Note on photobiological quantities

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Foreword

At its 16th meeting in 2001, the CCPR has formed a working group to produce a document showing the formalism to trace photobiological measurements using action spectra directly to the SI. The present document is the result of the work of this working group for which A. Bittar, M. L. Rastello, M. Stock and J. Bastie (convenor) have provided input.

Introduction

Among the base units the candela has a special place. It is used to quantify the response of the human eye to visible light; it is therefore the measurement of a biological response to an optical radiation.

According to the present definition adopted by the 16th General Conference of Weights and Measures, in 1979, the candela is the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540x10^{12} hertz and that has a radiant intensity in that direction of 1/683 watt per steradian. This definition gives only a numerical relationship between the luminous quantities and the radiometric quantities at a single wavelength.

In order to implement this definition practically the 10th CCPR meeting has approved the monograph “Principles governing photometry” (1983) [1]. The purpose of this document is to bring together the definitions and the tables of numerical values already adopted (or recommended) and published, by the Conférence Générale des Poids et Mesures (CGPM), by the Comité International des Poids et Mesures (CIPM), or by the Commission Internationale de l’Eclairage (CIE). Also in this document the special characteristic of photometric quantities have been pointed out by defining them as it follows : “Thus photometric quantities must take into account both the purely physical characteristics of the radiant power stimulating the visual system and the spectral responsivity of the latter. The subjective nature of the second of these two factors sets photometric quantities apart from purely physical quantities.”

According to the above publication the candela can be also defined by (written in a numerical form with) the following equation :

$$I_v = K_m \int_\lambda I_{e,\lambda}(\lambda).V(\lambda).d\lambda$$

This definition links the luminous intensity $\boldsymbol{I_v}$ to the spectral radiant intensity $\boldsymbol{I_{e,\lambda}}$, through a weighting function, the ***V(λ)*** function, and a multiplicative constant $\boldsymbol{K_m}$. ***V(λ)*** is the spectral luminous efficiency function of the standard observer defined by the CIE in 1924 and $\boldsymbol{K_m}$ is the maximum luminous efficiency which fixes the relationship between luminous and radiant quantities. According to the above definition $\boldsymbol{K_m}$ is equal to 683 lm/W. The luminous efficiency function ***V(λ)*** applies to the photopic vision (high level of luminance) but measurement can also be carried out at low level of luminance in the scotopic vision. In this case it is the ***V’(λ)*** function which is used. Both functions have been defined by the CIE and endorsed by the CIPM (annex 1).

But there exists a large number of other effects involving optical radiation and photobiological response. Erythema, photokeratitis, photocarcinogenesis, photoconjonctivitis and bilirubin dissociation are the most well known among the photobiological responses in humans. Photosynthesis, phototropism, and chlorophyll synthesis are the most well known responses in plants.

Measurement of photobiological quantities

Quantitative measurement of any of these photobiological responses requires the definition of a unit and the assignment of a numerical value and an uncertainty to the quantity associated with that unit.

In accordance with what has been done for the measurement of photometric quantities it is possible to define a biological unit and determine a numerical value for the corresponding photobiological quantity using the following equation :

$$I_{bio} = K \int_{\lambda} I_{e,\lambda}(\lambda).F_{bio}(\lambda).d\lambda$$

with :

$\boldsymbol{I_{bio}}$ is the intensity of the photobiological effect

$\boldsymbol{K}$ is a constant depending on the chosen unit for defining the photobiological effect

$\boldsymbol{I_{e,\lambda}}$ is the spectral radiant intensity of the radiation impinging on the photobiological receiver

$\boldsymbol{F_{bio}(\lambda)}$ is the action spectrum of the photobiological effect.

The previous equation has been written for the intensity of a photobiological quantity but it could be also written in the same way for any of the others quantities defined for photometric or radiometric measurements such as radiance, irradiance, exposure, etc.

