Designation: E 991 – 06

Standard Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method[1]

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INTRODUCTION

The fundamental procedure for evaluating the color of a fluorescent object is to obtain spectrometric data for specified illuminating and viewing conditions, and then use this data to compute tristimulus values based on an International Commission on Illumination (CIE) standard observer and a CIE standard illuminant. For a fluorescent object-color specimen, the spectral radiance factors used to calculate tristimulus values are made up of two components — an ordinary reflectance factor and a fluorescence factor ($\beta = \beta_S + \beta_F$). The magnitude of the fluorescent radiance factors, and consequently the measured total radiance factors and derived color values, vary directly with the spectral distribution of the instrument source illuminating the specimen. Consequently, the colorimetry of fluorescent object-color specimens requires greater control of the measurement parameters in order to obtain precise spectrometric and colorimetric data. In order to obtain repeatable and reproducible color values for fluorescent objects it is necessary that the illumination at the specimen surface closely duplicate the standard illuminant used in the color calculations. The considerations involved and the procedures used to obtain spectrometric data and compute colorimetric values for fluorescent specimens using a one-monochromator spectrometer are contained in this practice.

1. Scope

1.1 This practice applies to the instrumental color measurement of fluorescent specimens excited by near ultraviolet and visible radiation that results in fluorescent emission within the visible range. It is not intended for other types of photoluminescent materials such as phosphorescent, chemiluminescent, or electroluminescent, nor is this practice intended for the measurement of the fluorescent properties for chemical analysis.

1.2 This practice describes the instrumental measurement requirements, calibration procedures, and material standards needed for the color measurement of fluorescent specimens when illuminated by simulated daylight approximating CIE Standard Illuminant D65 (CIE D65).

1.3 This practice is limited in scope to colorimetric spectrometers providing continuous broadband polychromatic illumination of the specimen and employing only a viewing monochromator for analyzing the radiation leaving the specimen.

1.4 This practice can be used for calculating total tristimulus values and total chromaticity coordinates for fluorescent colors in the CIE Color System for either the CIE 1931 Standard Colorimetric Observer or the CIE 1964 Supplementary Standard Colorimetric Observer.

1.5 *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]

D 985 Test Method for Brightness of Pulp, Paper, and Paperboard (Directional Reflectance at 457 nm)

D 2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates

[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.

E 179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials
E 284 Terminology of Appearance
E 308 Practice for Computing the Colors of Objects by Using the CIE System
E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E 1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation
E 1247 Practice for Detecting Fluorescence in Object-Color Specimens by Spectrophotometry
E 1345 Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements
E 1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials
E 2152 Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data
E 2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color
E 2214 Practice for Specifying and Verifying the Performance of Color-Measuring Instruments
E 2301 Test Method for Daytime Colorimetric Properties of Fluorescent Retroreflective Sheeting and Marking Materials for High Visibility Traffic Control and Personal Safety Applications Using 45°:Normal Geometry

2.2 *CIE Publications and Standards:* [3]

CIE Publication CIE15:2004 Colorimetry, 3rd Edition
CIE Publication No: 51.2 A Method for Assessing the Quality of Daylight Simulators for Colorimetry
CIE Publication No. 76 Intercomparison on Measurement of (Total) Spectral Radiance Factor of Luminescent Specimens

2.3 *TAPPI Standards:* [4]

T 571om-03 Diffuse brightness of paper and paperboard (d/0)

2.4 *ISO Standards:* [5]

ISO 10526:1999/CIE S005/E-1998 CIE Standard Illuminants for Colorimetry
ISO 11475:2004 Paper and board — Determination of CIE whiteness, D65/10 degrees (outdoor daylight)
ISO 2469:1994 Paper, board and pulps — Measurement of diffuse reflectance factor

3. Terminology

3.1 *Definitions*: The definitions contained in Guide E 179, Terminology E 284, Practice E 1164, Practice E 1767, and Practice E 2153 are applicable to this test method.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *fluorescence*, *n*—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 (see Practice E 2153).

