Spectral Energy Distribution of the International Commission on Illumination Light Sources A, B, and C

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Standard light sources A, B, and C were adopted by the International Commission on Illumination (CIE) in 1931 for the colorimetry of materials. Source A is an incandescent lamp operated at 2,854° K. Sources B and C, representative of average noon sunlight and average daylight, respectively, are produced by passing radiant flux from source A through specified Davis-Gibson filters described in Bureau Miscellaneous Publication M114 (1931).

The CIE published relative energy data only from 370 to 720 mμ. The present paper gives data for these sources in the ultraviolet and extends the data in the red to 780 mμ. The new data were reported through the U. S. Secretariat Committee to the CIE at its 1951 meeting.

1. Introduction

In 1931 the International Commission on Illumination (Commission Internationale de l'Eclairage, CIE) recommended that three light sources, A, B, and C, be adopted for the general colorimetry of materials [1].[1] These were defined as: A, a gas-filled lamp at the color temperature of 2,848° K ($c_2 = 14,350$ micron degrees).[2] B, the same lamp used with a filter consisting of a layer, 1-cm thickness, of each of two solutions * * * contained in a double cell with colorless optical-glass plates. The compositions of the two solutions are specified in the resolution. C, the same lamp in combination with a second filter of the same type but with different composition, also specified in the recommendation.

Source A is intended to be typical of light from the gas-filled tungsten-filament incandescent lamp; source B is an approximate representation of noon sunlight; and source C is an approximate representation of average daylight (see fig. 1). The relative spectral-energy distributions for sources B and C are given in the CIE recommendations over the wavelength range from 370 to 720 mμ.

The two filters that, in combination with source A, comprise sources B and C are of the type designed by Davis and Gibson and described in detail in Bureau Miscellaneous Publication M114 [2]. They are two of a large number of such filters designed for the reproduction of the various phases of sunlight and daylight and the conversion of low to higher color temperatures. The particular filters used to obtain sources B and C are designated in [2] as 2,848° to 4,800° K and 2,848° to 6,500° K because they were designed to produce exactly the colors corresponding to 4,800° and 6,500° K, respectively, for the observer defined by the "Optical Society of America (OSA) excitations extrapolated". For the 1931 CIE standard observer [3, 4] and the modification of it tentatively proposed in 1951 [5], the colors produced are slightly too purple to match the colors of the black body at any temperature. The temperatures of the black body most similar to these colors (called correlated color temperatures) are as follows [6]:

Observer	Correlated color temperature				Departure from design color temperature	
	$c_2=14,350$		$c_2=14,380$			
	Source B	Source C	Source B	Source C	Source B	Source C
	°K	°K	°K	°K	μrd	μrd
OSA "Escitations."	4,800	6,500	4,810	6,514	0.0	0.0
1951 CIE tentative.	4,815	6,560	4,825	6,574	.7	1.4
1931 CIE standard.	4,860	6,726	4,870	6,740	2.6	5.4

From the indicated departures from the design color temperatures of 4,800° and 6,500° K, respectively, it will be noted that these designations are only approximate if the 1931 CIE standard observer is used to assess the colors. But if the tentative 1951 modified observer is used, the designations may be considered precise for ordinary observing conditions under which differences in reciprocal color

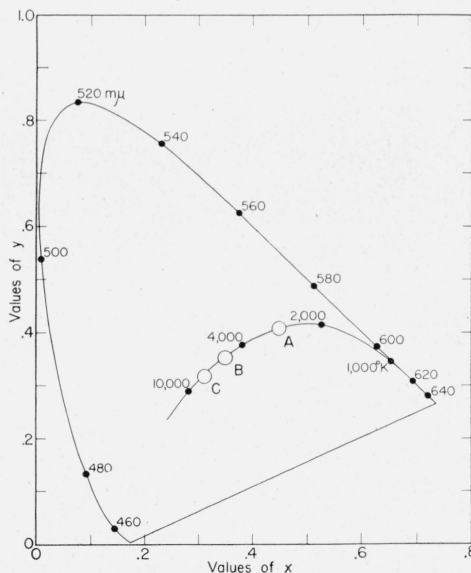FIGURE 1. *Chromaticities of CIE light sources A, B, and C, together with spectrum locus and black-body locus, plotted on the 1931 CIE chromaticity diagram.*

Those unfamiliar with this chromaticity diagram will find it discussed in references [1, 3, 4, and 6].

[1] Figures in brackets indicate the literature references at the end of this paper.
[2] Equivalent to 2,854° K, with $c_2=14,380$ micron degrees.

temperature in the neighborhood of 1.0 μrd (micro-reciprocal-degree) are imperceptible.

Regardless of this, however, the spectral distributions of CIE light sources B and C define these sources in unambiguous terms, irrespective of observer or color temperature, and these distributions give approximately the colors of noon sunlight and average daylight.

