# Standard Practice for
# Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials[1]

This standard is issued under the fixed designation E1767; 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.[2,3]

## 1. Scope

1.1 This practice describes 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:*[4]

E284 Terminology of Appearance

2.2 *Other Standard:*

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

## 3. Terminology

3.1 *Definitions:*

3.1.1 The terminology used in this practice is in accordance with Terminology E284.

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 an angular distribution of flux in an incident beam or 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 away from the specular axis.

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.

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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 E12.03 on Geometry.

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[2] ISO1/5 Photograhpy — Density Measurements — Part 1: Terms, symbols, and notations.

[3] ANSI PH2.36–1974 American National Standards terms, symbols, and notation for optical transmission and reflection measurements.

[4] 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.

[5] Available from American National Standards Institute (ANSI), 25 W. 43rd St., 4th Floor, New York, NY 10036, http://www.ansi.org.

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, in the direction of 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, in the direction of the receiver.

3.2.6 *efflux region, n*—region in the reference plane from which flux is sensed by the observer.

3.2.7 *influx, n*—radiant flux received from the illuminator at a specimen, a reflection standard, or open sampling aperture.

3.2.8 *influx, adj*—associated with radiant flux received from the illuminator at a specimen, a reflection standard, or open sampling aperture.

3.2.9 *influx region, n*—region in the reference plane on 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 reference plane.

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

3.2.12 *reference plane, n*—the plane in which the surface of a plane specimen is placed for observation or measurement, or in the case of a nonplanar specimen, the plane with respect to which the measurement is made.

3.2.13 *sampling aperture, n*—the region in the reference plane on which a measurement is made, the intersection of the influx region and the efflux region.

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 geometric axis of the incident beam.

3.2.14.1 *Discussion*—This term is applied to an incident beam subtending a small angle at the origin, not to diffuse or annular illuminators.

3.2.15 *specular direction, n*—the direction of the specular axis, the positive direction being away from the origin.

3.2.16 *uniplanar geometry, n*—geometry in which the receiver is in the plane of incidence.

3.3 *Symbols:*

$de$ = general symbol for diffuse geometry with specular component excluded.
$di$ = general symbol for diffuse geometry with specular component included.
$E$ = identifies the direction of the axis of an efflux distribution on a diagram.
$g$ = general symbol, in functional notation, for efflux geometry.
$G$ = general symbol, in functional notation, for influx geometry.
$i$ = subscript for incident.
$I$ = identifies the direction of the axis of an influx distribution on a diagram.
$m$ = subscript for half cone angle subtended by the entrance pupil of a test photometer.
$M$ = optical modulation.
$n$ = subscript for half cone angle subtended by a test source.
$N$ = identifies the direction of the normal to the reference plane on a diagram.
$o$ = point of origin of a rectangular coordinate system, in the reference plane, at the center or centroid of the sampling aperture.
$r$ = subscript for reflected.
$S$ = identifies the specular direction on a diagram.
$t$ = subscript for transmitted.
$x$ = distance from the origin, along the $x$-axis, in the reference plane, passing through point $o$.
$y$ = distance from the origin, along the $y$-axis, in the reference plane, passing through point $o$, and normal to the $x$-axis.
$z$ = distance from the origin, along 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 reference plane.
$\alpha$ = aspecular angle.
$\beta$ = aspecular azimuthal angle.
$\delta$ = in a pyramidal distribution, the half-angle measured in the direction normal to the plane of incidence.
$\varepsilon$ = in a pyramidal distribution, the half-angle measured in the plane of incidence.
$\eta$ = azimuthal angle, measured in the reference plane, from the positive $x$-axis, in the direction of the positive $y$-axis.
$\theta$ = anormal angle.
$\kappa$ = half cone angle of a conical flux distribution.
$\Phi$ = radiant flux
*45°*a = general symbol for 45° annular geometry
*45°*c = general symbol for 45° circumferential geometry

## 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 comparisons of the geometric specifications of viewing situations and measuring instruments.

## 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 in the reference plane at the center or centroid of the sampling aperture.

6.2 Instruments are usually designed to minimize the variation of the product of illumination and receiver sensitivity, as a function of the azimuthal direction. That practice minimizes the variation in modulation as the specimen is rotated in its own plane. Even in instruments with an integrating sphere, residual variation of the product, known as "directionality," can cause variations in measurements of textured specimens rotated in their plane. To minimize variation among routine product measurements 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 toward the projection of the center of the exit port on the reference plane.

