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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for
Specifying the Geometry of Observations and Measurements to Characterize the Appearance of Materials[1]

This standard is issued under the fixed designation E 1767; 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.

INTRODUCTION

The appearance of objects depends on how they are illuminated and viewed. When measurements are made to characterize appearance attributes such as color or gloss, the measured values depend on the geometry of the illumination and the instrumentation receiving light from the specimen. This practice for specifying the geometry in such applications is largely based on an international standard ISO 5/1, dealing with the precise measurement of optical density in photographic science, based on an earlier American National Standard, which was based on a publication by McCamy.[2]

1. Scope

1.1 This practice covers the geometry of illuminating and viewing specimens and the corresponding geometry of optical measurements to characterize the appearance of materials. It establishes terms, symbols, a coordinate system, and functional notation to describe the geometric orientation of a specimen, the geometry of the illumination (or optical irradiation) of a specimen, and the geometry of collection of flux reflected or transmitted by the specimen, by a measurement standard, or by the open sampling aperture.

1.2 Optical measurements to characterize the appearance of retroreflective materials are of such a special nature that they are treated in other ASTM standards and are excluded from the scope of this practice.

1.3 The measurement of transmitted or reflected light from areas less than 0.5 mm in diameter may be affected by optical coherence, so measurements on such small areas are excluded from consideration in this practice, although the basic concepts described in this practice have been adopted in that field of measurement.

1.4 The specification of a method of measuring the reflecting or transmitting properties of specimens, for the purpose of characterizing appearance, is incomplete without a full description of the spectral nature of the system, but spectral conditions are not within the scope of this practice. The use of functional notation to specify spectral conditions is described in ISO 5/1.

2. Referenced Documents

2.1 *ASTM Standards:*

E 284 Terminology of Appearance[3]

2.2 *Other Standard:*

ISO 5/1 Photography—Density Measurements—Part 1: Terms, Symbols and Notations[4]

3. Terminology

3.1 *Definitions:*

3.1.1 The terminology used in this practice is in accordance with Terminology E 284.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *anormal angle*, *n*—an angle measured from the normal, toward the reference plane, to the central axis of a distribution, which may be a distribution of flux in an incident beam or an angular distribution of sensitivity of a receiver.

3.2.2 *aspecular angle*, *n*—the angle subtended at the origin by the specular axis and the axis of the receiver, the positive direction being from the specular axis toward the normal.

3.2.3 *aspecular azimuthal angle*, *n*—the angle subtended, at the specular axis in a plane normal to the specular axis, by the projection of the axis of the receiver and the projection of the *x*-axis on that plane, measured from the projection of the *x*-axis in a right-handed sense with respect to the specular axis.

3.2.4 *efflux*, *n*—radiant flux reflected by a specimen or reflection standard, in the case of reflection observations or measurements, or transmitted by a specimen or open sampling aperture, in the case of transmission observations or measurements, and sensed by the receiver.

3.2.5 *efflux*, *adj*—associated with the radiant flux reflected by a specimen or reflection standard, in the case of reflection observations or measurements, or transmitted by a specimen or open sampling aperture, in the case of transmission observations or measurements, and sensed by the receiver.

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[1] This practice is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.03 on Geometry.

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[2] McCamy, C. S., "Concepts, Terminology, and Notation for Optical Modulation", *Photographic Science and Engineering*, Vol 10, 1966, pp. 314–325.

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

[4] Available from American National Standards Institute, 13th Floor, 11 W. 42nd St., New York, NY 10036.

3.2.6 *efflux sampling aperture*, *n*—the region on the reference plane from which flux is sensed by the receiver.

3.2.7 *influx*, *n*—radiant flux directed toward a specimen, a reflection standard, or open sampling aperture.

3.2.8 *influx*, *adj*—associated with radiant flux directed toward a specimen, a reflection standard, or open sampling aperture.

3.2.9 *influx sampling aperture*, *n*—the region on the reference plane within which flux is incident.

3.2.10 *optical modulation*, *n*—a ratio indicating the magnitude of the propagation by a specimen of radiant flux from a specified illuminator or irradiator to a specified receiver, a general term for reflectance, transmittance, reflectance factor, transmittance factor, or radiance factor.

3.2.11 *plane of incidence*, *n*—the plane containing the axis of the incident beam and the normal to the specimen.

3.2.11.1 *Discussion*—This plane is not defined if the axis of the incident beam is normal to the specimen.

3.2.12 *reference plane*, *n*—the plane in which the surface of the specimen is placed for observation or measurement.

3.2.13 *sampling aperture*, *n*—the limited area of the specimen selected for measurement, the smaller of the influx sampling aperture or the efflux sampling aperture.

3.2.14 *specular axis*, *n*—the ray resulting from specular reflection at an ideal plane mirror in the reference plane, of the ray at the axis of the incident beam.

3.2.14.1 *Discussion*—This term is applied to illuminators providing an incident beam of small angular subtense, not to diffuse or annular illuminators.

3.3 *Symbols:Symbols*:

o = the point of origin of a rectangular coordinate system, in the reference plane, at the center of the influx sampling aperture.
x = distance from the origin, measured along an axis, the x-axis, in the reference plane and passing through point o.
y = distance from the origin, measured along an axis, the y-axis, in the reference plane, passing through point o, and normal to the x-axis.
z = distance from the origin, measured on an axis, the z-axis, normal to the reference plane, passing through point o, and having its positive direction in the direction of the vector component of incident flux normal to the sampling aperture.
θ = anormal angle.
α = aspecular angle.
β = aspecular azimuthal angle.
η = azimuthal angle, measured in the reference plane, from the positive x-axis, in the direction of the positive y-axis.
κ = half angle of a cone.
i = subscript for incident.
r = subscript for reflected.
t = subscript for transmitted.
G = general symbol, in functional notation, for influx geometry.
g = general symbol, in functional notation, for efflux geometry.
m = subscript for half angle subtended by the entrance pupil of a test photometer.
n = subscript for half angle subtended by a test source.
M = optical modulation.

4. Summary of Practice

4.1 This practice provides a method of specifying the geometry of illuminating and viewing a material or the geometry of instrumentation for measuring an attribute of appearance. In general, for measured values to correlate well with appearance, the geometric conditions of measurement must simulate the conditions of viewing.

5. Significance and Use

5.1 This practice is for the use of manufacturers and users of equipment for visual appraisal or measurement of appearance, those writing standards related to such equipment, and others who wish to specify precisely conditions of viewing or measuring attributes of appearance. The use of this practice makes such specifications concise and unambiguous. The functional notation facilitates direct comparison of the geometric specifications of a viewing situation and a measuring instrument.

6. Coordinate System

6.1 The standard coordinate system is illustrated in Fig. 1. It is a left-handed rectangular coordinate system, following the usual optical convention of incident and transmitted flux in the positive direction and the usual convention for the orientation of x and y for the reflection case. The coordinates are related to a reference plane in which the first surface of the specimen is placed for observation or measurement. The origin is at the center of the area on the specimen being observed or measured. The influx and efflux sampling apertures are taken to be normal to and centered on the z axis.

6.2 Instruments are usually designed to minimize the variation of the product of illumination and receiver sensitivity, as a function of the azimuthal angle η. That practice minimizes the variation in modulation as the specimen is rotated in its own plane. Even in instruments with an integrating sphere, residual nonuniformity, known as "directionality", can cause variations in measurements of textured specimens. To minimize variation due to this effect, the "warp", "grain", or other" machine direction" of specimens must be consistently oriented with respect to the x-axis, which is directed according to the following rules, intended to place the positive x-axis in the azimuthal direction for which the product of illumination and receiver sensitivity is a minimum.

6.2.1 For an integrating-sphere instrument with diffuse illumination, the positive x-axis is directed from the center of the specular port (or the normal to the specimen) toward the center of the exit port.

