INTERNATIONAL

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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.

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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.6 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

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:*

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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 Photography — 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.

3.2.1 *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.

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.
α	=	aspecular angle.
β	=	aspecular azimuthal angle.
δ	=	in a pyramidal distribution, the half-angle measured in the direction normal to the plane of incidence.
ε	=	in a pyramidal distribution, the half-angle measured in the plane of incidence.
η	=	azimuthal angle, measured in the reference plane, from the positive *x*-axis, in the direction of the positive *y*-axis.
θ	=	anormal angle.
κ	=	half cone angle of a conical flux distribution.
Φ	=	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 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 gonioradiometry and goniospectrometry, 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

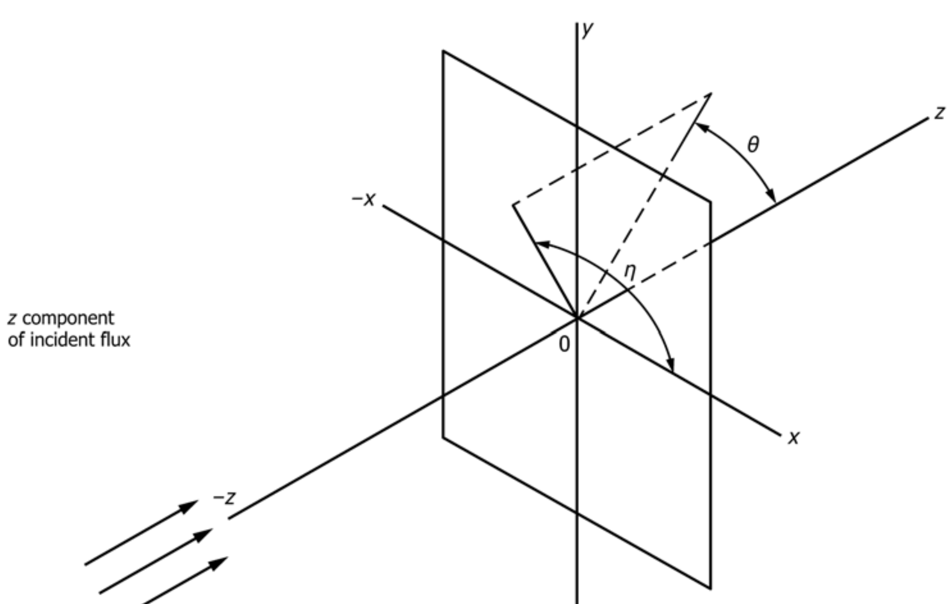

FIG. 1 Coordinate System for Describing the Geometric Factors Affecting Transmission and Reflection Measures

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 α 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 and azimuthal angles, as defined in 6.5, but an aspecular azimuthal angle β 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 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 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 α and β. When α and β are used to define the direction of the receiver, α 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 θ and η and the half cone angle is given the symbol κ. 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.

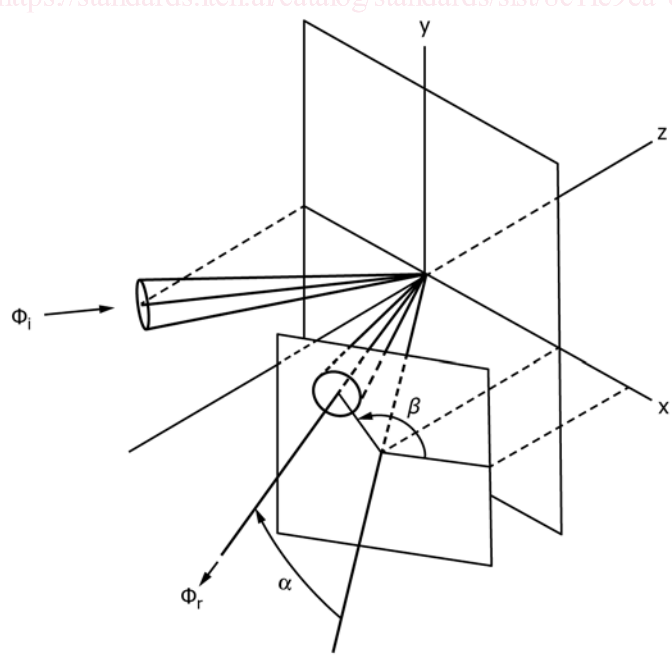

FIG. 2 Angles α and β Relative to the Specular Axis

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 δ and ε, where δ 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 ε 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 δ and ε 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