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StandardPractice for Obtaining Spectrometric Data for Object-Color Evaluation[1]

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INTRODUCTION

The fundamental procedure for evaluating the color of a reflecting or transmitting object is to obtain spectrometric data for specified illuminating and viewing conditions, 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 spectrometric data are contained in this practice. The values and procedures for computing CIE tristimulus values from spectrometric data are contained in Practice E308. Considerations regarding the selection of appropriate illuminating and viewing geometries are contained in Guide E179.

1. Scope

1.1 This practice covers the instrumental measurement requirements, calibration procedures, and material standards needed to obtain precise spectral data for computing the colors of objects.

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

1.3 Most sections of this practice apply to both spectrometers, which can produce spectral data as output, and spectrocolorimeters, which are similar in principle but can produce only colorimetric data as output. Exceptions to this applicability are noted.

1.4 This practice is limited in scope to spectrometers and spectrometric colorimeters that employ only a single monochromator. This practice is general as to the materials to be characterized for color.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 *This standard does not purport to address 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]

D1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics
E179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials
E259 Practice for Preparation of Pressed Powder White Reflectance Factor Transfer Standards for Hemispherical and Bi-Directional Geometries
E275 Practice for Describing and Measuring Performance of Ultraviolet and Visible Spectrophotometers
E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E387 Test Method for Estimating Stray Radiant Power Ratio of Dispersive Spectrophotometers by the Opaque Filter Method
E805 Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials
E925 Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Bandwidth does not Exceed 2 nm
E958 Practice for Measuring Practical Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers
E991 Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method

[1] This practice is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.02 on Spectrophotometry and Colorimetry.

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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.

E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials
E2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color
E2194 Practice for Multiangle Color Measurement of Metal Flake Pigmented Materials

2.2 *NIST Publications:*
LC-1017 Standards for Checking the Calibration of Spectrophotometers [3]
TN-594-12 Optical Radiation Measurements: The Translucent Blurring Effect—Method of Evaluation and Estimation [3]
SP-260-66 Didymium Glass Filters for Calibrating the Wavelength Scale of Spectrophotometers—SRM 2009, 2010, 2013, and 2014 [3]
SP-692 Transmittance MAP Service [3]

2.3 *CIE Publications:*
CIE No. 15.2 Colorimetry, 2nd edition [4]
CIE No. 38 Radiometric and Photometric Characteristics of Materials and Their Measurement [4]
CIE No. 46 Review of Publications on Properties and Reflection Values of Material Reflection Standards [4]
CIE No. 51 Method for Assessing the Quality of Daylight Simulators for Colorimetry [4]
CIE No. 130 Practical Applications of Reflectance and Transmittance Measurements [4]

2.4 *ISO Publications:*
ISO 2469 Paper, Board and Pulps — Measurement of Diffuse Reflectance Factor [5]

2.5 *ISCC Publications:*
Technical Report 2003-1 Guide to Material Standards and Their Use in Color Measurement [5]

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 *influx, n*—the cone of light rays incident upon the specimen from the illuminator in a color measuring instrument (see Practice E1767).

3.2.2 *efflux, n*—the cone of light rays reflected or transmitted by a specimen and collected by the receiver in a color measuring instrument (see Practice E1767).

3.2.3 *regular transmittance factor, T_r, n*—the ratio of the flux transmitted by a specimen and evaluated by a receiver to the flux passing through the same optical system and evaluated by the receiver when the specimen is removed from the system.

3.2.3.1 *Discussion*—In some cases, this quantity is practically identical to the transmittance, but it may differ considerably. It exceeds unity if the system is such that the specimen causes more light to reach the receiver than would in its absence.

4. Summary of Practice

4.1 Procedures are given for selecting the types and operating parameters of spectrometers used to provide data for the calculation of CIE tristimulus values and other color coordinates to document 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 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.

5. Significance and Use

5.1 The most general and reliable methods for obtaining CIE tristimulus values or, through transformation of them, other coordinates for describing the colors of objects are by the use of spectrometric data. Colorimetric data are obtained by combining object spectral data with data representing a CIE standard observer and a CIE standard illuminant, as described in Practice E308.

