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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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# Standard Practice for Obtaining Spectrophotometric 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 spectrophotometric 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 spectrophotometric data are contained in this practice. The values and procedures for computing CIE tristimulus values from spectrophotometric data are contained in Method E 308. Considerations regarding the selection of appropriate illuminating and viewing geometries are contained in Guide E 179.

## 1. Scope

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

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

1.3 Most sections of this practice apply to both spectrophotometers, 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 general in scope rather than specific as to instrument or material.

1.5 *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:*

D 1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics[2]

E 179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials[3]

E 259 Practice for Preparation of Pressed Powder White Reflectance Factor Transfer Standards for Hemispherical Geometry[3]

E 275 Practice for Describing and Measuring Performance of Ultraviolet, Visible, and Near-Infrared Spectrophotometers[4]

E 284 Terminology of Appearance[3]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[3]

E 387 Test Method for Estimating Stray Radiant Power Ratio of Spectrophotometers by the Opaque Filter Method[4]

E 805 Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials[3]

E 925 Practice for the Periodic Calibration of Narrow Band-Pass Spectrophotometers[4]

E 958 Practice for Measuring Practical Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers[4]

E 991 Practice for Color Measurement of Fluorescent Specimens[3]

2.2 *NBS Publications:*

LC-1017 Standards for Checking the Calibration of Spectrophotometers[5]

TN-594-12 Optical Radiation Measurements: The Translucent Blurring Effect—Method of Evaluation and Estimation[5]

SP-260-66 Didymium Glass Filters for Calibrating the Wavelength Scale of Spectrophotometers—SRM 2009,

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[1] This practice is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.02 on Spectrophotometry and Colorimetry.

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[2] *Annual Book of ASTM Standards*, Vol 08.01.

[3] *Annual Book of ASTM Standards*, Vol 06.01.

[4] *Annual Book of ASTM Standards*, Vol 03.06.

[5] Available from National Institute of Standards and Technology, Gaithersburg, MD 20899.

2010, 2013, and 2014[5]
SP-692 Transmittance MAP Service[5]

2.3 *CIE Publications:*

CIE No. 15.2 Colorimetry, 2nd edition[6]

CIE No. 38 Radiometric and Photometric Characteristics of Materials and Their Measurement[6]

CIE No. 46 Review of Publications on Properties and Reflection Values of Material Reflection Standards[6]

CIE No. 51 Method for Assessing the Quality of Daylight Simulators for Colorimetry[6]

## 3. Terminology

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

3.2 *Definitions:*

3.2.1 *annular*, *adj*—descriptor for directional illuminating (on viewing) geometry in which the illuminator provides radiation (or the receiver possesses responsivity) that is distributed continuously and uniformly throughout the 360° of azimuth of the measurement. (See also *circumferential*.)

3.2.2 *circumferential*, *adj*—descriptor for directional illuminating (or viewing) geometry in which the illuminator provides radiation (or the receiver possesses responsivity) in many beams (or directions), normally distributed at uniform intervals throughout the 360° of azimuth of the measurement. The number and angular distribution of the beams (or directions) should be specified. (See also *annular*.)

3.2.3 *rotation angle,* $\epsilon$, *n*—angle indicating the orientation of the specimen when it is rotated about a selected axis fixed in it (for plane specimens, usually the specimen normal); *in retroreflection*, angle indicating orientation after rotation about the retroreflector axis.

3.2.4 *spectrocolorimeter*, *n*—spectrophotometer, one component of which is a dispersive element (such as a prism, grating, or interference filter or wedge), that is normally capable of producing as output only colorimetric data (such as tristimulus values and derived color coordinates) but not the underlying spectral data from which colorimetric data are derived.

3.2.5 *uniplanar*, *adj*—descriptor for illuminating and viewing geometry in which the axes of the illuminator and the receiver and the normal to the specimen surface are in the same plane; thus directional illumination or viewing is provided by one beam, or by two beams spaced 180° apart in azimuth. The number and angular distribution of the beams should be specified.

## 4. Summary of Practice

4.1 Procedures are given for selecting the types and operating parameters of spectrophotometers 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 obtain the highest measurement precision. Parameters are identified that must be specified when spectrophotometric measurements are required in specific test methods or other documents.

