Designation: E 1347 – 97

Standard Test Method for Color and Color-Difference Measurement by Tristimulus (Filter) Colorimetry[1]

This standard is issued under the fixed designation E 1347; 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.

1. Scope

1.1 This test method describes the instrumental measurement of color coordinates and color differences by using a tristimulus (filter) colorimeter, also known as a color-difference meter. This test method does not apply to the use of a spectrocolorimeter, which is a spectrophotometer that is normally capable of producing as output colorimetric data, but not the underlying spectral data from which color coordinates are calculated. Measurement by using a spectrocolorimeter is covered in Practice E 1164 and methods on color measurement by spectrophotometry.

1.2 Provision is made in this test method for the measurement of color coordinates and color differences by reflected light using either a hemispherical optical measuring system, such as an integrating sphere, or a bidirectional optical measuring system, such as annular, circumferential, or uniplanar 45/0 or 0/45 geometry. Provision is also made for measurement by transmitted light using a hemispherical optical measuring system.

1.3 Because of the limited absolute accuracy of tristimulus (filter) colorimeters, this test method specifies that, when color coordinates are required, the instrument be standardized by use of a standard having similar spectral (color) and geometric characteristics to those of the specimen. The use of a product standard of suitable stability is highly desirable.

1.4 Because of the inability of tristimulus (filter) colorimeters to detect metamerism or paramerism, or to correctly measure metameric or parameric pairs of specimens, this test method specifies that, when color differences are required, the two specimens must have similar spectral (color) and geometric characteristics. In this case, the instrument may be standardized for reflectance measurement by use of a white reflectance standard or, for transmittance measurement, with no specimen or standard at the specimen position.

1.5 While this test method is generally suitable for all object-color specimens, it should not be used without observing certain restrictions on the geometries and standardization procedures appropriate for different types of specimens and uses, and on the spectral character (metamerism or paramerism) of specimens and standards.

1.6 *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:*

D 2244 Test Method for Calculation of Color Differences from Instrumentally Measured Color Coordinates[2]

D 4086 Practice for Visual Evaluation of Metamerism[2]

E 167 Practice for Goniophotometry of Objects and Materials[2]

E 179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials[2]

E 284 Terminology Relating to Appearance[2]

E 805 Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials[2]

E 991 Practice for Color Measurement of Fluorescent Specimens[2]

E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation[2]

3. Terminology

3.1 *Definitions:*

3.1.1 The definitions in Guide E 179, Terminology E 284, and Practice E 1164 are applicable to this test method.

4. Summary of Test Method

4.1 This test method provides procedures for measuring object-color specimens with a tristimulus (filter) colorimeter (hereafter referred to as a colorimeter) by use of the following geometric conditions and standardization procedures:

4.1.1 Color differences by reflected light of nonmetameric, nonparameric pairs of opaque or translucent specimens by use of either hemispherical geometry, with an integrating sphere, or bidirectional geometry, such as annular, circumferential, or uniplanar 45/0 or 0/45 geometry. The colorimeter may be standardized by use of a white reflectance standard.

[1] This test method is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.02 on Spectrophotometry and Colorimetry.

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

4.1.2 Color differences by transmitted light of nonmetameric, nonparameric pairs of transparent or translucent specimens by use of hemispherical geometry. The colorimeter may be standardized by use of a white standard at the reflection port of the integrating sphere and with no specimen in place. When translucent specimens are measured, they should be placed flush against the transmission port of the sphere, and the white standard should, for maximum accuracy, have the same reflectance and chemical composition as that of the lining of the sphere.

4.1.3 Color coordinates by reflected light of opaque or translucent specimens by use of either bidirectional or hemispherical geometry. The colorimeter may be standardized by use of a standard having spectral (color) and geometric characteristics similar to those of the specimens. Such standards, often called *hitching-post* standards, are hereafter referred to as local standards.[3]

4.1.4 Color coordinates by transmitted light of transparent or translucent specimens by use of hemispherical geometry. The colorimeter may be standardized by use of a local standard.

4.1.5 When the specimens are retroreflective or fluorescent, only bidirectional geometry is to be used.

4.1.6 When the specimens exhibit directionality, and a colorimeter with uniplanar bidirectional geometry is used, information on directionality may be obtained by measuring the specimens at more than one rotation angle, typically at two angles 90° apart. When such information is not required, these measurements may be averaged, or a colorimeter with annular or circumferential bidirectional geometry may be used.

4.2 This test method includes two different procedures for standardizing the colorimeter, one utilizing a white standard of reflectance factor, the other a local standard.

4.2.1 When absolute values of color coordinates are to be determined, the use of a white standard is recommended only with colorimeters in which there is good conformance of the colorimeter readings to CIE tristimulus values, as determined by measurement of suitable verification standards (see Practice E 1164, 9.5). With instruments not meeting this requirement, the use of local standards is recommended, but only when the signal level from the use of each colorimeter filter is adequately high.