It happened that charts illustrating these particular filters and the resulting spectral distributions were not given [2] among those chosen for illustration. The chart for the 2,848° to 4,800° K filter and source was later published [7] but that for the 2,848° to 6,500° K filter has not been published. Accordingly, as a matter of convenience, these are both reproduced in slightly revised form in the present paper, see figures 2 and 3. Hereafter the sources (and filters) will be designated as sources B and C (or filters B and C), as they were designated by the CIE in 1931.
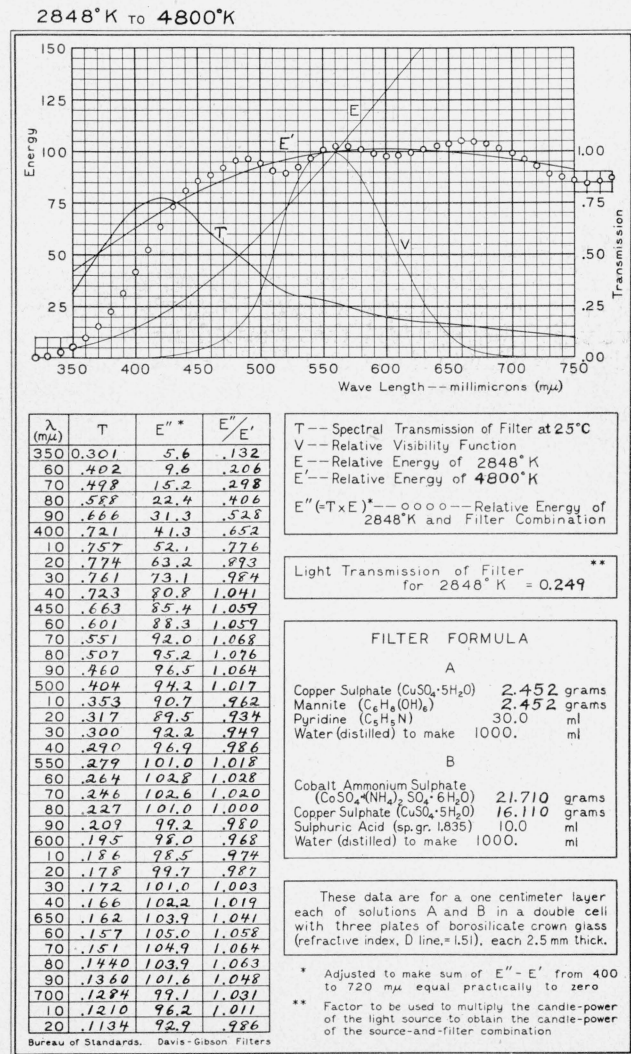
Figures 1, 2, and 3 give considerable information about these filters and the resulting light sources. Many other details relating to the filters are given in the original publication [2].

In the (U. S.) Secretariat questionnaire and report prepared for the 1948 meetings of the CIE in Paris [8], the question of standard sources was raised anew, and the following question was asked:

"In view of the possible influence of ultraviolet irradiation on the colours of fluorescent samples, do you believe that the definition of standard illuminant A, B and C should be made more precise in regard to the ultraviolet?"

The authors of [2] offered to extend the data for sources B and C below 350 mμ if that seemed desirable.

Replies to the above question were received from several countries, and after discussion at the meetings the following recommendation was adopted [8]:
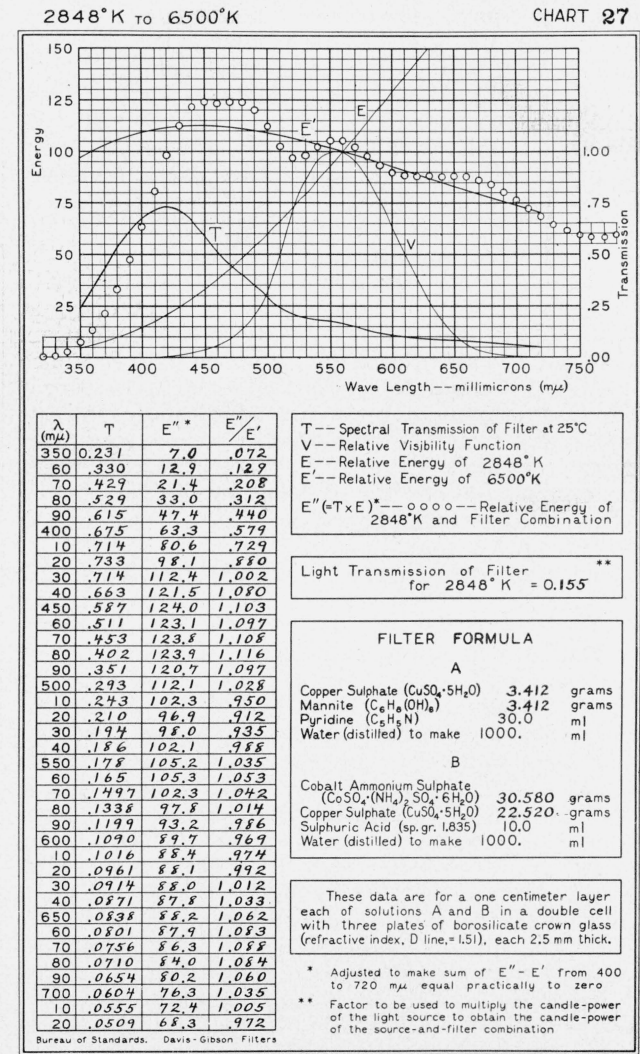
2848°K to 4800°K

