



Designation: E 810 – 03

## Standard Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry<sup>1</sup>

This standard is issued under the fixed designation E 810; 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 reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

### 1. Scope

1.1 This test method describes an instrument measurement of the retroreflective performance of retroreflective sheeting.

1.2 The user of this test method must specify the entrance and observation angles to be used, and may specify the rotation angles.

1.3 This test method is intended as a laboratory test and requires a facility that can be darkened sufficiently so that stray light does not affect the test results. The testing apparatus must be able to achieve the coplanar geometry.

1.4 Portable and bench retroreflection measuring equipment may be used to determine  $R_A$  values provided the geometry and appropriate substitution standard reference panels, measured in accordance with this test method, are utilized. In this case the methods of Procedure B in Practice E 809 apply. Additional information on the use of portable retroreflectometers may be found in Test Method E 1709.

1.5 *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:

- E 284 Terminology of Appearance<sup>2</sup>
- E 308 Practice for Computing the Colors of Objects by Using the CIE System<sup>2</sup>
- E 691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method<sup>3</sup>
- E 808 Practice for Describing Retroreflection<sup>2</sup>
- E 809 Practice for Measuring Photometric Characteristics of Retroreflectors<sup>2</sup>
- E 1709 Test Method for Measurement of Retroreflective

Signs Using a Portable Retroreflectometer<sup>2</sup>

#### 2.2 Other Document:

CIE Publication No 54 Retroreflection—Definition and Measurement<sup>4</sup>

### 3. Terminology

3.1 The terms and definitions in Terminology E 284 and Practice E 808 apply to this test method.

#### 3.2 Definitions:

3.2.1 *coefficient of retroreflection,  $R_A$* —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 ( $\text{cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2}$ ).  $R_A = R_i/A$ .

3.2.1.1 *Discussion*—The equivalent inch-pound units for coefficient of retroreflection are candelas per foot-candle per square foot ( $\text{cd}\cdot\text{fc}^{-1}\cdot\text{ft}^{-2}$ ). The SI and inch pound units are numerically equal, because the units of  $R_A$  reduce to  $1/\text{sr}$ . 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 meter ( $\text{cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2}$ ) are recommended by ASTM.

3.2.1.2 *Discussion*— $R_A$  is a useful engineering quantity for determining the photometric performance of such retroreflective surfaces as highway delineators or warning devices.  $R_A$  may also be used to determine the minimum area of retroreflective sheeting necessary for a desired level of photometric performance.  $R_A$  has been used extensively in the specification of retroreflective sheeting.

3.2.2 *coplanar geometry,  $n$* —retroreflection geometry in which the retroreflector axis, illumination axis, and observation axis lie in one plane.

3.2.2.1 *Discussion*—In the coplanar geometry: the second entrance angle component,  $\beta_2$ , is equal to  $0^\circ$ ; presentation angle,  $\gamma$ , is equal to either  $0^\circ$  or  $180^\circ$ ; orientation angle,  $\omega_s$ , is equal to either the rotation angle,  $\epsilon$ , or to  $\epsilon + 180^\circ$  or  $\epsilon - 180^\circ$ .

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

<sup>1</sup> 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.

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<sup>2</sup> Annual Book of ASTM Standards, Vol 06.01.

<sup>3</sup> Annual Book of ASTM Standards, Vol 14.02.

<sup>4</sup> Available from USNC/CIE Publications Office, TLA Lighting Consultants, Inc. 77 Pond St., Salem, MA 01970.

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

3.2.5 *entrance angle,  $\beta$ , n*—the angle between the illumination axis and the retroreflector axis.

3.2.5.1 *Discussion*—The entrance angle is usually no larger than  $90^\circ$ , but for completeness its full range is defined as  $0^\circ \leq \beta \leq 180^\circ$ . In the CIE (goniometer system)  $\beta$  is resolved into two components  $\beta_1$  and  $\beta_2$ . Since by definition  $\beta$  is always positive, the common practice of referring to the small entrance angles that direct specular reflections away from the photoreceptor as a negative value is deprecated by ASTM. The recommendation is to designate such negative values as belonging to  $\beta_1$ .

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

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

3.2.8 *observation angle,  $\alpha$ , n*—the angle between the illumination axis and the observation axis.

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

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

3.2.10 *receiver, n*—the portion of a photometric instrument that receives the viewing beam from the specimen, including a collector such as an integrating sphere, if used, often the monochromator or spectral filters, the detector, and associated optics and electronics.

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]<sup>B</sup>

3.2.12 *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, retroreflective fabrics, transfer films, beaded paint, highway surface signs, or pavement striping).

