Standard Practice for Specifying the Geometry of Multiangle Spectrophotometers[1]

This standard is issued under the fixed designation E2175; 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 metallic coatings and plastics usually depends on the directions of illumination and viewing, a phenomenon called "gonioappearance." This phenomenon is also observed with other materials, such as lustrous textiles and materials containing pearlescent or interference pigments. The characteristic appearance of most such materials is accentuated by directional illumination, such as that provided by the sun on a clear day or a small lamp at night. The variation in color, as a function of geometry, is usually measured by spectrophotometry with several specified sets of geometric conditions. Measurement of this kind, at a few selected angles, is called "multiangle spectrophotometry," as distinguished from measurement over a broad range of angles, which is called "goniospectrophotometry." Spectrophotometric aspects of these measurements, including spectral resolution and linearity of photometric scales, are treated in other standards, including Practice E308 and Practice E1164. Practice E1767 provides practice for specifying the geometry of measurements. Retroreflectors exhibit a special kind of gonioappearance, which is treated in other ASTM documents. The present document provides standard practice for specifying influx and efflux angles, angular selectivity, spatial distributions of illuminators and receivers, and angular aspects of standardizing the photometric scale, that are peculiar to multiangle spectrophotometry. Directional illumination emphasizes the gonioappearance of most materials, but when interference pigments are used, such as those used in ink to mark paper currency, the effect is observed with diffuse illumination and varying angles of viewing, so these materials are also measured with diffuse illumination.

1. Scope

1.1 This practice provides a way of specifying the angular and spatial conditions of measurement and angular selectivity of a method of measuring the spectral reflectance factors of opaque gonioapparent materials, for a small number of sets of geometric conditions.

1.2 Measurements to characterize the appearance of retroreflective materials are of such a special nature that they are treated in other ASTM documents and are not included in the scope of this standard.

1.3 *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

E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation

E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials

3. Terminology

3.1 For definitions of appearance terms used in this practice, refer to Terminology E284.

4. Significance and Use

4.1 This practice is for the use of manufacturers and users of instruments to measure the appearance of gonioapparent

[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] 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.

materials, those writing standard specifications for such instruments, and others who wish to specify precisely the geometric conditions of multiangle spectrophotometry. A prominent example of industrial usage is the routine application of such measurements by material suppliers and automobile manufacturers to measure the colors of metallic paints and plastics.

5. Components of Apparatus

5.1 The apparatus shall consist of one or more illuminators and one or more spectrometric receivers at fixed or adjustable angles with respect to a reference plane, a means of positioning specimens in a reference plane, a means of indicating the area on the specimen to be measured, shielding to avoid stray light, and a means of displaying spectral or colorimetric data and/or communicating such data to a data-recorder or computer. (The terms "light," "illuminator," "illumination," and "illuminance" are used here for simplicity, though the corresponding terms "radiant power," "irradiator," "irradiation," and "irradiance" would be more accurate when the incident flux includes ultraviolet flux, as is necessary if the appearance of a fluorescent material is measured.)

6. Geometric Types of Apparatus

6.1 The geometric configuration of the instrument may be uniplanar, annular, circumferential, or diffuse. In all cases, the specimen is taken to be a flat surface lying in a plane called the "reference plane," which is designated the x, y plane. When there is a single directional illuminator, the *x* direction is the direction of the projection of the axis of the incident beam on the reference plane. If there are several directional illuminators or a single diffuse illuminator, the direction of the x-axis must be selected and specified. The area of the reference plane on which measurements are made is called the "sampling aperture" and the center of that area is designated the origin, o, of the geometric space used to specify the configuration. The normal to the sampling aperture, at the origin, is the -z-axis. Angles subtended at the origin and measured from that normal are called "anormal angles." The specular direction is the direction of the beam from a directional illuminator after specular reflection by an ideal plane mirror at the sampling aperture. Angles subtended at the origin and measured from the specular direction are called" aspecular angles" and are positive in sign when measured in the direction toward the normal. The normal and the axis of a directional illuminator define a plane, known as the "plane of incidence." The specular direction necessarily lies in that plane.

6.1.1 To facilitate simple and precise geometric specification of the sampling aperture, it shall be either circular or rectangular.

6.1.2 To facilitate simple and precise geometric specification of directional influx or efflux distributions, they shall be either conical or pyramidal. For purposes of describing geometry by functional notation, a diffuse distribution may be considered a conical distribution centered on the normal and having a half angle of 90 degrees.