λ (mμ)	T	E″ *	E″/E′
350	0.301	5.6	.132
60	.402	9.6	.206
70	.498	15.2	.298
80	.588	22.4	.406
90	.666	31.3	.528
400	.721	41.3	.652
10	.757	52.1	.776
20	.774	63.2	.893
30	.761	73.1	.984
40	.723	80.8	1.041
450	.663	85.4	1.059
60	.601	88.3	1.059
70	.551	92.0	1.068
80	.507	95.2	1.076
90	.460	96.5	1.064
500	.404	94.2	1.017
10	.353	90.7	.962
20	.317	89.5	.934
30	.300	92.3	.949
40	.290	96.9	.986
550	.279	101.0	1.018
60	.264	1028	1.028
70	.246	1026	1.020
80	.227	101.0	1.000
90	.209	99.2	.980
600	.195	98.0	.968
10	.186	98.5	.974
20	.178	99.7	.987
30	.172	101.0	1.003
40	.166	102.2	1.019
650	.162	103.9	1.041
60	.157	105.0	1.058
70	.151	104.9	1.064
80	.1440	103.9	1.063
90	.1360	101.6	1.048
700	.1284	99.1	1.031
10	.1210	96.2	1.011
20	.1134	92.9	.986

T — Spectral Transmission of Filter at 25°C
V — Relative Visibility Function
E — Relative Energy of 2848° K
E′ — Relative Energy of 4800° K
E″ (=T×E) * – – ○○○○ – Relative Energy of 2848° K and Filter Combination

Light Transmission of Filter **
for 2848° K = 0.249

FILTER FORMULA

A

Copper Sulphate (CuSO₄·5H₂O)	2.452	grams
Mannite (C₆H₈(OH)₆)	2.452	grams
Pyridine (C₅H₅N)	30.0	ml
Water (distilled) to make	1000.	ml

B

Cobalt Ammonium Sulphate (CoSO₄·(NH₄)₂SO₄·6H₂O)	21.710	grams
Copper Sulphate (CuSO₄·5H₂O)	16.110	grams
Sulphuric Acid (sp. gr. 1.835)	10.0	ml
Water (distilled) to make	1000.	ml

These data are for a one centimeter layer each of solutions A and B in a double cell with three plates of borosilicate crown glass (refractive index, D line, = 1.51) each 2.5 mm thick.

* Adjusted to make sum of E″ – E′ from 400 to 720 mμ equal practically to zero

** Factor to be used to multiply the candle-power of the light source to obtain the candle-power of the source-and-filter combination

Bureau of Standards.   Davis-Gibson Filters

FIGURE 2. *CIE light source B.*

Spectrophotometric data, and other information on this source and the filter used to obtain it. This chart is similar to the charts of reference [2] and [7]. Values below 350 and above 720 mμ are given in table 4.

2848°K to 6500°K   CHART 27

λ (mμ)	T	E″ *	E″/E′
350	0.231	7.0	.072
60	.330	12.9	.129
70	.429	21.4	.208
80	.529	33.0	.312
90	.615	47.4	.440
400	.675	63.3	.579
10	.714	80.6	.729
20	.733	98.1	.880
30	.714	112.4	1.002
40	.663	121.5	1.080
450	.587	124.0	1.103
60	.511	123.1	1.097
70	.453	123.8	1.108
80	.402	123.9	1.116
90	.351	120.7	1.097
500	.293	112.1	1.028
10	.243	102.3	.950
20	.210	96.9	.912
30	.194	98.0	.935
40	.186	102.1	.988
550	.178	105.2	1.035
60	.165	105.3	1.053
70	.1497	102.3	1.042
80	.1338	97.8	1.014
90	.1199	93.2	.986
600	.1090	89.7	.969
10	.1016	88.4	.974
20	.0961	88.1	.992
30	.0914	88.0	1.012
40	.0871	87.8	1.033
650	.0838	88.2	1.062
60	.0801	87.9	1.083
70	.0756	86.3	1.088
80	.0710	84.0	1.084
90	.0654	80.2	1.060
700	.0604	76.3	1.035
10	.0555	72.4	1.005
20	.0509	68.3	.972

T — Spectral Transmission of Filter at 25°C
V — Relative Visibility Function
E — Relative Energy of 2848° K
E′ — Relative Energy of 6500° K
E″ (=T×E) * – – ○○○○ – Relative Energy of 2848° K and Filter Combination

Light Transmission of Filter **
for 2848° K = 0.155

FILTER FORMULA

A

Copper Sulphate (CuSO₄·5H₂O)	3.412	grams
Mannite (C₆H₈(OH)₆)	3.412	grams
Pyridine (C₅H₅N)	30.0	ml
Water (distilled) to make	1000.	ml

B

Cobalt Ammonium Sulphate (CoSO₄·(NH₄)₂SO₄·6H₂O)	30.580	grams
Copper Sulphate (CuSO₄·5H₂O)	22.520	grams
Sulphuric Acid (sp. gr. 1.835)	10.0	ml
Water (distilled) to make	1000.	ml

These data are for a one centimeter layer each of solutions A and B in a double cell with three plates of borosilicate crown glass (refractive index, D line, = 1.51) each 2.5 mm thick.