3.2.13 *retroreflective sheeting*—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]<sup>B</sup>

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

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. The retroreflector axis usually coincides with the axis of symmetry of the retroreflector. For retroreflective sheeting the normal to the surface is chosen as the retroreflector axis.

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

3.2.17 *rotation angle,  $\epsilon$ , n*—the angle in a plane perpendicular to the retroreflector axis from the observation half-plane to the datum axis, measured counterclockwise from a viewpoint on the retroreflector axis.

3.2.17.1 *Discussion*—Range:  $-180^\circ < \epsilon \leq 180^\circ$ . The definition is applicable when entrance angle and viewing angle are less than  $90^\circ$ . 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 ( $\epsilon$ ) and the orientation angle ( $\omega_s$ ) equally.

3.2.18 *rotationally uniform, adj*—having substantially constant  $R_A$ , when rotated about the retroreflector axis, while the source, receiver, retroreflector center and retroreflector axis all remain in a fixed spatial relation.

3.2.18.1 *Discussion*—The degree of rotational uniformity can be specified numerically.

3.2.19 *source, n*—an object that produces light or other radiant flux.

## 4. Summary of Test Method

4.1 This test method involves the use of a light projector source, a receiver, a device to position the receiver with respect to the source and a test specimen holder in a suitable darkened area. The specimen holder is separated from the light source by 15 m.

4.2 The general procedure involved is to determine the ratio of the light retroreflected from the test surface to that incident on the test surface.

4.3 The photometric quantity, coefficient of retroreflection, is calculated from these measurements.

## 5. Significance and Use

5.1 Measurements made by this test method are related to visual observations of retroreflective sheeting as seen by the human eye when illuminated by tungsten-filament light sources such as a motor vehicle headlamp.

5.2 The values determined relate to the visual effects for a given geometric configuration as specified by the user of the test method. This test method has been found useful for tests at observation angles between  $0.1$  and  $2.0^\circ$  (observation angles between  $0.1^\circ$  and  $0.2^\circ$  may be achieved by careful design of source and receiver aperture configuration), and at entrance angles up to  $60^\circ$ . It has been used to determine coefficient of retroreflection values as low as  $0.1 \text{ cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2}$ , but for values less than  $1 \text{ cd}\cdot\text{lx}^{-1}\cdot\text{m}^{-2}$  special attention must be given to the responsivity of the receiver and to the elimination of very small amounts of stray light.

## 6. Apparatus

6.1 *Light Source*—The light source shall be of the projector type and shall meet the following requirements (an illuminance at the 15 m specimen distance of about 10 lx is commonly available within these restrictions):

6.1.1 The spectral energy distribution of the source shall be proportional to CIE standard Source A (a correlated color temperature of 2856 K, see Practice E 308). The projection lamp together with the projection optics shall be operated such that it illuminates the test specimen with this spectral power distribution.

6.1.2 An unpolarizing light source shall be used.

6.1.3 The source aperture shall be a standard circular aperture as defined in Practice E 809. For measurements at observation angles ( $\alpha$ ) of  $0.2^\circ \leq \alpha \leq 2.0^\circ$ , the exit aperture of the source shall be uniformly radiant, circular and 26 mm ( $\pm 2$  mm) in diameter. This corresponds to  $0.1^\circ$  angular aperture at 15 m test distance. For measurements at observation angles ( $\alpha$ ) of  $0.1^\circ \leq \alpha < 0.2^\circ$ , the exit aperture of the source shall be uniformly radiant, circular and 13 mm ( $\pm 1$  mm) in diameter. This corresponds to  $0.05^\circ$  angular aperture at 15 m test distance.

6.1.4 The illumination at the sample produced by the projector shall be such that the test specimen and only a minimum of the background is illuminated. This is commonly accomplished by placing a restrictive aperture in the projector slide port.

6.1.5 The source shall be regulated such that the illuminance at the test surface does not change by more than  $\pm 1\%$  for the duration of the test.

6.1.6 The illuminance produced on the sample surface shall be uniform within  $\pm 5\%$  of the average illuminance normal to the source at the distance of 15 m.

6.2 Receiver—The receiver shall meet the requirements that follow. (In this test, for 10 lx incident upon a  $1 \text{ cd}\cdot\text{lx}^{-1} \cdot \text{m}^{-2}$  retroreflective sheeting test specimen with area of  $0.04 \text{ m}^2$ , the incident normal illuminance at the receiver will be about  $1.8 \times 10^{-3} \text{ lx}$ ).

6.2.1 The responsivity and range of the receiver shall be sufficient so that readings of both the incident normal illuminance (at the specimen) and the retroreflected light at the observation position can be measured with a resolution of at least 1 part in 50 on the readout scale.

6.2.2 The spectral responsivity of the receiver shall match that of the 1931 CIE Standard Photopic Observer (see Annex A1 of Practice E 809).

