NATIONAL BUREAU OF STANDARDS REPORT

4844

CHROMATICITIES OF 16 GLASS FILTERS

SUBMITTED BY

THE TINTOMETER, LTD.

TO DUPLICATE THE RELOCATED AND RESPACED UNION COLOR SCALE

FOR

LUBRICATING OIL AND PETROLATUM

DEVELOPED BY ASTM COMMITTEE D-2, RESEARCH DIVISION IX

by

Deane B. Judd and Margaret M. Balcom

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside back cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Ceramic Engineering. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Applications Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services.

Radio Propagation Engineering. Frequency Utilization Research. Tropospheric Propagation Research.

Radio Standards. High Frequency Standards Branch: High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Microwave Standards Branch: Extreme High Frequency and Noise. Microwave Frequency and Spectroscopy. Microwave Circuit Standards.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0201-20-0200	September, 1956	4844

CHROMATICITIES OF 16 GLASS FILTERS

SUBMITTED BY

THE TINTOMETER, LTD.

TO DUPLICATE THE RELOCATED AND RESPACED UNION COLOR SCALE

FOR

LUBRICATING OIL AND PETROLATUM

DEVELOPED BY ASTM COMMITTEE D-2, RESEARCH DIVISION IX

by

Deane B. Judd and Margaret M. Balcom

Photometry and Colorimetry Section

National Bureau of Standards

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Chromaticities of 16 Glass Filters

Submitted by

The Tintometer, Ltd.

To Duplicate the Relocated and Respaced Union Color Scale

by

Deane B. Judd, and
Margaret M. Balcom

Abstract

As a part of our cooperation with Research Division IX, ASTM Committee D-2, to develop an improved method for color grading petroleum products, the chromaticities of 16 glass filters designed spectrophotometrically by The Tintometer, Ltd. to duplicate the relocated and respaced Union color scale (RP2103) have been determined by visual colorimetric comparison with the set of master standards for this scale (NBS Report 4295). It was found that 7 of the 16 glass filters comply with the relocated and respaced Union color scale within the tolerances proposed, while 4 of them do not. The remaining 5 filters probably comply, though this has not been proved.

I. INTRODUCTION

In 1950 the Union color scale used in the color grading of lubricating oils and petrolatum was relocated to give uniform perceptual spacing (1).

Hellige, Inc. in 1951 submitted a set of 12 glass filters matching the original Union scale, and from detailed spectrophotometric analysis of these 12 filters, Mr. John C. Schleter of the National Bureau of Standards designed a set of 16 filters to conform to the newer uniform spacing (2). Helped by spectrophotometric analysis of 17 glass filters then submitted by Hellige, Inc. to satisfy these design specifications (3), a satisfactory set of 17 Hellige glass filters was finally derived which passed the tolerance limits both in chromaticity and transmittance (4). This satisfactory set of filters was retained here at the National Bureau of Standards as master standards for the relocated Union scale, and used as such in the present study.

In 1954 Mr. G. J. Chamberlin, managing director of the Tintometer, Ltd., indicated that his company wished to duplicate the relocated and respaced scale by means of combinations of Lovibond red, yellow, and blue glasses, and also requested that Lovibond notations for the colors be included in the specifications. Dr. Deane B. Judd of this Bureau agreed to check the Lovibond notations to be supplied by Mr. Chamberlin. It was found subsequently by Mr. Chamberlin, however, that many of the combinations of Lovibond red and yellow glasses required to produce the specified chromaticities of the relocated Union color scale failed to transmit sufficiently high fractions of incident daylight to meet the transmittance requirements of the proposed specification. To meet these specifications, The Tintometer Ltd. found it necessary to develop special multi-component glass filters some components of which do not belong to the Lovibond red and yellow scales, and are of higher transmittance.

2. MATERIAL

The 16 glasses so developed were received from The Tintometer Ltd. in November 1955 in accord with a letter from Mr. Chamberlin of 11 October 1955 enclosing a table of chromaticity coordinates (r,g,b) and daylight transmittances (T) found by them spectrophotometrically. In this letter Mr. Chamberlin stated in part, "The enclosed Schedule shows our calculated r,g,b, and T values, and they are all well within the tolerance. On the other hand, I realize that it is unlikely your spectrophotometer will produce exactly the same figures, and I only hope that you will agree that we are within the tolerance."

3. SPECTROPHOTOMETRIC MEASUREMENTS

Although funds were not available to support a completely reliable spectrophotometric study of these glasses, component by component, such as was done for the Hellige glasses (4), a recording was made on a General Electric spectrophotometer(5,6) for each multi-component combination by means of the "normal" cam. Since such recordings are known to be unreliable for transmittances less than 1%, these curves have not been read, but they are shown (Fig. 1) as an indication of the degree to which they duplicate the corresponding curves for the Hellige glasses. The General Electric recording spectrophotometer used for these measurements is equipped with slits equivalent to approximately 10 mμ of spectrum for the spectral region 400 to 750 mμ.

Fig. 2 pictures spectral curves for the original design specifications (2) based on Hellige glasses. While these curves do not represent the final Hellige standards used in this study, they are characteristic of the types of glass used in the standards, the only difference being in thickness of components. Comparison of the spectral-transmittance curves of the Tintometer glasses (Fig. 1) with the curves of the Hellige glasses (Fig. 2) reveals important dissimilarities. In the 0.5, 1.0, 1.5, and 2.0 Hellige glasses there is a transmission band at 470 mμ, not present in the Tintometer glasses; and in the 1.0, 1.5, 2.0 and 2.5 Tintometer glasses there is an absorption band at 526 mμ not shown in the Hellige glasses. The transmission curves of the 6.5 and 7.0 Hellige glasses cut off sharply with decreasing wavelength, while the curves of the Tintometer glasses of the same numbers decline gradually, and that of the 6.5 glass rises again to a low maximum near 540 mμ. These and other differences in shape of spectral-transmittance curves indicate that different constituent glasses have been chosen for the two sets of filters. Any pair formed by taking corresponding filters from each set, if they color match, must then be strongly metameric*, and whether they are seen to match may depend importantly on the spectral composition of the illuminant, on the color-mixture functions of the observer, and on the angular subtense of the comparison field.

