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Standard Practice for Describing Retroreflection[1]

This standard is issued under the fixed designation E808; 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 practice provides terminology, alternative geometrical coordinate systems, and procedures for designating angles in descriptions of retroreflectors, specifications for retroreflector performance, and measurements of retroreflection.

1.2 Terminology defined herein includes terms germane to other ASTM documents on retroreflection.

1.3 *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

2.2 *Federal Standard:*

Fed. Std. No. 370 Instrumental Photometric Measurements of Retroreflecting Materials and Retroreflecting Devices[3]

2.3 *CIE Document:*

CIE Publication No. 54 Retroreflection-Definition and Measurement[4]

3. Terminology

3.1 Terms and definitions in Terminology E284 are applicable to this standard.

3.1.1 In accordance with the convention appearing in the Significance and Use section of Terminology E284, the superscript *B* appearing after [CIE] at the end of a definition indicates that the given definition is a modification of that cited with little difference in essential meaning.

NOTE 1—The terminology given here describes visual observation of luminance as defined by the CIE V (λ) spectral weighting function for the photopic observer. Analogous terms for other purposes can be defined by using appropriate spectral weighting.

3.2 *Definitions:*

3.2.1 The delimiting phrase "in retroreflection" applies to each of the following definitions when used outside the context of this or other retroreflection standards.

3.2.2 *coefficient of line retroreflection, R_M, n*—of a retroreflecting stripe, the ratio of the coefficient of luminous intensity (R_I) to the length (l), expressed in candelas per lux per metre ($cd \cdot lx^{-1} \cdot m^{-1}$). $R_M = R_I/l$.

3.2.2.1 *Discussion*—R_M depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.3 *coefficient of luminous intensity, R_I, n*—of a retroreflector, ratio of the luminous intensity (I) of the retroreflector in the direction of observation to the illuminance ($E_\perp$) at the retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux ($cd \cdot lx^{-1}$). $R_I = (I/E_\perp)$.

3.2.3.1 *Discussion*—In a given measurement one obtains the average R_I over the solid angles of incidence and viewing subtended by the source and receiver apertures, respectively. In practice, I is often determined as the product of the illuminance at the observer and the distance squared ($I = E_r\, d^2$). R_I depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.3.2 *Discussion*—Also called *coefficient of (retroreflected) luminous intensity*. Equivalent commonly used terms are *CIL* and *SI* (specific intensity). CIE Publication 54 uses the symbol R for R_I. The ASTM recommendation is to use the symbol R_I.

3.2.4 *coefficient of retroreflected luminance, R_L, n*—the ratio of the luminance, L, in the direction of observation to the normal illuminance, $E_\perp$, at the surface on a plane normal to the incident light, expressed in candelas per square metre per lux [$(cd \cdot m^{-2}) \cdot lx^{-1}$].

$$R_L = (L/E_\perp) = (R_I/A\cos v) = (I/EA\cos v) = (R_A/\cos v) \quad (1)$$

[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 Standardization Documents Order Desk, DODSSP, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5098, http://www.dodssp.daps.mil.

[4] 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.

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where:

A = surface area of the sample, and
ν = viewing angle.

3.2.4.1 *Discussion*—The units millicandela per square metre per lux [(mcd·m^{-2})·lx^{-1}] are usually used to express the R_L values of road marking surfaces. This quantity is also referred to as specific luminance. Historically the symbol *SL* was used for R_L. In some references *CRL* is used. These are all equivalent, but R_L is preferred.

3.2.4.2 *Discussion*—R_L depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.5 *coefficient of (retroreflected) luminous flux, R_Φ, n*—the ratio of the luminous flux per unit solid angle, Φ'/Ω', in the direction of observation to the total flux Φ incident on the effective retroreflective surface, expressed in candelas per lumen (cd·lm^{-1}).

$$R_\Phi = (\Phi'/\Omega')/\Phi = I/\Phi = R_A/\cos\beta \quad (2)$$

3.2.5.1 *Discussion*—The units for this photometric quantity, candelas per lumen, are sometimes abbreviated as *CPL*.

3.2.5.2 *Discussion*—R_Φ, depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.6 *coefficient of retroreflection, R_A, n*—of a plane retroreflecting surface, the ratio of the coefficient of luminous intensity (R_I) to the area (A), expressed in candelas per lux per square metre (cd·lx^{-1} · m^{-2}). $R_A = R_I/A$.

