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STANDARDIZATION OF THE LUMINOUS-TRANSMISSION SCALE USED IN THE SPECIFICATION OF RAILROAD SIGNAL GLASSES

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ABSTRACT

This is the first of several papers dealing with the development and description of the signal-glass specifications formulated by the Signal Section of the Association of American Railroads in 1935 and 1938. The present paper gives the spectral transmissions of the basic standards—red, yellow, green, blue, purple, and lunar-white glasses—on which the AAR scale of luminous transmission is based, and defines that scale in fundamental, absolute units. Comparison is made with the scales defined in the 1908 and 1918 signal-glass specifications.

CONTENTS

I. INTRODUCTION

This is the first of several papers describing the work of the National Bureau of Standards on the color standardization of railroad signal glasses. This standardization has resulted from the cooperative efforts of the Signal Section of the Association of American Railroads (formerly the American Railway Association), Corning Glass Works, and the National Bureau of Standards. The Bureau's work was actively started in 1930 and has been formally reported to the cooperating organizations at various times since then.[1] These papers will

[1] Standardization of railway signal glasses—Reports on measurements and investigations undertaken by the Colorimetry Section of the National Bureau of Standards at the request of the Signal Section, American Railway Association.

Reports 1 to 5, K. S. Gibson and Geraldine K. Walker, published in Signal Section Proc., Am. Ry. Assoc. **30,** 384 (1933):

Report 1. The transmission (ARA scale) of 36 specimens of signal glass relative to transmission of 6 ARA standards marked "J. C. Mock 10-3-30," a report on measurements made at Corning Glass Works December 9–11, 1930 (June 1, 1932).

Report 2. Measurements of spectral and luminous transmissions leading to the derivation of new ARA transmissions for the 36 glasses listed in report 1 (October 24, 1932).

Report 3. Spectral and luminous transmissions and derivation of new values of ARA transmission for the 22 "limit" glasses selected by committee VI, ARA, at Corning, November 5–6, 1931, and engraved "J. C. M. 11-6-31" (December 2, 1932).

Report 4. Chromaticities and luminous transmissions, with illuminants at 1,900° K and 2,848° K, for the 22 "limit" glasses described in report 3 (January 30, 1933).

Report 5. Tentative specifications for railway signal colors (April 27, 1933).

Reports 6 and 7, K. S. Gibson, Geraldine Walker Haupt, and H. J. Keegan, published in Signal Section Proc., Assoc. Am. R. R. **36,** 136 (1939):

Report 6. Examination of 65 duplicate limit glasses (July 26, 1934).

Report 7. Colorimetric data leading to specification 59–38 for kerosene hand lantern globes; comparison of specifications 59–38, 69–38, and 69–35; certification of duplicate lantern glasses (September 28, 1938).

present a summary of these reports, to which the reader is referred for additional details, illustrate and discuss the new specifications resulting from this work, namely, AAR Signal Section Specifications 69–35, 69–38,[2] and 59–38,[3] and give supplementary information not elsewhere published. Comparison will also be made with other signal-glass specifications.

The authors acknowledge with pleasure the interest and support of J. C. Mock, signal engineer, Michigan Central Railroad, who has been identified with the railroad signal glass standardization since 1904, and who has served as chairman of subcommittee A (of committee VI, Designs, Signal Section) in charge of the standardization of pressware and disk glasses, and of A. S. Haigh, chairman of subcommittee C in charge of the standardization of lantern glasses and present chairman of committee VI; also the invaluable advice and assistance of H. P. Gage, chief, Optical Division, Corning Glass Works, who has prepared the large number of glasses necessary for the successful carrying out of the signal-glass standardization.

A history of railroad signal-glass standardization prior to 1928 has been given by Dr. Gage in an important paper entitled, Practical Considerations in the Selection of Standards for Signal Glass in the United States.[4] In that paper are noted the signal-glass specifications adopted in 1908 and 1918 by the then Railway Signal Association, the latter specification, No. 6918, being quoted in part. There are also given information on the selection and uses of signal colors and the various types of signal ware and spectrophotometric and colorimetric data on signal glasses in use prior to the adoption of specification 69–35.[5]

II. ASSOCIATION OF AMERICAN RAILROADS SCALE OF LUMINOUS TRANSMISSION

In 1908 the Railway Signal Association, with the cooperation of Corning Glass Works, adopted certain glass roundels, for use with the kerosene flame, to represent the most desirable colors then available for signal purposes. The colors were designated as red, yellow, green, blue, purple, and lunar white. Each of these roundels was designated arbitrarily as having a "photometric value" of 100, regardless of the absolute or true value of its luminous transmission. They were also designated as the "standard" or "medium intensity" roundels. To allow the necessary manufacturing tolerances, certain limits of photometric value above and below the standard were specified, such as "light" and "dark" limits of 120 and 80, 125 and 75, or 130 and 70, within which a glass would be acceptable for signalling purposes. Chromaticity limits were not specified as such, but the light and dark

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[2] AAR Signal Section Specification 69-38, Signal Glasses (Exclusive of Kerosene Hand Lantern Globes); approved, 1938. The 1935 issue of this specification appeared in that year under the number 69-35. The differences between 69-35 and 69-38 are very slight, and no change at all was made in the transmission scale. The present transmission scale will be considered to have been established in 1935, although the data on which it is based were obtained and reported in 1930-32.

[3] AAR Signal Section Specification 59-38, Kerosene Hand Lantern Globes; approved, 1938. The present AAR scale of transmission is incorporated in Specification 59-38 (so far as applicable) as well as in 69-38. Specifications 59-38 and 69-38 may be obtained from R. H. C. Balliet, secretary, AAR Signal Section, 30 Vesey Street, New York, N. Y.

[4] Proc. Int. Cong. Illum., Saranac Inn, N. Y., p. 834 (September 1928).

[5] Further information on the early history of railroad signal-glass standardization is given in reports by Mr. Mock and Dr. Gage, Signal Section Proc., Am. Ry. Assoc., **30**, 373, 377 (1933).

limits were apparently tacitly used as chromaticity limits.[6] By specifying the spectral transmissions of the standard roundels, a fundamental record of the colors of the glasses was attempted. The values so specified are given in table 1 and illustrated in figures 1 to 6.

TABLE 1.—*Spectral transmissions of the standard or medium roundels, designated as having a value of $T_{RSA}=100$; 1908 specification* [1]

Wave length		Red	Yellow	Green	Blue	Purple	Lunar white
Fraunhofer line	(Millimicron equivalent)						
		%	%	%	%	%	%
A	(761)	60	0	0	0	0	0
a	(716)	65	38	0	0	42	62
B	(687)	70	50	0	0	42	49
C	(656)	72	43	0	0	0	17
D	(589)	0	41	4	3	0	15
E	(527)	0	12	27	4	0	25
b	(517)	0	9	40	6	0	38
F	(486)	0	3	45	24	2	65
G	(431)	0	0	25	40	43	74
H	(397)	0	0	0	46	42	0

[1] Values taken from a copy of the original Specifications for Signal Roundels, Lenses, and Glass Slides, Proc. Ry. Signal Assoc. vol. 5 (1908), kindly furnished the authors by R. H. C. Balliet, present secretary, AAR Signal Section.

In 1918, as a result of improvements in glass-making technique, the medium values for red, yellow, and green roundels were increased from 100 to 130, 120, and 150, respectively, with corresponding increases in the light and dark limits. A new specification was formulated, designated both as 1918 and 6918, in which new tables of spectral transmission were given for the medium roundels. These values are given in table 2 and illustrated in figures 1 to 6. They are considered further below.

This extension of the transmission (photometric) limits to higher values was based in considerable part, apparently, on values obtained by direct photometric comparisons of glasses of somewhat differing chromaticity, which introduced undesirable personal uncertainties common to heterochromatic photometry. The situation was eventually made still worse with the introduction of "electric purples," "electric lunar whites" (glasses designed for use solely with incandescent-lamp illuminants), and other types of glass differing notably in both luminous transmission and chromaticity from the original standards having transmission values designated as 100. Furthermore, the original standards had become lost. The first step in the present standardization, therefore, was to select new replicas of the lost standards and measure and define the transmissions of these new standards in fundamental terms.

