Standard Test Method for Nighttime Retroreflected Chromaticity of Retroreflective Sheeting[1]

This standard is issued under the fixed designation E3165; 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 determination of the nighttime retroreflected chromaticity coordinates of retroreflective sheeting.

1.2 This method includes a procedure based on tristimulus filter colorimetery and a procedure based on spectral measurements.

1.3 A single set of test geometries (using 0.33° observation angle and 5° entrance angle) and apertures are described in this method.

1.4 The resulting chromaticity coordinates are for use with the CIE 1931 chromaticity system utilizing CIE Illuminant A.

1.5 If measurements and calculations are required for other sources of illumination, or geometries, or other materials, the user is referred to the general practice described in Practice E811.

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

1.7 *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.*

1.8 *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]

D4956 Specification for Retroreflective Sheeting for Traffic Control

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

E808 Practice for Describing Retroreflection

E809 Practice for Measuring Photometric Characteristics of Retroreflectors

E810 Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry

E811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions

2.2 *CIE and ISO Documents:*[3]

CIE Publication 15:2004 Colorimetry

CIE Technical Report 54.2 Retroreflection: Definition and Measurement

CIE Technical Report 72 Guide to the Properties and Uses of Retroreflectors at Night

ISO 11664–1:2007 (CIE S 014–1/E:2006) Colorimetry—Part 1: CIE Standard Colorimetric Observers

ISO 11664–2:2007 (CE S 014–2/E:2006) Colorimetry—Part 2: CIE Standard Illuminants

2.3 *U. S. Federal Regulations:*[4]

US Code of Federal Regulations (CFR) Title 23: Highways: Part 655—Traffic Operations, Subpart F—Traffic Control

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[1] This test method is under the jurisdiction of ASTM Committee E12 on Color and Appearance and is the direct responsibility of Subcommittee E12.10 on Retroreflection.

Current edition approved July 1, 2018. Published September 2018. DOI: 10.1520/E3165-18.

[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 U.S. National Committee of the CIE (International Commission on Illumination), C/o Alan Laird Lewis, 282 E. Riding, Carlisle, MA 01741, http://www.cie-usnc.org.

[4] Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, http://www.access.gpo.gov.

Devices on Federal-Aid and Other Streets and Highways

3. Terminology

3.1 The terms and definitions in Terminology E284 apply to this test method.

3.2 *Definitions:*

3.2.1 *chromaticity coordinates, n*—the ratio of each of the tristimulus values of any viewed light to the sum of the three.

3.2.1.1 *Discussion*—Chromaticity coordinates in the CIE 1931 system of color specification are designated by *x*, *y*, and *z*.

3.2.2 *spectral coefficient of retroreflection $R_A(\lambda)$, n*—the ratio of the spectral coefficient of radiant intensity $R_I(\lambda)$ of the retroreflector for a given geometrical configuration to the area *A* of the retroreflector.

$$R_A(\lambda) = \frac{R_I(\lambda)}{A}$$

3.2.3 *spectral coefficient of retroreflected radiant intensity $R_I(\lambda)$, n*—the ratio of the spectral radiant intensity $I_e(\lambda)$ of the retroreflector for a given geometrical configuration to the spectral irradiance $E_e(\lambda)$ of the incident light source at the retroreflector on a plane perpendicular to the illumination axis.

$$R_I(\lambda) = \frac{I_e(\lambda)}{E_{e\perp}(\lambda)}$$

4. Summary of Test Method

4.1 The general procedure is to illuminate the test specimen with the specified source, in the prescribed geometry, and analyze the reflected light using the calculation in DIE Publication 15.

4.2 The geometric arrangement can be either a longer-distance photometric range or an optically-reduced equivalent geometry for laboratory bench or field work.

4.3 The measurements may be performed using a substitution standard calibrated by an appropriate calibration laboratory. Measurements are then relative to this standard.

5. Significance and Use

5.1 The results of this test method are used to assess conformance of retroreflective sheeting to the nighttime color requirements of industry standards and government regulations, such as Specification D4956 and U.S. Code of Federal Regulations Title 23 Part 655 Subpart F.