* Adjusted to make sum of E″ – E′ from 400 to 720 mμ equal practically to zero

** Factor to be used to multiply the candle-power of the light source to obtain the candle-power of the source-and-filter combination

Bureau of Standards.   Davis-Gibson Filters

FIGURE 3. *CIE light source C.*

Spectrophotometric data and other information on this source and the filter used to obtain it. This chart is similar to those of reference [2]. Values below 350 and above 720 mμ are given in table 4.

"Ultraviolet Content of Standard Illuminants.—(a) It is recommended that the offer made through the United States Committee by Messrs. Davis and Gibson to determine the relative energy distributions of illuminants B and C below 370 mμ, including the spectral transmission factor of the cells, be accepted."

It was also recommended that the National Committees study the question of a standard source having relatively more ultraviolet energy than sources A, B, and C for the colorimetry of fluorescent materials.

In compliance with the first recommendation, the spectral transmittances of the B and C filters have been redetermined and extended in the ultraviolet, and these transmittances and the resulting spectral energy distributions were reported to the 1951 meetings of the Commission in Stockholm through the (U. S.) Secretariat Committee [9].

The present paper describes the measurements on which these new data are based, and gives the resulting values over the spectral range from 320 to 400 mμ. In addition, there are given some published and unpublished data for the long-wave end of the visible spectrum. In the charts of reference [2], as illustrated in figures 2 and 3 of the present paper, the data covered the visible range only to 720 mμ, this being the long-wave limit of the OSA excitations used in that work. However, the spectrophotometric data on the component filter parts had been determined to 750 mμ [2], so that extension of the transmission and energy data could readily be made.

When the CIE distributions defining the new standard observer were adopted, they were extended as far as 780 mμ [1]. At the request of Smith and Guild [3] values of relative energy for sources B and C were extended to 780 mμ. These values were published in table V, p. 102, of their paper. They were also published by Judd [4]. As the data entering into this extension of values have never been published, they are given in the present paper.

2. Spectrophotometric Measurements and Computations

The spectral transmittances of the filters (designated as spectral transmissions in [2]), given in figures 2 and 3 in the columns headed T were derived by computation from spectrophotometric measurements made on certain standard solutions, as explained in [2], including a study of Beer's law for the respective components over the range of concentrations of interest. This previous spectrophotometric work on the standard solutions was very extensive. It involved, for each standard component of the filter, measurements with several different solutions, at cell thicknesses from 1 to 10 cm and with three or four spectrophotometers. A detailed discussion of these measurements is given in [2]. All data were obtained at 25° C. Check measurements were also made on the complete filters.

No such elaborate series of measurements was considered necessary for the present purpose, which was primarily to extend the values of spectral transmittance and energy below 350 mμ, as far as there was significant transmittance. Because the filter cell contains three borosilicate glass plates of total thickness of about 7 mm, this transmittance could not in any case extend much below 300 mμ.

Two sets of solutions were prepared, one in February 1950 and one in January 1951. Spectrophotometric measurements were made on each set of solutions within 1 to 4 weeks from the date of preparation. In each case two methods of determining the filter transmittance were used: (1) The spectral transmittancies of the four standard filter components were measured and the transmittances of the B and C filters computed for the appropriate concentrations, as was done for all the filters of [2], (2) direct measurements of spectral transmittance were made on B and C filters prepared in accordance with the specifications.

The Beckman quartz (DU) spectrophotometer was used for all the present measurements, with temperatures of filters and components kept at 25° C. The 1950 and 1951 measurements were equivalent in every respect, the repetition being made to obtain greater certainty in the results. The 1950–51 data presented are averages of the results obtained.

2.1. Standard Filter Components

These components are the A′, B′$_1$, and B′$_2$ solutions, and the double cell filled with distilled water. They are as follows [2]:

Solution A′

Unfiltered, thickness 10.00 mm, temperature 25° C, having the composition:

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Copper sulfate 3 (CuSO4·5H2O) _____ g__3. 000
Mannite (C6H8(OH)6) _____ g__3. 000
Pyridine 4 (C5H5N) _____ ml__30. 0
Water (distilled) to make _____ ml__1, 000
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Solution B′$_1$

Unfiltered, thickness 10.00 mm, temperature 25° C, having the composition:

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Copper sulfate (CuSO4·5H2O) _____ g__20. 000
Sulfuric acid (specific gravity 1.835) _ml__10. 0
Water (distilled) to make _____ ml__1, 000
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Solution B′$_2$

Unfiltered, thickness 10.00 mm, temperature 25° C, having the composition: 5

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Cobalt ammonium sulfate 6
     (CoSO4·(NH4)2SO4·6H2O) _____ g__14. 481
Sulfuric acid (specific gravity 1.835) _ml__10. 0
Water (distilled) to make _____ ml__1, 000
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3 Chemical analysis showed the copper sulfate to have 99.7 percent of the theoretical copper content.

4 Titration showed the pyridine to have an effective strength of 98.4 percent, including 2½ percent of picoline as an impurity.

