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Standard Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions[1]

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1. Scope

1.1 This practice describes the instrumental determination of retroreflected chromaticity coordinates of retroreflectors. It includes the techniques used in a photometric range to measure retroreflected (nighttime) chromaticity with either a telecolorimeter or telespectroradiometer.

1.2 This practice covers the general measurement procedures. Additional requirements for specific tests and specifications are described in Section 7.

1.3 The description of the geometry used in the nighttime colorimetry of retroreflectors is described in Practice E808 and the methods for calculation of chromaticity are contained in Practice E308.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

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

2.2 *CIE Documents:*[3]

CIE Publication No. 15.2 Colorimetry, 2d ed.

CIE Standard S 001/ISO IS 10526, Colorimetric Illuminants

CIE Standard S 002/ISO IS 10527, Colorimetric Observers

CIE Technical Report 54.2 Retroreflection: Definition and Measurement

3. Terminology

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

3.2 *Definitions:*

3.2.1 *chromaticity coordinates, n*—the ratios of each of the tristimulus values of a psychophysical color to the sum of the tristimulus values.

3.2.1.1 *Discussion*—Chromaticity coordinates in the CIE 1931 system of color specification are designated by x, y, z and in the CIE 1964 supplementary system by x_{10}, y_{10}, z_{10}.

3.2.2 *CIE 1931 (x, y)-chromaticity diagram*—the chromaticity diagram for the CIE 1931 standard observer, in which the CIE 1931 chromaticity coordinates are plotted with x as the abscissa and y as the ordinate.

3.2.3 *CIE 1931 standard observer, n*—ideal colorimetric observer with color matching functions $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ corresponding to a field of view subtending a 2° angle on the retina; commonly called the "2° standard observer." **[CIE]**[B4]

3.2.3.1 *Discussion*—The color matching functions of the CIE 1931 standard observer are tabulated in Practice E308, CIE Publication No. 15.2, and CIE Standard S 002.

3.2.4 *CIE standard illuminant A, n*—colorimetric illuminant, representing the full radiation at 2855.6 K, defined by the CIE in terms of a relative spectral power distribution. **[CIE]**[B]

3.2.4.1 *Discussion*—The relative spectral power distribution of CIE standard illuminant *A* is tabulated in Practice E308, CIE Publication No. 15.2, and CIE Standard S 001.

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

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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 U.S. National Committee of the CIE (International Commission on Illumination), C/o Thomas M. Lemons, TLA-Lighting Consultants, Inc., 7 Pond St., Salem, MA 01970, http://www.cie-usnc.org.

[4] Stephenson, H. F., "The Colorimetric Measurement of Retroreflective Materials. Progress Report on International Exchange Tests,"*Proceedings of the CIE*, 18th Session (London), pp. 595–609, 1975.

3.2.5 *CIE standard source A, n*—a gas-filled tungsten-filament lamp operated at a correlated color temperature of 2855.6 K. [CIE][B]

3.2.6 *entrance angle,* β, *n*—the angle between the illumination axis and the retroreflector axis.

3.2.6.1 *Discussion*—The entrance angle is usually no larger than 90°, but for completeness its full range is defined as $0° \leq \beta \leq 180°$. In the CIE (goniometer) system β is resolved into two components, β_1 and β_2. Since by definition β is always positive, the common practice of referring to the small entrance angles that direct specular reflections away from the photoreceptor as negative valued is deprecated by ASTM. The recommendation is to designate such negative values as belonging to β_1.

3.2.7 *goniometer, n*—an instrument for measuring or setting angles.

3.2.8 *illumination axis, n—in retroreflection*, a line from the effective center of the source aperture to the retroreflector center.

3.2.9 *observation angle, n*—angle between the axes of the incident beam and the observed (reflected) beam, (*in retroreflection*, α, angle between the illumination axis and the observation axis).

3.2.10 *observation axis, n—in retroreflection*, a line from the effective center of the receiver aperture to the retroreflector center.

3.2.11 *retroreflection, n*—reflection in which the reflected rays are preferentially returned in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays. [CIE][B]

3.2.12 *retroreflective device, n*—deprecated term; use *retroreflector*.

3.2.13 *retroreflective sheeting, n*—a retroreflective material preassembled as a thin film ready for use.