5.2 Requirements in specifications referring to this test method are for the chromaticity of the material as viewed at night. These requirements are generally stated using four or five corner points that form a box that limits the range of acceptable chromaticity. Most of these specifications are categorical in nature; they describe a small range of colors that are recognizable from a color naming or coding purpose

5.3 The method for compliance with the specification is to plot the measured (*x*, *y*) values and determine if the measured point falls within the specification box for the color of interest.

6. Apparatus

6.1 The apparatus consists of a light source, a receptor (tristimulus or spectral) and the geometric arrangement (either in a photometric range or an optically-reduced design for laboratory bench or field use).

6.2 The light source shall closely approximate the spectral distribution of CIE Illuminant A (a correlated color temperature of 2856 K, see Practice E308).

NOTE 1—Non-fluorescent samples may be illuminated with non-Illuminant A (for example, broadband) light sources using this method. The CIE Illuminant A light source is considered the referee condition for this test method.

6.3 The receptor shall closely approximate the CIE tristimulus functions when used. For spectral testing the dispersing elements shall provide a range from 380 to 740 nm with a 5 nm increment and a 5 nm bandpass. (For spectral measurements made by systems with increment and bandpass ≤5 nm, for example, array detectors, integration techniques are acceptable to obtain the equivalent of a 5 nm bandpass).

NOTE 2—Other bandpass specifications may be used. For example, the precision and bias data contained in Section 12 were collected by equipment having either 5 nm or 10 nm bandpass. The 5 nm bandpass is considered the referee condition for this test method.

7. Sampling, Test Specimens, and Test Units

7.1 Multiple samples shall be gathered from the retroreflective sheeting material in a manner so as to constitute a representative sampling. One example of a sampling procedure is described in Section 9 of Specification D4956. Deviations from this procedure shall be described in the report.

7.2 The reference test specimen in this procedure shall be 200 ± 100 mm by 200 ± 100 mm in size. The entire specimen to be measured shall be illuminated.

NOTE 3—The sample dimensions specified above refer to the referee laboratory measurement. Field measurements may dictate other sample dimension requirements. In all cases, the minimum illuminated area shall be a circle having a 25 mm diameter.

7.3 Retroreflective sheeting materials may have color characteristics that vary slowly with changes in observation, entrance, and orientation angle. Care should be taken to ensure careful preparation of the sample and placement in the measurement system.

7.4 Retroreflective sheeting may produce small "rainbow like" diffraction effects at some observation angles. If there is concern that these effects are present, then the maximum fixed aperture size (10 min of arc; see 9.2) is to be used as the referee configuration. In general, measurements at apertures less than the maximum size will provide no significant effect on the results and may be used.

7.5 *Measurement Angles*—This method uses the CIE goniometer system (α, β_1, β_2, ε). The angles used in the measurement are: observation angle $\alpha = 20$ min of arc (0.33°), entrance angle $\beta_1 = 5°$, entrance angle $\beta_2 = 0°$, and rotation angles ε of 0° and 90°.

8. Calibration and Standardization

8.1 Calibration of these instruments is to be performed relative to a known spectral or tristimulus standard from a reliable source.

8.2 *Calibration of Tristimulus Detectors*—The instrument is adjusted to read the reference standard chromaticity values. This may be done by calibration to a specific color or by verification using multiple colors ensuring that the readings are consistent with the values on the standard.

8.3 *Calibration of Spectral Method Dispersing Devices*—For spectral measurements the calibration standard shall have spectral coefficient of retroreflection values from 380 to 740 nm with a 5 nm increment and a 5 nm bandpass. The instrument is then adjusted to read the correct values at each wavelength before measurements are begun.

8.4 *Calibration of Light Sources*—For spectral energy distribution of the source shall be proportional to CIE Illuminant A (a correlated color temperature of 2856 K, see Practice E308). The projection lamp together with the projection optics shall be operated such that they illuminate the test specimen with this spectral power distribution.

9. Measurement Geometry

9.1 The observation angle (α) shall be 20 min of arc (0.33°). The entrance angle (β_1) shall be 5° as described in Practice E808.