6.1.3 In a uniplanar configuration, a directional illuminator is used, the axes of the receivers lie in the plane of incidence, and their positions are specified by aspecular angles. A uniplanar configuration is illustrated in Fig. 1. To simplify the figure, only one receiver is shown.

6.1.3.1 For a conical influx distribution, the flux incident on the origin comes from an area of a directional illuminator uniformly filling a circle on a plane normal to the beam. For a conical efflux distribution, flux from the origin is uniformly collected and evaluated over an area of the receiver that is a circle on a plane normal to the beam. A uniplanar configuration with conical influx and efflux distributions is illustrated in Fig. 2. To simplify the figure, only one receiver is shown.

6.1.3.2 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. 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. A pyramidal configuration can be used to subtend a small angle in the plane of incidence, to enhance angular selectivity, but have a large enough solid angle to provide adequate flux for reliable measurements. A uniplanar configuration with pyramidal influx and efflux distributions is illustrated in Fig. 3. To simplify the

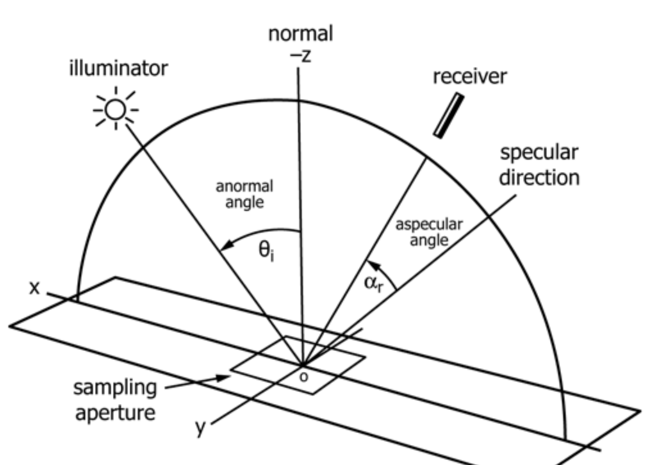

FIG. 1 Uniplanar Configuration

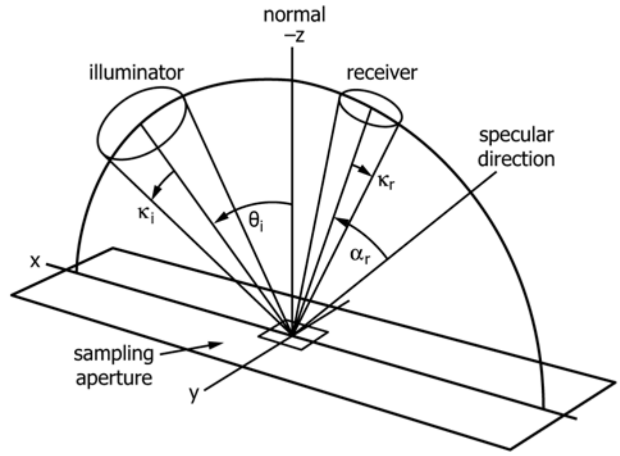

FIG. 2 Uniplanar Configuration with Conical Influx and Efflux Distributions

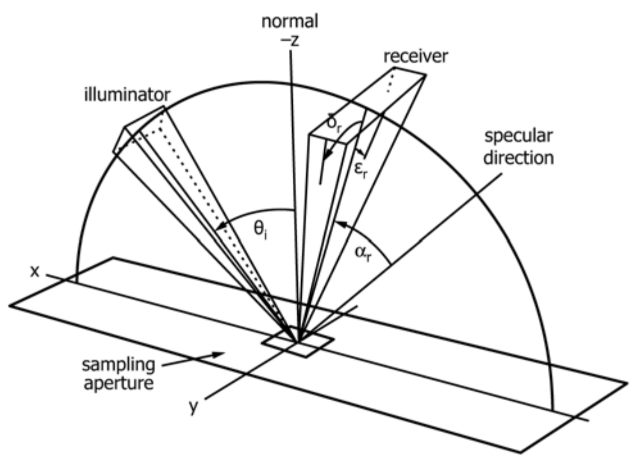

FIG. 3 Uniplanar Configuration with Pyramidal Influx and Efflux Distributions

figure, only one receiver is shown and the angles δ and ε are shown for the receiver, but not for the illuminator.

