

Standard Practice for Calculation of Weighting Factors for Tristimulus Integration¹

This standard is issued under the fixed designation E2022; 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 practice describes the method to be used for calculating tables of weighting factors for tristimulus integration using custom spectral power distributions of illuminants or sources, or custom color-matching functions.
- 1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.
- 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 its use.

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

E2729 Practice for Rectification of Spectrophotometric Bandpass Differences

2.2 CIE Standard:

CIE Standard S 002 Colorimetric Observers³

3. Terminology

- 3.1 *Definitions*—Appearance terms in this practice are in accordance with Terminology E284.
 - 3.2 Definitions of Terms Specific to This Standard:
- 3.2.1 *illuminant*, *n*—real or ideal radiant flux, specified by its spectral distribution over the wavelengths that, in illuminating objects, can affect their perceived colors.
- 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.
- Current edition approved Aug. 1, 2016. Published August 2016. Originally approved in 1999. Last previous edition approved in 2011 as E2022 11. DOI: 10.1520/E2022-16.
- ² For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
- ³ Available from CIE (International Commission on Illumination), http://www.cie.co.at or http://www.techstreet.com.

- 3.2.2 *source*, *n*—an object that produces light or other radiant flux, or the spectral power distribution of that light.
- 3.2.2.1 *Discussion*—A source is an emitter of visible radiation. An illuminant is a table of agreed spectral power distribution that may represent a source; thus, Illuminant A is a standard spectral power distribution and Source A is the physical representation of that distribution. Illuminant D65 is a standard illuminant that represents average north sky daylight but has no representative source.
- 3.2.3 spectral power distribution, SPD, $S(\lambda)$, n—specification of an illuminant by the spectral composition of a radiometric quantity, such as radiance or radiant flux, as a function of wavelength.

4. Summary of Practice

- 4.1 CIE color-matching functions are standardized at 1-nm wavelength intervals. Tristimulus integration by multiplication of abridged spectral data into sets of weighting factors occurs at larger intervals, typically 10-nm; therefore, intermediate 1-nm interval spectral data are missing, but needed.
- 4.2 Lagrange interpolating coefficients are calculated for the missing wavelengths. The Lagrange coefficients, when multiplied into the appropriate measured spectral data, interpolate the abridged spectrum to 1-nm interval. The 1-nm interval spectrum is then multiplied into the CIE 1-nm color-matching data, and into the source spectral power distribution. Each separate term of this multiplication is collected into a value associated with a measured spectral wavelength, thus forming weighting factors for tristimulus integration.

5. Significance and Use

- 5.1 This practice is intended to provide a method that will yield uniformity of calculations used in making, matching, or controlling colors of objects. This uniformity is accomplished by providing a method for calculation of weighting factors for tristimulus integration consistent with the methods utilized to obtain the weighting factors for common illuminant-observer combinations contained in Practice E308.
- 5.2 This practice should be utilized by persons desiring to calculate a set of weighting factors for tristimulus integration who have custom source, or illuminant spectral power distributions, or custom observer response functions.

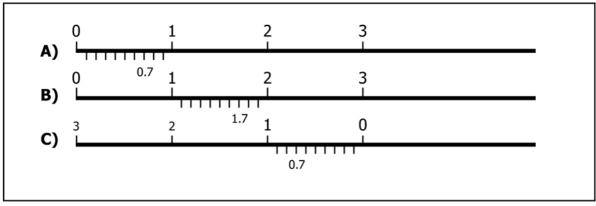


FIG. 1 The Values of *i* in Eq 1 are Plotted Above the Abscissa and the Values of *r* are Plotted Below for A) the First Measurement Interval; B) the Intermediate Measurement Intervals; and, C) the Last Measurement Interval Being Interpolated

6. Procedure

6.1 Calculation of Lagrange Coefficients—Obtain by calculation, or by table look-up, a set of Lagrange interpolating coefficients for each of the missing wavelengths.⁴

6.1.1 The coefficients should be quadratic (three-point) in the first and last missing interval, and cubic (four-point) in all intervals between the first and the last missing interval.

6.1.2 Generalized Lagrange Coefficients—Lagrange coefficients may be calculated for any interval and number of missing wavelengths by Eq 1:

$$L_{j}(r) = \prod_{i=0}^{n} \frac{(r-r_{i})}{(r_{i}-r_{i})}, \text{ for } j=0,1,...n$$
 (1)

where:

π

n = degree of coefficients being calculated,⁵

i and *j* = indices denoting the location along the abscissa,

along the abscissa,
= repetitive multiplication of
the terms in the numerator
and the denominator, and

indices of the interpolant, r = chosen on the same scale as the values i and j.

