Designation: E 1501 – 99$^{\epsilon 1}$

Standard Specification for Nighttime Photometric Performance of Retroreflective Pedestrian Markings for Visibility Enhancement[1]

This standard is issued under the fixed designation E 1501; 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.

ε[1] NOTE—Editorial changes made throughout in September 2000.

INTRODUCTION

The use of appropriate retroreflective markings can significantly enhance the night visibility and safety of the user. As the first in a series addressing overall visibility for individual safety, this standard is intended to establish minimum retroreflective performance requirements and test methods for retroreflective pedestrian markings.

1. Scope

1.1 This specification covers the performance of retroreflective markings to be used on objects worn by pedestrians for the purpose of enhanced conspicuity. It addresses conspicuity from viewpoints around the entire object, and it allows for freedom of design of the markings so long as the minimum requirements are achieved. Objects include but are not limited to jackets, shirts, vests, trousers, socks, backpacks, hats, and footwear. An adjustment for the brightness/luminance ratio as a function of color is also made.

1.2 This specification applies only to nighttime viewing conditions in which the observer is positioned near a source of illumination. The most common example is that of a motor vehicle operator seeing by means of the light from the headlamps of the vehicle.

1.3 This specification describes the minimum retroreflective performance required for a reasonable level of nighttime conspicuity. It does not address potentially diminished performance of retroreflective markings that may be experienced with general storage, use, wear, and care.

1.4 SI (metric) units shall be used in referee decisions under this specification.

1.5 The following safety hazards caveat pertains to specifying materials by this standard specification. Although the markings described in this specification are intended to significantly enhance safety through increased conspicuity under most conditions of illumination and viewing of the type described in 1.2 above, they do not guarantee significantly enhanced conspicuity under all such conditions. Individuals exposed to adverse weather conditions or associated with high levels of vehicular or hazards exposure may require other types or amounts of retroreflective markings. *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[2]

E 808 Practice for Describing Retroreflection[2]

E 809 Practice for Measuring Photometric Characteristics of Retroreflectors[2]

E 811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions[2]

F 923 Guide Properties of High Visibility Materials Used to Improve Individual Safety[2]

2.2 *Other Standards:*

Publication CIE No. 54, Retroreflection—Definitions and Measurements, Central Bureau of the CIE, Vienna, 1982[3]

3. Terminology

3.1 *Definitions*—Definitions of terms relating to retroreflection in Terminology E 284, Practice E 808, and Guide F 923 are applicable to this specification.

3.1.1 *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

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[2] *Annual Book of ASTM Standards*, Vol 06.01.

[3] Available from the USNC–CIE Publications Office, c/o Mr. Thomas M. Lemons, TLA-Lighting Consultants, 7 Pond Street, Salem, MA 01970-4819.

retroreflector on a plane perpendicular to the direction of the incident light, expressed in candelas per lux ($cd \cdot lx^{-1}$). $R_I = (I/E_\perp)$.

3.1.2 *conspicuity*, *n*—the characteristics of an object that determine the likelihood that it will come to the attention of an observer.

3.1.3 *observation angle*, α, *n*—*in retroreflection*, angle between the illumination axis and the observation axis.

3.1.3.1 *Discussion*—The observation angle is always positive and is restricted to small acute angles.

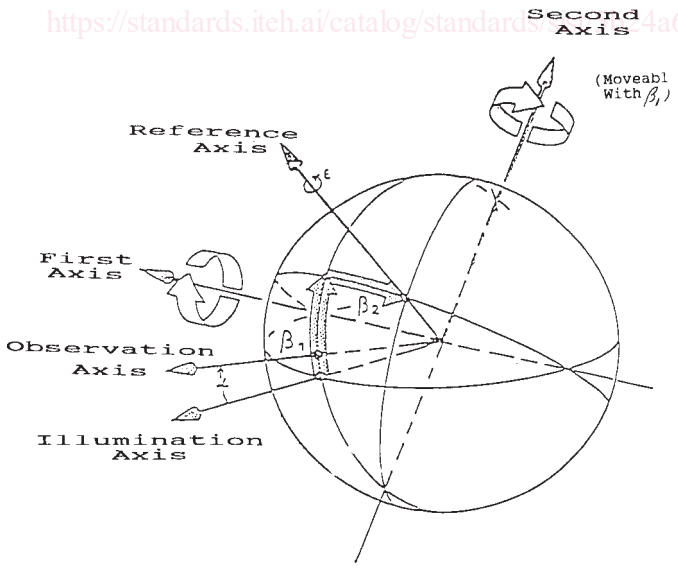
3.1.4 *observation half-plane*, *n*—the half-plane that originates on the line of the illumination axis and contains the observation axis.

3.1.5 *pedestrian*, *n*—any person on foot (standing or moving) who is located on a highway or street. **F 923**

3.1.6 *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.