6.2.2 For an integrating-sphere instrument with diffuse collection, the positive x-axis is directed from the center of the specular port (or the normal to the specimen) toward the center of the entrance port.

6.2.3 For an instrument with annular or circumferential

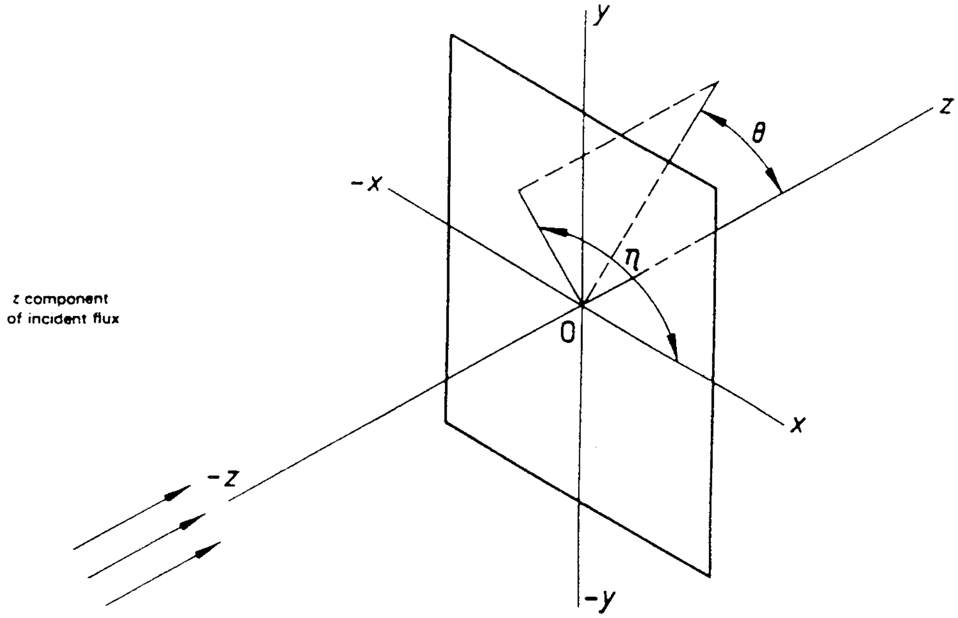


FIG. 1 Coordinate System for Describing the Geometric Factors Affecting Transmission and Reflection Measures

45°:0° or 0°:45° geometry, the positive x-axis is in the azimuthal direction for which the product of illumination and receiver sensitivity is a minimum.

6.2.4 For an instrument with directional illumination of small angular subtense, such as is used in the measurement of gloss or goniochromatism, the positive x-axis is directed opposite the azimuthal direction of the illuminator.

6.3 Anormal angles are specified with respect to rays passing through the origin. (In a later section of this standard, allowance is made for the size of the specimen by the tolerances on the influx and efflux angles.) The anormal angle of a ray is the angle θ between the ray and the z-axis. Anormal angles of incident and reflected rays are measured from the negative z-axis. Anormal angles of transmitted rays are measured from the positive z-axis.

6.4 The azimuthal angle of a ray is the angle η, measured in the reference plane from the positive x-axis in the direction of the positive y-axis, to the projection of the ray on the reference plane. The direction of a ray is given by θ and η, in that order. Angle η is less than 360° and θ is 180° or less, and usually less than 90°.

6.5 In goniophotometry and goniospectrophotometry, the efflux angle θ_r or θ_t may be measured from the normal, but for reflection measurements to characterize goniochromatism, it is often measured from the specular axis. The aspecular angle, α, is the angle subtended at the origin by the specular axis and the axis of the receiver. In most goniophotometric measurements, the axis of the receiver is in the same plane as the axis of the influx beam and the normal, the plane of incidence, and the aspecular angle is measured in that plane. The positive direction of α is from the specular axis toward the normal.