6.1.2.1 Fig. 1 assist the user in selecting the values of i, j, and r for these calculations.

6.1.2.2 Eq 1 is general and is applicable to any measurement interval or interpolation interval, regular or irregular.

6.1.3 10-nm Lagrange Coefficients—Where the measured spectral data have a regular or constant interval, the equation reduces to the following:

$$L_0 = \frac{(r-1)(r-2)(r-3)}{-6} \tag{2}$$

$$L_1 = \frac{(r)(r-2)(r-3)}{2} \tag{3}$$

$$L_2 = \frac{(r-1)(r)(r-3)}{-2} \tag{4}$$

$$L_3 = \frac{(r-1)(r-2)(r)}{6} \tag{5}$$

for the cubic case, and to

$$L_0 = \frac{(r-1)(r-2)}{2} \tag{6}$$

$$L_1 = \frac{(r)(r-2)}{-1} \tag{7}$$

$$L_2 = \frac{(r-1)(r)}{2} \tag{8}$$

for the quadratic case. In each of the above equations, as many or as few values of r as required are chosen to generate the necessary coefficients.

6.1.3.1 Eq 2-8 are applicable when the spectral data are abridged at 10-nm intervals, and the interpolated interval is regular with respect to the measurement interval, presumably 1-nm.

6.1.4 Tables 1 and 2 provide both quadratic and cubic Lagrange coefficients for 10-nm intervals.

6.2 With the Lagrange coefficients provided, the intermediate missing spectral data may be predicted as follows:

$$P(\lambda) = \sum_{i=0}^{n} L_i m_i \tag{9}$$

where:

P = the value being interpolated at interval λ ,

L = the Lagrange coefficients, and

m = the measured abridged spectral values.

TABLE 1 The Lagrange Quadratic Interpolation Coefficients
Applicable to the First and Last Missing Interval for Calculation
of 10-nm Weighting Factors for Tristimulus Integration

Index of Missing Wavelength	Lo	L ₁	L_2
1	0.855	0.190	-0.045
2	0.720	0.360	-0.080
3	0.595	0.510	-0.105
4	0.480	0.640	-0.120
5	0.375	0.750	-0.125
6	0.280	0.840	-0.120
7	0.195	0.910	-0.105
8	0.120	0.960	-0.080
9	0.055	0.990	-0.045

⁴ Hildebrand, F. B., *Introduction to Numerical Analysis*, Second Edition, Dover, New York, 1974, Chapter 3.

⁵ Fairman, H. S., "The Calculation of Weight Factors for Tristimulus Integration," *Color Research and Application*, Vol 10, 1985, pp. 199–203.

TABLE 2 The Lagrange Cubic Interpolation Coefficients
Applicable to the Interior Missing Intervals for Calculation of
10-nm Weighting Factors for Tristimulus Integration

Index of Missing Wavelength	Lo	<i>L</i> ₁	L ₂	L ₃
1	-0.0285	0.9405	0.1045	-0.0165
2	-0.0480	0.8640	0.2160	-0.0320
3	-0.0595	0.7735	0.3315	-0.0455
4	-0.0640	0.6720	0.4480	-0.0560
5	-0.0625	0.5625	0.5625	-0.0625
6	-0.0560	0.4480	0.6720	-0.0640
7	-0.0455	0.3315	0.7735	-0.0595
8	-0.0320	0.2160	0.8640	-0.0480
9	-0.0165	0.1045	0.9405	-0.0285

Because the measured spectral values are as yet unknown, it may be best to consider this equation in its expanded form:

$$P(\lambda) = L_0 m_0 + L_1 m_1 + L_2 m_2 + L_3 m_3 \tag{10}$$

- 6.3 Multiply each $P(\lambda)$ by the 1-nm interval relative spectral power of the source or illuminant being considered.
- 6.3.1 It may be necessary to interpolate missing values of the source spectral power distribution $S(\lambda)$, if the source has been measured at other than 1-nm intervals.
 - 6.3.2 Doing so results in the following equation:

$$S(\lambda)P(\lambda) = S(\lambda)L_0 m_0 + S(\lambda)L_1 m_1 + S(\lambda)L_2 m_2 + S(\lambda)L_3 m_3$$
(11)

6.4 Multiply the weighted power at each 1-nm wavelength by the appropriate custom color-matching function value for that wavelength. Using the CIE color-matching functions as an example, obtain the CIE 1-nm data from CIE Standard S 002, Colorimetric Observers. Doing so results in the following equation:

$$\bar{x}(\lambda)S(\lambda)P(\lambda) = \left[\bar{x}(\lambda)S(\lambda)L_0\right]m_0 + \left[\bar{x}(\lambda)S(\lambda)L_1\right]m_1 + \left[\bar{x}(\lambda)S(\lambda)L_2\right]m_2 + \left[\bar{x}(\lambda)S(\lambda)L_2\right]m_3$$
(12)

where:

- $\bar{x}(\lambda)$ = the value of the CIE X color-matching function at wavelength λ , and the calculations are carried out for each of the three CIE color-matching functions, $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, and $\bar{z}(\lambda)$.
- 6.5 In the four terms on the right-hand side of this equation, the numerical values of the three factors in the brackets are

known and should be multiplied into a single coefficient. The fourth factor, m_i , in each of the four additive terms is associated with a different measured wavelength.

6.6 Add all multiplicative coefficients dependent upon each different measured wavelength into a single coefficient applicable to that wavelength. This results in a single set of weighting factors that then will contain one value for each measured wavelength in each of three color-matching functions. The partial contribution to the tristimulus value at wavelength m_0 is:

$$\left[\left(\bar{x}(\lambda_0) S(\lambda_0) L_0 \right) + \left(\bar{x}(\lambda_1) S(\lambda_1) L_0 \right) + \dots \right] m_0 = w t_0 m_0 \tag{13}$$

6.7 Normalize the weighting factors by calculating the following normalizing coefficient:

$$k = \frac{100}{\sum S(\lambda)\bar{y}(\lambda)} \tag{14}$$

where:

k = the normalizing coefficient,

 $S(\lambda)$ = the power in the 1-nm spectrum, and

 $y(\lambda)$ = the CIE Y color-matching function.

- 6.8 Multiply the weighting factors by k to normalize the set to Y = 100 for the perfect reflecting diffuser.
- 6.9 Beginning in January of 2010, rectification of bandpass differences is no longer accomplished by building the correction factors into a weight set for tristimulus integration. This is because to do so fails to correct the spectrum itself and corrects only the tristimulus values. Bandpass rectification is now under the jurisdiction of Practice E2729.

7. Precision

7.1 The precision of the practice is limited only by the precision of the data provided for the source spectral power distribution. The CIE color-matching functions are precise to six digits by definition. The Lagrange coefficients are precise to seven digits.

8. Keywords

8.1 color-matching functions; illuminant; illuminantobserver weights; source; tristimulus weighting factors



APPENDIXES

(Nonmandatory Information)

X1. EXAMPLE OF THE CALCULATIONS

X1.1 Table X1.1 gives the spectral power distribution (SPD) of a typical 3-band fluorescent lamp with a correlated color temperature of about 3000K. The first step is to multiply each value of the SPD by the appropriate CIE color matching function (\bar{y} in this case), wavelength by wavelength, which is shown in Table X1.2 for three spectral regions: near 360 nm, 560 nm, and 830 nm. Table X1.3 shows a typical interpolation of a measured reflectance curve from a 10-nm reported interval to the 1-nm interval that matches the SPD- \bar{y} product in the

same three spectral regions. Tables X1.4-X1.6 illustrate how the same measured data, used to interpolate the missing reflectance data in several different intervals, can be combined with the illuminant-color matching function product to form a single weight at a single measurement point. Finally, Table X1.7 shows the resulting weight set for this 3000K source and the 1964 10° color matching functions. Table X1.7 is compatible with Tables 5 in Practice E308.



TABLE X1.1 Spectral Power Distribution of Typical 3-Band Fluorescent Lamp with Correlated Color Temperature of 3000 K (1-nm measurement interval)

No. SPD X						measureme	nt interva	al)				
Sect 0.004585	λ	SPD	λ	SPD	λ	SPD	λ	SPD	λ	SPD	λ	SPD
Set C.006895												
Section Sect												
986												
984 0.038270 4694 0.014750 544 0.014750 545 0.0145100 5247 0.022740 728 0.002340 314 0.000000 386 0.059140 459 0.014470 546 0.054800 835 0.022740 728 0.002371 815 0.0000000 386 0.059140 459 0.014110 546 0.054800 838 0.022740 728 0.002410 818 0.000000 388 0.00500 459 0.014110 546 0.022500 838 0.023730 728 0.002410 818 0.000000 389 0.000700 459 0.014110 546 0.022500 838 0.023730 728 0.002410 818 0.000000 389 0.000700 459 0.013760 550 0.141700 840 0.020170 730 0.001170 320 0.00000 320 0.000000 377 0.00410 460 0.013760 550 0.141700 840 0.020170 730 0.001100 320 0.00000 320 0.000000 377 0.000700 469 0.013760 550 0.014700 840 0.002170 730 0.001100 820 0.000000 377 0.00000 320 0.000000 320 0.000000 327 0.000000 320 0.000000 320 0.000000 327 0.000000 320 0.000000 320 0.000000 327 0.000000 320 0.000000 320 0.000000 327 0.000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000 320 0.0000000000												
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TABLE X1.1 Continued

λ	SPD	λ	SPD								
433	0.020610	523	0.006590	613	0.558200	703	0.008540	793	0.000000		
434	0.029590	524	0.006610	614	0.298100	704	0.010140	794	0.000000		
435	0.241400	525	0.007150	615	0.223100	705	0.024700	795	0.000000		
436	0.453200	526	0.007690	616	0.148200	706	0.039250	796	0.000000		
437	0.233900	527	0.008285	617	0.112500	707	0.047360	797	0.000000		
438	0.014620	528	0.008880	618	0.076780	708	0.055470	798	0.000000		
439	0.014530	529	0.009030	619	0.074490	709	0.047700	799	0.000000		
440	0.014450	530	0.009180	620	0.072200	710	0.039920	800	0.000000		
441	0.014400	531	0.011460	621	0.075760	711	0.047550	801	0.000000		
442	0.014340	532	0.013750	622	0.079320	712	0.055180	802	0.000000		
443	0.014430	533	0.018810	623	0.084640	713	0.033360	803	0.000000		
444	0.014510	534	0.023880	624	0.089950	714	0.011550	804	0.000000		
445	0.014490	535	0.024380	625	0.090240	715	0.007855	805	0.000000		
446	0.014470	536	0.024890	626	0.090530	716	0.004160	806	0.000000		
447	0.014650	537	0.044580	627	0.085950	717	0.002845	807	0.000000		
448	0.014820	538	0.064270	628	0.081370	718	0.001530	808	0.000000		
449	0.014850	539	0.113300	629	0.096260	719	0.002970	809	0.000000		

TABLE X1.2 Product of the SPD Values with a CIE Standard Observer Function (1-nm interval)

	2(1) -		2(1) -		2(2) =
λ	$S(\lambda) \times \bar{y}$	λ	$S(\lambda) \times \bar{y}$	λ	$S(\lambda) \times \bar{y}$
360	0.004880 × 0.00000001340	540	0.162400 × 0.96198800000	790	0.000000 × .00000701280
361	$0.004595 \times 0.00000002029$	541	$0.277600 \times 0.96754000000$	791	0.000000 × .00000658580
362	$0.004310 \times 0.00000003056$	542	$0.392800 \times 0.97223000000$	792	0.000000 × .00000618570
363	$0.020290 \times 0.00000004574$	543	$0.353900 \times 0.97617000000$	793	$0.000000 \times .00000581070$
364	$0.036270 \times 0.00000006805$	544	$0.315100 \times 0.97946000000$	794	$0.000000 \times .00000545900$
365	$0.047350 \times 0.00000010065$	545	$0.429800 \times 0.98220000000$	795	$0.000000 \times .00000512980$
366	$0.058440 \times 0.00000014798$	546	$0.544600 \times 0.98452000000$	796	$0.000000 \times .00000482060$
367	$0.031870 \times 0.00000021627$	547	$0.383500 \times 0.98652000000$	797	$0.000000 \times .00000453120$
368	$0.005300 \times 0.00000031420$	548	$0.222500 \times 0.98832000000$	798	$0.000000 \times .00000425910$
369	$0.004700 \times 0.00000045370$	549	$0.182100 \times 0.99002000000$	799	$0.000000 \times .00000400420$
370	$0.004100 \times 0.00000065110$	550	$0.141700 \times 0.99176100000$	800	$0.000000 \times .00000376473$
371	$0.003785 \times 0.00000092880$	551	$0.113500 \times 0.99353000000$	801	$0.000000 \times .00000353995$
372	$0.003470 \times 0.00000131750$	552	$0.085290 \times 0.99523000000$	802	$0.000000 \times .00000332914$
373	$0.003540 \times 0.00000185720$	553	$0.070050 \times 0.99677000000$	803	$0.000000 \times .00000313115$
374	$0.003610 \times 0.00000260200$	554	$0.054810 \times 0.99809000000$	804	$0.000000 \times .00000294529$
375	$0.003615 \times 0.00000362500$	555	$0.046030 \times 0.99911000000$	805	$0.000000 \times .00000277081$
376	$0.003620 \times 0.00000501900$	556	$0.037250 \times 0.99977000000$	806	$0.000000 \times .00000260705$
377	$0.004210 \times 0.00000690700$	557	$0.034310 \times 1.00000000000$	807	$0.000000 \times .00000245329$
378	$0.004800 \times 0.00000944900$	558	$0.031360 \times 0.99971000000$	808	$0.000000 \times .00000230894$
379	$0.005170 \times 0.00001284800$	559	$0.030480 \times 0.99885000000$	809	$0.000000 \times .00000217338$
380	$0.005540 \times 0.00001736400$	560	$0.029590 \times 0.99734000000$	810	$0.000000 \times .00000204613$
381	$0.005240 \times 0.00002332700$	561	$0.029650 \times 0.99526000000$	811	$0.000000 \times .00000192662$
382	$0.004940 \times 0.00003115000$	562	$0.029700 \times 0.99274000000$	812	$0.000000 \times .00000181440$
383	$0.004615 \times 0.00004135000$	563	$0.029530 \times 0.98975000000$	813	$0.000000 \times .00000170895$
384	$0.004290 \times 0.00005456000$	564	$0.029360 \times 0.98630000000$	814	$0.000000 \times .00000160988$
385	$0.003750 \times 0.00007156000$	565	$0.029200 \times 0.98238000000$	815	$0.000000 \times .00000151677$
386	$0.003210 \times 0.00009330000$	566	$0.029040 \times 0.97798000000$	816	$0.000000 \times .00000142921$
387	$0.003050 \times 0.00012087000$	567	$0.029500 \times 0.97311000000$	817	$0.000000 \times .00000134686$
388	$0.002890 \times 0.00015564000$	568	$0.029960 \times 0.96774000000$	818	$0.000000 \times .00000126945$
389	$0.002980 \times 0.00019920000$	569	$0.029480 \times 0.96189000000$	819	$0.000000 \times .00000119662$
390	$0.003070 \times 0.00025340000$	570	$0.029000 \times 0.95555200000$	820	$0.000000 \times .00000112809$
391	$0.002795 \times 0.00032020000$	571	$0.029140 \times 0.94860100000$	821	$0.000000 \times .00000106368$
392	$0.002520 \times 0.00040240000$	572	$0.029280 \times 0.94098100000$	822	$0.000000 \times .00000100313$
393	$0.002395 \times 0.00050230000$	573	$0.029390 \times 0.93279800000$	823	$0.000000 \times .00000094622$
394	$0.002270 \times 0.00062320000$	574	$0.029500 \times 0.92415800000$	824	$0.000000 \times .00000089263$
395	$0.002285 \times 0.00076850000$	575	$0.040510 \times 0.91517500000$	825	$0.000000 \times .00000084216$
396	0.002300 × 0.00094170000	576	0.051530 × 0.90595400000	826	0.000000 × .00000079464
397	$0.002420 \times 0.00114780000$	577	$0.060840 \times 0.89660800000$	827	$0.000000 \times .00000074978$
398	0.002540 × 0.00139030000	578	0.070160 × 0.88724900000	828	0.000000 × .0000070744
399	0.002640 × 0.00167400000	579	$0.079050 \times 0.87798600000$	829	0.000000 × .00000066748
400	0.002740 × 0.00200440000	580	0.087930 × 0.86893400000	830	0.000000 × .0000062970



TABLE X1.3 Interpolation of Measured Reflectance Factor from a 10-nm Measurement Interval to a 1-nm Interval for the First 10 nm interval (360 nm to 370 nm), an Intermediate Interval (550 nm to 560 nm), and for the Last Intermediate Interval (820 nm to 830 nm)

λ	Reflectance Factor	λ	Reflectance Factor	λ	Reflectance Factor
360	R0	540	R0	790	R4
361	0.855 × R0 +0.190 × R1 -0.045 × R2	550	R1	800	R3
362	0.720 × R0 +0.360 × R1 -0.080 × R2	551	-0.029 × R0 +0.941 × R1 +0.105 × R2 -0.016 × R3	810	R2
363	0.595 × R0 +0.510 × R1 -0.105 × R2	552	-0.048 × R0 +0.864 × R1 +0.216 × R2 -0.032 × R3	820	R1
364	0.480 × R0 +0.640 × R1 -0.120 × R2	553	$-0.060 \times R0 +0.774 \times R1 +0.332 \times R2 -0.046 \times R3$	821	0.055 × R0 +0.990 × R1 -0.045 × R2
365	0.375 × R0 +0.750 × R1 -0.125 × R2	554	$-0.064 \times R0 +0.672 \times R1 +0.448 \times R2 -0.056 \times R3$	822	0.120 × R0 +0.960 × R1 -0.080 × R2
366	0.280 × R0 +0.840 × R1 -0.120 × R2	555	−0.063 × R0 +0.563 × R1 +0.563 × R2 −0.063 × R3	823	0.195 × R0 +0.910 × R1 -0.105 × R2
367	0.195 × R0 +0.910 × R1 -0.105 × R2	556	$-0.056 \times R0 +0.448 \times R1 +0.672 \times R2 -0.064 \times R3$	824	0.280 × R0 +0.840 × R1 -0.120 × R2
368	0.120 × R0 +0.960 × R1 -0.080 × R2	557	$-0.045 \times R0 +0.331 \times R1 +0.774 \times R2 -0.060 \times R3$	825	0.375 × R0 +0.750 × R1 -0.125 × R2
369	0.055 × R0 +0.990 × R1 -0.045 × R2	558	-0.032 × R0 +0.216 × R1 +0.864 × R2 -0.048 × R3	826	0.480 × R0 +0.640 × R1 -0.120 × R2
370	R1	559	$-0.016 \times R0 +0.105 \times R1 +0.941 \times R2 -0.029 \times R3$	827	0.595 × R0 +0.510 × R1 -0.105 × R2
380	R2	560	R2	828	0.720 × R0 +0.360 × R1 -0.080 × R2
390	R3	570	R3	829	0.855 × R0 +0.190 × R1 -0.045 × R2
400	R4	580	R4	830	R0