The action spectrum of a photobiological response which is of the same kind as V(λ) for photometry is defined in the same way as V(λ), by consensus among the users. The Commission Internationale de l'Eclairage (CIE) has adopted action spectra for photokeratitis [2], photoconjunctivitis [3], photocarcinogenesis [4], and erythema [5, 6, 7, 8] and had also published information on photobiological effects in plant growth but not yet adopted action spectra in this field [8]. At the present time, several technical committees of the CIE are working on action spectra, for example TC 6-23 "Develop generalised action spectra for plant response to waveband from 280 to 1100 nm", TC 6-31 "Immediate pigmentation darkening", TC 6-44 "Illuminators for treatment of infant hyperbilirubinemia" and TC 6-46 "Standardised action spectrum for UV disinfection". There is an increasing demand for quantitative measurements in the photobiological field for reasons of both safety and medical treatments.

Although the method for determining the numerical value of a photobiological quantity is clearly indicated by the example of photometric measurements, the definition of a relevant unit is not so easy. Due to historical reasons, a specific system of units, with special names, has been developed for the various quantities involved in the measurements of photometric quantities (candela, lumen, lux, etc.). Considering the large number of existing photobiological quantities it seems completely unrealistic to do the same for each individual photobiological quantity.

At its 9th session, in 1977, the CCPR had a long discussion on this issue and offered a recommendation to the CIPM. In this recommendation it was suggested to choose the action spectrum functions without unit and to use the corresponding radiometric unit. Defining the unit of a photobiological quantity by this method sets the constant K, in the above equation, to 1. For

example, the interaction between a radiant power and a photobiological response could have the watt as unit (Annex 2).
CIE, in its publications on photobiology has started to use with success this method for giving the results of the measurement of various actinic quantities. In these publications the various photobiological quantities are defined using the corresponding radiometric quantities and adding the appropriate subscript, and the units used are the radiometric units. For example, in the ISO 17166 / CIE S007 : Joint ISO/CIE standard erythema reference action spectrum and standard erythema dose. (1999) [8], the erythema action spectrum is written $s_{er}(\lambda)$, the erythemal effective irradiance is defined by

$$E_{er} = \int E_{\lambda} s_{er} d\lambda$$

and the erythemal effective radiant exposure by

$$H_{er} = \iint E_{\lambda} s_{er}(\lambda) d\lambda dt$$

and the standard erythemal dose is **100 J.m^{-2}**.

Proposal to the CCPR

Measurements in the field of biology, health and safety are becoming more and more important and need to be directly linked to the SI system (annex 3). In the specific field of biology, the units of photobiological quantities can be easily connected to the SI system in a similar way to the candela which is both one of the base units of the SI system and also a photobiological unit.

Now, the Consultative Committee for Units is preparing the 8th edition of the SI Brochure which is the reference brochure for implementing the SI system. It may be useful to take the opportunity of this new edition to introduce some information about photobiological quantities and their measurement. The objective of this proposal is not to create a new class of unit in the SI as it was done previously by R. A. Nelson and L. Ruby [10] but only to give practical advice to measure photobiological quantities using the SI by recommending the implementation of the CCPR 1977 recommendation in order to avoid the proliferation of non SI unit in the field of photobiology.
Perhaps it could also be possible, if useful, to extend this concept of measurement in a general way to all other possible quantities defined using a weighting function.

The content of the information to be put in the brochure at the right place could be :

- The definition of a photobiological quantity (or a quantity weighted by a function)
- The definition of the action spectra (or weighting functions)
- The way to derive units for photobiological quantities (or a weighted quantity) from SI units according to the recommendation of the CCPR (1977) using the radiometric units corresponding to the various type of measurements.

One question which could be of interest is the usefulness of the approval of action spectra by one or several international organisations especially by the CIPM.

A formal recommendation to the CIPM to include method for assigning radiometric units to photobiological quantities (or weighted quantities) in the SI brochure could be made by the CCPR.

Annex 1

History of V(λ) and V'(λ)

1924 – Adoption by CIE of the V(λ) function every ten nanometer
1933 – Endorsement by CIPM of V(λ)
1937 – Resolution by CIPM on the use of the V(λ) function
1951 – Adoption by CIE of the V'(λ) function
1971 – Adoption by CIE of the present values of V(λ) (every nanometer)
1972 – Endorsement by CIPM of these values
1976 – Endorsement by CIPM of the V'(λ).

