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Standard Practice for Obtaining Spectrometric Data for Object-Color Evaluation[1]

This standard is issued under the fixed designation E1164; 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.

ε^1 NOTE—Editorial corrections were made throughout in May 2017.

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.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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

[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.

E925 Practice for Monitoring the Calibration of Ultraviolet-Visible Spectrophotometers whose Spectral Bandwidth does not Exceed 2 nm
E958 Practice for Estimation of the Spectral Bandwidth of Ultraviolet-Visible Spectrophotometers
E991 Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method
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 Test Method 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 Colorimetry[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 [6]

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.

[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 CIE (International Commission on Illumination), http://www.cie.co.at or http://www.techstreet.com.
[5] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.
[6] Available from the Inter-Society Color Council, http://www.iscc.org/functions/pc/pc51.php.

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.

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**),[7] Practice E308, and CIE No. 15.

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).

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.

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 (**3**) 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.

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

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, 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 (**4**).

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 (**5**, **6**, 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 internal reflecting area of the receiver, the condition is designated $0{:}T_t$ and the measurement provides the total transmittance factor (T_t). When the regularly transmitted beam is excluded, for example by the use of a light trap, the condition is designated $0{:}T_d$ and the diffuse transmittance (T_d) is obtained. Details of the size, shape, and reflectance of the light trap should be specified. The results of diffuse measurements made on specimens having broad regular-transmittance factor peaks will depend importantly on the size of the reflected beam and the size of the light trap.

8.1.4.3 A portion of the transmitted flux may be regularly transmitted and a portion diffusely transmitted. It is essential that these portions impinge on areas of the sphere wall having the same reflectance. If a white reflecting standard is used at the sample reflectance port, care must be taken to ensure that it has the same reflectance as the walls of the integrating sphere. Care must also be taken to avoid discoloring of either area due to prolonged radiation or dirt, or partial translucency due to insufficient thickness of the coating.

8.1.4.4 In all measurements of translucent, diffusing, or hazy specimens, it is essential that the specimen be placed flush against the entrance port of the receiver, in order that all the flux emerging from the specimen enter the sphere.

8.1.4.5 To further ensure that as much as possible of the flux traveling from side to side within the specimen is collected, either (*1*) illuminate a very small central area of the specimen and view it with a large specimen port; or (*2*) uniformly illuminate a very large area of the specimen and measure a small central portion of it (**5, 6**, and NBS TN-594-12).

8.1.4.6 The requirements of 8.1.4.5 may be approximately met by use of a conventional integrating sphere with the largest possible illuminated area and the smallest possible viewed area, or the reverse. In such cases, it is recommended **(6)** to use the substitution method of measurement rather than the comparison method **(4).** However, the substitution method introduces an error due to change in the sphere efficiency when the specimen is removed (substitution of "no sample" for sample). Care must be taken to correct for this error (**4**, Test Method D1003).

8.1.4.7 The use of transmittance factor standards is recommended, provided that they are available with diffusing characteristics similar to those of the specimens being measured and are correctly calibrated using appropriate geometry (**7**, Test Method D1003).

8.1.4.8 If instruments with conventional integrating spheres are used to measure translucent, diffusing, or hazy specimens, their measured transmittance factor will almost certainly be low and specific to the instrument and conditions used.

8.1.4.9 For the total:normal and diffuse:normal conditions, the requirements for illumination and viewing are interchanged from those just described.

NOTE 6—For all the conditions described in 8.1, the receiver should be arranged, with respect to both area and extent of angular acceptance, to view either considerably less than or considerably more than the entire beam emitted by the illuminator, so that the measurements are not sensitive to slight distortions of the beam by refraction in the specimen.

8.2 *Selection of Illuminating and Viewing Conditions*—The following guidelines **(8)** may be useful for the selection of geometric conditions of illuminating and viewing for a variety of specimens and purposes. See also Guide E179 and Practice E805. Geometric notations may be found in Practice E1767.

8.2.1 For the formulation of product colors by computations involving Kubelka-Munk or other turbid-medium theory, either the bi-directional conditions **(9)** or the hemispherical diffuse conditions obtained by using an integrating sphere may be used. Special considerations for the interactions between an instrument geometry and the specimen surface are cited in the following sections and will also apply to the formulation of product colors.

8.2.2 For assessing the color of highly glossy or fully matte specimens, the *45:0* or *0:45* conditions should be used. Alternatively, the *de:0* or *0:de* conditions may be used, but different results may be obtained compared to those from the *45:0* or *0:45* conditions or the *de:8* or the *8:de* conditions.

8.2.3 For assessing the color of plane-surface low-gloss (matte) specimens, the *8:de* or *de:8* conditions (specular component excluded), or the *di:8* or *8:di* conditions (specular component included) may be used. Alternatively, the *45:0* or *0:45* conditions or the *0:de* or *de:0* conditions may be used, but their use may lead to different results unless the specimens are perfectly Lambertian diffusers.

8.2.4 For assessing the color of plane-surface specimens of intermediate gloss of textured-surface specimens, including textiles, where the first-surface reflection component may be distributed over a wide range of angles, the preferred geometry may have to be determined experimentally. Use of most geometries will not allow complete separation of the surface effects from the color. The preferred geometry will be the one that minimizes the surface effects, thereby optimizing the separation. The *di:8* or *8:di* conditions (specular component included) may be used, but it may be difficult to correlate visual judgements of the color to such measurements.

8.2.5 When a specimen surface exhibits directionality, use of hemispherical, annular or circumferential geometry will provide data that may average over the effect. When the degree of directionality of the specimen is to be evaluated, uniplanar geometry should be used. The specimen should be measured at two or more rotation angles 45° apart to obtain the information on its directionality; alternatively, its rotation angle should be varied in successive measurements to obtain maximum and minimum instrument readings. The angles at which these readings occur should be noted in reference to the orientation of the specimen. When information on directionality is not required, the several measurements may be averaged. When the specimen does not exhibit directionality, any of the bi-directional geometries may be used.

8.2.6 For the measurement of fluorescent specimens, the *45:0* or *0:45* conditions are normally required; see Practice E991.

8.2.7 For the measurement of the daytime color of retroreflective specimens, the *45:0* or *0:45* conditions are normally required. Some modern, high brightness, retroreflective sheeting has been shown to exhibit geometric artifacts if the cone angles are too narrow. In these cases, it may be more appropriate to use larger cone angles, with appropriate tolerances. Subcommittee E12.10 is working on this issue.

8.2.8 For the measurement of materials pigmented with metallic flakes multiple angles of viewing are required. See Practice E2194.

9. Test Specimens

9.1 Measurement results will not be better than the test specimens used in the measurements. Test specimens shall be representative of the materials being tested, and shall also conform to the following geometric and optical requirements set by the nature of the measuring instruments. When the specimens do not have these desired characteristics, departures should be noted.

9.1.1 Specimens should be uniform in optical properties over the area illuminated and measured.

9.1.2 Opaque specimens should have at least one plane surface; translucent and transparent specimens should have two surfaces that are essentially plane and parallel.

9.1.3 When reflecting specimens are not completely opaque, the following considerations are important:

9.1.3.1 The measurement results will depend on the spectral reflectance factor of the material behind the specimen; this should be a specified or calibrated backing material.

9.1.3.2 The measurement results will depend upon the thickness of the specimen.

9.1.3.3 An indeterminate amount of radiation may escape from the sides of the specimen, markedly affecting the measurement results. (**5** and NBS TN-594-12.)

9.1.4 Measurement data for transparent specimens will depend upon the thickness of the specimen, but correction for thickness can be made; see CIE No. 38 and CIE No. 130.

9.1.5 Special considerations, some of which have been noted, apply to the measurement of fluorescent, retroreflective, or translucent specimens.

9.1.6 Specimens should be handled carefully to avoid contamination. Care should be taken not to touch the area to be measured except for application of a suitable cleaning procedure. The condition of the specimens before and after measurement should be noted and reported.

10. Standardization and Material Standards

10.1 Standardization and its verification are essential steps in ensuring that accurate results are obtained by spectrometric measurement (**10, 11**), and Practice E275). Standardization and verification may require the use of material standards not normally supplied by the instrument manufacturer. The instrument user must assume the responsibility for obtaining the necessary material standards. (See Ref (**11**), NBS LC-1017 and ISCC Publication Technical Report 2003-1.)