TABLE X1.4 Formation of the CIE Triple Product (Interpolated Reflectance Factor) X (Illuminant) X (Standard Observer Function) Shown for the First 10-nm Interval (360 nm to 370 nm)

λ	Reflectance Factor \times $S(\lambda) \times \bar{y} \times \text{First 10-nm Interval}$
360	(0.004880 × 0.00000001340) × R0
361	$(0.855 \times 0.004595 \times 0.00000002029) \times R0 + (0.190 \times 0.004595 \times 0.00000002029) \times R1 + (-0.045 \times 0.004595 \times 0.00000002029) \times R2$
362	$(0.720 \times 0.004310 \times 0.00000003056) \times R0 + (0.360 \times 0.004310 \times 0.0000003056) \times R1 + (-0.080 \times 0.004310 \times 0.0000003056) \times R2$
363	$(0.595 \times 0.020290 \times 0.00000004574) \times R0 + (0.510 \times 0.020290 \times 0.00000004574) \times R1 + (-0.105 \times 0.020290 \times 0.00000004574) \times R2$
364	$(0.480 \times 0.036270 \times 0.00000006805) \times R0 + (0.640 \times 0.036270 \times 0.0000006805) \times R1 + (-0.120 \times 0.036270 \times 0.0000006805) \times R2$
365	$(0.375 \times 0.047350 \times 0.00000010065) \times R0 + (0.750 \times 0.047350 \times 0.00000010065) \times R1 + (-0.125 \times 0.047350 \times 0.00000010065) \times R2$
366	$(0.280 \times 0.058440 \times 0.00000014798) \times R0 + (0.840 \times 0.058440 \times 0.00000014798) \times R1 + (-0.120 \times 0.058440 \times 0.00000014798) \times R2$
367	$(0.195 \times 0.031870 \times 0.00000021627) \times R0 + (0.910 \times 0.031870 \times 0.00000021627) \times R1 + (-0.105 \times 0.031870 \times 0.00000021627) \times R2$
368	$(0.120 \times 0.005300 \times 0.00000031420) \times R0 + (0.960 \times 0.005300 \times 0.00000031420) \times R1 + (-0.080 \times 0.005300 \times 0.00000031420) \times R2$
369	$(0.055 \times 0.004700 \times 0.00000045370) \times R0 + (0.990 \times 0.004700 \times 0.00000045370) \times R1 + (-0.045 \times 0.004700 \times 0.00000045370) \times R2$
370	(0.004100 × 0.00000065110) × R1
380	(0.005540 × 0.00001736400) × R2
390	(0.003070 × 0.00025340000) × R3
400	(0.002740 × 0.00200440000) × R4

TABLE X1.5 Formation of the CIE Triple Product (Interpolated Reflectance Factor) X (Illuminant) X (Standard Observer Function) Shown for an Intermediate 10-nm Interval (550 nm to 560 nm)