NOTE 1—Of necessity, the above requirements are in part subjective, as the methods for verifying conformance to the requirements may not be available to the average user. Each user must decide whether the standardization procedure selected results in a loss of accuracy in the measurements that is negligibly small for the purpose for which data are obtained.

4.2.2 When color differences are to be measured, only relative measured values are required for the two members of the color-difference pair, and standardization by use of either a white standard or a local standard is satisfactory. In those cases where a computer program is being used to predict color tolerances, accuracy of the absolute values of the product standard color coordinates may become more important (see 4.2.1).

4.2.3 The restrictions to nonmetameric, nonparameric specimens apply to the considerations of this section and throughout.

4.3 Procedures for selecting specimens suitable for precision measurement are included in this test method.

4.4 Most modern colorimeters can compute the color coordinates of the specimen during the measurement. When this is the case, the user of this test method must designate the color system to be used in the computation (see Method D 2244).

5. Significance and Use

5.1 The most direct and accessible methods for obtaining the color differences and color coordinates of object colors are by instrumental measurement using colorimeters or spectrophotometers with either hemispherical or bidirectional optical measuring systems. This test method provides procedures for such measurement by use of a tristimulus (filter) colorimeter with either a bidirectional or a hemispherical optical measuring system.

5.2 This test method is suitable for measurement of color differences of nonmetameric, nonparameric pairs of object-color specimens, or color coordinates of most such specimens. A further limitation to the use of colorimeters having hemispherical geometry is the existence of a chromatic integrating-sphere error that prevents accurate measurement of color coordinates when the colorimeter is standardized by use of a white standard.[4]

5.3 For the measurement of retroreflective or fluorescent specimens by this test method, the use of bidirectional geometry is preferred for maximum accuracy (see Guide E 179, Practice E 805, and Practice E 991).

5.4 A requirement for the use of a tristimulus (filter) colorimeter to obtain accurate color coordinates is that the combination of source, filter, and detector characteristics duplicate accurately the combined characteristics of a CIE standard illuminant and observer. When this requirement is not met, this test method requires the use of local standards for improving accuracy in the measurement of color coordinates (see also 4.2). For the measurement of small color differences between nonmetameric, nonparameric specimens, accuracy in absolute color coordinates is less important and standardization of the colorimeter by use of a white standard is satisfactory. However, accurate color-difference measurement requires that specimen pairs be neither metameric nor parameric, that is, the members have similar spectral and geometric characteristics.

6. Apparatus

6.1 *Tristimulus (filter) Colorimeter*, designed for the measurement of object-color specimens, using either hemispherical or bidirectional geometry.

6.2 *Calibration Standards*, either supplied by the manufacturer or obtained separately, as follows:

6.2.1 *White Reflecting Tile or Standard (Mandatory)*—(If the colorimeter has hemispherical geometry, a standard of hemispherical reflectance factor is required; if bidirectional

[3] Hunter, R. S., "Photoelectric Tristimulus Colorimetry with Three Filters," *Journal, Optical Society of America*, Vol 32, 1942, pp. 509–558.

[4] Hoffman, K., "Chromatic Integrating-Sphere Error in Tristimulus Colorimeters," *Journal of Color and Appearance*, Vol 1, No. 2, 1971, pp. 16–21.

geometry, a standard of bidirectional reflectance factor is required.)

6.2.2 *Local Calibration Standards*, having spectral (color) and geometric characteristics similar to those of specimens to be measured, as required for the measurement of color coordinates (recommended).

6.2.3 *Light Trap (Hemispherical) or Polished Black Glass (Bidirectional) Standards*, for setting or verifying the zero reading of the colorimeter (recommended; mandatory if so indicated by the manufacturer).

6.3 *Verification Standards*, either supplied by the manufacturer or obtained separately (recommended).

6.4 *Standard Backing Material(s)*, for backing translucent specimens during measurement (recommended).

7. Test Specimens

7.1 For highest precision and accuracy, select specimens with the following properties:

7.1.1 High material uniformity and freedom from blemishes in the area to be measured, and

7.1.2 Opaque specimens that have at least one plane surface; translucent and transparent specimens that have two essentially plane and parallel surfaces and that have a standard thickness, when one is specified.

7.2 Determine that specimen pairs are neither metameric nor parameric, either by visual examination under two or more different light sources (see Practice D 4086) or by spectrophotometric comparison of spectral characteristics (see Practice E 1164) and, if necessary, goniophotometric comparison of geometric characteristics (see Practice E 167).

8. Standardization and Verification

8.1 *Standardization for the Measurement of Color Differences of Nonmetameric, Nonparameric Specimen Pairs*:

8.1.1 Standardize the colorimeter by use of the white standard and the zero-reading standard (if required), following the manufacturer's instructions (mandatory).

8.1.2 Verify the accuracy of the calibration and the instrument performance by measuring a series of verification standards (recommended).

8.2 *Standardization for Measurement of Color Coordinates*:

NOTE 2—If the verification tests of 8.2.2 are not to be carried out, omit 8.2.1 and 8.2.2 and proceed to 8.2.3.