6.2.2 For an integrating-sphere instrument with diffuse collection, the positive $x$-axis is directed toward the projection of the center of the entrance port on the reference plane.

6.2.3 For an instrument with annular (circumferential) 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 highly directional illumination, off the normal, such as is used in the measurement of gloss or goniochromatism, the positive $x$-axis is directed along the projection of the specular direction on the reference plane.

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 sampling aperture by the tolerances on the influx and efflux angles.) 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 $\eta$, 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 $\theta$ and $\eta$, in that order. Angle $\eta$ is less than 360° and $\theta$ is 180° or less, and usually less than 90°.

6.5 In gonioradiometry and goniospectrometry, the efflux angle $\theta_r$ or $\theta_t$ may be measured from the normal, but for reflection measurements to characterize goniochromatism, it is often measured from the specular axis. The aspecular angle $\alpha$ is the angle subtended at the origin by the specular axis and the axis of the receiver. In most gonioradiometric measurements, the axis of the receiver is in the plane of incidence and the aspecular angle is measured in that plane. In that case, the positive direction of $\alpha$ is from the specular direction 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

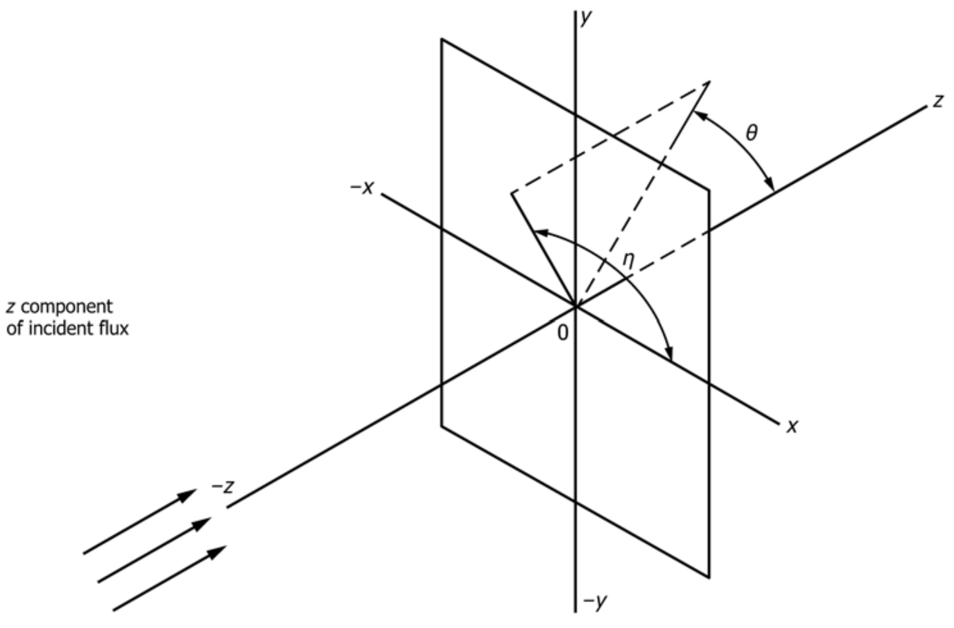


FIG. 1 Coordinate System for Describing the Geometric Factors Affecting Transmission and Reflection Measures

and azimuthal angles, as defined in 6.5, but an aspecular azimuthal angle $\beta$ may be useful. 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 $\beta$.) 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 direction 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 $\alpha$ and $\beta$. When $\alpha$ and $\beta$ are used to define the direction of the receiver, $\alpha$ is always positive.

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 $\theta$ and $\eta$ and the half cone angle is given the symbol $\kappa$. 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. 3.