~	Reflectance Factor $ imes S(\lambda) imes ar{y} imes Interior 10-nm Intervals^A$
540	(0.162400 × 0.96198800000) × R0
220	(0.141700 × 0.99176100000) × R1
551	$(-0.029 \times 0.113500 \times 0.99353000000) \times R0 + (0.941 \times 0.113500 \times 0.99353000000) \times R1 + (0.105 \times 0.113500 \times 0.99353000000) \times R2 + (-0.016 \times 0.113500 \times 0.9935300000) \times R2 + (-0.016 \times 0.113500 \times 0.99353000000) \times R3$
552	$(-0.048 \times 0.085290 \times 0.99523000000) \times R0 + (0.864 \times 0.085290 \times 0.99523000000) \times R1 + (0.216 \times 0.085290 \times 0.99523000000) \times R2 + (-0.032 \times 0.085290 \times 0.9952300000) \times R2 + (-0.032 \times 0.085290 \times 0.0852$
553	$(-0.060 \times 0.070050 \times 0.99677000000) \times R0 + (0.774 \times 0.070050 \times 0.99677000000) \times R1 + (0.331 \times 0.070050 \times 0.99677000000) \times R2 + (-0.045 \times 0.070050 \times 0.99677000000) \times R3$
554	$(-0.064 \times 0.054810 \times 0.99809000000) \times R0 + (0.672 \times 0.054810 \times 0.99809000000) \times R1 + (0.448 \times 0.054810 \times 0.99809000000) \times R2 + (-0.056 \times 0.054810 \times 0.99809000000) \times R3$
222	$(-0.063 \times 0.046030 \times 0.99911000000) \times R0 + (0.563 \times 0.046030 \times 0.99911000000) \times R1 + (0.563 \times 0.046030 \times 0.99911000000) \times R2 + (-0.063 \times 0.046030 \times 0.99911000000) \times R3$
226	$(-0.056 \times 0.037250 \times 0.99977000000) \times R0 + (0.448 \times 0.037250 \times 0.99977000000) \times R1 + (0.672 \times 0.037250 \times 0.99977000000) \times R2 + (-0.064 \times 0.037250 \times 0.99977000000) \times R3$
222	$(-0.045 \times 0.034310 \times 1.00000000000) \times R0 + (0.331 \times 0.034310 \times 1.00000000000) \times R1 + (0.774 \times 0.034310 \times 1.00000000000) \times R2 + (-0.060 \times 0.034310 \times 1.00000000000) \times R3$
228	$(-0.032 \times 0.031360 \times 0.99971000000) \times R0 + (0.216 \times 0.031360 \times 0.99971000000) \times R1 + (0.864 \times 0.031360 \times 0.99971000000) \times R2 + (-0.048 \times 0.031360 \times 0.99971000000) \times R3$
229	$(-0.016 \times 0.030480 \times 0.99885000000) \times R0 + (0.105 \times 0.030480 \times 0.99885000000) \times R1 + (0.941 \times 0.030480 \times 0.99885000000) \times R2 + (-0.029 \times 0.030480 \times 0.99885000000) \times R2 + (-0.029 \times 0.030480 \times 0.99885000000) \times R3$
260	(0.029590 × 0.99734000000) × R2
220	(0.029000 × 0.95555200000) × R3
280	(0.087930 × 0.86893400000) × R4
A C+O	A Strame E I and Strame D E "Infliance of Specification Clife on Trictimalise Calculations" Orlar Deceased and Amiliarities 10 1080 nn 057-050

Steams, E. I and Steams, R. E., "Influence of Spectophotometer Slits on Tristimulus Calculations," Color Research and Application, Vol 13, 1988, pp. 257-259.

TABLE X1.6 Formation of the CIE Triple Product (Interpolated Reflectance Factor) X (Illuminant) X (Standard Observer Function) Shown for the Last 10-nm Interval (820 nm to 830 nm)

λ	Reflectance Factor \times $S(\lambda)$ \times \bar{y} \times Last 10-nm Intervals
790	$(0.000000 \times .00000701280) \times R4$
800	$(0.000000 \times .00000376473) \times R3$
810	$(0.000000 \times .00000204613) \times R2$
820	$(0.000000 \times .00000112809) \times R1$
821	$(0.055 \times 0.000000 \times .00000106368) \times R0 + (0.990 \times 0.000000 \times .00000106368) \times R1 + (-0.045 \times 0.000000 \times .00000106368) \times R2$
822	$(0.120 \times 0.000000 \times .00000100313) \times R0 + (0.960 \times 0.000000 \times .00000100313) \times R1 + (-0.080 \times 0.000000 \times .00000100313) \times R2$
823	$(0.195 \times 0.000000 \times .0000094622) \times R0 + (0.910 \times 0.000000 \times .00000094622) \times R1 + (-0.105 \times 0.000000 \times .00000094622) \times R2$
824	$(0.280 \times 0.000000 \times .00000089263) \times R0 + (0.840 \times 0.000000 \times .00000089263) \times R1 + (-0.120 \times 0.000000 \times .00000089263) \times R2$
825	$(0.375 \times 0.000000 \times .00000084216) \times R0 + (0.750 \times 0.000000 \times .00000084216) \times R1 + (-0.125 \times 0.000000 \times .00000084216) \times R2$
826	$(0.480 \times 0.000000 \times .00000079464) \times R0 + (0.640 \times 0.000000 \times .00000079464) \times R1 + (-0.120 \times 0.000000 \times .00000079464) \times R2$
827	$(0.595 \times 0.000000 \times .00000074978) \times R0 + (0.510 \times 0.000000 \times .00000074978) \times R1 + (-0.105 \times 0.000000 \times .00000074978) \times R2$
828	$(0.720 \times 0.000000 \times .00000070744) \times R0 + (0.360 \times 0.000000 \times .00000070744) \times R1 + (-0.080 \times 0.000000 \times .00000070744) \times R2$
829	$(0.855 \times 0.000000 \times .00000066748) \times R0 + (0.190 \times 0.000000 \times .00000066748) \times R1 + (-0.045 \times 0.000000 \times .00000066748) \times R2$
830	$(0.000000 \times .0000062970) \times R0$

