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Standard Practice for
Measuring Photometric Characteristics of Retroreflectors[1]

This standard is issued under the fixed designation E809; 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 describes the general procedures for instrumental measurement of the photometric characteristics of retroreflective materials and retroreflective devices.

1.2 This practice is a comprehensive guide to the photometry of retroreflectors but does not include geometric terms that are described in Practice E808.

1.3 This practice describes the parameters that are required when stating photometric measurements in specific tests and specifications for retroreflectors.

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

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:*[2]

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E808 Practice for Describing Retroreflection

2.2 *CIE Documents:*

CIE Publication No. 54.2 Retroreflection—Definition and Measurement[3]

CIE Publication DS 17.2/E:2009 International Lighting Vocabulary[3]

CIE Publication No. 69-1987 Methods of Characterizing Illuminance Meters and Luminance Meters[3]

3. Terminology

3.1 Terms and definitions in Terminology E284 and E808 are applicable to this practice. In general, the terminology in this practice agrees with that in CIE Publications DS 17.2/E:2009 and 54.2.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *annular aperture, n*—the difference between the angular diameters of the external boundary circle and the internal boundary circle.

3.2.2 *circular aperture, n*—the angular diameter of a circular aperture surface.

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

3.2.4 *photopic receiver, n*—a receiver of radiation with a spectral responsivity which conforms to the $V(\lambda)$ distribution of the CIE Photopic Standard Observer that is specified in Practice E308.

3.2.5 *receiver aperture, n*—angular dimensions from the retroreflector center to the entrance aperture or pupil of the receiver.

3.2.6 *rectangular aperture, n*—the angular height and width of a rectangular aperture surface.

3.2.6.1 *Discussion*—The orientation of the sides of the rectangular aperture surface should be supplied together with the angular height and width.

3.2.7 *reflected illuminance, E_r, n*—illuminance at the receiver measured on a plane perpendicular to the observation axis.

3.2.7.1 *Discussion*—This quantity is used in the calculation of the coefficient of luminous intensity, R_I: $R_I = (I/E_\perp) = (E_r d^2)/E_\perp$, where d is the distance from the retroreflector to the receptor.

3.2.8 *retroreflectometer aperture angles, n*—the maximum angular diameter of the pencil of light (see Fig. 1).

3.2.8.1 *Discussion*—In practice the illumination arrives at the retroreflector center within a narrow pencil of light surrounding the illumination axis and the light reflected to the photoreceptor is contained within another narrow pencil. The distribution of light within such pencils is the "aperture" function and the maximum angular diameter of the pencil is the "aperture angle." It is generally assumed that the aperture

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[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 the CIE Webshop at http://www.cie.co.at.

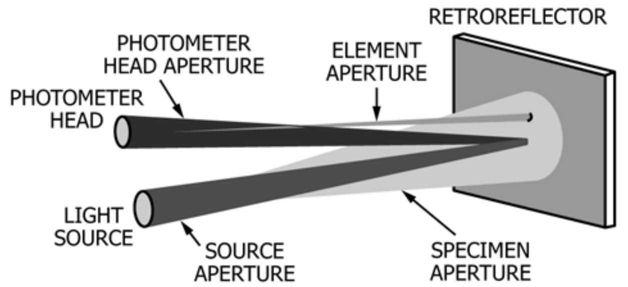

FIG. 1 Illustration of Apertures used in Retroreflection Measurement

functions are rotationally symmetrical and even uniform, but this is often false, especially for illumination.

3.2.9 *retroreflector aperture surface, n*—the aperture surface of a retroreflector is given by the retroreflector itself, or by a diaphragm enclosing part of the retroreflector.

3.2.10 *retroreflector element aperture, n*—angular dimension of the aperture surface of a retroreflective element as seen from the receiver's center.

3.2.10.1 *Discussion*—The element aperture quantifies an error source in the setting of the observation angle. This is a critical feature for testing large retroreflective elements or at short distances. When using collimated optics, placing the source and receiver at virtual infinity, the retroreflector element aperture is virtually zero.

3.2.11 *retroreflector (or specimen) aperture, n*—angular dimensions from the source point of reference to the aperture surface of the retroreflector (or specimen).

3.2.11.1 *Discussion*—As the source and receiver are generally close to each other, distinction is not made between aperture angles seen from the source and receiver. When using collimated optics where the source and receiver are at virtual infinity, the retroreflector aperture is virtually naught. The retroreflector aperture describes the maximum variation of the entrance angle of the aperture surface of the retroreflector.

3.2.12 *source aperture, n*—angular dimensions from the retroreflector center to the exit aperture stop or pupil of the light source.

4. Summary of Practice

4.1 The fundamental procedure described in this practice involves measurements of retroreflection based on the ratio of the retroreflected illuminance at the observation position to the incident illuminance measured perpendicular to the illumination axis at the retroreflector. From these measurements, along with the geometry of test, various photometric quantities applicable to retroreflectors can be determined.

4.2 Also described are methods of comparative testing where unknown specimens are measured relative to an agreed-upon standard retroreflector (a substitution test method).

5. Significance and Use

5.1 This practice describes procedures used to measure photometric quantities that relate to the visual perception of retroreflected light. The most significant usage is in the relation to the nighttime vehicle headlamp, retroreflector, and driver's eye geometry. For this reason the CIE Standard Source A is used to represent a tungsten vehicle headlamp and the receptor has the photopic, $V(\lambda)$, spectral responsivity corresponding to the light adapted human eye. Although the geometry must be specified by the user, it will, in general, correspond to the relation between the vehicle headlamp, the retroreflector, and the vehicle driver's eye position.

6. Uses and Applications

6.1 *Coefficient of Retroreflection*—This quantity is used to specify the performance of retroreflective sheeting. It considers the retroreflector as an apparent point source whose retroreflected luminous intensity is dependent on the area of the retroreflective surface involved. It is a useful engineering quantity for determining the photometric performance of such retroreflective surfaces as highway delineators or warning devices. The coefficient of retroreflection may also be used to determine the minimum area of retroreflective sheeting necessary for a desired level of photometric performance.