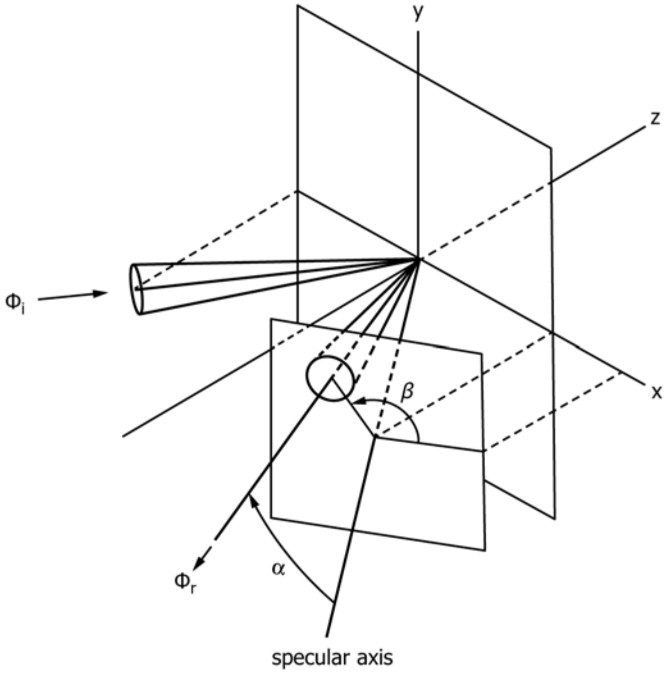


FIG. 2 Angles $\alpha$ and $\beta$ Relative to the Specular Axis

## 8. Pyramidal Description

8.1 In some instruments, influx or efflux distributions are of pyramidal rather than conical form. For a pyramidal influx distribution, flux incident on the origin comes from an area of a directional illuminator uniformly filling a rectangle on a plane normal to the beam, with two sides parallel to the plane of incidence. For a pyramidal efflux distribution, flux from the origin is uniformly collected and evaluated over an area of the receiver that is a rectangle on a plane normal to the beam, with two sides parallel to the plane of incidence. A pyramidal configuration can be used to subtend a small angle in the plane of incidence, to enhance angular selectivity, but large enough solid angle to provide adequate flux for reliable measurements. A uniplanar configuration with pyramidal influx and efflux distributions is shown in Fig. 4.

8.2 A pyramidal distribution is specified by angles $\delta$ and $\varepsilon$, where $\delta$ is the angle subtended at the origin from the central axis of the distribution to the edge, measured in the direction normal to the plane of incidence, and $\varepsilon$ is the angle subtended at the origin from the central axis of the distribution to the edge, measured in the plane of incidence. See Fig. 4. To simplify the figure, the angles $\delta$ and $\varepsilon$ are shown for the receiver, but not for the illuminator.

## 9. Functional Notation

9.1 The description of the geometry can be greatly abbreviated by the use of mathematical functional notation. The symbolism $F(q)$ means that the value of $F$ is a function of, that is, depends on, the value of $q$. 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.)

9.2 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 specified by separate tolerances. Ranges stated are not tolerances but are mandatory ranges of inclusion. The solid angle of receiver sensitivity is considered in a similar way.

9.3 Conical specifications are given in the following order, separated by commas: $\kappa$, $\theta$, $\eta$. Using the conical method of

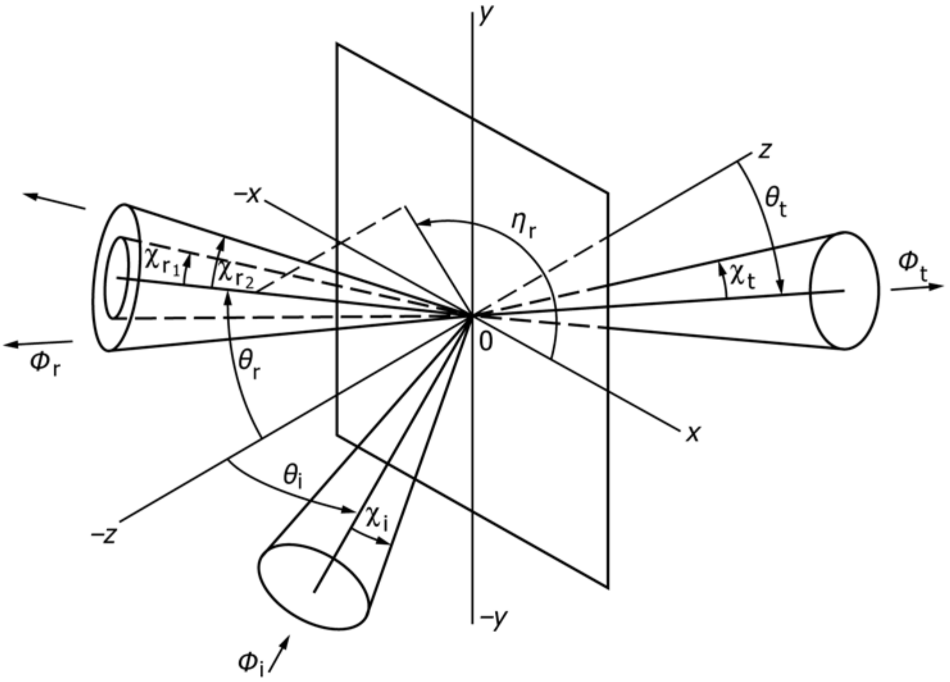
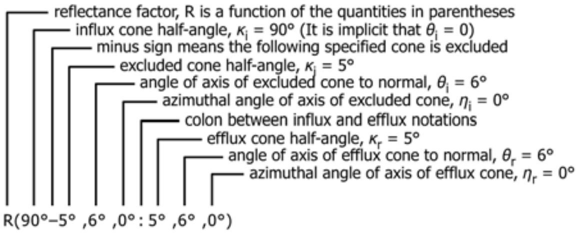