5 These data apply also throughout the visible spectrum to a similar solution made up with 10.3 g of cobalt sulfate (CoSO4·7H2O).

6 Chemical analysis showed a cobalt (plus nickel) content of 100.0 percent of the theoretical, the ratio of nickel to cobalt (metals) being 1 to 200.

GLASS-WATER DOUBLE CELL

Three glass plates, each approximately 2.4 mm thick (borosilicate crown, refractive index, D line,$=$ approximately 1.52); two 1.000-cm thicknesses of distilled water; two air-glass surfaces; four glass-water surfaces.

The spectral transmittancies of the A', B_1', and B_2' solutions (relative to distilled water) were measured in 1.000-cm cells with quartz end plates over the range from 300 to 400 mμ and at 404.7 and 435.8 mμ.[7] The transmittance of the glass-water double cell was measured at the same wavelengths.[8]

Solution	Wave-length	Transmittancy	
		Observed	Reference [2]
	$m\mu$		
A'_____	587.6	0.208	0.207
B_1'_____	667.8	.483	.480
B_2'_____	501.6	.679	.682

The purpose of the determinations at 435.8 and 404.7 mμ was to give correlation with the standard values in [2]. As is shown in that publication, the most extensive and reliable spectrophotometric determinations were made at eight Hg and He wavelengths, including these two. Below 404.7 mμ the standard values were subject to increasing uncertainty.

[7] In addition, a measurement at a region of relatively high absorption in the visible was made with each solution as a check on the concentration. The following values were obtained and were considered to be satisfactory checks, the deviation in each being less than 1 percent of the value.

[8] As a matter of interest, the spectral transmittancies of the three standard solutions were also examined in 1-cm thicknesses between 210 and 300 mμ. No measureable transmittancy was detected for the A' solution below 320 mμ. The transmittancy of the B_1' solution decreases rapidly below 300 mμ, approaching zero at 270 mμ and having no measureable value below this wavelength. The B_2' solution transmits freely between 210 and 300 mμ.

It was believed that the best correlation between the present measurements and the previous determinations would be obtained if the present values of transmittancy and transmittance were adjusted slightly, if necessary, to bring them into agreement with the previous standard values at these two wavelengths, 435.8 and 404.7 mμ; the resulting degree of agreement from 400 to 350 mμ could then be studied and new standard values for the four components from 300 to 400 mμ thereupon adopted. These adjustment factors, the averages of $T_{[2]}/T_{1950-51}$ for the two Hg wavelengths, were as follows:

Component	Ratio: $T_{[2]}/T_{1950-51}$		Adjustment factor
	404.7 mμ	435.8 mμ	
A'_____	1.0130	1.0095	1.011
B_1'_____	1.0030	1.0040	1.004
B_2'_____	1.0073	1.0067	1.007
W_____	0.9966	1.0011	0.999

In table 1 are given these adjusted values of transmittancy or transmittance for the various components, together with the values previously published in [2] and the newly adopted values. The following comments may be made regarding these values:

1. In deriving the adopted values, weights of 10, 8, 6, 4, 2, and 0 were given to the former values at 400, 390, 380, 370, 360, and 350 mμ, respectively. Corresponding weights of 0, 2, 4, 6, 8, and 10 were given to the 1950-51 adjusted values at these same wavelengths. From 340 to 300 mμ the 1950-51 adjusted values were used.

2. Solutions B_1' and B_2' show very close agreement between the former values and the 1950-51 adjusted values. Although there are no certain differences

TABLE 1. *Revision and extension of standard data for Davis-Gibson filter components*
Solutions A', B_1, and B_2', and double glass cell filled with distilled water, W

Wavelength	Transmittancy, 10.00 mm, at 25° C									Transmittance at 25° C of glass-water cell, W		
	Solution A'			Solution B_1'			Solution B_2'					
	Reference [2]	1950-51 average, adjusted ($f=1.011$)	Adopted values	Reference [2]	1950-51 average, adjusted ($f=1.004$)	Adopted values	Reference [2]	1950-51 average, adjusted ($f=1.007$)	Adopted values	Refer-ence [2]	1950-51 average, adjusted ($f=0.999$)	Adopted values
$m\mu$												
300_____	-----	0.000	0.000	-----	0.548	0.548	-----	0.986	0.986	-----	0.010	0.010
310_____	-----	.000	.000	-----	.788	.788	-----	.988	.988	-----	.102	.102
320_____	-----	.006	.006	-----	.899	.899	-----	.989	.989	-----	.314	.314
330_____	-----	.069	.069	-----	.945	.945	-----	.991	.991	-----	.536	.536
340_____	-----	.214	.214	-----	.968	.968	-----	.992	.992	-----	.702	.702
350_____	0.339	.334	.334	0.979	.980	.980	0.991	.992	.992	0.817	.798	.798
360_____	.437	.426	.428	.986	.986	.986	.991	.992	.992	.851	.848	.849
370_____	.541	.528	.533	.989	.991	.990	.989	.990	.990	.873	.870	.871
380_____	.646	.636	.642	.992	.994	.993	.985	.986	.985	.885	.869	.879
390_____	.746	.737	.744	.994	.994	.994	.980	.978	.980	.889	.886	.888
400_____	.825	.821	.825	.995	.995	.995	.972	.969	.972	.891	.893	.891
404.7_____	.855	.854	.855	.995	.996	.995	.967	.967	.967	.892	.894	.892
435.8_____	.959	.960	.959	.997	.996	.997	.904	.904	.904	.895	.893	.895
750_____	.446	-----	.446	.152	-----	.152	.994	-----	.994	.861	-----	.861
760_____	[a] .471	-----	.471	[a] .139	-----	.139	[a] .994	-----	.994	[b] .862	-----	.862
770_____	[a] .497	-----	.497	[a] .129	-----	.129	[a] .994	-----	.994	[b] .864	-----	.864
780_____	[a] .522	-----	.522	[a] .122	-----	.122	[a] .994	-----	.994	[b] .866	-----	.866

