



Designation: E 2153 – 01

Standard Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color¹

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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. The considerations involved and the procedures used to obtain precise bispectral photometric data are contained in this practice. Values and procedures for computing CIE tristimulus values from bispectral photometric data are contained in Practice E 2152. General considerations regarding the selection of appropriate irradiating and viewing geometries are contained in Guide E 179; further specific considerations applicable to fluorescent specimens are contained in this practice.

1. Scope

1.1 This practice addresses the instrumental measurement requirements, calibration procedures, and material standards needed for obtaining precise bispectral photometric data for computing the colors of fluorescent specimens.

1.2 This practice lists the parameters that must be specified when bispectral photometric measurements are required in specific methods, practices, or specifications.

1.3 This practice applies specifically to bispectrometers, which produce photometrically quantitative bispectral data as output, useful for the characterization of appearance, as opposed to spectrofluorimeters, which produce instrument-dependent bispectral photometric data as output, useful for the purpose of chemical analysis.

1.4 The scope of this practice is limited to the discussion of object-color measurement under reflection geometries; it does not include provisions for the analogous characterization of specimens under transmission geometries.

1.5 *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.*

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. Referenced Documents

2.1 ASTM Standards:

E 179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials²

E 284 Terminology of Appearance²

E 925 Practice for the Periodic Calibration of Narrow Band-Pass Spectrophotometers³

E 958 Practice for Measuring Practical Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers³

E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation²

E 1341 Practice for Obtaining Spectroradiometric Data from Radiant Sources for Colorimetry²

E 2152 Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data²

2.2 NPL Publications:

NPL Report MOM 12 Problems of spectrofluorimetric standards for reflection and colorimetric use⁴

2.3 CIE Publications:

CIE No. 38 Radiometric and Photometric Characteristics of Materials and Their Measurement⁵

² Annual Book of ASTM Standards, Vol 06.01.

³ Annual Book of ASTM Standards, Vol 03.06.

⁴ Available from National Physical Laboratory, Queens Road, Teddington, Middlesex, United Kingdom TW11 0LW.

⁵ Available from USNC/CIE Publications Office, TLA-Lighting Consultants, Inc, 7 Pond St., Salem, MA 01970-4819.

CIE No.15.2 Colorimetry, 2nd Edition⁵

CIE Report of TC-2.25: Calibration Methods and Photoluminescent Standards for Total Radiance Factor Measurement⁵

2.4 NIST Publications:

NBS No. 260-66 Didymium Glass Filters for Calibrating the Wavelength Scale of Spectrophotometers⁶

3. Terminology

3.1 *Definitions*—The definitions contained in Terminology E 284 are applicable to this practice.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *bispectral fluorescence radiance factor, $b_{F\lambda}(\mu)$* —the ratio of the spectral radiance at wavelength λ due to fluorescence from a point on the specimen when irradiated at wavelength μ to the total radiance of the perfectly reflecting diffuser similarly irradiated and viewed (see NPL Report MOM 12).

3.2.2 *bispectral radiance factor, $b_{\lambda}(\mu)$* —the ratio of the spectral radiance (radiance per unit waveband) at wavelength λ from a point on a specimen when irradiated at wavelength μ to the total (integrated spectral) radiance of the perfectly reflecting diffuser similarly irradiated and viewed.

$$b_{\lambda}(\mu) \equiv L_{\lambda}(\mu)/L(\mu)_d \quad (1)$$

3.2.3 *bispectral reflection radiance factor, $b_{R\lambda}(\mu)$* —the ratio of the spectral radiance at wavelength λ due to reflection from a point on the specimen when irradiated at wavelength μ to the total radiance of the perfectly reflecting diffuser similarly irradiated and viewed.

3.2.4 *bispectrometer*—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. (6)

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.

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

3.2.6 *diagonal fluorescence*—the contribution of fluorescence to diagonal values of a bispectral radiance factor matrix, due to the finite range of actual irradiation and viewing wavelengths when nominal irradiation and viewing wavelengths are equal ($\mu = \lambda$).

3.2.7 *discrete bispectral radiance factor, $B(\mu, \lambda)$* —the matrix defined for specified irradiation and viewing bandpass functions, and viewing-wavelength sampling interval ($\Delta\lambda$) as follows:

$$B(\mu, \lambda) \equiv \bar{b}_{\lambda}(\mu) \cdot \Delta\lambda \quad (2)$$

where:

$\bar{b}_{\lambda}(\mu)$ = the average bispectral radiance factor of the specimen, as weighted by the specified irradiation and viewing bandpass functions.

3.2.8 *Donaldson radiance factor, $D(\mu, \lambda)$* —a special case of the discrete bispectral radiance factor, for which the specified irradiation and viewing bandpass functions are perfectly rectangular, with bandwidth equal to irradiation and viewing-wavelength sampling interval.

NOTE 2—The Donaldson radiance factor is approximately equal to the ratio of the specimen radiance within the rectangular waveband of width $\Delta\lambda$ centered at λ to the radiance of the perfect reflecting diffuser when each is irradiated over the rectangular waveband of width $\Delta\lambda$ centered at μ .

3.2.9 *fluorescence*—this standard uses the term “fluorescence” as a general term, including both true fluorescence (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.

3.2.10 *near-diagonal element*—off-diagonal elements of an uncorrected bispectral matrix whose values include a significant reflection component, due to reflection overspill. For instruments with irradiation and viewing bandpass functions which approximate the recommended trapezoidal or triangular shape, this should be limited to within two to three bands of the diagonal.

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

3.2.12 *reflection overspill*—the contribution of reflection to off-diagonal values of the discrete bispectral radiance factor matrix, due to the partial overlap of irradiation and viewing wavebands when nominal irradiation and viewing wavelengths are not equal ($\mu \neq \lambda$).