6.2 *Coefficient of Luminous Intensity*—This term is used to specify the performance of retroreflective devices. It considers the retroreflected luminous intensity as a function of the perpendicular illuminance incident on the device. It is recommended for use in describing performance of RPMs, taillight reflex reflectors and roadway delineators.

6.3 *Coefficient of Line Retroreflection (of a Reflecting Stripe)*—This term may be used to describe the retroreflective performance of long narrow strips of retroreflective materials, when the actual width is not as important as is the reflectivity per unit length.

6.4 *Reflectance Factor (of a Plane Reflecting Surface)*—This is a useful term for comparing surfaces specifically designed for retroreflection to surfaces which are generally considered to be diffuse reflectors. Since almost all natural surfaces tend to retroreflect slightly, materials such as $BaSO_4$ can have a reflectance factor much higher than one (as much as four) at small observation angles. Such diffuse reflectance standards should be used for calibration only at large observation angles, for example, 45°.

6.5 *Coefficient of Retroreflected Luminance* (also called *Specific Luminance*)—This term considers the retroreflector as a surface source whose projected area is visible as an area at the observation position. The coefficient of retroreflected luminance relates to the way the effective retroreflective surface is focused on the retina of the human eye and to the visual effect thereby produced. It is recommended for describing the performance of highway signs and striping or large vehicular markings which are commonly viewed as discernible surface areas.

6.6 *Coefficient of Luminous Flux per Unit Solid Angle, R_Φ*—This measurement is used to evaluate retroreflectors on the basis of flux ratios. It is numerically very nearly equal to the coefficient of retroreflected luminance at small entrance angles. It is recommended for use in the design of retroreflectors but not for specification purposes.

7. Requirements When Measuring Retroreflectors

7.1 When describing photometric measurements of retroreflectors, items in paragraphs 7.1.1 – 7.1.11 must be included. Refer to Fig. 2 for a diagram of measurement geometry terminology.

7.1.1 Retroreflective photometric quantity, such as: coefficient of luminous intensity (R_I), coefficient of retroreflected luminance (R_L) (also called specific luminance), coefficient of retroreflection (R_A), coefficient of line retroreflection (R_M), reflectance factor (R_F), or coefficient of luminous flux per unit solid angle (R_Φ).

7.1.1.1 In specifications, a minimum acceptable quantitative value is usually established.

7.1.2 Units in which each quantity is to be measured (for example $cd \cdot lx^{-1} \cdot m^{-2}$).

7.1.3 Observation angle.

7.1.4 Components of the entrance angle, (β_1 and β_2).

7.1.4.1 When both β_1 and β_2 are near zero, care must be taken to prevent specular reflection from entering the photoreceptor.

7.1.4.2 Entrance angle β equals $\cos^{-1}(\cos\beta_1 \cos\beta_2)$.

7.1.5 Rotation angle and the datum mark position shall be specified if random rotational orientation of the test specimen is not suitable.

7.1.6 Test distance or minimum test distance.

7.1.7 Test specimen size and shape.

7.1.8 Photoreceptor angular aperture.

7.1.9 Source angular aperture.

7.1.10 Retroreflector center.

7.1.11 Retroreflector axis. The retroreflector axis is usually perpendicular to the surface of retroreflective sheeting. In such complex devices as automobile or bicycle reflectors, the retroreflector axis and retroreflector center may be defined with respect to the illumination direction.

8. Apparatus

8.1 *General*—The apparatus shall consist of a photoreceptor, a light projector source, a specimen goniometer, an observer goniometer, (sometimes known as the observation angle positioner), and a photometric range.

8.1.1 Aperture angles are a very important consideration when measuring retroreflectors as Fig. 1 illustrates. See Table 1 for recommendations for maximum angular aperture of optical elements. See 9.1 on selection of angular apertures.

8.2 *Photoreceptor*—The photoreceptor shall be equipped as follows:

8.2.1 *Photopic Filter*—The photoreceptor shall be equipped with a light filter such that the spectral responsivity of the receptor should match the *V*(λ) response of the CIE Standard photopic observer with an f_1' tolerance no greater than 3 %. Spectral correction filters to the *V*(λ) function may be used provided that they are determined on material which has been previously measured by spectroradiometric means and closely corresponds in their spectral coefficient of retroreflection to the specimen under test. See Annex A1 for uncertainty tests and compensation.

8.2.2 *Photoreceptor Stability and Linearity*—The stability and linearity of the photometric scale reading must be within 1 % over the range of values to be measured (see Annex A2). The responsivity and range of the photoreceptor should be sufficient such that readings of the projector light source and the retroreflector under test will have a resolution of at least 1 part in 50.

8.2.3 *Photoreceptor Angular Aperture*—The photoreceptor must be equipped with a means to limit the angular collection of retroreflective luminous flux. This may be accomplished with an objective lens and field aperture or with light baffling. The field of view shall be limited such that the effect of stray light is negligible. The field of view should be limited to the smallest aperture that includes the entire test specimen or the illuminated area when testing horizontal coating materials. When an objective lens is used, it shall be capable of focusing at the test distance. Angular apertures for the photoreceptor are specified in degrees subtended at the specimen. The responsivity across the aperture shall be uniform.

