

## THE INVESTIGATION OF A COLORIMETRIC SPECIFICATION FOR GAA GROUP VI/S.W.O.P. PROOFING INKS

By the GAA Task Force for Color Certification

(Participants and credits listed at conclusion  
of this paper)

The electronic revolution, with respect to the Graphic Arts Industry, over the last decade, has given us the ability to produce four color separations much faster than any time in the history of color reproduction. With this revolution, we have the ability to manipulate and correct, enhance, and create images which was not commercially viable in past years. However, with the advent of this revolution we have in some ways overlooked the basic principles of photographic science with respect to color reproduction.

It should be remembered that the principles of color reproduction are to correct for the deficiencies and secondary absorbancies of inks on a particular paper or stock to be used. This is true whether one uses electronic scanning reproduction, direct or indirect screening methods, this fact seems, to have been overlooked and we now have a situation where many images which are produced for production, either by gravure or offset, have not been separated for the correct ink and paper conditions. It should be pointed out at this time that density measurements alone will not allow for these calculation to be made in a non-metameric fashion, therefore, the need for a color measurement system, based on a standard observer function, or someone with normal eyesight is obviously needed.

There are a number of colorimetric specifications for printing inks on a worldwide basis. For instance, ISO2846 is an international standard for the specification of cyan, yellow, magenta, red, green and blue inks used in offset printing. Other affiliations to this are DIN16539, which is the German standard and relates directly to ISO2846. BS4666, which is the British standard, is also related to the ISO standard, as is CIE1367. In fact, all of the specifications are the same. The only disadvantage of directly using these calculations for our proofing or production inks is the variation which is allowed within the specification itself. An example would be that in the

case of ISO2846 and a yellow printing ink. A centerpoint is given for the particular yellow with what is known as a delta E color difference. However, this delta E color difference is a sum difference of the attributes of color, i.e., hue, chroma and lightness and darkness and therefore gives equal weighting visually to each one of these visual attributes. Recent studies by Souter and Edge, (3M) and Schlapfer (EMPA/VGRA), have indicated that this equal weighting is very misleading when one looks at the visual appearance of proofs and prints, particularly when they are formed from different mediums, such as ink on paper or multilayered proofing systems.

A further disadvantage of the ISO standard is that it is expressed in illuminant C. While from a colorimetric point of view this is not a disadvantage, from a viewing point of view illuminant C is an extremely difficult illuminant to produce and few, if any, viewing conditions that are used in the Graphic Arts Industry comply to this condition. Therefore, it would seem advantageous to have a colorimetric specification for inks which is based on the illumination conditions that they will be viewed under in their final printed on proofed form.

To address this subject in a rational way, a task force has been set up under the guidance of the GAA, in conjunction with members from S.W.O.P., IPA, NAPIM and GATF. The objective of this task force is to assess the feasibility of setting a colorimetric specification for cyan, yellow, magenta and black in conjunction with normal proofing papers and to investigate the secondary and tertiary responses to insure a colorimetric match under comparable printing conditions.

Twenty-six wet ink samples were gathered from service houses and ink manufacturers across the country. These wet ink samples were compared to the master set of Borden Proofing Inks held by GATF. The ink testing method will be described later in this paper, as will the results and nomenclature shown in CIELAB.

However, before this information is given, the terms of reference used for this task force need to be discussed.

## SECTION ONE - TERMS OF REFERENCE

### Proposed GAA Group VI/S.W.O.P. Ink Testing Specification

A standard base should be used which is in conformance with that used to print the S.W.O.P. high/low density references. This base should be non-fluorescing, free from mechanical wood pulp, non-thermochromic and light fast.

#### Density Ranges/Target

Where it is necessary, density ranges for colors should be in accordance with the S.W.O.P. publication (May 1986), where the range midpoint becomes the target density. Density measurements should be made with a densitometer fitted with filters which record only complementary absorbing wavelengths and are calibrated to manufacturers specifications. Standard and samples should be backed with materials with a neutral density of not less than 1.5 (I.S.O. 5/4-1983).

#### Colorimetry

A spectrophotometer or colorimeter should be used to express reflectance (CIE recommendations are at no greater than 5 nm wavelengths with a range of 380 to 780 nm). "Colorimetry", 2nd edition, publication CIE No.15.2 (1986). If more abridged values are used, they should be no greater than 20 nm, and at least covering a range of 400 to 700 nm.

#### Measuring Geometry

The CIE Normal/45° symbolized as 0/45 (CIE Publication No. 15.2, 1986) is recommended as the principal geometry. However, if an integrating sphere is used, then the specular component should be excluded.

#### Illuminants

The CIE daylight illuminant D50 should be used as the principle illuminant with CIE standard illuminant A referenced for metamerism (CIE Publication No. 15.2 (1986) pages 11 to 15).

#### Tristimulus Values

Calculations of the tristimulus values X, Y and Z should be in accordance with CIE recommendations (CIE Publication 15.2 (1986)). Under these conditions  $X_n$ ,  $Y_n$ ,  $Z_n$  are the

tristimulus values of the standard illuminant with  $Y_n$  equal to 100.

### Numerical Nomenclature

Samples will be returned to the supplier for their own assessment, where necessary. Information included will be the standard, in terms of:

- 1) Reflectance luminance factor expressed as a percentage relative to a value of 100 for the perfect white diffuser.
- 2) The tristimulus values X, Y & Z (see illuminant & Standard Observer charts).
- 3) Values for CIE -  $L^*$ ,  $a^*$ ,  $b^*$   $C^*_{ab}$   $h_{ab}$  (CIE Daylight Illuminant D50).

The sample being compared to the standard will be expressed in a similar manner with color difference expressed in  $\Delta$  values from the standard, i.e.

$$\Delta L^*_{ab}$$

$$\Delta C^*_{ab}$$

$$\Delta h_{ab}$$

$$\Delta E^*_{ab}$$

(It should be noted that  $H^*_{ab}$  and  $h_{ab}$  are not the same.)

### The Use of Different Color Spaces

It is recommended that the principle color space should be that of CIELAB. However, as the reflectance values are given for each color @ 10nm increments, and also the tristimulus values, it is possible to transform these values to another color space, such as CIELUV for example. However, it should be noted that the tolerance given in CIELAB coordinates will not be a linear transformation in CIELUV coordinates.