4. QUALITATIVE VISUAL COMPARISONS

A preliminary visual comparison of the Hellige and Tintometer filters was made by fluorescent daylight. The filters were viewed through two holes in a black diaphragm, each hole subtending about 1° at the eye of the observer, the distance between the two holes also subtending about 1°. The colors of the two sets of glasses were found (DBJ, HJK) to differ only slightly under these conditions, and most of the differences were in the sense corresponding to the differences between the two sets of color specifications derived from spectrophotometry. These preliminary visual comparisons thus justified a hope that the Tintometer filters would be found to satisfy the requirements of the proposed specification of the relocated and respaced Union color scale if actual measurements of the color differences between the Tintometer filters and the master standards (4) could be carried out. This result of the preliminary visual comparison was reported to Mr. Chamberlin in a letter of December 1, 1955.

---

* A metameric pair consists of two colors having identical tristimulus values (or identical luminances and chromaticity coordinates) but differing in spectral composition.

Two subsequent qualitative visual comparisons of the Tintometer filters with the master standards were made (DBJ), the first by viewing the overcast sky successively through the corresponding filters of the two sets, the second by means of the 9 x 13° double-trapezoid field of the Lummer-Brodhun contrast photometer head of the chromaticity-difference colorimeter to be described later, the filters being illuminated by incandescent-lamp light after passage through a Corning Daylite (5900) glass of sufficient thickness to yield a color temperature closely equal to that (6,740°K) of CIE Source C (representative of average daylight). Table I gives the results of these comparisons.

An outstanding result, and one indeed to be expected, is that the differences that appeared slight for 1° viewing are very prominent, and easy to detect, for viewing in fields of large angular subtense. Another noteworthy result is that the filter pairs for Union colors 1.0 and 1.5 are metameric in such a way as to reveal the entoptic phenomenon known as Maxwell's spot (7) usually considered as ascribable to the macular pigment, an irregular spot of yellowish pigment covering the central 3 or 4° of the retina. Note that the color difference between the filters for Union color 1.5 depended on whether the observer reported what he saw in the center of the field, or what he saw in the periphery of the field. Finally it should be pointed out that the results of the visual comparison depend somewhat on whether the comparison is made successively by light from the overcast sky, or whether it is made simultaneously by artificial daylight with luminance adjustment. Some of these minor discrepancies (2.0, 2.5, 3.0, 3.5, 4.0, 5.0) may be described in terms of the expected tendency of the simultaneous comparison in the 9 by 13° double-trapezoid fields to emphasize saturation differences by allowing the observer to become adapted to the average color of the two fields. Two minor exceptions (4.5, 7.5) and an apparent reversal (8.0) are possibly the result of the difference in spectral energy distribution of the two sources used (natural overcast-sky light and Corning artificial daylight).

These large-field visual comparisons made it appear doubtful whether many of the Tintometer filters would pass the requirements of the proposed specification, though they do not prove it one way or another any more than the small-field comparisons which seemed to justify a hope that all would pass.

Table I, - Results of visual comparisons under two observing conditions of the Tintometer filters with the corresponding master standard (4) prepared by Hellige.

Tintometer Glass No.	Color of Tintometer filter compared to that of the master standard of the same number (Obs. DBJ) By light from the overcast sky	By Corning artificial daylight in a 9 by 13° double-trapezoid field	Chromaticity Differences (DBJ) △x	△y
0.5	More saturated	More saturated	0.002	0.004
1.0	More saturated and redder	Weaker and redder (center of field)	.003	-.006
1.5	More saturated and redder except for central spot which was weaker and redder	Weaker and redder (center of field)	.001	-.010
2.0	More saturated and perhaps greener	More saturated	.009	.007
2.5	More saturated	Much more saturated and redder	.014	.000
3.0	More saturated and slightly greener	Much more saturated and redder	.008	.001*
3.5	Greener	Much more saturated and slightly greener	.007	.000*
4.0	Slightly more saturated	Much more saturated and redder	.006	-.005*
4.5	More saturated and redder	Redder	.0004	-.0004*
5.0	Redder and perhaps more saturated	Much more saturated and redder	.002	-.002*
5.5	Slightly greener and weaker	Greener and weaker	-.003	.003
6.0	Greener and weaker	Much greener and weaker	-.006	.006*
6.5	Greener and weaker	Much greener and weaker	-.008	.008*
7.0	Much greener and weaker	Much greener and weaker	-.012	.012*
7.5	Slightly weaker	Redder and weaker	.001	-.001*
8.0	Yellower and weaker	Slightly more saturated	.0002	-.0002*