**FIG. 3 Coordinate System and Angular Conventions for Describing Distributions in Terms of Cones**



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**

description, *G* may be specified by $\kappa_i$, $\theta_i$, $\eta_i$ and *g* may be specified, for the transmission case, by $\kappa_t$, $\theta_t$, $\eta_t$ and, for the reflection case, by $\kappa_r$, $\theta_r$, $\eta_r$.

9.4 If conical 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 distribution is a broken annulus, in which case it is necessary to give values for η.

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

9.6 A combination of discrete cones can be annotated by the use of the plus sign, for example $\theta_1$ to $\theta_2 + \theta_3$ to $\theta_4$. Similarly a void in a region may be indicated by the use of the minus sign. Where two values of θ are used in functional notation for an annular distribution, they are separated by a minus sign, as in the notation *R*(50°-40°:5°).

9.7 Pyramidal specifications are given in the following order, separated by commas: δ, ε, θ, η, using subscripts for influx and efflux as in the case of conical distributions.

9.8 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.

9.9 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)*.

9.10 *Examples of Functional Notation:*

9.10.1 *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 the receiver collect flux through a circular port centered on the normal and subtending a half cone angle of 5°. The functional notation is *R*(50°-40°:5°).

9.10.2 *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 the receiver collect flux through a circular port centered on the normal and subtending a half cone angle of 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°).

9.10.3 *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 with its center in the *x* direction, at 6° from the normal and subtending a half cone angle of 5°. The functional notation is *R*(90°-5°, 6°, 0°:5°, 6°, 0°). The components of this notation are indicated in Fig. 5.

9.10.4 *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, with its center in the *x* direction at 6° from the normal and subtending a half cone angle of 5°. The functional notation is *R*(90°-5°, 6°, 0°-5°, 6°, 180°:5°, 6°, 0°).

9.10.5 *Measurements to Characterize Goniochromatism*—For the measurement of reflectance factor, let the illuminator subtend a half cone angle of 1.5° and have its axis centered at an angle of 45° to the normal, at an azimuthal angle of 180°, and let the receiver subtend a half cone angle of 1°, and have its axis centered 6° from the specular ray, at an aspecular azimuthal angle of 20°. In the aspecular form, as defined in 6.5 and 9.8, the functional notation is *R*(1.5°, 45°, 180°:1°, 6°, 20°).

9.10.6 An example of functional notation, with components labeled, is illustrated in Fig. 5.

## 10. Sampling Aperture

10.1 The influx region is the region in the reference plane on which flux is incident. The efflux region is the region in the reference plane on which flux is sensed by the receiver. The sampling aperture is the region in the reference plane on which a measurement is made. It is the intersection of the influx region and the efflux region.

10.2 If a specimen is uniform, the size and shape of the sampling aperture is usually immaterial, but for non-uniform or textured specimens, the size and shape of the sampling aperture may affect measured values. The sampling aperture is specified in linear dimensions, preferably millimetres. The size of a circular sampling aperture is specified by its diameter. A rectangular sampling aperture is oriented with its sides parallel with the *x* and *y* axes and the dimensions in the *x* and *y* directions are specified.

10.3 Translucent specimens, such as candle wax, scatter flux outside the influx region. Some of that flux is again scattered toward the receiver. If the efflux region is enough larger than the influx region, the flux scattered towards the receiver will be included in the measurement and the efflux region is said to be "underfilled." If the influx region is enough larger efflux region, the scattered light will have no effect on the measurement and the efflux region is said to be "overfilled." The two arrangements generally give the same results, unless the specimen is photoluminescent. The effect of scattering usually diminishes to a negligible amount a few millimeters outside the influx region.