6.6 If the axis of the receiver is not in the plane of incidence, the direction of the axis may be described in terms of anormal and azimuthal angles, as defined in 6.5, but an aspecular azimuthal angleβ may be of interest. The aspecular azimuthal angle is a special kind of azimuthal angle, measured in a plane normal to the specular axis, with positive direction in the right-handed sense. (With the right thumb along the specular axis and directed away from the origin, the right hand fingers point in the positive direction of β.) See Fig. 2. The aspecular azimuthal angle is measured from the projection of the x-axis on the plane normal to the specular axis, to the projection of the axis of the receiver. As the angle of incidence approaches zero (near normal to the specimen), the aspecular azimuthal angle approaches the azimuthal angle. Aspecular angular excursions of the receiver may be completely described in terms of the components α and β. When α and β are used to define the direction of the receiver, α is always positive.

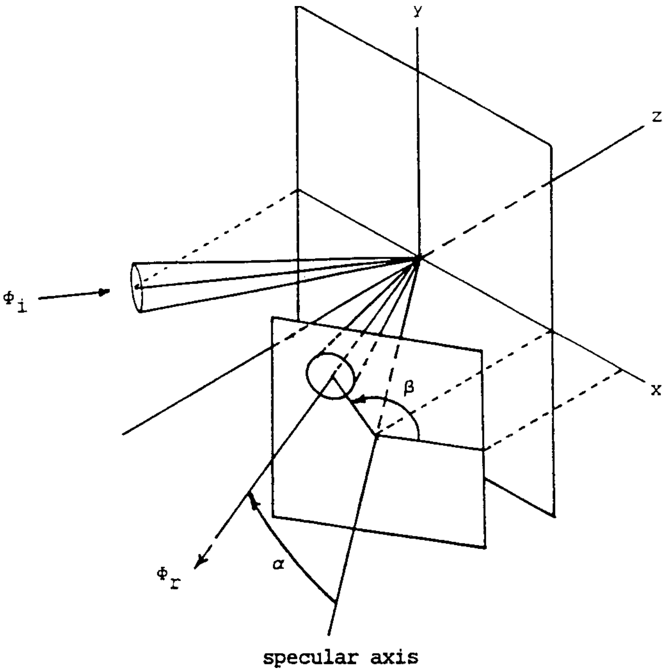


FIG. 2 Angles α and β Relative to the Specular Axis

6.7 Subscripts *i*, *r*, and *t* are used to identify fluxes or the angles describing them as incident, reflected, or transmitted, respectively.

6.8 If specimen thickness must be taken into account, efflux angles may be described relative to a secondary origin o' displaced in the positive *z* direction by the thickness h of the specimen. Then $x' = x$, $y' = y$, and $z' = z - h$.

7. Conical Description

7.1 Given this standard coordinate system, any distribution of the influx and efflux may be described, but the description may be very complicated. Fortunately, most such distributions in instruments used to measure appearance can be approximated by uniform pencils bounded by right circular cones. The eye, the receiver in the case of visual observation, may be described in this way. In such cases, the description can be relatively simple. For this purpose, the direction of the axis of the cone is given by θ and η and the half cone angle is given the symbol κ; the aperture angle (full cone angle) is 2κ. This method of description is illustrated in Fig. 3. Annular distributions, such as those often used in reflection measurements, can be described by the rays between two cones. In that case the numbers 1, for the smaller, and 2, for the larger, are added to the subscripts, as shown in Fig. 2.

8. Functional Notation

8.1 The description of the geometry can be greatly abbreviated by the use of mathematical functional notation. The symbolism *F(a)* means that the value of *F* is a function of, that is, depends on, the value of *a*. Most measurements of appearance are based on measurements of reflectance factor *R* or transmittance factor *T*. They are functions of the influx geometry *G* and the efflux geometry *g*. In functional notation, we simply write *R(G:g)* or *T(G:g)*, the colon separating influx and efflux parameters. Using the general concept of optical modulation, we may express either or both of these (or some combination) as *M(G:g)*. (In the complete form of this notation, given in the ISO standard cited, spectral conditions are specified by functional notation, with semicolons separating geometric from spectral parameters, but spectral parameters are not treated in this practice.)