3.2.2 *fluorescent white*, *n*—white and near white specimens containing fluorescent whitening agents.

3.2.3 *near ultraviolet radiation*, *n*—optical radiation within the wavelength range from 300 to 380 nm.

3.2.4 *referee procedure*, *n*—a mutually agree upon testing procedure utilized to resolve disputes over instrumentally tested material properties that are expressed numerically.

4. Summary of Practice

4.1 This practice applies to the instrumental color measurement of fluorescent specimens that are excited by near ultraviolet and visible radiation and emit within the visible range. For methods to determine whether specimens exhibit fluorescence see Practice E 1247. This practice provides procedures for measuring the total spectral radiance factors of fluorescent object-color specimens under simulated daylight approximating CIE D65 using a one-monochromator colorimetric spectrometer and calculating total tristimulus values (XYZ) and total chromaticity coordinates (x,y) in the CIE Color System for either the CIE 1931 Standard Colorimetric Observer or the CIE 1964 Supplementary Standard Colorimetric Observer (see CIE Publication CIE15:2004 15).

4.2 The instrument source should provide broadband illumination of the specimen from 300 to 780 nm and the spectral distribution of the illumination on the specimen should closely duplicate CIE D65 (see ISO 10526:1999/CIE S005/E-1998). When highest measurement precision and reproducibility are required, the wavelength range should extend from 300 to 830 nm. Precise colorimetry of ultraviolet-activated fluorescent specimens requires the instrument provide significant illumination intensity below 380 nm. For the measurement of visible-activated fluorescent specimens, which have negligible excitation below 380 nm, it is only required that the illumination on the specimen provide a close match to CIE D65 over the wavelength range 380 to 780 nm.

4.3 The colorimetric spectrometer should employ a bidirectional optical measuring system with 45:0 or 0:45 illuminating and viewing geometry. The wavelength dispersive element (monochromator) shall be positioned between the specimen and the detector system (see CIE Pub. 76). The instrument may employ annular, circumferential, or uniplanar influx or efflux optics. The use of Practice E 1767 functional notation is recommended for the complete description of instrumentation geometry including cone angles, aperture size, etc. When the specimen exhibits directionality, and an instrument with uniplanar geometry is used, information on directionality may be obtained by measuring the specimens at two or more rotation angles. If information on directionality is not required, then multiple uniplanar measurements may be averaged, or an instrument with annular or circumferential geometry may be used. However, even with annular or circumferential influx or

[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.

[4] Available from Technical Association of the Pulp and Paper Industry (TAPPI), P.O. Box 105113, Atlanta, GA 30348; 15 Technology Parkway South, Norcross, GA 30092.

[5] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

efflux optics, some of the variability induced by specimen-optical system interactions may remain and the application of the methods in Practice E 1345 may help to reduce measurement variability.

4.4 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 minimize the specimen's contribution to the measurement imprecision. Parameters are identified that must be specified when spectrometric measurements are required in specific test methods or other documents.

4.5 Most modern colorimetric spectrometers have the capacity to compute the color coordinates of the specimen immediately following the measurement. When this is the case, the user shall select the CIE Color System and CIE D65, then chose either the CIE 1931 (2°) Standard Observer or CIE 1964 (10°) Supplementary Observer (see Practice E 308).

5. Significance and Use

5.1 The most general method for obtaining CIE tristimulus values or, through their transformation, other coordinates for describing the colors of fluorescent objects is by the use of spectrometric data obtained under defined and controlled conditions of illumination and viewing. This practice describes the instrumental measurement requirements, calibration procedures, and material standards needed for measuring the total spectral radiance factors of fluorescent specimens illuminated by simulated daylight approximating CIE D65 and calculating total tristimulus values and total chromaticity coordinates for either the CIE 1931 or 1964 observers.

