Designation: E 167 – 96

Standard Practice for
Goniophotometry of Objects and Materials[1]

This standard is issued under the fixed designation E 167; 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.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 Goniophotometry is a general procedure for evaluating the manner in which an object or a material geometrically distributes the unabsorbed portion of incident light, whether by reflection or by transmission.

1.2 The two former, essentially identical, Practices for Goniophotometry, E 166 for transmitted light and E 167 for reflected light, are now combined in this one practice.

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:*

E 284 Terminology of Appearance[2]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[2]

E 1767 Practice for Specifying the Geometry of Observations and Measurements to Characterize the Appearance of Materials[2]

3. Terminology

3.1 *Definitions:*

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *directional reflectance factor,* R_d, *n*—the ratio of the flux reflected from a specimen in a specified solid angle to the flux reflected from the perfect reflecting diffuser under the same geometric and spectral conditions of measurement.

3.2.2 *directional transmittance factor,* T_d, *n*—the ratio of the flux transmitted by a specimen in a specified solid angle to the flux transmitted under the same geometric and spectral conditions of measurement but in the absence of the specimen.

3.3 For other appearance terms and definitions see Terminology E 284.

4. Significance and Use

4.1 Spatial distribution of reflected or transmitted light is a physical property that can be used, in addition to shape and color, to characterize the appearance of an object or material.

4.2 Distribution of light by nearly uniform scattering in all directions, either by reflection or transmission, is termed diffusion. Distribution by reflection, mostly in and near the direction of specular (mirror) reflection, correlates with gloss. Distribution by reflection, mostly in and near the direction of the light source, is associated with retroreflection. Distribution by transmission, in a continuation of the direction of incidence, is termed regular transmission. As most objects and materials display varying combinations of these modes, and as the final visual effect is dependent upon this combination, goniophotometry provides an important technique for studying appearance.

4.3 Goniophotometric data may also be used in studying surface structure, rates of degradation, and suspended solids. It may also be used as a guide to choosing specific directions of illumination and view, to be used for more routine evaluation of objects or materials of a specific type.

5. Apparatus

5.1 *Geometric Components* (see Fig. 1 and Fig. 2):

5.1.1 *Specimen Mounting*, located at the intersection of the axes of the source arm and the receptor arm. In the reflection mode, the intersection should lie on the specimen surface; in the transmission mode it may lie within the specimen or at either face of the specimen, but the location should be specified.

5.1.2 *Source Arm*—A light source and lens for projecting an incident beam of light rays onto the specimen within a narrow cone about the central angle of incidence, *i*.

5.1.3 *Receptor Arm*—An optical system and detector for receiving rays that leave the specimen in a narrow cone about the central angle of view, *v*.

5.1.4 *Parallel- and Converging-Ray Light-Beam Configurations*—The parallel-ray configuration is shown in Fig. 1. This configuration has lenses in both source and

[1] This recommended practice is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.03 on Geometry.

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

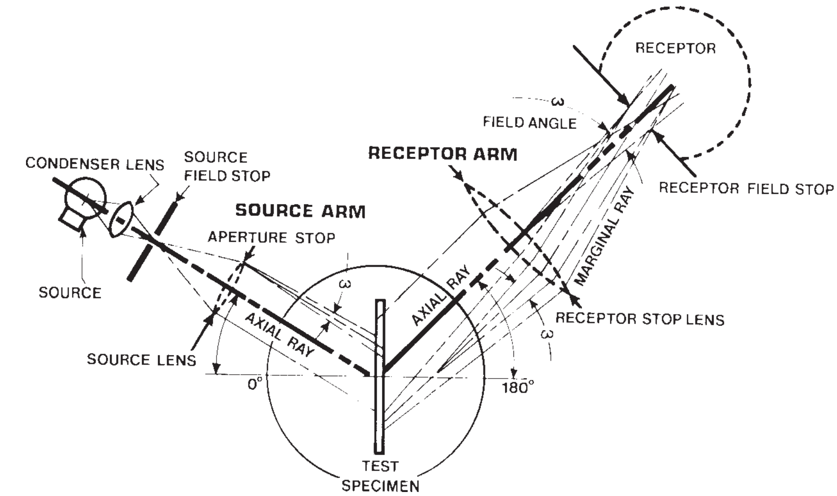

FIG. 1 Components of a Parallel-Beam Goniophotometer in Transmission Configuration

