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SPECTROPHOTOMETRIC AND COLORIMETRIC DETERMINATION OF THE COLORS OF THE TCCA STANDARD COLOR CARDS

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ABSTRACT

The color cards of the Textile Color Card Association of the United States are widely used in the textile and allied industries and by many procuring agencies of the Federal Government. The Textile Color Card Association issues both seasonal and standard color cards. The seasonal cards provide a color-forecasting service to textile manufacturers and promote color coordination among the trades; the standard cards present colors for which there is a popular and continuing demand. Most important of the color cards is the Standard Color Card of America, the current ninth edition containing 216 colors. Preeminent among the many special sets of color cards issued by the Association for use of the Federal Government is the United States Army Color Card showing 22 official colors for the arms and services. The specification of the colors of the Ninth Edition Standard Color Card and the United States Army Color Card has been undertaken for the purpose of correlating these textile standards with American War Standard Z44–1942 for the specification and description of color. The 238 samples comprising these color cards have been examined by basic spectrophotometric and colorimetric procedures. From this study there have been found daylight reflectance, Y, chromaticity coordinates (x,y), Munsell renotations, and ISCC–NBS color designations for these samples, as recommended by American War Standard Z44–1942. As more than half of these textile standards are fluorescent, and as existing spectrophotometers are not suited to the evaluation of such samples, considerable reliance has been placed on quantitative colorimetric and photometric comparisons with the Munsell color standards, both by means of a chromaticity-difference colorimeter and by the Martens photometer.

As a closing check, Munsell book notations of these textile standards have been obtained by a direct visual comparison with the color scales of the Munsell Book of Color.

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I. INTRODUCTION

Since its formation, growing out of interference with normal communication with Europe in the First World War, the Textile Color Card Association of the United States has performed two distinct services for the textile and allied industries. The first is a color-forecasting service so that the textile manufacturer, dyer, and dyestuff producer may each plan his production with confidence that his choice of colors will be both procurable and salable and will dovetail satisfactorily with that for merchandise from other industries serving the fashion trades. In this way the manufacturer and retailer are protected to a considerable extent from accumulating large stocks of goods that will not sell, and the customer is supplied with a coordinated instead of haphazard selection. The second service is to standardize colors for the textile and allied industries so that the standard name will always signify the same color. By this standardization, the ordering of merchandise is greatly facilitated.

The color standardization is accomplished chiefly by the issuance of the TCCA Standard Color Card of America, which is supplemented by seasonal cards giving the color forecast. All seasonal colors are automatically standardized under the TCCA system of numbering and naming colors. The ninth edition of the Standard Color Card of America [32] [2] was issued in 1941, and includes 216 colors for which there is a continuing demand. These cards are widely used in the textile and allied industries and are there the accepted authority. They are also used in color specification by governmental agencies and by industries quite unrelated to the fashion trades.

In addition to these services to industry, the Textile Color Card Association has cooperated with the procuring agencies of the Federal Government by issuing many special sets of color standards for textiles. Preeminent among these is the United States Army Color Card [33] showing the official colors for the arms and services. This card was originally issued in 1930; it was revised first in 1938 and again in 1943 so as to include 22 colors. It has been approved and accepted by the Quartermaster General, United States Army.

Paralleling the TCCA work, another step to aid the procurement of war goods covered by a color requirement was taken by the American Standards Association. In 1942 there was formulated and issued American War Standard Z44–1942 [1] for the specification and description of color. This standard was intended primarily to assist subcontractors to comply with color requirements by providing a unified set of coordinated procedures for color specification. The standard provides (1) that the spectrophotometer shall be recognized as the basic instrument in color specification, (2) that spectrophotometric

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

data shall be reduced in accord with the methods recommended in 1931 by the International Commission on Illumination [9, 15, 28, 30], (3) that suitably calibrated working standards of color, such as those of the Munsell Book of Color [25] be used wherever applicable, and (4) that if a color designation is required for general comprehensibility, with precision unimportant, the ISCC–NBS method of designating colors be used [18].

The specification of the colors of the ninth edition of the Standard Color Card of America and of those of the United States Army Color Card has been undertaken for the purpose of correlating these textile standards with the general methods covered by Z44–1942. Some of the fruits of this correlation have already been garnered in the form of information supplied in advance of publication to war agencies that have to write specifications of color requirements for goods that they desire to procure. It is the purpose of the present paper to describe the measurements made of the textile samples, to give the adopted colorimetric results in the form recommended by Z44–1942, and to describe the checks by means of which the accuracy of the adopted values has been established.

II. GENERAL CONSIDERATIONS

The samples of the ninth edition of the Standard Color Card of America are made of satin-finish pure-dye silk, the back, or matte side, being displayed over most of the area of each. The samples of the Army card are of pure-dye silk ribbon, half of satin-finish, half of grosgrain, or ribbed, finish. The brilliance of many of the colors of both sets is partly due to the use of fluorescent dyes. The high luster of the silk fibers and the fluorescence of the dyes combine to interpose formidable obstacles to the colorimetry of these samples, and have a determining influence upon the choice of method.

It is obvious that to be generally useful the correlation between the TCCA standards and nonfluorescent nonlustrous working standards, such as the Munsell standards, evaluated according to Z44–1942, must hold for comparison of such samples in natural diffused daylight near a window. This is the customary condition under which such comparisons are carried out. This requirement gives an approximate definition both of the spectral distribution of the illumination which has to be adopted and of its angular distribution. As sufficiently close to the spectral character of average natural diffused daylight, ICI standard illuminant *C* [9, 15, 28] as recommended by Z44–1942, or alternatively, Macbeth artificial daylight [28] at a color temperature of about 6,800° K has been taken in this work. To characterize the desired angular distribution, illumination incident on the samples along angles spreading through a range of 50° to 70°, roughly centering upon an angle of 45° from the surface has been taken. Standard angular conditions are not specified in Z44–1942 nor are there spectrophotometers or colorimeters available that conform even within these rather wide tolerances. Only near a north window in the daytime or by installations of artificial daylight particularly designed for the purpose are these requirements fulfilled. The general principle of the method, therefore, is to make visual estimations of the Munsell book notations of the 238 samples under these conditions, then to measure the samples with available instruments, and compare the results. It has been found possible to reduce the data in a systematic way yielding no important discrepancy between instrumental result and visual estimate. Incidental to the development of methods of reducing the data in accord with this principle, the discrepancies that would arise through routine application of methods customary for nonlustrous, nonfluorescent samples have been evaluated.

1. FLUORESCENCE

The difficulties involved in the measurement of lustrous and fluorescent textile samples are well known, but some of them will now be recalled. A fluorescent sample is one that when irradiated by energy of one wavelength emits energy of a different (usually greater) wavelength. The complete specification of such a sample requires a separate analysis of the emitted energy for irradiation of the sample by each portion of the spectrum eliciting fluorescence in addition to the usual spectrophotometric analysis covering the entire visible spectrum; that is, instead of one spectrophotometric curve, there would have to be obtained a whole set of them; instead of one column of tabulated values, there would be required several, perhaps as many as 30 columns; instead of being restricted to the visible spectrum, evaluation of fluorescence at least for irradiation by the near ultraviolet portion of the spectrum of the standard illuminant would have to be included. No existing recording photoelectric spectrophotometer is provided with means to disperse both the incident and emitted energy, and, therefore, accurate spectrophotometric analysis of fluorescent samples is not now feasible.

Despite the fact that many commercial materials are fluorescent to a detectable degree, such materials have often been studied by the spectrophotometer in the usual routine way with useful results. Although important exceptions have been noted [5], it has been customary to assume that the degree of the fluorescence of such samples is too slight to invalidate the measurements, just as it has been assumed that samples whose fluorescence is not detectable by visual examination may safely be so measured. All the 238 samples were accordingly examined for fluorescence, both for excitation by ultraviolet energy from a mercury arc and filter and by energy from an incandescent lamp and a green gelatin filter. Doubtful samples were also examined for excitation by each portion of the visible spectrum by energy from the monochromator of a spectrophotometer. More than half were found to be noticeably fluorescent, and an attempt was made to judge whether the fluorescence was strong or weak, but it was, of course, impossible to judge whether the fluorescence of a given sample would or would not introduce a significant error in the measurements. Checks, both instrumental and visual, were therefore carried out, as will be presently described, and if these checks failed to agree well with the spectrophotometric result, the sample was usually classified as strongly fluorescent, although other sources of discrepancy also had to be given consideration.

Samples that fluoresce strongly for excitation by ultraviolet energy require more rigid control of the spectral composition of the illuminant than nonfluorescent samples. The question may be raised, for example, whether Macbeth artificial daylight at a color temperature of 6,800° K, known to be a close representative of average natural diffused daylight transmitted by window glass insofar as intercomparison of nonfluorescent samples is concerned, is sufficiently close to it for strongly fluorescent samples. Visual checks by natural daylight have therefore been made for all strongly fluorescent samples evaluated by colorimetric comparisons under Macbeth daylight.

2. LUSTER

Difficulties arising from the luster of the fibers composing the samples are of two sorts. Because of the regularity of the fabric weave, light striking the samples from some one direction, say perpendicularly, is incident obliquely on many regularly recurring elements of the fiber surface and is reflected, either directly or after incidence on one or more fiber surfaces, and leaves the sample in a partially polarized state. If polarizing instruments are used for the measurement, special precautions have to be taken [3, 23]. Another difficulty arises from the dependence of the appearance or color of the sample on the directions according to which it is illuminated and viewed. There are two rather widely used conditions of illuminating and viewing samples for colorimetry. One is to illuminate the sample at 45° and view it perpendicularly [30], or the reciprocal condition of perpendicular illumination and 45° viewing, which is equivalent [22]. The other is to illuminate the sample diffusely and view it perpendicularly [23], or the equivalent reciprocal condition [11, 12]. It will be noted that neither of these observing conditions conforms exactly to observation near a window, although each agrees in one respect—45°-normal agrees insofar as light from a window comes preponderantly from the direction of about 45°; diffuse-normal agrees insofar as light from a window is diffused to a considerable degree. Information is to be given as to the degree to which the colors of the TCCA standards vary, depending upon which of these conditions is used.

III. METHOD

The present measurements were carried out on 4-inch-square samples of the Standard Color Card of America supplied especially for these studies by the Textile Color Card Association. The measurements were made on the matte side of the samples; none were made on the shiny side. Five of the Army cards were also supplied, and measurements were made on the grosgrain portions only. Figure 1, A, is a photomicrograph (magnification 18 diameters) of the matte portion of a sample (Terra Cotta, 70161) of the standard card; figure 1, B, shows similarly the grosgrain portion of a sample (Brick Red, 65020) from the Army card. Although these views show only the matte portions of the samples, the highlights revealing either surface-reflected light or light that has penetrated only one or two fibers are clearly evident.

In addition to the instrumental measurements, all samples in the official copy of the Standard Color Card of America that had been placed in the vaults of the National Bureau of Standards early in 1942, all samples of the Army card, and many of the 4-inch-square samples were compared with the color scales of the Munsell Book of Color. The 4-inch-square samples were also compared with the corresponding sample in the official copy.

1. RECORDING SPECTROPHOTOMETER

Four-inch-square samples of the fabrics of the standard color card were prepared for spectrophotometric measurement by doubling and backing them with white cardboard similar to that used in the card itself. The white cardboard was attached to a wooden block cut to angles needed for consistent alinement of the sample. For the colors of the Army card, composite samples were made up by mounting four rows of ribbon overlapping on a white cardboard in such a way that only the grosgrain portion was presented for measurement. The spectrophotometer was the General Electric photoelectric recording type [10, 24], an instrument with slits transmitting a 4-mμ spectral band being used for the samples of the Army card and for about one-third of the samples of the standard card, the remainder being measured by means of an instrument with 10-mμ slits. The instrument using a 4-mμ band irradiates the samples along the perpendicular; that using a 10-mμ band at 6°. Both instruments collect the energy reflected in all directions, except for a small solid angle centering on the direction of mirror reflection. Tests indicated that slight discrepancies possibly ascribable to the different characteristics of the two instruments were considerably less than differences that were obtained by measuring a different area of the sample on the same instrument.

Each curve sheet was completely calibrated [6] and the samples were run twice, first with the ridges at 45° from the vertical, second with the sample rotated in its own plane through 90° from the first position. Figure 2 shows a typical curve sheet with zero line, the Vitrolite curve that was used in lieu of the 100-percent curve, and the didymium-glass curve that was used for calibration of the wavelength scale. These instruments measure spectral reflectance for nearly perpendicular incidence relative to that of magnesium oxide [29], which is numerically equal to directional reflectance for diffuse illumination and nearly perpendicular viewing. The wavelength-scale corrections were determined and applied, the curves were read twice independently through the aid of a mechanical and optical device developed by one of us [31] (GBR) to present to the operator a magnified image of the reflectance scale, the corrected wavelength scale, and the spectrophotometric curve close to the point to be read. Readings differing by 0.002 or more were repeated a second time. In this way the spectral reflectance of each sample relative to that of magnesium oxide was determined and checked for each 10-mμ interval from 400 to 750 mμ. Values of spectral reflectance were extrapolated to 380 and 770 mμ and luminous reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y, were computed by the method of 10-mμ summation [28].

Possible sources of error in the measurements of the samples of the Army card are small variations in color from one ribbon to another from which the composite sample was made. Furthermore, the area viewed by the spectrophotometer was not completely filled by the grosgrain portion of the sample, a small fraction of the area being unavoidably occupied by the salvage and possibly a small portion of the satin-finish of one of the five ribbons. Care was taken, however, to insert the sample so that the beam fell entirely on the grosgrain

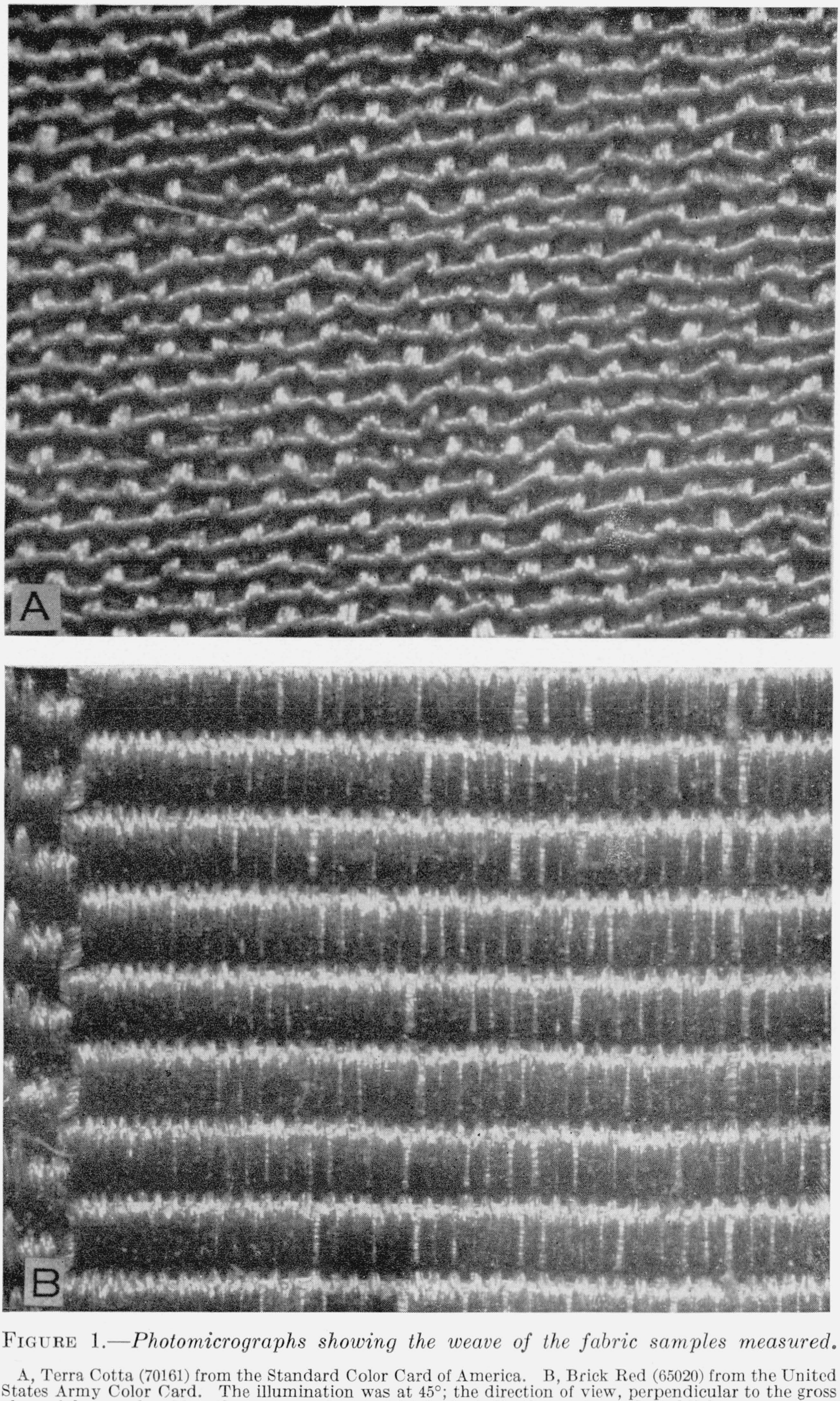

FIGURE 1.—*Photomicrographs showing the weave of the fabric samples measured.*

A, Terra Cotta (70161) from the Standard Color Card of America. B, Brick Red (65020) from the United States Army Color Card. The illumination was at 45°; the direction of view, perpendicular to the gross plane of the sample Note the presence of many highlights, indicating surface-reflected light.

surface. Subsequent checks failed to reveal uncertainties significantly greater for these samples than for the samples of the standard card.