8.2 Functional notation is used to indicate the nominal or ideal geometry, the geometric specification of the physical quantity intended to be observed or measured. Tolerances on the nominal specifications are not included in the functional notation. When the notation specifies that flux is incident within a given solid angle, the intent is that the distribution is uniform within that solid angle. Any nonuniformity is a matter of separate tolerancing. Ranges stated are not tolerances but are mandatory ranges of inclusion. The solid angle of receiver sensitivity is considered in a similar way.

8.3 Geometric parameters are given in the following order, separated by commas: κ, θ, η. Using the conical method of description, *G* may be specified by κ_i, θ_i, η_i and *g* may be specified, for the transmission case, by κ_t, θ_t, η_t and, for the reflection case, by κ_r, θ_r, η_r.

8.4 If the influx and efflux distributions are centered on the normal to the reference plane, $\theta = 0$ and η is indeterminate, so the distributions can be completely described by values of κ, unless the annulus is broken, in which case it is necessary to give values for η .

8.5 A hemispherical distribution, such as that obtained by an integrating sphere is regarded as a cone with a half angle of 90°, annotated by $\kappa = 90°$.

8.6 A combination of discrete cones can be annotated by the use of the plus sign, for example κ_1 to κ_2 + κ_3 to κ_4. Similarly a void in a region may be indicated by the use of the minus sign. Where two values of κ are used in functional notation for

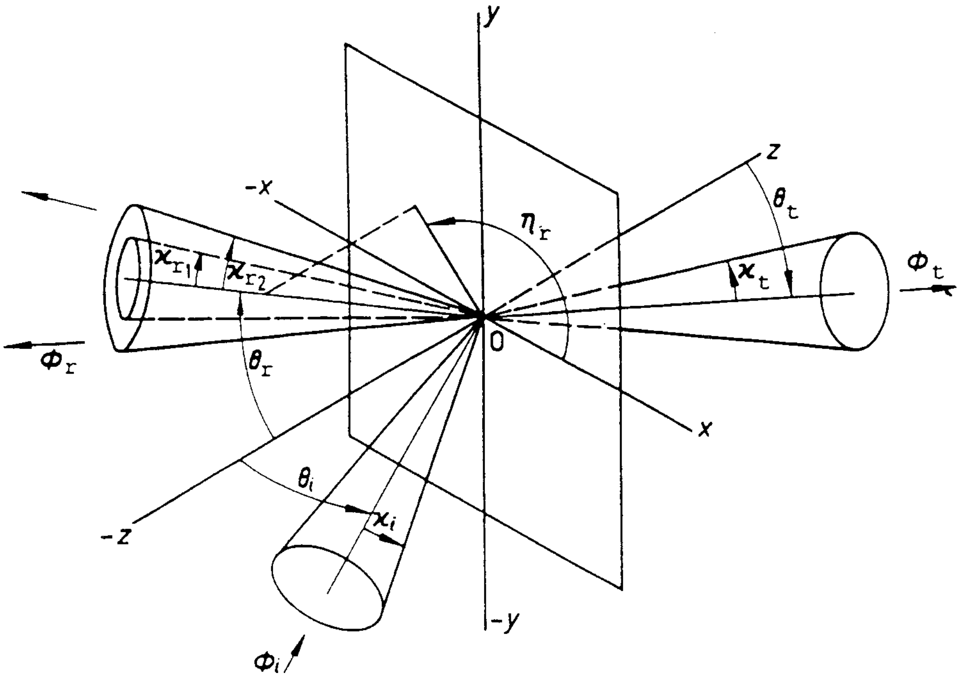


FIG. 3 Coordinate System and Angular Conventions for Describing Distributions in Terms of Cones

an annular distribution, they are separated by a minus sign, as in the notation *R* (50° − 40°:5°).

8.7 If aspecular angles are used to describe the efflux, α and β replace θ and η. If this usage is not clear from the context or not otherwise indicated, the numerical designations of these angles shall be underlined.