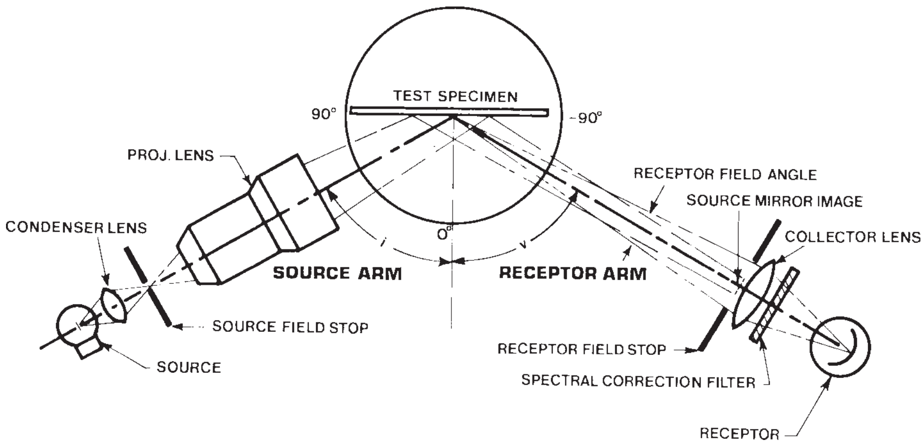

FIG. 2 Components of a Converging-Beam Goniophotometer in Reflection Configuration

receptor beams to render light rays, respectively, incident upon, and received from the specimen as nearly parallel as possible. Note that one of the lenses (the receptor lens in Fig. 1) must be larger than the other to avoid vignetting. The converging-ray configuration has only one lens, which, in the example shown in Fig. 2, is in the source arm. The principal rays of the converging beam design, shown in Fig. 2, are not parallel to each other as they strike and then leave the specimen. However, this design is less susceptible to vignetting, requires centering of only one, not two, lens systems, and offers higher angular resolution than the parallel beam design. For one or more of these reasons, it is widely used for goniophotometry.

NOTE 1—Two of the foregoing three components must be free to rotate about the intersection of their axes in the specimen plane, so that the angles of the incident and viewing beams, *i* and *v*, respectively, are variable at will. These angles are measured between the axis and the perpendicular to the illuminated specimen plane at the point of intersection. By convention, in retroreflection studies, incidence angles are designated as negative if both receptor and source arms are in the same quadrant and angle *v* is larger than angle *i*.

NOTE 2—Although Fig. 1 illustrates a parallel-beam configuration used in a transmission goniophotometer, and Fig. 2 shows a converging-beam configuration used in a reflection goniophotometer, either configuration can be used for either purpose.

NOTE 3—Most goniophotometric measurements are confined to a plane that is perpendicular to the specimen plane, hence are termed monoplane. Where measurements in other planes are desired, the specimen may be rotated about an axis in its own plane. Alternatively, either the source or the receptor arm may be constructed to permit movement about an axis perpendicular to the specimen plane, as required.

5.1.5 *Source Aperture Stop*, s_i, should be variable to adjust the size of the specimen illuminated for measurement. Source and receptor field angles, ω_i and ω_v, should be variable to accommodate different types of specimens involving different measurement problems. These field angles are solid angles and may have either pyramidal or conical shapes.

NOTE 4—For a more detailed analysis of the geometry of light beams, consult references on optical instrument design and Practice E 1767.[3]

5.1.6 When specimens are translucent, the viewed area on the specimen from the receptor should always be larger than the illuminated area to minimize the edge loss.[4]

[3] Smith, W. J., *Modern Optical Engineering*, McGraw-Hill, New York, 1966.

[4] "The Translucent Blurring Effect—Method of Evaluation and Estimation," *NISTS Technical Note 594-12*, National Institute of Standards and Technology, October 1976.

5.2 *Spectral Conditions*—Unless otherwise indicated, the spectral emittance of the source should correspond to CIE Illuminant C. The spectral response of the receptor shall be that of the CIE luminous efficiency function for photopic vision ($\bar{y}$ in Practice E 308).