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

3.1.7.1 *Discussion*—This is sometimes called the reference axis (Fig. 1). It is used to establish a coordinate system fixed with respect to the retroreflector by which its location and angular orientation can be specified. When symmetry exists, the retroreflector axis usually coincides with the axis of symmetry of the retroreflector. This is the axis of maximum reflectivity. It is typically normal to the face of retroreflective sheeting. For injection-molded retroreflectors, its direction may vary, and must be defined as a result of testing or by consulting the manufacturer.



See Publication CIE No. 54. The principal fixed axis is the illumination axis. The first axis is perpendicular to the plane containing the observation axis and the illumination axis. The second axis is perpendicular to both the first axis and the reference axis. The reference axis is fixed with respect to the retroreflector or object but movable with the components β_1 and β_2 of the entrance angle. All axes, angles, and directions of rotation are shown positive.

FIG. 1 The CIE Angular Reference System for Specifying and Measuring Retroreflectors

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *color factor* F_c, *n*—a chromatic adjustment to coefficient of luminous intensity R_I to account for the ratio of brightness to luminance.

3.2.2 *entrance angle component for object inclination*, β_1, *n*—angle from the illumination axis to the plane containing the object reference axis and the first axis for the object (see Fig. 1 and Fig. 2). Range: $-90° < \beta_1 \leq 90°$.

3.2.3 *entrance angle component for object rotation*, β_2, *n*—angle from the plane containing the observation half-plane to the object reference axis (see Fig. 1 and Fig. 2). Range: $-180° < \beta_2 \leq 180°$

3.2.4 *first axis for the object*,, *n*—axis through the approximate center of the object and perpendicular to the observation half-plane (see Fig. 1 and Fig. 2).

3.2.5 *marking*, *n*—that portion of an object that retroreflects.

3.2.6 *object*, *n*—the item worn by a pedestrian, to be marked for increased conspicuity under this specification.

3.2.7 *object reference axis*,, *n*—a designated line segment that extends outward from the approximate center of the object and is horizontial when the object is oriented in its usual upright position (see Fig. 1 and Fig. 2).

3.2.8 *retroreflective return*, R_R, *n*—the sum of the coefficients of luminous intensity, R_I, measured at two selected observation angles and adjusted for chromaticity.

3.2.8.1 *Discussion*—This quantity is used to describe the effective performance of the object. (See 6.6.)

3.2.9 *second axis for the object*, *n*—axis through the approximate center of the object, lying in the plane of the illumination axis and observation axis, and perpendicular to the object reference axis (see Fig. 1 and Fig. 2).

4. Classification of Objects

4.1 To facilitate testing objects, they are classified as follows:

4.1.1 *Type 1*—Coats, jackets, and coveralls. Sleeved garments with markings on front, back, and sleeves. A typical example is shown in Fig. 3.

4.1.2 *Type 2*—Vests. Sleeveless garments to cover front, back, and sides of upper torso. Markings are provided on the front and back. A typical example is shown in Fig. 4.

4.1.3 *Type 3*—Trousers (short or long), leg bands, leggings, socks (to be worn with short trousers), and other leg coverings. A typical example is shown in Fig. 5.

4.1.4 *Type 4*—School bags and backpacks. Back-carried using shoulder and/or front straps. Markings are on surfaces away from the body, including carrying straps. A typical example is shown in Fig. 6.

4.1.5 *Type 5*—Hats, helmets, head bands, and other head gear. Garments worn on the head for protection, warmth, or increased conspicuity. A typical example is shown in Fig. 7.

4.1.6 *Type 6*—Shoes and other footwear. Objects worn on the feet. A typical example is shown in Fig. 8.

4.2 Other types 4.1.1-4.1.6 are not limited to the example or marking placement shown in Figs. 3-8.

5. Performance Requirements

5.1 *Retroreflective return* (R_R):