5.2 This practice provides procedures for selecting the operating parameters of spectrometers 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 When Using Spectrometry

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

6.1.1 The relative radiometric quantity determined, such as reflectance factor, radiance factor, or transmittance factor.

6.1.2 The geometry of the influx and efflux as defined in Practice E1767, including the following:

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

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

6.1.3 The spectral parameters, including the wavelength range, wavelength measurement interval, and spectral bandpass or bandpass function in the case of variable bandpass.

6.1.4 Identification of the standard of reflectance factor, (see 10.2.1).

6.1.5 The computation variables specified in Practice E308, Section 6, including the standard observer and standard illuminant, if their values must be set at the time of measurement, whether the spectral bandpass has been adjusted or not, and

6.1.6 Special requirements determined by the nature of the specimen, such as the type of illuminating source for fluorescent specimens (see Practice E991) or the absolute geometric conditions and tolerances for retroreflective specimens.

[3] Available from National Institute of Standards and Technology (NIST), 100 Bureau Dr., Stop 1070, Gaithersburg, MD 20899-1070, http://www.nist.gov.

[4] 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.

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

6.1.7 Some specimens (particularly textiles, pulp and paper) are sensitive to variations in temperature (thermochromism), humidity (hygrochromism) and ambient lighting. In those cases these conditions should be specified and recorded. For example, specimens made from cellulosic materials should be conditioned to an agreed upon temperature and humidity and possibly a length of time of a specified light exposure.

7. Apparatus

7.1 *Spectrometer*—The basic instrument requirement is a spectrometer designed for the measurement of reflectance factor and, if applicable, transmittance factor, using one or more of the standard influx and efflux geometries for color evaluation described in Section 8. The spectrometer may be either a typical colorimetric spectrometer, designed specifically for the measurement of object color or a more traditional analytical spectrometer equipped with accessories for the output of the spectral values to a digital computer.

7.2 *Illuminator*—For the measurement of nonfluorescent specimens, the exact spectral nature of the illuminator, of which the light source is a component, is immaterial so long as the source is stable with time and has adequate energy at all wavelengths in the region required for measurement. Commonly used light sources include incandescent lamps, either operated without filters or filtered to simulate CIE standard illuminants (see Publication CIE No. 51), and flashed or continuous-wave xenon-arc lamps. More recently, discrete pseudo-monochromatic sources, such as light emitting diodes (LED) have also been used as sources in colorimetric spectrometers. Considerations required when measuring fluorescent specimens are contained in Practice E991. The use of pseudo-monochromatic sources is not currently recommended by Subcommittee E12.10 for the measurement of the color of retroreflective materials.

7.3 *Dispersive Element:*

7.3.1 The dispersive element, which separates energy in narrow bands of wavelength across the visible spectrum, may be a prism, a grating, or one of various forms of interference filter arrays or wedges. The element should conform to the following requirements:

7.3.2 When highest measurement accuracy is required, the wavelength range should extend from 360 to 830 nm; otherwise, the range 380 to 780 nm should suffice. Use of shorter wavelength ranges may result in reduced accuracy. Each user must decide whether the loss of accuracy in his measurements is negligibly small for the purpose for which data are obtained. See Ref (**1**),[6] Practice E308, and CIE No. 15.2.

NOTE 1—Accuracy is here defined as agreement with results obtained by the use of the recommended measurement conditions and procedures. (1 nm measurement interval with a 1 nm spectral bandwidth and numerical summation of the data multiplied by CIE tabulated values at 1 nm intervals).

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

7.3.2.1 Fluorescent specimens should be measured with a wavelength scale beginning as close to 300 nm as possible, if their characteristics when illuminated by daylight are desired. See Practice E991.

7.3.3 When highest accuracy is required, the wavelength measurement interval should be 1 nm; otherwise, an interval of 5 nm should suffice. Use of a wider interval, such as 10 nm or 20 nm, will result in a significant loss of accuracy. Each user must decide whether the loss of accuracy in his measurements is negligibly small for the purpose for which data are obtained. See Ref (**1**), Practice E308, and CIE No. 15.2.

