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AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

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

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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:*

C 346 Test Method for 45-deg Specular Gloss of Ceramic Materials[2]

C 347 Test Method for Reflectance, Reflectivity, and Coefficient of Scatter of White Porcelain Enamels[3]

C 523 Test Method for Light Reflectance of Acoustical Materials by the Integrating Sphere Reflectometer[4]

C 584 Test Method for Specular Gloss of Glazed Ceramic Whitewares and Related Products[5]

D 523 Test Method for Specular Gloss[6]

D 1003 Test Method for Haze and Luminous Transmittance of Transparent Plastics[7]

D 1455 Test Method for 60-deg Specular Gloss of Emulsion Floor Polish[8]

D 1494 Test Method for Diffuse Light Transmission Factor of Reinforced Plastics Panels[9]

D 1746 Test Method for Transparency of Plastic Sheeting[7]

D 1834 Test Method for 20-deg Specular Gloss of Waxed Paper[10]

D 4039 Test Method for Reflection Haze of High-Gloss Surfaces[6]

D 4061 Test Method for Retroreflectance of Horizontal Coatings[6]

E 97 Test Method for Directional Reflectance Factor, 45-deg, 0-deg, of Opaque Specimens by Broad-Band Filter Reflectometry[4]

E 167 Practice for Goniophotometry of Objects and Materials[6]

E 284 Terminology of Appearance[6]

E 429 Test Method for Measurement and Calculation of

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[2] *Annual Book of ASTM Standards*, Vol 02.05.

[3] Discontinued; see *1990 Annual Book of ASTM Standards*, Vol 02.05.

[4] Discontinued; see *1991 Annual Book of ASTM Standards*, Vol 14.02.

[5] *Annual Book of ASTM Standards*, Vol 15.02.

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

[7] *Annual Book of ASTM Standards*, Vol 08.01.

[8] *Annual Book of ASTM Standards*, Vol 15.04.

[9] *Annual Book of ASTM Standards*, Vol 08.04.

[10] *Annual Book of ASTM Standards*, Vol 05.01.

Reflecting Characteristics of Metallic Surfaces Using Integrating Sphere Instruments[6]

E 430 Method for Measurement of Gloss of High Gloss Surfaces by Goniophotometry[6]

E 808 Practice for Describing Retroreflection[6]

E 809 Practice for Measuring Photometric Characteristics of Retroreflectors[6]

E 810 Test Method for Coefficient of Retroreflection of Retroreflective Sheeting[6]

E 811 Practice for Measuring Colorimetric Characteristics of Retroreflectors Under Nighttime Conditions[6]

E 991 Practice for Color Measurement of Fluorescent Specimens[6]

E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation[6]

E 1767 Practice for Specifying the Geometry of Observations and Measurements to Characterize the Appearance of Materials[6]

F 768 Method for Specular Reflectance and Transmittance Measurements of Optically Flat-Coated and Non-Coated Specimens[11]

2.2 *CIE Publications:*[12]

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—the time rate of flow of radiant energy; radiant power (Terminology E 284).

3.1.2 *incident flux,* Φ_i—flux incident on the specimen at a specified illumination angle and aperture angle.

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

3.1.4 *reference reflected flux,* $\Phi_{r.r}$—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—flux transmitted through the specimen at a specified viewing angle and field angle.

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

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

3.1.8 *transmittance,* τ—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 E 284 and CIE Publication Nos. 17.4 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 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.

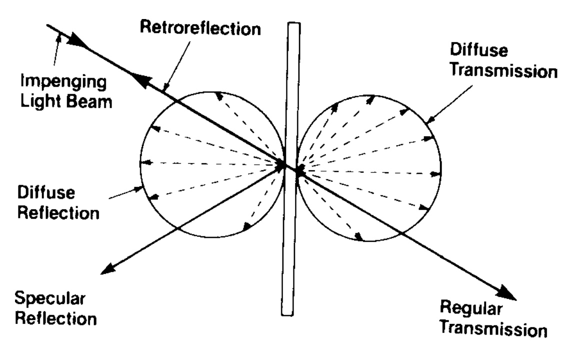


FIG. 1 Idealizations of Reflection and Transmission Phenomena, Showing Components

[11] Discontinued; see 1995 *Annual Book of ASTM Standards*, Vol 06.01.

