Designation: E2301 − 12 (Reapproved 2022)

Standard 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[1]

This standard is issued under the fixed designation E2301; 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.

1. Scope

1.1 This test method describes the instrumental measurement of the colorimetric properties (CIE tristimulus values, luminance factors, and chromaticity coordinates) of fluorescent-retroreflective sheeting and marking materials when illuminated by daylight.

1.2 This test method is generally applicable to any sheeting or marking material having combined fluorescent and retroreflective properties used for daytime high visibility traffic control and personal safety applications.

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

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *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]

D2244 Practice for Calculation of Color Tolerances and Color Differences from Instrumentally Measured Color Coordinates
E179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials
E284 Terminology of Appearance
E308 Practice for Computing the Colors of Objects by Using the CIE System
E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method
E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation
E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials
E2152 Practice for Computing the Colors of Fluorescent Objects from Bispectral Photometric Data
E2153 Practice for Obtaining Bispectral Photometric Data for Evaluation of Fluorescent Color

2.2 *CIE Document:*[3]

CIE 15:2004 Colorimetry

3. Terminology

3.1 *Definitions*—The definitions contained in Guide E179, Terminology E284, and Practice E1164 are applicable to this test method.

4. Summary of Test Method

4.1 This test method provides a procedure for measuring the colorimetric properties of fluorescent-retroreflective sheeting and markings under simulated daylight illumination. Colorimetric properties are determined for CIE D65, which approximates outdoor illumination at midday, and Daylight 15 000 K, which is an alternate D illuminant chosen to represent low ambient light/dawn/dusk daylight illumination conditions (see CIE 15:2004).

[1] This test method 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.

[3] Available from CIE (International Commission on Illumination) at www.cie.co.at or www.techstreet.com.

4.2 This test method requires the use of a calibrated bispectrometer (two-monochromator spectrometer) with either 45:0 or 0:45 geometry that can measure the specimen's Donaldson matrix (see Practice E2153).

4.3 This test method provides for calculation and reporting of separated fluorescence, reflectance and total tristimulus values (*XYZ*) and luminance factors (*Y*, %), and total chromaticity coordinates (*x,y*) from the Donaldson matrix for the CIE 1931 Standard Colorimetric Observer.

5. Significance and Use

5.1 This test method provides procedures for obtaining tristimulus values, luminance factors and chromaticity coordinates of fluorescent-retroreflective materials by bispectral colorimetry using a 45:0 or 0:45 optical measuring system.

5.2 The CIE 1931 (2°) standard observer is used to calculate the colorimetric properties of fluorescent-retroreflective sheeting and markings used in daytime high visibility traffic control and personal safety applications because in practice these materials are primarily viewed from a distance where they subtend less than 4° of the visual field.

5.3 This test method is applicable to object-color specimens of any gloss level.

5.4 Due to the retroreflective properties of these materials the colorimetric data may not be suitable for use in computer colorant formulation.

5.5 This test method is suitable for quality control testing of fluorescent-retroreflective sheeting and marking materials.

NOTE 1—Separation of the fluorescence and reflectance components from the total colorimetric properties provides useful and meaningful information to evaluate independently the luminescent and diffuse reflective efficiency and consistency of these materials.

5.6 This test method is the referee method for determining the conformance of fluorescent-retroreflective sheeting and marking materials to standard daytime colorimetric specifications.

6. Apparatus

6.1 *Bispectrometer,* with either 45:0 or 0:45 (illumination:viewing) geometry.

6.1.1 The tolerance on the inclination of the 45-degree axis shall be 2 degrees (45 ± 2 degrees).

6.1.2 The tolerance on the 0-degree axis shall be 2 degrees from the normal (0 ± 2 degrees).

NOTE 2—For maximum reproducibility smaller tolerances on the axis angles are recommended.

6.1.3 For the 45:0 condition, the illumination geometry may be annular, circumferential or uniplanar and the viewing shall be normal to the specimen. For the 0:45 condition, the illumination shall be normal to the specimen and the viewing geometry may be annular, circumferential or uniplanar.

6.1.4 The referee geometry shall be annular 45:0.

NOTE 3—Reciprocity between 45:0 and 0:45 geometry for commercial instruments may not be observed in practice for retroreflective materials because of the variation in axis angles and aperture sizes of instruments.