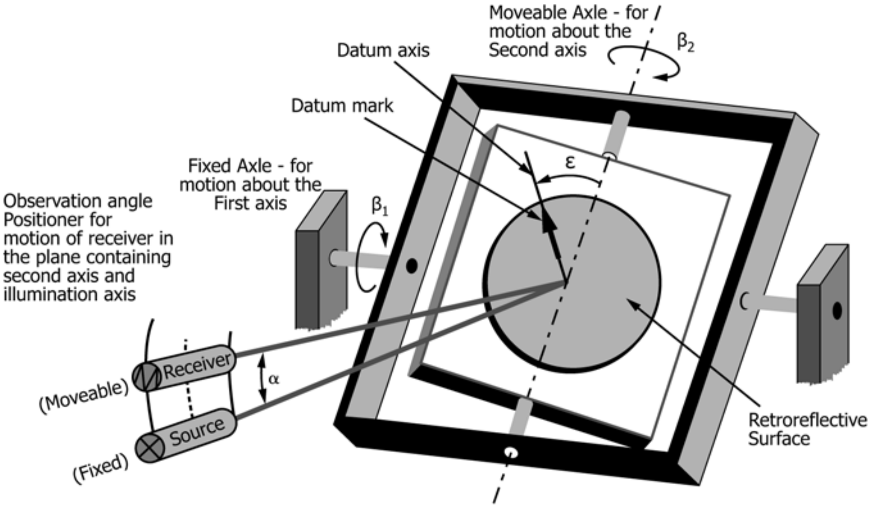

FIG. 2 View of Test Geometer for Measuring Retroreflection

TABLE 1 Optical Element Angular Apertures[A]

Standard apertures	0.05°	0.–1°	0.167°	0.333°
Angular aperture of an individual retroreflective element, °	0.01° max	0.02° max	0.04° max	0.08° max

[A] Optical element angular aperture maximum requirements apply to all noncollimating instruments.

8.3 *Light Projector Source*—The light source shall be a projector type capable of uniformly illuminating the specimen with appropriate reflector and lenses to provide illumination on the test sample with a spectral power distribution conforming to the 1931 CIE Standard Illuminant Source A (a tungsten filament lamp operated at a correlated color temperature of 2856°K ± 20K, see Practice E308). The normal illuminance on the sample shall be uniform within 5 % of the average normal illuminance over the area of the retroreflector at the test distance. The light projector shall be equipped with an adjustable iris diaphragm or a selection of fixed apertures. The intensity of light shall be regulated and shall not vary more than 1 % for the duration of the test.

8.3.1 The current of the projection lamp must be adjusted to provide a correlated color temperature of 2856°K. An adjustment procedure is described in Annex A3. Such adjustment often requires lowering the power from the nominal value since many projector lamps are designed to operate at correlated color temperatures greater than 2856°K.

8.3.2 The size and shape of the projector exit aperture and the angle this aperture subtends at the test specimen must be specified. The radiance across the aperture shall be uniform.

8.4 *Specimen Goniometer* (Test Specimen Holder)—This goniometer shall be capable of movements in three axes and sufficiently large to support the test specimen in the prescribed geometric arrangement. The motions of the axis shall be in accordance with Practice E808. For most materials, the tolerance of setting the angles β_1 and β_2 should be less than 0.1°. The rotation angle ε tolerance should be less than ±0.2°. The setting tolerance refers to the goniometer mechanism alone. The goniometer must be set in accordance with 11.1.4.

8.5 *Observer Goniometer*—This goniometer is used to accurately set the separation of the projector (light source) and photoreceptor. This setting determines the observation angle. This is sometimes referred to as an observation angle positioner (OAP). The positioning tolerance of the photoreceptor with respect to the light source should be held to 1 % of the angular aperture of the photoreceptor. For example, at 10m, a standard aperture of 0.1° would be equal to ±0.001° or 0.17 mm separation.

8.6 *Photometric Range*—The photometric range provides the dark work area for testing retroreflectors. To minimize the effect of stray light, the background behind the test specimen shall be flat black. Light baffles shall be located, as necessary, between the projector and the test specimen. Goniometer parts, exposed range walls, ceiling, and floor not baffled and exposed to the light beam shall be painted flat black.

9. Selection of Photometric Range Parameters

9.1 *Selection of Angular Apertures:*

9.1.1 *Standard Circular Apertures*—The following uniform circular apertures are considered standard.

9.1.1.1 0.05° (3 arc min) for both light source and photoreceptor.

9.1.1.2 0.1° (6 arc min) for both light source and photoreceptor.

9.1.1.3 0.167° (10 arc min) for both light source and photoreceptor.

9.1.1.4 0.333° (20 arc min) for both light source and photoreceptor.

9.1.1.5 For all standard circular apertures, the tolerances are ±8 %.

9.1.2 *Discussion*—With standard circular aperture, the defined observation angle is based on the center to center separation of the apertures.

9.1.3 Commonly used standard circular apertures are:

9.1.3.1 0.05° (3 arc min) for observation angles of 0.1°.

9.1.3.2 0.1° (6 arc min) for observation angles from 0.2° to 0.5°.

9.1.3.3 0.167° (10 arc min) for 0.33° spectral measurements.

9.1.3.4 0.333° (20 arc min) for 1.0° observation angles and larger.

9.1.4 In theory, retroreflection is defined with apertures that are infinitely small. Measurements using the standard angular apertures in 9.1.1 will not always be equal to measurements using much smaller apertures. The standard apertures give sufficient sensitivity for practical measurement and ensure reproducibility between laboratories providing the same standard aperture pairs are used.

9.2 *Selection of Observation Distance*—The observation distance and illumination distance must be specified in testing retroreflectors. They are limited by angular aperture requirements, the requirement to test a minimum sample area, for example 0.01 m^2 in the case of retroreflective sheeting or the desire to test an entire retroreflector at once. The observation distance and the illumination distance should not differ by more than 20 mm (for a 15 meter illumination distance) so as to not introduce errors in the observation angle over the test specimen. The tolerance on the setting of the observation and illumination distances should be ±0.05 %.

10. Test Specimen

10.1 The test specimen shall consist of one entire retroreflector. A large retroreflector may be tested by summing the values obtained from segments of the device.

10.2 When testing retroreflective sheeting, it is recommended that the test area be between 0.01 and 0.1 m^2. This may be accomplished, for example, by selecting a single square test specimen 0.2 m on each side or by averaging the measurements over several representative pieces totaling between 0.01 and 0.1 m^2 in area.