6.2.3 The receiver shall be insensitive to the polarization of light.

6.2.4 The linearity of the photometric scale over the range of readings to be taken shall be within  $\pm 1\%$ . Correction factors may be used to ensure a linear response. Linearity verification tests must be made utilizing the entire receiver readout device including the detector, load, range selection system and readout display device.

6.2.5 The stability of the receiver shall be such that readings from a constant source do not vary any more than 1 % for the duration of the test.

6.2.6 The field of view shall be limited by use of light baffles or a field aperture on the instrument so that the entire test sample is fully within the field of view, rejecting stray light as much as practical. A background light level  $m_b$  less than 5 % of the smallest  $m_1$  reading is acceptable.

6.2.7 The receiver aperture shall be a standard circular aperture as defined in Practice E 809. For measurements at observation angles ( $\alpha$ ) of  $0.2^\circ \leq \alpha \leq 2.0^\circ$ , the receiver shall be provided with an entrance aperture 26 mm ( $\pm 2$  mm) in diameter. This corresponds to  $0.1^\circ$  angular aperture at 15 m test distance. For measurements at observation angles ( $\alpha$ ) of  $0.1^\circ \leq \alpha < 0.2^\circ$ , the receiver shall be provided with an entrance aperture 13 mm ( $\pm 1$  mm) in diameter. This corresponds to a  $0.05^\circ$  angular aperture at 15 m test distance. The size of the entrance aperture stop must be small so that the receiver may be positioned physically close to the source exit aperture without shadowing any of the illuminating light beam.

6.3 Test Specimen Goniometer (Test Specimen Holder)—The specimen holder must hold a 200 mm square specimen and meet the following requirements (see Fig. 1):

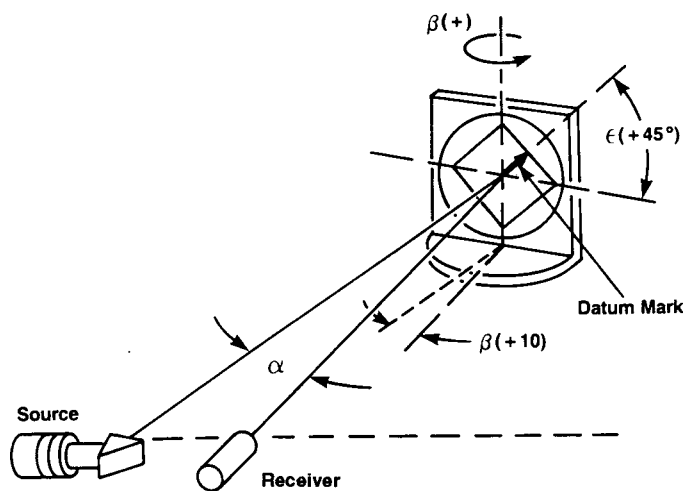
6.3.1 A means must be provided to rotate the specimen on an axis contained in the plane of the specimen surface if several entrance angles are to be used.

6.3.1.1 The entrance angle component  $\beta_1$  is used to set the goniometer when no specific component is specified (see Practice E 808).

6.3.2 The specimen surface must be positionable so that the entrance angle is accurate to within 0.5 % of its complement (that is, for a  $30^\circ$  entrance angle this angle must be accurately set to  $\pm 0.005 \times 60^\circ = \pm 0.3^\circ$ ). This is obtainable by providing an accurate optical means to align the test surface to the “0 degree” entrance angle and then adjusting the angular setting (within the required tolerance).

6.3.3 The specimen holder must be provided with a means of eliminating reflections from the edges of the specimen and the holder itself must be nonreflective (usually painted with a flat black paint).

6.3.4 The specimen holder should be constructed such that the receiver can easily be substituted for the specimen (required when incident light measurements are taken).



NOTE 1—This view shows the source-receiver in a horizontal plane and the entrance angle  $\beta$  ( $= \beta_1$ ) as a rotation about a vertical axis. The rotation angle  $\epsilon$  is shown at  $+45^\circ$  for illustration purposes— default position is  $\epsilon = 0^\circ$ .

FIG. 1 Pictorial View of a Goniometer—Specimen Holder Assembly

6.4 *Observer Goniometer (Device for Receiver/Light Source Separation)*—A device (sometimes called an observation angle positioner) must be provided to adequately support and separate the receiver from the source at the observation position. It must allow the observation angle to be varied (see Fig. 2). The usual range is at least 0.2° to 2.0°.

6.4.1 The accuracy of separation of the source exit aperture from the receiver entrance aperture is dependent on the test sample. For most materials, a positioning accuracy of ±0.1 mm (or ±0.5 % of the receiver angular subtense at 15 m distance) is adequate. A common method of fixing this distance is to provide a bar with holes machined in it at separations corresponding to the desired observation angles.

