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Standard Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials[1]

This standard is issued under the fixed designation E179; 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

This is a guide describing the selecting of geometric conditions of measurement of appearance attributes such as color, gloss, reflectance, opacity, and transmittance. It includes a selection of numerical scales for appearance attributes other than color.

In describing appearance, wavelength (or spectral) variability is primarily responsible for color, while geometric (or directional) selectivity is primarily responsible for gloss, luster, translucency, and like attributes. However, geometric conditions not only affect geometric variables such as gloss and transparency, but also affect color, diffuse reflectance, and transmittance. Likewise spectral conditions can affect the measurement of geometric attributes of appearance. Therefore both the spectral and geometric conditions of measurement must be identified in specifying an appearance attribute of a specimen.

This guide describes the selection of geometric conditions and as a consequence should help improve agreement in these measurements as well as providing useful guidance in resolving differences between spectral-type measurements that are related to geometry.

1. Scope

1.1 This guide is intended for use in selecting terminology, measurement scales, and instrumentation for describing or evaluating such appearance characteristics as glossiness, opacity, lightness, transparency, and haziness in terms of reflected or transmitted light. This guide does not consider the spectral variations responsible for color, but the geometric variables described herein can importantly affect instrumentally measured values of color. This guide is general in scope rather than specific as to instrument or material.

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C346 Test Method for 45-deg Specular Gloss of Ceramic Materials
C347 Test Method for Reflectance, Reflectivity, and Coefficient of Scatter of White Porcelain Enamels[3]
C523 Test Method for Light Reflectance of Acoustical Materials by the Integrating Sphere Reflectometer
C584 Test Method for Specular Gloss of Glazed Ceramic Whitewares and Related Products
D523 Test Method for Specular Gloss
D1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics
D1455 Test Method for 60 Specular Gloss of Emulsion Floor Polish
D1494 Test Method for Diffuse Light Transmission Factor of Reinforced Plastics Panels
D1746 Test Method for Transparency of Plastic Sheeting
D1834 Test Method for 20 Specular Gloss of Waxed Paper
D4039 Test Method for Reflection Haze of High-Gloss Surfaces
D4061 Test Method for Retroreflectance of Horizontal Coatings

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[1] This guide 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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Current edition approved July 1, 2012. Published September 2012. Originally approved in 1961. Last previous edition approved in 2003 as E179 – 96 (2003) which was withdrawn April 2012 and reinstated in July 2012.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Withdrawn. The last approved version of this historical standard is referenced on www.astm.org.

E97 ~~Test~~ Method of Test for Directional Reflectance Factor, ~~45-deg, 0-deg,~~45-Deg 0-Deg, of Opaque Specimens by Broad-Band Filter Reflectometry
E167 Practice for Goniophotometry of Objects and Materials
E284 Terminology of Appearance
E429 Test Method for Measurement and Calculation of Reflecting Characteristics of Metallic Surfaces Using Integrating Sphere Instruments
E430 Test Methods for Measurement of Gloss of High-Gloss Surfaces by Abridged Goniophotometry
E808 Practice for Describing Retroreflection
E809 Practice for Measuring Photometric Characteristics of Retroreflectors
E810 Test Method for Coefficient of Retroreflection of Retroreflective Sheeting Utilizing the Coplanar Geometry
E811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions
E991 Practice for Color Measurement of Fluorescent Specimens Using the One-Monochromator Method
E1164 Practice for Obtaining Spectrometric Data for Object-Color Evaluation
E1331 Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry
E1348 Test Method for Transmittance and Color by Spectrophotometry Using Hemispherical Geometry
E1349 Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional (45:0 or 0:45) Geometry
E1767 Practice for Specifying the Geometries of Observation and Measurement to Characterize the Appearance of Materials
E2194 Practice for Multiangle Color Measurement of Metal Flake Pigmented Materials
E2539 Practice for Multiangle Color Measurement of Interference Pigments
F768 Method for Specular Reflectance and Transmittance Measurements of Optically Flat-Coated ~~and Non-Coated~~ Specimens[0]

2.2 *CIE Publications:*[4]
CIE Publication No. 15.2 Colorimetry, second edition 1986
CIE Publication No. 17.4 International Lighting Vocabulary, fourth edition, 1987
CIE Publication No. 38 Radiometric and Photometric Characteristics of Materials and Their Measurement, 1977

3. Terminology

3.1 *Definitions:*

3.1.1 ~~*flux (radiant),* Φ~~flux (radiant), Φ, *n*—the time rate of flow of radiant energy; radiant power (Terminology E284).