[a] Extrapolated, unpublished.
[b] Unpublished experimental data obtained at same time as data of [2].

between the two sets of data, the same system of weighting was used in adopting the final values.

3. Below 400 mμ there were slight but consistent differences between the 1950 and 1951 data for the A′ solutions. However, neither set of data differed from the average (either before or after adjustment) by more than 0.01 at any wavelength. Further work was considered unwarranted.

4. With the double glass cell filled with water a slight absorption band centering at 380 mμ was noted in the present determinations. This is caused by the glass plates and was not detected in the previous measurements. This is considered further in the next section.

5. The values at 750 mμ are as published in [2]. The values from 760 to 780 mμ for the three solutions were obtained by extrapolating the final $-\log_{10}T$ versus λ curves, on which the data of [2] are based. The uncertainty of this extrapolation increases of course as the wavelength interval from 750 mμ increases. At 760 and 770 mμ this uncertainty is considered very small, and the reliability of the values at these two wavelengths is considered wholly adequate for the purpose. For the glass-water cell, the values are as measured in 1926 and show clearly the water absorption band near 750 mμ.

2.2. Glass-Water Double Cell

A precise duplication of the spectral energy distributions given herein for sources B and C depends, among other things, on the adequate duplication of the spectral transmittance of the two-compartment glass cell when filled with distilled water. Borosilicate crown glass varies slightly in its index of refraction and in its spectral transmittance, particularly in the ultraviolet.

The D-line index of the glass used in 1926 to obtain the published data [2] was about 1.51. A new supply of borosilicate crown glass was obtained in 1929 with an index of about 1.52. This was used in the present measurements, the original pieces no longer being available. The agreement in spectral transmittance from 350 to 435.8 mμ, table 1, indicates that no important difference in the visible spectrum is to be expected. This has also been confirmed many times during the years by spectrophotometric measurements throughout the visible on various of the Davis-Gibson filters.

The slight absorption band centering at 380 mμ (table 1) was not detected in the 1926 measurements, those data having been derived from measurements made only at the mercury wavelengths below 400 mμ. With the Beckman spectrophotometer this band can be readily measured. It is present in all of the few samples of borosilicate crown recently measured, but in varying degree. It is probably caused by iron impurities since a greenish slide rule glass showed the band very strikingly.

This slight absorption has been ignored because (1) it varies from one glass to another, so that an extensive study would be necessary to determine what would be the most probable or representative value. It is, of course, also possible that some boro-

silicate crown glass would not show this slight absorption band, (2) needless confusion would be caused by the resulting trivial and unimportant changes in the energy distributions of the B and C sources.

Below 360 mμ there is some scatter among the spectral transmittances of different borosilicate crown glasses. This is also of little importance, however, because of the much greater absorption of the copper-pyridine (A′) solution, as shown in table 1.

In accordance with the CIE request there are given in table 2 the complete spectral transmittance data for the double glass cell filled with water entering into the derivation of the energy distributions of the B and C sources over the range from 300 to 780 mμ.[9]

TABLE 2. *Spectral transmittance of glass-water double cell*

Three glass plates, each 2.4[a] mm thick (borosilicate crown, refractive index, D line=1.52)[a], two 1,000-cm thicknesses of distilled water; two air-glass surfaces, four glass-water surfaces.

Wave-length	Trans-mittance	Wave-length	Trans-mittance
mμ		*mμ*	
290	0.000	550	0.904
300	.010	60	.904
10	.102	70	.904
20	.314	80	.904
30	.536	90	.903
40	.702	600	.902
350	.798	10	.902
60	.849	20	.902
70	.871	30	.901
80	.885	40	.900
90	.889	650	.900
400	.891	60	.900
10	.892	70	.900
20	.893	80	.900
30	.894	90	.898
40	.895	700	.897
450	.896	10	.893
60	.897	20	.883
70	.898	30	.871
80	.900	40	.863
90	.901	750	.861
500	.902	60	.862
10	.903	70	.864
20	.904	80	.866
30	.904		
40	.904		

[a] From 380 to 780 mμ the values were obtained with 2.5-mm plates with index 1.51 [2], but within the uncertainties of the data and the variability of borosilicate crown glass the data are valid for the conditions specified.

By measuring the spectral transmittance of his own glass-water cell, any user of these filters can tell if there are any important deviations of his cell from those of the authors.