11. Calibration

11.1 The following components required in this practice must be calibrated prior to use.

11.1.1 *Projector Source*—The source must be calibrated to a correlated color temperature of 2856°K ± 20K and closely duplicate the spectral power distribution of CIE Standard Illuminant Source A. A method of calibration is described in Annex A3 based on tristimulus colorimetry. Spectroradiometric methods of calibration are also suitable.

11.1.2 *Photoreceptor Spectral Responsivity*—The photoreceptor spectral responsivity must be verified in terms of the spectral power distributions measured in this practice. A procedure for verification of spectral responsivity is described in Annex A1. Errors in the photopic fit of the receptor are direct systematic errors in the test result. Determination of the error f_1' should be followed from CIE Publication 69. The f_1' should be no greater than 3 %.

11.1.3 *Photoreceptor Linearity*—The procedures in this practice require the measurement of both incident and reflected light levels which may be several orders of magnitude different in value. To ensure accuracy, the photoreceptor and readout system must be linear or appropriate corrections for nonlinearity must be applied. Annex A2 describes a method for verification of photoreceptor linearity.

11.1.4 *Goniometer Calibration*—The goniometer shall be calibrated at the 0° entrance angle position. All measurements shall be made relative to this point and shall be checked each time the goniometer or light projector is moved. If measurements are to be made at extreme angles of 75° to near 90°, it is recommended that the goniometer be calibrated in the same 75° to 90° range of entrance angle for greatest accuracy.

11.1.4.1 Calibration of the goniometer at the 0° entrance angle position may be accomplished by several means. One example is by substituting an approximately 200 mm (8 in.) square high quality plane mirror in place of the sample. A 200 mm cross, centered on the surface of the mirror can be made with photographic black tape. A 400 mm square piece of white construction paper, with a small (5 mm) hole in the center, can be centered over the light projector exit aperture. By observing the white paper, the goniometer can be adjusted so that the shadow of the cross is reflected directly on the exit aperture of the projector. This position of the goniometer is the 0° entrance angle.

12. Test Procedure

12.1 The geometry used to determine the photometric performance of retroreflectors shall be in accordance with Practice E808. There are several methods that can be used in determining this performance. These are the ratio method, the substitution method, the direct luminous intensity method, and the direct luminance method.

12.2 *The Ratio Method*—In this method, use the same instrument with the same apertures and field of acceptance to measure the reflected illuminance (E_r) and the normal illuminance ($E_\perp$). Therefore, the photoreceptor need not be calibrated, and the uncalibrated meter readings of E_r and $E_\perp$ are referred to as m_1 and m_2, respectively. Do not use different instruments to measure E_r and $E_\perp$.

12.3 *Procedure A*—Ratio Method.

12.3.1 *General*—Select the smallest available field aperture large enough to include both the entire retroreflector as seen from the photoreceptor, and the source as viewed from the retroreflector, for measurement of M_1 and m_2. Measure the normal illuminance at the face of the sample by substituting the photoreceptor for the sample. Place the photoreceptor entrance aperture where the test specimen is mounted and record m_2. (Alternatively the light source may be substituted for the test specimen at the test distance and the incident normal illuminance can then be measured without moving the photoreceptor.) Then, return the photoreceptor and the test specimen to their original positions, and record m_1 in the same units as m_2.

12.3.2 Measure the amount of stray light by replacing the test specimen with a black surface of the same shape and area at angles such that the gloss does not affect the reading. A high gloss black surface is preferred. In some cases a flat black with reflectance less than 4 % could be used. Subtract the stray light readings, m_0 from the reading m_1. The value m_1' in the following equations is the value of m_1 less the stray light reading m_b.

12.3.3 Unless the photoreceptor has a repeatability of ±0.3 % between power-on cycles, it is recommended that the photoreceptor remain energized between measurement of m_2 and m_1'.

12.3.4 If the photoreceptor is deficient in its correction to the CIE photopic standard observer, a color correction factor must be applied (see Annex A1). This correction factor K is applied by means of a filter having a spectral transmittance proportional to the spectral retroreflectance of the test specimen.

12.3.4.1 **Warning—**If close spectral matches in permanent filters are not available, it is recommended that the correction factor not be used. If the correction factor is used, it is determined by the following relation:

$$K = m_2 T / m_f$$

where:

K = correction factor,
m_2 = reading of the photoreceptor while measuring the normal illuminance at the position of the retroreflective test specimen (that is, an uncalibrated $E_\perp$),
m_f = reading of the photoreceptor placed at the same position as for the m_2 reading, but with the addition of the color filter placed immediately in front of the acceptance aperture, and
T = known (total) luminance transmittance of the filter for a 2856°K source (CIE Source A).

12.4 *Procedure B*—Substitution Method. Substitution relies on the use of retroreflectors with assigned measurement values, either calibrated reference standards, or retroreflectors with measurement values calibrated by one of the other methods. This method is a comparison procedure that is particularly useful when a large number of performance measurements on similar test specimens are to be made. When used it is critical that the working standard be similar in size, color, and performance value to the unknown. It allows the use of optical means to shorten the photometric test distance within the limitations stated.

12.4.1 *General*—To use this procedure first determine the performance value of the working standard in accordance with Procedure A or use a calibrated reference standard. Next determine the photometric performance of the test specimen by placing the working standard or reference standard on the goniometer and take the m_1 (std) reading, then replace the standard with the test specimen and take reading m_1 (test). Then proceed with the calculations as in 13.2 for Procedure B.

12.4.2 *Optical Limitations*—In this procedure frequently collimating optics are used with the source and receptor at the focal distance from the optical element. This effectively reduces the required test distance while maintaining equivalent angular apertures. The collimating optical system also allows the test specimen and working standard to be separated by a small distance from the collimating optics that has been found convenient for multiple measurements.