3.1.2 *incident flux,* Φ~~$_i$~~i, *n*—flux incident on the specimen at a specified illumination angle and aperture angle.

3.1.3 *reflected flux,* Φ_r, *n*—flux reflected from the specimen at a specified viewing angle and ~~aperature~~aperture angle.

3.1.4 *reference reflected flux,* Φ~~$_{r.r}$~~r.r, *n*—flux reflected from a reference standard of reflectance, illuminated and viewed in the same manner as the specimen under consideration.

3.1.5 *transmitted flux,* Φ~~$_t$~~t, *n*—flux transmitted through the specimen at a specified viewing angle and field angle.

3.1.6 ~~*reflectance, ρ*~~reflectance, ρ, *n*—ratio of the reflected flux to the incident flux defined as $\rho = \Phi_r / \Phi_i$.

3.1.7 ~~*reflectance factor, R*~~reflectance factor, R, *n*—ratio of the reflected flux to the reference reflected flux defined as $R = \Phi_r / \Phi_{r.r}$.

3.1.8 ~~*transmittance, τ*~~transmittance, τ, *n*—ratio of the transmitted flux to the incident flux defined as $\tau = \Phi_t / \Phi_i$.

3.1.8.1 *Discussion*—A companion term, transmittance factor, is not normally used in the measurement of appearance attributes.

3.1.9 For other definitions see Terminology E284 and CIE Publication Nos. 17.4 and 38 ~~and 38~~.

4. Summary of Guide

4.1 When light impinges upon a material, several phenomena can occur. Part of the light may be reflected, part may be transmitted, and part may be absorbed. This guide deals with the reflected and transmitted light and the selection of geometric conditions for its measurement.

4.2 An idealization of the light reflected and transmitted by a material is shown in Fig. 1. Fig. 2 illustrates luminance distributions more like those actually encountered in practice.

5. Types of Measurement Scales

5.1 *Type of Scale*—The terms defined in 3.1.6-3.1.8 to may be further identified by a preceding adjective, such as specular, regular, diffuse, total, or directional, thereby identifying the basis for the measurement scale. The significance of each of these adjectives is as follows:

5.1.1 *regular*—indicates that only light that has been reflected or transmitted without scattering or diffusion is included for measurement. When a specimen scatters or diffuses the incident light on reflection or transmission, the values obtained will depend on the angular size of the illuminator and receiver used in the measurement.

5.1.2 *specular*—indicates that only the light that is mirror-reflected is included for measurement. The CIE prefers the modifier *regular* instead of *specular* although *specular* reflectance is recognized. *Specular* has also sometimes been used to refer to regular

[4] Information on how to obtain CIE documents should be requested from the U.S. National Committee, CIE, c/o Radiometric Physics Division, National Institute of Standards and Technology, Bldg. 220, Room B-306, Gaithersburg, MD 20899.

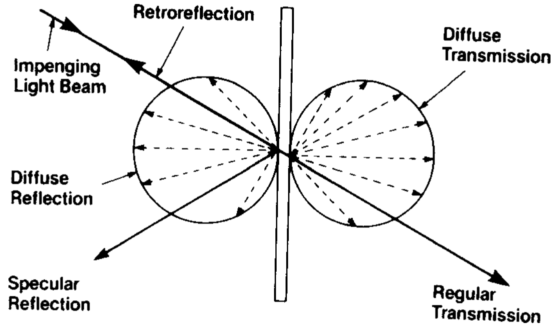

FIG. 1 Idealizations of Reflection and Transmission Phenomena, Showing Components