2.3. B and C Filters

a. Computed Values

Based on the newly adopted standard components data of table 1, and by the same methods as previously used in the computation of such filters [2], the spectral transmittances of the B and C filters were computed and are shown in table 3.

b. Observed Values

In both 1950 and 1951, as already noted, spectrophotometric measurements were made directly on B

[9] At 380 and 390 mμ these values agree with the "Reference [2] values" rather than with the "adopted values" of table 1. The adopted values of table 1 were used in deriving the computed values of table 3, as indicated. However, since the energy distributions of the B and C sources and the spectral transmittances of the B and C filters were kept unchanged at 380 and 390 mμ for reasons given in section 2.3. c, the appropriate values for table 2 should be as given therein.

TABLE 3. *Revision and extension of standard data for filters and light sources B and C*

Wave-length	Spectral transmittance of filter B				Relative energy distribution of source B		Spectral transmittance of filter C				Relative energy distribution of source C	
	Former values	1950–51 data		New values	Former values	New values	Former values	1950–51 data		New values	Former values	New values
		Computed from adopted values of table 1	Observed values (no adjustment)					Computed from adopted values of table 1	Observed values (no adjustment)			
mμ												
300	------	0.000	0.000	0.000	------	------	------	0.000	0.000	0.000	------	------
310	------	.000	.001	.000	------	------	------	.000	.000	.000	------	------
320	------	.003	.004	.003	------	0.0_2	------	.001	.001	.001	------	0.0_1
330	------	.049	.047	.048	------	.5	------	.027	.022	.025	------	.4
340	------	.176	.173	.175	------	2.4	------	.126	.114	.120	------	2.7
350	0.309	.298	.304	.301	5.7	5.6	0.243	.234	.228	.231	7.4	7.0
360	.403	.396	.407	.402	9.7	9.6	.335	.328	.331	.330	13.2	12.9
370	.498	.492	.504	.498	15.2	15.2	.433	.427	.431	.429	21.6	21.4
380	.588	.585	.585	.588	22.4	22.4	.529	.525	.520	.529	33.0	33.0
390	.666	.664	.666	.666	31.3	31.3	.615	.613	.612	.615	47.4	47.4
400	.721	.722	.725	.721	41.3	41.3	.675	.676	.680	.675	63.3	63.3
720	.1134	------	------	.1134	92.9	92.9	.0509	------	------	.0509	68.3	68.3
730	[a] .1063	------	------	.1063	------	89.4	[a] .0467	------	------	.0467	------	64.4
740	[a] .1007	------	------	.1007	------	86.9	[a] .0435	------	------	.0435	------	61.5
750	[a] .0964	------	------	.0964	------	85.2	[a] .0409	------	------	.0409	------	59.2
760	[a] .0938	------	------	.0938	------	84.7	[a] .0392	------	------	.0392	------	58.1
770	[a] .0926	------	------	.0926	------	85.4	[a] .0385	------	------	.0385	------	58.2
780	[a] .0925	------	------	.0925	------	87.0	[a] .0384	------	------	.0384	------	59.1

[a] From 730 to 750 mμ these values are derived from the published data of [2].
From 760 to 780 mμ the values are derived from the data of table 1.

and C filters prepared according to the specifications. These consisted of two-compartment glass cells (index 1.52) filled with the appropriate solutions prepared in the respective years. The filters were kept at 25° C during the measurements. The average values so obtained are given in table 3. These are as directly observed, without any adjustment. (No values are given at 404.7 and 435.8 mμ, because data at these wavelengths were not published in [2 and 7] for the filters themselves.)

c. New Values

In table 3, in addition to the computed and observed values of spectral transmittance, are given the new transmittance values for filters B and C, together with the values previously derived by the methods and data of [2]. With respect to the new values it may be noted that:

1. The former values are retained without change from 380 to 400 mμ. This is highly desirable, as already implied, because these values from 380 to 400 mμ were incorporated in the energy distributions of sources B and C in 1931, and have been used in thousands of colorimetric computations since that date.[10] If the 1950–51 values differed certainly and importantly from the former values from 380 to 400 mμ, serious consideration would have to be given to changing the standard values. However, inspection of the data of table 3 at these wavelengths shows that in only one case out of 12 (observed value at 380 mμ for the C filter) does a computed or observed 1950–51 value differ from the former value by as much as 1 percent of the value.

[10] Although the CIE adopted values of energy distribution also at 370 mμ, the standard observer was defined by data ending at 380 mμ. The energy values at 370 mμ, so far as known, have never been used in colorimetric computations. The authors, therefore, felt free to revise both the values of transmittance and the resulting energy at 370 mμ.

2. At 360 mμ the slight absorption found in the 1950–51 borosilicate crown glass plates is reflected in the relatively low values for both the computed and observed data for both the B and the C filters. However, even if it were not desirable to retain the values at 380 mμ, for the reason just stated, one would hesitate to make any change on the basis of the present data alone, without a thorough study of borosilicate crown glass plates.