In 1924, CIE have adopted "provisionally" the V(λ) function and officially it is always a provisional function. In order to give an "official" status to V(λ) and V'(λ) CIE is preparing a standard which is, at present time, at the end of the adoption process by National Committees. It will be available very soon with the title : CIE Standard S XXX "Photometry - The CIE System of Physical Photometry"

Annex 2

Recommandation P 1 (1977)

Le Comité Consultatif de Photométrie et Radiométrie,
considérant

- que l'on doit mesurer de nombreuses grandeurs mettant en jeu des rayonnements électromagnétiques et des facteurs biologiques,
- que le nombre des unités SI ayant des noms spéciaux ne doit pas être augmenté sans des raisons impératives,

recommande
qu'avant d'admettre dans le SI un nouveau nom spécial pour une unité d'une grandeur mettant en jeu des rayonnements électromagnétiques et des facteurs biologiques, on étudie attentivement la possibilité de choisir une unité SI existante. Par exemple, pour une grandeur résultant de la pondération d'une répartition spectrale de puissance énergétique par une fonction spectrale photobiologique, la fonction de pondération pourrait être choisie sans dimension et en conséquence la grandeur serait exprimée en watts.

Annex 3

Resolution 4

The 21st Conférence Générale des Poids et Mesures,
considering that

- the effects on the geosphere and biosphere of industrial and commercial activities and of many other human pursuits, as well as natural phenomena, and the consequences for human health and well-being are the subject of major studies worldwide,
- governments are increasingly faced with decisions of great economic and political significance concerning the regulation of these activities,

• the policies of governments are influenced by studies depending critically on accurate and mutually compatible measurements often requiring very large economic investments,
• much of the important scientific evidence required for decisions by governments comes from measurements of small changes in certain key parameters, measurements sometimes extending over several decades,
• certain critical measurements have traditionally been made in *ad hoc* units, based upon special instrumentation or procedures, and not in the well-characterised and internationally agreed SI units,
• experience over many years has shown that measurements not directly linked to the International System of Units (SI) cannot be relied upon in the long term, cannot be compared with similar measurements made elsewhere and do not adequately bring out possible relationships with measurements made in other scientific disciplines,
• increasing demands for reliability in measurements made for medical and therapeutic purposes are leading to more demanding regulation in these areas,
recommends that those responsible for studies of Earth resources, the environment, human well-being and related issues ensure that measurements made within their programmes are in terms of well-characterised SI units so that they are reliable in the long term, are comparable worldwide and are linked to other areas of science and technology through the world's measurement system established and maintained under the Metre Convention.

Bibliography

[1] BIPM Monograph : Principle governing photometry (1983)

[2] CIE Publication 106-1993 : CIE collection in photobiology and photochemistry (1993)
– 106/2 Photokeratitis.

[3] CIE Publication 106-1993 : CIE collection in photobiology and photochemistry (1993)
– 106/3 Photoconjunctivitis.

[4] CIE Publication 138-2000 : CIE collection in photobiology and photochemistry (2000)
– 138/2 Action spectrum for photocarcinogenesis (non melanoma skin cancers).

[5] CIE Publication 103-1993 : CIE collection (1993)
– 103/3 Reference action spectra for ultraviolet induced erythema and pigmentation of different human skin types.

[6] CIE Publication 106-1993 : CIE collection in photobiology and photochemistry (1993)
– 106/4 A reference action spectrum for ultraviolet induced erythema in human skin.

[7] CIE Publication 125-1997 : Standard erythema dose.

[8] ISO 17166 / CIE S007 : Joint ISO/CIE standard erythema reference action spectrum and standard erythema dose. (1999).

[9] CIE Publication 106-1993 : CIE collection in photobiology and photochemistry (1993)
– 106/5 Photobiological effects in plant growth.

[10] Physiological Units in the SI, R. A. Nelson and L. Ruby, Metrologia 1993, **30**, 55-60.