Although the original standards were missing, the transmission scale itself had undoubtedly been maintained close to its original value by means of duplicate working standards at Corning Glass Works. To reestablish the scale on an official basis, Mr. Mock, in October 1930, endorsed six roundels as the new ARA standards, engraving each "J. C. Mock, 10–3–30." The designated trans-

[6] However, the 1908 specification does state that "The manufacturer must submit samples of glasses showing the extreme limits of colors which it is proposed to furnish. These shall bear labels showing the photometric values * * *." There were also given in the specification certain qualitative restrictions tending to prevent glass of undesirable color from being used. This original specification is considered further in section IV, below.

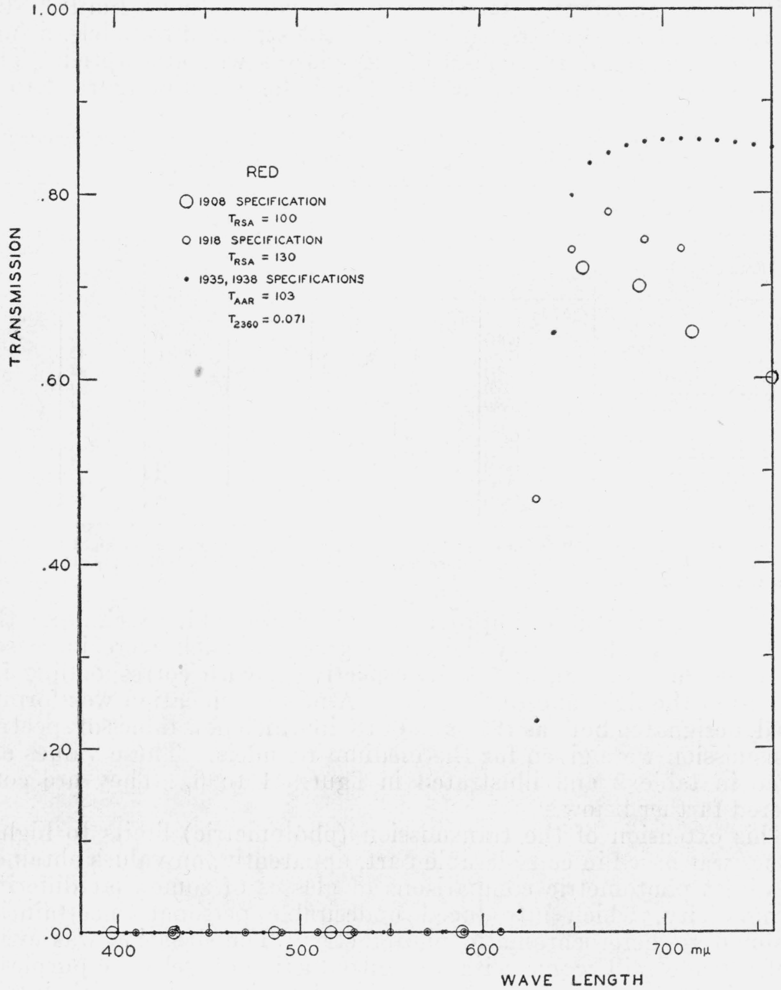

FIGURE 1.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* red, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specifications, now in effect, are designated as AAR Signal Section Specifications 59-38 and 69-38.

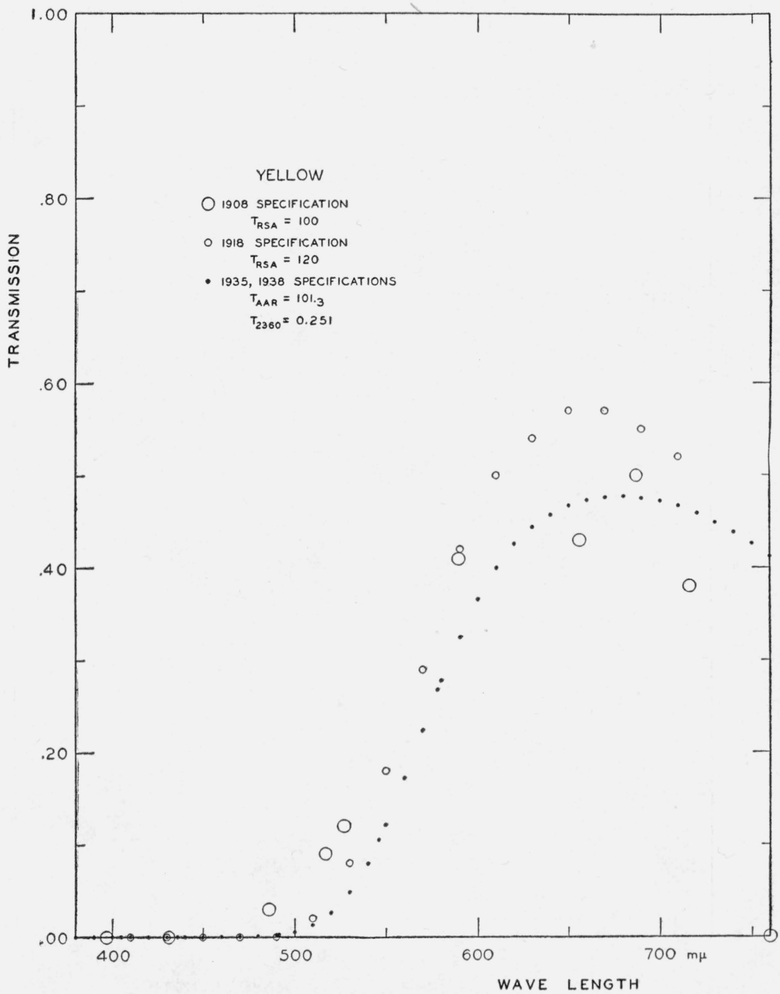

FIGURE 2.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* yellow, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specifications, now in effect, are designated as AAR Signal Section Specifications 59–38 and 69–38.

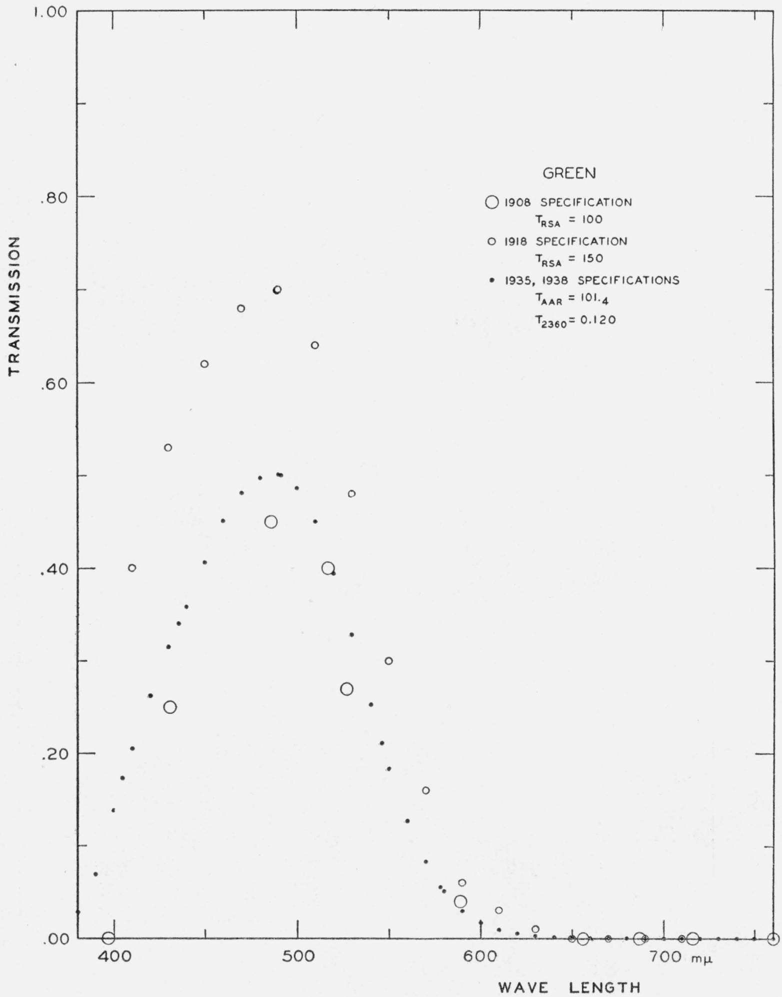

FIGURE 3.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* green, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specifications, now in effect, are designated as AAR Signal Section Specifications 59-38 and 69-38.

