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An Evaluation of the Luminous-Transmittance Requirements for Railroad-Signal Glassware in Terms of Standard Source A of the International Commission on Illumination

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As an extension of Research Paper 1688, an estimate has been made of the transmittance for illuminant A of signal glassware having the minimum transmittance acceptable under the specifications of the Signal Section of the Association of American Railroads, which are formulated in terms of tests at 2,360° K.

In connection with the preparation of the last Secretariat Report on Colors of Signal Lights [1] [1] for the International Commission on Illumination, it was desired to include values for the minimum transmittance for railroad-signal glassware used in this country and to show these values for light sources of color temperature 2,850° K since the other countries had reported transmittance values for their glassware for lamps of that color temperature. The revision of the specifications for railroad-signal glassware, which is now being considered by the Signal Section of the Association of American Railroads (AAR), suggests that this information may now have a wider interest. A method for computing minimum transmittance at 2,850° K from the currently specified minimum-transmittance values is accordingly described below.

AAR Specifications 59–39 and 69–48 control the transmittance of railroad-signal glasses by limits assigned on a scale known as the T_{AAR} scale. This scale (actually six scales, one for each of six signal colors) was established by a procedure described in RP1209 [2]. It is defined in terms of six luminous-transmittance values for a source of 2,360° K, each of these values being applicable to glasses having chromaticity characteristics similar to the filters used for one of the railroad-signal colors. The transmittance values for the six signal colors corresponding to $T_{\text{AAR}}=100$ are listed in table 6 RP1209 [2], and in table 1 in RP1688 [3]. In practice, the T_{AAR} values of glasses submitted for inspection are determined by finding the ratio of the transmittance of the glass being tested to the transmittance of one of the "limit" filters and multiplying this ratio by the T_{AAR} value of the limit filter. The transmittance values for the primary-standard "limit" filters for sources of color temperature 1,900° K, 2,360° K, and 2,848° K [2] have been published, together with their T_{AAR} values at 2,360° K, in table 4 of RP1688 [3].

The inspection of signal glassware is carried out at color temperature 2,360° K,[3] but the glassware is used in service with sources ranging from 1,900° K to 2,850° K. For a source of color temperature 2,360° K, the minimum acceptable transmittance is readily computed from the simple proportion:

$$(T)_{\min}/(T)_{\text{std}}=(T_{\text{AAR}})_{\min}/(T_{\text{AAR}})_{\text{std}}, \tag{1}$$

in which:

$(T)_{\min}$ = transmittance of glass of minimum acceptable T_{AAR},
$(T)_{\text{std}}$ = transmittance of standard filter at 2,360° K,
$(T_{\text{AAR}})_{\min}$ = T_{AAR} stated in specification as minimum acceptable,
$(T_{\text{AAR}})_{\text{std}}$ = T_{AAR} value of standard filter.

This simple proportion does not give correct values of transmittance for sources of other temperatures since the ratio of the transmittance at one color temperature to that at another varies with the value of T itself. This variation, however, is systematic and with respect to each type of glassware, it may, to a first degree of approximation, be considered as linear.

[1] Figures in brackets indicate the literature references at the end of this paper.

[2] The numerical designations of color temperature used in RP1688 [3] were based upon C_2=14,350 micron degrees in Planck's formula. We here use the same designations in order to avoid confusion. The presently-accepted value of C_2 is 14,380 micron degrees, and the corresponding values of color temperature are:

C_2=14,350 micron degrees	C_2=14,380 micron degrees
° K	° K
1,900	1,904
2,360	2,365
2,848	2,854

In service there is considerable variation in color temperature for each type of source so that the approximate values 1,900° K, 2,350° K, and 2,850° K may be used when the reference is to service conditions.

[3] The latest draft for the revision of specification AAR 69–48 provides that inspection will be made at 2,854° K.