### Standard Observer

The CIE Standard Observers, both 10° and 2° can be used with illuminant D50. ("Colorimetric Observers" CIE 002, (1987), CIE Central Bureau, Vienna 1987). The calculations for both observer functions can be found in the appendix.

## Color Space

The color space of choice is that of the CIE  $L^* a^* b^*$  (CIE Publication No. 15.2, pages 30 to 33) where:

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

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

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

$X/X_n, Y/Y_n, Z/Z_n > 0.01$

(If the Pauli equations are used, then  $X/X_n, Y/Y_n, Z/Z_n > 0.008856$ )

## Color Difference

Color difference tolerances should be expressed in the values of CIE:

1976 Lightness ( $L^*$ )

CIE 1976  $a^*, b^*$  Chroma ( $C^*_{ab}$ )

CIE 1976  $a^*, b^*$  Hue-angle ( $h_{ab}$ )

$$\Delta L^*_{ab} = L^*_1 - L^*_2$$

$$C^*_{ab} = (a^{*2} + b^{*2})^{1/2}$$

$$\Delta a^* = a^*_1 - a^*_2$$

$$\Delta b^* = b^*_1 - b^*_2$$

$$\Delta C^*_{ab} = C^*_1 - C^*_2$$

$$h_{ab} = \arctan (b^*/a^*)$$

$$\Delta h = h_1 - h_2$$

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

1 = standard, 2 = sample

## Ink Testing Procedure

Should be in conformance to GATF standard procedures (see GATF publication).

- I. The procedure of printing and colorimetric measurement were the same as those used in the National Association of Printing Ink Manufacturers/Specifications for Web Offset Proofing.
- II. Twenty six four color ink sets were solicited from NAPIM and Gravure Association of America (GAA) offset proofing ink suppliers and proofing houses. Each ink was compared to the Borden standard of the same color.
- III. Each ink was printed on three different substrates: Appleton Adproof, Champion Textweb, and Transfer Base\*. Adproof and Textweb are the approved SWOP proofing papers. Transfer Base\* is a titanium dioxide coated polyester chosen for the flatness and high level of the reflectance curve (whiteness).
  - . Adproof paper is a free sheet, and is used exclusively in the present ink verification program. The SWOP ink density references available from the International Prepress Association (IPA) are printed on Adproof.
- IV. Prints were made on each substrate with an IGT AC2 Printability Tester. The IGT allowed printing at a controlled speed (1.6 m/sec) and pressure (90 kgf).
- V. The distribution system of the IGT allowed multiple film splits to work the inks to a representative ink film thickness.
- VI. The amount of ink applied to the system was controlled by volume. The amount of ink applied to the disc was controlled by the length of time the disc was allowed to rotate on the distribution system. Each ink was on the distribution system for approximately five minutes. Photomicrographs show that for the same ink, paper, and density, the IGT can simulate the ink "lay" and consequently the ink and paper interaction of a larger offset press.
- VII. Each ink and substrate combination was printed to three different solid ink densities determined by the IPA high and low density references.
- VIII. Prints were dried overnight and measured with a COSAR 61 densitometer.

- IX. The foot of the densitometer was traced on the prints to indicate color measurement locations. This precaution allowed GATF, 3M, Kodak, and duPont to make spectrophotometer measurements in the same printed areas.
- X. The resulting 952 samples were measured with a spectrophotometer to give spectral curves and CIELAB colorimetric coordinates.
- XI. At GATF, the measurements were made with a Hunter D54 integrating sphere spectrophotometer, specular component included, two degree standard observer, D65 illuminant. Data were plotted in terms of CIELAB two dimensional diagrams and frequency histograms for the individual colorimetric factors. Colorimetric measurements were also made on each sample by 3M, and the next part of the presentation will feature 3M data.

\*Transfer base was originally used for comparison purposes because of its closeness to the "perfect white diffuser". However due to its diffusing characteristics it requires a much greater ink-film thickness to obtain the correct spectral density, as compared to either Adproof or Textweb. Therefore at this point its use as a reference base is not recommended.

## Measurement Nomenclature

In the ink color study, the objective was to compare a population of proofing inks to the standard Borden reference set. Measurement of the samples on a spectrophotometer were used to quantify the reflectance of light by the sample throughout the visible spectrum. This reflectance is depicted as a reflectance curve showing the fraction of light reflected by the sample at each wavelength from 380 nm to 700 nm in 10 nm intervals. The reflectance scale depicts a perfect white diffuser representing almost 100% reflectance.

The reflectance curve for each trial sample color (yellow, magenta, cyan and black) will be presented in separate plots, with the appropriate color identified in the title for the plot. The reflectance curve of the standard ink color will also be presented on the same plot to indicate their relative similarity or difference. A perfect non-metameric color match between standard and sample would result in the two reflectance curves being superimposed. However, one of the quirks of spectrophotometry is that often reflectance curves which do not overlay each other can also be judged as a visual match.

The reflectance curves have been generated for samples prepared on Adproof and Textweb papers. The appropriate paper is identified in the title for the plot. Comparison of the plots for the ink samples on the two papers allows discernment of substrate effects upon color measurement of the inks.

### Scatterplot - trial population vs. standard

The reflectance curve provides the basic information necessary for a color or object to be measured, but is not convenient for the description and specification of color alone. Therefore the results of this study are presented using the CIELAB 1976 color order system.

Reflectance data for a sample is combined with data describing a standard observer function and a standard illuminant condition which allow the calculation of the CIE tristimulus values (X,Y,Z) to be made.

CIELAB information (using D50 illuminant and the 10 degree observer) from the ink study is depicted by plots of  $L^*$ ,  $a^*$  and  $b^*$  values for the entire population of samples. These plots present an  $a^*$  vs  $b^*$  plane, with the  $L^*$  axis independently located to the left edge of the plot. The standard color is identified in the plots, and for each supplier location, the

specific sample presented by the location is also identified. A perfect color match between standard and sample would be represented by two points superimposed. Color differences are indicated by the distance ( $\Delta L^*$ ,  $\Delta a^*$  and  $\Delta b^*$ ) between the two points.

CIELAB plots for each sample color (yellow, magenta, cyan and black) are presented on a separate page, with the appropriate color identified in the title for the plot. Separate CIELAB plots are also presented for ink samples prepared on both Adproof and Textweb papers, with the appropriate substrate identified in the title for the plot.