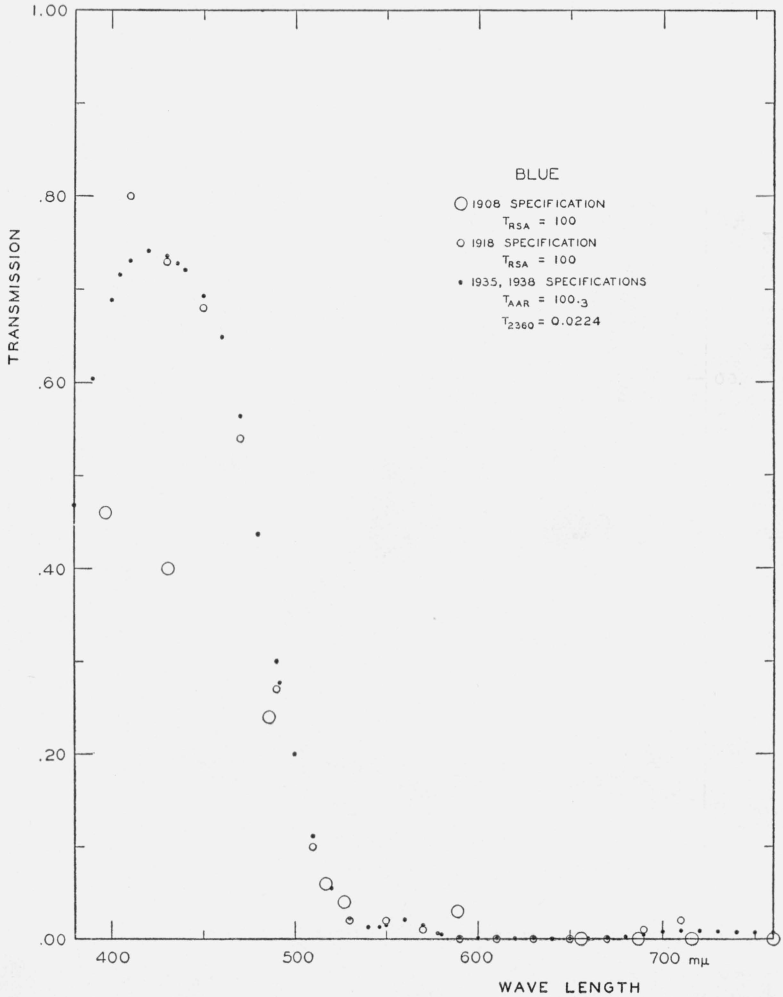

FIGURE 4.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* blue, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specifications, now in effect, are designated as AAR Signal Section Specifications 59-38 and 69-38.

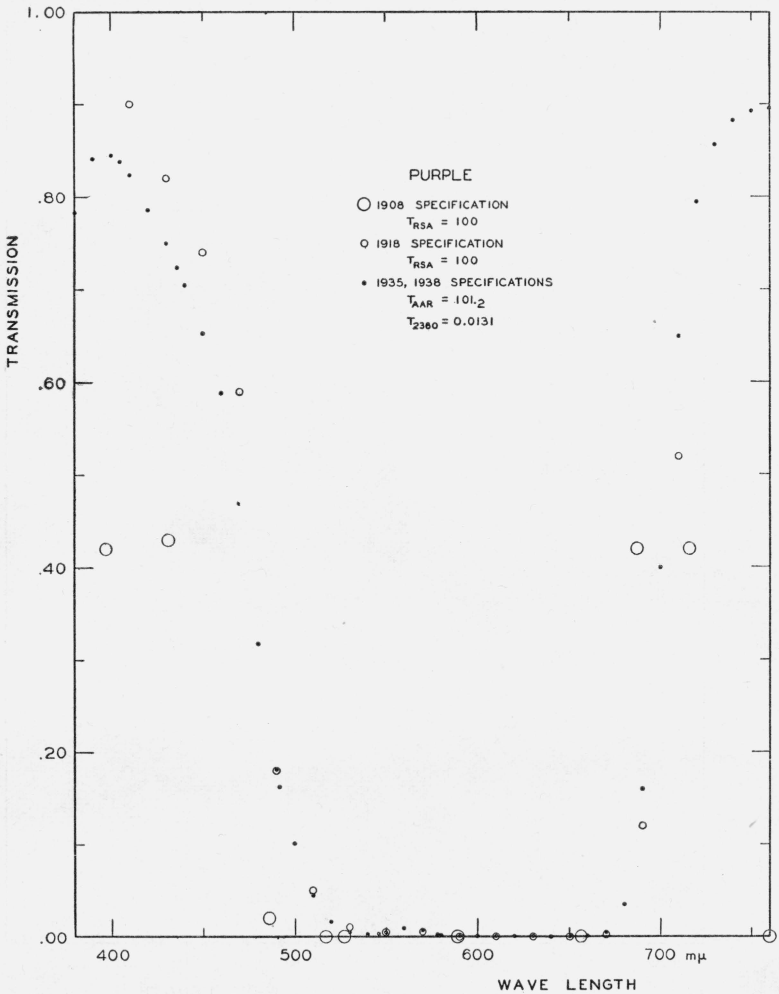

FIGURE 5.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* purple, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specification, now in effect, is designated as AAR Signal Section Specification 69-38.

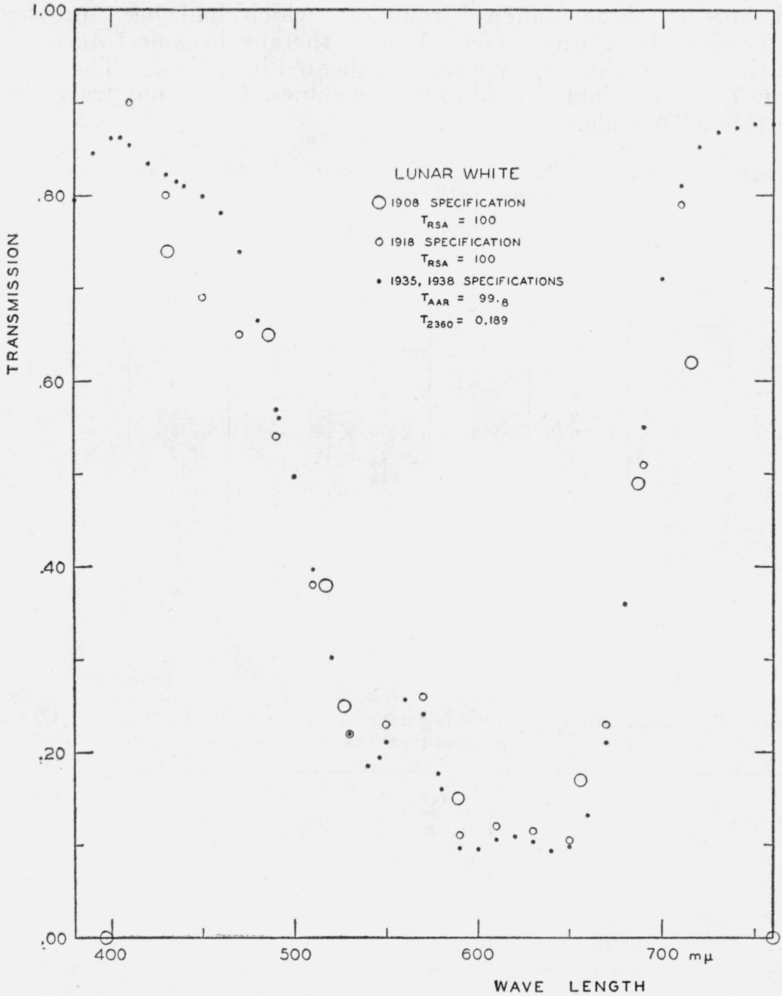

FIGURE 6.—*Spectral transmissions defining the scales of luminous transmission for glasses designated as* lunar white, *as established respectively in the 1908 and 1918 specifications of the Railway Signal Association and in the 1935 and 1938 specifications of the Signal Section of the Association of American Railroads.*

The 1938 specification, now in effect, is designated as AAR Signal Section Specification 69-38.

missions of these standard roundels, which had been previously determined by Corning Glass Works, thereby became transmissions on the ARA scale. They were as indicated in table 3. The designation T_{ARA} is hereinafter used to denote values of luminous transmission on this ARA scale.