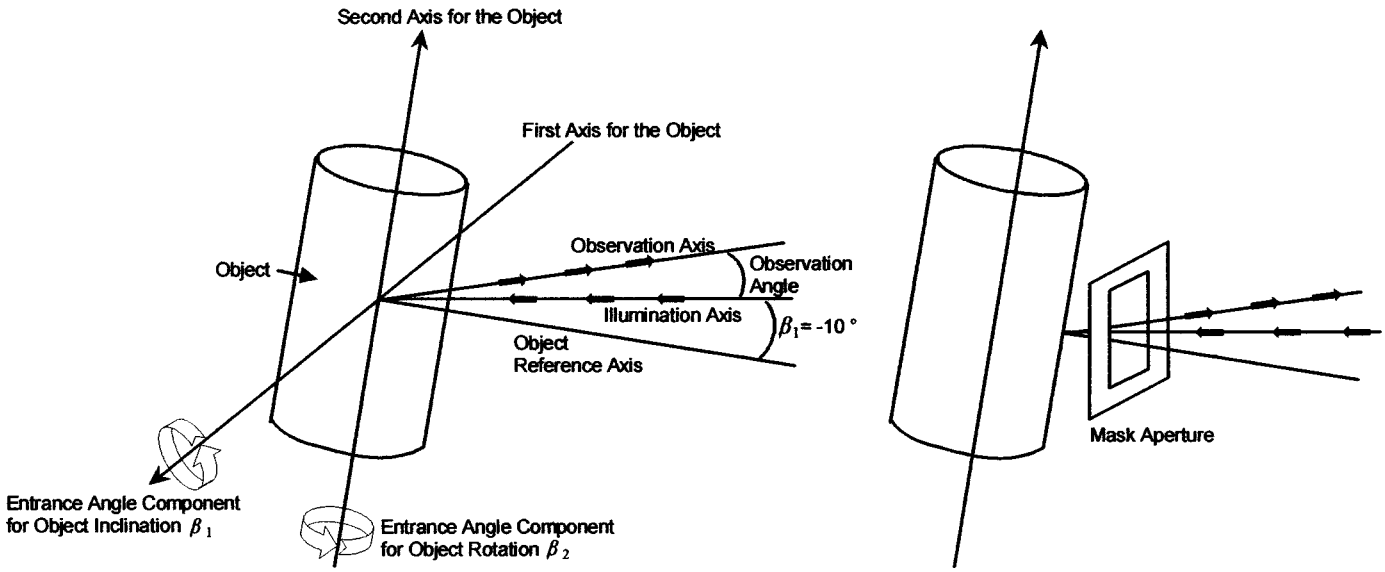


FIG. 2 The Angular Reference System Used in this Specification

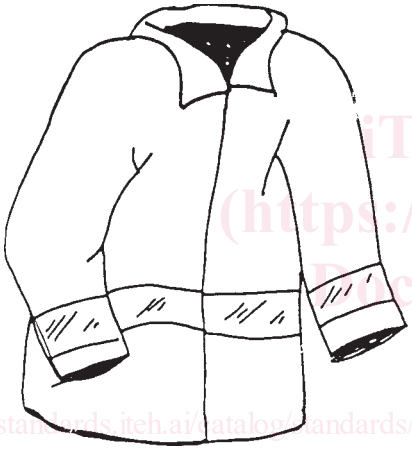


FIG. 3 A Type 1 Object (Coats, Jackets, and Coveralls) Showing Location of Markers

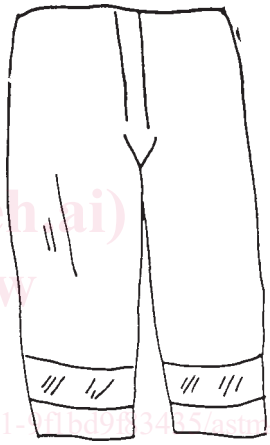


FIG. 5 A Type 3 Object (Trousers and Other Leg Coverings) Showing Location of Markers

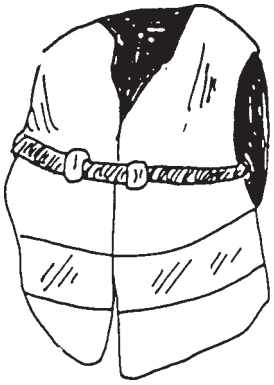


FIG. 4 A Type 2 Object (Vests) Showing Location of Markers

5.1.1 For each distance simulation and each entrance angle component for object rotation β_2 the retroreflective return, R_R is calculated by the following formula:

$$R_R = F_c\,[R_{I1} + R_{I2}]\,[A_0 / A]^{0.6} \quad (1)$$

where:

F_c = is the color factor for the markings as determined in 6.5,

F_c = is defined to be dimensionless, so R_R has the same physical dimensions as R_I,

R_{I1} = is the coefficient of luminous intensity, R_I measured through an aperture mask (see Section 6) at observation angle α_1 as given in Table 1,

R_{I2} = is the coefficient of the luminous intensity, R_I measured through an apertured mask (see Section 6) at observation angle α_2 as given in Table 1,

A_0 = is the minimum area for any mask aperture for each distance simulation as given in Table 1, and

A = is the sum of the areas of the apertures in the mask; the minimum dimensions for area A_0 and dimension D_0 of a mask aperture are given in Table 1.