### Data page

Each ink sample from the ink color study has a separate page representing the data used to generate the reflectance curve and CIELAB plots. Each sample color (yellow, magenta, cyan and black) is identified in the title of the data page, as is the identity of the location supplying that specific sample of ink. The left portion of each data page presents data for the ink sample printed on Textweb paper, while the right portion of each data page presents data for the same ink sample printed on Adproof paper.

Data on the page consists of:

- reflectance of the standard ink and sample ink
  - \* in 10nm increments
  - \* from 380nm to 700nm
- identification of illuminant (D50) and observer (10 degree) used in calculations of tristimulus and CIELAB values.
- calculated tristimulus values for the sample (X,Y,Z)
- calculated CIELAB values for the sample ( $L^*$ ,  $a^*$ ,  $b^*$ )
- calculated hue angle ( $h_{ab}$ ) and chroma ( $C^*_{ab}$ ) for the sample
  - \* used in polar coordinate description of CIELAB data
- color difference between the standard ink and the sample ink
  - \* in polar coordinate CIELAB space
  - \*  $\Delta L^*$ ,  $\Delta h_{ab}$   $\Delta C^*_{ab}$

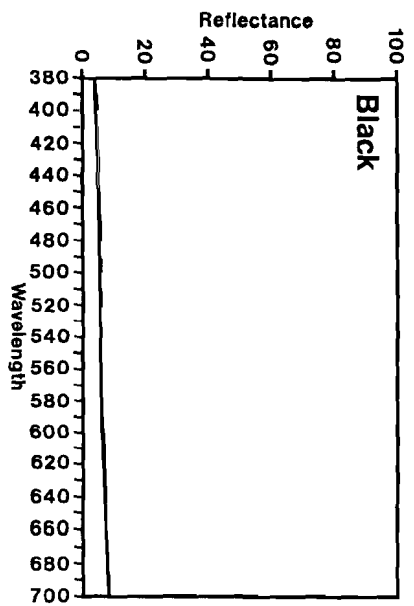
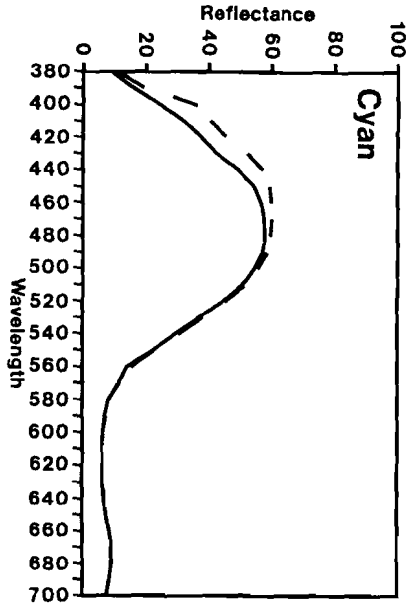
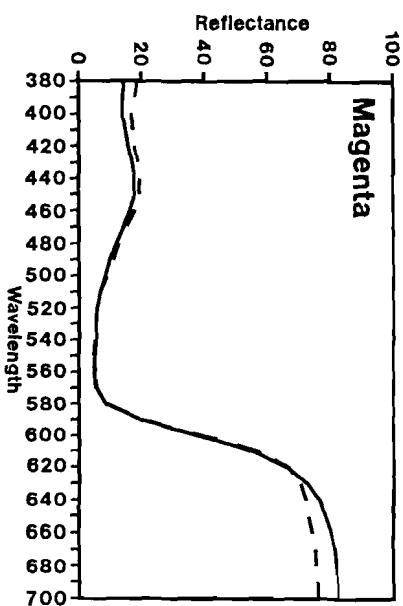
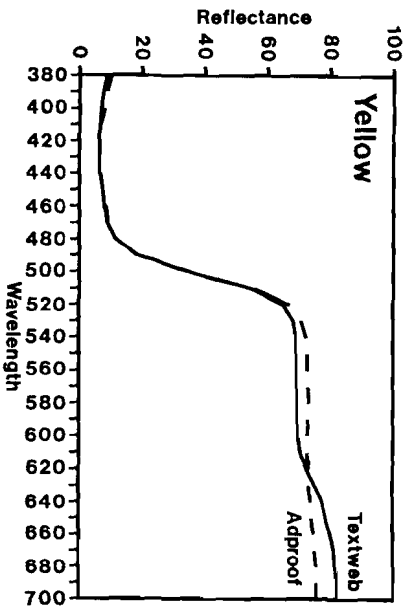
Conclusion:

\*The chromatic colors measured in this survey do not match the Borden reference samples well enough to be considered a useful specification.

GAA Distribution Task Force For Group VI/Swop Color Certification

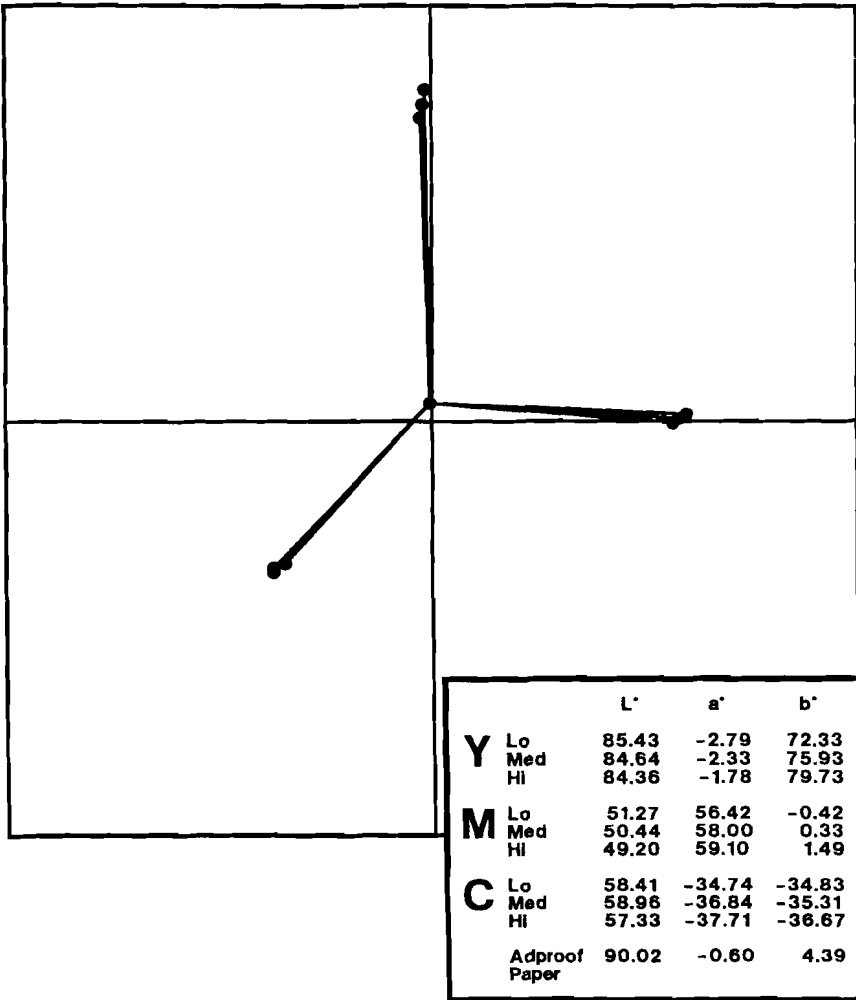
John Souter - Chairman - 3M  
Bill Sullivan - SWOP Chairman - Southview Graphics  
Vince Bellini - General Printing Ink  
Paul Borth - International Pre-Press Association  
Sam Colvin - 3M  
Don Demarest - Young & Rubicam, Inc.  
Joe Dooley - BASF Corporation - Inmont Div.  
Dan Enright - General Printing Ink  
Harvey George - Gravure Association of America  
Joseph Gugliotta - BASF Corporation - Inmont Div.  
Leon Hart - E.I. duPont de Nemours & Co.  
Henry Hatch - International Pre-Press Association  
John Lind - Graphic Arts Technical Foundation  
Barry Neal - Gravure Association of America  
Jim Renson - National Association of Printing Ink Manufacturers  
Chuck Rinehart - Eastman Kodak  
Joel Rubin - Phototype Color Graphics  
Bill Schaeffer - Graphic Arts Technical Foundation  
Yair Toor - Gravure Association of America  
Jim Tubay - R.R. Donnelley & Sons Company  
Gustavo Vergara - Reader's Digest Association, Inc.  
Paul Volpe - National Association of Printing Ink Manufacturers

# *Borden Inks on Textweb and Adproof Bases*



# **SWOP Ink Color Survey**

## **Effects on Color Measurement**

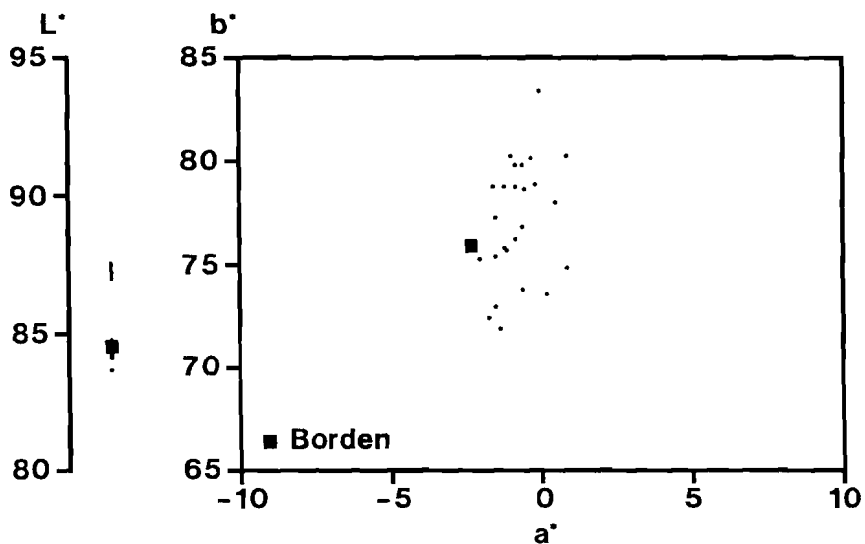


**2. Ink Film Thickness**  
 - SWOP Hi, Lo and Mid Point Densities

# ***SWOP Ink Color Survey***

## **Results**

**Yellow Ink on Adproof Stock**

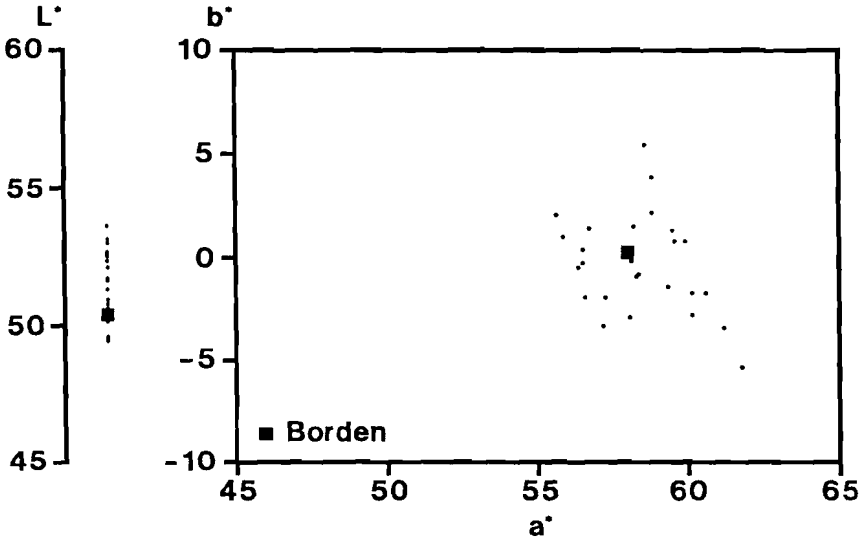


	<u>Min</u>	<u>Mean</u>	<u>Max</u>	<u>Borden</u>
<b>L*</b>	<b>83.70</b>	<b>86.07</b>	<b>87.64</b>	<b>84.64</b>
<b>a*</b>	<b>-2.33</b>	<b>-0.79</b>	<b>0.93</b>	<b>-2.33</b>
<b>b*</b>	<b>71.94</b>	<b>77.13</b>	<b>83.40</b>	<b>75.93</b>
<b>h<sub>ab</sub></b>	<b>89.32</b>	<b>90.59</b>	<b>91.76</b>	<b>91.76</b>
<b>c*</b>	<b>71.95</b>	<b>77.14</b>	<b>83.40</b>	<b>75.97</b>

# ***SWOP Ink Color Survey***

## **Results**

**Magenta Ink on Adproof Stock**

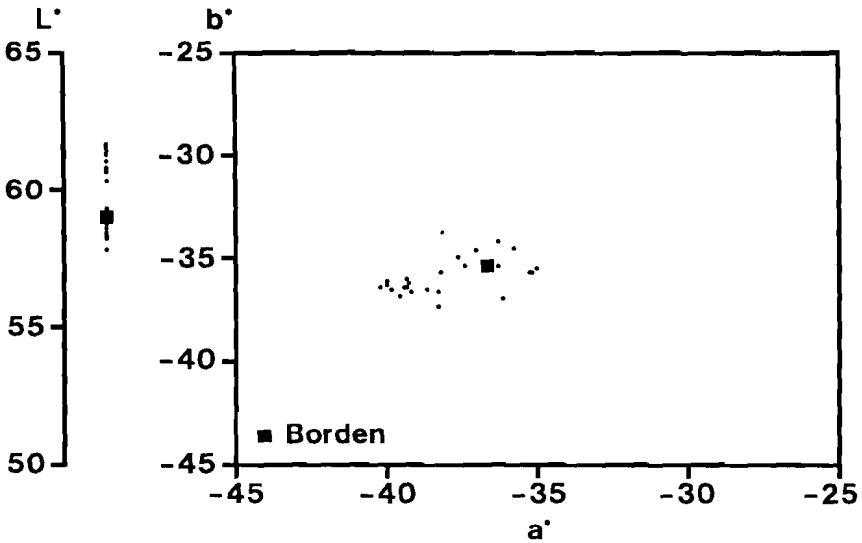


	<u>Min</u>	<u>Mean</u>	<u>Max</u>	<u>Borden</u>
<b>L*</b>	<b>49.46</b>	<b>51.50</b>	<b>53.74</b>	<b>50.44</b>
<b>a*</b>	<b>55.75</b>	<b>58.30</b>	<b>61.78</b>	<b>58.00</b>
<b>b*</b>	<b>-5.34</b>	<b>-0.18</b>	<b>5.35</b>	<b>0.33</b>
<b>h<sub>ab</sub></b>	<b>355.06</b>	<b>359.84</b>	<b>5.21</b>	<b>0.33</b>
<b>c*</b>	<b>55.78</b>	<b>58.34</b>	<b>62.01</b>	<b>58.00</b>

# **SWOP Ink Color Survey**

## **Results**

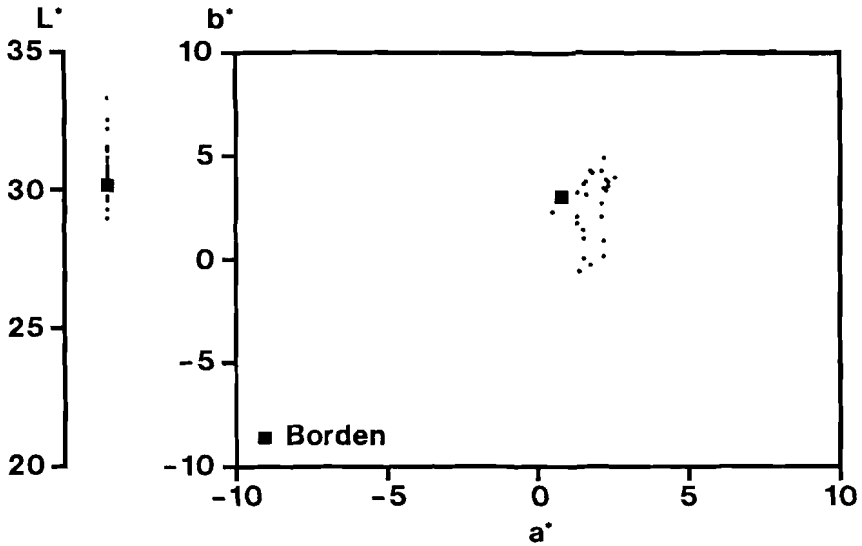
**Cyan Ink on Adproof Stock**



	<u>Min</u>	<u>Mean</u>	<u>Max</u>	<u>Borden</u>
<b>L*</b>	<b>57.91</b>	<b>59.86</b>	<b>61.65</b>	<b>58.96</b>
<b>a*</b>	<b>-40.22</b>	<b>-37.90</b>	<b>-35.02</b>	<b>-36.84</b>
<b>b*</b>	<b>-37.30</b>	<b>-35.83</b>	<b>-33.73</b>	<b>-35.31</b>
<b>h<sub>ab</sub></b>	<b>221.49</b>	<b>223.41</b>	<b>226.19</b>	<b>223.79</b>
<b>c*</b>	<b>49.78</b>	<b>52.17</b>	<b>54.26</b>	<b>51.03</b>

# **SWOP Ink Color Survey Results**

## **Black Ink on Adproof Stock**



	<u>Min</u>	<u>Mean</u>	<u>Max</u>	<u>Borden</u>
L*	28.95	30.67	33.30	30.05
a*	0.58	1.84	2.61	1.85
b*	-0.61	2.59	4.94	2.96
h <sub>ab</sub>	4.31	74.35	353.49	57.99
c*	1.46	3.37	5.42	3.49

$\lambda$ (nm)	(A) S( $\lambda$ )	(D <sub>50</sub> ) S( $\lambda$ )	(D <sub>65</sub> ) S( $\lambda$ )	$\lambda$ (nm)	(A) S( $\lambda$ )	(D <sub>50</sub> ) S( $\lambda$ )	(D <sub>65</sub> ) S( $\lambda$ )
300	0.93	0.02	0.03	450	33.09	87.25	117.0
05	1.13	1.03	1.7	55	35.41	88.93	117.4
10	1.36	2.05	3.3	60	37.81	90.61	117.8
15	1.62	4.91	11.8	65	40.30	90.99	116.3
20	1.93	7.78	20.2	70	42.87	91.37	114.9
325	2.27	11.26	28.6	475	45.52	93.24	115.4
30	2.66	14.75	37.1	80	48.24	95.11	115.9
35	3.10	16.35	38.5	85	51.04	93.54	112.4
40	3.59	17.95	39.9	90	53.91	91.96	108.8
45	4.14	19.48	42.4	95	56.85	93.84	109.1
350	4.74	21.01	44.9	500	59.86	95.72	109.4
55	5.41	22.48	45.8	05	62.93	96.17	108.6
60	6.14	23.94	46.6	10	66.06	96.61	107.8
65	6.95	25.45	49.4	15	69.25	96.87	106.3
70	7.82	26.96	52.1	20	72.50	97.13	104.8
375	8.77	25.72	51.0	525	75.79	99.61	106.2
80	9.80	24.49	50.0	30	79.13	102.10	107.7
85	10.90	27.18	52.3	35	82.52	101.43	106.0
90	12.09	29.87	54.6	40	85.95	100.75	104.4
95	13.35	39.59	68.7	45	89.41	101.54	104.2
400	14.71	49.31	82.8	550	92.91	102.32	104.0
05	16.15	52.91	87.1	55	96.44	101.16	102.0
10	17.68	56.51	91.5	60	100.00	100.00	100.0
15	19.29	58.27	92.5	65	103.58	98.87	98.2
20	20.99	60.03	93.4	70	107.18	97.74	96.3
425	22.79	58.93	90.1				
30	24.67	57.82	86.7				
35	26.64	66.32	95.8				
40	28.70	74.82	104.9				
45	30.85	81.04	110.9				

**Relative Spectral Power Distributions of Standard Illuminants A, D<sub>50</sub>, and D<sub>65</sub> from 300 to 830 nm at 5 nm Intervals**

$\lambda$ (nm)	(A) S( $\lambda$ )	(D <sub>50</sub> ) S( $\lambda$ )	(D <sub>65</sub> ) S( $\lambda$ )	$\lambda$ (nm)	(A) S( $\lambda$ )	(D <sub>50</sub> ) S( $\lambda$ )	(D <sub>65</sub> ) S( $\lambda$ )
575	110.80	98.33	96.1	725	213.27	81.68	65.7
80	114.44	98.92	95.8	30	216.12	86.51	69.9
85	118.08	96.21	92.2	35	218.92	89.55	72.5
90	121.73	93.50	88.7	40	221.67	92.58	75.1
95	125.39	95.59	89.3	45	224.36	85.40	69.3
600	129.04	97.69	90.0	750	227.00	78.23	63.6
05	132.70	98.48	89.8	55	229.59	67.96	55.0
10	136.35	99.27	89.6	60	232.12	57.69	46.4
15	139.99	99.16	88.6	65	234.59	70.31	56.6
20	143.62	99.04	87.7	70	237.01	82.92	66.8
625	147.24	97.38	85.5	775	239.37	80.60	65.1
30	150.84	95.72	83.3	80	241.68	78.27	63.4
35	154.42	97.29	83.5	85	243.92	78.91	63.8
40	157.98	98.86	83.7	90	246.12	79.55	64.3
45	161.52	97.26	81.9	95	248.25	76.48	61.9
650	165.03	95.67	80.0	800	250.33	73.40	59.5
55	168.51	96.93	80.1	05	252.35	68.66	55.7
60	171.96	98.19	80.2	10	254.31	63.92	52.0
65	175.38	100.60	81.2	15	256.22	67.35	54.7
70	178.77	103.00	82.3	20	258.07	70.78	57.4
675	182.12	101.07	80.3	825	259.86	72.61	58.9
80	185.43	99.13	78.3	30	261.60	74.44	60.3
85	188.70	93.26	74.0				
90	191.93	87.38	69.7				
95	195.12	89.49	70.7				
700	198.26	91.60	71.6				
05	201.36	92.25	73.0				
10	204.41	92.89	74.3				
15	207.41	84.87	68.0				
20	210.36	76.85	61.6				

***Relative Spectral Power Distributions of Standard Illuminants A, D<sub>50</sub>, and D<sub>65</sub> from 300 to 830 nm at 5 nm Intervals***

$\lambda$ (nm)	Spectral Tristimulus Values			Chromaticity Coordinates		
	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	$x(\lambda)$	$y(\lambda)$	$z(\lambda)$
380	0.0014	0.0000	0.0065	0.1741	0.0050	0.8209
385	0.0022	0.0001	0.0105	0.1740	0.0050	0.8210
390	0.0042	0.0001	0.0201	0.1738	0.0049	0.8213
395	0.0076	0.0002	0.0362	0.1738	0.0049	0.8215
400	0.0143	0.0004	0.0679	0.1733	0.0048	0.8219
405	0.0232	0.0006	0.1102	0.1730	0.0048	0.8222
410	0.0435	0.0012	0.2074	0.1726	0.0048	0.8226
415	0.0776	0.0022	0.3713	0.1721	0.0048	0.8231
420	0.1344	0.0040	0.6456	0.1714	0.0051	0.8235
425	0.2148	0.0073	1.0391	0.1703	0.0058	0.8239
430	0.2839	0.0116	1.3856	0.1689	0.0069	0.8242
435	0.3285	0.0168	1.6230	0.1669	0.0086	0.8245
440	0.3483	0.0230	1.7471	0.1644	0.0109	0.8247
445	0.3481	0.0298	1.7828	0.1611	0.0138	0.8251
450	0.3362	0.0380	1.7721	0.1566	0.0177	0.8257
455	0.3187	0.0480	1.7441	0.1510	0.0227	0.8263
460	0.2908	0.0600	1.6692	0.1440	0.0297	0.8263
465	0.2511	0.0739	1.5281	0.1355	0.0399	0.8246
470	0.1954	0.0910	1.2876	0.1241	0.0578	0.8181
475	0.1421	0.1126	1.0419	0.1096	0.0868	0.8036
480	0.0956	0.1390	0.8130	0.0913	0.1327	0.7760
485	0.0580	0.1693	0.6162	0.0687	0.2007	0.7306
490	0.0320	0.2080	0.4652	0.0454	0.2950	0.6596
495	0.0147	0.2586	0.3533	0.0235	0.4127	0.5638
500	0.0049	0.3230	0.2720	0.0082	0.5384	0.4534
505	0.0024	0.4073	0.2123	0.0039	0.6548	0.3413
510	0.0093	0.5030	0.1582	0.0139	0.7502	0.2359
515	0.0291	0.6082	0.1117	0.0389	0.8120	0.1491
520	0.0633	0.7100	0.0782	0.0743	0.8338	0.0919
525	0.1096	0.7932	0.0573	0.1142	0.8262	0.0596
530	0.1655	0.8620	0.0422	0.1547	0.8059	0.0394
535	0.2257	0.9149	0.0298	0.1929	0.7816	0.0255
540	0.2904	0.9540	0.0203	0.2298	0.7543	0.0161
545	0.3597	0.9803	0.0134	0.2658	0.7243	0.0099
550	0.4334	0.9950	0.0087	0.3016	0.6923	0.0061
555	0.5121	1.0000	0.0057	0.3373	0.6589	0.0038
560	0.5945	0.9950	0.0039	0.3731	0.6245	0.0024
565	0.6784	0.9786	0.0027	0.4087	0.5896	0.0017
570	0.7621	0.9520	0.0021	0.4441	0.5547	0.0012

***CIE 1931 Standard Colorimetric Observer. Abridged Set of Spectral Tristimulus Values  $\bar{x}(\lambda)$ ,  $\bar{y}(\lambda)$ ,  $\bar{z}(\lambda)$  and Corresponding Chromaticity Coordinates  $x(\lambda)$ ,  $y(\lambda)$ ,  $z(\lambda)$  for  $\lambda = 380$  to  $780$  nm at 5 nm Intervals.***

$\lambda$ (nm)	Spectral Tristimulus Values			Chromaticity Coordinates		
	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$	$x(\lambda)$	$y(\lambda)$	$z(\lambda)$
575	0.8425	0.9154	0.0018	0.4788	0.5202	0.0010
580	0.9163	0.8700	0.0017	0.5125	0.4866	0.0009
585	0.9786	0.8163	0.0014	0.5448	0.4544	0.0008
590	1.0263	0.7570	0.0011	0.5752	0.4242	0.0006
595	1.0567	0.6949	0.0010	0.6029	0.3965	0.0006
600	1.0622	0.6310	0.0008	0.6270	0.3725	0.0005
605	1.0456	0.5668	0.0008	0.6482	0.3514	0.0004
610	1.0026	0.5030	0.0003	0.6658	0.3340	0.0002
615	0.9384	0.4412	0.0002	0.6801	0.3197	0.0002
620	0.8544	0.3810	0.0002	0.6915	0.3083	0.0002
625	0.7514	0.3210	0.0001	0.7006	0.2993	0.0001
630	0.6424	0.2650	0.0000	0.7079	0.2920	0.0001
635	0.5419	0.2170	0.0000	0.7140	0.2859	0.0001
640	0.4479	0.1750	0.0000	0.7190	0.2809	0.0001
645	0.3608	0.1382	0.0000	0.7230	0.2770	0.0000
650	0.2835	0.1070	0.0000	0.7260	0.2740	0.0000
655	0.2187	0.0816	0.0000	0.7283	0.2717	0.0000
660	0.1649	0.0610	0.0000	0.7300	0.2700	0.0000
665	0.1212	0.0446	0.0000	0.7311	0.2689	0.0000
670	0.0874	0.0320	0.0000	0.7320	0.2680	0.0000
675	0.0636	0.0232	0.0000	0.7327	0.2673	0.0000
680	0.0468	0.0170	0.0000	0.7334	0.2666	0.0000
685	0.0329	0.0119	0.0000	0.7340	0.2660	0.0000
690	0.0227	0.0082	0.0000	0.7344	0.2656	0.0000
695	0.0158	0.0057	0.0000	0.7346	0.2654	0.0000
700	0.0114	0.0041	0.0000	0.7347	0.2653	0.0000
705	0.0081	0.0029	0.0000	0.7347	0.2653	0.0000
710	0.0058	0.0021	0.0000	0.7347	0.2653	0.0000
715	0.0041	0.0015	0.0000	0.7347	0.2653	0.0000
720	0.0029	0.0010	0.0000	0.7347	0.2653	0.0000
725	0.0020	0.0007	0.0000	0.7347	0.2653	0.0000
730	0.0014	0.0005	0.0000	0.7347	0.2653	0.0000
735	0.0010	0.0004	0.0000	0.7347	0.2653	0.0000
740	0.0007	0.0002	0.0000	0.7347	0.2653	0.0000
745	0.0005	0.0002	0.0000	0.7347	0.2653	0.0000
750	0.0003	0.0001	0.0000	0.7347	0.2653	0.0000
755	0.0002	0.0001	0.0000	0.7347	0.2653	0.0000
760	0.0002	0.0001	0.0000	0.7347	0.2653	0.0000
765	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
770	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
775	0.0001	0.0000	0.0000	0.7347	0.2653	0.0000
780	0.0000	0.0000	0.0000	0.7347	0.2653	0.0000

**CIE 1931 Standard Colorimetric Observer. Abridged Set of Spectral Tristimulus Values  $\bar{x}(\lambda)$ ,  $\bar{y}(\lambda)$ ,  $\bar{z}(\lambda)$  and Corresponding Chromaticity Coordinates  $x(\lambda)$ ,  $y(\lambda)$ ,  $z(\lambda)$  for  $\lambda = 380$  to  $780$  nm at 5 nm Intervals.**

$\lambda$ (nm)	Spectral Tristimulus Values			Chromaticity Coordinates		
	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
380	0.0002	0.0000	0.0007	0.1813	0.0197	0.7990
385	0.0007	0.0001	0.0029	0.1809	0.0195	0.7996
390	0.0024	0.0003	0.0105	0.1803	0.0194	0.8003
395	0.0072	0.0008	0.0323	0.1795	0.0190	0.8015
400	0.0191	0.0020	0.0860	0.1784	0.0187	0.8029
405	0.0434	0.0045	0.1971	0.1771	0.0184	0.8045
410	0.0847	0.0088	0.3894	0.1755	0.0181	0.8064
415	0.1406	0.0145	0.6568	0.1732	0.0178	0.8090
420	0.2045	0.0214	0.9725	0.1706	0.0179	0.8115
425	0.2647	0.0295	1.2825	0.1679	0.0187	0.8134
430	0.3147	0.0387	1.5535	0.1650	0.0203	0.8147
435	0.3577	0.0496	1.7985	0.1622	0.0225	0.8153
440	0.3837	0.0621	1.9673	0.1590	0.0257	0.8153
445	0.3867	0.0747	2.0273	0.1554	0.0300	0.8146
450	0.3707	0.0895	1.9948	0.1510	0.0364	0.8126
455	0.3430	0.1063	1.9007	0.1459	0.0452	0.8088
460	0.3023	0.1282	1.7454	0.1389	0.0589	0.8022
465	0.2541	0.1528	1.5549	0.1295	0.0779	0.7926
470	0.1956	0.1852	1.3176	0.1152	0.1090	0.7758
475	0.1323	0.2199	1.0302	0.0957	0.1591	0.7452
480	0.0805	0.2536	0.7721	0.0728	0.2292	0.6980
485	0.0411	0.2977	0.5701	0.0452	0.3275	0.6273
490	0.0162	0.3391	0.4153	0.0210	0.4401	0.5389
495	0.0051	0.3954	0.3024	0.0073	0.5625	0.4302
500	0.0038	0.4608	0.2185	0.0056	0.6745	0.3199
505	0.0154	0.5314	0.1592	0.0219	0.7526	0.2256
510	0.0375	0.6067	0.1120	0.0495	0.8023	0.1482
515	0.0714	0.6857	0.0822	0.0850	0.8170	0.0980
520	0.1177	0.7618	0.0607	0.1252	0.8102	0.0646
525	0.1730	0.8233	0.0431	0.1664	0.7922	0.0414
530	0.2365	0.8752	0.0305	0.2071	0.7663	0.0267
535	0.3042	0.9238	0.0206	0.2436	0.7399	0.0165
540	0.3768	0.9620	0.0137	0.2786	0.7113	0.0101
545	0.4516	0.9822	0.0079	0.3132	0.6813	0.0055
550	0.5298	0.9918	0.0040	0.3473	0.6501	0.0026
555	0.6161	0.9991	0.0011	0.3812	0.6182	0.0007
560	0.7052	0.9973	0.0000	0.4142	0.5858	0.0000
565	0.7938	0.9824	0.0000	0.4469	0.5531	0.0000
570	0.8787	0.9556	0.0000	0.4790	0.5210	0.0000

***CIE 1964 Supplementary Standard Colorimetric Observer. Abridged Set of Spectral Tristimulus Values  $\bar{x}_{10}(\lambda)$ ,  $\bar{y}_{10}(\lambda)$ ,  $\bar{z}_{10}(\lambda)$  and Corresponding Chromaticity Coordinates  $x_{10}(\lambda)$ ,  $y_{10}(\lambda)$ ,  $z_{10}(\lambda)$ , for  $\lambda = 380$  to  $780$  nm at 5 nm Intervals***

$\lambda$ (nm)	Spectral Tristimulus Values			Chromaticity Coordinates		
	$\bar{x}_{10}(\lambda)$	$\bar{y}_{10}(\lambda)$	$\bar{z}_{10}(\lambda)$	$x_{10}(\lambda)$	$y_{10}(\lambda)$	$z_{10}(\lambda)$
575	0.9512	0.9152	0.0000	0.5096	0.4904	0.0000
580	1.0142	0.8689	0.0000	0.5386	0.4614	0.0000
585	1.0743	0.8256	0.0000	0.5654	0.4346	0.0000
590	1.1185	0.7774	0.0000	0.5900	0.4100	0.0000
595	1.1343	0.7204	0.0000	0.6166	0.3884	0.0000
600	1.1240	0.6583	0.0000	0.6306	0.3694	0.0000
605	1.0891	0.5939	0.0000	0.6471	0.3529	0.0000
610	1.0305	0.5280	0.0000	0.6612	0.3388	0.0000
615	0.9507	0.4618	0.0000	0.6731	0.3269	0.0000
620	0.8563	0.3981	0.0000	0.6827	0.3173	0.0000
625	0.7549	0.3396	0.0000	0.6898	0.3102	0.0000
630	0.6475	0.2835	0.0000	0.6955	0.3045	0.0000
635	0.5351	0.2283	0.0000	0.7010	0.2990	0.0000
640	0.4316	0.1798	0.0000	0.7059	0.2941	0.0000
645	0.3437	0.1402	0.0000	0.7103	0.2898	0.0000
650	0.2683	0.1076	0.0000	0.7137	0.2863	0.0000
655	0.2043	0.0812	0.0000	0.7156	0.2844	0.0000
660	0.1526	0.0603	0.0000	0.7168	0.2832	0.0000
665	0.1122	0.0441	0.0000	0.7179	0.2821	0.0000
670	0.0813	0.0318	0.0000	0.7187	0.2813	0.0000
675	0.0579	0.0226	0.0000	0.7193	0.2807	0.0000
680	0.0409	0.0159	0.0000	0.7198	0.2802	0.0000
685	0.0286	0.0111	0.0000	0.7200	0.2800	0.0000
690	0.0199	0.0077	0.0000	0.7202	0.2798	0.0000
695	0.0138	0.0054	0.0000	0.7203	0.2797	0.0000
700	0.0096	0.0037	0.0000	0.7204	0.2796	0.0000
705	0.0066	0.0026	0.0000	0.7203	0.2797	0.0000
710	0.0046	0.0018	0.0000	0.7202	0.2798	0.0000
715	0.0031	0.0012	0.0000	0.7201	0.2799	0.0000
720	0.0022	0.0008	0.0000	0.7199	0.2801	0.0000
725	0.0015	0.0006	0.0000	0.7197	0.2803	0.0000
730	0.0010	0.0004	0.0000	0.7195	0.2806	0.0000
735	0.0007	0.0003	0.0000	0.7192	0.2808	0.0000
740	0.0005	0.0002	0.0000	0.7189	0.2811	0.0000
745	0.0004	0.0001	0.0000	0.7186	0.2814	0.0000
750	0.0003	0.0001	0.0000	0.7183	0.2817	0.0000
755	0.0002	0.0001	0.0000	0.7180	0.2820	0.0000
760	0.0001	0.0000	0.0000	0.7176	0.2824	0.0000
765	0.0001	0.0000	0.0000	0.7172	0.2828	0.0000
770	0.0001	0.0000	0.0000	0.7169	0.2831	0.0000
775	0.0000	0.0000	0.0000	0.7165	0.2835	0.0000
780	0.0000	0.0000	0.0000	0.7161	0.2839	0.0000

***CIE 1964 Supplementary Standard Colorimetric Observer. Abridged Set of Spectral Tristimulus Values  $\bar{x}_{10}(\lambda)$ ,  $\bar{y}_{10}(\lambda)$ ,  $\bar{z}_{10}(\lambda)$  and Corresponding Chromaticity Coordinates  $x_{10}(\lambda)$ ,  $y_{10}(\lambda)$ ,  $z_{10}(\lambda)$ , for  $\lambda = 380$  to  $780$  nm at 5 nm Intervals***