* Denote differences along the Union-color locus only

5. MEASUREMENTS BY THE CHROMATICITY-DIFFERENCE COLORIMETER

If the chromaticity differences (Δx, Δy) between corresponding pairs of the two sets of filters could be determined, the chromaticity coordinates (x,y) for the Tintometer filters could be calculated by applying these differences to the known chromaticity coordinates of the master standards (4). An instrument applicable to colors not too selective in spectral energy distribution is the chromaticity-difference colorimeter (8). Two double wedges, one greenish, the other of yellowish glass, are adjusted on the side of the comparison field to match the standard field. By means of a Lummer-Brodhun cube these fields form a trapezoid pattern subtending 9 x 13° at the observer's eye. Additional filters of the same glass as the wedges can be added to either comparison or standard side to obtain a match. In these measurements CIE Source C (6740°K) was approximated by using dense Corning Daylite glass with a 400-watt incandescent lamp operated at 2915°K, giving the same artificial daylight used for the comparisons reported in Column 3, Table I. The limitation of this instrument to colors of moderate spectral selectivity arises from the fact that strongly selective colors are too little changed by viewing through the yellowish and greenish wedges to permit a match to be obtained except in special cases. As applied to the colors of the Union scale the chromaticity-difference colorimeter should apply perfectly for colors 0.5 to 2.0, but for colors of higher number (see Figs. 1 and 2), the yellow wedge can produce only negligible color changes. Variation of the green wedge, though changing the color along the Union-scale locus so as to produce a minimum color difference will not succeed in making this minimum equal to zero unless the two filters being compared depart equally from this locus. It was further recognized that the highly metameric character of any color matches that might be set up between corresponding filters in these two sets would render the results somewhat dependent on the color-vision characteristics of the observer making the settings.

In spite of the probability that use of the chromaticity-difference colorimeter would fail to give a definitive result for each pair of filters, an attempt to measure the chromaticity differences, Δx, Δy, for each pair of filters has been made by two observers (DBJ, MMB), first to show the degree of dependence of such settings on the color-vision characteristics of individual observers, and second because such settings can indicate the nearest match on the locus of Union-scale chromaticities produced by each of the Tintometer filters. It was thought that information on dependence of color matches on observers would be valuable to Research Division IX because color matches

between petroleum products and either set of glass filters involve metamerism of similar degree to that between corresponding pairs of filters from the two sets. It was further thought that information on the nearest match on the locus of Union-scale chromaticities produced by each of the Tintometer filters would also be of interest to Research Division IX. If the nearest match for a given filter is outside the tolerance, that filter cannot possibly pass the requirements of the proposed specification; and conversely, if the nearest match is well within the tolerance, the filter is probably satisfactory, though whether it actually meets the requirements would have to be settled by difficult spectrophotometry, component by component. A third reason for making the attempt to use the chromaticity-difference colorimeter is to prepare for the possibility that sets of color standards for the relocated and respaced Union color scale will be submitted to the National Bureau of Standards for certification. It is known that the chromaticity-difference colorimeter is applicable to such certification provided the color standards are made from the same kinds of glass as the master standards with which they are to be compared. The question to be decided is whether it is feasible to certify in this way sets of color standards, such as the Tintometer filters, not made from the same kinds of glass as the master standards.

Accordingly, the 16 Tintometer filters in turn were carefully compared by two observers (DBJ and MMB) with the equivalent Hellige filters of the set of master standards. It was found that the size of the Hellige filters (15 mm diam) is too small to fill the field of the colorimeter even with the 5-diopter lenses customarily used with small specimens. To fill the field it was necessary to add 10-diopter lenses to the 5-diopter lenses between the glasses (both instrument and test) and the Lummer-Brodhun cube. It was found possible to set up a chromaticity match on the colorimeter for Union colors 0.5, 1.0, 1.5, 2.0, 2.5, 5.5, and 7.5; for the other 9 colors a determination of nearest match was made. The two filters were then interchanged, and new settings of chromaticity match or nearest chromaticity match were made.

If the settings after interchange of the filters are identical to those set before, and both result in a chromaticity match, then the two chromaticities are identical. Any difference in settings of the yellowish and greenish wedges is a measure of the chromaticity difference. If one or both of these settings were for nearest chromaticity match, the difference in settings is a measure simply of

the component of the chromaticity difference introduced by the green wedge. This component turned out in each of the 9 comparisons to refer to chromaticity changes along the locus of the Union-scale colors; so the difference in settings of the wedges corresponding to the nearest chromaticity match is a measure of the difference in nearest match along the locus of the Union-scale colors. The wedge-setting differences, both for chromaticity match and nearest chromaticity match, have been expressed in terms of the 1931 CIE standard chromaticity coordinates, x,y, (9). For observer DBJ these differences ($\Delta x, \Delta y$) are shown in the final two columns of Table I, the differences based on nearest chromaticity match being marked by asterisks. It will be noted that these quantitative results are in accord with the results of the qualitative visual comparisons obtained under the same observing conditions by the same observer (DBJ); see third column of Table I.

The next step is to apply these differences, $\Delta x, \Delta y$, to the known chromaticity coordinates, of the master standards and so find values of x,y, either for the Tintometer filters or for the nearest match on the Union-scale locus for the Tintometer filter. These values of chromaticity coordinates, x,y, were then transformed to chromaticity coordinates, r,b, in the UCS system(10) by means of the usual transformation equations:

$$r = \frac{2.7760x + 2.1543y - 0.1192}{-1.0000x + 6.3553y + 1.5405}$$

$$g = \frac{-2.9446x + 5.0323y + 0.8283}{-1.0000x + 6.3553y + 1.5405}$$

$$b = 1.0000 - 1.0000r - 1.0000g$$

Table II shows these chromaticity coordinates, r,b, (individual results) together with remarks on the appearance of the colorimeter field for the setting. The chromaticity coordinates corresponding to the settings of nearest chromaticity match are distinguished from those, r,b, for match by being labeled, r_n, b_n. The values of r_n, b_n, for Union colors 3.0, 3.5, 4.0, 4.5, and 5.0 were adjusted slightly (adjustments less than 0.001) to make them conform to the Union locus by taking advantage of the property of the UCS chromaticity diagram that the nearest chromaticity point on a locus from a point off the locus is the normal to the locus from the off-locus point.

Table II - Chromaticity coordinates, r,b, for match, or chromaticity coordinates, r_n, b_n, for the nearest match on the Union locus, for the Tintometer glasses.