10.2 *Reflectance or Transmittance Scales:*

10.2.1 *Full-Scale Standardization*—For reflectance-factor measurement, it is necessary to standardize the spectrometer so that the values of the ideal (white) standard of reflectance factor are assigned the numerical value 100.0 (%). The CIE recommends that this ideal standard of reflectance factor be the perfect reflecting diffuser, and the calibration of the white reflectance standard furnished with many instruments is made on this basis. Other standards calibrated to the perfect reflecting diffuser (for example, NBS SRM 2040 or 2044)[3] can be obtained and utilized. In other cases, use may be made of another white material, with assigned reflectance factors of 100.0 at each wavelength with a resulting increase in the uncertainty of the results (**12**, Practice E259, and CIE No. 46.) For transmittance measurement, the reading obtained in the absence of a specimen is regularly assigned the value 100.0. Some national laboratories will accept user supplied white material standards and supply a calibration of the reflectance factor or transmittance of those standards (NIST service 38060S for reflectance and 38061S for transmittance)[3].

10.2.2 *Zero Standardization or its Verification*—When a standardization of the zero point of the instrument scale is required, it should be carried out by one of the following methods, selected as appropriate to the type of illuminating and viewing geometry of the instrument. The same method should be used to verify the zero reading in instruments that do not require such a calibration step.

10.2.2.1 For instruments with *45:0* or *0:45* geometry, use a highly polished black glass standard with an assigned reflectance factor of zero. The presence of surface contaminants will critically affect the reliability of this standard. Dust, dirt and even finger prints will cause the apparent reflectiviity to increase.

10.2.2.2 For instruments equipped with hemispherical illuminators or receivers (such as integrating spheres), used for reflectance-factor measurement, use a black-cavity light trap, placed flush against the specimen measurement port, with an assigned reflectance factor of zero. If the black-cavity traps light by utilizing asymmetric or off-axis black optics then a preferred orientation of the cavity relative to the optical axis should be identified and marked on the cavity. Whenever the cavity is employed it should always be presented to the instrument in the indicated orientation.

10.2.2.3 For transmittance factor measurement, verify the zero reading by blocking the sample light beam of the instrument. Blocking should be carried out by replacing the specimen with an opaque object of the same size and shape as the specimen, placed in the same position. The use of large opaque screens or electronic shutters may only be appropriate if the operator's experience has demonstrated experimentally that there is no significant level of homochromatic stray light within the specimen chamber.

10.2.2.4 Some instruments may not accurately measure scale values below a specified minimum, such as 1 %. In such cases, verify the accuracy of the reading at the low end of the photometric scale by using a calibrated standard with reflectance factor or transmittance factor slightly higher than the specified minimum, for example, NBS SRM 2052[3] black reflecting tile for reflectance-factor measurements, or a calibrated carbon-yellow filter (NIST service 38030C) or the NBS transmittance MAP service (see NBS SP-692) for transmittance measurements.

10.2.2.5 Publication CIE No. 130 provides a method for establishing both the full-scale and the zero scale standardization using a pair of standards, one near-white and the other near-black. While this method works fine in theory, great care must be taken to maintain the reflectance of the near-black standard. Keeping the surface clean is essential as errors in apparent reflectance are additive in the measurement chain. Errors in the apparent reflectance of the near-white standard are multiplicative and thus impact the measurement chain more slowly.

10.2.3 *Linearity Verification*—After the full-scale and zero-scale photometric readings are verified, the linearity of the scale should be verified by measuring one or more calibrated standards having intermediate reflectance factor or transmittance factor, for example, NBS SRM 2030[3] neutral-density filter or one or more of the gray Ceramic Colour Standards (**13**). If the instrument requires calibration with a Grey tile to evaluate the single-beam integrating-sphere photometric nonlinearity, the linearity verification test should be made in addition, using a different material standard.

10.3 *Wavelength Scale*

10.3.1 *Scale Calibration or Verification*—The wavelength scale should be calibrated, if possible, or verified, if not, for linearity and lack of offset as follows.

10.3.1.1 For instruments with a spectral bandpass of about 10 nm or less, the didymium filter (for example, NIST SRM 2014)[3] or a holmium-oxide solution (for example, (**14**) and NIST SRM 2034)[3] should be used, following the procedures given in NBS SP-260-66 or (**15**) or a series of appropriate emission lines may be used if the peaks are appropriately over-sampled and mathematically fitted to a peaked dispersion function (**16**).