12.4.3 *Angular Limitations*—Under Procedure B optical means such as high quality mirrors or lenses may be used. Under these conditions the angular subtense of the illumination source and receptor using optical means to shorten the photometric range must conform to the values given in 9.1.1. When the optical distance is shortened without collimating optics, particular attention must be given to the maximum angular aperture limitation of the individual optical element, which can be quite large in some cube corner retroreflector elements (see Fig. 1). With collimating optics the individual optical element is at infinity and the element aperture size is not critical.

12.4.4 *Spectral Limitations*—Since the working standard must be similar or, preferably, virtually the same color as the test specimen, the system spectral requirements are not as critical. Periodic recalibration of the working standard is required to compensate for aging.

12.5 *Procedure C—Direct Luminous Intensity Method*—In this method the illuminance at the retroreflector is measured by a separate illuminance meter, the calibration of which must be known. The luminous intensity of the retroreflector is determined by placing a calibrated reference lamp of known luminance intensity at the position of the retroreflector to calibrate the scale of the photoreceptor. The overall uncertainty of the method is limited by the combined errors in the calibration of both the illuminance meter, the reference lamp and the photoreceptor. The errors can be minimized by using the reference lamp to calibrate both the illumination meter and the photoreceptor.

12.6 *Procedure D—Direct Luminance Method*—In this method the illuminance is measured as in 12.5 with an illuminance meter and the luminance meter is used to measure the luminance of the specimen directly. This method is used widely in measuring horizontal coating materials. The field of measurement (collection) must lie entirely within the specimen area when the specimen is completely illuminated.

13. Calculation

13.1 *Procedure A:*

13.1.1 Coefficient of Luminous Intensity:

$$R_I = m_1'd^2/m_2$$

13.1.2 Coefficient of Retroreflected Luminance (Specific Luminance):

$$R_L = m_1'd^2/m_2 A\cos\nu$$

13.1.3 Coefficient of Retroreflection:

$$R_A = m_1'd^2/m_2 A$$

13.1.4 Coefficient of Line Retroreflection:

$$R_M = m_1'd^2/m_2 l$$

13.1.5 Reflectance Factor:

$$R_F = (\pi)m_1'd^2/m_2 A\cos\beta\cos\nu$$

13.1.6 Coefficient of Luminous Flux per Unit Solid Angle:

$$R\Phi = m_1'd^2/m_2 A\cos\beta$$

where:

d = observation distance, in meters,
A = area of test specimen in square meters,
l = length of line meters,
ν = viewing angle,
β = entrance angle,
m_1' = meter reading (minus stray light) used to measure reflected illuminance at observation position, relative units, and
m_2 = meter reading used to measure normal illuminance, relative units.

13.2 *Procedure B:*

13.2.1 Coefficient of Luminous Intensity:

$$R_I = [m_1'(\text{test})/m_1'(\text{std})] \times R_I(\text{std})$$

13.2.2 Coefficient of Retroreflected Luminance (Specific Luminance):

$$R_L = [A(\text{std})m_1'(\text{test})/A(\text{test})m_1'(\text{std})] \times R_L(\text{std})$$

13.2.3 Coefficient of Retroreflection:

$$R_A = [A(\text{std})m_1'(\text{test})/A(\text{test})m_1'(\text{std})] \times R_A(\text{std})$$

13.2.4 Coefficient of Retroreflection:

$$R_M = [l(\text{std})m_1'(\text{test})/l(\text{test})m_1'(\text{std})] \times R_M(\text{std})$$

13.2.5 Reflectance Factor:

$$R_F = [A(\text{std})m_1'(\text{test})/A(\text{test})m_1'(\text{std})] \times R_F(\text{std})$$

13.2.6 Coefficient of Luminous Flux per Unit Solid Angle:

$$R_\Phi = [A\ (\text{std})m_1'(\text{test})/A\ (\text{test})m_1'(\text{std})] \times R(\text{std})$$

where:

m_1'(std) = photoreceptor reading (uncalibrated) from the working standard, measured in accordance with Procedure A,
m_1'(test) = illuminance (uncalibrated) of the test specimen at the photoreceptor aperture, measured in accordance with Procedure A,
R_I(std) = coefficient of luminance intensity determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_A(std) = coefficient of retroreflection determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_M(std) = coefficient of line retroreflection determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,

R_L(std) = coefficient of retroreflected luminance determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
R_F(std) = reflectance factor determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard
R (std) = coefficient of luminous flux per unit solid angle determined by Procedure A (relative to a fixed set of test conditions) and assigned to the working standard,
A(std) = retroreflective area of working standard,
A(test) = retroreflective area of the test specimen,
1(std) = length of working standard, and
1(test) = length of test specimen.

13.3 *Procedure C:*

13.3.1 Coefficient of Luminous Intensity:

$$R_I = I/E_1$$

13.3.2 Coefficient of Retroreflection:

$$R_A = I/AE_I$$

13.3.3 Coefficient of Retroreflected Luminance:

$$R_L = I/AE_1 cosv$$

where:

I = luminous intensity in candelas of the test specimen measured at the position of the photoreceptor.
E = illuminance of the light source measured perpendicular to the principle ray from the source at the position of the test specimen.
A = area of the test specimen
v = viewing angle ($\cos v = (\beta_1 - \alpha)\cos\beta_2$).

13.4 *Procedure D:*

13.4.1 Coefficient of Retroreflected Luminance:

$$R_L = L/E_I$$

NOTE 1—The coefficient of retroreflected luminance may also be determined using the same luminance meter by the following equation:

$$R_L = \beta L/\pi L_S$$

where:

L_S = luminance of the uniform perfect diffuse reflector at 45° viewing angle of β luminance factor illuminated perpendicularly by the light source.

14. Report

14.1 The report shall indicate the value of the photometric quantity determined, the procedure used (A, B, C, or D), and all of the measurement requirements stated in Section 7 of this practice.