The desired transmittance values for 2,854° K were computed in accordance with the following assumptions:

(1) That for each type and color, the glassware in service has the same characteristics as the pale limit and transmission standard filters which should be true if it contains the same colorants in about the same proportions as the filters which control it;

(2) That the ratio $T_{2,848}/T_{2,360}$ is approximately a linear function of the transmittance.

Using the vaues of transmittance listed in table 4 RP1688 [3], the ratio $T_{2,848}/T_{2,360}$ was computed for each filter and these ratios were plotted as functions of the corresponding T_{AAR} values at 2,360° K (see fig. 1). The value of minimum acceptable transmittance for a source at 2,848° K was then computed from the formula:

$$(T_{2,848})_{\min}=0.01\ (T_{\mathrm{AAR}})_{\min}\times(T_{2,360})_{100}\times(T_{2,848}/T_{2,360})_{\min} \tag{2}$$

in which:

$(T_{2,848})_{\min}$ = transmittance of glass of minimum acceptable transmittance for light of color temperature 2,848° K,

$(T_{\mathrm{AAR}})_{\min}$ = T_{AAR} stated in specification as minimum acceptable,

$(T_{2,360})_{100}$ = transmittance corresponding to 100 on T_{AAR} scale for light of color temperature 2,360° K,

$(T_{2,848}/T_{2,360})_{\min}$ = ratio of transmittances at minimum acceptable T_{AAR} value, read from graph.