3.2.6.1 *Discussion*—The equivalent inch-pound units for coefficient of retroreflection are candelas per foot candle per square foot. The SI and inch-pound units are numerically equal, because the units of R_A reduce to 1/sr. An equivalent term used for coefficient of retroreflection is specific intensity per unit area, with symbol SIA or the CIE symbol R'. The term coefficient of retroreflection and the symbol R_A along with the SI units of candelas per lux per square metre are recommended by ASTM.

3.2.6.2 *Discussion*—The radiometric BRDF is not the analogue of R_A but rather of R_Φ.

3.2.6.3 *Discussion*—R_A depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.7 *co-entrance angle, e, n*—the complement of the angle between the retroreflector axis and the illumination axis.

3.2.7.1 *Discussion*—e=90°-β. Range 0°<e≤90°. For horizontal road markings, the retroreflector axis is considered to be the normal to the road surface, making e the angle of inclination of the illumination axis over the road surface.

3.2.8 *co-viewing angle, a, n*—the complement of the angle between the retroreflector axis and the observation axis.

3.2.8.1 *Discussion*—a= 90°-ν. Range 0°<a≤90°. For horizontal road markings, the retroreflector axis is considered to be the normal to the road surface, making a the angle of inclination of the observation axis over the road surface.

3.2.9 *datum axis, n*—a designated half-line from the retroreflector center perpendicular to the retroreflector axis.

3.2.9.1 *Discussion*—The datum axis together with the retroreflector center and the retroreflector axis establish the position of the retroreflector.

3.2.10 *datum mark, n*—an indication on the retroreflector, off the retroreflector axis, that establishes the direction of the datum axis.

3.2.11 *datum half-plane, n*—the half-plane that originates on the line of the retroreflector axis and contains the datum axis.

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

3.2.12.1 *Discussion*—The entrance angle is usually no larger than 90°, but for completeness its full range is defined as 0°≤β≤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.

3.2.13 *entrance angle component, β_1, n*—the angle from the illumination axis to the plane containing the retroreflector axis and the first axis. Range: –180°<β_1≤180°.

3.2.14 *entrance angle component, β_2, n*—the angle from the plane containing the observation half-plane to the retroreflector axis. Range: –90°≤β_2≤90°.

3.2.14.1 *Discussion*—For some measurements it is convenient to extend the range of β_2 to –180°<β_2≤180°. β_1 must then be restricted to –90°<β_1≤90°.

3.2.15 *entrance half-plane, n*—the half-plane that originates on the line of the illumination axis and contains the retroreflector axis.

3.2.16 *first axis, n*—the axis through the retroreflector center and perpendicular to the observation half-plane.

3.2.17 *fractional retroreflectance, R_T, n*—the fraction of unidirectional flux illuminating a retroreflector that is received at observation angles less than a designated value, α_{max}.

3.2.17.1 *Discussion*—R_T has no meaning unless α_{max} is specified.

3.2.17.2 *Discussion*—For a flat retroreflector R_T may be calculated as follows:

$$\int_{\alpha=0}^{\alpha_{max}} \int_{\rho=-\pi}^{\pi} \alpha \frac{R_A(\alpha,\rho)}{\cos\beta} \, d\alpha d\rho. \quad (3)$$

For a non-flat retroreflector R_T may be calculated as follows:

$$\int_{\alpha=0}^{\alpha_{max}} \int_{\rho=-\pi}^{\pi} \alpha \frac{R_I(\alpha,\rho)}{A_P} \, d\alpha d\rho. \quad (4)$$

A_P is the area of the retroreflector as projected in the direction of illumination. Angles β and ω_s must remain fixed through the integration. Angles α and ρ are in radians: R_T is unitless. Presentation angle γ may replace ρ in these formulas. For very small values of β, rotation angle ε may replace ρ in these formulas. For example, for β=5° the resulting error will be less than, usually much less than, 0.5 % of the calculated R_T.

3.2.17.3 *Discussion*—R_T is usually expressed in percent.

3.2.18 *illumination axis, n*—the half-line from the retroreflector center through the source point.

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3.2.19 *illumination distance, n*—the distance between the source point and the retroreflector center.