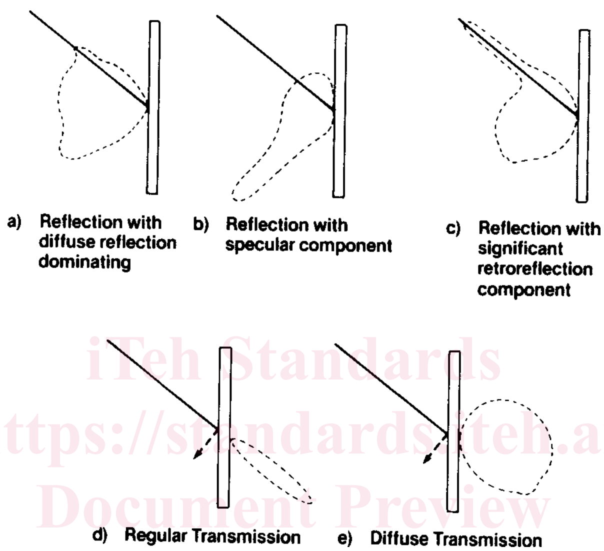

FIG. 2 Representations of Actual Reflection and Transmission Phenomena with Mixtures of Components

TABLE 1 Differences Between Concepts of Regular (Specular) and Diffuse Components of Reflection and Transmission

Measurement	Geometric Distribution of Light	Structural Elements Responsible	Resulting Appearance Characteristic When Component Dominates
Reflectance:			
Specular component	reflected only in direction of mirror reflection	smoothness of surface or skin of specimen	glossiness or shininess
Diffuse component	distributed in all directions	pigment granules and cavities within specimen, surface roughness	lightness (expressed on black-gray-white scale)
Transmittance:			
Regular component	a continuation of the incident beam	clear homogeneous medium with plane, parallel faces	clearness or transparency
Diffuse component	distributed in all directions	scattering and refracting particles of a nonopaque specimen, surface roughness	translucency, turbidity, or haziness

transmittance. This is a misnomer because specular refers to a mirror.

5.1.3 *diffuse*—indicates that only the light reflected or transmitted in directions other than the specular or regular direction is included in the measurement.

NOTE 1—The differences between the concepts of regular and diffuse components of reflection and transmission are shown in Table 1.

5.1.4 *total*—indicates that the light reflected or transmitted in all directions is included for measurement.

5.1.5 *directional*—indicates that the light reflected or transmitted in specified directions only is included for measurement. Directional values depend on the illumination and viewing angles and refer to light reflected or transmitted in directions that differ moderately from the centroid direction or axis of the beam.

6. Geometric Directions of Incidence and Viewing

6.1 Geometric directions may be identified by preceding the adjective with the angular directions, by including a detailed geometric description, or by placing after the symbols a subscript that represents the measurement condition.

NOTE 2—This guide is concerned with bidirectional or hemispherical measurement systems. For gonophotometric methods, see Practice E167. For methods of specifying the geometry of measurements, see Practice E1767.

6.2 *illumination and viewing angles*—the angles of illumination and viewing are identified as follows (see Fig. 3):

6.2.1 *illumination angle,* θ_i—the angle between the incident-beam axis and the normal (perpendicular) to the surface of the specimen (the specimen normal).

6.2.2 *viewing angle for reflection,* θ_r—angle between the surface normal and the axis of the receiver.

6.2.3 *viewing angle for transmission,* θ_t—angle between the axis of the transmitted beam and the axis of the receiver.

6.3 *aperture angles*—the angles subtended at a point on the specimen by the maximum dimension of the apparent illuminator and receiver. They are a necessary part of the geometric specification because the finite size of every practical illuminator limits collimation.

6.4 *azimuthal angle,* η—the angle between the plane containing the illuminator axis and the specimen normal and the plane containing the receiver axis and the specimen normal. Unless an azimuthal angle is specified, the illuminator axis, the specimen normal, and the receiver axis are taken to be in the same plane.

6.5 *rotation angle,* ε—the angle indicating the orientation of the test specimen when it is rotated in its own plane. The orientation of the specimen is considered to be part of the specimen description in this guide (see ~~10.2.7~~12.2.7).

6.6 Complete geometric specifications are necessary for measuring such geometrically dependent factors as gloss, transparency, and haze. For ideally specular or ideally regular or diffuse reflection or transmission, specification of only the directions of illumination and view is usually adequate.

7. Measured Quantities

7.1 The following quantities, defined and described in more detail in the Illuminating and Viewing Conditions section of Practice E1164 and in CIE Publication No. 15.2~~,~~, are those most commonly measured by spectrophotometry and tristimulus (filter) colorimetry for the assessment of color and related appearance attributes.