8.2.1 Standardize the colorimeter by use of the white standard and the zero-reading standard (if required), following the manufacturer's instructions (mandatory).

8.2.2 Verify the accuracy of the calibration and the instrument performance by measuring a series of verification standards (recommended).

8.2.3 Standardize the colorimeter by use of the appropriate local standard for the specimens to be measured and the zero-reading standard (if required), following the manufacturer's instructions (mandatory).

9. Procedure

9.1 When required, select the color scales to be used in the computation of color coordinates or color differences.

9.2 Handle the specimen carefully; avoid touching the area to be measured. When necessary, clean the specimen by an agreed procedure.

9.3 When hemispherical geometry is used, make the following selections:

9.3.1 For the measurement of reflecting specimens, select inclusion or exclusion of the specular component of reflection as desired (see Guide E 179 and Practice E 805).

9.3.1.1 If the specimen is translucent, back it with a standard backing material during the measurement.

9.3.2 For the measurement of fully transparent specimens by transmission, place the specimen in the transmission compartment of the colorimeter.

9.3.2.1 If total luminous quantities are desired, place the specimen flush against the transmission measurement port of the integrating sphere.

9.3.2.2 If regular luminous quantities are desired, place the specimen as far away from the sphere port as possible.

9.3.3 For the measurement of translucent specimens, place the specimen in the transmission compartment, flush against the transmission measurement port of the integrating sphere. For maximum accuracy, the white standard at the reflection port should have the same reflectance and chemical composition as that of the lining of the integrating sphere.

9.4 When bidirectional geometry is used, make the following selections:

9.4.1 If the specimen exhibits directionality and the instrument has uniplanar geometry, measure the specimen at two rotation angles 90° apart, usually parallel to and perpendicular to the machine or processing direction, or use another specified procedure.

9.5 Measure the specimen, following the instrument manufacturer's instructions.

9.5.1 If the specimen is translucent, back it with a standard backing material during the measurement.

9.6 Transcribe the data required for the report, when not printed by the instrument.

10. Calculation

10.1 Perform any desired calculations of color coordinates that are not made automatically by the instrument (see Method D 2244).

10.1.1 When specimens exhibiting directionality are measured at two or more rotation angles with instruments using uniplanar bidirectional geometry, average the instrumental data

TABLE 1 Comparison of Colorimeters with Reference Spectophotometer 24 Glossy and Matt Tiles (Whites, Greys, Blacks, Reds, Greens, Yellows, Cyans, Pinks, Oranges)

	Laboratory 15 0/45 2° observer Illuminant C	Laboratory 16 0/45 2° observer Illuminant C	Laboratory 22 SPEX 2° observer D65	Laboratory 22 SPIN 2° observer D65	Laboratory 24 0/45 2° observer D65	NPL uncertainty
Mean ΔE	0.92	1.23	1.82	2.69	2.32	0.36
Max ΔE	3.01	4.56	3.82	7.36	4.87	0.60

at all rotation angles measured when information on directionality is not required.

11. Report

11.1 Report the following information:

11.1.1 Specimen description (see Practice E 1164, 12),

11.1.2 Date of measurement,

11.1.3 Instrument measuring geometry—

11.1.3.1 For bidirectional geometry: 45/0 or 0/45 illumination and viewing; annular, circumferential, or uniplanar geometry; and number and angular distribution of multiple illumination or viewing beams.

11.1.4 Instrument parameters as specified in steps 9.1 and 9.3 or 9.4,

11.1.5 Measurement results, in the form of color-scale values or color differences (see Test Method D 2244),

11.1.6 Identification of backing material used,

11.1.7 Identification of local standard(s),

11.1.8 Indicate averaged or single reading,

11.1.9 Instrument model and serial number,

11.1.10 Temperature,

11.1.11 Humidity, and

11.1.12 Operator.

12. Precision and Bias

12.1 An important use of this class of instrument is in determining color differences between similar specimens. No data concerning the precision and bias typical of this use are available. It is expected, however, that precision and bias for color difference would be significantly better than precision and bias for measurement of color coordinates of individual specimens.

12.2 Intercomparison of color coordinates is a stringent test for colorimeters. The best colorimeters provide color coordinates that differ from those obtained with a reference spectrophotometer by about four times the difference, on average, from those obtained with other spectrophotometers. Differences on neutral targets, however, may be much smaller.

12.3 Table 1 lists the average and maximum CIELAB color differences between measurement by colorimeter of 24 tiles and measurement by a reference spectrophotometer at the National Physical Laboratory (see NPL Report QU 113).[5]

13. Keywords

13.1 bidirectional geometry; color; color difference; colorimeter; filter colorimeter; integrating sphere; tristimulus colorimeter

[5] Verrill, J. F., Clarke, P. J., O'Halloran, J., and Knee, P. C., "NPL Spectrophotometry and Colorimetry Club Intercomparison of Colour Measurements," *NPL Report QU 113*, National Physical Laboratory, June 1995.