Tintometer Filter No.	Observer	Chromaticity coordinates r	b	r_n	b_n	Remarks on appearance of colorimeter field for the setting
0.5	DBJ	0.4621	0.0650			Match
	MMB	.4621	.0634			
1.0	DBJ	.4912	.0368			Match at center
	DBJ	.4908	.0352			Match for average of whole field
	MMB	.4916	.0327			Match at center
1.5	DBJ	.5204	.0191			Match at center
	DBJ	.5203	.0173			Match for average of whole field
	MMB	.5205	.0158			Match at center
2.0	DBJ	.5555	.0045			Match
	MMB	.5560	.0040			
2.5	DBJ	.5882	.0008			Match
	MMB			0.5851	0.0020	Nearest match
3.0	DBJ			.6147	.0010	Saturated and green*
	MMB			.6129	.0010	
3.5	DBJ			.6454	.0010	Saturated and green
	MMB			.6425	.0010	
4.0	DBJ			.6754	.0010	Saturated and green
	MMB			.6765	.0010	
4.5	DBJ			.7000	.0010	Weak and red
	MMB			.6998	.0010	
5.0	DBJ			.7375	.0000	Saturated and green
	MMB			.7356	.0000	
5.5	DBJ	.7611	.0000			Match
	MMB	.7592	.0000			
6.0	DBJ			.7914	.0000	Saturated and green
	MMB			.7914	.0000	
6.5	DBJ			.8216	.0000	Weak and red
	MMB			.8172	.0000	
7.0	DBJ			.8468	.0000	Weak and red
	MMB**					
7.5	DBJ			.9168	.0000	Weak and red
	MMB	.9112	.0004			Match
8.0	DBJ			.9549	.0000	Weak and red
				.9520	.0000	Nearest match

* Remarks refer to portion of the colorimeter field corresponding to Tintometer filter.

** For this observer, the setting for nearest chromaticity match was outside the color gamut provided by available green glasses.

It will be noted from Table II that a difference of not more than 0.002 in r and b occurs between the settings for chromaticity match in the center of the field and those for the whole field. It will be noted further that the settings for the two observers generally agree well (average difference in r or b equal to 0.0018 or 0.0007, respectively) though for two Union colors (6.5 and 7.5) the difference in r is about three times this average value. All of these differences are ascribable to the metameric character of the matches, and since petroleum products checked against either set of filters will yield similar metamerism, the rating of a product by this method is subject to uncertainties of about these amounts depending on the choice of observer. Each of these individual differences, however, corresponds to less than 0.1 of a unit on the Union scale.

Table III compares the average values of chromaticity coordinates of the Tintometer filters 0.5, 1.0, 1.5, 2.0, 2.5, 5.5, and 7.5 with the corresponding specified values. The final two columns show the differences for each filter to be not more than the recommended tolerances of ±0.006, and this is taken as substantiation of the claim by Tintometer Ltd. that these filters comply with the proposed specification. Table III also compares the chromaticity coordinates of the nearest match on the Union locus with the corresponding specified values for the remaining nine Tintometer filters (marked with asterisks).

The differences for four of the Tintometer filters (5.5, 6.0, 6.5, 7.0) are seen to exceed the recommended tolerances (±0.006) by substantial amounts. This result is taken as a strong indication that these filters do not comply with the proposed specification in spite of the indication to the contrary by spectrophotometric measurements by Tintometer Ltd; see Table IV. The fact that the differences for the remaining filters are less than 0.006 suggests that these filters do comply with the requirements of the proposed specifications, but particularly for Union colors 3.5 and 4.0 do not prove it because the Tintometer filters are off-locus by amounts that have not been quantitatively evaluated.

6. DISCUSSION

As a possible explanation of the discrepancy between the visual colorimetry of the Tintometer filters 5.5, 6.0, 6.5 and 7.0 and the spectrophotometry of them at The Tintometer Ltd. (see Table IV) it may be noted from Fig. 1 that the spectrophotometric curves for these four filters are part of a family having similar shapes, and that one of them (6.5) rises again to a small maximum near 540 mμ after having apparently sunk to zero near 570 mμ. The similarity in shape of

Table III,- Chromaticity coordinates (r,b) specifying the relocated and respaced Union color scale (1) compared with the chromaticity coordinates of the Tintometer filters, found at the National Bureau of Standards by visual comparison on the chromaticity-difference colorimeter with the glasses prepared by Hellige as master standards.

Glass No.	Recommended Specifications(1)		Tintometer Glasses NBS visual measurements (average of 2 observers)		Differences	
	r	b	r	b	△r	△b
0.5	.462	.065	.462	.064	.000	.001
1.0	.489	.036	.491	.035	.002	.001
1.5	.521	.015	.520	.017	.001	.002
2.0	.552	.006	.556	.004	.004	.002
2.5	.582	.002	.588	.001	.006	.001
3.0	.611	.001	.614*	.001*	.003	.000
3.5	.640	.001	.644*	.001*	.004	.000
4.0	.671	.001	.676*	.001*	.005	.000
4.5	.703	.001	.700*	.001*	.003	.000
5.0	.736	.000	.737*	.000*	.001	.000
5.5	.770	.000	.760	.000	.010**	.000
6.0	.805	.000	.791*	.000*	.014**	.000
6.5	.841	.000	.819*	.000*	.022**	.000
7.0	.877	.000	.847*	.000*	.030**	.000
7.5	.915	.000	.911	.000	.004	.000
8.0	.956	.000	.953*	.000*	.003	.000

* Nearest chromaticity match on the Union locus
** Outside recommended tolerance of ±0.006(1)

Table IV,- Chromaticity coordinates (r,b) of the Tintometer filters found at Tintometer, Ltd. by means of spectrophotometry compared with those found at the National Bureau of Standards by visual comparison on the chromaticity-difference colorimeter with the master standards prepared by Hellige.