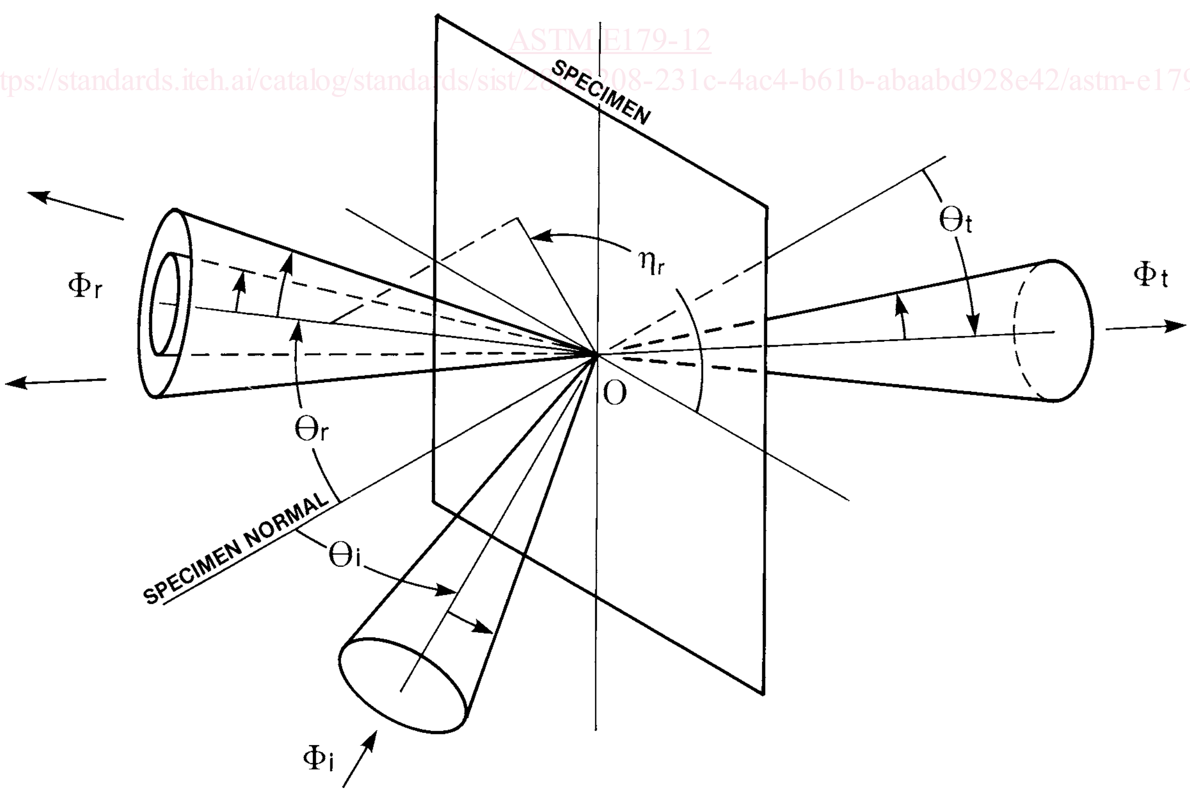

FIG. 3 Designations of Flux, Φ, and Angles θ, η, for Reflectance and Transmittance Measurement

7.1.1 *45°/normal (45/0) and normal/45° (0/45) reflectance factor*—for the 45/0 condition, the specimen is illuminated by one or more beams at an angle of 45° from the specimen normal to the specimen surface. The angle between the direction of viewing and the specimen normal should not exceed 10°. For the 0/45 condition, these requirements are interchanged. Suitable restrictions on the angles of illumination and viewing and on the aperture angles should be observed.

7.1.2 *total/normal (t/0) or diffuse/normal (d/0) and normal/total (0/t) or normal/diffuse (0/d) reflectance factor*—for the *t*/0 or *d*/0 conditions, the specimen is illuminated diffusely, for example by an integrating sphere. The angle between the normal to the specimen surface and the direction of viewing should not exceed 10°. If all specularly reflected light is included in the measurements, the condition is *t*/0; if all specularly reflected light is excluded, the condition is *d*/0. For the 0/*t* or 0/*d* conditions, the requirements for illumination and viewing are interchanged. Suitable restrictions on the aperture angles and the nature of the integrating sphere must be observed.