6.1.4.1 Circumferential instruments are acceptable provided the procedure described in 9.3.1 is followed.

6.1.4.2 Uniplanar instruments are acceptable provided the procedure described in 9.3.2 is followed.

6.1.5 The referee aperture sizes shall be 10 degrees for illumination and 10 degrees for viewing. Use of aperture sizes deviating from these may affect the measurement results. See Practice E1767 for fundamentals of specification of apertures.

NOTE 4—Fluorescent colorimetric properties (for example, Fluorescence tristimulus values $(XYZ)_F$) are not significantly influenced by the aperture sizes. Reflectance colorimetric properties (for example, Reflectance tristimulus values $(XYZ)_R$) may be greatly affected by aperture sizes. Consequently total colorimetric properties (for example, Total tristimulus values $(XYZ)_T$) may be greatly affected.

6.1.6 The illumination monochromator shall illuminate the specimen over the wavelength range from 300 nm to 780 nm at intervals of 10 nm or less.

6.1.7 The viewing monochromator shall detect the specimen radiance over the wavelength range from 380 nm to 780 nm at intervals of 10 nm or less.

6.1.8 The minimum illuminated sample area shall be 100 mm^2 with no dimension less than 5 mm.

6.2 *Calibration Standards,* as outlined in Practice E2153, supplied by the instrument manufacturer or obtained separately, with calibration values no older than 24 months.

6.3 *Verification Standards*—Verification of the precision and bias of the entire system, including calculation of tristimulus values, shall be conducted on an annual basis using non-retroreflective/non-fluorescent, fluorescent/non-retroreflective and fluorescent retroreflective color standards with calibration values traceable to an accredited National Standards Laboratory. The calibration values for the verification panels shall be no older than 36 months.

NOTE 5—Stable fluorescent/non-retroreflective and fluorescent retroreflective color artifact standards are not widely available as Standard Reference Materials (SRMs). However, measurement services are available from Independent Testing Laboratories and National Standards Laboratories to calibrate artifacts for use as Verification Standards.

7. Test Specimen

7.1 *Specimen Preparations:*

7.1.1 Samples shall be tested mounted on the substrate that will be utilized for the intended application. Apply the sample to the substrate in accordance with the recommendations of the material's manufacturer.

7.1.2 If the sample is not supplied with its intended substrate, or if the intended substrate is not defined, then the sample shall be mounted or backed by a black panel, such as a black tile. The black panel shall have a luminance factor (*Y*) of less than 4 %.

NOTE 6—The measurement results will depend upon the spectral reflectance properties of the material behind the specimen as well as the specimen thickness.

7.1.3 Specimens should be uniform in physical properties over the area measured.

7.1.4 *Number of Test Specimens*—Measurements shall be made on a minimum of 3 test specimens.

7.1.5 Specimens that have been subjected to additional testing, such as outdoor or machine exposure testing, shall be tested on the substrate used for these additional tests.

7.2 *Test Conditions*—Unless otherwise specified, condition all test specimens at a temperature of 23 °C ± 2 °C and 50 % ± 5 % relative humidity for 24 h prior to testing.

7.3 *Sampling*—Unless otherwise specified test samples shall be selected according to the following sampling plan.

7.3.1 *Sheeting for Traffic Control Applications*—Test samples shall be cut from 1 m^2 of sheeting. The test samples shall be cut from the lower left corner, center and upper right corner of the sheeting as shown in Fig. 1. This insures test samples reflect crossweb and downweb variability of the sheeting.

7.3.1.1 For materials manufactured in widths less than 1 m the size of the sample shall be such that the width times the length shall equal 1 m^2 (that is, length × width = 1 m^2). An example is shown in Fig. 1B.

7.3.2 *Marking Materials for Personal Safety Applications*—Test samples shall be cut from a 2 m length by sample width of material as shown in Fig. 2. Test samples shall be cut from the beginning, middle and end of the 2 m long length of test material. This insures test samples reflect variability of the marking material.

7.3.3 *Materials Subjected to Outdoor Exposure*—Sampling of materials subjected to outdoor exposure shall conform to these sampling requirements to the extent practical based on the number and size of the exposed test specimen.

8. Calibration and Verification

8.1 Calibrate the bispectrometer in accordance with Practice E2153, or

8.2 Verify the accuracy of the instrumental data by measurement of a series of calibrated verification standards.

9. Procedure

9.1 Handle the specimen carefully; avoid touching the area to be measured.

9.2 Clean the specimen prior to measurement as necessary, for example when measuring specimens that have been subjected to outdoor or machine exposure testing.

