdot K$			

Quantities
6-18.1 . . . 6-25.1

6. Light and related electromagnetic radiations (continued)

Item No.	Quantity	Symbol	Definition	Remarks
6-18.1	emissivity	ε	Ratio of radiant exitance of a thermal radiator to that of a full radiator (black body) at the same temperature.	These quantities are dimensionless.
6-18.2	spectral emissivity, emissivity at a specified wavelength	$\varepsilon(\lambda)$	Ratio of spectral concentration of radiant exitance of a thermal radiator to that of a full radiator (black body) at the same temperature.	The spectral emissivity is a function of wavelength; this is indicated by the symbol $\varepsilon(\lambda)$.
6-18.3	directional spectral emissivity	$\varepsilon(\lambda, \theta, \varphi)$	Ratio of spectral concentration of radiance in a given direction θ, φ of a thermal radiator to that of a full radiator (black body) at the same temperature.	
6-19.1	luminous intensity	$I, (I_v)$		See also 6-20.1. $I = \int I_\lambda \mathrm{d}\lambda$
6-20.1	luminous flux	Φ, (Φ_v)	The luminous flux $\mathrm{d}\Phi$ of a source of luminous intensity I in an element of solid angle $\mathrm{d}\Omega$ is $\mathrm{d}\Phi = I \mathrm{d}\Omega$.	$\Phi = \int \Phi_\lambda \mathrm{d}\lambda$ The luminous flux Φ is related to the spectral concentration of radiant energy flux $\Phi_{e\lambda}$ by the equation : $\Phi = \int K(\lambda) \Phi_{e\lambda} \mathrm{d}\lambda$ where $K(\lambda)$ is the luminous efficacy, see 6-26.2 and 6-27.2.
6-21.1	quantity of light	$Q, (Q_v)$	Time integral of luminous flux.	$Q = \int Q_\lambda \mathrm{d}\lambda$
6-22.1	luminance	L, (L_v)	At a point of a surface and in a given direction, the luminous intensity of an element of the surface, divided by the area of the orthogonal projection of this element on a plane perpendicular to the given direction.	$L = \int L_\lambda \mathrm{d}\lambda$
6-23.1	luminous exitance	M, (M_v)	At a point of a surface, the luminous flux leaving an element of the surface, divided by the area of that element.	Formerly called luminous emittance. $M = \int M_\lambda \mathrm{d}\lambda$
6-24.1	illuminance	E, (E_v)	At a point of a surface, the luminous flux incident on an element of the surface, divided by the area of that element.	$E = \int E_\lambda \mathrm{d}\lambda$
6-25.1	light exposure	H	$H = \int E \mathrm{d}t$	Formerly called quantity of illumination.

6. Light and related electromagnetic radiations (continued)

Units
6-19.a . . . 6-25.b

Item No.	Name of unit	International symbol for unit	Definition	Conversion factors	Remarks
6-19.a	candela	cd	The candela is the luminous intensity in a given direction of a source which emits monochromatic radiation of frequency 540×10^{12} hertz and of which the radiant intensity in that direction is 1/683 watt per steradian.		
6-20.a	lumen	lm	1 lm = 1 cd·sr		
6-21.a	lumen second	lm·s			
6-21.b	lumen hour	lm·h		1 lm·h = 3 600 lm·s (exactly)	
6-22.a	candela per square metre	cd/m^2			
6-23.a	lumen per square metre	lm/m^2			
6-24.a	lux	lx	1 lx = 1 lm/m^2		
6-25.a	lux second	lx·s			
6-25.b	lux hour	lx·h		1 lx·h = 3 600 lx·s (exactly)	

Quantities
6-26.1 . . . 6-29.1

6. Light and related electromagnetic radiations (continued)

Item No.	Quantity	Symbol	Definition	Remarks
6-26.1	luminous efficacy	K	$K = \dfrac{\Phi_v}{\Phi_e}$	$K = \dfrac{\int \Phi_{v\lambda} d\lambda}{\int \Phi_{e\lambda} d\lambda} = \dfrac{\int K(\lambda)\Phi_{e\lambda} d\lambda}{\int \Phi_{e\lambda} d\lambda}$
6-26.2	spectral luminous efficacy, luminous efficacy at a specified wavelength	$K(\lambda)$	$K(\lambda) = \dfrac{\Phi_{v\lambda}}{\Phi_{e\lambda}}$	For the notation $K(\lambda)$, see remark 6-18.2.
6-26.3	maximum spectral luminous efficacy	K_m	The maximum value of $K(\lambda)$.	For a monochromatic radiation of frequency 540×10^{12} Hz, the spectral luminous efficacy is equal to 683 lm/W.
6-27.1	luminous efficiency	V	$V = \dfrac{K}{K_m}$	These quantities are dimensionless. $V = \dfrac{\int V(\lambda)\Phi_{e\lambda} d\lambda}{\int \Phi_{e\lambda} d\lambda}$
6-27.2	spectral luminous efficiency, luminous efficiency at a specified wavelength	$V(\lambda)$	$V(\lambda) = \dfrac{K(\lambda)}{K_m}$	For the notation $V(\lambda)$, see remark 6-18.2. $\Phi_v = \int K(\lambda)\Phi_{e\lambda} d\lambda = K_m \cdot \int V(\lambda)\Phi_{e\lambda} d\lambda$ Standard values of $V(\lambda)$ relating to the light-adapted eye were adopted by the International Commission on Illumination in 1971 and approved by the Comité International des Poids et Mesures in 1972. Procès-Verbaux du CIPM **40** (1972) 29, 145.
6-28.1	CIE spectral tristimulus values	$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$	Thrichromatic components, in the "CIE (XYZ) thrichromatic system", of monochromatic light stimuli of equal energy. These functions are applicable to fields of observation of angular opening between 1° and 4°. For this standard colorimetric system $\bar{y}(\lambda) \stackrel{\text{def}}{=} V(\lambda)$.	These quantities are dimensionless. Formerly CIE-distribution coefficients. In 1964 the CIE adopted a supplementary standard colorimetric system with spectral tristimulus values $\bar{x}_{10}(\lambda)$, $\bar{y}_{10}(\lambda)$, $\bar{z}_{10}(\lambda)$ applicable to fields of observation of angular subtense greater than 4°.
6-29.1	chromaticity co-ordinates	x, y, z	For the relative spectral energy or power distribution $\varphi(\lambda)$ $x = \dfrac{\int \varphi(\lambda)\bar{x}(\lambda) d\lambda}{\int \varphi(\lambda)\bar{x}(\lambda) d\lambda + \int \varphi(\lambda)\bar{y}(\lambda) d\lambda + \int \varphi(\lambda)\bar{z}(\lambda) d\lambda}$ and similar expressions for y and z. For light sources $\varphi(\lambda) = \Phi_{e\lambda}(\lambda)/\Phi_{e\lambda}(\lambda_0)$ (relative spectral radiant flux). For object colours $\varphi(\lambda)$ is given by one of the three products $\varphi(\lambda) = \dfrac{\Phi_{e\lambda}(\lambda)}{\Phi_{e\lambda}(\lambda_0)} \cdot \begin{cases} \varrho(\lambda) \\ \tau(\lambda) \\ \beta(\lambda) \end{cases}$	These quantities are dimensionless. $\varphi(\lambda)$ is called colour tristimulus function. λ_0 is a reference wavelength. In the CIE 1964 supplementary standard colorimetric system, the symbols for the chromaticity co-ordinates are x_{10}, y_{10}, z_{10}.