## 11. Tolerances

11.1 The specifications described thus far were based on the tacit assumption that the specified cones or pyramids were uniformly filled, that is, that the influx was an angularly uniform distribution of irradiance and that the efflux was an angularly uniform distribution of sensitivity of the receiver. It was tacitly assumed that the distributions were zero at all angles outside the specified cones or pyramids. 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 11.2, may not be feasible with a

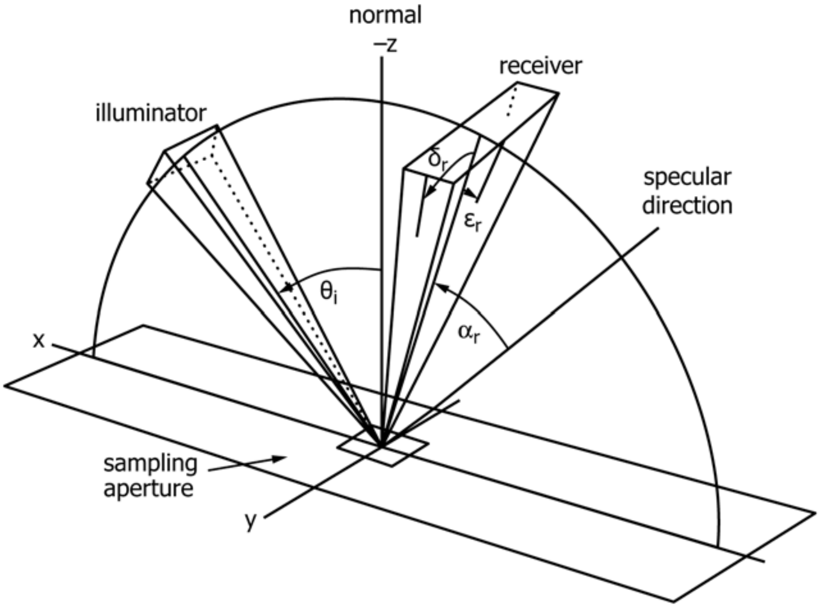


FIG. 5 A Pyramidal Configuration

complete instrument, but can be performed in a laboratory with components of the instrument.

11.2 Tolerances are specified for the angles describing the direction and extent of the influx distribution. 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 region) and measuring the flux radiated by the instrument source and emanating from the physical aperture in a small cone, of half cone angle $\kappa_m$, defined by the entrance pupil of a photometer. The measured radiance is a measure of the irradiance at a point on the influx region. The shape of the physical aperture should be similar to, and the size should be some specified small fraction, such as $\frac{1}{20}$, of the size of, the nominal influx region. The half cone angle $\kappa_m$ scanned by the photometer is some specified small fraction, such as $\frac{1}{20}$, of the half cone 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 $\kappa_m$ outside the nominal cone). Further tolerances are set on similar scans centered at points 3 and 5 times $\kappa_m$ outside the nominal cone and for all points beyond that.

11.3 Tolerances are specified for the angles describing the direction and extent of the efflux distribution. 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 region) and irradiating and angularly scanning this physical aperture with a small test source uniformly filling an incident cone having a half angle $\kappa_n$ 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 $\frac{1}{20}$, of the size of, the nominal efflux region. The half angle $\kappa_n$ scanned by the test source is some specified small fraction, such as $\frac{1}{20}$, 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 $\kappa_n$ outside the nominal cone). Further tolerances are set on similar scans centered at points 3 and 5 times $\kappa_n$ outside the nominal cone and for all points beyond that.

11.4 Similar procedures can be applied to pyramidal distributions.

11.5 Tolerances are specified for the linear dimensions of the influx region, the efflux region, and the sampling aperture and the tolerances described in 11.2 and 11.3 must be met for all positions in the sampling aperture of the specified physical test aperture.

## 12. Reversibility

12.1 According to a generally accepted principle, the geometry of instruments for measuring appearance may be reversed and obtain the same results. Thus, for example, M(0°:45°a) = M(45°a:0°).

12.2 This principle does not imply that the illuminator and the receiver can always simply be exchanged. The new angular distribution of illumination must be the same as the original angular distribution of receiver sensitivity and the new angular distribution of receiver sensitivity must be the same as the original angular distribution of illumination.

12.3 The principle of reversibility does not generally apply to photoluminescent specimens.

12.4 The geometry of a measuring instrument is called "reverse geometry," if it is the reverse of typical viewing geometry. Since the eye subtends a very small solid angle at a specimen and specimens are typically viewed along their normal, R(0°:45a°) is called "reverse geometry."

## 13. Keywords

13.1 appearance; color; colorimetry; geometry; gloss; goniochromatism; goniophotometry; gonioradiometry; goniospectrometry; goniospectrophotometry; multiangle spectrometry; multiangle spectrophotometry; photometry; reflectance factor; spectrometry; spectrophotometry; transmittance factor; viewing conditions