5.2 The precise colorimetry of fluorescent specimens requires the spectral distribution of the instrument light source illuminating the specimen closely duplicate the colorimetric illuminant used for the calculation of tristimulus values, which is CIE D65 in this practice. The fundamental basis for this requirement follows from the defining property of a fluorescent specimen: instantaneous light emission resulting from electronic excitation by absorption of radiant energy (η) where the wavelengths of emission (λ) are as a rule longer than the excitation wavelengths (**1**).[6] For a fluorescent specimen, the total spectral radiance factors used to calculate tristimulus values are the sum of two components – an ordinary reflectance factor, $\beta(\lambda)_S$, and a fluorescence factor, $\beta(\eta,\lambda)_F$: $\beta(\lambda) = \beta(\lambda)_S + \beta(\eta,\lambda)_F$. Ordinary spectral reflectance factors are solely a function of the specimen's reflected radiance efficiency at the viewing wavelength (λ) and independent of the spectral distribution of the illumination. The values of the spectral fluorescent radiance factors at the viewing wavelength (λ) vary directly with the absolute spectral distribution of illumination within the excitation range (η), and consequently so will the total spectral radiance factors and derived colorimetric values. One-monochromator colorimetric spectrometers used in this practice are generally designed for the color measurement of ordinary (non-fluorescent) specimens and the precision with which they can measure the color of fluorescent specimens is directly dependent on how well the instrument illumination simulates CIE D65.

5.3 CIE D65 is a virtual illuminant that numerically defines a standardized spectral illumination distribution for daylight and not a physical light source (**2**). There is no CIE recommendation for a standard source corresponding to CIE D65 nor is there a standardized method for rating the quality (or adequacy) of an instrument's simulation of CIE D65 for the general instrumental colorimetry of fluorescent specimens. The requirement that the instrument simulation of CIE D65 shall have a rating not worse than BB (CIELAB) as determined by the method of CIE Publication 51 has often been referenced. However, the method of CIE 51 is only suitable for ultraviolet-excited specimens evaluated for the CIE 1964 (10°) observer. The methods described in CIE 51 were developed for UV activated fluorescent whites and have not been proven to be applicable to visible-activated fluorescent specimens.

NOTE 1—Aging of the instrument lamp will occur with normal usage resulting in changes in the spectral distribution and intensity of the illumination on the specimen over time. Measurement of the spectral distribution of the illumination at the sample port and evaluation of the adequacy of the CIE D65 simulation at regular intervals are recommended.

5.4 Differences in the absolute spectral irradiance distribution on the specimen between instrument models can produce significant variation in the measured color values of fluorescent specimens and result in poor reproducibility (**3**). In order to adequately reproduce the spectral irradiance on the specimen required for maximum measurement reproducibility, it may be necessary for a single model of instrument to be specified for use by both buyer and seller.

5.5 This practice is primarily for the instrumental color measurement of chromatic fluorescent specimens. While use of this practice for the color measurement of fluorescent whites is not precluded, other standards are more commonly used for measurement of these types of specimens (**4,5,6**) (see Test Methods D 985, ISO 11475, ISO 2469, and TAPPI T 571).

5.6 For geometrically sensitive fluorescent specimens angular tolerances on the axes and the angular aperture sizes must be well defined by the user to ensure adequate repeatability and reproducibility. Significant variation in measurement results for engineered surfaces and optical materials, for example retroreflective sheeting, can result from differences in the absolute axis angles of illumination and viewing and absolute size of the apertures between instruments (**7**). In order to replicate the measurement geometry, absolute angles and angular tolerances between instruments that is required for maximum measurement reproducibility, it may be necessary for a single model of instrument to be specified for use by both buyer and seller.

NOTE 2—To ensure inter-instrument agreement in the measurement of specimens with intermediate gloss, for formulation, or retroreflective specimens, tight geometric tolerances are required of the instrument axis angles and the instrument aperture angles.

5.7 Bidirectional (45:0 or 0:45) geometry is recommended for this practice.

[6] The boldface numbers in parentheses refer to the list of references at the end of this practice.