9.2.1 *Washing Panels*—Gently wash the panels using a soft cloth or sponge and clean water or a dilute solution (1 % by weight in water, maximum concentration) of a mild detergent. After washing, rinse thoroughly with clean water, and blot dry with a soft clean cloth. After washing and drying, condition the panels at room temperature for at least 2 h prior to conducting any property measurements.

9.3 Position the test specimen at the measurement port of the instrument.

9.3.1 If the measurement geometry is circumferential, then the testing laboratory must verify that the apertures in the ring are sufficiently close for the measurement to approximate measurement with annular geometry. This may depend on the optical construction of the specimen, and must be determined by the testing laboratory. Otherwise treat the instrument as a uniplanar geometry (see 9.3.2).

9.3.2 If the measurement geometry is uniplanar, then a sequence of measurements shall be made on the same specimen area at incremental rotations, and the measurement values shall be averaged over all the rotations. The number of rotations must be sufficient to assure good approximation to an annular measurement. The number depends on the optical construction of the specimen and must be determined by the testing laboratory. The averaging over rotations shall be applied to the values in the Donaldson matrix.

9.4 Obtain the illuminant independent Donaldson matrix for each test specimen at illumination and viewing sampling intervals of no greater than 10 nm (see Practice E2153 and the instrument manufacturer's instructions).

10. Calculation

10.1 *Tristimulus Values:*

10.1.1 *Tristimulus Values for CIE D65*—Calculate the individual Total tristimulus values $(XYZ)_T$, Reflectance tristimulus values $(XYZ)_R$ and Fluorescence tristimulus values $(XYZ)_F$ for each test specimen from the respective Donaldson matrix for the CIE 1931 Standard Observer and CIE D65 (see Practice E2152).

10.1.1.1 Calculate the averages and standard deviations for the individual tristimulus values (*X*, *Y*, and *Z*) for each component (Total, Reflectance, and Fluorescence) for CIE D65 for each set of test specimens:

Total tristimulus values: X_T-average = $(\Sigma X_T)/n$; Y_T-average = $(\Sigma Y_T)/n$; Z_T-average = $(\Sigma Z_T)/n$);

Reflectance tristimulus values: X_R-average = $(\Sigma X_R)/n$; Y_R-average = $(\Sigma Y_R)/n$; Z_R-average = $(\Sigma Z_R)/n$);

Fluorescence tristimulus values: X_F-average = $(\Sigma X_F)/n$; Y_F-average = $(\Sigma Y_F)/n$; Z_F-average = $(\Sigma Z_F)/n$

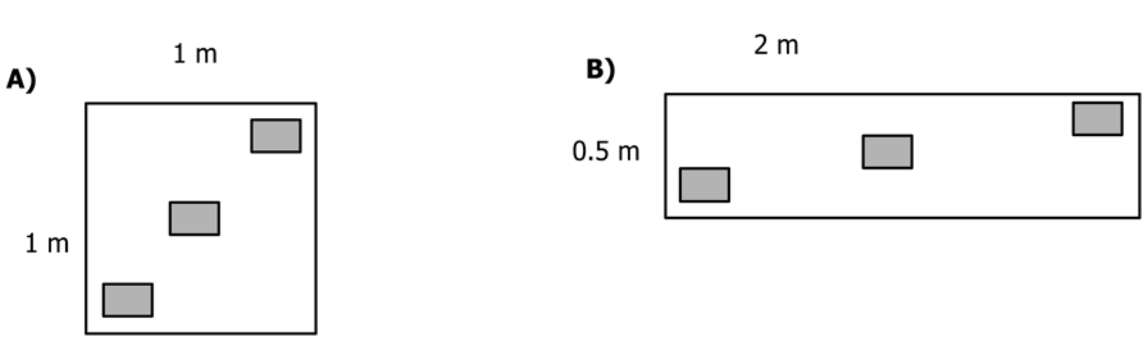

FIG. 1 Test Samples

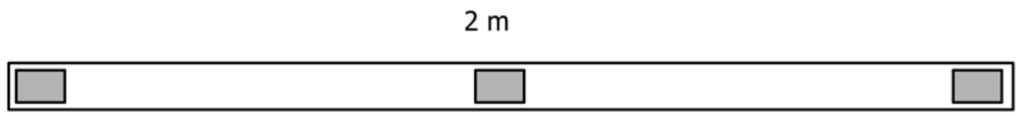

FIG. 2 Test Sample

10.1.2 *Tristimulus Values for Daylight 15 000 K*—Calculate the individual Total tristimulus values $(XYZ)_T$, Reflectance tristimulus values $(XYZ)_R$ and Fluorescence tristimulus values $(XYZ)_F$ for each test specimen from the respective Donaldson matrix for the CIE 1931 Standard Observer and Daylight 15 000 K (see Practice E2152).