TABLE 2.—*Spectral transmissions of the medium roundels, having values of T_{RSA} as indicated; 1918 specification as published*

Wave length ↓ / T_{RSA}=	Red 130	Yellow 120	Green 150	Blue 100	Purple 100	Lunar white 100
mμ	%	%	%	%	%	%
410	0	0	40	80	90	90
430	0	0	53	73	82	80
450	0	0	62	68	74	69
470	0	0	68	54	59	65
490	0	0	70	27	18	54
510	0	2	64	10	5	38
530	0	8	48	2	1	22
550	0	18	30	2	0.5	23
570	0	29	16	1	.5	26
590	0	42	6	0	0	11
610	0	50	3	0	0	12
630	47	54	1	0	0	11.5
650	74	57	0	0	0	10.5
670	78	57	0	0	.2	23
690	75	55	0	1	12	51
710	74	52	0	2	52	79

TABLE 3.—*Designations of roundels selected in 1930 as the basis of the ARA scale of luminous transmission*

Identifying number of roundel	Color designation of roundel	Corning values of transmission on ARA scale	Identifying number of roundel	Color designation of roundel	Corning values of transmission on ARA scale
5	Red	97	6	Blue	105
0	Yellow	100	4	Purple	101.3
4	Green	100	3	Lunar white	100

Although the ARA Signal Section and Corning Glass Works desired that fundamental measurements be made on their standard glasses and that such standard glasses be placed in the custody of the National Bureau of Standards, there were objections to using the six standard roundels for these purposes. These roundels were unpolished and relatively large (8 3/8 in. in diameter), and were therefore unsuitable for precise spectrophotometric measurements; furthermore, Corning Glass Works wished to retain them. Accordingly, Dr. Gage prepared six 2-in. polished squares for each of the six signal colors, these 2-in. squares duplicating the respective 8 3/8-in. roundels, both in chromaticity and in transmission, as closely as was feasible. At the request of the ARA subcommittee in charge, one of the authors thereupon went to Corning and measured the values of T_{ARA} for each of these 36 squares in terms of the respective standard roundels, using the same apparatus and method as had been used for several years in the maintenance of the standards at Corning Glass Works.[7] The values obtained are given in column 4 of table 4.

TABLE 4.—*Data obtained by one of the authors (K.S.G.) at Corning Glass Works on the glasses selected to replace the former ARA standard roundels*

1	2	3	4	5	6	7
Color designation	Number engraved on glass	ARA transmission		Column 4 minus column 3	Color relative to standard	Thickness
		As marked on label	As determined by K.S.G.			
						mm
Red	83	95.2	97.5	+2.3	Red	1.60
	86	101	102.6	+1.6	Match	1.61
	88	105	104.6	−0.4	do	1.61
	91	100	103.1	+3.1	Yellow	5.21
	92	100	106.4	+6.4	do	3.84
	93	97	102.0	+5.0	do	4.15
Mean		(99.7)	102.7	+3.0		
Yellow	114	100	101.3	+1.3	Red	6.60
	115	100	101.7	+1.7	do	6.60
	116	100	102.5	+2.5	do	6.60
	117	100	102.1	+2.1	do	6.60
	118	100	101.1	+1.1	do	6.60
	138	100	101.5	+1.5	do	6.59
Mean		(100)	101.7	+1.7		
Green	110	102	103.1	+1.1	Match	3.68
	111	102	102.7	+0.7	do	3.68
	112	102	102.1	+.1	do	3.70
	113	102	103.3	+1.3	do	3.68
	120	100	100.6	+0.6	do	3.74
	121	100	101.5	+1.5	do	3.74
Mean		(101.3)	102.2	+0.9		
Blue	52	100	101.4	+1.4		4.97
	53	100	100.6	+0.6	More saturated [1]	4.99
	54	100	99.4	−.6		5.00
	79	100	99.7	−.3	More saturated	5.00
	81	100	99.2	−.8		5.00
	82	100	100.7	+.7		4.99
Mean		(100)	100.2	+0.2		
Purple	38	100	101.0	+1.0	Match	4.86
	39	100	101.0	+1.0	do	4.86
	60	100	101.0	+1.0	do	4.83
	66	101	101.2	+0.2	do	4.83
	67	101	101.5	+.5	do	4.83
	68	100	100.3	+.3	do	4.84
Mean		(100.3)	101.0	+0.7		
Lunar white	40	101	101.0	0.0	Blue	6.18
	49	99.5	100.0	+.5	do	6.24
	67	100	98.9	−1.1	do	6.22
	68	100	100.1	+0.1	do	6.21
	69	100	99.5	−.5	do	6.23
	71	100	99.9	−.1	do	6.21
Mean		(100.1)	99.9	−0.2		

[1] The record shows comments on but 2 of the 6 blue glasses. It is uncertain whether the other 4 should be designated "more saturated" or "match."

[7] Details of these measurements are given in report 1, Signal Section Proc., Am. Ry. Assoc. **30**, 384 (1933).

It had been agreed [8] that, of these six 2-in. glass squares of each color, one pair was to be deposited with the National Bureau of Standards, one pair with the secretary or other designated custodian of the ARA, and one pair to remain the property of the Corning Glass Works Optical Laboratory. The Bureau's glasses are identified in table 6 as *B* and *B′*, the ARA glasses as *A* and *A′*, and the Corning glasses as *C* and *C′*. After the measurements at Corning, noted above, these glasses were taken to the Bureau for further measurement, it having been further agreed that when values had been finally assigned these glasses by the National Bureau of Standards they would then "become the official primary ARA standards and all others, including the present Corning standards, are to be subsidiary to them."

These further measurements at the Bureau are described below. On the basis of these measurements, the individual values of T_{ARA}, given in column 4 of table 4, were to be revised if necessary to secure more precise relative values among the six glasses of a given color; but such revision was not to change the mean values of T_{ARA}, given in column 4 for each color. These mean values were to be retained as correct and final, on the basis of which a fundamental definition of the ARA scale of transmission was to be adopted.

III. EXPRESSION OF THE ASSOCIATION OF AMERICAN RAILROADS SCALE OF TRANSMISSION ON A FUNDAMENTAL, ABSOLUTE BASIS

The measurements on these glasses at the Bureau consisted in:

1. *Measurement of the spectral transmission of the B glass of each color.*—The values obtained are given in table 5 and are illustrated in figures 1 to 6. The instruments and methods, visual and photoelectric, have been adequately described previously.[9] Measurements of transmission (where measurable) were made by one or both methods at every 10 mμ from 380 to 760 mμ, in addition to visual measurements at various wave lengths of the Hg and He spectra from 404.7 to 667.8 mμ. The overlapping of the wave-length ranges of the visual and photoelectric data was extensive in all cases, and the agreement of the data usually good. The values adopted, table 5, are considered uncertain in the last figure given.

2. *Measurement of the ratios of transmission of the A and C glasses to the respective B glasses as a function of wave length.*—The values obtained are illustrated in report 2.[10] From these measured ratios of transmission and the spectral transmissions of the *B* glasses, the spectral transmissions of the *A* and *C* glasses were computed. These are also given in table 5.

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[8] Memorandum entitled, Plan for Reexamination and Duplication of ARA Color Standards and Limits now Deposited with Corning Glass Works. This memorandum was prepared by H. P. Gage and represented the conclusions of the subcommittee of committee VI, ARA Signal Section, meeting at Corning on October 3, 1930.

[9] K. S. Gibson, *Direct-reading photoelectric measurement of spectral transmission*, J. Opt. Soc. Am. and Rev. Sci. Instr. **7**, 693 (1923).
H. J. McNicholas, *Equipment for routine spectral transmission and reflection measurements*, BS J. Research **1**, 793 (1928) RP30.
K. S. Gibson, *Spectrophotometry at the Bureau of Standards*, J. Opt. Soc. Am. **21**, 564 (1931).

[10] Signal Section Proc., Am. Ry. Assoc. **30**, 390 (1933).