In this type of spectrophotometer the energy is dispersed before striking the sample, but not after striking it. The reflected energy is

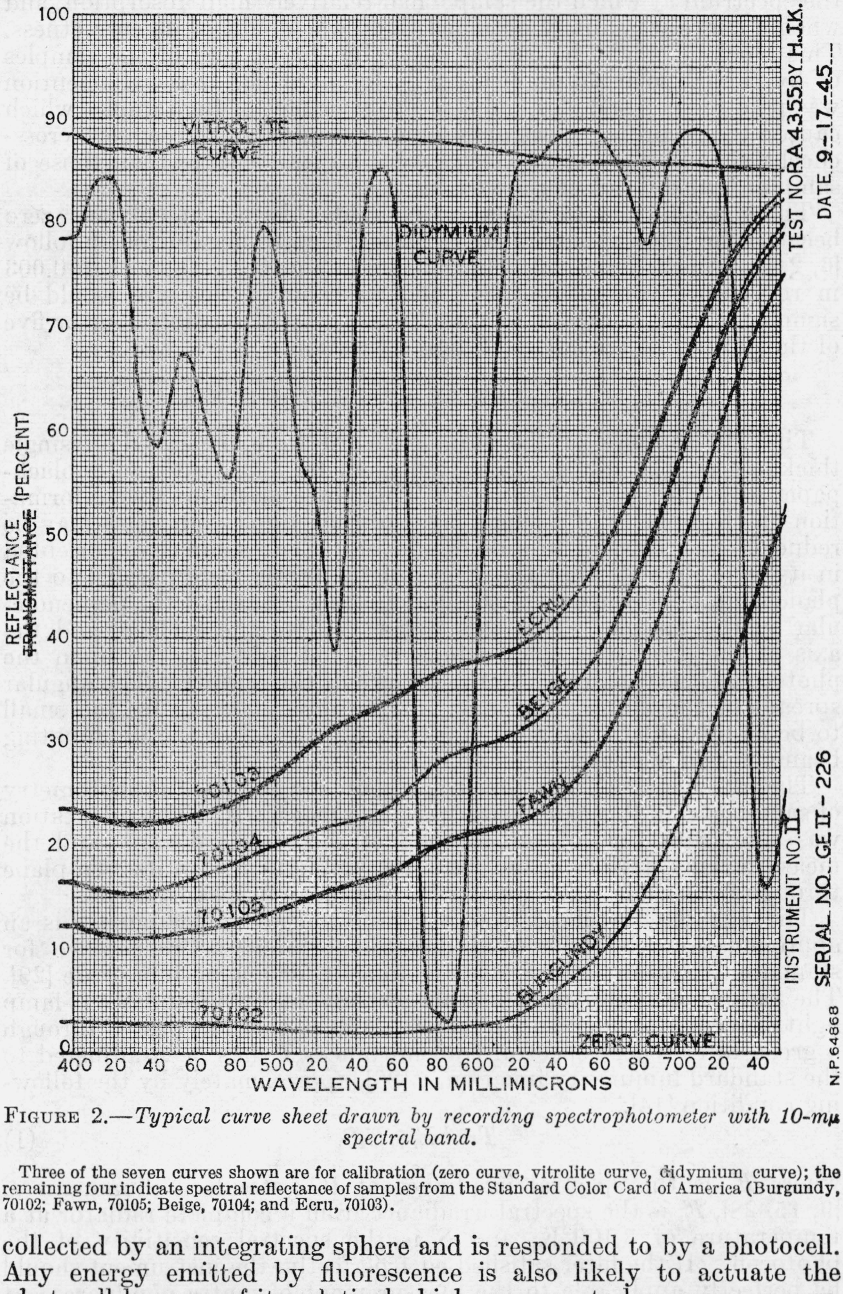

FIGURE 2.—*Typical curve sheet drawn by recording spectrophotometer with 10-mμ spectral band.*

Three of the seven curves shown are for calibration (zero curve, vitrolite curve, didymium curve); the remaining four indicate spectral reflectance of samples from the Standard Color Card of America (Burgundy, 70102; Fawn, 70105; Beige, 70104; and Ecru, 70103).

collected by an integrating sphere and is responded to by a photocell. Any energy emitted by fluorescence is also likely to actuate the photocell because of its relatively high response to long-wave energy, and as it is counted by the instrument as having the wavelength of the incident energy, an error of greater or less importance must result [5].

Some of the samples caused the instrument to block at a portion of the spectrum at which the sample had relatively high absorption, and when a curve was finally obtained there was doubt of its correctness. This blocking might be caused either by the texture of the samples or by partial polarization of the reflected light [3]. Special attention was paid to such samples and a record was kept of the samples which caused the recording spectrophotometer to block. Subsequent cross-checks showed that these curves were no less reliable than those of samples that did not cause blocking.

There is difficulty in the adjustment of this instrument near zero because the tangent-square curve is too steep for a cam rod to follow [6, 24]. Checks have failed to indicate any errors greater than 0.003 in reflectance from this cause, and an error of this size would be significant only in regard to the chromaticity of possibly four or five of the darkest of the colors of high saturation.

2. MULTIPURPOSE REFLECTOMETER

The 216 samples of the standard card were measured in single thickness on the multipurpose reflectometer [13], both with black-paper and white-paper backings. These measurements give information on the opacity of a single layer of the samples, and also may be reduced so as to refer to a double layer. Each sample was oriented in its own plane so that the ridges of the fabric were parallel to the plane containing the axis of the illuminating beam and the perpendicular to the sample. This axis was at 45° to the surface, and the axis of the directions along which reflected light can fall upon the photocell is perpendicular to the surface of the sample. The angular spreads of the illuminating and viewing directions are far too small to be equivalent to the desired 50° to 70° spread of the illuminating beams near a window.

The 22 composite specimens made up for the spectrophotometry of samples from the Army card were also measured. The orientation was similar to that of the samples of the standard card, and the measurements were repeated for each sample turned in its own plane through 90°. The value reported is the mean of these two.

The quantity obtained from the multipurpose reflectometer is an approximation to 45°-normal directional luminous reflectance for standard ICI illuminant C relative to that for magnesium oxide [29]. The sample is illuminated in this instrument by incandescent-lamp light at a color temperature of about 3,100°K that has passed through a green filter whose spectral transmittance, T, has been adjusted to the standard luminosity function, $\bar{y}$ [28], approximately by the following condition [14]:

$$T = kE_c\bar{y}/E_sS, \qquad (1)$$

where E_c is the spectral irradiance of ICI standard illuminant C [9, 15, 28], E_s is the spectral irradiance from a complete radiator at a temperature of 3,100°K, and S is the spectral sensitivity of the photocell. If the filter satisfied eq 1 perfectly, the instrument should be perfectly applicable to the measurement of matte nonfluorescent samples. Computations based upon the actual values of T were made to establish the limits of error ascribable to failure of T to comply with eq 1, and it was found that the maximum such error possible with these textile samples corresponds to about 0.3 Munsell value step.

As the actual illuminant differs from average daylight, and as the evaluation of the reflected flux by the bare photocell does not accord with that by the standard luminosity function, the multipurpose reflectometer, like the recording spectrophotometer, evaluates the fluorescent energy in a way that is generally different from its evaluation by a normal observer and must therefore be expected to produce an error of greater or less extent for all fluorescent samples.

In order to evaluate the directional luminous reflectance, R_2, of two layers backed by white paper, the data for the samples of the standard card were reduced according to the formula

$$R_2 = aR_w + bR_b, \tag{2}$$

where R_w and R_b are the measured values of directional luminous reflectance over white and black backings of reflectances 0.82 and 0.04, respectively, and a and b are weighting factors defined as

$$\left.\begin{aligned} a &\equiv (1/0.78)\,[(R_w + R_b)/2 - 0.04],\\ b &\equiv (1/0.78)\,[0.82 - (R_w + R_b)/2].\end{aligned}\right\} \tag{2a}$$

Formula 2 agrees closely with the Kubelka-Munk formulation [16, 20] for nonselective specimens, and the difference between R_w and R_b was found to be sufficiently small that no closer approximation seemed to be warranted. If it was found that R_w was less than R_b, the weights a and b were both set equal to 1/2. This condition was satisfied by a good many measurements of dark samples for which R_w and R_b must be expected to differ but little and was ascribed to unavoidable experimental error.

3. CHROMATICITY-DIFFERENCE COLORIMETER

Each of the 238 samples was compared by means of the chromaticity-difference colorimeter [17] with another TCCA sample of nearly the same color or with at least one of the Munsell standards. This comparison served as a cross-check on chromaticity errors of whatever cause, and also checked the classification of the sample as to importance of the fluorescence. This instrument has been modified since its original description [17] by installation of stray-light traps in the position of mirror reflection from the test and comparison samples into the Lummer-Brodhun cube, and by insertion of filters of Corning Daylite glass and Aklo heat-absorbing glass between the light source and the samples instead of the Daylite glass in the eyepiece. The samples are thus illuminated by artificial daylight of closely the same spectral composition as that produced by the Macbeth lamp of color temperature 6,800°K. The light is incident nearly along the perpendicular and the samples are viewed at 45° to the surface. Each sample was used in double thickness backed by white cardboard, and was oriented in its own plane so that the ridges of the fabric were parallel to the plane containing the viewing direction and the perpendicular to the sample. The angular spreads of the illuminating and viewing directions are far too small to be equivalent to the desired 50° to 70° spread of the illuminating beams near a window. Each Munsell standard was backed by a white card or a black card to correspond to the backing used in its original spectrophotometric calibration [7, 19].

By calibration of the wedges of yellowish and greenish glass, by means of which a chromaticity match is procured in the 9 by 13° double-trapezoid field of this instrument, the chromaticity difference between the two samples compared can be expressed in terms of the chromaticity coordinates, x and y, of the standard ICI system. Comparison of these differences with those obtained by means of the spectrophotometer serves to disclose most of the important errors in chromaticity coordinates. If the comparison is made with a previously measured Munsell standard [7, 19], the differences in chromaticity coordinates, x and y, may be added to the known values for the standard, and chromaticity coordinates, x and y, found for the sample. This was done for each sample classified as strongly fluorescent. It is to be noted that the illuminant used in this instrument conforms to the requirement that the spectral composition be essentially that of average natural daylight. Furthermore, the reflected light is evaluated by comparison with that from a nonfluorescent sample by means of an observer (either GBR, or both GBR and DBJ) at least approximately equivalent to the standard ICI observer. The method is therefore applicable to strongly fluorescent as well as nonfluorescent samples.

4. MACBETH-MARTENS REFLECTOMETER

Each of the 50 or more samples classified as strongly fluorescent were compared in double thickness to a Munsell standard of nearly the same color by means of a Macbeth lamp [28] and a Martens photometer [21]. The illumination centered about 45° to the sample surface and was somewhat diffused, as it came partly from the frosted bulb and partly from a white reflector by transmission through a 7-inch glass roundel ground on one side and separated from the sample by only 8 inches. The angular spread of the illumination was therefore about 48°, which seems to conform nearly to the desired angular spread of 50° to 70° taken to be representative of viewing by a window. Actually, however, visual comparisons as well as photometric measurements made under this illuminant were found to differ importantly from those made before a window illuminated by light from the sky. These comparisons agreed closely with measurements by the multipurpose reflectometer having much smaller angular spreads. This agreement was taken to indicate that the distribution of the illumination within this 48° spread, which is far from uniform, corresponds much more closely to unidirectional illumination at about 45° than to illumination diffused uniformly throughout a 48° spread. The direction of observation was about 7° from the perpendicular, the deviation from zero being introduced by the biprism of the Martens photometer, whose axis was at 0°.

Each sample was oriented in its own plane so that the ridges of the fabric were parallel to the plane containing the axis of the illuminating beam and the axis of the Martens photometer. The photometer was adjusted for equality of brightness between the two half fields and angle θ_1 was noted. Then the sample and standard were interchanged, the photometer reset for a brightness match, and angle θ_2 noted. The directional luminous reflectance, R_2, of the sample in double thickness was computed from the formula

$$R_2 \equiv R_s \tan(\theta_1) \cot(\theta_2), \qquad (3)$$

where R_s is the published luminous reflectance [7, 19] for the Munsell standard evaluated from spectrophotometric measurement for perpendicular illumination. There is a correction to be applied to R_2 found by this formula if the light reflected from the sample is not in the same state of polarization as that from the standard [23]. Measurement of the polarization of these beams for a few pairs that were compared indicated that the correction in no case would exceed 0.001, and accordingly no corrections were applied.

It will be noted that in this comparison the fluorescent sample is illuminated by a suitably close representative of natural daylight; and as with the chromaticity-difference colorimeter the reflected light is evaluated by comparison with that from a nonfluorescent standard by means of an observer at least approximately equivalent to the standard ICI observer. The method is therefore applicable to strongly fluorescent as well as to nonfluorescent samples.

5. MUNSELL BOOK NOTATIONS

Each of the 238 mounted samples was compared with the color scales of the Munsell Book of Color (complete 40-hue-chart edition, 1929 and 1942 [25]) by one observer (GBR) and Munsell book notation found in the usual way by visual interpolation and extrapolation along these scales. Some of these notations were checked by similar comparisons by one (GBR) or two (GBR, DBJ) observers with the unmounted samples used in the measurements. The samples and scales were placed in closely the same plane and illuminated at approximately 45° by light from the north sky passing through a window of such size as to yield an angular spread of directions of illumination between 50° and 70°. The samples were oriented so that the ridges of the fabric were parallel to the plane containing the central direction of illumination and the perpendicular to the sample. The direction of view was nearly perpendicular to the surfaces of the samples.

The Munsell book notation so found for each sample was converted into chromaticity coordinates, x and y, by interpolation and extrapolation on large-scale (x,y)-charts prepared for that purpose by Marion A. Belknap. These charts are similar to figures 2 to 8 of Research Paper RP1549 [19] and include points corresponding to the measurements of the third intermediate hues [7], and they include also broken lines for each chroma and each hue step to facilitate linear interpolation between the plotted points.

From the Munsell book notations there were also found estimates of daylight reflectance, Y. These estimates were found by converting book-notation value first into renotation value by adding to the book-notation value of the textile sample the average difference between the renotation and book-notation values of the neighboring Munsell samples. In taking this average the various differences were given weights either of zero or of one, in accord with the principle of counting one or both of two neighboring standards, depending on whether the unknown is very close to one or about equally distant from both. This accords with the technic of making the visual interpolations—if the hue of the unknown is very close to that of one of the constant-hue charts of the Munsell book, no attention is paid to other hue charts, but if the hue of the unknown is about midway between that of two charts, both are used. Similar considerations apply to Munsell value and chroma. Thus, the largest number of Munsell samples that could be given a weight different from zero in taking the average is eight; the smallest number is one. The division of the Munsell hue, value, and chroma scales according to whether the weight is to be zero or one is indicated by table 1, which gives an example of the division near 5R 4/2. The rule followed is to weight the samples equally throughout the central third of the interval between them, and outside of this central interval, to weight only the nearest sample.

TABLE 1.—*Division of the hue, value, and chroma scales according to whether one or both of the samples defining an interval is to be used in deriving renotation value from book-notation value (example near 5R 4/2)*

Hue scale	Weight of—		Value scale	Weight of—		Chroma scale	Weight of—	
	5.0R	7.5R		4.0	5.0		2.0	4.0
5.0R	1	0	4.00	1	0	2.0	1	0
.1	1	0	4.05	1	0	2.1	1	0
.2	1	0	4.10	1	0	2.2	1	0
.3	1	0	4.15	1	0	2.3	1	0
.4	1	0	4.20	1	0	2.4	1	0
5.5	1	0	4.25	1	0	2.5	1	0
.6	1	0	4.30	1	0	2.6	1	0
.7	1	0	4.35	1	0	2.7	1	1
.8	1	0	4.40	1	1	2.8	1	1
.9	1	1	4.45	1	1	2.9	1	1
6.0	1	1	4.50	1	1	3.0	1	1
.1	1	1	4.55	1	1	3.1	1	1
.2	1	1	4.60	1	1	3.2	1	1
.3	1	1	4.65	1	1	3.3	1	1
.4	1	1	4.70	0	1	3.4	0	1
6.5	1	1	4.75	0	1	3.5	0	1
.6	1	1	4.80	0	1	3.6	0	1
.7	0	1	4.85	0	1	3.7	0	1
.8	0	1	4.90	0	1	3.8	0	1
.9	0	1	4.95	0	1	3.9	0	1
7.0	0	1	5.00	0	1	4.0	0	1
.1	0	1						
.2	0	1						
.3	0	1						
.4	0	1						
7.5R	0	1						

The differences between renotation value and book-notation value were found from table III of the Final Report of the OSA Subcommittee on the Spacing of the Munsell Colors [26]. These differences were weighted as in table 1 and averaged. The average difference was applied to the book-notation value to find the renotation value. Renotation values were converted into daylight reflectance, Y, by means of table II of the same report.

IV. RESULTS

Table 2, A, gives daylight reflectance relative to freshly prepared magnesium oxide, Y, and chromaticity coordinates, x and y, obtained for the samples of the standard card by all the various methods just described. The samples have been divided into three groups, (1) nonfluorescent, (2) weakly fluorescent, and (3) strongly fluorescent. Samples for which no fluorescence could be detected by visual examination were classed as nonfluorescent. Samples yielding fluorescence that is visually striking were classed as strongly fluorescent. In addition, three samples tentatively classed as weakly fluorescent (70074, 70103, 70207) were included in the strongly fluorescent group because of studies which showed that the spectrophotometric analysis failed to agree with the estimated Munsell book notation by appreciable amounts that could not be ascribed to any other source of discrepancy. The remaining samples were classed as weakly fluorescent. The instrumental results of table 2, A, form the basis on which final values have been adopted; those derived from the estimations of Munsell book notation serve as a guide to the analysis and interpretation of the instrumental data, but have not been given any weight in computing the final averages. Table 2, B, gives similar results for the samples of the Army card.

TABLE 2.—*Summary of measurements of daylight reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y*

A. STANDARD COLOR CARD OF AMERICA

TCCA cable number	Daylight reflectance, Y						Chromaticity coordinates, x and y					
	Multipurpose			Spectrophotometer	Macbeth Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
	White backing	Black backing	From eq 2				*x*	*y*	*x*	*y*	*x*	*y*
NONFLUORESCENT SAMPLES												
70023	0.089	0.089	0.089	0.110	0.096	0.096	0.199	0.257	------	------	0.197	0.252
70024	.045	.042	.042	.052	------	.057	.201	.264	0.193	0.258	.18	.26
70033	.222	.215	.217	.228	------	.22	.305	.370	------	------	.312	.374
70034	.160	.159	.159	.173	------	.16	.315	.355	------	------	.312	.352
70035	.080	.079	.079	.096	------	.096	.307	.365	.305	.362	.310	.372
70036	.037	.037	.037	.044	------	.050	.302	.377	------	------	.309	.379
70044	.147	.145	.146	.160	------	.148	.249	.254	------	------	.253	.259
70045	.106	.105	.105	.127	------	.134	.239	.250	------	------	.243	.253
70046	.065	.068	.068	.078	------	.082	.231	.235	------	------	.238	.240
70047	.052	.051	.051	.065	------	.061	.214	.215	------	------	.21	.22
70048	.036	.036	.036	.047	------	.046	.227	.221	------	------	.223	.221
70060	.021	.021	.021	.024	------	.026	.238	.147	.231	.158	.25	.18
70061	.337	.323	.328	.358	------	.34	.353	.459	------	------	.349	.461
70062	.272	.267	.268	.301	------	.30	.324	.458	------	------	.322	.467
70065	.064	.064	.064	.074	------	.080	.264	.397	------	------	.264	.404
70066	.035	.036	.036	.040	------	.050	.273	.371	.283	.364	.294	.361
70068	.561	.463	.523	.537	.505	.51	.480	.447	.489	.453	.474	.447
70069	.396	.351	.370	.380	------	.36	.516	.419	------	------	.512	.418
70070	.372	.325	.344	.358	.327	.34	.519	.406	------	------	.515	.411
70071	.274	.250	.257	.262	------	.25	.555	.386	------	------	.556	.388
70075	.032	.033	.032	.038	------	.037	.218	.174	.229	.181	.227	.184
70076	.020	.025	.022	.029	------	.034	.230	.194	.239	.204	242	.206
70077	.018	.018	.018	.021	------	.022	.245	.221	.262	236	.263	.238
70078	.018	.017	.017	.020	------	.020	.256	.238	.272	248	.269	.247
70085	.070	.068	.068	.083	------	.077	.213	.187	.204	.179	218	.191
70086	.055	.055	.055	.061	------	.061	.201	.163	.199	.156	.206	.174
70087	.031	.031	.031	.040	------	.046	.189	.148	.190	.141	.198	.153
70088	.033	.033	.033	.036	------	.043	.232	.216	.232	.221	.241	.227
70089	.016	.022	.019	.026	------	.031	.240	.230	------	------	.245	.236
70090	.016	.016	.016	.018	------	.018	.263	.255	------	------	.273	.269
70092	.239	.229	.231	.237	.224	.21	.393	.366	------	------	.389	.365
70093	.175	.169	.170	.176	------	.16	.392	.362	------	------	.395	.366
70094	.113	.112	.113	.125	------	.114	.411	366	------	------	.419	.366
70095	.047	.048	.048	.048	.042	.057	.418	.358	------	------	.412	.361
70096	.039	.038	.038	.045	------	.037	.347	.331	------	------	.345	.331

TABLE 2.—*Summary of measurements of daylight reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y*—Continued

A. STANDARD COLOR CARD OF AMERICA—Continued

TCCA cable number	Daylight reflectance, *Y*						Chromaticity coordinates, *x* and *y*					
	Multipurpose			Spectrophotometer	Macbeth Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
	White backing	Black backing	From eq 2				*x*	*y*	*x*	*y*	*x*	*y*
NONFLUORESCENT SAMPLES—continued												
70102	0.026	0.025	0.025	0.028	------	0.028	0.354	0.289	------	------	0.365	0.290
70105	.169	.165	.166	.180	------	.18	.370	.356	------	------	.375	.363
70106	.116	.115	.115	129	------	.127	.366	.351	------	------	.376	.355
70107	.050	.052	.052	.053	------	.063	.396	.363	------	------	.395	.362
70108	.037	.036	.036	.039	------	.046	.357	.342	------	------	.372	.353
70111	.081	.080	.080	.092	------	.093	.279	.286	------	------	.284	.289
70112	.066	.066	.066	.071	------	.066	.271	.276	------	------	.282	.286
70113	.061	.059	.059	.070	------	.070	.275	.271	------	------	.283	.281
70114	.020	.027	.024	.030	------	.034	.267	.261	------	------	.286	.278
70117	.204	.196	.198	.211	------	.21	.430	380	------	------	.413	.369
70119	.064	.062	.063	.069	------	.075	.441	.368	------	------	.428	.364
70120	.041	.040	.040	.044	------	.050	.431	.354	------	------	.423	.362
70125	.183	.180	.180	.189	------	.18	.416	.331	0.429	0.332	.406	.330
70129	.173	.172	.172	.182	------	.19	.414	.387	------	------	.418	.392
70130	.169	.167	.167	.186	------	.18	.310	.352	------	------	.304	.353
70131	.126	.123	.123	.143	------	.127	.284	.346	------	------	.290	.347
70132	.034	.034	.034	.040	------	.043	.267	.337	------	------	.278	.336
70134	.094	.094	.094	.105	------	.104	.306	.226	------	------	.306	.229
70136	.412	.386	.398	.400	------	.43	.336	.341	------	------	.330	.336
70137	.070	.071	.071	.081	------	.075	.342	.340	------	------	.340	.336
70138	.055	.051	.051	.058	------	.061	.340	.336	------	------	.331	.328
70140	.126	.125	.125	.136	------	.127	.401	.355	------	------	.402	.355
70141	.046	.046	.046	.050	------	.057	.416	.355	------	------	.407	.355
70143	.116	.117	.116	.130	------	.141	.230	.246	------	------	.241	.255
70144	.076	.075	.075	.090	------	.085	.239	.245	------	------	.236	.244
70145	.252	.245	.247	.261	------	.27	.270	.315	------	------	.276	.316
70146	.126	.123	.123	.152	------	.134	.260	.303	------	------	.264	.306
70147	.058	.056	.056	.068	------	.061	.234	.272	.221	.266	.237	.278
70153	.163	.159	.160	.172	------	.17	.309	.307	------	------	.307	.307
70154	.288	.273	.278	.283	------	.27	.380	.450	------	------	.383	.460
70155	.184	.179	.180	.204	------	.20	.375	.441	------	------	.371	.445
70156	.074	.072	.072	.080	------	.085	.358	.421	.364	.424	.352	.409
70157	.304	.300	.301	.315	------	.32	.433	.428	------	------	.426	.422
70158	.263	.256	.258	.265	------	.28	.445	.427	------	------	.434	.428
70159	.077	.074	.074	.091	------	.085	.414	.402	------	------	.44	.43
70163	.101	.100	.100	.110	------	.114	.343	.256	.346	.252	.337	.262
70164	.024	.024	.024	.026	------	.031	.311	.237	------	------	.313	.249
70165	.024	.023	.023	.026	------	.026	.305	.268	.313	.281	.309	.287
70167	.144	.143	.143	.159	------	.16	.242	.450	.246	.462	.247	.420
70168	.069	.071	.071	.082	------	.090	.224	.460	------	------	.239	.459
70170	.184	.188	.187	.196	------	.20	.325	.317	------	------	.320	.315
70171	.055	.054	.054	.058	------	.061	.321	.316	------	------	.312	.310
70176	.081	.082	.082	.097	------	.090	.225	.254	------	------	.223	.256
70177	.075	.076	.076	.091	------	.087	.220	.235	------	------	.222	.242
70186	.081	.080	.080	.094	0.080	.096	.318	.319	------	------	.321	.324
70188	.263	.263	.263	.279	------	.28	.366	.365	------	------	.367	.368
70190	.038	.037	.037	.042	------	.044	.362	.260	.368	.265	.366	.272
70192	.092	.092	.092	.102	------	.096	.419	.353	.425	.353	.419	.348
70198	.200	.194	.195	.208	------	.20	.378	.267	------	------	.382	.271
WEAKLY FLUORESCENT SAMPLES												
70001	0.764	0.596	0.743	0.778	------	0.77	0.320	0.327	------	------	0.316	0.324
70002	.776	.610	.755	.795	------	.77	.329	.335	------	------	.322	.330
70003	.754	.599	.740	.772	------	.74	.334	.344	------	------	.328	.336
70004	.650	.550	.622	.663	------	.63	.348	.354	------	------	.343	.349
70005	.636	.549	.611	.634	------	.63	.371	.376	------	------	.370	.376

TABLE 2.—*Summary of measurements of daylight reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y*—Continued

A. STANDARD COLOR CARD OF AMERICA—Continued

TCCA cable number	Daylight reflectance, *Y*						Chromaticity coordinates, *x* and *y*					
	Multipurpose			Spectrophotometer	Macbeth Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
	White backing	Black backing	From eq 2				*x*	*y*	*x*	*y*	*x*	*y*
WEAKLY FLUORESCENT SAMPLES—continued												
70006	0.645	0.534	0.612	0.622	-------	0.63	0.409	0.403	-------	-------	0.403	0.403
70007	.650	.545	.620	.653	0.627	.63	.305	.317	-------	-------	.301	.313
70008	.543	.471	.514	.550	-------	.51	.285	.300	-------	-------	.286	.297
70009	.556	.470	.522	.557	-------	.51	.281	.298	-------	-------	.275	.294
70010	.381	.356	.367	.405	-------	.40	.275	.292	0.270	0.292	.267	.279
70011	.408	.375	.390	.450	-------	.40	.267	.280	.255	.277	.267	.280
70012	.367	.338	.350	.388	-------	.38	.243	.265	.237	.265	.240	.262
70013	.693	.571	.664	.683	.640	.65	.340	.327	-------	-------	.341	.328
70014	.671	.549	.638	.644	-------	.65	.348	.319	-------	-------	.346	.318
70015	.603	.507	.570	.584	-------	.59	.359	.316	-------	-------	.361	.321
70016	.584	.495	.552	.562	.530	.53	.362	.313	-------	-------	.361	.314
70017	.500	.417	.462	.466	.436	.43	.385	.309	.385	.306	.389	.309
70018	.334	.307	.317	.321	-------	.31	.398	.310	.404	.310	.390	.310
70019	.564	.495	.538	.560	-------	.54	.299	.323	-------	-------	.294	.323
70020	.484	.436	.462	.485	-------	.49	.271	.316	-------	-------	.274	.323
70021	.343	.322	.330	.371	-------	.34	.246	.298	.231	.288	.24	.29
70022	.225	.217	.219	.240	-------	.22	.202	.262	.210	.256	.216	.269
70031	.525	.461	.498	.523	-------	.53	.340	.377	.338	.381	.335	.376
70032	.365	.357	.360	.411	-------	.40	.311	.371	-------	-------	.311	.380
70041	.169	.150	.152	.164	-------	.16	.592	.344	.592	.338	.597	.338
70042	.134	.120	.122	.133	-------	.134	.587	.327	-------	-------	.581	.323
70043	.326	.311	.316	.337	-------	.34	.262	.274	-------	-------	.264	.270
70054	.040	.039	.039	.042	-------	.046	.428	.246	.441	.246	.41	.25
70063	.148	.154	.153	.174	-------	.16	.287	.472	.284	.500	.283	.482
70064	.060	.060	.060	.072	-------	.080	.290	.434	-------	-------	.292	.435
70067	.687	.542	.649	.673	-------	.66	.414	.424	-------	-------	411	.417
70073	.157	.155	.156	.182	-------	.18	.259	.232	.245	.218	.259	.234
70080	.163	.146	.148	.149	.136	.148	.567	.307	-------	-------	.556	.309
70091	.530	.476	.508	.519	-------	.51	.366	.358	-------	-------	.369	.361
70097	.407	.368	.385	.382	.368	.36	.377	.298	.382	.297	.377	.303
70104	.247	.239	.241	.253	.228	.23	.368	.355	-------	-------	.364	.353
70109	.342	.331	.335	.340	-------	.34	.293	.304	-------	-------	.295	.303
70110	.185	.182	.182	.193	-------	.20	.286	.293	-------	-------	.289	.297
70115	.377	.345	.358	.374	.362	.35	.414	.389	-------	-------	.407	.383
70116	.328	.310	.316	.321	.284	.29	.438	.394	-------	-------	.428	.387
70121	.413	.383	.397	.414	-------	.42	.283	.288	-------	-------	.285	.291
70122	.266	.262	.263	.280	-------	.26	.264	.264	-------	-------	.269	.269
70123	.127	.125	.126	.150	-------	.134	.253	.247	.238	.234	.247	.244
70124	.315	.296	.302	.310	-------	.30	.390	.332	.395	.331	.385	.332
70127	.615	.532	.589	.595	.586	.56	.377	.365	-------	-------	.366	.358
70128	.345	.333	.337	.340	.311	.32	.389	.374	-------	-------	.387	.372
70135	.026	.035	.031	.040	-------	.037	.298	.222	-------	-------	.302	.221
70139	.350	.329	.337	.358	.334	.35	.352	.347	-------	-------	.346	.343
70142	.227	.226	.226	.251	-------	.24	.247	.275	-------	-------	.259	.284
70148	.573	.493	.544	553	-------	.52	.395	.358	-------	-------	.400	.359
70151	.306	.297	.300	.310	-------	.30	.322	.325	-------	-------	.318	.323
70152	.283	.273	.276	.294	-------	.30	.314	.316	-------	-------	.311	.312
70166	.261	.255	.257	.287	-------	.26	.320	.401	-------	-------	.311	.405
70169	.300	.292	.295	.299	-------	.30	.332	.330	-------	-------	.325	.324
70175	.199	.194	.195	.212	-------	.22	.250	.269	-------	-------	.258	.276
70181	.511	.455	.487	.486	-------	.47	.362	.323	-------	-------	.358	.323
70182	.284	.271	.275	.286	.269	.30	.383	.310	-------	-------	.375	.312
70183	.431	.401	.415	.433	-------	.42	.378	.397	-------	-------	.378	.403
70185	.391	.370	.379	.394	-------	.39	.325	.325	-------	-------	.317	.318
70187	.405	.376	.389	.403	-------	.40	.369	.369	-------	-------	.365	.366
70189	.211	.202	.204	.207	-------	.21	.356	.288	.364	.287	.363	.290
70191	.309	.296	.300	.308	-------	.31	.383	.354	-------	-------	.393	.362
70193	.390	.368	.378	.384	-------	.39	.324	.330	-------	-------	.324	.331
70194	.399	.368	.382	.392	-------	.40	.372	.339	.368	.338	.366	.339
70195	.249	.240	.242	.291	-------	.27	.285	.292	-------	-------	.280	.290

684201—46——2

TABLE 2.—*Summary of measurements of daylight reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y*—Continued

A. STANDARD COLOR CARD OF AMERICA—Continued

TCCA cable number	Daylight reflectance, *Y*						Chromaticity coordinates, *x* and *y*					
	Multipurpose			Spectrophotometer	Macbeth Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
	White backing	Black backing	From eq 2				*x*	*y*	*x*	*y*	*x*	*y*
WEAKLY FLUORESCENT SAMPLES—continued												
70196	0.394	0.366	0.378	0.390	0.358	0.38	0.398	0.394	0.403	0.399	0.397	0.397
70197	.506	.454	.484	.514	--------	.52	.313	.379	--------	--------	.313	.379
70199	.470	.416	.444	.456	--------	.43	.339	.342	--------	--------	.332	.338
70200	.386	.357	.369	.409	--------	.40	.310	.342	.302	.342	.298	.345
70201	.307	.369	.341	.400	--------	.39	.362	.350	--------	--------	.359	.347
70203	.584	.510	.558	.556	--------	.57	.412	.416	--------	--------	.422	.424
70204	.214	.212	.212	256	--------	.24	.273	.301	--------	--------	.266	.303
70208	.513	.443	.482	.497	--------	.48	.419	.469	.419	.478	.423	.483
70209	.088	.084	.085	.108	.099	.107	.176	.170	.169	.160	.18	.18
70211	.102	.102	.102	.126	--------	.104	.217	.226	--------	--------	.217	.225
70215	.349	.326	.335	.354	--------	.34	.460	.460	.460	.470	.448	.461
70216	.033	.045	.039	.056	--------	.050	.201	.145	.193	.132	.195	.140
STRONGLY FLUORESCENT SAMPLES												
70025	0.609	0.507	0.575	0.624	0.543	0.56	0.369	0.354	0.400	0.331	0.389	0.330
70026	.557	.473	.524	.559	.513	.51	.399	.357	.416	.343	.411	.349
70027	.571	.476	.535	.598	.512	.51	.384	.368	.435	.330	.411	.341
70028	.517	.433	.480	.540	.374	.40	.405	.371	.462	.327	.434	.344
70029	.305	.276	.285	.310	.241	.26	.446	.371	.494	.331	.483	.347
70030	.214	.193	.197	.209	.171	.18	.532	.339	.556	.336	.529	.333
70037	.464	.406	.435	.453	.399	.43	.406	.375	.415	.375	.406	.368
70038	.485	.412	.450	.480	.424	.43	.440	.376	.446	.372	.432	.369
70039	.388	.342	.361	.388	.325	.31	.460	.373	.486	.354	.479	.358
70040	.200	.187	.189	.196	.161	.19	.549	.354	.549	.338	.54	.34
70049	.143	.132	.133	.141	.116	.134	.460	.263	.474	.259	.472	.263
70050	.098	.093	.093	.109	.076	.080	.496	.278	.501	.270	.47	.26
70051	.079	.077	.077	.088	.072	.075	.469	.260	.456	.260	.447	.260
70052	.060	.056	.056	.067	.048	.061	.461	.269	.486	.256	.45	.26
70053	.062	.060	.060	.069	.054	.061	.452	.262	.476	.254	.442	.256
70055	.332	.314	.320	.367	.289	.32	.308	.289	.300	.270	.304	.276
70056	.196	.187	.189	.210	.176	.20	.308	.253	.303	.245	.311	.253
70057	.173	.163	.165	.209	.161	.16	.297	.235	.286	.212	.292	.216
70058	.136	.135	.135	.167	.120	.134	.267	.208	.257	.179	.268	.197
70059	.038	.037	.037	.054	.033	.046	.245	.145	.227	.131	.248	.156
70072	.239	.209	.216	.224	.192	.21	.568	.369	.574	.361	.595	.380
70074	.102	.100	.100	.135	.099	.120	.247	.204	.217	.169	.243	.202
70079	.237	.205	.212	.239	.190	.21	.481	.323	.518	.296	.466	.304
70081	.091	.084	.084	.087	.075	.090	.552	.298	.552	.298	.510	.298
70082	.055	.054	.054	.055	.045	.057	.513	.284	.507	.286	.459	.287
70083	.037	.036	.036	.039	.030	.043	.460	.293	.447	.288	.435	.290
70084	.035	.034	.034	.036	.031	.046	.405	.290	.399	.289	.401	.294
70098	.265	.243	.249	.253	.231	.23	.417	.293	.426	.290	.420	.296
70099	.165	.159	.160	.190	.137	.141	.424	.293	.424	.281	.416	.285
70100	.085	.085	.085	.100	.079	.075	.429	.280	.436	.269	.424	.271
70101	.031	.029	.029	.041	.025	.035	.420	.298	.389	.280	.387	.283
70103	.358	.342	.348	.343	.332	.33	.374	.347	.354	.355	.357	.357
70118	.144	.142	.142	.147	.145	.16	.461	.383	.467	.379	.460	.384
70126	.048	.046	.046	.058	.046	.057	.455	.336	.441	.327	.421	.328
70133	.439	.410	.424	.483	.406	.40	.310	.289	.311	.274	.314	.270
70149	.326	.290	.302	.317	.282	.29	.482	.358	.500	.346	.487	.350
70150	.134	.127	.128	.133	.112	.130	.514	.335	.528	.336	.495	.330
70160	.199	.187	.189	.191	.173	.18	.506	.374	.519	.377	.499	.369
70161	.087	.086	.086	.088	.077	.090	.515	.357	.517	.355	.491	.350
70162	.083	.081	.081	.097	.069	.085	.473	.361	.474	.346	.467	.346

TABLE 2.—*Summary of measurements of daylight reflectance relative to magnesium oxide, Y, and chromaticity coordinates, x and y*—Continued

A. STANDARD COLOR CARD OF AMERICA—Continued

TCCA cable number	Daylight reflectance, *Y*						Chromaticity coordinates, *x* and *y*					
	Multipurpose			Spectrophotometer	Macbeth Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
	White backing	Black backing	From eq 2				*x*	*y*	*x*	*y*	*x*	*y*
STRONGLY FLUORESCENT SAMPLES—continued												
70172	0.091	0.089	0.089	0.105	0.086	0.090	0.338	0.193	0.324	0.179	0.328	0.187
70173	.053	.050	.050	.061	.046	.053	.315	.174	.294	.158	.31	.17
70174	.048	.046	.046	.055	.042	.050	.316	.191	.305	.182	.309	.197
70178	.323	.288	.300	.320	.290	.31	.463	.345	.484	.317	.457	.329
70179	.152	.138	.140	.138	.131	.134	.569	.308	.568	.309	.556	.313
70180	.084	.079	.080	.080	.070	.085	.600	.305	.590	.307	.550	.310
70184	.096	.096	.096	.118	.086	.107	.405	.388	.398	.390	.387	.387
70202	.381	.356	.367	.381	.329	.32	.329	.279	.324	.270	.336	.267
70205	.581	.508	.556	.578	.592	.63	.409	.404	.427	.446	.428	.452
70206	.469	.392	.431	.458	.439	.43	.414	.339	.428	.314	.42	.32
70207	.205	.201	.202	.236	.221	.22	.238	.294	.218	.297	.222	.296
70210	.150	.134	.136	.147	.114	.130	.516	.289	.549	.284	.492	.284
70212	.117	.117	.117	.147	.120	.130	.270	.205	.251	.181	.263	.199
70213	.136	.121	.123	.143	.118	.134	.367	.200	.408	.190	.392	.216
70214	.252	.239	.242	.304	.291	.29	.269	.408	.254	.424	.253	.405

B. UNITED STATES ARMY COLOR CARD

TCCA cable number	Daylight reflectance, *Y*				Chromaticity coordinates, *x* and *y*					
	Multipurpose	Spectrophotometer	Macbeth-Martens	Visual estimate via Munsell scales	Spectrophotometer		Subtractive colorimeter		Visual estimate via Munsell scales	
					x	*y*	*x*	*y*	*x*	*y*
NONFLUORESCENT SAMPLES										
65001	0.436	0.462	--------	0.43	0.475	0.459	0.479	0.461	0.458	0.453
65005	.641	.713	--------	.66	.328	.335	.330	.336	.327	.335
65007	.077	.078	--------	.085	.295	.408	.293	.412	.294	.402
65008	.285	.333	--------	.30	.319	.325	.319	.324	.318	.325
65009	.055	.062	--------	.059	.252	.169	.236	.151	.26	.18
65010	.048	.054	--------	.050	.181	.132	.170	.109	.184	.141
65011	.044	.047	--------	.040	.227	.201	.225	.195	.230	.207
65012	.029	.025	--------	.026	.300	.299	.301	.305	.306	.308
65014	.222	.246	--------	.22	.268	.288	.260	.285	.273	.290
65015	.440	.496	--------	.45	.394	.379	.404	.386	.395	.382
65018	.029	.025	--------	.026	.302	.304	.307	.314	.309	.312
65019	.044	.039	--------	.040	.230	.221	.235	.225	.224	.217
65020	.066	.061	--------	.080	.529	.326	.516	.328	.502	.329
65021	.372	.414	--------	.39	.426	.428	.427	.431	.429	.428
65022	.194	.212	--------	.21	.364	.448	.363	.445	.363	.454
WEAKLY FLUORESCENT SAMPLES										
65002	0.406	0.422	--------	0.39	0.507	0.438	0.521	0.442	0.491	0.428
65006	.109	.096	--------	.101	.556	.318	.564	.322	.54	.32
65016	.074	.070	--------	.080	.424	.366	.422	.367	.420	.364
65017	.044	.043	--------	.043	.386	.307	.385	.306	.398	.309
STRONGLY FLUORESCENT SAMPLES										
65003	0.342	0.350	0.316	0.31	0.502	0.413	0.518	0.402	0.505	0.401
65004	.250	.258	.212	.20	.541	.377	.572	.363	.55	.36
65013	.104	.098	.083	.085	.483	.275	.503	.272	.465	.276

Table 3 shows the degree of agreement of the spectrophotometric determinations of chromaticity differences (Δx, Δy) between samples of the standard card having neighboring chromaticities with the determination of the same differences by means of the subtractive, or chromaticity-difference, colorimeter. These cross-checks were carried out wherever possible to evaluate the importance of the known sources of error and to detect any unsuspected sources which might have affected the results. Every sample that was not cross-checked in this way was compared to some other known color standard, chiefly with one of the Munsell standards; see tables 2, A, and 2, B.

TABLE 3.—*Agreement of the spectrophotometric determinations of chromaticity differences (Δx, Δy) between neighboring samples of the Standard Card with the determination of the same differences by the subtractive colorimeter*

Nonfluorescent pairs			Pairs involving only weakly and nonfluorescent samples			Pairs involving strongly fluorescent samples		
TCCA cable numbers	Discrepancy in—		TCCA cable numbers	Discrepancy in—		TCCA cable numbers	Discrepancy in—	
	Δx	Δy		Δx	Δy		Δx	Δy
70023, 70024	0.005	0.004	70001, 70002	0.001	0.001	70025, 70026	0.014	0.010
70034, 70130	.009	.004	70002, 70003	.002	.002	70027, 70028	.005	.007
70034, 70035	.000	.000	70003, 70004	.001	.001	70029, 70149	.030	.003
70036, 70066	.003	.003	70004, 70005	.004	.003	70030, 70150	.048	.004
70044, 70143	.002	.001	70006, 70203	.001	.000	70037, 70038	.003	.003
70046, 70144	.001	.001	70007, 70008	.005	.005	70039, 70149	.008	.006
70047, 70048	.007	.003	70008, 70009	.000	.000	70049, 70050	.011	.004
70062, 70061	.009	.003	70010, 70011	.007	.003	70051, 70050	.015	.009
70069, 70070	.001	.002	70011, 70012	.006	.004	70052, 70053	.002	.005
70071, 70070	.006	.001	70013, 70014	.001	.001	70054, 70053	.011	.008
70075, 70076	.004	.004	70015, 70016	.000	.001	70056, 70057	.012	.021
70077, 70078	.002	.006	70017, 70097	.006	.002	70058, 70057	.006	.000
70085, 70086	.004	.003	70018, 70017	.007	.002	70072, 70040	.006	.008
70087, 70086	.002	.000	70019, 70020	.004	.003	70081, 70180	.012	.002
70088, 70089	.004	.006	70032, 70197	.003	.002	70082, 70083	.007	.006
70090, 70114	.002	.005	70033, 70032	.001	.000	70084, 70083	.007	.004
70093, 70092	.002	.001	70064, 70065	.009	.001	70099, 70098	.009	.010
70094, 70140	.002	.002	70067, 70203	.003	.000	70101, 70190	.027	.023
70095, 70119	.003	.001	70080, 70042	.003	.005	70102, 70101	.033	.018
70095, 70141	.001	.001	70104, 70105	.001	.001	70118, 70117	.004	.001
70096, 70108	.003	.006	70109, 70195	.011	.004	70133, 70055	.010	.004
70106, 70105	.003	.002	70110, 70195	.008	.003	70134, 70057	.011	.023
70107, 70095	.001	.003	70115, 70128	.002	.002	70148, 70038	.002	.003
70108, 70107	.001	.000	70116, 70115	.010	.002	70161, 70162	.002	.013
70111, 70112	.002	.001	70121, 70122	.002	.002	70172, 70173	.006	.001
70113, 70112	.005	.004	70122, 70043	.004	.000	70173, 70174	.010	.006
70120, 70095	.004	.003	70127, 70091	.001	.000	70178, 70206	.007	.004
70129, 70117	.002	.001	70135, 70164	.000	.006	70179, 70080	.001	.001
70131, 70130	.000	.001	70142, 70175	.002	.002	70184, 70159	.007	.002
70132, 70066	.000	.001	70145, 70020	.005	.004	70188, 70103	.020	.008
70137, 70138	.000	.002	70146, 70204	.003	.003	70198, 70098	.000	.001
70143, 70045	.008	.005	70152, 70151	.001	.001	70202, 70133	.007	.007
70155, 70154	.008	.002	70153, 70152	.005	.001	70212, 70058	.011	.001
70158, 70157	.002	.002	70169, 70185	.001	.001			
70168, 70167	.003	.009	70170, 70152	.002	.002			
70171, 70186	.002	.002	70181, 70015	.000	.000			
70176, 70177	.000	.002	70182, 70097	.004	.003			
			70183, 70031	.012	.004			
			70187, 70005	.004	.001			
			70191, 70092	.001	.001			
			70193, 70136	.002	.001			
			70199, 70136	.000	.001			
			70201, 70045	.005	.003			
			70201, 70139	.004	.002			
Averages	0.003	0.003	Averages	0.004	0.002	Averages	0.011	0.007

Every sample of the official copy of the standard card was compared visually with the corresponding unmounted sample, and for 134 of the 216 colors noticeable differences could be discerned. Eight of these differences were considered large enough to warrant evaluation and Munsell book notations of the corresponding unmounted samples were found by one observer (GBR) for comparison with those already found for the mounted samples. This comparison is given in table 4. As these samples are cut from the same piece of fabric and from the same dyeing, these differences must be due to a fugitive character of the dyestuff itself. Elsewhere in this paper the results refer to the unmounted samples supplied especially for this study.

TABLE 4.—*Munsell book notations for 8 colors for which the differences between the mounted and unmounted samples were considered large enough to warrant evaluation*

TCCA cable number	Munsell book notation	
	Mounted	Unmounted
70008	2.0PB 7.5/2.5	1.5PB 7.5/2.5
70021	2.0B 6.2/5.5	2.0B 6.3/6.0
70055	7.0P 6.1/2.8	6.5P 6.1/3.5
70073	9.5PB 4.6/5.5	9.0PB 4.6/6.0
70074	8.5PB 4.0/7.0	9.5PB 3.9/8.0
70187	2.5Y 6.8/3.2	2.0Y 6.9/3.2
70200	2.5G 6.6/2.0	2.5G 6.7/2.2
70204	10.0BG 5.2/2.4	1.0B 5.3/2.8

V. DISCUSSION

From columns 2 and 3 of table 2,A, it may be seen that generally, as should be expected, the daylight reflectance of the sample with a white backing was found to be higher than that with a black backing. None of the reversals exceed 0.007, and it is reasonable to ascribe them to a greater or less bulging of the sample into the reflectometer, which it was impossible to avoid.

Column 4 of table 2,A, contains the reflectances for two layers of the samples backed by white paper computed by eq 2. Comparison of these reflectances with those obtained for the nonfluorescent samples from reduction of the spectrophotometric data (column 5) reveals a fairly consistent tendency of the former to be lower by about 0.010. The difference is ascribed to the acceptance by the spectrophotometer (nearly normal illumination, nearly diffuse viewing) of a greater proportion of the surface-reflected light from these samples than was accepted by the multipurpose reflectometer (approximately 45° illumination, normal viewing). If the spectrophotometric data were not available, it may be seen that a fairly reliable indication of what would be obtained spectrophotometrically on nonfluorescent and weakly fluorescent samples of this material and weave is given by adding 0.010 to the reflectances in column 4. The adopted values in section VI for the nonfluorescent and weakly fluorescent samples are therefore found by adding 0.010 to the values obtained by the multipurpose reflectometer (column 4) and averaging with the spectrophotometric daylight reflectances (column 5).

The validity of this procedure was checked by measurements of daylight reflectance of 15 weakly fluorescent samples by comparison with Munsell standards by way of the Macbeth-Martens reflectometer; see table 2,A, column 6. The results of these measurements are lower than the adopted values by fairly consistent amounts, both for the five nonfluorescent samples and for the 15 weakly fluorescent samples. By comparison of five Munsell neutrals with five nearly neutral nonfluorescent samples of the standard card both on the Macbeth-Martens reflectometer and under the angular conditions (nearly diffuse-normal) of the recording spectrophotometer, it was shown that the Macbeth-Martens reflectometer read lower on the textile samples by an average amount of 0.011. Remaining discrepancies in table 2,A, of about 0.010 are unexplained, but are ascribable in part to failure of the Munsell standards used to agree exactly with the published specifications.

Column 7 of table 2, A, gives estimates of the daylight reflectances obtained by way of Munsell notations found by comparing the textile samples with the charts of the Munsell Book of Color. These estimates serve as a closing check on errors of all sorts. It will be noted that the agreement is generally good. These visual estimates also serve to indicate whether to correct the spectrophotometric measurements by subtracting 0.010 or 0.011 as a correction for specularly reflected light included in the measurement, or whether to correct the multipurpose-reflectometer results by adding 0.010 and the Macbeth-Martens results by adding 0.011 (as was actually done). The visual estimates for the standard card were found to agree on the average with the spectrophotometric results of daylight reflectance. It was concluded that the conditions of normal illumination with nearly diffuse viewing accords with viewing near a window more closely than does the 45°-normal condition for these textile samples. Corrections accordingly were applied to the 45°-normal results. This procedure assures that the adopted reflectances will be in agreement with comparisons to the Munsell standards carried out in the customary way.

From the cross-checks of table 3 it may be seen that the spectrophotometer and the colorimeter agree for the nonfluorescent pairs and for the pairs involving only weakly and nonfluorescent samples on the average within about 0.003 in x or y. The maximum difference found for these samples is 0.012. But pairs involving one or more strongly fluorescent samples sometimes yield discrepancies of more than 0.020. Although the chromaticity coordinates (x,y) do not yield scales of uniform perceptibility, it may be safely stated that a difference equal to 0.001 in x or y within the range of these samples is definitely detectable by means of the chromaticity-difference colorimeter. Many of the cross-checks therefore reveal discrepancies much too large to be ascribed to experimental uncertainty.

Analysis of the chromaticity data of tables 2, A and B, by plotting the spectrophotometric results on the (x,y)-diagram, together with the results by means of the chromaticity-difference, or subtractive, colorimeter and by visual estimate also indicates many discrepancies too large to ascribe to experimental error of setting the colorimeter. On this account, studies were made of the various sources of such discrepancies. These sources were found to be (a) variations in angular conditions of illuminating and viewing the samples, (b) metamerism, or differences in spectral character of two samples of similar color, (c) fluorescence, and (d) uncertainties in estimation of Munsell book notation.

1. ANGULAR CONDITIONS

One of the possible reasons why the spectrophotometric result and the colorimetric result should fail to agree with each other and with the visual estimates is the disparity in angular conditions. From an analysis of the reflectance data it was found that the nearly normal-diffuse angular conditions of the recording spectrophotometers used have caused the daylight reflectances derived therefrom to be higher on the average by about 0.010 than those found by use of 45°-normal angular conditions. This regular disparity is ascribed to the greater proportion of surface-reflected light accepted for measurement by the spectrophotometer, and as this surface-reflected light is spectrally very similar to the illuminant, it would be expected that the chromaticity points found by comparison with the considerably less glossy Munsell standards by way of the chromaticity-difference colorimeter (approximately normal-45° angular conditions) would be generally further on the (x,y)-diagram from the illuminant point than the corresponding chromaticity points evaluated by way of the spectrophotometer. Furthermore, it is to be expected from the analysis of reflectance results, that the same disparity would be found between the colorimeter results and those by visual estimate.

Analysis of the chromaticity data of tables 2, A and B, have borne out this expectation to a very satisfactory degree. For graphical comparison therefore, the colorimetric results have been adjusted to accord with addition of a specular component equal to 0.010 as follows:

$$X_a = X + 0.010X_0,\quad Y_a = Y + 0.010Y_0,\quad Z_a = Z + 0.010Z_0, \tag{4}$$

where Y is the daylight reflectance relative to magnesium oxide determined for 45°-normal angular conditions, X and Z are found from the chromaticity coordinates (x,y,z) determined by comparison with the Munsell standards under normal-45° angular conditions by eq 4a:

$$X = Y(x/y),\quad Z = Y(z/y) = Y(1-x-y)/y, \tag{4a}$$

and X_0, Y_0, Z_0 are the tristimulus values for the illuminant, in this case, ICI standard illuminant C [9, 15, 28], which corresponds to $X_0=0.980$, $Y_0=1.000$, $Z_0=1.181$. The adjusted chromaticity coordinates (x_a,y_a) are found in the usual way by eq 4b:

$$x_a = X_a/(X_a+Y_a+Z_a),\ y_a = Y_a/(X_a+Y_a+Z_a). \tag{4b}$$

Figure 3 shows on the (x, y)-chromaticity diagram a comparison of the chromaticities of a number of nonfluorescent and weakly fluorescent samples of the standard card found (circles) by way of the spectrophotometer, (dots) by chromaticity-difference colorimeter comparisons with the Munsell standards adjusted by eq 4 to correspond to more surface-reflected light, and (triangles) by visual estimate along the scales of the Munsell Book of Color. It will be noted that the major discrepancies occur along lines which would nearly intersect the illuminant point (C), that is, along lines close to those of constant dominant wavelength [27]. These discrepancies are ascribed partly to uncertainty in the zero-adjustment of the recording spectrophotometer and partly to small differences in luster between the various textile samples which make one single adjustment as by eq 4 not perfectly adequate. The differences ascribable to these causes are estimated as less than 0.010 in x or y, except for the very dark chromatic samples (such as 70060, 70066, 70075, 70088, and 70165).

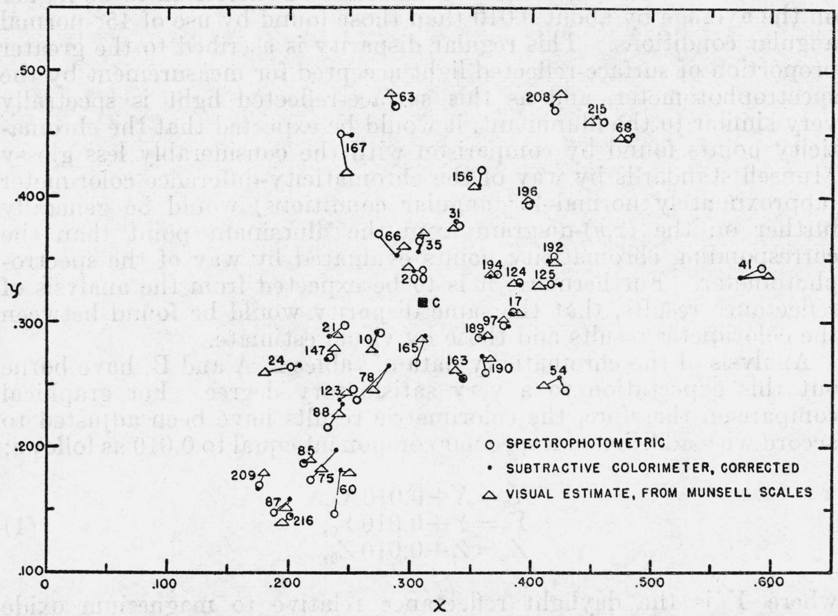

Figure 3.—*Chromaticities of a number of nonfluorescent and weakly fluorescent samples of the Standard Color Card of America obtained by three different methods (see text).*

The major portion of the discrepancies indicated occur along straight lines which, if extended, would pass close to the illuminant point (*C*).

There are also minor deviations in dominant wavelength, which are generally erratic and ascribable to experimental error, except for certain colors of orange-red hue. The visual estimates for these samples (see 70026, 70028, 70029, and 70072 in fig. 5; also 70027, 70039, 70149, and 70178, not shown) deviate toward orange from the dominant wavelength of the adopted values. These deviations would be explained if the highlights resulted from a combination of the purely surface-reflected light with an appreciable component which had penetrated one or two fiber layers, thus acquiring the more orange characteristic of the same dye applied in a lower concentration, or strength, and it is likely that this is the correct explanation. This conjecture has not been subjected to experimental verification.

2. METAMERISM

Two samples form a metameric pair if they are visually identical or nearly identical and at the same time spectrally considerably different. In a study of the cross-checks given in table 3, it was found that a somewhat greater discrepancy may be expected for highly metameric pairs than for pairs showing little or no metamerism. Figure 4 shows the spectral-reflectance curves of four nonfluorescent samples (70034, 70035, 70130, 70131) of the standard card. Samples 70034 and 70035 correspond to the same or similar dye mixtures with some difference in strength of the dyeing, and the same remark applies to 70130 and 70131. Table 3 shows a virtually perfect cross-check for these two nearly nonmetameric pairs. Samples 70034 and 70130,

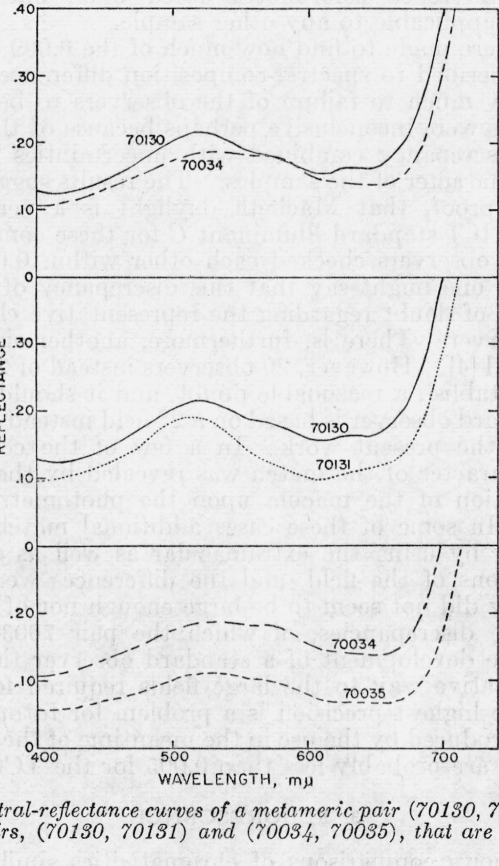

FIGURE 4.—*Spectral-reflectance curves of a metameric pair (70130, 70034) of samples and of two pairs, (70130, 70131) and (70034, 70035), that are nearly nonmetameric.*

The cross-check of the first pair revealed a discrepancy of 0.009 in chromaticity coordinates (x,y); those of the other two, 0.001 and 0.000, respectively.

however, form a metameric pair; they have nearly the same color but show a considerable difference in shape of spectrophotometric curve. Table 3 also shows that Δx for this pair obtained by the spectrophotometer differs from that by the subtractive colorimeter by 0.009, and the corresponding discrepancy in Δy is 0.004. This study suggests that differences in spectral composition of a degree to cause uncertainty of about 0.010 in chromaticity coordinates (x,y) may be frequently encountered in textile dyeings. It is likely that other similar discrepancies among the nonfluorescent and weakly fluorescent samples listed in table 3 have the same explanation.

Metamerism of the various pairs influences these comparisons (1) because of difference between the illumination used in reducing the spectrophotometric data (ICI standard illuminant *C*) and that effective in comparisons by means of the chromaticity-difference colorimeter (Macbeth daylight), and (2) because of difference in spectral sensitivity of the observers, the standard ICI observer being used to reduce the spectrophotometric data, and one or two normal but somewhat nonstandard observers being used to obtain the colorimetric comparisons. Metamerism also prevents calibration of the chromaticity-difference colorimeter based upon one sample from being strictly applicable to any other sample.

Attempts were made to find how much of the 0.009 discrepancy in x should be ascribed to spectral-composition difference in the illuminant, and how much to failure of the observers to be nonstandard; but the results were inconclusive perhaps because of the rather small size of the discrepancy combined with uncertainties introduced by the lustrous character of the samples. The results suggested, without being actual proof, that Macbeth daylight is a very satisfactory substitute for ICI standard illuminant *C* for these comparisons.

As the two observers checked each other within 0.003 in x and y in every trial, one might say that this discrepancy of 0.009 raises a certain degree of doubt regarding the representative character of the standard observer. There is, furthermore, another similar disagreement on record [4]. However, 20 observers instead of 2 or 3 would be required to establish a reasonable doubt, and it should be noted also that the standard observer is based on a 2° field instead of the 9 by 13° field used in the present work. In a few of the comparisons the metameric character of the match was revealed by the presence of a visible projection of the macula upon the photometric field of the colorimeter. In some of these cases additional matches were made with difficulty by using the extramacular as well as some with the macular portions of the field, and the differences were appreciable. However, they did not seem to be large enough nor of the right kind to resolve the discrepancies, of which the pair 70034–70130 is an example. The development of a standard observer that shall apply in a representative way to the large fields required for colorimetric settings of the highest precision is a problem for future study. Uncertainties introduced by the use in the meantime of the present standdard observer are probably less than 0.005 for the TCCA samples.

3. FLUORESCENCE

Figure 5 shows comparisons of chromaticities similar to those of figure 3 but with reference to strongly fluorescent samples. Of the 55 strongly fluorescent samples of the standard card, only 33 are represented in figure 5, the remaining 22 being omitted for the sake of clarity and because they show discrepancies very similar to those which are represented. It will be noted that a large number of the strongly fluorescent samples have caused the spectrophotometer to yield a significantly wrong result. For strongly fluorescent samples the adopted values are based upon the adjusted results from the chromaticity-difference colorimeter and the Macbeth-Martens reflectometer, with no weight given either to the spectrophotometric result or to those by the multipurpose reflectometer.

Although the cross-checks summarized in table 3 for pairs including strongly fluorescent samples serve to reveal most of the corresponding errors arising from fluorescence, they do not invariably reveal them. See, for example, the good check obtained by comparing 70037 with 70038. The spectrophotometric evaluation of the difference in x and y between these two samples agrees with that by the chromaticity-difference colorimeter within 0.003. These two samples are fluorescent to about the same extent and in about the same way. Each sample is evaluated by routine application of the recording spectrophotometer with closely the same error, the difference between these erroneous

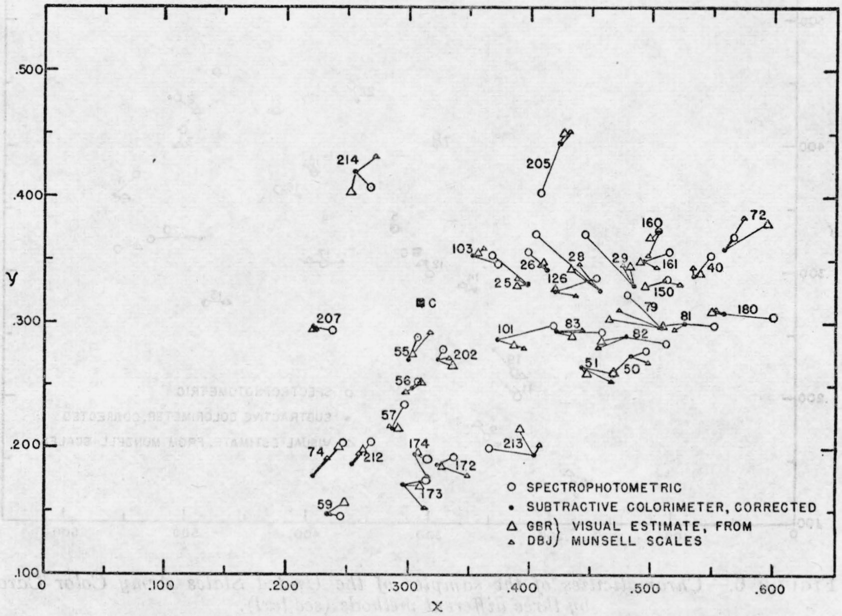

FIGURE 5.—*Chromaticities of 33 out of the 55 strongly fluorescent samples of the Standard Color Card of America obtained by three different methods (see text).*

Note that the spectrophotometric result for a large number of these samples differs importantly from those by the other two methods known to be applicable to fluorescent samples. It is therefore presumed that the degree and kind of fluorescence is such as to make the recording spectrophotometer inapplicable to these samples.

evaluations being closely correct. In order to be sure that an unknown sample is not too strongly fluorescent to prevent reliable use of the spectrophotometer, the cross-check must involve one nonfluorescent sample. The spectrophotometric evaluation of some of these strongly fluorescent samples is in error by more than 0.020 in x or y. However, the adopted values are considered to be uncertain by less than 0.005 from this cause.

4. MUNSELL BOOK NOTATIONS

In figures 3 and 5 and in figure 6, which shows a similar plot for the samples of the Army card, it will be noted that the visual estimates of chromaticity coordinates, x and y, found by interpolation and extrapolation along the scales of the Munsell Book of Color, with a few exceptions agree well with corrected values from the chromaticity-difference colorimeter and with the spectrophotometric values for nonfluorescent and weakly fluorescent samples. As many of these estimates involve extrapolation of two kinds, first to find the Munsell book notation by extrapolation along the color scales, and, finally, to estimate the corresponding chromaticity coordinates by extrapolation on large-scale (x,y)-plots, the chromaticity coordinates of the 55 strongly fluorescent samples were estimated independently by a second observer (DBJ). Some of these are plotted on figure 5 (small triangles), and it may be seen that the discrepancies are considerable

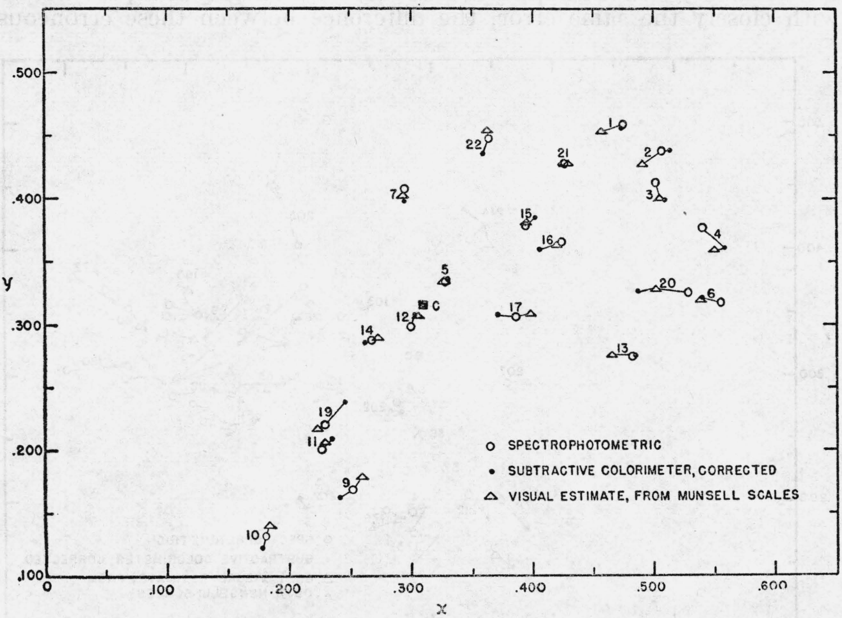

FIGURE 6.—*Chromaticities of the samples of the United States Army Color Card by three different methods (see text).*

Three of the samples (65003, 65004, and 65013) are strongly fluorescent (see table 2, B); the spectrophotometric results for these samples should not be expected to agree well with those by the other two methods.

for some samples (70050, 70172, 70173, 70213, and 70214). These discrepancies give an indication of the uncertainty ascribable partly to the texture difference but chiefly to extrapolation, and because of this uncertainty, the adopted values of Munsell book notation are given only to the nearest hue step or chroma step if extrapolation of more than one chroma step is involved.

From the rather large fraction (52/238) of these textile standards that can be given Munsell book notations only by extrapolation of considerable extent it may be seen that the TCCA standards cover color ranges somewhat beyond those covered by the matte, evenly spaced nonfluorescent Munsell standards. This increase in color range has been achieved by using dyes (some of them fluorescent) instead of pigments, and by making no sacrifice of purity for the sake of uniform spacing. Most of these TCCA standards are also outside the range covered by the Jacobson-Foss Color Harmony Manual [8]. As the colors represented are those for which there has been demonstrated to be a continuing demand, and as no other calibrated set of material color standards covers this range fully, it may be seen that the TCCA standards fill an important and unique need. This need is not confined to textiles alone but relates also to this extended color range procurable with fluorescent colorants in any medium (paints, plastics, ceramics).

VI. FUNDAMENTAL SPECIFICATION OF THE TEXTILE COLOR CARD ASSOCIATION STANDARDS

Table 5 shows the adopted color specifications of the Standard Color Card of America and of the United States Army Card, both issued by the Textile Color Card Association of the United States. This table gives the TCCA name and cable number, and the ICI specification [9, 15, 28], consisting of daylight reflectance, Y, relative to magnesium oxide, and chromaticity coordinates x and y.[3] There are also given the Munsell renotation [26] and book notation [25], and finally the ISCC-NBS color designation [18], all derived in the customary way from the ICI specification. All the recommendations of American War Standard Z44–1942 [1] have thus been complied with.

The Munsell book notations relate to comparisons obtainable with the Munsell charts current in 1945; they are for immediate practical use. The Munsell renotations refer to the ideal system that these standards are expected to approach as the years go on; they are for the future.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of American, ninth edition, and the U. S. Army Color Card*

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	x	y	Renotation, $H\ V/C$	Book notation, $H\ V/C$	
STANDARD COLOR CARD OF AMERICA							
White	70001	0.753	0.320	0.327	2.5Y 8.8/0.7	2.5Y 9.1/0.7	Yellowish white.
Ivory	70002	.765	.329	.335	1.0Y 8.9/1.3	2Y 9.1/1.6	Very pale orange.
Cream	70003	.750	.334	.344	3.5Y 8.8/1.7	4.0Y 9.1/2.2	Pale yellow.
Eggshell	70004	.632	.348	.354	1.6Y 8.2/2.5	2.3Y 8.3/3.1	Weak yellowish orange.
Leghorn	70005	.621	.371	.376	2.4Y 8.2/4.2	2.5Y 8.3/4.8	Do.
Maize	70006	.622	.409	.403	1.1Y 8.2/6.8	1.0Y 8.2/7.4	Moderate yellowish orange.
Pale Blue	70007	.634	.305	.317	8.4BG 8.2/0.5	8B 8.2/0.7	Light bluish gray.
Pastel Blue	70008	.524	.285	.300	0.2PB 7.6/2.6	9.6B 7.6/2.2	Very pale blue.
Baby Blue	70009	.532	.281	.298	.2PB 7.7/3.0	10.0B 7.6/2.8	Do.
Sky Blue	70010	.377	.273	.292	9.4B 6.6/3.4	9.0B 6.4/3.0	Pale blue.
Blue Flower	70011	.400	.262	.279	1.2PB 6.8/4.7	1.2PB 6.7/4.6	Do.
Forget-me-not	70012	.360	.241	.265	0.2PB 6.5/6.4	0.7PB 6.3/6.9	Light blue.
Flesh Pink	70013	.662	.340	.327	9.9R 8.4/2.6	9R 8.5/2	Pale to weak pink.
Baby Pink	70014	.648	.348	.319	3.4R 8.3/4.1	6R 8.5/5	Light to moderate pink.
Pastel Pink	70015	.580	.359	.316	2.0R 7.9/5.4	5R 7.9/6	Moderate pink.
Arbutus Pink	70016	.552	.362	.313	1.0R 7.8/5.9	4R 7.7/7	Moderate to strong pink.
Rose Pink	70017	.459	.384	.308	0.2R 7.2/7.9	2.2R 7.2/10.2	Strong pink.
Sea Pink	70018	.327	.400	.310	1.5R 6.2/8.2	2.5R 6.2/9.4	Light purplish red.
Tourmaline	70019	.548	.299	.323	3.4BG 7.8/1.3	7BG 7.7/1.3	Light bluish gray.
Turquoise	70020	.472	.271	.316	8.5BG 7.3/3.7	7.5BG 7.1/4.1	Light blue green.

[3] Mention should be made of the Dictionary of Colour Standards issued together with ICI specifications in 1938 by the British Colour Council, an organization based on the Textile Color Card Association and patterned after it. The published color specifications [2] are not comparable to those of the present study, first because the shiny portion of the fabric was measured rather than the ribbed, and second, because ICI standard illuminant *B* was used instead of illuminant *C*.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of America, ninth edition, and the U. S. Army Color Card*—Continued

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	x	y	Renotation, H V/C	Book notation, H V/C	
STANDARD COLOR CARD OF AMERICA—Continued							
Blue Turquoise	70021	0.340	0.239	0.293	2.7B 6.3/5.6	1.9B 6.2/6.0	Light greenish blue.
Grotto Blue	70022	.229	.207	.260	5.1B 5.3/7.4	5.3B 5.2/6.7	Moderate blue.
Peacock	70023	.106	.199	.257	4.2B 3.8/6.0	3.2B 3.6/6.6	Moderate greenish blue.
Duckling	70024	.052	.205	.264	2.9B 2.7/4.5	4B 2.4/5	Dusky to dark blue.
Tea Rose	70025	.554	.398	.331	6.2R 7.8/7.4	9R 7.9/9	Strong pink.
Salmon Pink	70026	.524	.414	.343	8.5R 7.6/7.7	10R 7.7/9	Strong orange pink.
Shell Pink	70027	.523	.432	.330	5.6R 7.6/10.1	8R 7.6/10	Strong pink.
Melon Pink	70028	.385	.458	.326	5.1R 6.7/11.5	7R 6.7/10	Light reddish orange.
Tigerlily	70029	.252	.486	.330	5.9R 5.6/11.3	7R 5.7/11	Moderate to strong reddish orange.
Flame Red	70030	.182	.542	.335	7.3R 4.8/12.7	6.7R 4.9/12.6	Strong reddish orange.
Nile	70031	.508	.339	.378	4.9GY 7.5/3.3	3.9GY 7.5/3.4	Pale to weak yellow green.
Pistache	70032	.370	.311	.371	0.4G 6.6/3.6	10.0GY 6.5/3.3	Weak yellowish green.
Tarragon	70033	.228	.305	.370	1.1G 5.3/3.4	1.2G 5.3/2.9	Weak green.
Palmetto	70034	.171	.315	.355	8.7GY 4.7/2.0	9GY 4.6/1.8	Dusky yellow green.
Reseda	70035	.092	.306	.361	0.8G 3.5/2.3	1G 3.2/1.7	Dusky green.
Evergreen	70036	.046	.302	.377	.6G 2.5/2.8	1.0G 2.0/2.5	Very dusky green.
Apricot	70037	.410	.412	.374	5.5YR 6.9/6.1	6.4YR 7.0/6.1	Weak orange.
Honeydew	70038	.435	.442	.370	2.5YR 7.0/8.3	2.4YR 7.2/9.0	Moderate orange.
Salmon	70039	.336	.480	.353	8.8R 6.3/10.7	9.0R 6.2/11.2	Strong reddish orange.
Tangerine	70040	.172	.535	.337	7.4R 4.7/11.9	7.0R 4.8/12.2	Do.
Paprica	70041	.162	.583	.340	8.2R 4.6/14.3	7.5R 4.5/15	Vivid reddish orange.
Pimento	70042	.132	.587	.327	7.2R 4.2/14.1	6R 4.0/15	Vivid red.
Sistine	70043	.326	.262	.273	2.6PB 6.2/4.7	2.5PB 5.9/4.1	Pale blue.
Copenhagen	70044	.158	.249	.254	4.2PB 4.5/4.8	4.3PB 4.3/4.7	Weak purplish blue.
Tile Blue	70045	.121	.239	.250	2.5PB 4.0/4.7	2.0PB 3.9/4.7	Weak blue.
Flemish Blue	70046	.078	.231	.235	3.7PB 3.3/4.7	3.6PB 3.1/4.7	Weak purplish blue.
Peking Blue	70047	.063	.214	.215	4.0PB 3.0/5.5	4.1PB 2.8/5.9	Moderate purplish blue.
Marine Corps	70048	.046	.227	.221	4.9PB 2.5/4.4	5.4PB 2.3/4.0	Dusky purplish blue.
Cherry	70049	.127	.464	.262	8.8RP 4.1/12.4	9RP 3.9/14	Vivid purplish red.
Harvard Crimson	70050	.087	.484	.274	0.7R 3.4/10.3	1.5R 3.2/12	Deep purplish red.
Ruby	70051	.083	.443	.265	8.6RP 3.4/9.2	0.4R 3.1/10.4	Do.
American Beauty	70052	.059	.465	.263	0.2R 2.8/8.8	1R 2.6/11	Do.
Magenta	70053	.066	.458	.261	9.3RP 3.0/9.0	1R 2.8/11	Do.
Redgrape	70054	.049	.426	.251	8.2RP 2.6/7.8	10RP 2.2/9	Very dark purplish red.
Lavender	70055	.300	.300	.271	5.5P 6.0/4.8	5.7P 6.1/4.1	Pale purple.
Lilac	70056	.187	.303	.248	6.5P 4.9/6.4	6.0P 4.9/5.5	Moderate purple.
Mauve	70057	.172	.287	.216	5.2P 4.7/9.3	5.2P 4.6/8.7	Do.
Violet	70058	.130	.259	.184	2.6P 4.2/11.0	2.6P 4.1/9.7	Strong purple.
Pansy	70059	.044	.234	.147	0.9P 2.4/10.0	1P 2.2/10	Deep bluish purple.
Purple	70060	.027	.241	.165	.6P 1.8/6.9	1P 1.6/8	Dark bluish purple.
Spring Green	70061	.348	.353	.459	6.3GY 6.4/7.2	6.8GY 6.2/6.8	Moderate yellowish green.
Mintleaf	70062	.289	.324	.458	8.8GY 5.9/7.6	9.6GY 5.7/7.5	Do.
Emerald	70063	.163	.286	.478	1.2G 4.6/8.2	1.4G 4.5/8.8	Do.
Hunter	70064	.070	.290	.434	1.0G 3.1/5.1	1.5G 2.8/4.6	Very dark yellowish green.
Myrtle	70065	.074	.264	.397	4.5G 3.2/5.1	5.2G 2.9/4.3	Dark green.
Bottle Green	70066	.043	.281	.363	4.9G 2.4/2.9	4.1G 2.1/2.6	Very dusky green.
Jasmine	70067	.659	.414	.424	3.6Y 8.4/7.7	3.5Y 8.2/8.0	Moderate yellow.
Spanish Yellow	70068	.525	.482	.448	0.4Y 7.6/12.2	10YR 7.6/11	Strong yellowish orange.
Orange	70069	.380	.516	.419	5.7YR 6.6/12.7	5YR 6.6/13	Strong orange.
Princeton Orange	70070	.347	.519	.406	4.3YR 6.4/12.5	3.3YR 6.4/12.6	Do.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of America, ninth edition, and the U. S. Army Color Card*—Continued

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	*x*	*y*	Renotation, *H V/C*	Book notation, *H V/C*	
STANDARD COLOR CARD OF AMERICA—Continued							
Golden Poppy	70071	0.264	0.555	0.386	1.6YR 5.7/13.8	1YR 5.6/14	Strong reddish orange.
Indian Orange	70072	.203	.560	.359	9.4R 5.1/13.2	9R 5.1/14	Do.
Perwinkle	70073	.166	.253	.227	8.7PB 4.6/6.8	8.8PB 4.5/6.6	Moderate bluish purple.
Cornflower Blue	70074	.110	.222	.176	8.4PB 3.8/9.8	9PB 3.8/11	Strong bluish purple.
Old Glory Blue	70075	.040	.229	.186	8.2PB 2.3/6.1	8.6PB 2.1/5.3	Dark bluish purple.
Independence	70076	.030	.241	.209	7.8PB 2.0/4.3	8.0PB 1.8/3.1	Dusky bluish purple.
National Flag Blue	70077	.025	.259	.238	7.6PB 1.7/2.5	8PB 1.5/1.8	Dusky purplish blue.
Homage Blue	70078	.023	.269	.252	7.7PB 1.7/2.0	8PB 1.5/1.4	Purplish black.
Geranium	70079	.201	.509	.297	2.7R 5.0/14.0	3R 5.0/15	Vivid purplish red.
Scarlet	70080	.153	.567	.307	4.9R 4.5/14.9	5R 4.4/15	Vivid red.
Cardinal	70081	.086	.528	.300	4.1R 3.4/10.6	4R 3.3/12	Deep red.
Dark Cardinal	70082	.056	.480	.290	2.8R 2.8/7.7	4R 2.5/10	Do.
Garnet	70083	.041	.422	.294	3.0R 2.3/4.9	4.6R 2.0/7.0	Very dark red.
Maroon	70084	.042	.383	.294	1.0R 2.4/3.5	2.9R 2.1/3.9	Very dusky purplish red.
Lustre Blue	70085	.081	.213	.188	6.6PB 3.3/7.9	6.8PB 3.2/8.3	Moderate purplish blue.
Yale Blue	70086	.063	.204	.165	7.3PB 2.9/8.8	7.2PB 2.9/9.1	Strong purplish blue.
Royal Blue	70087	.041	.195	.153	6.9PB 2.3/8.4	7.3PB 2.1/7.7	Dark purplish blue.
Navy 1	70088	.039	.238	.226	5.8PB 2.3/3.9	6.2PB 2.1/2.8	Dusky purplish blue.
Navy 2	70089	.027	.240	.230	5.7PB 1.8/3.2	6.0PB 1.7/2.6	Do.
Midnight	70090	.022	.263	.255	6.0PB 1.6/1.9	6PB 1.4/1.5	Bluish black.
Champagne	70091	.518	.366	.358	8.5YR 7.6/3.5	9.2YR 7.5/4.0	Pale to weak orange.
Cork	70092	.237	.393	.366	6.8YR 5.4/4.0	7.3YR 5.4/4.1	Light brown.
Sandalwood	70093	.178	.392	.362	6.0YR 4.8/3.6	6.9YR 4.6/3.3	Do.
Oakwood	70094	.124	.411	.366	5.2YR 4.1/3.7	5.5YR 3.8/3.3	Moderate brown.
Tobacco	70095	.053	.418	.358	4.3YR 2.7/3.1	4.2YR 2.5/3.7	Dark brown.
African Brown	70096	.046	.347	.331	4.7YR 2.5/1.1	5YR 2.4/1.2	Brownish black.
Vassar Rose	70097	.387	.379	.298	8.1RP 6.7/8.1	9RP 6.5/9	Light purplish red.
Peach Blossom	70098	.242	.422	.291	9.2RP 5.5/10.3	9.5RP 5.2/10.3	Strong purplish red.
Strawberry	70099	.148	.418	.283	8.8RP 4.4/8.8	9.8RP 4.1/8.6	Moderate purplish red.
Raspberry	70100	.090	.425	.273	8.6RP 3.5/8.2	9.5RP 3.3/8.7	Dark purplish red.
Claret	70101	.036	.374	.287	9.9RP 2.2/3.4	1.3R 1.8/3.8	Very dusky purplish red.
Burgundy	70102	.032	.354	.289	8.7RP 2.0/2.3	0.5R 1.6/2.0	Very dusky red purple.
Ecru	70103	.343	.353	.354	0.9Y 6.4/2.3	1.4Y 6.2/2.3	Pale brown.
Beige	70104	.245	.368	.355	7.8YR 5.5/2.8	8.4YR 5.4/3.0	Do.
Fawn	70105	.178	.370	.356	8.1YR 4.8/2.6	8.7YR 4.7/2.5	Do.
Beaver	70106	.127	.366	.351	7.6YR 4.1/2.0	8YR 4.0/1.9	Weak brown.
Autumn Brown	70107	.058	.396	.363	7.1YR 2.8/2.5	8.2YR 2.6/2.7	Do.
Seal	70108	.043	.357	.342	7.1YR 2.4/1.3	9YR 2.1/1.6	Dusky brown.
Old Blue	70109	.345	.293	.304	1.2PB 6.4/1.7	10B 6.2/1.2	Medium bluish gray.
Mistiblu	70110	.192	.286	.293	3.5PB 4.9/2.0	3PB 4.8/1.5	Pale purplish blue.
West Point	70111	.091	.279	.286	3.6PB 3.5/1.7	2PB 3.4/1.4	Dark bluish gray.
Bluesteel	70112	.073	.271	.276	4.0PB 3.2/2.0	3PB 3.1/1.8	Weak purplish blue.
Stone Blue	70113	.069	.275	.271	6.0PB 3.1/2.0	6PB 3.0/1.8	Do.
Graphite Blue	70114	.032	.267	.261	6.2PB 2.0/2.0	6PB 1.9/1.4	Bluish black.
Amberlite	70115	.371	.414	.389	8.6YR 6.6/5.9	8.8YR 6.4/5.7	Dusky yellowish orange.
Topaz	70116	.311	.438	.394	7.3YR 6.1/6.8	7.2YR 5.9/6.8	Weak orange.
Burnished Straw	70117	.209	.430	.380	5.8YR 5.1/5.5	6.1YR 5.2/5.6	Light brown
Gold Brown	70118	.156	.456	.374	3.4YR 4.5/6.2	3.6YR 4.3/6.1	Moderate brown.
Brown	70119	.071	.441	.368	4.2YR 3.1/4.2	4.3YR 2.8/4.3	Do.
Caramel Brown	70120	.047	.431	.354	3.1YR 2.5/3.5	3YR 2.2/4	Dusky reddish brown.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of America, ninth edition, and the U. S. Army Color Card*—Continued

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	x	y	Renotation, H V/C	Book notation, H V/C	
STANDARD COLOR CARD OF AMERICA—Continued							
Starlight Blue	70121	0.407	0.283	0.288	5.2PB 6.8/3.2	5.6PB 6.6/2.7	Very pale purplish blue.
Lupine	70122	.273	.264	.264	5.6PB 5.8/5.0	6.0PB 5.5/4.7	Pale purplish blue.
Hydrangea Blue	70123	.136	.248	.243	5.7PB 4.2/5.1	6.0PB 4.1/5.2	Moderate purplish blue.
Grecian Rose	70124	.312	.390	.331	6.8R 6.1/5.5	7.1R 5.9/5.1	Weak reddish orange.
Bois de Rose	70125	.190	.419	.331	6.6R 4.9/6.1	7.2R 4.9/5.0	Do.
Mahogany	70126	.057	.421	.325	6.8R 2.8/3.8	8R 2.5/4	Very dusky red.
Sunset	70127	.598	.377	.365	8.2YR 8.0/4.4	8.6YR 8.1/5.2	Weak yellowish orange.
Tan	70128	.334	.389	.374	8.7YR 6.3/4.4	9.0YR 6.1/4.3	Light yellowish brown.
Maple Sugar	70129	.182	.414	.387	9.0YR 4.8/4.5	9.1YR 4.8/4.4	Moderate yellowish brown.
Almond Green	70130	.182	.310	.352	0.2G 4.8/2.0	10GY 4.6/1.7	Weak green.
Blue Spruce	70131	.138	.284	.346	7.3G 4.3/2.8	7.5G 4.0/2.1	Weak blue green.
Jungle Green	70132	.042	.267	.337	1.1BG 2.4/2.7	0.6BG 2.2/2.1	Very dusky green.
Orchid	70133	.418	.311	.275	7.5P 6.9/5.8	8P 6.7/5	Light reddish purple.
Amethyst	70134	.104	.306	.226	7.4P 3.8/7.2	7.0P 3.7/6.2	Moderate purple.
Plum	70135	.041	.298	.222	6.4P 2.3/4.9	6.5P 2.2/4.1	Very dusky purple.
Sand	70136	.404	.336	.341	1.4Y 6.8/1.5	2.6Y 6.8/1.6	Yellowish gray.
Castor	70137	.081	.342	.340	9.8YR 3.3/1.0	1Y 3.1/1.0	Brownish gray.
Taupe	70138	.060	.340	.336	8.6YR 2.9/0.9	10YR 2.8/0.9	Do.
Nude	70139	.346	.352	.347	8.4YR 6.4/2.2	9.3YR 6.3/2.4	Pale brown.
Toast Brown	70140	.135	.401	.355	3.6YR 4.2/3.7	4.2YR 4.0/3.0	Weak to moderate brown.
Spicebrown	70141	.053	.416	.355	3.6YR 2.7/3.1	3.6YR 2.4/3.5	Dark brown.
Brittany Blue	70142	.236	.247	.275	8.6B 5.4/4.8	7.7B 5.2/4.2	Weak blue.
Old China	70143	.128	.230	.246	1.5PB 4.1/5.4	1.0PB 4.0/5.3	Moderate blue.
Peasant Blue	70144	.087	.239	.245	3.4PB 3.4/4.2	3.1PB 3.2/4.0	Dusky blue.
Aqua	70145	.259	.270	.315	8.0BG 5.6/3.0	7.1BG 5.4/3.0	Moderate blue green.
River Blue	70146	.143	.260	.303	1.1B 4.3/3.0	8.2BG 4.2/2.8	Do.
Teal	70147	.067	.232	.271	5.3B 3.0/3.3	5.3B 2.9/3.3	Dusky Blue.
Peach	70148	.554	.395	.358	3.5YR 7.8/5.7	5YR 7.8/7	Pale to light orange.
Crab Apple	70149	.293	.493	.345	7.7R 5.9/11.5	7.4R 5.9/12.2	Strong reddish orange.
Lacquer	70150	.123	.511	.334	7.3R 4.0/9.5	7.5R 3.8/10.2	Dark reddish orange.
Silver	70151	.310	.322	.325	8.0YR 6.1/0.6	10YR 6.1/0.6	Light brownish gray.
Nickel	70152	.286	.314	.316	1.2R 5.9/0.5	10RP 5.9/0.3	Medium gray.
Steel	70153	.171	.309	.307	6.3P 4.7/0.8	7P 4.6/0.5	Medium purplish gray.
Limepeel	70154	.285	.380	.450	2.7GY 5.9/6.0	2.8GY 5.7/5.5	Moderate yellow green.
Mosstone	70155	.197	.375	.441	2.7GY 5.0/5.0	3.0GY 4.9/5.0	Dark yellow green.
Olive	70156	.081	.357	.415	3.1GY 3.3/3.2	3.1GY 3.1/4.5	Moderate olive green.
Old Gold	70157	.313	.433	.428	2.3Y 6.1/6.9	2.4Y 5.9/6.2	Dusky yellowish orange.
Gold	70158	.266	.445	.427	1.3Y 5.7/7.1	1.1Y 5.5/7.0	Strong yellowish brown.
Bronze	70159	.088	.414	.402	1.8Y 3.5/3.8	2Y 3.2/4	Dark yellowish brown.
Burnt Orange	70160	.184	.506	.373	1.5YR 4.8/9.2	1.2YR 4.8/9.8	Moderate reddish orange.
Terra Cotta	70161	.088	.494	.350	9.8R 3.5/7.0	9.9R 3.2/8.0	Moderate reddish brown.
Henna	70162	.080	.454	.342	9.4R 3.3/5.3	9.8R 3.0/5.8	Do.
Heliotrope	70163	.110	.343	.256	2.3RP 3.8/5.9	2.5RP 3.6/5.4	Moderate red purple.
Prune	70164	.030	.311	.237	8.6P 2.0/4.0	8.5P 1.8/3.2	Very dusky reddish purple.
Eggplant	70165	.030	.308	.279	7.5P 1.9/1.5	7P 1.8/1.2	Purplish black.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of America, ninth edition, and the U. S. Army Color Card*—Continued