6.1.4 In an annular configuration, the incident beam uniformly fills the space between two right-circular cones, with their axes on the normal and apices at the origin. An annular configuration can be used to provide a flux distribution with a small range of anormal angles, to enhance anormal angular selectivity, but of large enough solid angle to provide adequate flux for reliable measurements. The nominal angle of an annular distribution is the average of the half-angles of the two defining cones. For multiangle spectrophotometry, provision must be made for several annular distributions with different nominal angles. The efflux distribution is a conical distribution with its axis on the normal and its apex at the origin.

6.1.5 A circumferential configuration approximates an annular configuration, except that flux incident on the origin comes from a ring of discrete directional illuminators, all having their axes at the same anormal angle, but arrayed at various azimuthal angles. The nominal angle of incidence is measured from the normal to the axes of the illuminators. For multiangle spectrophotometry, provision must be made for illuminators at several different nominal angles. A circumferential configuration with three illuminators is illustrated in Fig. 4. To simplify the figure, the angles κ_i, θ_i, and η_i are shown for the first illuminator only.

6.1.5.1 The discrete illuminators shall all have the same nominal angle of incidence, for a given measurement.

6.1.6 In a diffuse configuration, the incident flux is diffuse. Ideally, the illuminator illuminates the sampling aperture at all angles within the hemisphere on the -z side of the reference plane, except those directions occupied by receivers. The use of an integrating sphere to produce uniform diffuse illumination requires non-selective diffusing baffles to obscure the entrance port and the area on the sphere wall at which the flux entering the sphere is first reflected. When diffuse illumination is used, the receivers are all in one plane defined by the normal and having an arbitrarily designated x-axis. The positions of the receivers are specified by anormal angles.

6.2 Given a geometric configuration, the reverse geometry is considered equivalent, if all other components of the instrument design are equivalent.

7. Nominal Geometric Specifications

7.1 Angles for these specifications are customarily given in degrees.

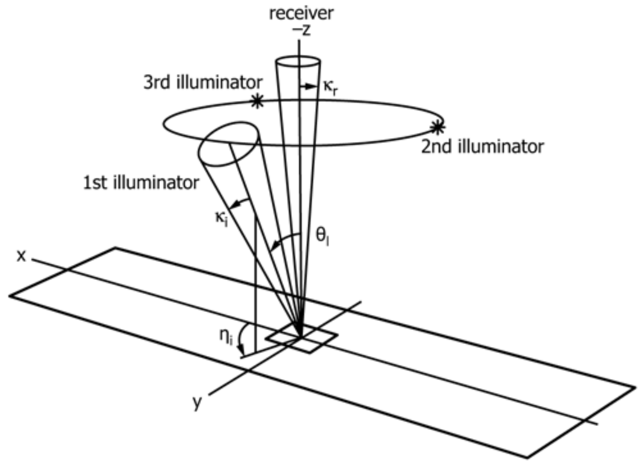

FIG. 4 Circumferential Configuration

7.2 *Uniplanar Geometry:*

7.2.1 The direction of a conical distribution is specified by the angle θ subtended at the origin from the normal to the axis of the distribution or the angle α subtended at the origin from the specular direction to the axis of the distribution. The extent of a conical distribution is specified by the angle κ subtended at the origin by the radius of the circular distribution at the illuminator or receiver, with subscripts i and r indicating illuminator and receiver, respectively. (See Fig. 2.) When more than one illuminator or receiver is involved, they are distinguished by alphabetic subscripts a, b, c, etc., the half-angles being given symbols of the form κ_{ia}, κ_{ib}, κ_{ic}, … and κ_{ra}, κ_{rb}, κ_{rc} … .

7.2.2 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. Subscript i and r distinguish half-angles for the illuminator and receiver, respectively. Letter subscripts are added to identify multiple distributions, as in the case of circular conical distributions. (See Fig. 3.)

7.3 An annular distribution is specified by a half-angle κ_{i1} or κ_{r1} for the smaller of the two cones limiting the annulus and κ_{i2} or κ_{r2} for the larger of the two. Subscripts a,b,c, etc. are used to distinguish multiple distributions, as in the case of conical distributions, for example, κ_{i1c}. The nominal angle of incidence or angle of reflection is given the same symbol without the 1 or 2, for example κ_{ic}. (See Fig. 4.)

7.4 A circumferential distribution is specified by the anormal angle θ of the axes of the discrete illuminators, the conical or pyramidal description of the discrete illuminators, and the azimuthal positions of their axes with respect to some identified direction, considered the *x* direction.