5.3 *Measurement Mechanism*—The receptor-measurement mechanism shall be linear to within ±2 % of full scale or to within ±10 % of the magnitude of a reading, whichever is the smaller. Repeatability shall be within one half of the linearity limits.

6. Choice Between Variation of Incidence and Viewing Angles

6.1 The amount of light accepted for measurement is a function of the angle of incidence and the angle of viewing, as well as the sizes of source and receptor apertures. Measurement as a function of direction may be made by varying the angle of incidence, *i*, or the angle of viewing, *v*.

6.1.1 When measurements are made by varying *i*, for a fixed value of *v*, the light falling on the photoreceptor is proportional to the directional reflectance or transmittance factors expressed in terms of the perfect reflecting diffuser.

6.1.2 When information is desired on the change of light as a function of the angle of view, or where specimens are such that the amount of light reflected or transmitted in different directions may vary with the illuminated specimen area, the viewing angle, *v*, should be varied.

7. Procedure

7.1 *Selection of Angular Conditions of Measurement*—The materials being investigated and the information that is desired will influence selection of the angular conditions of measurement. In general, the following shall prevail:

7.1.1 Select the fixed directions to be used for the materials being investigated.

7.1.2 Select the aperature field angles sufficiently narrow that the narrowest concentration of light flux by the specimens can be faithfully differentiated, yet, at the same time, provide adequate detector signal.

NOTE 5—The resolution of the human eye (the angular separation of two points discerned as separate, as measured at the eye) is approximately 0.01°. The corresponding angular resolution of the goniophotometer optical diagrams in Fig. 1 and Fig. 2 approximates ω_i, ω_v, whichever is larger.

7.1.3 Provide a receptor aperature angle ω_v somewhat larger than the source aperature angle ω_i.

7.1.4 When the angle of incidence, *i*, is to be varied, make aperture stop, S_i, so narrow that the incident beam does not exceed the specimen width at the largest angle of incidence for which measurement is desired.

7.1.5 When measurement conditions require illumination of a large area of sample and a variable angle of viewing, *v*, make the viewing aperture stop so narrow that the viewed area is uniformly illuminated at the largest angle of viewing for which measurement is desired.

7.2 *Calibration*—The method chosen for calibration by means of ASTM standards is determined by the character of the materials to be measured.

7.2.1 If the specimens are strong diffusers, calibrate in terms of 45/0 or 0/45 bidirectional reflectance factor. This is done as follows: Use a calibrated 45°, 0° standard and set $i = 45°$, $v = 0°$ (or the converse if more convenient). Adjust the meter or chart for convenience to make the numerical indication equal to the assigned value of the standard times an integral power of 10.

7.2.2 For specular reflection or transmission measurement, calibrate in terms of fractional reflectance, that is the ratio of the flux reflected from, to that incident on, a specimen for specified solid angles. Allow the incident beam to fall on the receptor and adjust the readout to provide an indication near maximum. For calibration at lower values, use a polished black glass standard for which the gloss reflectance factor has been computed for the angle of incidence to be used, or is otherwise known. Set $v = i$ and adjust the instrument to indicate the known gloss reflectance factor of the standard times an integral power of 10.

7.3 *Measurement*—Insert the test specimen (marked with an arrow showing the direction of illumination) in accordance with a prearranged plan. Take data in the manner prescribed for the instrument.

NOTE 6—Where specimens are translucent, instruments will give low readings when light, striking the specimen near the edges of the specimen window, travels within the specimen and is trapped.

7.3.1 For nonrecording instruments, take readings at angular intervals sufficiently small to ensure adequate rendition of the goniophotometric curve. In and near the direction of specular reflection, or direction of greatest transmission, readings should be taken at no greater than 1° intervals, elsewhere at no greater than 5° intervals. Make at least one repeat setting for each individual specimen at each angle, preferably in reverse order.

7.3.2 For recording instruments, to assure that the recording pen does not lag behind rapid changes in light flux, reduce the angular scanning rate (change in angle per unit time) in the vicinity of flux concentration. Make at least one repeat curve for each specimen.

7.3.3 To eliminate the effect of steady instrumental drift, take repetitions in reverse order. Repeat calibration with the standard at least every 5 min and at the end of each series of observations.