3.2.13 *spectral efficiency factor, $b(\mu)$* —the ratio of the total (integrated spectral) radiance from a point on a specimen when irradiated at wavelength μ to the total radiance of the perfectly reflecting diffuser identically irradiated and viewed.

$$b(\mu) \equiv L(\mu)/L(\mu)_d \quad (3)$$

4. Summary of Practice

4.1 Procedures are given for selecting the types and operating parameters of bispectrometers used to provide data for the calculation of CIE tristimulus values and other colorimetric values to quantify the colors of objects. The important steps in the calibration of such instruments, and the material standards required for these steps, are described. Guidelines are given for the selection of specimens to obtain the highest measurement precision. Parameters are identified which must be specified when bispectral photometric measurements are required in specific test methods or other documents.

4.2 In this practice, the measuring instrument, a bispectrometer, 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

⁶ Available from National Institute of Standards and Technology (NIST), 100 Bureau Drive, Stop 3460, Gaithersburg, MD 20899–3460.

wavelengths (μ) in the excitation band of the specimen, and for each μ , using the viewing monochromator to record readings for each wavelength (λ) in the specimen's emission range. The resulting array, once properly corrected, is known as the Donaldson matrix (2), and the value of each element (μ, λ) of this array is the Donaldson radiance factor ($D(\mu, \lambda)$).

4.3 While recognizing the CIE recommendation (in CIE Publication 15.2) of numerical integration at 1 nm intervals as the basic definition, this practice is limited in scope to measurements and calculations using spectral intervals greater than or equal to 5 nm.

5. Significance and Use

5.1 The bispectral or two-monochromator method is the definitive method for the determination of the general (illuminant-independent) radiation-transfer properties of fluorescent specimens (2). 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.

5.2 This practice provides a procedure for selecting the operating parameters of bispectrometers used for providing data of the desired precision. It also provides for instrument calibration by means of material standards, and for selection of suitable specimens for obtaining precision in the measurements.

6. Requirements for Bispectral Photometry

6.1 When describing the measurement of specimens by the bispectral method, the following must be specified:

6.1.1 The photometric quantity determined, such as Donaldson radiance factor or spectral efficiency factor.

6.1.2 The geometry of irradiation and viewing, including the following:

6.1.2.1 For bi-directional geometry, whether annular, circumferential, or uniplanar measurement conditions are to be used, and the number and angular distribution of any multiple beams.

6.1.2.2 For hemispherical geometry, whether total or diffuse measurement conditions (specular component of reflectance included or excluded) are to be used.

6.1.3 The spectral parameters for both irradiation and viewing, including wavelength range, wavelength measurement interval, and spectral bandpass.

6.1.4 Identification of the material standards used for instrument calibration.

6.1.5 Special requirements determined by the nature of the specimen, such as measurement orientation for anisotropic specimens.

7. Apparatus

7.1 *Bispectrometer*—The basic instrumental requirement is a bispectrometer designed for measurement of Donaldson radiance factor using one or more of the standard irradiation and viewing geometries described in Section 8.

7.2 *Irradiator*—The irradiator, which consists of the radiation source, a dispersive element and related optical components, shall irradiate the specimen with monochromatic radiation of known wavelength bandpass and measurement interval.

7.2.1 The radiation source must be stable with time and have adequate energy output over the wavelength range used for specimen irradiation.

7.2.2 The dispersive element, which provides energy in narrow wavelength bands across the UV and visible spectral range, may be a prism, a grating, or one of various forms of interference filters or wedges. The element should conform to the following requirements:

7.2.2.1 When highest measurement accuracy is required, the wavelength range should extend from 300-830 nm; otherwise the range from 300 to 780 nm should suffice. For specimens confirmed to be non-fluorescent or those exhibiting only visible-activated fluorescence (negligible excitation below 380 nm), the wavelength range from 380-780 nm can be used. Each user must decide whether the loss of accuracy in the measurements is negligibly small for the purpose for which data are obtained.

7.2.2.2 The wavelength interval should be 5 or 10 nm. Use of wider wavelength intervals, such as 20 nm, may result in reduced accuracy. Each user must decide whether the loss of accuracy in the measurements is negligibly small for the purpose for which data are obtained.

7.2.2.3 The irradiation wavelength interval should equal the viewing wavelength interval.

7.2.2.4 The spectral bandpass (full-width at half maximum power in the band of wavelengths transmitted by the dispersive element) should, for best results, be equal to the wavelength interval. The spectral bandpass function should be symmetrical, and approximately triangular or trapezoidal.

7.2.3 The irradiator should uniformly irradiate the sample.

7.3 *Receiver*—The receiver consists of the detector, a dispersive element and related optical components.

7.3.1 The detector must be a suitable photodetector such as a photoelectric device or silicon photodiode. The detector must be stable with time and have adequate responsivity over the wavelength range used.

7.3.2 The dispersive element, which provides energy in narrow wavelength bands across the visible spectral range, may be a prism, a grating, or one of various forms of interference filters or wedges. The element should conform to the following requirements:

7.3.2.1 The receiver's dispersive element may either be coupled with a slit, in order to function as part of a scanning monochromator, or coupled directly to a detection array, in order to function as a spectrograph (polychromator) (3).

7.3.2.2 When highest measurement accuracy is required, the wavelength range should extend from 360-830 nm; otherwise the range from 380 to 780 nm should suffice. Each user must decide whether the loss of accuracy in the measurements is negligibly small for the purpose for which data are obtained.

7.3.2.3 The wavelength interval should be 5 or 10 nm. Use of wider wavelength intervals, such as 20 nm, may result in reduced accuracy. Each user must decide whether the loss of