7.1.3 *regular transmittance of fully transparent specimens*—the specimen is illuminated with an illumination angle not exceeding 5°. The requirements for illumination and viewing may be interchanged. Suitable restrictions on the aperture angles should be observed.

7.1.4 *normal/total (0/t) or normal/diffuse (0/d) and total/normal (t/0) or diffuse/normal (d/0) transmittance of translucent, diffusing, or hazy specimens*—for the 0/*t* or 0/*d* conditions, the specimen is illuminated at an angle of less than 5° from the normal to its surface. The transmitted flux is collected by an integrating sphere, with the specimen placed flush against the port of the sphere. With suitable restrictions on the nature of the sphere, the condition is 0/*t* if the regularly transmitted flux is included and 0/*d* if it is excluded. The results should be interpreted with caution and may be specific to the instrument used. For the *t*/0 and *d*/0 conditions, the requirements for illumination and viewing are interchanged. Suitable restrictions on the aperture angles should be observed.

~~**8.**~~

8. Reflectance

8.1 If the specimen being measured is a specular (non-scattering) reflector (for example, a mirror, high-gloss metal surface, or coated window glass), proceed to 8.2, otherwise proceed to 8.3.

8.2 *Specular Reflector*—If the specimen being measured is a specular (non-scattering) reflector (for example, a mirror, high-gloss metal surface, or coated window glass), then measure using hemispeherical illumination, or view, with the specular component included in accordance with Test Method E1331.

8.3 If the specimen being measured is known to contain gonioapparent pigments, such as metallic or pearlescent flake, then proceed to 8.4. If the specimen being measured is a body-color reflector (a specimen having diffuse reflectance) then proceed to 8.5.

8.4 *Gonioapparent Materials*—If the specimen is gonioapparent, color changes with change in illumination or viewing angle, then a multiangle measurement geometry is required to describe the color of the specimen. There are two standards relating to the measurement of gonioapparent specimens, Practices E2194 and E2539. If the specimen exhibits STRONG hue flop, then Practice E2539 may be required depending on the intended use of the data. For most specimens however, the geometries specified in Practice E2194 should be adequate. The user is referred to the Significance and Use section of each standard for further guidance.

8.5 *Body-Color Specimen*—If the specimen being measured is a body-color (scattering) reflector (for example, a specimen having diffuse reflectance), assess the end-use to which the measurement will be put. If the measurements are intended for computer-assisted color-matching, proceed to 8.5.1. If the measurements being made are intended for quality-control purposes, proceed to 8.5.2. If the user is most interested in assessing appearance attributes of the specimen, proceed to 8.5.3.

8.5.1 *Computer-Assisted Color-Matching*—If the results are intended for match prediction in computer-assisted color-matching, then measure using hemispherical illumination, or collection, with the specular component included in accordance with Test Method E1331.

8.5.2 *Quality Control*—If the measurements being made are intended for quality-control purposes, assess whether the first-surface characteristics (gloss and texture attributes) of the standard and the trial are similar or dissimilar. If similar, proceed to 8.5.2.1. If dissimilar, proceed to 8.5.2.2.

8.5.2.1 If the first-surface of the standard specimen, and the first-surface of the trial specimen are similar, or identical, for gloss and texture characteristics, then measurement may be made by several methods. The user may choose hemispherical illumination, or collection, with the specular component included, or may elect that the specular component be excluded, both in accordance with Test Method E1331. For best discrimination of differences, and visual correlation, the user could under these conditions choose 45°/0° geometry in accordance with Test Method E1349. Each of these three methods produces a result that is consistent within its own set of geometrical conditions. Each is arbitrary in the sense that it is slightly, but significantly, different from the other geometries. Measurements made in one geometry are not interchangeable with measurements made in another geometry.

8.5.2.2 If the first-surface of the standard specimen and the first-surface for the trial specimen are dissimilar as to gloss or texture, then measure using hemispherical illumination with the specular component included in accordance with Test Method E1331.

8.5.3 *Appearance Attributes*—If the user is most interested in the results for assessing appearance attributes of the specimen, and good correlation to the average visual assessment, then measure using 45°/0° geometry in accordance with Test Method E1349.