[12] 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.

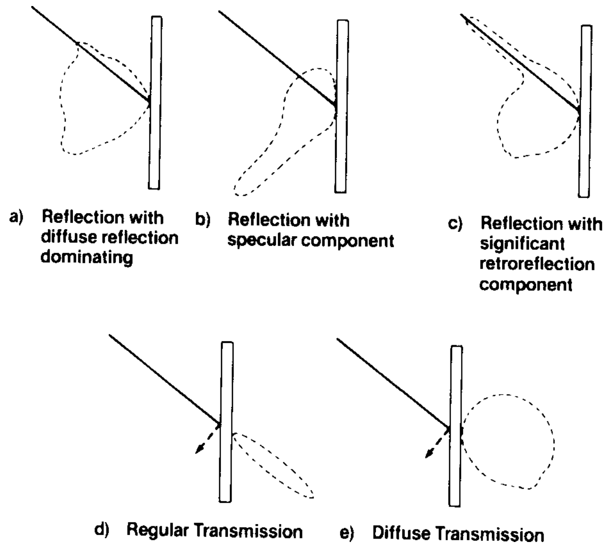


FIG. 2 Representations of Actual Reflection and Transmission Phenomena with Mixtures of Components

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

NOTE 2—This guide is concerned with bidirectional or hemispherical measurement systems. For gonophotometric methods, see Practice E 167. For methods of specifying the geometry of measurements, see Practice E 1767.

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).

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 E 1164 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.

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

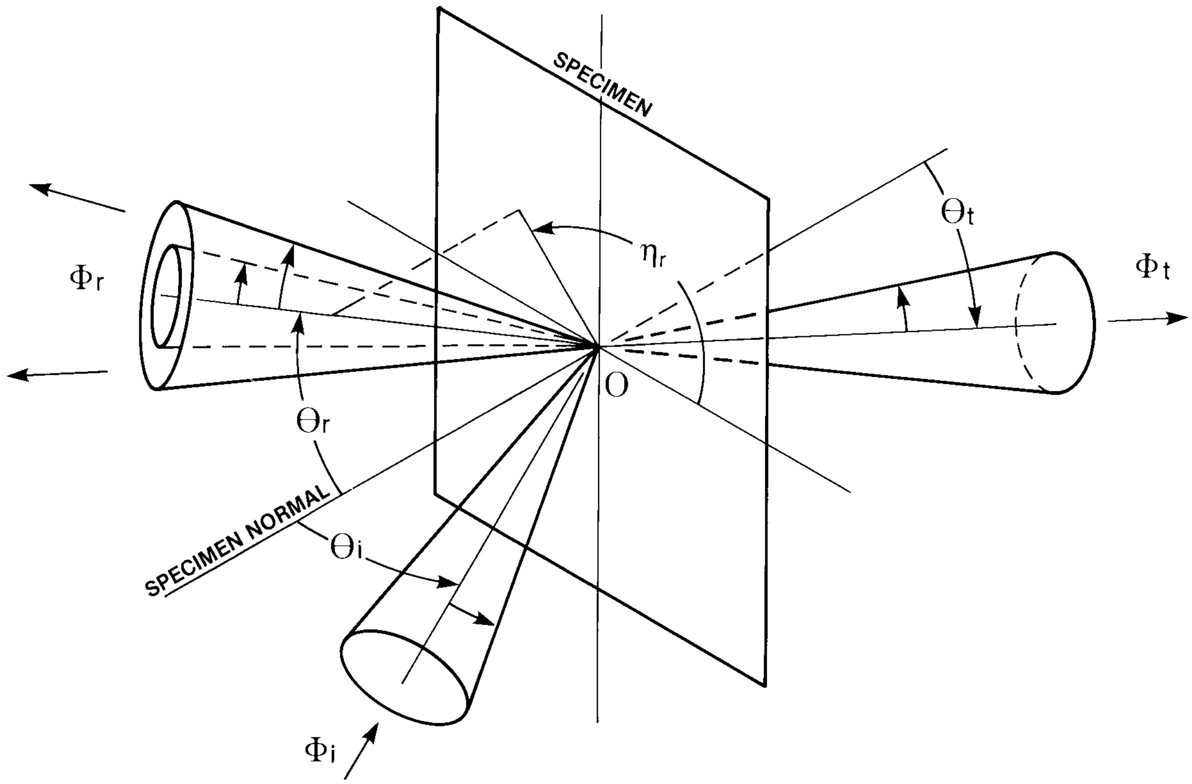


FIG. 3 Designations of Flux, Φ, and Angles θ, η, for Reflectance and Transmittance Measurement