7.3.4 The spectral bandpass (width in nanometers at half energy of the band of wavelengths transmitted by the dispersive element) should, for best results, be equal to the wavelength measurement interval or just slightly smaller than but no less than 80 % of the wavelength measurement interval (**2**). If the spectral interval and bandpass are greater than 1 nm then it is recommended that the spectral data be interpolated and then deconvolved (**21**) down to the 1 nm interval before computing tristimulus values as recommended in Practice E308.

7.3.5 The use of tables of tristimulus weighting factors (see Practice E308) is a convenient means of treating data obtained for a shorter wavelength range than that specified in 7.3.2, or a wider measurement interval than that specified in 7.3.3, or both, for obtaining CIE tristimulus values. However, the use of a wider interval can lead to significant loss of measurement accuracy for specimens with reflectance or transmittance factors that change rapidly as a function of wavelength. Each user must decide whether the loss of accuracy in his measurements is negligibly small for the purpose for which data are obtained.

7.3.6 For the measurement of nonfluorescent specimens, the dispersive element may be placed either between the source and the specimen or between the specimen and the detector. However, for the measurement of fluorescent specimens the dispersive element must be placed between the specimen and the detector so that the specimen is irradiated by the entire spectrum of the source. A still better method for characterizing fluorescent specimens is to use a bispectrometric method as described in Practice E2153.

7.4 *Receiver*—The receiver consists of the detector and related components. The detector may be a photoelectric device (phototube or photomultiplier), a silicon photodiode or diode array, or another suitable photodetector. The detector must be stable with time and have adequate responsivity over the wavelength range used.

8. Influx and Efflux Conditions

8.1 *Types and Tolerances*—Unless special considerations requiring other tolerances are applicable, the instrument shall conform to the following geometric requirements, based on those proposed for the new revision of Publication CIE No. 15.2, Publication CIE No. 130, and following the notations contained in Practice E1767, for the various types of reflectance-factor and transmittance factor measurements. In this specification, it is understood that each beam axis may be within 0.5° of the nominal direction, and each cone half-angle may be within 0.25° of the nominal value.

NOTE 2—With the possible exception of the measurement of unusually structured or fluorescent specimens, the same results will be obtained in each case by using the reciprocal geometric arrangement, that is, with the influx and efflux geometries interchanged. For example, the value of the reflectance factor obtained when illuminating the specimen with a hemispherical illuminator (such as an integrating sphere) and viewing it at an angle of 8° from the normal to the specimen surface will be the same as that obtained when illuminating the specimen at an angle of 8° and viewing it with a hemispherical receiver. In order to avoid implying unnecessary restrictions on instrumentation that can be used, when referencing this practice one should (except in those cases of fluorescent specimens for which it has been proven that reciprocity does not apply) make an explicit statement that reciprocal measurement conditions are permissible. The following paragraphs incorporate such a statement.

8.1.1 *45°:Normal (45:0) and Normal:45° (0:45) Reflectance Factor*—For the 45°:normal condition, the specimen is illuminated by one or more beams each of whose nominal axes is at an angle of 45° from the normal to the specimen surface. The angle between the direction of viewing and the normal to the specimen surface should not exceed 0.5°. Generally, for obtaining excellent inter-instrument agreement, the instruments should have illumination beam cone nominal half-angles within 2° of each other. The same restriction applies to the viewing beam. Instruments that make their beam cone nominal half-angles all 2° or less achieve this condition automatically. The same restriction applies to the viewing beam. When the illuminating beam is continuous and uniform throughout the 360° of azimuth, the condition is designated annular (45a:0). When many illuminating beams are provided at uniform intervals around the 360° of azimuth, the condition is designated circumferential (45c:0). When only one illuminating beam is used, or when there are two illuminating beams 180° apart in azimuth, the condition is designated uniplanar (45x:0). Detailed descriptions of these geometries can be found in the appropriate sections of Practice E1767. For the normal:45° condition, the requirements for illumination and viewing are interchanged from those just described.

