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Standard Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data[1]

This standard is issued under the fixed designation E2152; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

The fundamental procedure for evaluating the color of a fluorescent specimen is to obtain bispectral photometric data for specified irradiating and viewing geometries, and from these data to compute tristimulus values based on a CIE (International Commission on Illumination) standard observer and a CIE standard illuminant. Procedures for such computation are contained in this practice. This practice also contains procedures for computing illuminant-specific spectral radiance factor values from illuminant-independent bispectral photometric data.

1. Scope

1.1 This practice provides the values and practical computation procedures needed to obtain tristimulus values, designated X, Y, Z and X_{10}, Y_{10}, Z_{10} for the CIE 1931 and 1964 observers, respectively, from bispectral photometric data for the specimen. Procedures for obtaining such bispectral photometric data are contained in Practice E2153.

1.2 Procedures for conversion of results to color spaces that are part of the CIE system, such as CIELAB and CIELUV are contained in Practice E308.

1.3 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color

2.2 *CIE Standards:*

CIE Publication 15.2, Colorimetry[3]

2.3 *ISO Standards:*

ISO 11476 Paper and Board—Determination of CIE-Whiteness, C/2 Degrees[4]

3. Terminology

3.1 *Definitions*—The definitions contained in Terminology E284 are applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bispectrometer*, *n*—an optical instrument equipped with a source of irradiation, two monochromators, and a detection system, such that a specimen can be measured at independently-controlled irradiation and viewing wavelengths. The bispectrometer is designed to allow for calibration to provide quantitative determination of the bispectral radiation-transfer properties of the specimen.(5)

NOTE 1—Typically, a reference detection system monitors the radiation incident on the specimen. This reference detection system serves to compensate for both temporal and spectral variations in the flux incident upon the specimen, by normalization of readings from the instrument's emission detection system.

3.2.2 *diagonal elements*, *n*—elements of a bispectral matrix for which irradiation and viewing wavelengths are equal.

3.2.3 *fluorescence*, *n*—this standard uses the term "fluorescence" as a general term, including both true fluorescence

[1] This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.05 on Fluorescence.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from U.S. National Committee of the CIE (International Commission on Illumination), C/o Thomas M. Lemons, TLA-Lighting Consultants, Inc., 7 Pond St., Salem, MA 01970, http://www.cie-usnc.org.

[4] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

(with a luminescent decay time of less than 10^{-8} s) and phosphorescence with a delay time short enough to be indistinguishable from fluorescence for the purpose of colorimetry.

3.2.4 *off-diagonal element*, *n*—any element of a bispectral matrix for which irradiation and viewing wavelengths are not equal.

4. Summary of Practice

4.1 *Procedures*—Procedures are given for computing from bispectral photometric measurements the CIE tristimulus values X, Y, Z for the CIE 1931 standard observer and the CIE 1964 supplementary standard observer. While recognizing the CIE recommendation of numerical integration at 1 nm intervals (in Publication 15.2) as the basic definition, this practice is limited in scope to measurements and calculations using spectral intervals greater than or equal to 5 nm.

4.2 *Calculations*—CIE tristimulus values X, Y, Z or X_{10}, Y_{10}, Z_{10} are calculated by numerical summation of the products of weighting factors for selected illuminants and observers with the bispectral Donaldson radiance factor of the specimen. The tristimulus values so calculated may be converted to coordinates in a more nearly uniform color space such as CIELAB or CIELUV.

5. Significance and Use

5.1 The bispectral or two-monochromator method is the definitive method for the determination of the general radiation-transfer properties of fluorescent specimens (**4**). In this method, the measuring instrument is equipped with two separate monochromators. The first, the irradiation monochromator, irradiates the specimen with monochromatic light. The second, the viewing monochromator, analyzes the radiation leaving the specimen. A two-dimensional array of bispectral photometric values is obtained by setting the irradiation monochromator at a series of fixed wavelengths *(μ)* in the ultraviolet and visible range, and for each μ, using the viewing monochromator to record readings for each wavelength *(λ)* in the visible range. The resulting array, once properly corrected, is known as the Donaldson matrix, and the value of each element *(μ,λ)* of this array is here described as the Donaldson radiance factor *(D(μ,λ))*. The Donaldson radiance factor is an instrument- and illuminant-independent photometric property of the specimen, and can be used to calculate its color for any desired illuminant and observer. The advantage of this method is that it provides a comprehensive characterization of the specimen's radiation-transfer properties, without the inaccuracies associated with source simulation and various methods of approximation.

6. Procedure

6.1 *Selecting Standard Observer*—Select standard observer according to the guidelines of Practice E308.

6.2 *Selecting Illuminants*—Select illuminants that are similar to the light under which the objects will be viewed or for which their colors will be specified or evaluated. In general, follow the recommendations of Practice E308. For fluorescent samples, however, special attention must be given to the relative UV content of the selected illuminants and the light under which the objects will be viewed.

6.2.1 When object will be viewed indoors, by daylight filtered through a glass window, use values for the extended version of Illuminant C defined in ISO 11476.

6.2.2 When object will be viewed outdoors, by unfiltered daylight, use values for CIE Illuminant D65, or other daylight illuminants, as defined by the formulas developed by Judd, and presented in CIE 15.2.

6.2.3 When object will be viewed under well-defined special conditions of irradiation which are not similar to any standard illuminant, a provisional illuminant may be defined. Such a provisional illuminant must represent the relative spectral irradiance upon the object surface under these special conditions.

7. Calculation

7.1 *Calculation of Colorimetric Quantities*—Use the method of calculating tristimulus values at 5 nm intervals over the viewing wavelength range 380 to 780 nm, and irradiation wavelength range 300 to 780 nm.

7.2 *Calculation of Tristimulus Values*—The calculation procedures described below involve numerical summation of the products of the Donaldson radiance factor of the specimen and a bispectral factor derived from the tabulated standard illuminant and observer functions. After normalization, the sums are the CIE tristimulus values X, Y, Z. (**3**, **4**, **5**)

7.2.1 *Application of Illuminant Weights*—Select the desired CIE standard illuminant from Tables given in Practice E308. Multiply each element *D(μ,λ)* of the specimen's Donaldson matrix by the tabulated value of the relative spectral power of the illuminant Φ at the element's irradiation wavelength *(μ)*.

7.2.2 *Calculation of Stimulus Function*—Obtain the sum over *μ* of these products at 5 nm intervals over the wavelength range 300 to 780 nm. The sum obtained at each viewing wavelength λ is the value of the specimen's stimulus function (relative spectral radiance) *F(λ)*, under the specified conditions of irradiation. From these values, either tristimulus values or spectral radiance factor values may be derived.

$$F(\lambda) = \sum_{\mu=300}^{780} \Phi(\mu) D(\mu,\lambda) \tag{1}$$

7.2.3 *Derivation of Tristimulus Values*—Use the color-matching functions selected in 6.1. Multiply the specimen's stimulus function at each viewing wavelength *(λ)* by the corresponding tabulated values of the observer color-matching functions. Obtain the sum of these spectral products at 5 nm intervals over the wavelength range 380 to 780 nm:

$$X = k \sum_{\lambda=380}^{780} \bar{x}(\lambda) F(\lambda) \tag{2}$$

$$Y = k \sum_{\lambda=380}^{780} \bar{y}(\lambda) F(\lambda)$$

$$Z = k \sum_{\lambda=380}^{780} \bar{z}(\lambda) F(\lambda)$$

where:

k = the normalization constant:

$$k = \frac{100}{\sum_{\lambda=380}^{780} \Phi(\lambda) \bar{y}(\lambda)} \tag{3}$$