TABLE 5.—*Spectral transmissions of the A, B, and C glasses (comprising 18 of the 36 glasses listed in tables 4 and 6)*

Wave length (millimicrons)	Red			Yellow			Green			Blue			Purple			Lunar white		
	92 *A*	86 *B*	83 *C*	115 *A*	118 *B*	114 *C*	111 *A*	121 *B*	110 *C*	53 *A*	82 *B*	54 *C*	38 *A*	60 *B*	66 *C*	71 *A*	68 *B*	49 *C*
Hg 404.7	--------	0.0000	--------	--------	0.0000	--------	--------	0.173	--------	--------	0.716	--------	--------	0.838	--------	--------	0.862	--------
Hg 435.8	--------	.0000	--------	--------	.0000	--------	--------	.340	--------	--------	.728	--------	--------	.724	--------	--------	.815	--------
Hg 491.6	--------	.0000	--------	--------	.0026	--------	--------	.500	--------	--------	.277	--------	--------	.162	--------	--------	.560	--------
Hg 546.1	--------	.0000	--------	--------	.1053	--------	--------	.211	--------	--------	.0130	--------	--------	.0031	--------	--------	.194	--------
Hg 578.0	--------	<.0001	--------	--------	.268	--------	--------	.0554	--------	--------	.0060	--------	--------	.0022	--------	--------	.177	--------
380	0.0000	.0000	0.0000	0.0000	.0000	0.0000	0.028	.028	0.028	0.477	.468	0.472	0.783	.783	0.783	0.795	.795	0.795
90	.0000	.0000	.0000	.0000	.0000	.0000	.070	.069	.070	.616	.604	.610	.845	.841	.840	.845	.845	.846
400	.0000	.0000	.0000	.0000	.0000	.0000	.139	.138	.139	.695	.689	.693	.852	.845	.844	.862	.861	.862
10	.0000	.0000	.0000	.0000	.0000	.0000	.207	.205	.206	.738	.731	.737	.830	.824	.824	.854	.854	.855
20	.0000	.0000	.0000	.0000	.0000	.0000	.264	.262	.264	.749	.742	.749	.791	.786	.786	.834	.834	.834
30	.0000	.0000	.0000	.0000	.0000	.0000	.317	.315	.317	.742	.736	.742	.755	.750	.750	.822	.822	.823
40	.0000	.0000	.0000	.0000	.0000	.0000	.360	.358	.359	.726	.721	.726	.709	.705	.705	.810	.810	.812
450	.0000	.0000	.0000	.0000	.0000	.0000	.407	.406	.407	.699	.693	.698	.657	.653	.653	.799	.799	.801
60	.0000	.0000	.0000	.0001	.0001	.0001	.451	.451	.452	.655	.649	.653	.593	.589	.589	.780	.781	.783
70	.0000	.0000	.0000	.0003	.0003	.0003	.481	.481	.481	.569	.564	.567	.473	.471	.473	.738	.739	.741
80	.0000	.0000	.0000	.0008	.0008	.0008	.497	.497	.497	.440	.437	.439	.318	.318	.320	.664	.665	.667
90	.0000	.0000	.0000	.0022	.0021	.0021	.501	.501	.501	.302	.300	.301	.181	.181	.182	.569	.569	.570
500	.0000	.0000	.0000	.0056	.0054	.0055	.486	.486	.485	.201	.200	.200	.1010	.1015	.1023	.497	.497	.497
10	.0000	.0000	.0000	.0132	.0128	.0130	.450	.450	.450	.1120	.1115	.1112	.0443	.0447	.0449	.397	.397	.397
20	.0000	.0000	.0000	.0266	.0261	.0265	.395	.394	.395	.0551	.0550	.0546	.0161	.0163	.0163	.302	.302	.301
30	.0000	.0000	.0000	.0494	.0483	.0489	.330	.328	.329	.0222	.0222	.0220	.0048	.0049	.0049	.220	.220	.219
40	.0000	.0000	.0000	.0814	.0798	.0807	.255	.253	.255	.0131	.0132	.0131	.0027	.0028	.0028	.184	.185	.184
550	.0000	.0000	.0000	.1237	.1218	.1228	.185	.183	.185	.0152	.0152	.0150	.0042	.0043	.0043	.210	.211	.210
60	.0000	.0000	.0000	.174	.172	.173	.1289	.1268	.1289	.0210	.0210	.0208	.0091	.0092	.0092	.257	.257	.257
70	.0000	.0000	.0000	.226	.224	.225	.0844	.0824	.0844	.0146	.0147	.0145	.0067	.0069	.0069	.241	.241	.240
80	.0000	.0001	.0000	.280	.278	.280	.0525	.0509	.0526	.0045	.0046	.0045	.0016	.0017	.0017	.160	.160	.159
90	.0000	.0002	.0002	.327	.325	.326	.0309	.0296	.0309	.0011	.0011	.0011	.0003	.0003	.0003	.0964	.0962	.0954
600	.0001	.0005	.0004	.368	.366	.367	.0174	.0165	.0174	.0008	.0008	.0008	.0002	.0002	.0002	.0951	.0950	.0938
10	.0013	.0019	.0013	.402	.400	.401	.0099	.0093	.0099	.0008	.0008	.0008	.0003	.0003	.0003	.1059	.1058	.1047
20	.065	.022	.015	.428	.426	.428	.0055	.0051	.0055	.0006	.0006	.0006	.0004	.0004	.0004	.1090	.1090	.1082
30	.38	.23	.18	.446	.444	.446	.0030	.0027	.0030	.0004	.0004	.0004	.0003	.0003	.0003	.1036	.1035	.1025
40	.60	.65	.61	.459	.457	.458	.0017	.0015	.0017	.0003	.0003	.0003	.0002	.0002	.0002	.0936	.0935	.0923

TABLE 5.—*Spectral transmissions of the A, B, and C glasses (comprising 18 of the 36 glasses listed in tables 4 and 6)*—Continued

Wave length (millimicrons)	Red			Yellow			Green			Blue			Purple			Lunar white		
	92 *A*	86 *B*	83 *C*	115 *A*	118 *B*	114 *C*	111 *A*	121 *B*	110 *C*	53 *A*	82 *B*	54 *C*	38 *A*	60 *B*	66 *C*	71 *A*	68 *B*	49 *C*
650	.678	.798	.785	.469	.467	.468	.0009	.0008	.0009	.0002	.0002	.0002	.0003	.0003	.0003	.0980	.0980	.0970
60	.717	.833	.823	.475	.473	.474	.0005	.0004	.0005	.0004	.0004	.0004	.0008	.0008	.0008	.132	.132	.131
70	.738	.844	.834	.478	.476	.477	.0002	.0002	.0002	.0009	.0009	.0009	.005	.005	.005	.21	.21	.21
80	.754	.852	.841	.479	.477	.479	.0001	.0001	.0001	.0021	.0021	.0021	.034	.035	.036	.36	.36	.36
90	.764	.856	.846	.477	.475	.477	.0000	.0000	.0000	.0045	.0045	.0044	.16	.16	.16	.55	.55	.55
700	.769	.858	.848	.474	.472	.473	.0000	.0000	.0000	.008	.008	.008	.40	.40	.40	.71	.71	.71
10	.772	.859	.850	.468	.467	.468	.0000	.0000	.0000	.009	.009	.009	.65	.65	.65	.810	.810	.811
20	.770	.858	.850	.460	.459	.460	.0000	.0000	.0000	.0085	.0085	.0085	.798	.795	.795	.851	.852	.853
30	.768	.857	.849	.450	.449	.450	.0000	.0000	.0000	.008	.008	.008	.860	.857	.857	.868	.868	.869
40	.764	.855	.848	.439	.438	.439	.0000	.0000	.0000	.0075	.0075	.0075	.885	.883	.883	.873	.873	.873
750	.758	.852	.845	.427	.426	.427	.0000	.0000	.0000	.007	.007	.007	.896	.893	.893	.876	.877	.877
60	.751	.849	.842	.413	.412	.412	.0000	.0000	.0000	.0065	.0065	.0065	.900	.896	.896	.876	.877	.877
	LUMINOUS TRANSMISSION, T_{2360} (C_2=14,350)																	
------------	0.07341	0.07110	0.06628	0.2526	0.2508	0.2520	0.1218	0.1205	0.1217	0.02246	0.02240	0.02233	0.01299	0.01306	0.01312	0.1889	0.1890	0.1882

The uncertainty in these values for the *A* and *C* glasses is not much greater than that in the respective values for the *B* glasses, because the ratios of transmission, T_A/T_B and T_C/T_B could be determined as a function of wave length with high precision. This was possible since for each of the colors, except red, the *A*, *B*, and *C* glasses were of the same melt and approximately of the same thickness and therefore had nearly identical spectral transmissions.

3. *Derivation of the luminous transmissions of the A, B, and C glasses.*—Luminous transmission, T_θ, is herein defined as

$$T_\theta=\frac{\Sigma E_\theta VT}{\Sigma E_\theta V},$$

in which θ is the color temperature of the illuminant, E_θ is the relative spectral energy of the illuminant, *V* is the relative spectral luminosity (visibility) function, *T* is the spectral transmission, and in which the summations were made with values taken at every 10 mμ from 400 to 760 mμ. The value of θ was taken at 2,360° K,[11] this being the color temperature, approximately, at which similar determinations had for several years been made at Corning Glass Works. Values of E_{2360} were taken from a published table;[12] values of *V* were those adopted by the International Commission on Illumination in 1924.[13] The luminous transmissions for illuminant at 2,360° K, T_{2360}, were thus computed and are given in the respective columns at the bottom of table 5.

Figure 7 has been prepared to assist in imparting an understanding of the computation of T_{2360}, as just outlined. In this figure are given the spectral-distribution curves of (1) E_{2360}, arbitrarily unity at 560 mμ, (2) *V*, arbitrarily unity at the maximum, (3) the light, VE_{2360} (the product of *V* and E_{2360}, taken at each wave length) for a source at 2,360° K, and (4) the light from this source transmitted through the respective *B* glasses having spectral transmissions, *T*, this transmitted light having the distribution TVE_{2360}. The ratio of summations given above in defining T_{2360} is, for each of the six colors, equivalent to the ratio of the area beneath the TVE_{2360} curve to the area beneath the VE_{2360} curve. Furthermore, of course, the areas beneath the TVE_{2360} curves have the same relative values as do the respective values of T_{2360}, the area beneath the curve for the yellow glass being the greatest, that beneath the curve for the purple glass the least, just as the luminous transmission of the yellow glass is the greatest and that of the purple glass the least.

4. *Determination of the relative luminous transmissions of the A, B, and C glasses of each of the six colors from the computed values of* T_{2360}.—These relative transmissions are given in column 5 of table 6, that for the *B* glass being taken as unity in all cases.

[11] With C_2=14,350 micron-degrees. For continuity with the published reports, all values of color temperature in this paper are expressed on this basis. On the color-temperature scale more recently established at the Bureau (H. T. Wensel, D. B. Judd, and W. F. Roeser, BS J. Research **12**, 527 (1934) RP677), for which C_2=14,320, the same energy distribution is given by 2,355° K. For values of C_2=14,330 (J. F. Skogland, BS Misc. Pub. M86) and 14,360 (H. T. Wensel, *International Temperature Scale and some related physical constants*, J. Research NBS **22**, 375 (1939) RP1189) the respective values of θ are equal to 2,357 and 2,362.

[12] R. Davis and K. S. Gibson, *Filters for the reproduction of sunlight and daylight and the determination of color temperature*, BS Misc. Pub. M114, table 2 (1931). However, the values there given do not extend above 720 mμ. Values from 730 to 760 mμ were used as published in report 2.

[13] Proceedings Sixth Meeting of Intern. Comm. Illum., Geneva, p. 67. These adopted values are those recommended by Gibson and Tyndall (Visibility of radiant energy, Sci. Pap. BS **19**, 131, table 3 (1923) S475) and are incorporated in the so-called 1931 ICI standard observer (Proceedings Eighth Meeting of Intern. Comm. Illum., Cambridge, p. 19 (1931). D. B. Judd, The 1931 ICI standard observer and coordinate system for colorimetry, J. Opt. Soc. Am. **23**, 359 (1933)).

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5. *Direct photometric measurement of the relative luminous transmissions of all six glasses of each of the six colors.*—These measurements were made with the Martens photometer by each of three observers [14] and with the illuminant at 2,360° K. The mean values so obtained are given in column 3 of table 6, and in column 4 are shown the average deviations of each observer's values from the mean values of column 3.

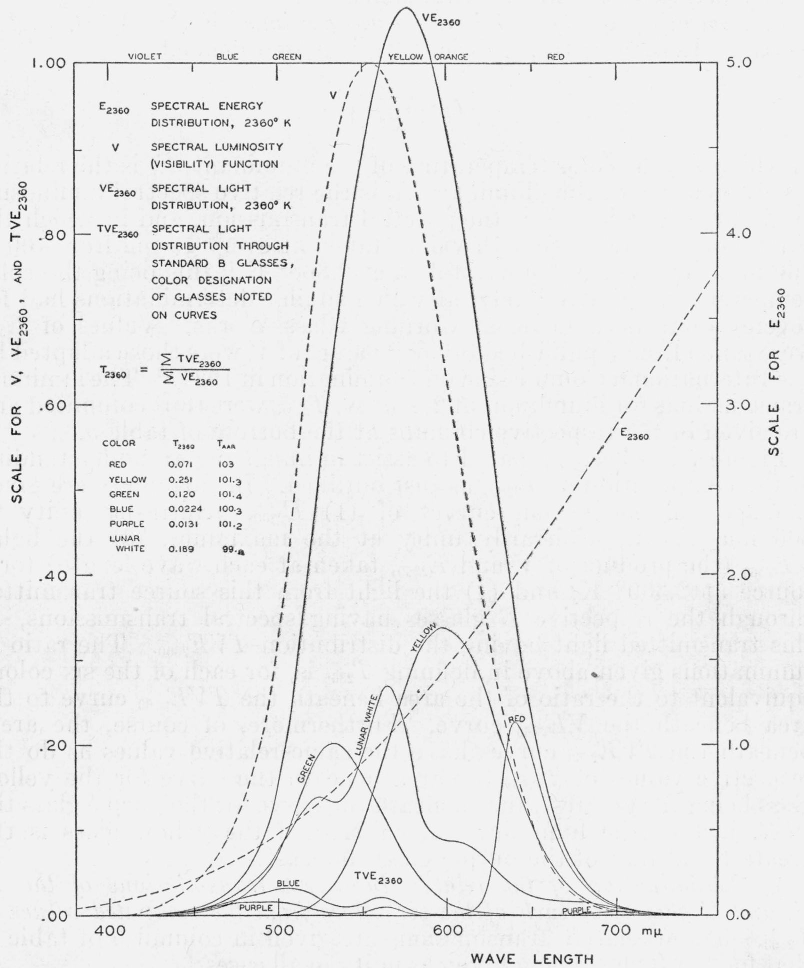

Figure 7.—*Spectral-distribution curves of illuminant at 2,360° K and of the light transmitted by the respective B glasses, having values of T_{AAR} close to 100.*

These curves illustrate the graphical equivalent of the relation defining T_{2360}.

6. *Adoption of final values of relative luminous transmission for the six glasses of each of the six colors.*—These values are given in column 6 of table 6. For the *A*, *B*, and *C* glasses these relative values are the means of the values obtained by spectrophotometric and photometric methods, columns 5 and 3, respectively. For the other glasses the values of column 3 are carried directly to column 6. Different methods

[14] H. J. Keegan assisted the authors in these observations.

of weighting might perhaps have been used, but the deviations (column 7) of the *A*, *B*, and *C* values in columns 5 and 3 from the mean values of column 6, in no case exceeding 0.3 percent, show that any other reasonable weighting of the values would not give importantly different results.

7. *Conversion of these relative luminous transmissions to the ARA scale.*—It will be recalled that the mean values of column 9 of table 6 (and column 4 of table 4) were to be accepted as correct and final. Therefore, by dividing these mean values of column 9 by the respective mean values of column 6, factors are obtained, one for each color, by which the individual values of column 6 may be converted to revised ARA transmissions. These factors are given in parentheses in place of the means in columns 7 and 8, and the revised transmissions on the ARA scale are given in column 10. These revised transmissions were designated as T'_{ARA} throughout reports 1 to 6. After the American Railway Association changed its name in 1933 to Association of American Railroads, it was deemed desirable to change the symbol T'_{ARA} to T_{AAR}, eliminating the use of the prime mark. The meaning of T_{AAR} is in all cases identical to that of T'_{ARA} wherever the latter is used or published.