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. Instrumentation Characteristics

8.1 *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 *The Helmholtz Reciprocal Relation*[13]—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. Separation of Regular and Diffuse Components

9.1 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. Test Specimens

10.1 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.

10.2 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:

10.2.1 Supporting or underlying material,

10.2.2 Thickness and method of preparation,

10.2.3 Drying and conditioning technique,

10.2.4 Light exposure history,

[13] 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.

10.2.5 Packing condition in powders,
10.2.6 Size distribution and orientation of particles,
10.2.7 Orientation of specimen,
10.2.8 Entrapment of air in liquids, and
10.2.9 Gross surface planarity and parallelism.

TABLE Geometric Scales of Reflectance and Transmittance Used for Evaluation of Appearance Attributes

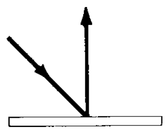
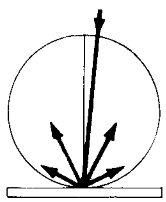
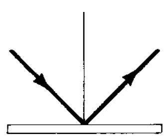
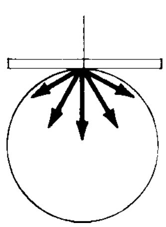
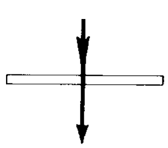
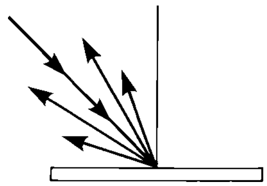
Appearance Attributes	Measurement Geometry	Characteristic Materials	ASTM Designations
Lightness, opacity, and color of surfaces	*R* (45/0) 	paints, papers, porcelain enamels, textiles, other nonmetallic surfaces	E 97 E1164 C347 F768
		fluorescent specimens	E991
		retroreflective specimens	E1164
	R (0) 	almost all nonmetallic materials	E 1164
		metallic surfaces	C523 E429 E430
Glossiness	$G_s(\Phi_i, \theta_i, \Phi_r, \theta_r)$ 		
	60° specular, 4.4° wide receiver	paints, plastics, waxes	D 523, D1455, C584
	85° specular, 4.0° wide receiver	low-gloss paint	D 523
	20° specular, 1.8° wide receiver	high-gloss paint, plastics	D 523
	75° specular, 11.4° diameter receiver	paper	
	45° specular, 8.0° wide receiver	porcelain enamels, plastics	C 346
	20° specular, 5.0° diameter receiver	waxed paper	D 1834
	30° specular, 0.4° wide receiver	metallic surfaces	E 430
	30° incidence, off specular by 0.3°, 2°, 5°	metallic surfaces	E 430
	reflection haze	nonmetallic surfaces	D 4039
Lightness and color by transmission, haze	τ(0/d) 	turbid solutions, plastic sheets	D 1003, D1494, F768
Transparency by transmission	τ(0/180) 	films and sheets	D 1746

TABLE *Continued*

Appearance Attributes	Measurement Geometry	Characteristic Materials	ASTM Designations
Retroreflection		retroreflective specimens	E 808, E809, E810, E811, D4061

11. Identification of Reflection and Transmission Quantities

11.1 Give values of reflectance or transmittance, and identify the following:

11.1.1 Specimen source and preparation,

11.1.2 Geometric scale from Table 2, together with the illuminating, viewing, and aperture angles as required,

11.1.3 Instrument used, together with such factors as area illuminated, measurement system, and specimen orientation, and

11.1.4 Standard of reflectance factor, if used, and its calibration information.

12. Keywords

12.1 geometric conditions; reflection; transmission