15. Precision and Bias

15.1 The precision and bias of this practice will vary with the materials tested and the test geometry and, therefore, a specific statement is not included. In general, however, under some test geometries (0.2° observation and −4° entrance angle) agreement between laboratories in the order of 5 to 10 % (standard deviation) has been reported (**1**).[4]

16. Keywords

16.1 photometric characteristics; photometric measurements; photometric range; retroreflective; retroreflection; retroreflectors

ANNEXES

(Mandatory Information)

A1. METHOD FOR VERIFYING PHOTOPIC RESPONSIVITY

A1.1 Scope

A1.1.1 This method covers a procedure for verifying the adequacy of the spectral response of the photoreceptor used in the photometry of retroreflectors. (Reference CIE Pub. 69.)

A1.1.2 This procedure is required when a new photoreceptor is put into service or when the suitability of an established photoreceptor for a specific color measurement is in question.

A1.1.3 Adequate color correction for one product does not necessarily imply adequate correction for other products. Color correction for whites and greens is much easier to obtain than for deep blues and highly saturated reds.

A1.2 Significance and Use

A1.2.1 A method of determining the adequacy of the photopic match of the photoreceptor and the possible need for correction is to compare the photoreceptor responsivity to the retroreflected spectral curve. The spectroradiometric test in A1.3 provides an outline of this method. In many cases where facilities to actually make these spectroradiometric measurements are unavailable, the spectral responsivity and spectral reflectance factors can be obtained directly from the manufacturer of the photoreceptor and the manufacturer of the retroreflector.

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[4] The boldface numbers in parentheses refer to the list of references at the end of this practice.

A1.2.2 In the past the use of the color correction factor *K* generated by using a colored filter with spectral transmittance matching the retroreflected spectrum was considered acceptable as a method of compensating for errors in the spectral responsivity of the photoreceptor. At present this use is deprecated.

A1.3 Spectroradiometric Procedure

A1.3.1 *Determination of Spectral Responsivity:*

A1.3.1.1 Set up a regulated tungsten light source, a monochromator for the visible spectrum with 10-nm bandwidth and provision to ensure that stray light and second order spectra are reduced to negligible levels.

A1.3.1.2 Using either a thermopile reference receiver with a flat responsivity with respect to wavelength or a calibrated silicon detector, calibrate the monochromator and source through the visible spectrum at 10 nm intervals and as far into the ultraviolet and infrared as necessary to cover the photoreceptor responsivity.

A1.3.1.3 Now replace the calibrated reference receivers with the photoreceptor to be used in the testing of the retroreflector. Measure and compute the responsivity of the photoreceptor at 10-nm intervals.

A1.3.1.4 Taking the response of the thermopile equal to 100 at each wavelength, tabulate the relative responsivity of the photoreceptor at 10-nm intervals.

A1.3.1.5 Normalize the response of the photoreceptor at each wavelength so that the summation $[\sum]s(\lambda) = [\sum]V(\lambda)$, where $V(\lambda)$ is the CIE standard luminosity function (obtainable from Practice E308) label this $s^*(\lambda)$. Compute the error f'_1 using the following equation:

$$f_1' = \frac{\int_0^\infty |s^*(\lambda)_{rel} - V(\lambda)|\,d\lambda}{\int_0^\infty V(\lambda)\,d\lambda}$$

The integral may be replaced by the sum ($\sum$) with the interval $\Delta = 10$ nm and the wavelength range from 380-780 nm.

A2. METHOD FOR DETERMINING PHOTORECEPTOR LINEARITY

A2.1 Scope

A2.1.1 This method covers the determination of photoreceptor linearity corrections for use in the photometry of retroreflectors.

A2.1.2 This procedure is required when a new photoreceptor is put into service or when the suitability of an established photoreceptor is in question.

A2.2 Apparatus

A2.2.1 *Projectors,* two, for use as sources of illumination.

A2.2.2 *Adjustable Irises and Holders,* two.

A2.2.3 *Shutters and Holders,* two.

A2.2.4 *Enclosure or Photometric Range,* large enough so that photoreceptor can be illuminated approximately perpendicularly from both light sources.

A2.3 Procedure

A2.3.1 Set up the two light sources, irises, shutters and photoreceptor/readout system to be calibrated as shown in Fig. A2.1. The light sources should be arranged such that the illumination from each source is perpendicular (±1°) to the entrance aperture of the photoreceptor. The light sources must be stabilized and their voltages or currents monitored.

A2.3.2 Determine the lowest reading attainable on the photoreceptor/readout device (for example 0.000001 units). This will be the starting illumination level for the test.

A2.3.3 With both shutters closed, set the photoreceptor/readout device to read zero.

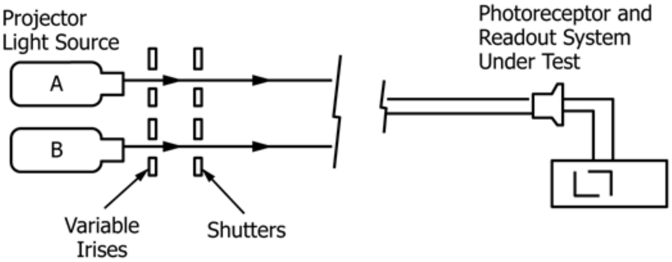


FIG. A2.1 Arrangement of Apparatus for Two Source Linearity Test

A2.3.4 Open the shutter on Source A and adjust the iris for the starting reading determined in A2.3.2. Close the shutter on Source A and open the shutter on Source B and adjust the iris for the same reading. Record these readings in Columns 1 and 2 of the data sheet in Fig. A2.2.

A2.3.4.1 Switch back and forth between the two sources and the zero readings to be sure irises and zero are accurately set.

A2.3.5 Now open shutters simultaneously. Record the reading in Column 3 of the data sheet.