NOTE 3—For certain applications of the *45:0 or 0:45* conditions, including measurement for formulation (8.2.1), significantly tighter tolerances than those given in 8.1.1 may be required for the instrument angles of illumination and viewing, in order to ensure inter-instrument agreement.

8.1.2 *Total:Normal (di:8) or Diffuse:Normal (de:8 or d:0) and Normal:Total (8:di) or Normal:Diffuse (8:de or 0:d) Reflectance Factor*—For the total:normal or diffuse:normal conditions, the specimen is illuminated diffusely by a hemispherical illuminator, such as an integrating sphere. The angle between the normal (perpendicular) to the surface of the specimen (the specimen normal) and the axis of the viewing beam shall be 8° ± 2°. For some specific applications, such as that defined in ISO 2469, the viewing angle is exactly 0° and the tolerances described for 8° apply similarly except where they may contradict the requirements of ISO 2469. In general, spectral reflectance factor readings taken with *de:8* will not be in close agreement with those taken with *d:0* geometry. The short-hand notation for the ISO 2469 geometry does not include the lower case "e," indicating exclusion of the specular component, as it is impossible to capture the efflux in a cone centered at 0° and properly include the specular component. Thus there is only one mode of measurement possible for the *d:0* geometry. The illuminator may be of any diameter provided the total area of the ports does not exceed 5 % of the internal reflecting area. The angle between the axis and any ray of the viewing beam should not exceed 2°. When all regularly (that is, specularly) reflected light is included in the measurement, the condition is designated *di:8*; when all regularly reflected light is excluded, the condition is designated *de:8 or d:0*. For the normal:total or normal:diffuse conditions, the requirements for illumination and viewing are interchanged from those just described.

NOTE 4—Corrections for errors in the use of integrating spheres for the measurement of hemispherical reflectance factor have been discussed (**3**).

8.1.3 *Regular Transmittance of Fully Transparent Specimens, Free from Translucency, Diffusion, or Haze*—The specimen is illuminated by a beam whose effective axis is at an angle not exceeding 5° from the specimen normal and with the angle between the axis and any ray of the illuminating beam not exceeding 5°. The geometric arrangement of the viewing beam may be the same as that of the illuminating beam, or may differ, for example, by the use of a hemispherical receiver such as an integrating sphere. The requirements for illuminating and viewing may be interchanged.

NOTE 5—When a hemispherical receiver such as an integrating sphere is used, and the specimen is placed flush against the transmission port of the sphere, (essentially) total transmittance factor is obtained. When the specimen is placed in the transmission compartment as far away from the sphere port as possible, (essentially) regular transmittance factor is obtained.

8.1.4 *Normal:Total ($0{:}T_t$) or Normal:Diffuse ($0{:}T_d$) and Total:Normal ($T_{t:0}$) or Diffuse:Normal ($T_d{:}0$) Transmittance Factor of Translucent, Diffusing, or Hazy Specimens*—The characteristics of translucent, diffusing, or hazy specimens may be such that it is very difficult if not impossible to obtain measured transmittance factors that are device-independent, that is, independent of the details of the geometry and construction of the instrument used. Special precautions, outlined here, must be observed to minimize the effects of these characteristics; the use of special equipment beyond the scope of this practice may be required to eliminate the effects entirely.

8.1.4.1 The visual phenomena of translucency, diffuseness, or haze arise from diffusely scattered flux within the specimens that can emerge through their sides or surfaces, often at locations significantly removed from the illuminated region of the specimen (**4**, **5**, and NBS TN-594-12). Unless these emergent fluxes are all measured, the indicated transmittance factor may be significantly low.

8.1.4.2 *General Influx and Efflux Conditions*—For the normal:total or normal:diffuse conditions, the specimen is illuminated by a beam whose effective axis is at an angle not exceeding 2° from the specimen normal and with the angle between the axis and any ray of the illuminating beam not exceeding 5°. The hemispherical transmitted flux is collected with a hemispherical receiver, such as an integrating sphere as described in Test Method D1003. When the reflectance of the receiver reflecting surface or other material at the point of impingement of the regularly transmitted beam, or at the point of impingement of the illuminating beam in the absence of a specimen, is identical to the reflectance of the remainder of the