TABLE X1.7 Final Table of Weights Summing all Coefficients of Each 10-nm Intervals of the Measured Reflectance Factor

	147	14/	144
λ	Wx	Wy	Wz
360.0	0.000	0.000	0.001
370.0	0.001	0.000	0.003
380.0	0.001	0.000	0.003
390.0	-0.004	-0.000	-0.019
400.0	0.053	0.001	0.250
410.0	0.072	0.002	0.343
420.0	-0.071	-0.007	-0.370
430.0	1.868	0.096	9.226
440.0	2.765	0.156	13.733
450.0	0.340	0.051	1.858
460.0	0.445	0.092	2.555
470.0	0.269	0.093	1.715
480.0	0.228	0.461	2.132
490.0	0.244	2.392	3.304
500.0	0.013	0.743	0.676
510.0	0.005	0.399	0.098
520.0	0.023	0.419	0.051
530.0	-0.232	-0.036	0.039
540.0	7.759	22.891	0.392
550.0	9.035	22.674	0.262
560.0	1.680	2.402	-0.003
570.0	2.480	3.111	0.006
580.0	8.184	7.581	0.000
590.0	11.055	8.260	0.013
600.0	6.821	4.203	0.006
610.0	31.663	15.566	0.010
620.0	14.219	6.566	0.003
630.0	4.856	1.953	0.000
640.0	1.102	0.427	0.000
650.0	0.742	0.278	0.000
660.0	0.363	0.134	-0.000
670.0	0.126	0.046	0.000
680.0	0.053	0.040	0.000
690.0	0.036	0.019	0.000
700.0	0.036	0.004	0.000
710.0	0.012	0.004	0.000
720.0	0.002	0.001	0.000
730.0	0.000	0.000	0.000
740.0	0.000	0.000	0.000
750.0	0.000	0.000	0.000
760.0	0.000	0.000	0.000
770.0	-0.000	-0.000	0.000
780.0	0.000	0.000	0.000
790.0	0.000	0.000	0.000
800.0	0.000	0.000	0.000
810.0	0.000	0.000	0.000
820.0	0.000	0.000	0.000
830.0	0.000	0.000	0.000
Sums:	106.229	100.000	36.301

X2. PREVIOUS PRACTICE WITH RESPECT TO BANDPASS CORRECTION

X2.1 Prior to January 2010, rectification of spectral bandpass error was handled by Practice E308. At that time control of bandpass correction was transferred to Practice E2729. Both Practice E308 and this present practice utilized a Stearns' correction⁶ with Venable coefficients. Interior passbands were corrected by

 $R_{c,i}=-0.083\cdot R_{m,i-1}+1.166\cdot R_{m,i}-0.083\cdot R_{m,i+1}$ (X2.1) where R is a reflectance value at an indexed passband, c indicates a bandpass-corrected reflectance, and m indicates a measured reflectance. The index i varies from the second-measured passband to the next-to-last measured passband. The first and last passbands were corrected by

 $R_{c,i} = 1.083 \cdot R_{m,i} - 0.083 \cdot R_{m,i\pm 1}$ (X2.2) where the symbols are the same as Eq X2.1 and the index i

and \pm refer to the first and last measured passbands, respectively.

X2.1.1 By substituting weights appropriately for reflectances in the above equations, one could build the bandpass correction of the spectrum into the weight set, and it was the practice to do this until the advent of Practice E2729. See 6.9.

X2.2 In research that led to Practice E2729, a Task Group in the committee having jurisdiction over this practice found that the three-point formula was not the optimal correction, and a five-point formula was standardized in Practice E2729. Further the Task Group found that the Venable coefficients that had been in use were not even the best available set of coefficients for a three-point formula. The coefficients of Stearns and Stearns⁶, which are

 $R_{c,i}=-0.10\cdot R_{m,i-1}+1.20\cdot R_{m,i}-0.10\cdot R_{m,i+1}, \qquad (X2.3)$ give superior performance to the previously used coefficients.

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⁶ Stearns, E. I. and Stearns, R. E., "Influence of Spectrophotometer Slits on Tristimulus Calculations," *Color Research and Application*, Vol 13, 1988, pp. 257–259.