3.2.14 *retroreflector, n*—a reflecting surface or device from which, when directionally irradiated, the reflected rays are preferentially returned in directions close to the opposite of the direction of the incident rays, this property being maintained over wide variations of the direction of the incident rays. [CIE, 1982][B]

3.2.15 *retroreflector axis, n*—a designated line segment from the retroreflector center that is used to describe the angular position of the retroreflector.

3.2.15.1 *Discussion*—The direction of the retroreflector axis is usually chosen centrally among the intended directions of illumination; for example, the direction of the road on which or with respect to which the retroreflector is intended to be positioned. In testing horizontal road markings the retroreflector axis is usually the normal to the test surface.

3.2.16 *retroreflector center, n*—a point on or near a retroreflector that is designated to be the center of the device for the purpose of specifying its performance.

3.2.17 *rotation angle,* ε, *n*—the angle in a plane perpendicular to the retroreflector axis from the observation halfplane to the datum axis, measured counter-clockwise from a viewpoint on the retroreflector axis.

3.2.17.1 *Discussion*—Range: $-180° < \varepsilon \leq 180°$. The definition is applicable when entrance angle and viewing angle are less than 90°. More generally, rotation angle is the angle from the positive part of second axis to the datum axis, measured counterclockwise from a viewpoint on the retroreflector axis.

3.2.17.2 *Discussion*—Rotation of the sample about the retroreflector axis while the source and receiver remain fixed in space changes the rotation angle (ε) and the orientation angle (ω_s) equally.

3.2.18 *spectroradiometer, n*—an instrument for measuring the spectral distribution of radiant energy or power.

3.2.19 *tristimulus colorimeter, n*—instrument that measures psychophysical color, in terms of tristimulus values, by the use of filters to convert the relative spectral power distribution of the illuminator to that of a standard illuminant, and to convert the relative spectral responsivity of the receiver to the responsivities prescribed for a standard observer.

3.2.19.1 *Discussion*—In some instruments, the filters may be combined into one set placed in the receiver; in such cases, caution should be observed when measuring fluorescent specimens.

3.2.20 *viewing angle, v, n*—in retroreflection, the angle between the retroreflector axis and the observation axis.

3.3 *Definitions of Terms Specific to This Standard:*

3.3.1 *telecolorimeter, n*—a tristimulus colorimeter equipped with collection optics for viewing a limited area at a distance from the instrument.

3.3.2 *telespectroradiometer, n*—a spectroradiometer equipped with collection optics for viewing a limited area at a distance from the instrument.

4. Summary of Practice

4.1 Two procedures are described in this practice (see also Practice E809). Procedure A is based on a calibrated light source, colored reference filters, a white reference standard and a telecolorimeter equipped with tristimulus filters. In this procedure, measurements of the incident light on the white standard at the specimen position are made using the colored filters and correction factors developed. Then the retroreflected light is measured under the test geometry and the corrected relative tristimulus values are computed. In Procedure B, spectral measurements are made of the incident light and of the retroreflected light under the test geometry required. From these spectral measurements, the relative tristimulus values are determined. In both procedures, the chromaticity coordinates *x*, *y* are based on the CIE 1931 Standard Color Observer.

5. Significance and Use

5.1 This practice describes a procedure for measuring the chromaticity of retroreflectors in a nighttime, that is, retroreflective, geometry of illumination and observation. CIE Standard Source A has been chosen to represent a tungsten automobile headlamp. Although the geometry must be specified by the user of this practice, it will, in general, correspond to the relationship between the vehicle headlamp, the retroreflector, and the vehicle driver's eyes. Thus, the chromaticity coordinates determined by the procedures in this practice describe numerically the nighttime appearance of the retroreflector.[5]

6. Use of the CIE Chromaticity Diagram for the Specification of Color

6.1 *Tristimulus Values for a Colored Sample*—The spectral nature of the light coming to the eye from a retroreflector depends upon the spectral distribution of the radiation from the source, $S(\lambda)$, and a quantity proportional to the spectral reflectance of the retroreflector, $R(\lambda)$. For nighttime colorimetric measurements of retroreflectors, $S(\lambda)$ is Illuminant A. The spectral tristimulus values, $\bar{x}, \bar{y},$ *and* $\bar{z}$, the illuminant power $S(\lambda)$, and the reflectance quantity $R(\lambda)$ are used together to calculate three numbers, the tristimulus values X, Y, and Z as follows:

$$X = k \int_{380}^{740} S_A(\lambda)\, R(\lambda)\, \bar{x}(\lambda) d\lambda$$

$$Y = k \int_{380}^{740} S_A(\lambda)\, R(\lambda)\, \bar{y}(\lambda) d\lambda$$

$$Z = k \int_{380}^{740} S_A(\lambda)\, R(\lambda)\, \bar{z}(\lambda) d\lambda$$

where:

$S_A(\lambda)$ = spectral power distribution of Illuminant A,
$R(\lambda)$ = spectral reflectance factor of the sample, and
$\bar{x}(\lambda), \bar{y}(\lambda), \bar{z}(\lambda)$ = color matching functions of the CIE standard observer.

$$100/k = \int_{380}^{740} S_A\, \bar{y}(\lambda) d\lambda$$

Integration of each curve across the visible region (380 to 740 nm) give the numerical value for the corresponding tristimulus value X, Y, or Z.

6.2 *Chromaticity Coordinates*—The chromaticity coordinates x, y, and z are computed from the tristimulus values X, Y, and Z as follows:

$$x = X/(X+Y+Z)$$
$$y = Y/(X+Y+Z)$$
$$z = Z/(X+Y+Z)$$

The normalization constant k in the equations for X, Y, and Z cancels out in calculating x, y, and z. Thus, x, y, and z express the color of the reflected light without regard to its intensity. Because the sum of x, y, and z is always equal to one, only two of these quantities are needed to describe the chromaticity of a light. The chromaticity coordinates x and y are chosen for this purpose.

6.3 *CIE 1931 (x, y) Chromaticity Diagram*—The chromaticity coordinates x and y can be plotted as shown in Practice E308, Fig. 1. The outline in the figure encloses the entire range of combinations of x and y that correspond to real colors. The points at which monochromatic radiation of various wavelengths falls are indicated on this boundary, with the more nearly neutral colors being represented by points toward the center of the bounded region.

6.4 *Specifying Color Limits*—A color point representing the x and y chromaticity coordinates of a test sample can be located on the CIE diagram. A specification for a specific retroreflective color limit would require that the color point for a sample of this color fall within specified boundaries of the diagram. The area within these boundaries is referred to as a color area, and is defined exactly by specifying four sets of chromaticity coordinates in the specification.

6.5 *Daytime versus Nighttime Color Limits*—Different color limits are required to specify daytime and nighttime color. Nighttime and daytime color limits are different for two major reasons: the quality of the illuminating light and the geometry or direction of the illuminating light. Daytime color is viewed under a source of daylight quality, and nighttime color is viewed under Source A (a CIE source corresponding to an incandescent lamp, such as an automobile headlamp). Illumination in the daytime is from skylight, and diffusely reflected light is observed; illumination in the nighttime comes from a point very near the observer, and retroreflected light is observed.

7. Requirements to be Stated in Specifications

7.1 When stating colorimetric retroreflective requirements, the following requirements shall be given in the specification for the material:

7.1.1 Limits of the color area on the 1931 CIE chromaticity diagram (usually four pairs of chromaticity coordinates (x and y) are required to define an area on the diagram).

7.1.2 Chromaticity coordinate limits and spectral transmittance limits of the standard filter when Procedure A is used. (These may be specified by giving the filter glass type and thickness or the manufacturer's part number of the filter.)

7.1.3 Observation angle (α).

7.1.4 Entrance angle (β) and when required the components of the entrance angle β_1, and β_2. (When specifying entrance angles near 0°, care must be taken to prevent "white" specular reflection from entering the receptor. Therefore, instead of specifying 0°, the entrance angle is usually specified so that specular light is reflected away from the receptor.)

7.1.5 Rotation angle (ε) and the location of the datum mark, if random orientation of the test specimen is not suitable.

7.1.6 Observation distance (d).

7.1.7 Test specimen dimensions and shape.

7.1.8 Receptor angular aperture, usually either 6 min or 10 min of arc.

7.1.9 Source angular aperture, usually either 6 min or 10 min of arc.

7.1.10 Reference center of the retroreflector.

7.1.11 Reference axis of the retroreflector. (The reference axis is usually perpendicular to the surface of sheeting. In such complex devices as automobile or bicycle reflectors, the

[5] Rennilson, J. J., "Chromaticity Measurements of Retroreflective Material Under Nighttime Geometry," *Applied Optics*, Vol 45, April 15, 1980.