3. From 320 to 370 mμ the new values are taken as the average of the observed and computed values. While one might believe that the observed values should be given more weight than the computed values, the experimental conditions render the measurements somewhat more difficult and uncertain in the former case. Furthermore, at the very low values of transmittance the computed values are considered more reliable than the directly observed values.

4. The values of transmittance at 720 mμ are as given in figures 2 and 3. The values of transmittance from 730 to 780 mμ are derived from the data of table 1 or the published data of [2] by the same computational procedures used to derive the corresponding values of figures 2 and 3 at the other wavelengths.

2.4. Light Sources B and C

The values of relative spectral energy distribution for sources B and C are derived by multiplying, wavelength by wavelength, the relative-energy values of source A by the respective spectral transmittances of filters B and C, and reducing in each case by a factor to the same scale as used in [2].

In table 3 are given the values of relative energy for sources B and C, first the former values, which are consistent with the data of [2], and then as revised on

TABLE 4. *Relative spectral-energy distributions E of CIE light sources A, B, and C, and spectral transmittances T of CIE filters B and C*

Wave-length	E_A	E_B	E_C	T_B	T_C
mμ					
320	1.92[a]	0.0_2	0.0_1	0.003	0.001
30	2.66	.5	.4	.048	.025
40	3.58	2.4	2.7	.175	.120
350	4.74	5.6	7.0	.301	.231
60	6.14	9.6	12.9	.402	.330
70	7.82	15.2	21.4	.498	.429
80	9.79	22.4	33.0	.588	.529
90	12.09	31.3	47.4	.666	.615
400	14.71	41.3	63.3	.721	.675
10	17.68	52.1	80.6	.757	.714
20	21.00	63.2	98.1	.774	.733
30	24.67	73.1	112.4	.761	.714
40	28.70	80.8	121.5	.723	.663
450	33.09	85.4	124.0	.663	.587
60	37.82	88.3	123.1	.601	.511
70	42.87	92.0	123.8	.551	.453
80	48.25	95.2	123.9	.507	.402
90	53.91	96.5	120.7	.460	.351
500	59.86	94.2	112.1	.404	.293
10	66.06	90.7	102.3	.353	.243
20	72.50	89.5	96.9	.317	.210
30	79.13	92.2	98.0	.300	.194
40	85.95	96.9	102.1	.290	.186
550	92.91	101.0	105.2	.279	.178
60	100.00	102.8	105.3	.264	.165
70	107.18	102.6	102.3	.246	.1497
80	114.44	101.0	97.8	.227	.1338
90	121.73	99.2	93.2	.209	.1199
600	129.04	98.0	89.7	.195	.1090
10	136.34	98.5	88.4	.186	.1016
20	143.62	99.7	88.1	.178	.0961
30	150.83	101.0	88.0	.172	.0914
40	157.98	102.2	87.8	.166	.0871
650	165.03	103.9	88.2	.162	.0838
60	171.96	105.0	87.9	.157	.0801
70	178.77	104.9	86.3	.151	.0756
80	185.43	103.9	84.0	.1440	.0710
90	191.93	101.6	80.2	.1360	.0654
700	198.26	99.1	76.3	.1284	.0604
10	204.41	96.2	72.4	.1210	.0555
20	210.36	92.9	68.3	.1134	.0509
30	216.12	89.4	64.4	.1063	.0467
40	221.66	86.9	61.5	.1007	.0435
750	227.00	85.2	59.2	.0964	.0409
60	232.11	84.7	58.1	.0938	.0392
70	237.01	85.4	58.2	.0926	.0385
80	241.67	87.0	59.1	.0925	.0384

[a] E_A =0.93 at 300 mμ and 1.36 at 310 mμ.

the basis of the new spectral transmittances. The following points may be noted: (1) The values from 380 to 400 mμ are kept unchanged. This follows from the fact that the new spectral transmittances are kept unchanged at these wavelengths, for the reason already stated. (2) From 350 to 370 mμ the new values do not differ importantly from the former values. For source B they are not considered certainly different except at 350 mμ. For source C the new values are considered certainly different from the old values at both 350 and 360 mμ. (3) Effective termination of the energy distribution at 320 mμ results primarily from the absorption of the copper-pyridine component, with the increasing absorption of the glasses and the decreasing energy of source A contributing secondarily.

3. Final Data

As a matter of convenient reference there are given in table 4 over the spectral range from 320 to 780 mμ the relative spectral-energy distributions of CIE sources A, B, and C and the spectral transmittances of filters B and C.

For source A, the values from 380 to 780 mμ are identical with those published by Smith and Guild [3] and by Judd [4]. From 320 to 370 mμ the values have been derived by the authors from previous publications [10, 11], with allowance for differences in c_2 of Planck's equation.

For sources B and C the values from 380 to 720 mμ are identical with the published CIE values [11] [1], and with values published by Smith and Guild [3] and by Judd [4]. From 320 to 370 mμ the values are taken from table 3 of the present paper. From 730 to 780 mμ, the values are as published by Smith and Guild and by Judd.

For filters B and C the values from 380 to 720 mμ are unchanged from previous data. From 320 to 370 and from 730 to 780 mμ, the values are taken from table 3 of the present paper.

4. References

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[11] Except for the erroneous published value at 380mμ for source C.

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