10.3.1.2 For instruments with wider spectral bandpass, the method of linear filters should be used (**17**).

10.3.2 *Spectral Bandpass Verification*—The approximate spectral bandpass of the instrument should be verified by using a didymium filter (for example, NIST SRM 2014)[3], following the procedures given in (**11**), NBS SP-260-66, Practice E925, or Practice E958.

10.4 *Stray Light*—The level of stray light in the instrument should be verified as being adequately low by measuring a suitable specimen or specimens with low reflectance factor or transmittance factor, for example a low-reflectance-factor Ceramic Colour Standard (**13**), a low-transmittance neutral filter, or a cut-off filter (see, for example, Test Method E387).

10.5 *System Verification*—The precision and bias of the entire measurement system, including calculation of CIE tristimulus values, should be determined by periodic measurement of calibrated verification standards, either supplied by the instrument manufacturer or obtained separately. Examples of suitable verification standards include the reflecting Ceramic Colour Standards (**13**) and sets of transmitting filters (**11**) or NBS SP-692).

NOTE 7—Some verification standards can be used effectively to diagnose instrument malfunctions affecting its accuracy (**18, 19**).

11. Procedure

11.1 *Selection of Measurement Variables*—To the extent allowed by the measuring instrument(s) available, select the following measurement parameters:

11.1.1 If the specimen is fluorescent, select an appropriate source type (see Practice E991),

11.1.2 Select the illuminating and viewing geometry; for hemispherical geometries, select whether total or diffuse quantities will be measured, and for bi-directional geometries, select whether annular, circumferential, or uniplanar conditions will be used, and

11.1.3 Select the wavelength range and wavelength measurement interval and, when selectable, the spectral bandpass. (This step does not apply to spectrocolorimeters.)

11.2 *Selection of Computational Variables*—When the instrument incorporates or is interfaced to a computer so that calculation of CIE tristimulus values and derived color coordinates automatically follows measurement, select the variables defining these computations, following Practice E308, Section 6. It is highly recommended that instrumental readings be corrected for finite bandpass by a standard method of deconvolution (**3**).

11.3 Measure the specimen(s), following the instrument manufacturer's instructions.

12. Report

12.1 The report of the measurement of spectral data shall include the following:

12.1.1 *Specimen Description*—Including the following:

12.1.1.1 Type and identification,

12.1.1.2 Date of preparation or manufacture, if required,

12.1.1.3 Method of cleaning, and date, if cleaned,

12.1.1.4 Orientation of the specimen during measurement, and

12.1.1.5 Any changes in the specimen during measurement.

12.1.2 Date of measurement.

12.1.3 *Instrument Parameters*—All of the measurement parameters and special requirements stated in Section 6 of this practice.

12.1.4 The spectral data, in the form of tables of wavelength and measured quantity. (This step does not apply to spectrocolorimeters.)

12.1.5 Colorimetric data, such as tristimulus values and derived color coordinates, if their calculation automatically follows measurement.

13. Precision and Bias

13.1 Precision and bias depend on the nature of the materials being characterized. The information reported here reflects results taken from scientific reports in the literature generally using the Ceramic Colour Standards and as such will be representative of "best case" conditions and not typical results for industrial color control specimens.

13.2 *Repeatability*—Results reported in the literature (**20, 21**) obtained by the use of modern measuring instruments show that the repeatability of single instruments, expressed in terms of CIELAB color differences (see Practice E308 and CIE No. 15.2), is within 0.1 unit. On this scale, the smallest color difference that can be reliably observed is of the order of 0.3 unit; commercial color tolerances range upward from this to about 2 units.

13.3 *Reproducibility*—The reproducibility within a group of similar instruments was reported (**22**) to be less than 0.2 unit. Inter-instrument agreement comparing different types of instruments, especially if different geometric parameters of the illuminating and viewing conditions are involved, is likely to be an order of magnitude poorer (**23, 24**).

13.4 To these estimates of repeatability and reproducibility must be added the contribution due to the non-uniformity of the specimens measured.

13.5 Each user should determine, and verify periodically, the precision and bias of the instrument by routinely measuring typical specimens, and then decide whether the resulting uncertainties are negligibly small for the purpose for which the data are obtained.

14. Keywords

14.1 color; instrumental measurement—color; light—transmission and reflection; reflectance and reflectivity; spectrometry; transmittance and reflectance

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