8. *Fundamental basis of the T_{AAR} scale.*—The true luminous transmissions, T_{2360}, for the *A*, *B*, and *C* glasses, given in table 5, are also given in column 11 of table 6. From the values of T'_{ARA} in column 10 and these values of T_{2360} in column 11 may be derived the value of T_{2360} equivalent to $T'_{ARA}=T_{AAR}=100.0$. Such values are shown in column 12, together with the mean values thus obtained. These mean values afford a fundamental definition and conversion of values of T_{AAR}, being based upon spectrophotometric measurements, and are the values which should result if direct photometric measurements of the luminous transmissions (T_{2360}) of glasses having values of $T_{AAR}=100.0$ were made by a large number of observers under standard conditions of observation, or if the hypothetical 1931 ICI standard observer could make such measurements. The mean values of column 12 are, however, subject to considerable uncertainty in the last significant figure tabulated. The values of table 7 have therefore been adopted as expressing the fundamental relation between values of T_{AAR} and values of T_{2360}.

TABLE 6.—*Derivation of new ARA transmissions (redefined as AAR transmissions) for the 36 glasses listed in table 4*

1	2		3	4	5	6	7	8	9	10	11	12
Designation			Relative luminous transmission (at 2,360° K), as determined at National Bureau of Standards in 1932					ARA transmission				
Color	Ref.	No.	Mean, by three observers with Martens photometer	Average deviation of each observer from mean	Computed from spectral transmission	Mean, columns 3 and 5	Deviation from mean, col. 3 (or 5) minus col. 6	As labeled at Corning	By K.S.G. at Corning	New ARA transmission T'_{ARA}	Luminous transmission T_{2360}	T_{2360} equivalent to $T'_{ARA}=T_{AAR}=100.0$
Red	*C*	83	0.9383	0.0051	0.9323	0.9353	±0.0030	95.2	97.5	96.2	0.06628	0.06890
	B	86	1.0000	----------	1.0000	1.0000	.0000	101	102.6	102.9	.07110	.06910
	B′	88	1.0303	.0021	----------	1.0303	----------	105	104.6	106.0	----------	----------
	C′	91	1.0022	.0213	----------	1.0022	----------	100	103.1	103.1	----------	----------
	A	92	1.0335	.0120	1.0325	1.0330	.0005	100	106.4	106.3	.07341	.06906
	A′	93	.9886	.0103	----------	.9886	----------	97	102.0	101.7	----------	----------
Mean	----------	----------	----------	.0102	----------	.9982	(f=102.89)		102.7	102.7	----------	.0690
Yellow	*C*	114	1.0056	.0015	1.0047	1.0052	.0004	100	101.3	101.8	.2520	.2475
	A	115	1.0098	.0022	1.0073	1.0086	.0012	100	101.7	102.2	.2526	.2472
	A′	116	1.0051	.0018	----------	1.0051	----------	100	102.5	101.8	----------	----------
	B′	117	1.0038	.0017	----------	1.0038	----------	100	102.1	101.7	----------	----------
	B	118	1.0000	----------	1.0000	1.0000	.0000	100	101.1	101.3	.2508	.2476
	C′	138	1.0011	.0011	----------	1.0011	----------	100	101.5	101.4	----------	----------
Mean	----------	----------	----------	.0017	----------	1.0040	(f=101.29)		101.7	101.7	----------	.2474
Green	*C*	110	1.0134	.0021	1.0098	1.0116	.0018	102	103.1	102.6	.1217	.1186
	A	111	1.0158	.0019	1.0105	1.0132	.0026	102	102.7	102.8	.1218	.1185
	A′	112	1.0087	.0018	----------	1.0087	----------	102	102.1	102.3	----------	----------
	C′	113	1.0177	.0025	----------	1.0177	----------	102	103.3	103.2	----------	----------
	B′	120	.9952	.0014	----------	.9952	----------	100	100.6	100.9	----------	----------
	B	121	1.0000	----------	1.0000	1.0000	.0000	100	101.5	101.4	.1205	.1188
Mean	----------	----------	----------	.0019	----------	1.0077	(f=101.42)		102.2	102.2	----------	.1186

Blue	A′	52	1.0113	.0029	-----	1.0113	-----	100	101.4	101.4	-----	-----
	A	53	1.0024	.0020	1.0029	1.0026	.0002	100	100.6	100.6	.02246	.02233
	C	54	.9950	.0040	.9969	.9960	.0010	100	99.4	99.9	.02233	.02235
	C′	79	.9924	.0037	-----	.9924	-----	100	99.7	99.5	-----	-----
	B′	81	.9923	.0015	-----	.9923	-----	100	99.2	99.5	-----	-----
	B	82	1.0000	-----	1.0000	1.0000	.0000	100	100.7	100.3	.02240	.02233
Mean	-----	-----	-----	.0028	-----	.9991	(f=100.29)		100.2	100.2	-----	.02234
Purple	A	38	.9942	.0024	.9944	.9943	.0001	100	101.0	100.7	.01299	.01290
	A′	39	.9931	.0032	-----	.9931	-----	100	101.0	100.5	-----	-----
	B	60	1.0000	-----	1.0000	1.0000	.0000	100	101.0	101.2	.01306	.01291
	C	66	1.0051	.0018	1.0046	1.0048	.0002	101	101.2	101.7	.01312	.01290
	C′	67	1.0004	.0025	-----	1.0004	-----	101	101.5	101.3	-----	-----
	B′	68	.9937	.0023	-----	.9937	-----	100	100.3	100.6	-----	-----
Mean	-----	-----	-----	.0024	-----	.9977	(f=101.23)		101.0	101.0	-----	.01290
Lunar white	C′	40	1.0214	.0015	-----	1.0214	-----	101	101.0	101.9	-----	-----
	C	49	.9979	.0024	.9959	.9969	.0010	99.5	100.0	99.4	.1882	.1893
	A′	67	.9977	.0022	-----	.9977	-----	100	98.9	99.5	-----	-----
	B	68	1.0000	-----	1.0000	1.0000	.0000	100	100.1	99.8	.1890	.1894
	B′	69	.9946	.0006	-----	.9946	-----	100	99.5	99.2	-----	-----
	A	71	.9972	.0010	.9993	.9982	.0010	100	99.9	99.6	.1889	.1897
Mean	-----	-----	-----	.0015	-----	1.0015	(f=99.75)		99.9	99.9	-----	.1895

TABLE 7.—*Relation between values of T_{AAR} and of T_{2360}, which defines the luminous transmission scale established in the 1935 and 1938 AAR signal-glass specifications*

Color designation of glass	AAR transmission, T_{AAR}	Equivalent luminous transmission, 1931 ICI standard observer, illuminant 2,360° K, T_{2360}	Color designation of glass	AAR transmission, T_{AAR}	Equivalent luminous transmission, 1931 ICI standard observer, illuminant 2,360° K, T_{2360}
Red	100.0	0.069	Blue	100.0	0.0223
Yellow	100.0	.247	Purple	100.0	.0129
Green	100.0	.119	Lunar white	100.0	[1].190

[1] The original derived value was 0.1895 (table 6). This was at first cut back to 0.189 and was so published in report 5 and in J. Opt. Soc. Am. 24, 57 (1934). Later work has, however, indicated that 0.190 is a more accurate conversion factor than 0.189.

It may be noted that these conversion factors are valid only at 2,360° K; in fact, the T_{AAR} scale, by definition, exists only at this color temperature of illuminant. The variation of absolute luminous transmission, T_θ, with color temperature, θ, of illuminant will be shown for various signal glasses in a later paper.

The question may perhaps arise as to why, in a fundamental analysis and standardization of signal glasses and colors such as the present, the ARA scale of transmission was not entirely discarded in favor of the absolute scale. It is obviously just as convenient, and from the scientific standpoint preferable, to insert absolute rather than relative values in a specification. Such a change was not made, however, for the following reason:

The ARA scale of transmission (with perhaps some variation, see below) has been in existence for over 30 years and has been universally used by the signal engineers and glass manufacturers to designate the luminous transmission of a glass relative to its respective standard ($T_{ARA}=100$). It would be a matter of considerable inconvenience for the engineers and manufacturers to use a new scale, and continual reference to a conversion table would be necessary for a long time. Such confusion was deemed unnecessary and was avoided by the procedure outlined in this section, whereby the existing scale was kept in effect with relatively minor revisions but was placed on a consistent absolute basis by means of the conversion factors specified.

