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Standard Practice for Calculating the Colors of Objects by Using the ASTM Method¹

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INTRODUCTION

Computation of reflected-light tristimulus values, which are central to industrial color management, involves numerical integration over visible wavelength λ of the product of three functions: reflectance $R(\lambda)$, illuminant $S(\lambda)$, and an observer spectral sensitivity $q(\lambda)$, of which q is stored in matrix A . Typically, R , S , and q come from different sources and have different wavelength sampling intervals. The CIE regards 1 nm as the sampling interval at which the integration is represented by a simple Riemann sum. For other sampling intervals, interpolation to 1 nm must be done on input data prior to evaluating the products and their Riemann sum.

Industry evaluates a huge number of tristimulus values from spectral inputs R , S , and q . Accordingly, three metrics of an algorithm for tristimulus integration are the accuracy relative to actual 1 nm data, the time to compute the tristimulus values, and the required digital storage in typical workflows.

Practice E308 teaches one such algorithm, which is deemed by CIE to be adequate for need and performance. Practice E308 addresses both the computational and storage efficiency by adopting a structure called a weight set (or, more formally in Practice E308, a set of tristimulus weighting factors). A weight set is a wavelength-sampled product of illuminant S and triplets of color-matching functions q_j . It saves computational time because typical workflows run many reflectances for the same illuminant-observer combination. One can compute (and save) a weight set once and then use it multiple times on many reflectances. This advantage is enhanced by the fact that there are only a few Standard Illuminants in use, and only two Standard Observers. Furthermore, the weight sets are represented at the reduced resolution of 10 nm. Weight sets have historically been used in industrial color management, and Practice E308 captured that method.

This landscape has recently changed. New LED illuminants and the possibility of new standard observers (ranging over different ages and field sizes) have increased the number of options and decreased the utility of the weight set idea. Computational and storage efficiency also became moot in view of the advances in computer technology. Now, it is expedient to store all the inputs to a tristimulus integral and perform the computation “on the fly”. The present standard describes a way to do this. An important property of the new standard is its compatibility with Practice E308: For a given R , S , and q , if Practice E308 computes a tristimulus value, it will be identical to the one computed by the present standard, except for computer-precision round-off errors (see Appendix X3).

1. Scope

1.1 The scope of this practice is limited to the calculation of colors of objects by the ASTM International (ASTM) method.

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

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Practice E308 covers calculation of colors of objects by the Commission Internationale de l'Éclairage (CIE) method. The present practice provides methods of calculation of colors by methods that may be useful to users who require custom source definitions, or custom observer designations. The tristimulus values derived by the CIE method and by the ASTM method will produce insignificantly different results when identical input values are used.

1.2 While the title of this standard refers to the method as the “ASTM method”, this is merely to promulgate a short name to distinguish this method from that of Practice E308, already called in its title the “CIE method”. Both methods develop tristimulus values that are completely in compliance with CIE recommendations.

1.3 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*²

E284 Terminology of Appearance

E308 Practice for Computing the Colors of Objects by Using the CIE System

E2022 Practice for Calculation of Weighting Factors for Tristimulus Integration

E2729 Practice for Rectification of Spectrophotometric Bandpass Differences

2.2 *CIE Standards:*³

CIE Publication 15:2018 Colorimetry

ISO/CIE 11664-1:2019(E) Colorimetry—Part 1: CIE standard colorimetric observers

ISO/CIE 11664-2:2022(E) Colorimetry—Part 2: CIE standard illuminants

3. Terminology

3.1 *Definitions:*

3.1.1 Definitions of terms appearing in this standard are contained in Terminology E284.

4. Summary of Practice

4.1 In Practice E308, the standard data representing the observer and the illuminant source are gathered and premultiplied into a weight set for tristimulus integration. In this practice, the data is gathered but not multiplied together until the integration is performed. Both methods utilize 1 nm data representing the observer and the illuminant, which the CIE declares to be standard. The difference between the two methods is that the same calculations are performed in a

different order. The methods of this practice lend themselves favorably to the use of custom observer or illuminant source data.

4.2 Data is gathered into several matrices whose largest dimensions are 421 by 3. This covers a range from 360 nm to 780 nm on the wavelength scale and *R*, *G*, and *B* on the cone sensitivity axis. In order to maintain compatibility with the CIE method of tristimulus integration in Practice E308, the 1 nm dimension of 421 between 360 nm and 780 nm must be maintained.

4.3 An assumption is made that the reflectance and transmittance spectra whose tristimulus values are sought in this method have been previously band-pass corrected as is required by Practice E2729.

5. Significance and Use

5.1 The practices contained in this standard are useful for all illuminants and observers whether they are standard CIE definitions or are custom to a single usage only. The methods were, however, developed to accommodate those users who have need for custom defined source and observer functions. These do not lend themselves to easy calculation of weight sets for tristimulus integration, and as such the methods contained herein were developed specially to accommodate those persons having this requirement. Because either method derives tristimulus values that are insignificantly different from each other, the only selection criterion between them is whether there is a need for custom functions or not.

6. Symbols and Associated Parameters Used in the Procedure

6.1 *Symbol ‘A’*—A 421 by 3 matrix that contains in its lowest form in its rows the tristimulus values of the reference white. These data are the result of the original color-matching experiment such as those performed by Wright and Guild leading to the 1931 observer or by Stiles and Burch leading to the 1964 observer. The symbol *A* is retained as a place holder for the data as the matrix is processed into higher and higher form as the development of its final form takes place.

6.2 *Symbol ‘C’*—A 3 by 3 matrix that unitizes the tristimulus values of the reference-white to color-matching functions by transforming the tristimulus values of the white-point to be all-three equal to each other. The *C* matrix has coefficients in its major diagonal and zeros elsewhere.

6.3 *Symbol ‘K’*—A 3 by 3 matrix that transforms the units of the tristimulus values to a range of 0 to 100. The *K* matrix has coefficients in its major diagonal and zeros elsewhere.

6.4 *Symbol ‘N’*—A 421 by 1 vector that contains the 1 nm spectrum of color stimulus function in the case of a radiant function, the spectral reflectance function in the case of a reflective specimen, and the transmittance function in the case of a transmitting specimen.

6.5 *Symbol ‘Q’*—A 3 by 1 vector that contains the tristimulus values of the color stimulus function under consideration.

6.6 *Symbol ‘S’*—A 421 by 421 matrix that contains in its major diagonal the 1 nm spectral power distribution of the

² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at www.astm.org/contact. For *Annual Book of ASTM Standards* volume information, refer to the standard’s Document Summary page on the ASTM website.

³ Available from the International Commission on Illumination (CIE), CIE Central Bureau, Babenbergerstraße 9, 1010 Vienna, Austria 01741, <https://cie.co.at/>.