A2.3.6 Next, independently adjust each projector to combined reading obtained in A2.3.5. Record the individual readings in Columns 1 and 2 on the next line of the data sheet.

A2.3.7 Repeat A2.3.5 for the new illumination levels set in A2.3.6 and record the total in Column 3 of the data sheet.

A2.3.8 Repeat A2.3.4 through A2.3.6 until the maximum illumination levels available for the two light sources is reached.

1 Reading Source A Only	2 Reading Source B Only	3 Reading Source A + B Together	4 Calculated Sum A + B	5 Ratio 3 ÷ 4	6 Cumulative Ratio	7 Normalized Cell Linearity Correction
–	–	–	–	–	1.00	–

FIG. A2.2 Data Sheet for Photoreceptor Linearity Test

A2.3.9 Starting with a new data sheet, repeat A2.3.2 – A2.3.8 except use starting illuminations of 1.2, 1.5, 1.6 and 1.8 times the lowest illumination detectable with the photoreceptor/readout system.

A2.4 Calculation

A2.4.1 Add each reading in Column 1 to the reading in Column 2 to determine the results expected if the system is linear. Enter this mathematical sum in Column 4.

A2.4.2 Determine the ratio of the theoretical result to the actual result by dividing the individual readings in Column 3 by the readings on Column 4 and enter in Column 5.

A2.4.3 Determine the cumulative nonlinearity by multiplying the proportion in Column 5 times the previous cumulative result in Column 6 and enter in Column 6.

A2.4.4 Repeat the above calculations for all data points taken.

A2.4.5 Now interpolate between the reading in Column 3 and Column 6 to determine the correction factor for a readout response in the middle of the range (for example 0.001 units) to use as a reference point. Divide all the values in Column 6 by this result and enter in Column 7.

A2.4.6 The result in Column 7 is the normalized correction factor computed about the midrange reference point (for example, 0.001 units).

A2.4.6.1 The correction factors are normalized in this way so that all will be on the same basis for averaging below.

A2.4.7 Repeat the calculations in A2.4.1 – A2.4.6 for remaining data sheets.

A2.4.8 Finally, determine the correction factors at log equal spacing throughout the range of calibration by interpolation.

A2.4.9 Average these factors to determine the best linearity correction curve.

A2.4.10 These final values may be used to plot a linearity correction curve on semilog paper for manual correction or entered into a computer program for automatic correction of photometric test data for linearity.

A2.4.11 Linearity correction of data taken in the photometric test of a retroreflector is then obtained by dividing the "as read" value from the readout device by the correction factor obtained from the linearity correction curve just plotted.

A2.5 Measuring Linearity by Means of the Light Addition Method

A2.5.1 The linearity of the detector and electronics is measured using the light addition method. Two 45 triangular pieces of retroreflective sheeting with a 30.5 cm base and 30.5 cm height as shown in the Fig. A2.3 are illuminated at the specimen carrier. A rotating semicircular baffle covered with black cloth can block either triangle A or B or both at the same time. A measurement sequence is automatically done:
A+B. A,D,B,D,A,A+B,A,D,B,D,A,A+B,A,D,B,D,A,A+B.

where:

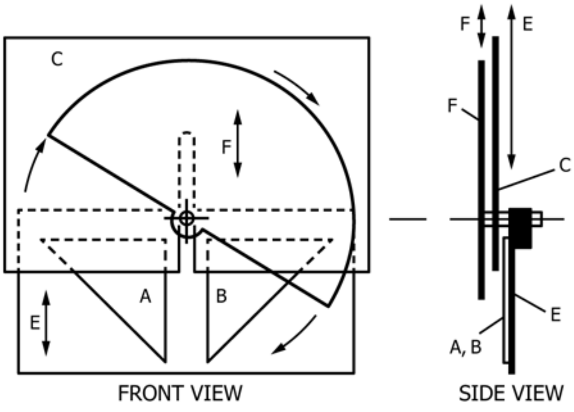
$A+B$ = signal with both triangles illuminated.
A = signal with B masked by the black cloth.
D = signal with A and B both masked.

The average of each type of reading is taken. Signals A,B and A+B must be corrected by subtracting the contribution due to reflection from the black cloth. This contribution to signal A is calculated by multiplying signal D by the ratio of black area exposed during reading A to the black area exposed during reading D:

$$D_{A=}D\cdot\left(\frac{a-a_a}{a}\right)$$

where:

a = total black area during reading D.
aa = area to triangle A.



NOTE 1—F = rotating nonreflecting semicircle; E = plate on which the two triangular retroreflectors A and B are mounted; and C = nonreflecting plate.

FIG. A2.3 Apparatus for Measuring Detector Linearity

The corrected value A' is then derived from:

$$A' = A - D_A = A - D\cdot\left(\frac{a - a_a}{a}\right)$$

and similarly for B and A+B. We may then define the fractional nonlinearity σ at the signal level (A' +B')⁄2 as

$$\sigma\left(\frac{A'+B'}{2}\right) = \frac{(A+B)'}{A'+B'} - 1$$

The exposed area of the triangles is then reduced by automatically raising them behind a black velvet cloth screen such that the signal (A+B) is reduced by a factor of 2. (It is not critical that it be exactly two.) The measurement sequence stated above is repeated, and a new value of σ is calculated that gives the nonlinearity at approximately one-fourth of the original signal. The process of stepping down is repeated until the signal is smaller than that which will be obtained from the test retroreflector. The nonlinearity ΔS at arbitrary signal S will be $\Delta S = \sigma(S)\ S$. The correction ΔS never exceeds 30 parts in 30,000 at the upper end of the scale. Over the dynamic range nominally used, the noise and nonlinearity area are indistinguishable. Thus, it is convenient to express linearity and noise together. This test need not be automated and may be done manually. It is also not necessary that the retroreflecting material be triangular although this simplifies obtaining small signal levels. Secondly, it is not necessary to use sheeting; it should be possible to use prismatic retroreflectors. Generally, the two retroreflectors used should give a signal larger than that obtained in the course of a measurement. This large signal is obtained when measuring the normal illuminance of the source. Many commonly used detectors have been shown to have a non-linearity which is wavelength independent, and it may be possible to make these measurements without the photopic correction filter. If black cloth is used to partially block the light, it is good practice to use an opaque backing since the retroreflector may reflect light back through the pores of the black cloth.

A3. METHOD FOR DETERMINING CORRELATED COLOR TEMPERATURE

A3.1 Scope

A3.1.1 This method covers the determination of correlated color temperature of a projector source of illumination using a tristimulus photoreceptor and standard reference lamp for use in the photometry of retroreflectors.

A3.1.2 This method is required when setting up a new light source or when the correlated color temperature of a source in use is in question.

A3.2 Apparatus

A3.2.1 *Standard Reference Lamp and Holder,* with voltage and current specified for 2856°K.

A3.2.2 *Voltmeter* (accurate to 0.5 %) or ammeter (accurate to 0.25 %), as appropriate to voltages or currents specified for standard reference lamp.

A3.2.3 *Photoreceptor,* equipped with tristimulus filters (X_r, X_b, Y, and Z filters).

A3.2.4 *$BaSO_4$* or other neutral white diffusing surface.

A3.2.5 *Test Enclosure* or photometric range.

A3.3 Procedure

A3.3.1 Set up standard reference lamp, projector to be calibrated, white diffusing surface and tristimulus receptor in a darkroom as shown in Fig. A3.1.

A3.3.2 Adjust the position (distance between source and diffusing surface) of the standard lamp and projector so that the illumination of each individually on the white diffusing surface is about the same. Allow lamps to warm up until stable (usually about 30 min.).

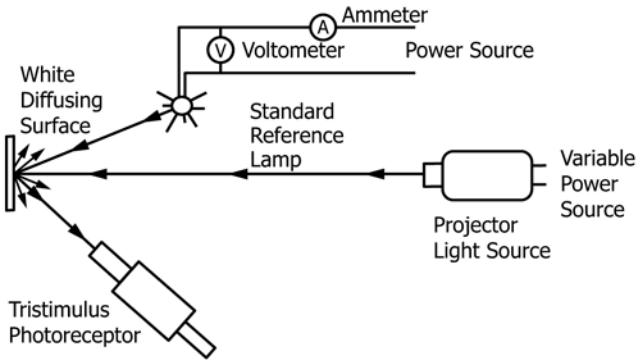


FIG. A3.1 Arrangement of Apparatus for Correlated Temperature Measurement of Projector

A3.3.3 Allow standard lamp only to illuminate the white diffusing surface. Carefully adjust the voltage or current as specified on calibration report for the standard reference lamp to obtain 2856°K.

A3.3.4 Measure the relative X_r, X_b, Y and Z tristimulus filter readings with the tristimulus photoreceptor.

A3.3.5 Turn off the standard lamp and turn on projector. Measure and record the X_r, X_b, Y and Z tristimulus values at several voltages bracketing the estimated correct setting for 2856°K (**2**, **3**).

A3.3.6 Calculate the CIE chromaticity coordinates for each voltage on the projector using the tristimulus readings of the standard lamp as a reference. That is, for 2856°K the correct tristimulus values are:

$$X_r = 104.47;\ X_b = 5.38;\ Y = 100;\ \text{and}\ Z = 35.58.$$

Thus, each of the “as read” values on the projector must be corrected to the reference standard as follows:

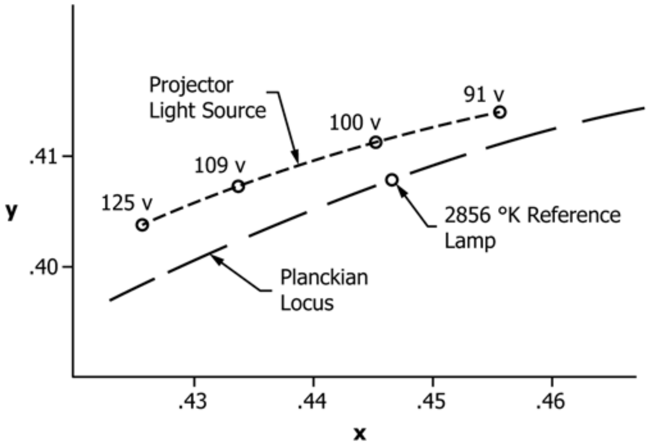


FIG. A3.2 Chromaticity Plot of Projector Light Source Relative to 2856°K Reference Lamp. In this example, 100 V would be the proper voltage at which to operate the projector source.

$$
\begin{aligned}
X_r\text{(corrected)} &= X_r \text{ (as read) } [104.47/X \text{ (as read std lamp)}]\\
X_b\text{(corrected)} &= X_b \text{ (as read) } [5.38/X \text{ (as read std lamp)}]\\
Y \text{ (corrected)} &= Y\text{(as read) } [100/Y\text{(as read std lamp)}]\\
Z \text{ (corrected)} &= Z\text{(as read) } [35.58/Z \text{ (as read std lamp)}]
\end{aligned}
$$

A3.3.7 Then the small x small y chromaticity coordinates are calculated as follows:

$$
\begin{aligned}
x &= (X_r + X_b)/X_r + X_b + Y + Z)\\
y &= Y/X_r + X_b + \mathrm{Y} + \mathrm{Z}
\end{aligned}
$$

A3.3.8 Finally, the chromaticity coordinates are plotted on graph paper **(4)** and the nearest point to 2856°K is selected as the best voltage to operate the projector for CIE Source A (see Fig. A3.2).

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(4) Kelly, K. L., "Lines of Constant Correlated Color Temperature Bases on MacAdam's (u, v) Uniform Chromaticity Transformation of the CIE Diagram," *Journal of the Optical Society of America*, Vol. 53, 1963, pp. 999–1002.

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