3.2.20 *observation angle,* α, *n*—the angle between the illumination axis and the observation axis.

3.2.20.1 *Discussion*—The observation angle is never negative and is almost always less than 10° and usually no more than 2°. The full range is defined as $0° \leq \alpha < 180°$.

3.2.21 *observation axis, n*—the half-line from the retroreflector center through the observation point.

3.2.22 *observation distance, d, n*—the distance between the retroreflector center and the observation point.

3.2.23 *observation half-plane, n*—the half-plane that originates on the line of the illumination axis and contains the observation axis.

3.2.24 *observation point, n*—the point taken as the location of the receiver.

3.2.24.1 *Discussion*—in real systems the receiver has finite size and the observation point is typically the center of the entrance pupil.

3.2.25 *orientation angle,* ω_s, *n*—the angle in a plane perpendicular to the retroreflector axis from the entrance half-plane to the datum axis, measured counter-clockwise from the viewpoint of the source.

3.2.25.1 *Discussion*—Range $-180° < \omega_s \leq 180°$. In the previous editions of Practice E808 as well as in CIE Pub. 54, 1982, orientation angle is defined as ω, the supplement of the above defined orientation angle ω_s. The change reverses the sense of orientation angle, making it now agree with the counterclockwise sense of rotation angle, ε, and exchanges the 0° and 180° points, making it now agree with Fed. Std. No. 370, §2.2.9b.

3.2.26 *presentation angle,* γ, *n*—the dihedral angle from the entrance half-plane to the observation half-plane, measured counter-clockwise from the viewpoint of the source.

3.2.26.1 *Discussion*—Range $-180° < \gamma \leq 180°$.

3.2.27 *retroreflectance factor,* R_F, *(of a plane retroreflecting surface), n*—the dimensionless ratio of the coefficient of luminous intensity (R_I) of a plane retroreflecting surface having area *A* to the coefficient of luminous intensity of a perfect reflecting diffuser of the same area under the same conditions of illumination and observation.

$$R_F = \frac{\pi R_I}{A \cos\beta \cos\nu} \tag{5}$$

3.2.27.1 *Discussion*—In the above expression β is the entrance angle and ν is the viewing angle. The quantity, R_F, is numerically the same as the reflectance factor, *R*.

3.2.27.2 *Discussion*—R_F depends on the spectral composition of the illumination which is usually CIE illuminant A.

3.2.28 *retroreflection, n*—reflection in which 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]

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

3.2.30 *retroreflective element, n*—a minimal optical unit that produces retroreflection.

3.2.31 *retroreflective material, n*—a material that has a thin continuous layer of small retroreflective elements on or very near its exposed surface (for example, retroreflective sheeting, beaded paint, highway sign surfaces, or pavement striping).

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

3.2.33 *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][B]

3.2.34 *retroreflector axis, n*—a designated half-line from the retroreflector center.

3.2.34.1 *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. When symmetry exists, the retroreflector axis usually coincides with the axis of symmetry of the retroreflector. For horizontal road markings the normal to the surface is chosen as the retroreflector axis.

3.2.35 *retroreflector center, n*—the point on or near a retroreflector that is designated to be the location of the device.

3.2.36 *rho angle,* ρ, *n*—the dihedral angle from the observation half-plane to the half-plane that originates on the line of the illumination axis and contains the datum axis, measured counter-clockwise from the viewpoint of the source.

3.2.36.1 *Discussion*—Range $-180° < \rho \leq 180°$.

3.2.37 *RM azimuthal angle, b, n*—the dihedral angle from the half-plane originating on the line of the retroreflector axis and containing the obverse of the illumination axis to the half-plane originating on the line of the retroreflector axis and containing the observation axis, measured clockwise from a viewpoint on the retroreflector axis.

3.2.37.1 *Discussion*—Range $-180° < b \leq 180°$.

3.2.38 *RM supplemental azimuthal angle, d, n*—the angle in a plane perpendicular to the retroreflector axis from the obverse of the datum axis to the half-plane that originates on the line of the retroreflector axis and contains the observation axis, measured clockwise from a viewpoint on the retroreflector axis.

3.2.38.1 *Discussion*—Range $-180° < d \leq 180°$.

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

3.2.39.1 *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.

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