International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

TECHNICAL NOTE

Relating Photochemical and Photobiological Quantities to Photometric Quantities

CIE TN 002:2014

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The following member of DR 2-67 “Relating Photochemical and Photobiological Quantities to Photometric Quantities” took part in the preparation of this Technical Note:

Blattner, P.	Switzerland

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Summary

Optical radiation has different effects on biological systems. To quantify these effects usually the spectral distribution of a radiant quantity is weighted with the action spectrum of that effect. By this a relation between the photobiological and radiometric quantities is made.

In very recent publications, mainly in the field of photobiological safety, a link between an actinic quantity and the corresponding photometric quantity is made mainly to give a simplified risk assessment procedure by means of absolute photometric measurements in combination with relative spectroradiometric measurements instead of absolute spectroradiometric measurements. Unfortunately, different terms or even units are used, e.g. “transformation factor” (Halbritter, 2011), „specific effective radiant ultraviolet power” (EC, 2009; IEC, 2011a), “proportionality factor” (IEC, 2011b), “WB/lm factor” (IEC, 2011b), or new units are defined, e.g. “Blue Watt”, “WB” (IEC, 2011b).

This Technical Note proposes the definition of new terms relating photobiological or photochemical quantities to photometric quantities. It adheres to the correct use of units within the present International System of Units SI (BIPM, 2006; ISO, 2009; ISO, 2008).

1 Background

According to the present definition of the SI “a photobiological or photochemical quantity is defined in purely physical terms as the quantity derived from the corresponding radiant quantity by evaluating the radiation according to its action upon a selective receptor. The quantity is given by the integral over wavelength of the spectral distribution of the radiant quantity weighted by the appropriate actinic action spectrum” (BIPM, 2006, Appendix 3).

Most of the action spectra are relative quantities and thus are dimensionless. Except for photometric quantities, the unit of the photobiological or photochemical quantity is the radiometric unit of the corresponding radiant quantity. When giving a quantitative value, it is essential to specify whether a radiometric or photobiological quantity is intended as the unit is the same.

As an example the blue light hazard (BLH) weighted radiance[1], L_B, (CIE, 2011, term 17-99) of a source is obtained by weighting the spectral radiance[2], $L_{\mathrm{e},\lambda}(\lambda)$, with the blue light hazard spectral weighting function[3], $B(\lambda)$, (CIE, 2011, term 17-102) (i.e. the effectiveness of radiation in respect of BLH) and integrating over all wavelengths λ present in the source spectrum. This can be expressed mathematically as

$$L_\mathrm{B} = \int L_{\mathrm{e},\lambda}(\lambda) \cdot B(\lambda) \cdot \mathrm{d}\lambda \,. \quad (1)$$

The blue light hazard weighted radiance, L_B, is usually quoted in the SI unit $\mathrm{W} \cdot \mathrm{m}^{-2} \cdot \mathrm{sr}^{-1}$.

NOTE The use of new units (e.g. “blue” Watt or "circadian equivalent lux") is not allowed within the present definition of the SI.

According to the SI (BIPM, 2006) the only photobiological quantities that are allowed to use specific units are related to the interaction of radiation with the human eye in vision (i.e.

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1 Note that in the ILV (CIE, 2011) the term “blue light hazard radiance”, symbol L_b, is used for the same quantity. This is an inconsistency in the ILV and will be corrected in the next revision.

2 Note that in the ILV (CIE, 2011) the symbol for spectral radiance is indicated as $L_\lambda(\lambda)$. This is an inconsistency in the ILV and will be corrected in the next revision.

3 Note that in the ILV (CIE, 2011) the symbol for the blue light hazard spectral weighting function is indicated as $b(\lambda)$. In this document the symbol as introduced in IEC 62471:2006/CIE S 009:2002 (IEC/CIE, 2006) is used. The symbol in the ILV will be corrected in the next revision.

candela, lux, lumen). For photopic vision, the luminance L_{v} is related to the spectral radiance $L_{\mathrm{e},\lambda}(\lambda)$ by (ISO/CIE, 2005; BIPM, 1983)

$$L_{\mathrm{v}} = K_{\mathrm{m}} \cdot \int L_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda \,. \tag{2}$$

where $V(\lambda)$ is the CIE spectral luminous efficiency function for photopic vision, and K_{m} the maximum luminous efficacy of radiation for photopic vision ($K_{\mathrm{m}} \cong 683\,\mathrm{lm} \cdot \mathrm{W}^{-1}$). The luminance, L_{v}, is quoted in the SI unit $\mathrm{cd} \cdot \mathrm{m}^{-2}$.

NOTE The above relation can be applied to any of the photometric quantities like luminous flux, illuminance, luminous intensity, luminous energy, luminous exitance (ISO/CIE, 2005). For example, luminous flux can be evaluated as

$$\Phi_{\mathrm{v}} = K_{\mathrm{m}} \cdot \int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda$$

where $\Phi_{\mathrm{e},\lambda}(\lambda)$ is the spectral radiant flux.

2 Proposal for New Terms

As already documented in the Summary with a few examples, a link between an actinic quantity and the corresponding photometric quantity is made in a number of very recent publications where different names are given for the same quantity.