7.5 A diffuse distribution is specified by specifying directions, if any, from which illumination is excluded, other than the obvious directions of receivers and necessary baffles. Excluded directions are specified in the same way as conical or pyramidal influx or efflux distributions.

8. Angular Selectivity

8.1 Angular selectivity is the degree to which the measured spectral quantity approaches the ideal value for the nominal angular geometry. Precise characterization of the effective angular "slit-width" of the measurement system can be difficult, but the fraction of the angular illumination distribution and the angular sensitivity distribution within specified angles can be determined by practical means.

8.2 Ideally, flux incident on the origin should come from the nominal direction specified for the measurement. At least ΔE_α % of the incident flux shall come from angles within $\Delta\alpha_1$ degrees of the nominal direction. All of the incident flux shall come from angles within $\Delta\alpha_2$ degrees of the nominal direction.

8.3 Ideally, the sensitivity of a receiver should be limited to the nominal direction. A fraction ΔS_α % of the angular sensitivity distribution shall be within $\Delta\alpha_3$ degrees of the nominal direction. All of the angular sensitivity distribution shall be within $\Delta\alpha_4$ degrees of the nominal direction.

9. Tolerances

9.1 The objective is to have the sampling aperture uniformly illuminated. Tolerances are specified for the departure from uniformity of the illuminance. The nominal specified angular extents of influx and efflux distributions should not be confused with tolerances. Tolerances are set on the specified boundaries. The objective is to have the specified nominal angular extents of influx and efflux distributions uniformly filled. Tolerances are specified for the departure from uniformity.

9.2 Angular tolerances are given the same symbols as nominal angles, preceded by the Greek delta symbol Δ, for example $\Delta\kappa_{ia}$, for a tolerance on the half-angle of conical influx distribution "a." Upper tolerances are specified by +Δ, lower tolerances are specified by -Δ, and symmetric tolerances are specified by ±Δ.

9.3 The illuminance *J* at any place on the sampling aperture shall be within ΔJ_a % of the mean illumination, when measured with a circular radiometric scanning aperture having a diameter Δd % of the diameter of a circular sampling aperture or measured with a square radiometric scanning aperture having a side Δw % of the smaller of the two dimensions of a rectangular sampling aperture.

NOTE 1—The usual symbol for illuminance is E, but in colorimetry, ΔE signifies total color difference, so to avoid confusion, the special symbol J is used here for illuminance.

9.4 The sampling aperture shall be shielded from light other than that from the illuminator used for measurement at the specified angle. The illuminance due to stray light from extraneous sources or unintended light paths shall not exceed ΔE_s % of that due to the intended light path.

9.5 The luminance K of a directional illuminator, in the direction of any point on the sampling aperture, shall not differ more than ΔK % from the mean luminance, when measured using a radiometer uniformly sensitive over a conic distribution having a half angle κ % of the diameter of the half angle of the illuminator or over a square-based pyramidal distribution, a side of the square base being a specified percent of the smaller of δ or ε.

NOTE 2—The usual symbol for luminance is L, but in colorimetry, ΔL signifies lightness difference, so to avoid confusion, the special symbol K is used here for luminance.

9.6 The luminance of an annular illuminator, in the direction of any point on the sampling aperture, shall not differ more than ΔK % from the mean luminance, when measured using a radiometer uniformly sensitive over a conic distribution having a half angle σ % of the difference in angles between the cones defining the annular distribution.

9.7 The sensitivity of a receiver S to light from any point on the sampling aperture shall be within ΔS_a % of the mean sensitivity, when exposed to a constant test beam uniform over a conic distribution having a half angle κ % of the diameter of the half angle of a conical receiver or over a square-based pyramidal distribution, a side of the square base being a specified percent of the smaller of δ or ε.

10. Standardization of the Photometric Scale:

10.1 In most spectrophotometry, the geometry is singular and fixed and the white standard used to standardize the photometric scale of the instrument is placed at the sampling aperture, in place of the specimen to be measured. In multiangle spectrophotometry, there are several different geometries. The white standard could be placed at the sampling aperture, be placed normal to the axis of the illuminator, be placed normal to the axis of the receiver, or be oriented in some other way. The practice must be specified. The most practical method is to place the white standard at the sampling aperture. The manner of calibration of the white standard and the way the calibration data are applied to standardizing the multiangle measurement must be specified.

11. Keywords

11.1 appearance; appearance difference; color; color difference; color matching; geometry; gonioappearance; goniochromatism; goniospectrophotometry; multiangle spectrophotometry; spectrophotometry