10.1.2.1 The spectral power distribution for Daylight 15 000 K shall be calculated in accordance with the procedure described in CIE 15:2004 for other D Illuminants (tabulated values at 10 nm intervals for CIE D65 and Daylight 15 000 K are provided in Annex A1).

10.1.2.2 Calculate the averages and standard deviations for the individual tristimulus values (*X*, *Y*, and *Z*) for each component (Total, Reflectance, and Fluorescence) for Daylight 15 000 K for each set of test specimens.

10.2 *Colorimetric Quantities:*

10.2.1 *CIE 1931 Total Chromaticity Coordinates (x,y) for CIE D65*—Calculate the average Total CIE 1931 Chromaticity Coordinates $(x,y)_T$-average from the average Total tristimulus values $(XYZ)_T$-average for CIE D65 in accordance with established procedures (see Practice E308).

10.2.2 *CIE 1931 Total Chromaticity Coordinates (x,y) for Daylight 15 000 K*—Calculate the average Total CIE 1931 Chromaticity Coordinates $(x,y)_T$-average from the average Total tristimulus values $(XYZ)_T$-average for Daylight 15 000 K in accordance with established procedures (see Practice E308).

10.2.3 *Other Colorimetric Quantities*—When other colorimetric properties or values, such as CIELAB, are specified, these shall be calculated from tristimulus values in accordance with Practices E308 or E2152 as applicable.

10.3 *Other Quantities:*

10.3.1 Other quantities derived from the Donaldson matrix, such as the Stokes Shift.

10.3.2 Tristimulus values and Colorimetric quantities for other alternate illuminants.

11. Report

11.1 Specimen description including the following:

11.1.1 Sample Identification including any commercial designation (for example, trade-name and product number) and manufacturer lot number.

11.1.2 Description of the exposure conditions and total exposure duration for any test specimens that have undergone outdoor or machine exposure testing.

11.2 *Date of Measurement.*

11.3 *Instrument Description:*

11.3.1 Make and Model number of Bispectrometer.

11.3.2 Instrument geometry (annular, circumferential or uniplanar).

11.4 *Calibration and Verification Information:*

11.4.1 Date of most recent instrument calibration.

TABLE 1 CIE 1931 Tristimulus Values for CIE D65

	X_F	Y_F	Z_F	X_R	Y_R	Z_R
Fluorescent Yellow Green ASTM Type IX						
Average	25.4	47.6	2.2	32.2	35.8	1.1
σ	1.6	2.5	0.4	1.6	1.9	0.2
SR 95 % CI	±4.5	±7.4	±1.2	±4.7	±5.3	±0.6
CV % R	18 %	16 %	--	15 %	15 %	--
Fluorescent Yellow ASTM Type IX						
Average	44.4	45.3	0.5	26.2	20.8	0.4
σ	1.9	2.0	0.5	1.2	1.1	0.1
SR 95 % CI	±5.5	±5.8	±1.5	±3.4	±3.0	±0.4
CV % R	12%	13 %	--	13 %	15 %	--
Fluorescent Orange ASTM Type VII						
Average	37.0	23.0	0.0	26.5	14.4	0.6
σ	1.9	1.3	0.4	5.1	2.9	0.1
SR 95 % CI	±5.5	±3.8	±1.3	±14.8	±8.3	±0.3
CV % R	15 %	16 %	--	56 %	58 %	--
Fluorescent Red ASTM Type IX						
Average	29.3	14.9	0.0	11.2	5.1	2.4
σ	1.0	0.6	0.4	0.8	0.4	0.3
SR 95 % CI	±3.0	±1.8	±1.1	±2.3	±1.2	±0.8
CV % R	10 %	12 %	--	21 %	23 %	--
White Non-fluorescent/ Non-retroreflective						
Average	0.0	0.1	-0.2	76.8	81.4	88.1
σ	0.66	0.64	0.53	1.00	1.01	1.28
SR 95 % CI	±1.9	±1.8	±1.5	±2.9	±2.9	±3.7
CV% R	--	--	--	4 %	4 %	4 %