8.8 If a secondary coordinate system is used to accommodate a specimen of thickness *h*, the value of *h* is placed between colons. Thus for transmittance factor, the form would be *T(G:h:g)*.

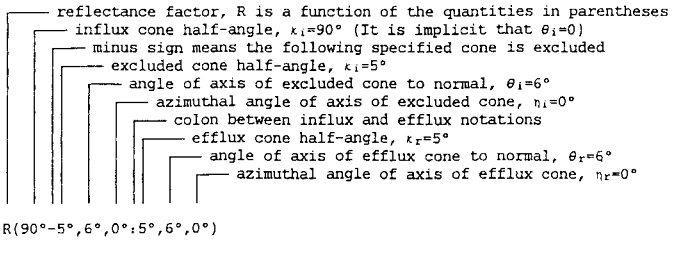
8.9 *Examples of Functional Notation*:

8.9.1 *Annular 45°:0° Reflection Geometry*—For the measurement of reflectance factor, let the specimen be illuminated from all azimuthal angles, at anormal angles between 40° and 50°. Let reflected flux be sensed by the receiver at all angles within 5° of the normal. The functional notation is *R* (50° − 40°:5°).

8.9.2 *Circumferential 45°:0° Reflection Geometry, Where the Annulus Is Not Filled at All Azimuthal Angles*—For the measurement of reflectance factor, let the specimen be illuminated at azimuth angles of 5° extent, located at 30° intervals around the annulus (circumference) at anormal angles between 40° and 50°. Let reflected flux be sensed by the receiver at all angles within 5° of the normal. The functional notation is *R* (50° − 40°, 0° to 5° + 30° to 35° + 60° to 65° + 90° to 95° + 120° to 125° + 150° to 155° + 180° to 185° + 210° to 215° + 240° to 245° + 270° to 275° + 300° to 305° + 330° to 335°:5°).

8.9.3 *Hemispherical Reflection Geometry, Diffuse Illumination with Specular Component Included*—For the measurement of reflectance factor, let the specimen be uniformly illuminated by a sphere, from all angles within a hemisphere, except for the direction of the exit port, and let the receiver collect flux through a circular exit port, centered on the positive *x*-axis at 6° from the normal and subtending a half angle of 5°. The functional notation is *R* (90° − 5°, 6°, 0°:5°, 6°, 0°). The components of this notation are indicated in Fig. 4.

8.9.4 *Hemispherical Geometry, Diffuse Illumination with Specular Component Excluded*—For the measurement of reflectance factor, let the specimen be uniformly illuminated by an integrating sphere, from all angles within a hemisphere, except for the direction of the exit port and the direction of the image of the exit port reflected in a specular specimen, and let the receiver collect flux through a circular exit port, centered on the positive *x*-axis at 6° from the normal and subtending a half angle of 5°. The functional notation is *R* (90° − 5°, 6°, 0° − 5°, 6°, 180°:5°, 6°, 0°).



NOTE 1—In this example the reflectance factor is measured with diffuse hemispherical illumination produced by an integrating sphere with an exit port subtending a half-angle of 5°, with its center 6° away from the normal, in the azimuthal direction of the *x*-axis. (This figure illustrates the large amount of information condensed in the functional notation.)

FIG. 4 Example of Functional Notation for Reflectance Factor

8.9.5 *Measurements to Characterize Goniochromatism*—For the measurement of reflectance factor, let the specimen be uniformly illuminated within a cone of half angle of 1.5° centered at an angle of 45° to the normal, at an azimuthal angle of 180°, and let the receiver subtend a cone of half angle of 1°, centered 6° from the specular axis, at an aspecular azimuthal angle of 20°. In the aspecular form, as defined in 6.5 and 8.7, the functional notation is *R* (1.5°, 45°, 180°:1°, 6°, 20°).