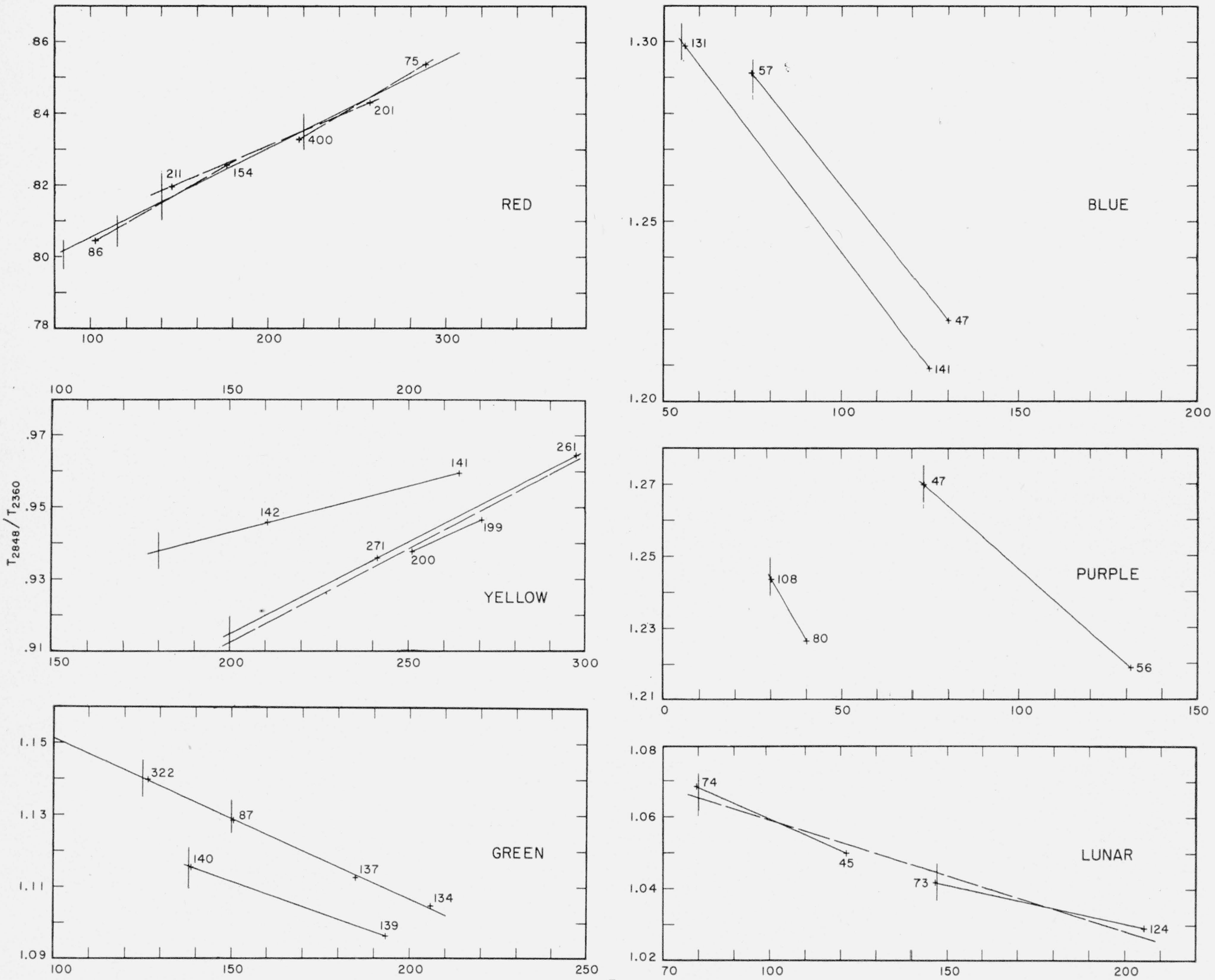

FIGURE 1. *Each of the above figures shows the relation between the ratio $T_{2,848}/T_{2.360}$ and the T_{AAR} value for the primary standard filters of one color.*

Each filter is indicated by a cross and identified by the filter number. The vertical lines mark the minimum acceptable T_{AAR} values for different classes of ware. Filters applying to the same type of ware are joined by lines and the lines representing the least-square equations have also been drawn. In each case the line used for the interpolation is shown as a full line.

TABLE 1. *Minimum acceptable transmittance for light of 2,848° K for railroad signal glassware*

Kind of ware	AAR filter numbers		At minimum acceptable transmittance			
	Pale limit[a]	Transmission Standard[a]	T_{AAR}	$T_{2,848}/T_{2,360}$ By graph	$T_{2,848}/T_{2,360}$ By L. S. Eq.	$T_{2,848}$
	Red glasses (for T_{AAR}=100, $T_{2,360}$=0.0690)					
Pressed ware, general	154	86	85	0.7993	[b]0.8018	0.0469
Thin disks	154	86	115	.8079	[b].8092	.0641
Electric lanterns	154	86	140	.8152	[b].8155	.0788
Kerosene lanterns	201	211	140	.8185	[b].8155	.0788
Highway Crossing	75	400	220	.8336	[b].8353	.1268
	Yellow glasses (for T_{AAR}=100, $T_{2,360}$=0.2474)					
Nonheat resisting	141	142	130	[b]0.9378	--------	0.301_6
Thin disks	199	200	--------	--------	--------	--------
Kerosene lanterns	261	271	200	[b].9147	.9124	$.452_6$
	Green glasses (for T_{AAR}=100, $T_{2,360}$=0.1186)					
Nonheat resisting	134	87	150	1.1287	[b]1.1289	0.2008
Thin disks	139	140	138	[b]1.1157	--------	.1826
Kerosene lanterns	137	322	125	1.1404	[b]1.1400	.1690
	Blue glasses (for T_{AAR}=100, $T_{2,360}$=0.0223)					
Nonheat resisting	47	57	75	[b]1.2907	--------	0.0216
Kerosene lanterns	141	131	55	[b]1.2987	--------	.0159
	Purple glasses (for T_{AAR}=100, $T_{2,360}$=0.0129)					
Kerosene illuminant	56	47	73	[b]1.2698	--------	0.0120
Electric illuminant	80	108	30	[b]1.2438	--------	.0048
	Lunar glasses (for T_{AAR}=100, $T_{2,360}$=0.1895)					
Kerosene illuminant	45	74	80	[b]1.0680	1.0651	0.162
Pressed-ware electric illuminant	124	73	147	[b]1.0416	1.0445	.290
Thin disks	124	73	--------	--------	--------	--------

[a] In RP1688 [3], these filters are called "light limit" and "dark limit" because these designations are used in the railroad specifications. "Light" refers to chromaticity, however, and the true dark limit is the T_{AAR} value, which makes the designations used above seem preferable.
[b] Used for computing $T_{2,848}$.