In accord with the understanding noted earlier in the paper, the A and A' glasses have been deposited with the Signal Section of the Association of American Railroads (letter of 1–5–38, Director NBS to Mr. Balliet, secretary, AAR Signal Section), the C and C' glasses have been deposited with Corning Glass Works (letter of 1–5–38, Director NBS to Corning Glass Works), and the B and B' glasses are in the custody of the Colorimetry and Spectrophotometry Section of the National Bureau of Standards. It should be noted, however, that the present standardization of the AAR scale of luminous transmission, being based upon fundamental measurements and computations, is independent of these standard glasses which were used in its determination, and if these material standards ever become lost or damaged, the accuracy and usefulness of the scale, as defined in table 7, will in no wise be affected.

IV. COMPARISON OF THE TRANSMISSION SCALES AS EXPRESSED IN THE 1908, 1918, AND 1935 (AND 1938) SPECIFICATIONS

It is of interest to compare the present AAR transmission scale, as defined for the six signal colors by the data of table 7, with the RSA scales, defined by the data of tables 1 and 2, taken from the 1908 and 1918 specifications, respectively. From the continuity of the signal-glass standardization since 1908, as outlined above, huge differences between the three scales[15] are not to be expected. On the other hand, it would be very surprising if the personal errors of heterochromatic photometry, which have been involved in the production and the maintenance of the earlier scales and to some extent in the transfer of standards illustrated in table 4, and the lack of precision of some of the earliest spectrophotometric data, did not cause real or apparent changes of many percent in the true luminous transmission of glasses having values of T_{RSA} or T_{AAR} equal to 100, as defined in the various specifications.

Reference to the spectral-transmission data of figures 1 to 6 is of interest in this connection. The spectral quality of the glasses would seem to have improved since 1908, particularly in the case of the yellow, blue, purple, and lunar-white glasses. This is indicated by the increase of transmission at the high transmissions, accompanied in many cases by a decrease of transmission at the low transmissions. On the basis of these data one would judge that glasses of purer, more saturated colors had been developed with no loss of luminous transmission; or, of greater practical importance, that signal glassware of considerably greater transmission had been developed with no loss of distinctness of the signal color. However, it is understood that no intentional changes have ever been made in the composition of the blue, purple, or lunar-white glasses. Probably, therefore, the apparent differences in these graphs are largely due to spectrophotometric error in the earlier data. Changes in either the type of glass or the medium value have been made at various times with the red, yellow, and green glasses, but these will be considered in the later papers.

It had been hoped to make accurate comparison of the three transmission scales from these spectrophotometric data by (1) deriving the luminous transmission, T_{2360}, of the glasses from the 1908 and 1918 data, as had been done from the 1935 data, and (2) reducing these values of T_{2360} by the proper ratio ($T_{RSA}/100$) to get the value of T_{2360} corresponding to $T_{RSA}=100$. However, the 1908 data are so meager that the uncertainties of interpolation would largely defeat the purpose. Furthermore, their reliability is open to some question, not only for the reason noted above but also in view of (1) the erratic values for the yellow glass at the longer wave lengths and (2) the zero values of transmission for certain of the glasses at the A line (761 mμ), which, in view of present knowledge of the spectral absorption of glasses, cannot be correct if the data at the a and B lines are reasonably accurate.

The 1918 data are more extensive and reliable, however. The data are given at every 20 mμ (table 2), and values of T_{2360} computed from these data should afford an interesting comparison. To make this

[15] In the preceding parts of the paper the various transmission scales to which reference is made in the present section have been mostly treated as various versions of the same scale. It is more convenient in this section to consider them as separate scales.

comparison as valid as possible, the values so computed have been compared with similar values computed from the recent spectrophotometric data (table 5) for the same wave lengths (every 20 mμ) instead of using the values of T_{2360} given in tables 5 and 6. The values for the *B* glasses were used for this purpose. Results are given in table 8.

It will be noted that none of the differences is as large as 10 percent. The differences for the blue and purple standards [16] are subject to large uncertainty, because but one significant figure is given in the 1918 spectral-transmission data for these glasses (table 2) in the region of high luminosity (510 to 650 mμ). The differences for the yellow, green, and lunar-white standards are subject to less uncertainty from this cause. Those for the yellow and green are probably explainable by the uncertainties of heterochromatic photometry. Reference to column 4 of table 6 shows average deviations for the red glasses up to 2 percent, and the chromaticity differences involved in those comparisons are probably much less than those present when the changes from 100 to 120 and 150 were made for the respective yellow and green medium glasses. (It follows, of course, that the close agreement shown in table 8 for the red standards is fortuitous.) The reason for the difference in the values for the lunar-white standards is uncertain.

Inspection of figures 1 to 6 would indicate that the original (1908) yellow and lunar-white standards would have a T_{2360} value considerably in excess of both the 1918 and the 1935 standards, but no certain differences are indicated by the data for the standards of the other colors. As already explained, it seemed inadvisable to attempt computations of T_{2360} from the 1908 data.

TABLE 8.—*Comparison of values of T_{2360} computed for values of T_{RSA}=100.0 from the 1918 specification, with similar values for T_{AAR}=100.0 computed from data on which the 1935 specification is based*

Color designation	T_{2360}		ΔT_{2360} (column 2 minus column 3)	Percentage of change in T_{2360} (column 4 divided by column 3, × 100)
	T_{RSA}=100.0 (1918)	T_{AAR}=100.0 (1935)		
Red	0.0662	0.0672	−0.0010	−1.5
Yellow	.268	.247	+.021	+8.5
Green	.129	.119	+.010	+8.4
Blue	.0203	.0221	−.0018	−8.1
Purple	.0134	.0124	+.0010	+8.1
Lunar white	.199	.189	+.010	+5.3

Question may also be raised as to the agreement of the ARA scale, as exemplified by the roundels endorsed by Mr. Mock in 1930, table 3, both with the 1918 RSA scale and with the 1935 AAR scale now in effect. This cannot be answered certainly without making spectral-transmission measurements on the roundels selected by Mr. Mock. However, if the values of T_{ARA} were assigned to these roundels by the same Corning observer as assigned the values of T_{ARA} for the six squares of each color, as given in column 3 of table 4, it may be concluded, by comparing the mean values of columns 3 and 4 of table 4, that the ARA and AAR scales are in close agreement. The differences are approximately 3 percent for the red, 2 percent for the yellow, and

[16] That is, hypothetical glasses having values of T_{RSA} or T_{AAR}=100.0.

1 percent or less for the glasses of the other colors. For the green, blue, purple, and lunar-white glasses, therefore, the 1930 ARA scale is in very close agreement with the 1935 AAR scale, and hence differs from the 1918 RSA scale by approximately the same values as are given in the last column of table 8. For the yellow glasses the ARA scale is intermediate between the RSA and AAR scales. For the red glasses the AAR scale appears intermediate between the other two, but the various data are too uncertain for any definite statement.

In conclusion, the authors wish to call attention to the pioneering work of the railroad signal engineers in color specification. No search of the literature has been made, but, so far as the authors are aware, the 1908 specification was the first effort, at least in this country, to place the colorimetric part of a purchase specification on a fundamental basis. This specification was the result of cooperation between the Railway Signal Association and Corning Glass Works. It followed logically the very excellent treatment given in a paper [17] entitled, The Roundel Problem, by Wm. Churchill of Corning Glass Works.

This 1908 specification contained the following features essential to all complete and adequate colorimetric specifications:

1. It was based fundamentally on spectrophotometric analysis of the standards.

2. It specified tolerances within which the manufactured product must come.

That the spectrophotometric analyses and the colorimetric specifications were somewhat inadequate, judged by present-day criteria, in no wise detracts from the foresight and judgment leading to the formulation of a specification so far in advance of its time. The lack of spectrophotometric precision was largely remedied in the 1918 specification, but the adequate colorimetric specification of the tolerances had to wait until first the Optical Society of America [18] and then the International Commission on Illumination [19] had set up computational procedures and data suitable for such purpose.[20] It is interesting to note, however, that the "mixture diagram", so essential in specifying the chromatic properties of signal lights, was illustrated in colors and used by Dr. Churchill in his study of the characteristics of signal glassware, to which reference has just been made.

WASHINGTON, March 28, 1939.

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[17] Presented at the Ninth Annual Meeting of the Railway Signal Association, Niagara Falls, N. Y., October 10-12, 1905.

[18] Report of Committee on Colorimetry for 1920-21, L. T. Troland, Chairman, J. Opt. Soc. Am. and Rev. Sci. Instr. *6*, 527 (1922).

[19] Proceedings of the Eighth Session, Cambridge, p. 19 (1931).

[20] This will be treated in the next paper.