9. Sampling Apertures

9.1 The influx sampling aperture is the region on the reference plane within which flux is incident. The efflux sampling aperture is the region on the reference plane from which light is collected by the receiver for measurement.

9.2 If a specimen is uniform, the size and shape of the sampling apertures is usually immaterial, but for nonuniform or textured specimens, the size and shape of the apertures may materially affect measured values. The apertures are specified in linear dimensions, preferably millimetres. Circular sampling apertures are specified by their diameters. Rectangular sampling apertures should be oriented with their sides parallel with the *x* and *y* axes and are specified by the lengths of their sides.

9.3 Translucent specimens scatter flux, some of which is reflected or transmitted outside the influx sampling aperture. If the efflux sampling aperture is enough larger than the influx sampling aperture, the flux scattered toward the receiver will be included in the measured flux. If the efflux sampling aperture is enough smaller than the influx sampling aperture, the scattered light will have no effect on the measurement. The effect of sideways scattering in the specimen usually diminishes to a negligible amount a few millimetres beyond the edge of the influx aperture. This distance must be considered when the sampling apertures are specified.

10. Tolerances

10.1 The specifications described thus far were based on the tacit assumption that the specified cones were uniformly filled, that is, that the influx cone represented an angularly uniform distribution of irradiance and that the efflux cone represented an angularly uniform distribution of sensitivity of the receiver. It was tacitly assumed that the angular distributions were zero at all angles outside the specified cones. These requirements must be made part of the specification and the tolerance for the degree of conformity to these requirements must be specified in operational terms. Some of the operations to test compliance, described in 10.2, may not be feasible with a complete instrument, but can be performed in a laboratory with components of the instrument.

10.2 The uniformity and extent of the influx cone can be measured by placing a small physical aperture at the origin (and successively at other points on the influx sampling aperture) and measuring the flux radiated by the instrument source and emanating from the physical aperture in a small cone, of half angle κ_m, defined by the entrance pupil of a photometer. The measured radiance is a measure of the irradiance at the influx sampling aperture. The shape of the physical aperture should be similar to, and the size should be some specified small fraction, such as 1⁄20, of the size of, the influx sampling aperture. The half angle κ_m scanned by the photometer is some specified small fraction, such as 1⁄20, of the half angle of the influx cone. The irradiance measured at all angles for which the entire scanning cone is within the nominal distribution is required to be within some fraction of the maximum. Tolerance limits are set on the irradiance, relative to the maximum, measured at all points where the entire scanning cone is outside of and just tangent to the nominal cone (centered κ_m outside the nominal cone). Further tolerances are set on similar scans centered at points 3 and 5 times κ_m outside the nominal cone and for all points beyond that.

10.3 The uniformity and extent of the efflux cone can be measured by placing a small physical aperture at the origin (and other points on the efflux sampling aperture) and irradiating and angularly scanning this physical aperture with a small test source uniformly filling an incident cone having a half angle κ_n and using the instrument receiver to measure the flux passing through the physical aperture. The measured value is a measure of the relative sensitivity of the receiver. The shape of the physical aperture should be similar to, and the size should be some specified small fraction, such as 1⁄20, of the size of, the efflux sampling aperture. The half angle κ_n scanned by the test source is some specified small fraction, such as 1⁄20, of the half angle of the efflux cone. The sensitivity, measured at all angles for which the entire scanning cone is within the nominal distribution, is required to be within some specified fraction of the maximum. Tolerance limits are set on the sensitivity, relative to the maximum, measured at all points where the entire scanning cone is outside of, and just tangent to, the nominal cone (centered κ_n outside the nominal cone). Further tolerances are set on similar scans centered at points 3 and 5 times κ_n outside the nominal cone and for all points beyond that.

10.4 Tolerances are placed on the linear dimensions of the sampling apertures and the tolerances described in 10.2 and 10.3 must be met for all positions of the physical aperture within the sampling aperture.

11. Keywords

11.1 appearance; color; colorimetry; geometry; gloss; photometry; reflectance factor; spectrophotometry; transmittance factor; viewing