Table 1 summarizes the computations. All the basic numerical values were taken from tables 2 and 4 of RP1688 [3] and table 6 of RP1209 [2]. The values of the ratio $T_{2,848}/T_{2,360}$ were obtained by graphical interpolation, supplemented by least-square solutions in the case of the red glassware and two types of green glassware that appeared to have similar chromaticity characteristics. The graphs used for these interpolations are presented in figure 1.

In the belief that the least-square differences may be an indication of the reliability of our basic assumption that $T_{2,848}/T_{2,360}$ is a linear function of the transmittance, these differences have been computed, not only for the red and green cases just mentioned, but also for four of the yellow filters and the four lunar white filters. These differences are listed in table 2. In no case is the difference greater than 0.3 percent of the ratio. While this value is large in comparison with the probable errors for the transmittances of the standard filters, it is not significant from the standpoint of the signal glassware in service.

The values given in column 5 of table 2 may also be used to compute the approximate transmittance for light of color temperature 2,854° K of replica filters which have been certified for light of color temperature 2,365° K (2,360° K for older certifications). It is only necessary to multiply the value given for $T_{2,848}/T_{2,360}$ corresponding to the primary standard by the certified transmittance of the replica at color temperature 2,365° K to obtain a value of transmittance for the replica at color temperature 2,854° K with an uncertainty which may be estimated from the values given in column 6 of the table.

TABLE 2. *Least-square solutions for groups of four or more related filters*

$T_{2,848}/T_{2,360}=K+k\ T_{AAR}/100$					
AAR filter number	Equation constants		$T_{2,848}/T_{2,360}$		Δ Column 5 minus column 4
	K	k	From measurements [1]	From equation	
1	2	3	4	5	6
Red	+0.78071	+0.02482			
75	--------	--------	0.8537	0.8522	−0.0015
86	--------	--------	.8045	.8062	+.0017
154	--------	--------	.8257	.8246	−.0011
201	--------	--------	.8430	.8444	+.0014
211	--------	--------	.8197	.8168	−.0029
400	--------	--------	.8329	.8347	+.0018
Yellow	+.80878	+.05180			
199	--------	--------	.9465	.9489	−.0024
200	--------	--------	.9377	.9388	−.0011
261	--------	--------	.9643	.9628	+.0015
271	--------	--------	.9358	.9337	+.0021
Green	+1.19562	−.04446			
87	--------	--------	1.1284	1.1287	−.0003
134	--------	--------	1.1048	1.1041	+.0007
137	--------	--------	1.1126	1.1134	−.0008
322	--------	--------	1.1398	1.1393	+.0005
Lunar	+1.08967	−.03071			
45	--------	--------	1.0499	1.0523	−.0024
73	--------	--------	1.0417	1.0447	−.0030
74	--------	--------	1.0682	1.0652	+.0030
124	--------	--------	1.0290	1.0266	+.0024

[1] For example, values in RP1688 [3].

References

[1] Proc. Intern. Comm. Illumination, Zurich, 13th Session, **1,** sec. 1.3.3, p. 28 (1955).

[2] Kasson S. Gibson and Geraldine Walker Haupt, Standardization of the luminous-transmission scale used in the specification of railroad signal glasses, J. Research, NBS **22,** 627 (1939) RP1209.

[3] Kasson S. Gibson, Geraldine Walker Haupt, and Harry J. Keegan, Specification of railroad signal colors and glasses, J. Research, NBS **36,** 1 (1946) RP1688.

WASHINGTON, August 12, 1957.