Designation: D 2244 – 93 (Reappproved 2000)

Standard Test Method for Calculation of Color Differences From Instrumentally Measured Color Coordinates[1]

This standard is issued under the fixed designation D 2244; 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.

INTRODUCTION

This test method originally resulted from the consolidation of a number of separately published methods for the instrumental evaluation of color differences. As revised in 1979, it included four color spaces in which color-scale values could be measured by instruments, many of which were obsolete, and the color differences calculated by ten equations for different color scales. The sections on apparatus, calibration standards and methods, and measurement procedures served little purpose in the light of modern color-measurement technology. The present revision omits these sections, and limits the color spaces and color-difference equations considered, to the three most widely used in the paint and related coatings industry.

1. Scope

1.1 This test method covers the calculation, from instrumentally measured color coordinates based on daylight illumination, of small color differences between nonfluorescent, nonmetameric, opaque specimens such as painted panels. (Where it is suspected that the specimens may be metameric, that is, possess different spectral curves though visually alike in color, Practices D 1729 and D 4086 should be used to verify instrumental results.) The color differences determined by these procedures are expressed in terms of approximately uniform visual color perception in CIE 1976 CIELAB opponent-color space **(1)**,[2] Hunter L_H, a_H, b_H opponent-color space **(2)**, and the Friele-MacAdam-Chickering (FMC-2) color space **(3)**.

1.2 For product specification, the permissible color difference between test specimen and reference and the procedure for calculating the color difference shall be agreed upon by the purchaser and the seller. Specific color tolerances may be required for each material and condition of use since other appearance factors (for example, proximity, gloss, and texture) may affect the correlation between the magnitude of a measured color difference and its commercial acceptability.

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 1729 Practice for Visual Evaluation of Color Differences of Opaque Materials[3]

D 3964 Practice for Selection of Coating Specimens for Appearance Measurements[3]

D 4086 Practice for Visual Evaluation of Metamerism[3]

E 179 Guide for Selection of Geometric Conditions for Measurement of Reflection and Transmission Properties of Materials[3]

E 284 Terminology of Appearance[3]

E 308 Practice for Computing the Colors of Objects by Using the CIE System[3]

3. Terminology

3.1 *Definitions*—For the following definitions as well as for other definitions of terms used in this test method, see Definitions E 284: tristimulus values, chromaticity coordinates, and opponent-color scales.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *color difference:*

3.2.1.1 *color difference (perceived)*—the magnitude and character of the difference between two colors described by such terms as redder, bluer, lighter, darker, grayer, or cleaner.

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

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

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

3.2.1.2 *color difference (computed)*—the magnitude and direction of the difference between two psychophysical color stimuli defined by tristimulus values, or by chromaticity coordinates and luminance factor, as computed by means of a specified set of color-difference equations.

4. Summary of Test Method

4.1 The differences in color between a reference and a test specimen are determined from measurements made by use of a spectrophotometer or a colorimeter. Reflectance readings from such instruments are converted by computations to color-scale values, or these color-scale values may be read directly from instruments that automatically make the computations. Color-difference magnitudes are computed, from differences in these color-scale values, that represent the perceived color differences between the reference and the test specimen.

5. Significance and Use

5.1 The original CIE color scales based on tristimulus values *X, Y, Z* and chromaticity coordinates *x, y* are visually nonuniform. Each subsequent color scale based on CIE values has had weighting factors applied to provide some degree of uniformity so that color differences in various regions of color space will be more nearly comparable. On the other hand, color differences obtained for the same specimens evaluated in different color-scale systems are not likely to be identical. To avoid confusion, color differences among specimens should be compared only when they are obtained for the same color-scale system. There is no simple factor that can be used to convert accurately color differences in one system to differences in another system for all colors of specimens.