8. Calculation

8.1 Calculate the average reading for each specimen at each angle, *v*. Calculate the average reading for the standard at angle $v = 0$ deg. Calculate the directional or fractional reflectance factor for each angle *i* and *v* from the perpendicular, as required, as follows:

$$\text{Directional reflectance factor, } R_d = \frac{S_x R_s}{s_s \cos v} \quad (1)$$

$$\text{Fractional reflectance, } R_f = \frac{S_x R_s}{S_s} \quad (2)$$

where:

cos *v* = correction factor for the change in viewed area with change in angle of viewing v, when the viewed area is larger than the illuminated area,

S_x = reading for the specimen,
R_s = assigned reflectance factor of the standard for perpendicular viewing, and
S_s = reflectance reading for the standard, also for perpendicular viewing.

8.1.1 For transmission, use analogous scales and terminology as follows:

$$\text{Directional transmittance factor, } T_d = \frac{\pi}{\omega_v}\left(\frac{S_x}{\cos\ v}\right)\frac{1}{S_o} \quad (3)$$

$$\text{Fractional transmittance, } T_f = S_x/S_o \quad (4)$$

where:
ω_v = fixed angle of viewing (steradians),
S_x = reading for the specimen, and
S_o = reading for the source directly.

9. Report

9.1 For each goniophotometric curve or table of goniophotometric data, the report shall include the following:

9.1.1 Instrument used.

9.1.2 Specimen, its preparation, mounting, and illuminated area. (Indicate area for i = 0 deg, when variable i is used.)

9.1.3 Fixed angle of illumination or viewing, size and shapes of the aperature solid angles of incidence and viewing, w_i and w_v.

9.1.4 Spectral radiance distribution of source when different from CIE Illuminant C and spectral response of receptor when different from the CIE luminous efficiency function for photopic vision.

9.1.5 Standard used and values assigned.

9.2 In any table of goniophotometric results, report for each specimen and for each geometric condition, the calculated reflectance or transmittance factors. Indicate whether diffuse or fractional basis is reported.

9.3 For reflecting specimens, plot as goniophotometric curves, either reflectance factor or fractional reflectance as functions of variable i or v. Indicate which reflectance scale is used. Polar logarithmic scales, as shown in Fig. 3, are convenient for this purpose. For transmitting specimens, use analogous scales and terminology.

10. Keywords

10.1 goniophotometry; reflection; transmission

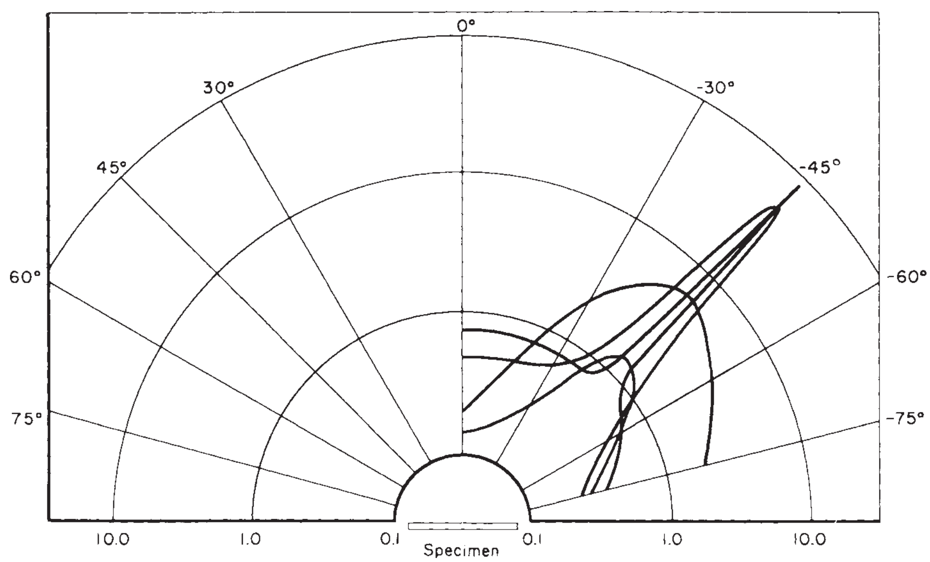

FIG. 3 Goniophotometric Reflection Curves of Several Materials (Angle of Incidence = 45°)