6.4.2 In this test method the minimum practical observation angle is approximately 0.2° using a receiver with an entrance aperture 26 mm (±2 mm) in diameter. If an observation angle ( $\alpha$ ) of  $0.1^\circ \leq \alpha < 0.2^\circ$  is to be used, a smaller aperture is needed as explained in 6.2.7.

6.5 *Photometric Range*—Sufficient working space is required so that the projector and sample can be separated by a 15 m distance.

6.5.1 The stray light in this facility must be such that it does not appreciably influence the test results. Flat black paint, black curtains, black tape and other means shall be used to eliminate unwanted light.

6.5.2 A measuring system must be provided in the photometric range to measure the 15 m test distance (from the retroreflector center to the receiver entrance aperture) accurately to ±0.01 m.

**7. Sampling**

7.1 The sampling procedure used for this test method shall be such that the test material is representative of the roll or batch.

7.2 When a roll of retroreflective sheeting is tested, at least three 0.2 by 0.2 m specimens shall be taken from the roll which are representative of crossweb and downweb variations if any. The average value of these three specimens will be reported. One method of meeting this requirement is to take three specimens—left, center, and right—diagonally across the roll.

7.2.1 If there is no datum mark already on the material and if the leading edge of the roll is not already indicated on the cut sample, then a datum mark should be made on the back of the sample at the time of cutting to indicate the leading edge of the

roll. If not otherwise agreed, this datum mark shall indicate 0° rotation angle for the test.

7.2.2 If a datum mark is already indicated on the material, this mark shall be used to orient the material for test as in 10.7.

7.3 When sampling a number of cut sheets of material, a random selection procedure will be used to ensure the sample is representative of the lot. At least three 0.2 by 0.2 m specimens will be selected and the average value reported.

7.4 When the material to be tested is smaller than 0.2 by 0.2 m in any dimension, the 0.2 by 0.2 m test specimen shall be obtained by piecing several small uniformly retroreflective parts together, with identical orientation, to form the required 0.2 by 0.2 m size test specimen.

**8. Test Specimen and Sample**

8.1 The test specimen in this procedure shall be 200 ± 100 mm by 200 ± 100 mm in size.

8.1.1 *Discussion*—The 200 mm square specimen with an area of 0.04 m<sup>2</sup> is suitable for most testing and convenient for storing and handling. Historically a 300 mm square specimen (1 ft<sup>2</sup>) has been used but this large a specimen can be clumsy to handle and does not significantly improve test accuracy. Specimens 100 mm square have been successfully used with modern receiver systems.

8.2 The specimen, when tested, shall be flat. This can be accomplished by applying the sample to a flat test panel or by providing a means of keeping the specimen adhered in a flat manner to the sample holder by tape, spray adhesive, mechanical means, or vacuum.

8.3 When it is desired to compare readings or individual panels between laboratories, a retroreflector datum mark should be provided on the sample to permit the same sample orientation between laboratories. This may be done by marking an arrow on the back of the specimen pointing toward the center of one of the 200 m sides. The direction of this arrow commonly corresponds to a “downweb” direction of manufacture.

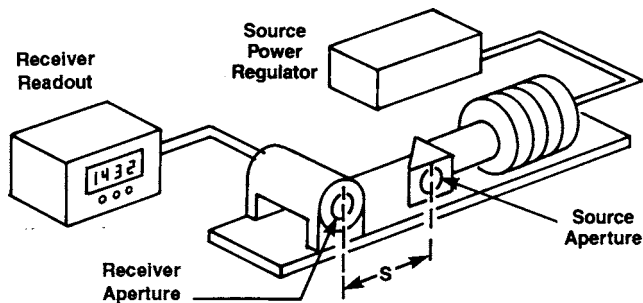
**9. Calibration and Standardization**

9.1 Prior to performing any tests by this test method, the calibration of the apparatus must be verified.

9.2 The light source must be calibrated to match the spectral distribution of CIE Standard Source A. When the proper voltage or current has been established for this requirement, the values or setting shall be recorded and used during the measurement procedure (see Annex A3 of Practice E 809).

9.3 The linearity of the receiver must be established. Either a set of data indicating that the receiver and readout device combination is linear when used over the range of the readings or a set of correction factors must be established (see Practice E 809, Annex A2) that correct the readings for nonlinearity.

9.4 The spectral responsivity of the receiver must be verified to be a sufficiently close match to the 1931 CIE photopic observer, for the color of the products to be measured (see Practice E 809, Annex A1).



NOTE 1—The distance *s* is adjusted to correspond to the desired observation angle.

FIG. 2 Pictorial View of Observation Angle Positioning Device