## 5. Significance and Use

5.1 The most direct and accessible methods for obtaining CIE tristimulus values or, through transformation of them, other coordinates for describing the colors of objects are by the use of spectrophotometric 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 Test Method E 308.

5.2 This practice provides a procedure for selecting the operating parameters of spectrophotometers 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 Spectrophotometry

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

6.1.1 The photometric quantity determined, such as reflectance factor or transmittance.

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

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

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

6.1.3 The spectral parameters, including the wavelength range, wavelength measurement interval, and spectral bandpass.

6.1.4 Identification of the standard of reflectance factor, if one is used (see 10.2.1).

6.1.5 The computation variables specified in Test Method E 308, Section 6, including the standard observer and standard illuminant, if their values must be set at the time of measurement, 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 E 991).

## 7. Apparatus

7.1 *Spectrophotometer*—The basic instrument requirement is a spectrophotometer designed for the measurement of reflectance factor and, if applicable, transmittance, using one or more of the standard illuminating and viewing geometries for color evaluation described in Section 8. Most such instruments are of the full or a simulated double-beam type, but this is not a requirement when highly stable instrument readings are obtained.

7.2 *Illuminator*—For the measurement of nonfluorescent specimens, the exact nature of the illuminator, of which the



[6] Available from U.S. National Committee CIE (International Commission on Illumination). Request ordering information from USNC/CIE Publications Office, c/o Mr. Thomas M. Lemons, TLA-Lighting Consultants, 7 Pond St., Salem, MA 01970-4819.

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 sources (see CIE No. 51), and flashed or continuous-output xenon-arc lamps. Considerations required when measuring fluorescent specimens are contained in Practice E 991.

7.3 *Dispersive Element*:

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

7.3.1.1 When highest measurement accuracy is required, the wavelength range should extend from 360 to 830 nm; otherwise, the range 380-780 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),**[7] Method E 308, 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.

7.3.1.2 Fluorescent specimens should be measured for wavelengths beginning at 300 nm if their characteristics when illuminated by daylight are desired. See Practice E 991.

7.3.1.3 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, may result in 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),** Method E 308, and CIE No. 15.2.

7.3.1.4 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 **(2).**

7.3.1.5 The use of tables of tristimulus weighting factors (see Test Method E 308) is a convenient means of treating data obtained for a shorter wavelength range than that specified in 7.3.1.1, or a wider measurement interval than that specified in 7.3.1.3, 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 factors or transmittances 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.

7.3.1.6 For the measurement of nonfluorescent specimens, the dispersive element can 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.

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

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.

7.5 *Readout*—For the intended use of the data, it is convenient that the readout of the spectral quantities be digital, with a printer as a desirable accessory. The availability of an analog device in the form of a plotter is also desirable, because a skilled technician can obtain much useful information for diagnostic and other purposes from observation of the spectral curves. (These considerations do not apply to spectrocolorimeters.) Many modern instruments are interfaced to or incorporate digital computers to facilitate further data treatment to obtain CIE tristimulus values and derived color coordinates.

## 8. Illuminating and Viewing 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 of CIE No. 15.2, for the various types of reflectance-factor and transmittance measurement.

NOTE 2—With the possible exception of measurement of unusually structured fluorescent specimens, the same results will be obtained in each case by using the reciprocal geometric arrangement, that is, with the illuminating and viewing 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 10° from the normal to the specimen surface will be the same as that obtained when illuminating the specimen at an angle of 10° 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 whose effective axes are at an angle of 45 ± 2° from the normal to the specimen surface. The angle between the direction of viewing and the normal to the specimen surface should not exceed 10°. The angle between the axis and any ray of an illuminating beam should not exceed 8°. 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. When many illuminating beams are provided at uniform intervals around the 360° of azimuth, the condition is designated circumferential. When only one illuminating beam is used, or when there are two illuminating beams 180° apart in azimuth, the condition is designated uniplanar. For the normal/45° condition, the requirements for illumination and viewing are interchanged from those just described.

8.1.2 *Total/Normal (t/0) or Diffuse/Normal (d/0) and Normal/Total (0/t) or Normal/Diffuse (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