Based on the example of blue light hazard the following terms and definitions are proposed:

2.1
blue light hazard efficacy of luminous radiation (of a source)
$K_{\mathrm{B,v}}$
quotient of the blue light hazard weighted radiant flux[1], Φ_{B}, to the luminous flux, Φ_{v},

$$K_{\mathrm{B,v}} = \frac{\Phi_{\mathrm{B}}}{\Phi_{\mathrm{v}}} = \frac{\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot B(\lambda) \cdot \mathrm{d}\lambda}{K_{\mathrm{m}} \cdot \int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda} \tag{3}$$

where

λ	is the wavelength;
$\Phi_{\mathrm{e},\lambda}(\lambda)$	is the spectral radiant flux;
$B(\lambda)$	is the blue light hazard spectral weighting function;
$V(\lambda)$	is the CIE spectral luminous efficiency function for photopic vision;
K_{m}	is the maximum value of the spectral luminous efficacy (683,002 $\mathrm{lm \cdot W^{-1}} \approx 683\ \mathrm{lm \cdot W^{-1}}$)

Note 1 to entry: The blue light hazard efficacy of luminous radiation is expressed in $\mathrm{W \cdot lm^{-1}}$, $\mathrm{mW \cdot klm^{-1}}$, $\mathrm{\mu W \cdot klm^{-1}}$, …

Note 2 to entry: The term "luminous radiation" refers to optical radiation weighted with the CIE spectral luminous efficiency function for photopic vision, $V(\lambda)$.

Note 3 to entry: The use of this term is only reasonable if parts of the optical radiation are in the visible range and thus $\Phi_{\mathrm{v}} \neq 0$.

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1 Note that in the ILV (CIE, 2011) the term "blue light hazard radiant flux", symbol Φ_{b}, is used for the same quantity. This is an inconsistency in the ILV and will be corrected in the next revision.

2.2
blue light hazard factor of luminous radiation
$a_{\mathrm{B,v}}$
ratio of the blue light hazard weighted radiant flux to the $V(\lambda)$ weighted radiant flux

$$a_{\mathrm{B,v}} = \frac{\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot B(\lambda) \cdot \mathrm{d}\lambda}{\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda} \quad (4)$$

where

λ	is the wavelength;
$\Phi_{\mathrm{e},\lambda}(\lambda)$	is the spectral radiant flux;
$B(\lambda)$	is the blue light hazard spectral weighting function;
$V(\lambda)$	is the CIE spectral luminous efficiency function for photopic vision

Note 1 to entry: The blue light hazard factor of luminous radiation is dimensionless with the unit one.

Note 2 to entry: Luminous radiation refers to optical radiation weighted with the CIE spectral luminous efficiency function for photopic vision, $V(\lambda)$.

Note 3 to entry: The use of this term is only reasonable if parts of the optical radiation are in the visible range and thus $\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot V(\lambda) \cdot \mathrm{d}\lambda \neq 0$.

3 Photobiological and Photochemical Evaluations Based on Photometric Measurements

The newly defined terms are useful for the assessment of hazards in situations where the primary use of the source is related to its visible content. An example is the determination of BLH radiance through a measurement of the luminance and the spectral distribution of the source. In theory this relation is valid if the spectral distribution is independent of the angle and point of emission within the field of view as well as the acceptance angle of the luminance meter. In practice this independence should be verified and considered in the uncertainty determination of the measurement. In addition care should be taken when measuring spectrally narrow sources (for example a blue light emitting LED), as due to spectral mismatch of the photometer to the CIE spectral luminous efficiency function for photopic vision ($V(\lambda)$) large errors are possible. Further guidance is given in CIE S 023 (CIE, 2013).

4 Further Considerations

4.1 Relationship between the Proposed Terms

The blue light hazard factor $a_{\mathrm{B,v}}$ is related to the blue light hazard efficacy $K_{\mathrm{B,v}}$ by

$$a_{\mathrm{B,v}} = K_{\mathrm{m}} \cdot K_{\mathrm{B,v}} \,. \quad (5)$$

where

K_{m}	is the maximum value of the spectral luminous efficacy (683,002 $\mathrm{lm \cdot W^{-1}} \approx 683\ \mathrm{lm \cdot W^{-1}}$).

4.2 Other Photochemical and Photobiological Effects

Similarly, quantities related to other photobiological or photochemical effects can be defined to relate them to a photometric quantity analogous to 2.1, e.g.

- $K_{\mathrm{c,v}}$: circadian efficacy of luminous radiation;
- $K_{\mathrm{er,v}}$: erythemal efficacy of luminous radiation;
- $K_{\mathrm{R,v}}$: retinal thermal efficacy of luminous radiation;
- $K_{\mathrm{UV-A,v}}$: UV-A efficacy of luminous radiation.

4.3 Relation to Radiometric Quantities

If a relation to a radiometric quantity is made, the quantities shall be called "xxx efficiency of radiation", where "xxx" stands for the photobiological or photochemical effect in question, e.g. the quantity "BLH efficiency of radiation" is defined as

$$\eta_{\mathrm{B}} = \frac{\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot B(\lambda) \cdot \mathrm{d}\lambda}{\int \Phi_{\mathrm{e},\lambda}(\lambda) \cdot \mathrm{d}\lambda}. \tag{6}$$

NOTE 1 Unit: 1.

NOTE 2 The blue light hazard efficiency of radiation, η_{B}, is related to the blue light hazard efficacy of luminous radiation, $K_{\mathrm{B,v}}$, through $\eta_{\mathrm{B}} = K \cdot K_{\mathrm{B,v}}$, where K is the luminous efficacy of radiation, and to the blue light hazard factor of luminous radiation, $a_{\mathrm{B,v}}$, through $\eta_{\mathrm{B}} = V \cdot a_{\mathrm{B,v}}$, where V is the luminous efficiency of radiation.

NOTE 3 For some applications it might be necessary to state both η_{B} and $K_{\mathrm{B,v}}$ (Rebec et al., 2014).

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