Glass No.	Tintometer spectrophotometric values		NBS visual colorimetric values (average of 2 observers)		Differences	
	r	b	r	b	△r	△b
0.5	0.462	0.064	0.462	0.064	.000	.000
1.0	.491	.034	.491	.035	.000	.001
1.5	.519	.016	.520	.017	.001	.001
2.0	.551	.006	.556	.004	.005	.002
2.5	.582	.002	.588	.001	.006	.001
3.0	.610	.001	.614	.001	.004	.000
3.5	.640	.001	.644	.001	.004	.000
4.0	.672	.001	.676	.001	.004	.000
4.5	.700	.002	.700	.001	.000	.001
5.0	.737	.000	.737	.000	.000	.000
5.5	.768	.000	.760	.000	.008	.000
6.0	.805	.000	.791	.000	.014	.000
6.5	.841	.000	.819	.000	.022	.000
7.0	.879	.000	.847	.000	.032	.000
7.5	.914	.000	.911	.000	.003	.000
8.0	.955	.000	.953	.000	.002	.000

curve permits us to conclude that they were made from identical glass components, only the thicknesses of the components having been varied. It is suggested that each of these curves may really be slightly greater than zero for a considerable spectral range below the wavelength of apparent cut-off. This would account for the green and weak appearance of these Tintometer filters compared to the corresponding master standards (see Table I), and it would also account for the measured value of r_n, being too low to comply with the requirements of the specification.

7. CONCLUSIONS

1. Metamerism may cause detectable discrepancies in the grading of petroleum products by the proposed relocated and respaced Union color scale depending on choice of light source, who does the observing, and the size of field used; but each such discrepancy indicated by the present test corresponds to less than 0.1 unit on the proposed scale.

2. Seven of the Tintometer filters have been shown to comply with the requirements of the proposed specification. Of the remaining nine Tintometer filters, three probably comply, two may comply, and four are shown not to comply.

3. The precise evaluation by spectrophotometry of the colors of filters of the type shown not to comply with the proposed specification is extremely difficult because they have spectral transmittances that approach zero very gradually with decreasing wavelength near the visually important middle of the spectrum, and it is suggested that small, hard-to-avoid errors may exist in the measurements of spectral transmittance on which Tintometer Ltd. based their filter designs. NBS Report 4295 deals with methods of eliminating these errors.

4. The use of the chromaticity-difference colorimeter for checking compliance of sets of filters to the requirements of the proposed specification is quick and convenient if these filters are made from glass components spectrally similar to those of the master standards; but if made of spectrally dissimilar components, such use, though of considerable value, is not wholly definitive. Other methods for checking compliance should be explored.

References

(1) D. B. Judd, L. Plaza, M. A. Belknap, A suggested relocation and respacing of the Union Colorimeter scale for lubricating oil and petrolatum, J. Research NBS 44, 559 (1950), RP2103.

(2) J. C. Schleter, Design of sixteen filters for the relocated and respaced Union Colorimeter scale for lubricating oil and petrolatum, NBS Report 2012, October 24, 1952.

(3) J. C. Schleter, Design of sixteen filters for the relocated and respaced Union Colorimeter scale for lubricating oil and petrolatum, Supplement I to NBS Report 2012, NBS Report 2935, December 15, 1953.

(4) J. C. Schleter, Spectrophotometric and colorimetric analysis of seventeen glass filters duplicating the relocated and respaced Union Color scale for lubricating oil and petrolatum for ASTM Committee D-2, Research Divixion IX, submitted by Hellige, Inc., NBS Report 4295, September 1955.

(5) A. C. Hardy, A new recording spectrophotometer, J. Opt. Soc. Am., 25, 305 (1935).

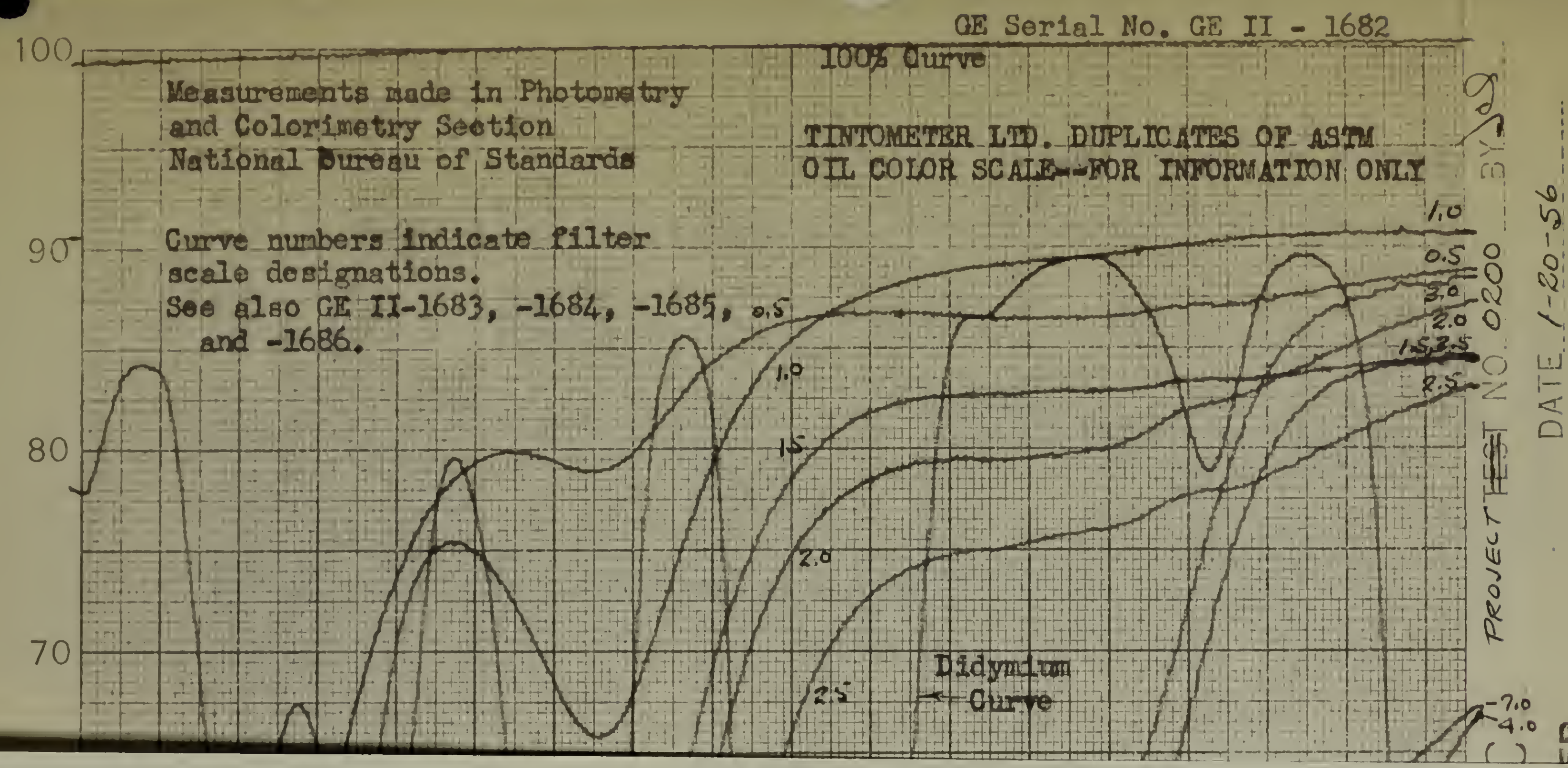
(6) J. L. Michaelson, Construction of the General Electric recording spectrophotometer, J. Opt. Soc. Am. 28, 365 (1938); also K. S. Gibson, and H. J. Keegan, Calibration and operation of the General Electric recording spectrophotometer of the National Bureau of Standards, J. Opt. Soc. Am., 28, 372 (1938).