5.2 For uniformity of practice, the CIE recommended in 1976 the use of two new improved color scales, of which the CIELAB scale, with its associated color-difference equation, has found wide acceptance in the coatings and related industries. However, it has not completely displaced the use of the Hunter L_H, a_H, b_H and the FMC-2 scales, which are still utilized to allow comparison with earlier results and because of their familiarity to those responsible for interpreting them. Therefore, all three scales are included in this method as the most widely used in industrial laboratories.

5.3 Users of color differences have found that, in each system, summation of three vector color-difference components into a single scalar value is useful for determining whether a specimen color is within a specified tolerance from a standard. However, for control of color in production, it is necessary to know not only the magnitude of the departure from standard but also the direction of this departure. Information on the direction of a color difference is easily included by giving the three instrumentally determined components of the color difference.

5.4 Selection of color tolerances based on instrumental values should be carefully correlated with a visual appraisal of the acceptability of differences in hue, lightness, and saturation obtained by using Practice D 1729.

6. Description of Color-Difference Equations

6.1 *CIE 1931 and 1964 Color Spaces*— The daylight colors of opaque specimens are represented by points in a space formed by three rectangular coordinates representing the lightness scale *Y* and chromaticity scales *x* and *y*, where:

$$x = \frac{X}{X + Y + Z} \quad (1)$$

$$y = \frac{Y}{X + Y + Z}$$

$$Y = Y$$

where *X*, *Y*, and *Z* are tristimulus values for either the 1931 CIE standard observer (2° observer) or the 1964 CIE supplementary standard observer (10° observer) and standard illuminant *C*, D_{65}, or another of daylight quality. These scales do not provide a perceptually uniform color space. Consequently, color differences are seldom if ever computed directly from differences in *x, y,* and *Y*.

6.2 *CIE 1976 L* a* b* Uniform Color Space and Color-Difference Equation* **(1, 4)**—This approximately uniform color space is a simplified version of the Adams-Nickerson color-scale system **(5-7).** It is produced by plotting in rectangular coordinates the quantities *L*, a*, b**, calculated as follows:

$$L^* = 116(Y/Y_n)^{1/3} - 16 \quad (2)$$

$$a^* = 500[(X/X_n)^{1/3} - Y/Y_n)^{1/3}]$$

$$b^* = 200[(Y/Y_n)^{1/3} - Z/Z_n)^{1/3}]$$

$$X/X_n;\ Y/Y_n;\ Z/Z_n > 0.01$$

The tristimulus values X_n, Y_n, Z_n define the color of the normally white object-color stimulus. Usually, the white object-color stimulus is given by the spectral radiant power of one of the CIE standard illuminants, for example, *C*, D_{65} or another of daylight quality, reflected into the observer's eye by the perfect reflecting diffuser. Under these conditions, X_n, Y_n, Z_n are the tristimulus values of the standard illuminant with Y_n equal to 100.

6.2.1 The total difference ΔE^*_{ab} between two colors each given in terms of *L*, a*, b** is calculated as follows:

$$\Delta E^*_{ab} = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (3)$$

NOTE 1—The color space defined above is called the CIE 1976 *L* a * b** space and the color-difference equation the CIE 1976 *L* a* b** color-difference formula. The abbreviation CIELAB is recommended.

6.2.2 The CIE 1976 (*L* a* b**) space fails to approximate uniform color spacing when one or more of the ratios X/X_n, Y/Y_n, and Z/Z_n is less than 0.01. In calculating *L**, values of Y/Y_n less than 0.01 may be included if the normal formula is used for values of Y/Y_n greater than 0.008856, and the following modified formula is used for values of Y/Y_n equal to or less than 0.008856.

$$L^* = 903.3(Y/Y_n) \qquad Y/Y_n \leq 0.008856 \quad (4)$$

6.2.3 In calculating *a** and *b**, values of X/X_n, Y/Y_n, Z/Z_n less than 0.01, may be included if the normal equations are replaced by the following modified equations for *all* calculations of *a** and *b**:

$$a^* = 500[f(X/X_n) - f(Y/Y_n)] \quad (5)$$

$$b^* = 200[f(Y/Y_n) - f(Z/Z_n)]$$

where: