Designation: E 313 – 98

AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates[1]

This standard is issued under the fixed designation E 313; 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 This practice provides numbers that correlate with visual ratings of yellowness or whiteness of white and near-white or colorless object-color specimens, viewed in daylight by an observer with normal color vision. White textiles, paints, and plastics are a few of the materials that can be described by the indices of yellowness or whiteness calculated by this practice.

1.2 For a complete analysis of object colors, by a specified observer and under a specified illuminant, use of three parameters is required. For near-white specimens, however, it is often useful to calculate single-number scales of yellowness or whiteness. This practice provides recommended equations for such scales and discusses their derivations and uses, and limits to their applicability (see also Ref **(1)**[2]).

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:*

D 1535 Practice for Specifying Color by the Munsell System[3]
D 1729 Practice for Visual Examination of Color Differences of Opaque Materials[3]
D 1925 Test Method for Yellowness Index of Plastics[4]
E 284 Terminology of Appearance[3]
E 308 Practice for Computing the Colors of Objects by Using the CIE System[3]
E 805 Practice for Identification of Instrumental Methods of Color or Color-Difference Measurement of Materials[3]
E 991 Practice for Color Measurement of Fluorescent Specimens[3]
E 1164 Practice for Obtaining Spectrophotometric Data for Object-Color Evaluation[3]
E 1247 Test Method for Identifying Fluorescence in Object-Color Specimens by Spectrophotometry[3]
E 1331 Test Method for Reflectance Factor and Color by Spectrophotometry Using Hemispherical Geometry[3]
E 1345 Practice for Reducing the Effect of Variability of Color Measurement by Use of Multiple Measurements[3]
E 1347 Test Method for Color and Color-Difference Measurement by Tristimulus (Filter) Colorimetry[3]
E 1348 Test Method for Transmittance and Color by Spectrophotometry Using Hemispherical Geometry[3]
E 1349 Test Method for Reflectance Factor and Color by Spectrophotometry Using Bidirectional Geometry[3]
E 1360 Practice for Specifying Color by Using the Optical Society of America Uniform Color Scales System[3]
E 1499 Guide to the Selection, Evaluation, and Training of Observers[3]
E 1541 Practice for Specifying and Matching Color Using the Colorcurve System[3]

3. Terminology

3.1 Terms and definitions in Terminology E 284 are applicable to this practice.

3.2 *Definitions:*

3.2.1 *perfect reflecting diffuser, n*—ideal reflecting surface that neither absorbs nor transmits light, but reflects diffusely, with the radiance of the reflecting surface being the same for all reflecting angles, regardless of the angular distribution of the incident light.

3.2.2 *whiteness, n*—the attribute of color perception by which an object color is judged to approach the preferred white.

3.2.3 *whiteness index, WI, n*—a number, computed by a given procedure from colorimetric data, that indicates the degree of departure of an object color from that of a preferred white.

3.2.4 *yellowness, n*—the attribute of color perception by which an object color is judged to depart from colorless or a preferred white toward yellow.

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[1] This practice is under the jurisdiction of ASTM Committee E-12 on Appearance and is the direct responsibility of Subcommittee E12.04 on Color and Appearance Analysis.

Current edition approved Oct. 10, 1998. Published December 1998. Originally published as E 313 – 67. Last previous edition E 313 – 96.

[2] The boldface numbers in parentheses refer to the list of references at the end of this practice.

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

[4] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 08.01.

3.2.5 *yellowness index, YI, n*—a number, computed by a given procedure from colorimetric or spectrophotometric data, that indicates the degree of departure of an object color from colorless or from a preferred white, toward yellow.

3.2.5.1 *Discussion*—Negative values of *YI* denote departure toward blue.

3.3 *Definitions of Terms Specific to This Practice*:

3.3.1 *near white, n*—a color having a Munsell value greater than 8.3 (luminous reflectance factor $Y = 63$) and Munsell chroma no greater than 0.5 for *B* hues, 0.8 for *Y* hues, and 0.3 for all other hues.

3.3.2 *preferred white, n*—color of a white standard used as the basis for calculating indices of whiteness or yellowness as the departure of the color of the specimen from that of the preferred white; *in this practice*, the perfect reflecting diffuser.

4. Summary of Practice

4.1 The calculations described in this practice assume that specimens have been measured according to Practices E 1164 and E 308 and one of the Test Methods E 1331, E 1347, E 1348, or E 1349, depending on the type of specimen and measuring instrument used (see also Practice E 805).

4.2 This practice takes as a starting point for the calculations CIE tristimulus values *X*, *Y*, and *Z* for one of the CIE standard observers and one of the CIE standard or recommended illuminants of daylight quality. Such tristimulus values are available by use of modern color measuring instruments.

4.3 Equations for the preferred methods of calculating *YI* and *WI* are described in Sections 6 and 7, respectively. Equations for calculating other quantities used as indices of yellowness or whiteness are given in Appendix X1 and Appendix X2, respectively.

5. Significance and Use

5.1 This practice should be used only to compare specimens of the same material and same general appearance. For example, a series of specimens to be compared should have generally similar gloss, texture, and (if not opaque) thickness, and translucency.

5.2 For yellowness measurement, this practice is limited to specimens having dominant wavelength in the range 570 to 580 nm, or Munsell hue approximately 2.5*GY* to 2.5*Y*. For whiteness measurement, this practice is limited to specimens having Munsell value greater than 8.3 (CIE *Y* greater than 65) and Munsell chroma no greater than 0.5 for *B* hues, 0.8 for *Y* hues, and 0.3 for all other hues (see 3.3.1).

5.3 The combination of measurement and calculation leading to indices of yellowness or whiteness is a psychophysical process, that is, the procedures specified are designed to provide numbers correlating with visual estimates made under specified typical observing conditions. Because visual observing conditions can vary widely, users should compare calculated indices with visual estimates to ensure applicability. Some standards addressing the visual estimation of color and color difference are Practices D 1535, D 1729, E 1360, and E 1541, and Guide E 1499.

5.4 This practice does not cover the preparation of specimens, a procedure that may affect significantly the quantities measured. In general, specimens should be prepared and presented for measurement in the manner that is standard for the test being performed. Select enough specimens or specimen areas to provide an average result that is representative of each sample to be tested. See Practice E 1345.

6. Yellowness Index

6.1 *Background*—The currently recommended equation for the calculation of yellowness index is derived from an equation due to Hunter **(2)** in 1942: $YI = (A - B)/G$, where *A*, *B*, and *G* are, respectively, amber or red, blue, and green colorimeter readings. Another version, used in the 1940s to 1960s for transparent plastics **(3, 4)**, was based on transmittances near the ends of the visible wavelength region: $YI = 100(T_{680} - T_{420})/T_{560}$ (with a factor of 100 introduced to give values of *YI* near unity). This equation failed to account correctly for differences in the spectral transmittance curves of such plastics, especially after the adoption of ultraviolet light absorbers to improve weathering, and was soon abandoned. When, in 1957, ASTM solicited new equations for calculating yellowness indices, Hunter's equation was converted **(5)** into CIE tristimulus value form by using Hunter's approximate relations between colorimeter readings and those tristimulus values; the resulting equation, $YI = 100(1.28X - 1.06Z)/Y$, was adopted for use in Test Method D 1925 in 1962. (This Test Method was withdrawn in 1995 with the understanding that the cited yellowness index equation would be revised and incorporated in the next revision of E 313.)

6.1.1 In the original form of Test Method E 313, an alternative equation was recommended for a yellowness index. In terms of colorimeter readings, it was $YI = 100(1 - B/G)$. Its derivation assumed that, because of the limitation of the concept to yellow (or blue) colors, it was not necessary to take account of variations in the amber or red colorimeter reading *A*. This equation is no longer recommended.

6.2 *Significant Digits and Precision*—The coefficients of Test Method D 1925 equation were rounded to the number of digits shown, commensurate with the precision of then-existing color measurement instrumentation. It was not intended that more significance should be attributed to values of *YI* than that implicit in this number of digits. As instrumentation was improved, however, it was found that some instruments unexpectedly gave nonzero values of *YI* for clear air or the perfect reflecting diffuser. One suggested (**(1)**, p. 205) remedy for this presumed failure of the equation was to increase the number of digits in the numerical coefficients from two to ten after the decimal point, despite the obvious lack of significance of most of these digits. With modern instrumentation, it is believed that two digits added to the coefficients in the original Test Method D 1925 equation suffice to bring the nonzero value of *YI* below 0.0005 on average. The new coefficients are given to this precision in 6.3.

6.3 *Derivation of Equations*—Several sets of coefficients are involved in the derivation of the final equations recommended for calculating yellowness indices. With them evaluated, it is possible to derive highly precise equations for both the CIE 1931 standard observer and the 1964 supplementary standard observer, in combination with either CIE standard illuminant *C* or D_{65}. The results are given in Table 1.

6.3.1 The first set of coefficients required, consists of the