(7) J. C. Maxwell, On the unequal sensibility of the foramen centrale to light of different colours, Rep. Brit. Assoc. for 1856, page 12.

(8) D. B. Judd, Specification of uniform color tolerances for textiles, Textile Research, 9, 253 (1939).

(9) Proceedings, Eighth Session, Commission Internationale de l'Eclairage, Cambridge, England, September 1931, p. 19 to 29; also A. C. Hardy, Handbook of Colorimetry, Cambridge, Technology Press (1936); also D. B. Judd, The 1931 I.C.I. standard observer and coordinate system for colorimetry, J. Opt. Soc. Am., 23, 359 (1933).

(10) D. B. Judd, A Maxwell triangle yielding uniform chromaticity scales, J. Research NBS 14, 41 (1935) RP756; also J. Opt. Soc. Am. 25, 24 (1935).



GE Serial No. GE II - 1682
100% Curve
Measurements made in Photometry
and Colorimetry Section
National Bureau of Standards
TINTOMETER LTD. DUPLICATES OF ASTM
OIL COLOR SCALE--FOR INFORMATION ONLY
Curve numbers indicate filter
scale designations.
See also GE II-1683, -1684, -1685,
and -1686.
Didymium
Curve
100
90
80
70
1.0
0.5
3.0
2.0
1.5
2.5
7.0
4.0
BY
PROJECT NO. 0200
DATE 1-20-56

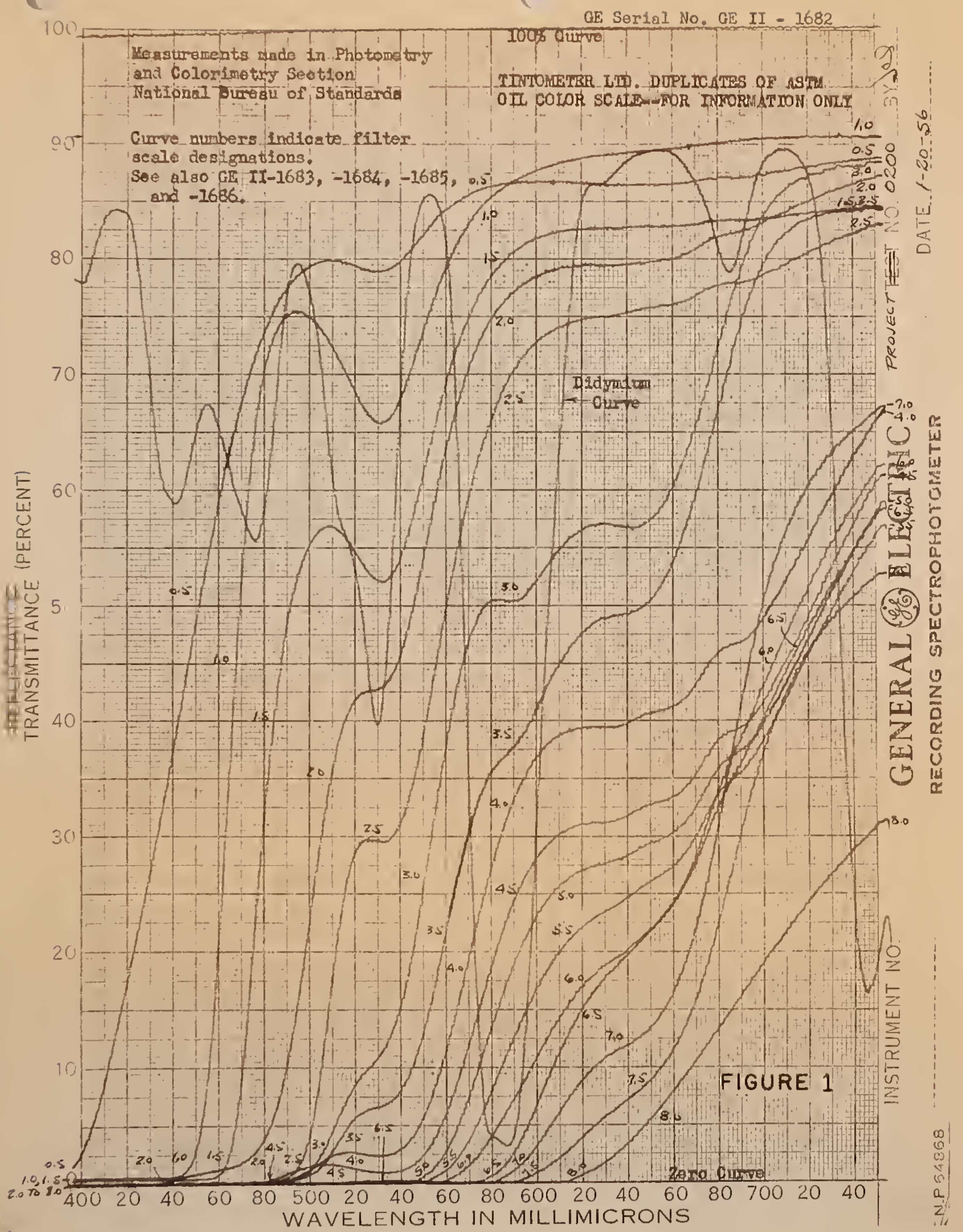
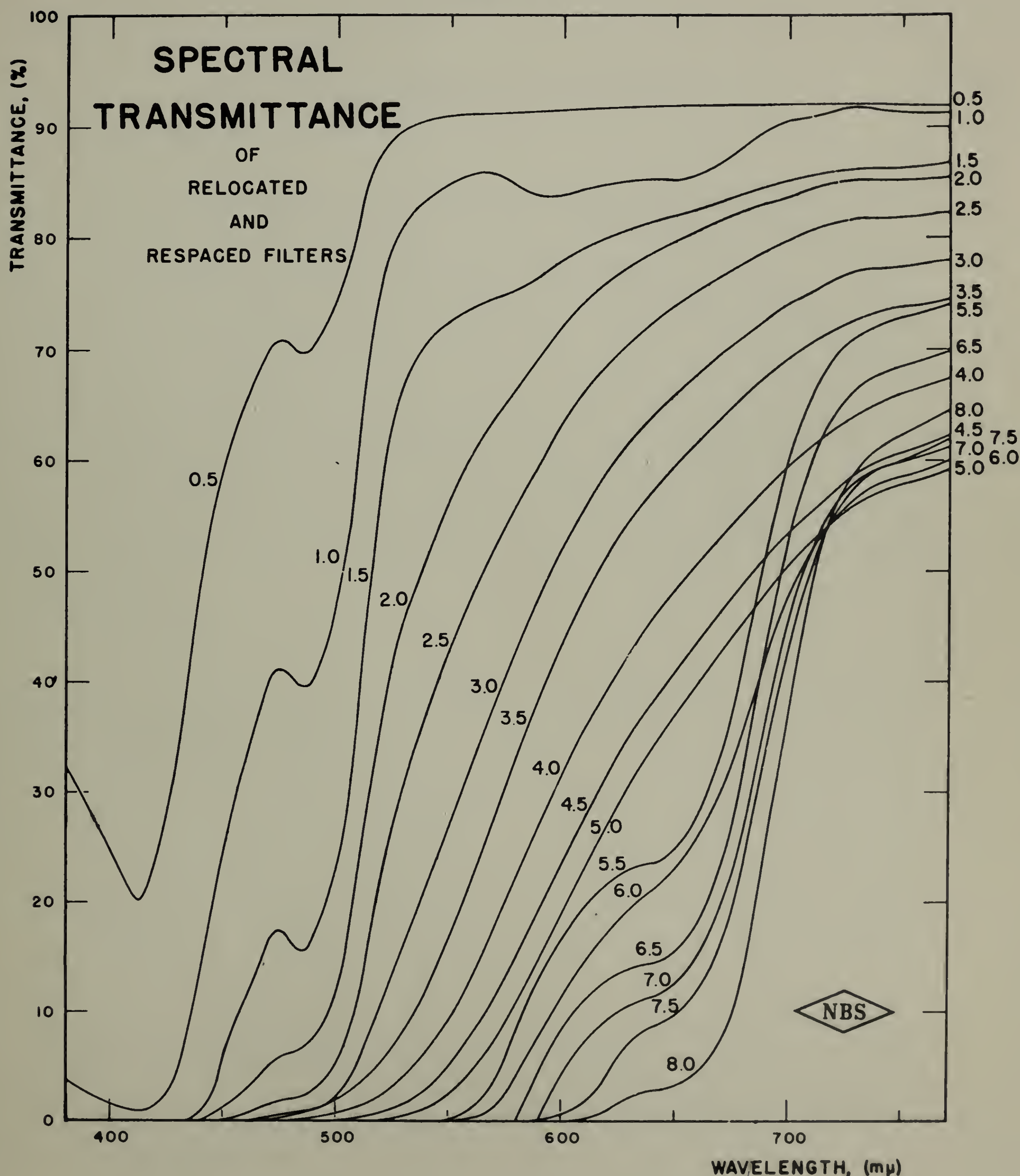

GE Serial No. GE II - 1682
100% Curve
Measurements made in Photometry
and Colorimetry Section
National Bureau of Standards
TINTOMETER LTD. DUPLICATES OF ASTM
OIL COLOR SCALE--FOR INFORMATION ONLY
Curve numbers indicate filter
scale designations.
See also GE II-1683, -1684, -1685,
and -1686.
Didymium
Curve
Zero Curve
TRANSMITTANCE (PERCENT)
WAVELENGTH IN MILLIMICRONS
400 20 40 60 80 500 20 40 60 80 600 20 40 60 80 700 20 40
100 90 80 70 60 50 40 30 20 10
PROJECT NO 0200
DATE 1-20-56
GENERAL ELECTRIC
RECORDING SPECTROPHOTOMETER
INSTRUMENT NO.
N.P. 54868