9.2 The maximum angular size of the source and detector as viewed from the specimen or its optical equivalent shall be 10 min of arc (0.167°). In either case the source and the detector may be interchanged. Examples of source and detector geometries using the required observation angle are shown in Fig. 1(a) using annular geometry and in Fig. 1(b) using point geometry.

9.2.1 Note that Fig. 1 depicts a 10 min of arc (0.167°) source/detector aperture. Other aperture sizes such as 6 min of arc (0.10°) may also be used. The size of the source/detector apertures should be specified as part of the data reporting to evaluate the comparability of measurements made with different aperture sizes.

9.3 Fig. 2 shows the general layout of source, receiver and specimen in the laboratory. Instrumentation may also use collimating optics to allow for smaller instrument sizes for either field or laboratory bench measurements.

10. Procedure

10.1 This method allows two procedures for determining the chromaticity coordinates of the test specimen: the tristimulus method and the spectral method. These methods are described in Practice E811.

10.2 *Procedure A*—The tristimulus method uses CIE Illuminant A and appropriate tristimulus receptors as prescribed by CIE Publication 15. Calculations are performed for CIE Illuminant A and the CIE 1931 Standard Observer. This method generates the chromaticity coordinates (x, y) for illumination using CIE Illuminant A.

10.3 *Procedure B* uses the spectral method. For the spectral method the calculation of the spectral power distribution is completed and the chromaticity coordinates (x, y) for CIE Illuminant A and the CIE 1931 Standard Observer are calculated as prescribed in CIE Publication 15.

10.4 Either procedure may use a photometric range or optically-reduced instruments for laboratory bench or field use. In each case, the retroreflection geometry and aperture limitations shall be maintained

11. Report

11.1 The report shall contain the following:

11.1.1 Sample identification,

11.1.2 Equipment used (manufacturer name and model),

11.1.3 Bandpass filter spectral width (5 nm or other value),

11.1.4 Source and detector aperture angular size, and

11.1.5 The individual chromaticity values (x, y) measured and the average chromaticity values (x, y) for 0° and 90° rotation angles (ε).

11.1.6 Any deviation from the requirements stated in this test method.

12. Precision and Bias

12.1 The precision and bias for this method is the same as reported in Practice E811. (More studies are recommended for use of the reduced-optical-length instruments and their calibration using substitutional standards.) From a practical view, the

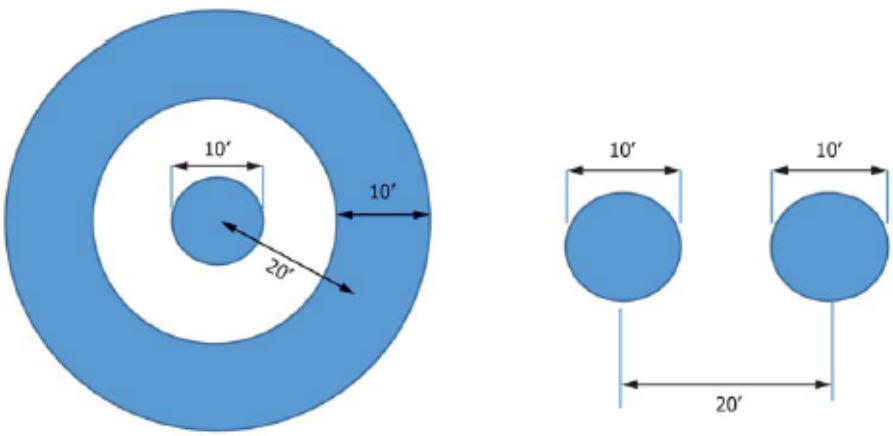

FIG. 1 Source and Detector Apertures for (a) Annular and (b) Point Geometries

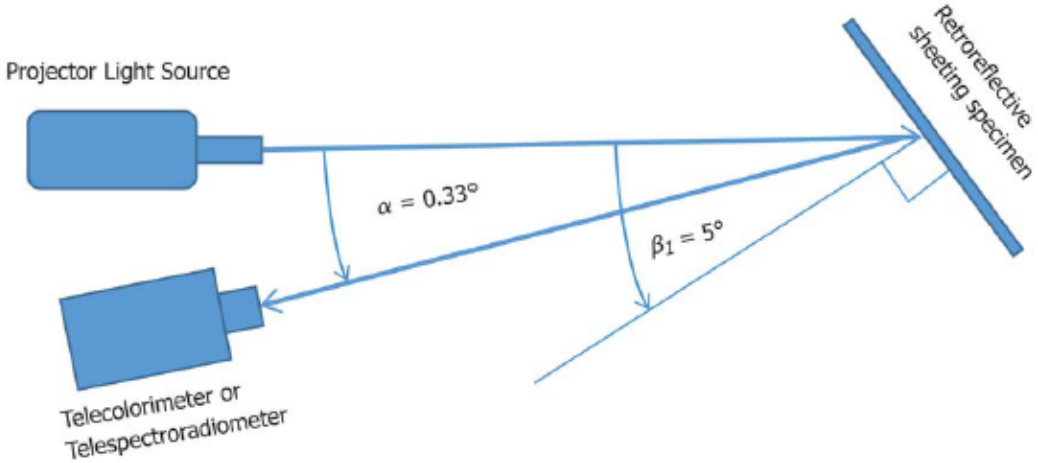

FIG. 2 Geometry of Source, Receiver, and Specimen for Measurement (using the point source/receiver geometry)

uncertainty in the (*x*, *y*) coordinates are generally considered adequate if the uncertainty is about 0.005 or less.

NOTE 4—The analysis used in this P&B section assumes that the chromaticity coordinates (*x*, *y*) are uncorrelated variables. However, the correct statistical analysis of this data should consider the chromaticity coordinates (*x*, *y*) as correlated variables. This corrected analysis should be included in a future revision of this standard. Until this revision is made, users of this standard are cautioned that the repeatability and reproducibility values stated below may underestimate the repeatability and reproducibility resulting from a bivariate correlation analysis.

12.2 The precision and bias information contained in this section is based on the work of the International Commission on Illumination (CIE) and technical committee TC 2-19 with the participating laboratories being exceptionally qualified and equipped for the interlaboratory study. The measurements were made on various grades and colors of retroreflective sheeting materials using spectral radiometers. The data were based on measurements at an entrance angle of 5° of arc and an observation angle of 0.33° of arc. The aperture size for both source and receptor was 10 min of arc. Table 1 shows the mean values of the chromaticity coordinates (*x*, *y*), from measurements on the test specimens made in the six laboratories that participated in the international intercomparison. Included for reference in this table is the mean value of the retroreflectance, R_A, of the test specimen calculated from the spectral measurements as described in CIE Technical Report 54.2.

12.3 *Precision*—Table 2 shows the average precision of the nighttime chromaticity coordinates *x*, *y*, measurements expressed as the mean standard deviation from the mean of repeat measurements in the individual laboratories.

12.4 *Repeatability*—Table 3 shows the expected repeatability, at the 95 % confidence interval, within laboratories using the methods of Practice E691.

12.5 *Reproducibility*—Table 4 shows the expected reproducibility, at the 95 % confidence interval, between laboratories expressed using the methods of Practice E691. It is based on measurements in six laboratories.

TABLE 1 Mean of Normalized Data—Retroreflectance (R_A) and Chromaticity *x*, *y* Values TC 2–19 Panel Designation

		R_A	x	y
Enclosed Lens				
1	A(White)	96	0.4572	0.4305
2	B(Yellow)	48	0.5463	0.4451
3	C(Red)	25	0.6564	0.3421
4	D(Blue)	6	0.1094	0.2826
5	E(Green)	10	0.1852	0.5937
6	F(Brown)	5	0.5972	0.3904
7	G(Orange)	30	0.6165	0.3712
Encapsulated Lens				
8	H(White)	233	0.4589	0.4289
9	J(Yellow)	161	0.5549	0.4415
10	K(Red)	49	0.6769	0.3202
11	L(Blue)	23	0.1596	0.3161
12	M(Green)	43	0.1689	0.6020
13	N(Brown)	10	0.6136	0.3795
Prismatic Materials				
15	R(White)	783	0.4500	0.4065
16	S(Yellow)	648	0.5478	0.4478
17	T(Red)	172	0.6792	0.3186
18	U(Blue)	53	0.1386	0.2509
19	V(Green)	70	0.1751	0.6857
20	W(Orange)	385	0.6161	0.3828

NOTE 5—The blue samples in this TC 2-19 study have larger repeatability and reproducibility than samples of some other colors. This is the result of the measurement being performed using CIE Illuminant A (which has low output in the short wavelength portion of the spectrum).

13. Keywords

13.1 chromaticity; nighttime color; nighttime retroreflected chromaticity; retroreflected chromaticity; retroreflected color; retroreflection; retroreflective

TABLE 2 The Pooled Standard Deviation From the Mean of Chromaticity Measurements From Each of the 6 Laboratories TC-19 Panel Designation

		x	y
Enclosed Lens			
1	A(White)	0.0005	0.0003
2	B(Yellow)	0.0003	0.0003
3	C(Red)	0.0003	0.0001
4	D(Blue)	0.0007	0.0015
5	E(Green)	0.0004	0.0016
6	F(Brown)	0.0025	0.0007
7	G(Orange)	0.0004	0.0002
Encapsulated Lens			
8	H(White)	0.0009	0.0001
9	J(Yellow)	0.0003	0.0003
10	K(Red)	0.0003	0.0001
11	L(Blue)	0.0007	0.0010
12	M(Green)	0.0004	0.0011
13	N(Brown)	0.0007	0.0002
Prismatic Materials			
15	R(White)	0.0005	0.0002
16	S(Yellow)	0.0002	0.0002
17	T(Red)	0.0002	0.0001
18	U(Blue)	0.0002	0.0006
19	V(Green)	0.0004	0.0004
20	W(Orange)	0.0002	0.0002

TABLE 3 The 95 % Repeatability Interval (Repeat Measurements Within a Singe Laboratory) TC 2–19 Panel Designation

		x	y
Enclosed Lens			
1	A(White)	0.0015	0.0007
2	B(Yellow)	0.0008	0.0008
3	C(Red)	0.0010	0.0004
4	D(Blue)	0.0021	0.0042
5	E(Green)	0.0012	0.0046
6	F(Brown)	0.0070	0.0019
7	G(Orange)	0.0011	0.0004
Encapsulated Lens			
8	H(White)	0.0024	0.0004
9	J(Yellow)	0.0009	0.0009
10	K(Red)	0.0007	0.0004
11	L(Blue)	0.0018	0.0028
12	M(Green)	0.0011	0.0030
13	N(Brown)	0.0019	0.0006
Prismatic Materials			
15	R(White)	0.0015	0.0006
16	S(Yellow)	0.0005	0.0005
17	T(Red)	0.0006	0.0003
18	U(Blue)	0.0005	0.0017
19	V(Green)	0.0012	0.0012
20	W(Orange)	0.0006	0.0007

TABLE 4 The 95 % Reproducibility Interval (Between Laboratories) TC 2–19 Panel Designation

		x	y
Enclosed Lens			
1	A(White)	0.0045	0.0026
2	B(Yellow)	0.0040	0.0022
3	C(Red)	0.0054	0.0031
4	D(Blue)	0.0099	0.0114
5	E(Green)	0.0109	0.0139
6	F(Brown)	0.0104	0.0030
7	G(Orange)	0.0063	0.0029
Encapsulated Lens			
8	H(White)	0.0049	0.0013
9	J(Yellow)	0.0037	0.0028
10	K(Red)	0.0050	0.0032
11	L(Blue)	0.0064	0.0116
12	M(Green)	0.0089	0.0098
13	N(Brown)	0.0069	0.0044
Prismatic Materials			
15	R(White)	0.0067	0.0051
16	S(Yellow)	0.0082	0.0105
17	T(Red)	0.0042	0.0037
18	U(Blue)	0.0057	0.0160
19	V(Green)	0.0115	0.0132
20	W(Orange)	0.0039	0.0045

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