8.6 For the determination of absolute specular reflectance of mirrors, mirror glasses, and polished metals, methods known as the "V-W" or "V-N method" can be used.[5] The description of these methods is beyond the scope of this guide.

9. Transmittance

9.1 If the specimen being measured is a liquid specimen, proceed to 9.2. If the specimen being measured is a solid specimen, proceed to 9.3.

9.2 *Liquid Specimen*—Choose a clear liquid of approximately the same index of refraction η as the sample being measured. Fill the sample cuvette with such liquid and standardize the instrument in accordance with Test Method E1348. Make the standardizing measurement with that liquid in place in the cuvette in the transmission sample holder of the instrument. Replace the liquid with the specimen liquid and make the trial measurement with hemispherical illumination, or collection, with the specular component included in accordance with Test Method E1348.

9.3 *Solid Specimen*—If the specimen being measured is a solid transmitting specimen, then measure using hemispherical illumination, or collection, with the specular component included in accordance with Test Method E1348.

9.4 Instruments with 0°/180° geometry may be useful for measuring the regular transmittance of both non-scattering liquids and non-scattering solids (see Table 2). The description of such geometry is beyond the scope of this guide.

9.5 See Fig. 4 for a flow chart of information contained in Sections 8 and 9.

10. Instrumentation Characteristics

8.1

10.1 *Vignetting*—There should be only one aperture stop in any instrument. This stop determines the cross-sectional area of the incident beam on the specimen. All incident rays within the limits of the illuminator aperture angle, and all rays within the receiver aperture angle, should reach the receiver and be given equal weight by the measurement system. Where the diameters of lenses or stops are too small, vignetting takes place. When vignetting occurs, the illumination, viewing, and aperture angles do not adequately describe the geometric properties of the instrument.

8.2

10.2 *The Helmholtz Reciprocal Relation*[6]—This relation states that the loss of flux density suffered by a bundle of rays due to reflection, refraction, absorption, or scattering by a specimen will not be changed if the direction of travel of the bundle is reversed. In other words, results of intercomparisons of specimens by reflectometers, glossmeters, etc., are not changed if the geometries of incident and viewing beams are interchanged. Because the pupil of the eye is small, visual instruments customarily have small receiver aperture angles. In any instrument with a large receiver window, rays entering different parts of the window should receive equal weight. Similarly, a large source should have uniform radiance in the direction of illumination. Several experimenters have presented evidence tending to refute the Helmholtz Reciprocal Relation, but it is strongly suspected that insufficient attention was given to the foregoing requirements for uniformity of weighting of all light fluxes leaving or entering the instrument apertures involved.

9.

11. Separation of Regular and Diffuse Components

911.1 Regularly and diffusely reflected and transmitted light are often not adequately differentiated and identified to enable their separation for measurement. Most objects and material distribute some light both regularly and diffusely; consequently the regular and diffuse components of reflection and transmission cannot be separated precisely for measurement.

10.12. Test Specimens

102.1 Surfaces for reflectance measurement should be flat and uniformly colored throughout the area exposed for measurement, while films and volumes for transmittance measurement should have two flat parallel faces. Where the specimens do not have these desired characteristics, departures should be reported.

10.2The12.2 The method of selecting, preparing, and conditioning specimens for reflectance and transmittance measurement should be identified. Some of the factors that may affect the measured results importantly are:

102.2.1 Supporting or underlying material,
102.2.2 Thickness and method of preparation,
102.2.3 Drying and conditioning technique,
102.2.4 Light exposure history,
102.2.5 Packing condition in powders,
102.2.6 Size distribution and orientation of particles,
10.2.712.2.7 Orientation of specimen,

[5] Clarke, F. J. J., and Parry, D. J., "Helmholtz Reciprocity: Its Validity and Application to Reflectometry," *Lighting Research and Technology*, Vol 17 , 1985, pp. 1–11.
[5] Springsteen, A., Techniques for the Measurement of Specular Reflectance , *Spectroscopy*, Vol 12, (9), 24-28, 1997.
[6] Clarke, F. J. J., and Parry, D. J., "Helmholtz Reciprocity: Its Validity and Application to Reflectometry," *Lighting Research and Technology*, Vol 17, 1985, pp. 1–11.