FIGURE 1

FIGURE 2



SPECTRAL
TRANSMITTANCE
OF
RELOCATED
AND
RESPACED FILTERS
TRANSMITTANCE, (%)
WAVELENGTH, (mμ)
100
90
80
70
60
50
40
30
20
10
0
400
500
600
700
0.5
1.0
1.5
2.0
2.5
3.0
3.5
5.5
6.5
4.0
8.0
4.5
7.5
7.0
6.0
5.0
NBS

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS

NATIONAL BUREAU OF STANDARDS REPORT

4835

A VISUAL COMPARATOR

FOR

MICA WAVINESS

By

CHARLES DEWITT COLEMAN

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major field laboratories in Boulder, Colorado, is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant reports and publications, appears on the inside back cover of this report.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Tubes. Electrical Instruments. Magnetic Measurements. Process Technology. Engineering Electronics. Electronic Instrumentation. Electrochemistry.

Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.

Heat and Power. Temperature Measurements. Thermodynamics. Cryogenic Physics. Engines and Lubrication. Engine Fuels.

Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment. AEC Radiation Instruments.

Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Gas Chemistry. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.

Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Organic Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion.

Mineral Products. Ceramic Engineering. Porcelain and Pottery. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.

Building Technology. Structural Engineering. Fire Protection. Heating and Air Conditioning. Floor, Roof, and Wall Coverings. Codes and Specifications.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analogue Systems. Applications Engineering.

- Office of Basic Instrumentation
- Office of Weights and Measures

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services.

Radio Propagation Engineering. Frequency Utilization Research. Tropospheric Propagation Research.

Radio Standards. High Frequency Standards Branch: High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Microwave Standards Branch: Extreme High Frequency and Noise. Microwave Frequency and Spectroscopy. Microwave Circuit Standards.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
0201-20-2340	September 1956	4835

A VISUAL COMPARATOR
FOR
MICA WAVINESS

by

Charles DeWitt Coleman
Photometry & Colorimetry Section
Optics and Metrology Division

Sponsored by
Emergency Procurement Service
General Services Administration
under
Contract No. DMP-122

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

1. Introduction

After the National Bureau of Standards had developed an objective means for evaluating the waviness of mica[1], members of the Emergency Procurement Service, General Services Administration, requested the construction of an instrument to aid inspectors in their visual evaluation of waviness. The Visual Mica Comparator was designed to help resolve disputes that arise when two individuals independently give different visual evaluations to the waviness of the same piece of mica. This device is not considered to be a satisfactory substitute for the photoelectric instrument described in an earlier report[1].

2. The Construction and Operation of the Comparator

2.1 Construction

Figure 1 shows the construction of the Visual Mica Comparator. The light source, A, consists of an 8-watt fluorescent lamp in a housing which is provided with a 1/8-inch slit along its length. An observer at C looking through the thin glass plate, D, can see a reflection of the source in the test specimen, B.

The observer can also see the image of a reference grid, E, reflected in the glass plate. The optical path from C to E is equal to that from C to A so that movement of the observer will not cause relative motion between the source image and the grid.

Mounted on the front panel is a variable-speed and reverse controller, F, for the motor, G. The motor drives a belt, H, which passes the mica across the observation table and out of the exit slot, I.

2.2 Operation

The operator places test samples of mica on the forward projection of the belt and runs them into the instrument. As each test specimen passes beneath the glass plate, the observer compares the image of the source with the image of the fixed grid and notes the maximum displacement of the source image for each piece.

3. Criteria of Waviness

3.1 Beam Displacement versus Beam Spread

There are two ways in which a wavy surface affects a beam of light reflected from it:

(1) It changes the beam spread;

(2) It displaces the reflected beam from a reference position.

1 National Bureau of Standards Report 4800

Curvature, P, is defined as the reciprocal of the radius of curvature, R.

$$P = \frac{1}{R} \qquad (3)$$

Combining equations (1), (2), and (3) shows that the displacement angle, β , measured with the comparator is a function of the curvature, P, and the distance S.

$$\tan \frac{\beta}{2} = SP \qquad (4)$$

Since S and P are independent, β is a function of two independent variables. If we take a single given curvature, thus establishing P, we find that our reading, β , depends on the distance, S, between the point under examination, M, and the point N. For each value of S, we have a different value for θ, though the curvature, P, is the same. However, at any point there is a constant rate of change of θ with respect to S for a given curvature, since θ is a small angle.

$$d\theta/dS = P \qquad (5)$$

The operator using a visual comparator, however, is unable to evaluate this rate of change which is equal to curvature and which has been defined as synonymous with waviness[2].

3.3 Conclusions

Referring to equation (4), if S and P were permitted to take on any value, one would be forced to conclude that a measure of beam displacement would be worthless as an index of waviness. Actually the magnitude of S is relatively small compared to P and usually will not vary over a wide range. This means that θ is much smaller than its limiting value, α , (the value of θ when the beam itself is tangent to the curved surface) and for this reason, observations with the comparator can be used to obtain a qualitative index of waviness.

With due regard to its limitations, the Visual Mica Comparator can be useful during the transition from the subjective (visual) method of grading to the objective (photoelectric) method recommended in NBS report 4800. The difficulties still inherent in the visual evaluation of beam spread and displacement for various mica samples may be demonstrated with the Comparator, thus enabling inspectors to readily appreciate the advantages of photoelectric instrumentation.

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the front cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office. Inquiries regarding the Bureau's reports and publications should be addressed to the Office of Scientific Publications, National Bureau of Standards, Washington 25, D. C.

NBS