5.1.2 For each of the two distance simulations and at each measurement point at 15° intervals of β_2 over a full 360° of rotation as the object is rotated about the second axis for the

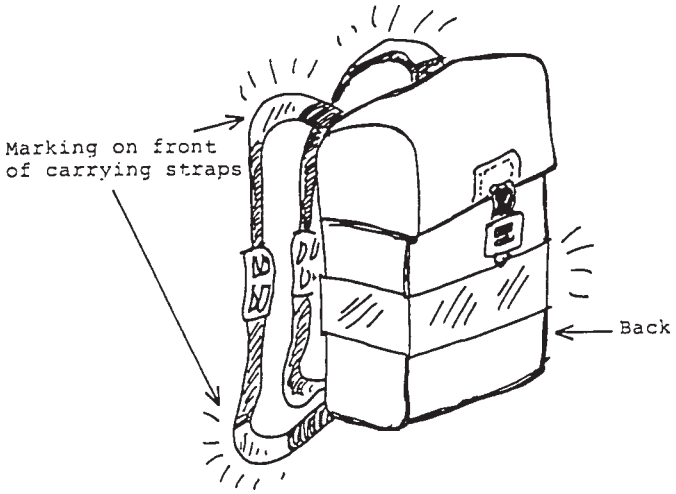


FIG. 6 A Type 4 Object (School Bags and Backpacks) Showing Location of Markers

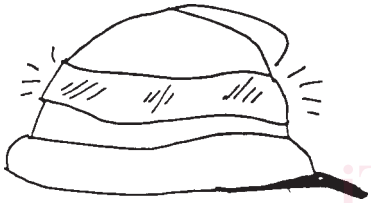


FIG. 7 A Type 5 Object (Hats and Other Headgear) Showing Location of Markers

FIG. 8 A Type 6 Object (Shoes and Other Footwear) Showing Location of Markers

TABLE 1 Measurement Parameters for Determining R_R Which are Specific to Simulated Viewing Distances

Distance Simulated	Observation α_1	Angles α_2	Minimum Aperture Area A_0	Minimum Aperture Dimension D_0
70 m	1.1°	0.5°	0.005 m^2 (7.56 $in.^2$)	0.07 m (2.75 in.)
230 m	0.3°	0.15°	0.053 m^2 (82 $in.^2$)	0.23 m (9.06 in.)

object with an entrance angle component for object inclination β_1 of −10°, R_R shall be equal to or greater than the minimum value shown in Table 2. Since, within prescribed limits, the dimensions of the mask aperture(s) are to be specified by the object manufacturer in order to allow a particular design to be evaluated under conditions favorable to it, in cases of dispute it is up to the person claiming an object meets the specifications to define the mask(s) for the measurements that will be made to verify compliance. (See 6.2.1 for further discussion of masks.)

TABLE 2 Required Minimum Values of R_R

Distance	Minimum R_R
70 m	0.40 cd/lx
230 m	2.30 cd/lx

5.2 *Control of the Position of Test Objects When Tested for Retroreflective Return*:

5.2.1 Objects shall be selected according to the appropriate classification (Section 4), prepared by the corresponding preparation method (6.2.8), and tested according to the test methods of 6.2.5 and 6.2.6.

5.2.2 Objects shall be oriented in their usual upright positions, with no rotation about the object reference axis. Entrance angle components for object inclination (β_1) and object rotation (β_2) shall be set according to 6.2 .

6. Test Methods

6.1 *Summary of Test Methods*:

6.1.1 Retroreflective marking test geometries and procedures.

6.1.1.1 Mask. (See 6.2.1.)

6.1.1.2 Observation angles, α. (See 6.2.2.)

6.1.1.3 Entrance angle component for object inclination, β_1. (See 6.2.3.)

6.1.1.4 Entrance angle component for object rotation, β_2. (See 6.2.4.)

6.1.1.5 Seventy metre simulation test for coefficient of luminous intensity, R_I. (See 6.2.5.)

6.1.1.6 Two hundred-thirty metre simulation test for coefficient of luminous intensity, R_I. (See 6.2.6.)

6.1.1.7 Test preparation for pedestrian object by classification. (See 6.2.8.)

6.1.2 Retroreflectometer parameters for instrumental measurements of the performance characteristics of retroreflective markings. (See 6.3.)

6.1.3 Parameters for measuring colorimetric characteristics of retroreflective markings under nighttime conditions. (See 6.4.)

6.1.4 Calculating color factor, F_c. (See 6.5.)

6.1.5 Calculating retroreflective return, R_R. (See 5.1 and 6.6.)

6.2 *Retroreflective Marking Test Geometries*:

6.2.1 For each measurement of R_I a matte black mask must be placed immediately before the object. The mask must exclude from the measurement all but the selected marking(s) or portion(s) of the marking(s) that are to be included in determining whether R_R meets this specification.

TABLE 3 Conditions for Measurement of Coefficient of Luminous Intensity R_I

Condition	70 m Simulation	230 m Simulation
Observation Angle		
α_1	1.10°	0.30°
α_2	0.50°	0.15°
Entrance Angle Component for Object Inclination β_1	−10°	−10°
Entrance Angle Component for Object Rotation β_2	–165° to +180° in 15° steps	–165° to +180° in 15° steps