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	*x*	*y*	Renotation, *H V/C*	Book notation, *H V/C*	
STANDARD COLOR CARD OF AMERICA—Continued							
Jade Green	70166	0.267	0.320	0.401	8.8GY 5.7/4.6	8.8GY 5.6/4.1	Weak yellowish green.
Primitive Green	70167	.156	.247	.450	3.6G 4.5/8.9	4.1G 4.4/8.5	Strong green.
Irish Green	70168	.081	.224	.460	4.0G 3.3/8.8	5G 3.1/8	Deep green.
Putty	70169	.305	.332	.330	6.5YR 6.0/1.2	7.5YR 6.0/1.2	Light brownish gray.
Pigeon	70170	.196	.325	.317	4.1R 5.0/1.1	6R 5.0/0.7	Reddish gray.
Smoke	70171	.061	.321	.316	5.1R 2.9/0.4	10R 2.9/0.4	Dark gray.
Purple Orchid	70172	.097	.323	.187	9.3P 3.6/12.1	10P 3.3/11	Deep reddish purple.
Dahlia Purple	70173	.057	.296	.171	7.0P 2.8/10.2	8P 2.6/10	Do.
Imperial Purple	70174	.054	.306	.195	7.9P 2.7/8.0	8.3P 2.6/7.6	Do.
Saxe Blue	70175	.205	.250	.269	0.8PB 5.1/4.6	0.8PB 5.0/4.2	Weak blue.
Electric	70176	.094	.225	.254	8.6B 3.6/4.6	7.8B 3.4/4.2	Dusky blue.
Majolica Blue	70177	.088	.220	.235	1.6PB 3.5/5.3	1.4PB 3.3/5.0	Dusky to dark blue.
Shrimp Pink	70178	.301	.478	.317	4.0R 6.0/12.8	5R 5.9/13	Brilliant red.
Apple Red	70179	.142	.551	.309	4.8R 4.3/13.6	5R 4.2/14	Vivid red.
Old Glory Red	70180	.082	.560	.308	5.5R 3.3/11.1	5R 3.1/14	Do.
Chalk Pink	70181	.497	.362	.323	5.0R 7.4/4.6	6.1R 7.4/4.8	Moderate pink.
Old Rose	70182	.282	.383	.310	1.1R 5.8/6.3	2.2R 5.7/6.5	Light purplish red.
Goldmist	70183	.425	.378	.397	5.3Y 7.0/4.5	6.6Y 7.0/4.6	Weak greenish yellow.
Lt. Olive Drab	70184	.097	.386	.381	1.8Y 3.6/2.7	2.2Y 3.5/2.8	Weak brown.
Gull	70185	.389	.325	.325	5.0YR 6.7/0.9	5YR 6.7/1.0	Pinkish gray.
Grebe	70186	.092	.318	.319	1.8YR 3.5/0.3	10YR 3.5/0.2	Dark gray.
Flax	70187	.399	.369	.369	1.2Y 6.8/3.5	1.7Y 6.8/3.4	Weak yellowish orange.
Khaki	70188	.276	.366	.365	1.1Y 5.8/2.7	1.2Y 5.7/2.9	Pale brown.
Ashes of Rose	70189	.214	.359	.288	5.5RP 5.2/5.9	6.0RP 5.1/5.7	Moderate red purple.
Catawba	70190	.044	.360	.267	5.0RP 2.4/4.7	6.9RP 2.2/3.6	Very dusky red purple.
Rose Beige	70191	.310	.383	.354	4.5YR 6.1/4.0	5.5YR 6.0/4.0	Light brown.
Cocoa	70192	.102	.417	.351	1.9YR 3.7/4.0	2.8YR 3.3/3.7	Moderate brown.
Pearl Gray	70193	.388	.324	.330	2.3Y 6.7/0.7	3Y 6.6/0.9	Yellowish gray.
Dusty Pink	70194	.392	.369	.338	0.4YR 6.7/3.9	1.4YR 6.6/3.6	Moderate orange pink
Dustblu	70195	.252	.285	.292	4.3PB 5.6/2.4	3.6PB 5.4/1.9	Pale purplish blue.
Chamois	70196	.379	.399	.395	1.5Y 6.6/5.1	1.6Y 6.5/4.9	Light yellowish brown.
Crayon Green	70197	.494	.313	.379	10.0GY 7.4/4.2	0.1G 7.2/4.2	Pale yellowish green.
Violine Pink	70198	.206	.378	.267	4.8RP 5.1/9.0	4.7RP 4.8/9.3	Strong red purple.
Natural	70199	.454	.339	.342	0.6Y 7.2/1.7	1Y 7.1/1.9	Very pale brown.
Spraygreen	70200	.379	.306	.342	1.7G 6.6/1.9	1G 6.6/1.6	Pale green.
Bisque	70201	.351	.362	.350	7.0YR 6.4/2.8	7.8YR 6.3/3.2	Light brown.
Crocus	70202	.340	.324	.271	0.2RP 6.3/6.4	0.6RP 6.1/6.7	Light reddish purple.
Popcorn	70203	.568	.412	.416	2.8Y 7.9/7.2	2.7Y 7.9/7.3	Moderate yellow.
Robin's Egg	70204	.222	.273	.301	4.7B 5.3/2.5	1.8B 5.2/2.2	Weak blue.
Lemon Yellow	70205	.603	.424	.443	4.7Y 8.1/8.7	4.4Y 8.2/8.9	Moderate yellow.
Coral	70206	.450	.426	.314	2.5R 7.1/10.6	5R 7.0/12	Vivid pink.
Parrot Blue	70207	.232	.222	.297	10.0BG 5.4/6.5	9.2BG 5.1/6.1	Moderate greenish blue.
Chartreuse	70208	.492	.418	.471	9.2Y 7.4/9.0	9.0Y 7.4/8.3	Moderate greenish yellow.
Oriental Blue	70209	.102	.176	.168	4.5PB 3.7/11.1	5PB 3.4/14	Vivid purplish blue.
Carmine	70210	.126	.533	.286	2.7R 4.1/13.8	3R 3.9/14	Vivid purplish red.
Bluebird	70211	.112	.217	.226	2.9PB 3.9/6.4	2.9PB 3.7/6.7	Moderate blue.
Parma Violet	70212	.131	.254	.187	1.7P 4.2/10.5	1.8P 4.1/9.7	Strong bluish purple
Fuchsia	70213	.129	.404	.195	3.3RP 4.1/17.2	4RP 3.8/16	Vivid red purple.
Scarab Green	70214	.302	.256	.420	4.3G 6.0/9.3	4.2G 6.0/7.7	Brilliant green.
Nugget Gold	70215	.345	.457	.462	3.9Y 6.4/9.3	3Y 6.3/9	Dark to deep yellow.
Sapphire Blue	70216	.049	.202	.145	7.9PB 2.6/10.0	8.3PB 2.4/9.6	Deep bluish purple.

TABLE 5.—*Adopted color specifications for the TCCA Standard Color Card of America, ninth edition, and the U. S. Army Color Card*—Continued

TCCA name	Cable number	ICI specification			Munsell		ISCC-NBS color designation
		Y	x	y	Renotation, H V/C	Book notation, H V/C	
UNITED STATES ARMY COLOR CARD							
Golden Yellow	65001	0.449	0.474	0.458	2.0Y 7.1/11.3	1Y 7.3/11	Strong yellowish orange.
Yellow	65002	.414	.510	.438	7.8YR 6.9/13.2	7YR 6.5/12	Strong orange.
Golden Orange	65003	.316	.510	.399	3.8YR 6.1/11.4	3.1YR 5.9/11.9	Do.
Orange	65004	.212	.559	.361	9.5R 5.2/13.2	9R 5.2/14	Strong reddish orange.
White	65005	.677	.329	.335	1.8Y 8.5/1.2	3Y 8.8/1.7	Yellowish white.
Scarlet	65006	.102	.548	.320	6.1R 3.7/11.2	6R 3.3/13	Deep to vivid red.
Green	65007	.078	.295	.403	1.2G 3.3/4.2	1.8G 2.9/3.3	Very dark yellowish green.
Silver Gray	65008	.309	.319	.324	1.0Y 6.1/0.5	1Y 6.0/0.4	Medium gray.
Pansy	65009	.058	.247	.166	1.4P 2.8/9.1	2P 2.6/9	Moderate bluish purple.
Ultramarine Blue	65010	.051	.180	.127	7.0PB 2.6/11.8	7.5PB 2.2/11.6	Deep purplish blue.
Cobalt Blue	65011	.045	.231	.205	6.9PB 2.5/5.2	7.2PB 2.3/4.0	Dusky purplish blue.
Dark Blue	65012	.027	.301	.304	7.3PB 1.8/0.4	5PB 1.6/0.3	Black.
Crimson	65013	.083	.485	.276	0.8R 3.4/10.2	2R 3.2/12	Deep purplish red.
Light Blue	65014	.234	.265	.287	9.0B 5.4/3.4	7.3B 5.2/2.9	Weak blue.
Buff	65015	.468	.398	.382	9.0YR 7.2/5.4	9.6YR 7.1/5.4	Weak yellowish orange.
Brown	65016	.072	.415	.363	5.0YR 3.1/3.3	5.0YR 2.8/3.5	Moderate brown.
Maroon	65017	.044	.378	.307	3.3R 2.4/2.7	4.7R 2.1/2.5	Very dusky red.
Black	65018	.027	.305	.309	5.1PB 1.8/0.2	9B 1.7/0.1	Black.
Sky Blue	65019	.041	.238	.230	5.3PB 2.4/3.8	5.8PB 2.1/2.9	Dusky purplish blue.
Brick Red	65020	.063	.508	.326	6.8R 3.0/7.5	7.5R 2.5/10	Deep reddish brown.
Old Gold	65021	.393	.425	.427	3.1Y 6.7/7.1	2.9Y 6.8/6.6	Moderate yellow.
Mosstone	65022	.203	.362	.442	4.8GY 5.0/5.1	4.6GY 4.9/5.6	Dark yellow green.

The adopted values given in table 5 were based upon the measured values given in table 2, A and B. For all nonfluorescent and weakly fluorescent samples that were cross-checked (see table 3), there is no basis for doubting the reliability of the spectrophotometric result. Accordingly, the spectrophotometric values for the chromaticity coordinates, x and y, were adopted. The remaining samples, which were too far in color from the nearest neighbor for cross-checking, were checked by comparison with Munsell standards on the chromaticity-difference colorimeter. For these samples the adopted values are equally weighted means of the spectrophotometric values and those by way of the Munsell standards. Before averaging, however, the results by this alternate method were corrected by the addition of 0.010 to correspond to the greater amount of surface-reflected energy collected by the spectrophotometer; see eq 4 and 4b. For samples classed as strongly fluorescent, however, the spectrophotometer cannot be relied upon. The adopted values are therefore based only on comparisons with the Munsell standards by means of the chromaticity-difference colorimeter adjusted to the amount of surface-reflected energy corresponding to the angular illuminating and viewing conditions of the recording spectrophotometer.

A similar plan was followed in deriving adopted values of daylight reflectance for the samples of the standard card. The spectrophotometric result for all but 21 of the nonfluorescent and weakly fluorescent samples was averaged with the multipurpose-reflectometer result corrected by the addition of 0.010. For the 21 nonfluorescent and weakly fluorescent samples measured by means of the Macbeth-Martens reflectometer, the adopted values consist of equally weighted means of three independent determinations each, one by the spectrophotometer, one by the multipurpose reflectometer plus a correction of 0.010, and one by the Macbeth-Martens reflectometer plus a correction of 0.011. For the strongly fluorescent samples of the standard card, however, only the latter determination was given weight, neither the spectrophotometer nor the multipurpose reflectometer being applicable.

A slightly different plan was followed in deriving adopted values of daylight reflectance for the samples of the Army card. The grosgrain weave of these samples is such that in one of the positions used for measurement by the multipurpose and Macbeth-Martens reflectometers (ridges in plane of illuminant) an excess of surface-reflected light is collected, and in the other (ridges perpendicular to plane of illuminant), a deficiency; therefore, no correction was applied to the average.

The Munsell renotations in table 5 were found from the ICI specifications of columns 3, 4, and 5, in accord with the recommendations of the OSA Subcommittee on the Spacing of the Munsell Colors [26]. The renotation values were found from table II of the report of that subcommittee, and the renotation hue and chroma, from large-scale plots of figures 1 to 9 of that report. The Munsell book notations were also found from the ICI specifications of columns 3, 4, and 5. The process of conversion is the reverse of that described in section III, 5. The ISCC–NBS color designations in the last column were found from these book notations in the usual way [18], except that a number of samples that fall on the boundary between two color designations have been given a single rather than a double designation by carrying out the conversion to Munsell book notations to one more decimal place than is given in this table.

It will be noted that the ISCC–NBS designations often correlate well with the TCCA name, and in these cases the two designations supplement each other in a useful way. There are, however, a number of notable exceptions, such as 70078, 70178, 65002, and 65020. A study of these exceptions shows that minor revisions of the ISCC–NBS boundaries are quite feasible that would bring the method into considerably improved agreement with accepted color terminology in textiles. It is possible that a proposal for such boundary revisions will be submitted to the Inter-Society Color Council.

Table 6 gives TCCA cable numbers, visually estimated Munsell book notations, and departures of these book notations from the adopted values of table 5. The uncertainty of these estimated book notations is equivalent to about two-thirds of a hue step, two-tenths of a value step, and one-half of a chroma step, except for those found by extrapolation over a considerable range, in which case the uncertainty of the chroma estimation may easily be double this amount. Notations uncertain because of extrapolation are given only to the nearest hue and chroma step; others, except hues of low-chroma samples, to tenths. The average hue, value, and chroma differences are, respectively, 0.5 (for samples of chroma greater than 2.0), 0.1, and 0.4. From the generally negligible size of these departures, it may be seen that as intended, the methods of deriving the adopted values are such as to conform to the customary method of using the TCCA standards, that is, comparison of unknown colors with them by light from the sky through a vertical window.

TABLE 6.—*Visually estimated Munsell book notations of the TCCA color standards, and the differences between these estimates and the adopted book notations*

Cable number	Estimated Munsell book notation	Differences (estimated−adopted)			Cable number	Estimated Munsell book notation	Differences (estimated−adopted)		
		Hue	Value	Chroma			Hue	Value	Chroma
STANDARD COLOR CARD OF AMERICA									
70001	2.5Y 9.2/0.3	0.0	+0.1	−0.4	70056	7.0P 4.9/5.0	+1.0	0.0	−0.5
70002	2.5Y 9.2/1.0	+.5	+.1	−.6	70057	5.5P 4.5/8.5	+0.3	−.1	−.2
70003	2.5Y 9.0/1.8	−1.5	−.1	−.4	70058	3.0P 4.0/9.0	+.4	−.1	−.7
70004	2.5Y 8.4/2.8	+0.2	+.1	−.3	70059	2P 2.2/10	+1	.0	0
70005	2.5Y 8.4/4.8	.0	+.1	.0	70060	10PB 1.6/8	−1	.0	0
70006	2.0Y 8.3/7.2	+1.0	+.1	−.2	70061	7.5GY 6.2/7.0	+0.7	.0	+.2
70007	10B 8.2/0.8	+2	.0	+.1	70062	9.8GY 5.9/9.0	+.2	+.2	+1.5
70008	1.5PB 7.5/2.5	+1.9	−.1	+.3	70063	1.5G 4.4/9.0	+.1	−.1	+0.2
70009	10.0B 7.5/3.5	0.0	−.1	+.7	70064	2.0G 2.9/4.8	+.5	+.1	+.2
70010	1.0PB 6.5/3.8	+2.0	+.1	+.8	70065	5.0G 3.0/4.5	−.2	+.1	+.2
70011	2.0PB 6.6/4.0	+0.8	−.1	−.6	70066	3.0G 2.1/2.2	−1.1	.0	−.4
70012	1.0PB 6.3/7.0	+.3	.0	+.1	70067	3.0Y 8.4/8.0	−0.5	+.2	.0
70013	10R 8.5/2	+1	.0	0	70068	10YR 7.6/11	0	.0	0
70014	6R 8.3/5	0	−.2	0	70069	5YR 6.4/12	0	−.2	−1
70015	6R 8.0/6	+1	+.1	0	70070	4.0YR 6.2/12.5	+.7	−.2	−0.1
70016	3R 7.6/7	−1	−.1	0	70071	1YR 5.4/14	0	−.2	0
70017	3.0R 7.0/10.0	+0.8	−.2	−.2	70072	10R 5.0/16	+1	−.1	+1
70018	2.5R 6.3/8.5	.0	+.1	−.9	70073	9.0PB 4.6/6.0	+0.2	+.1	−0.6
70019	8BG 7.9/2.0	+1	+.2	+.7	70074	9PB 3.9/8	0	+.1	−3
70020	6.5BG 7.2/4.0	−1.0	+.1	−.1	70075	8.5PB 2.0/5.1	−.1	−.1	−0.2
70021	2.0B 6.3/6.0	+0.1	+.1	.0	70076	8.8PB 1.9/3.5	+.8	+.1	+.4
70022	4.5B 5.2/6.0	−.8	.0	−.7	70077	8PB 1.4/1.8	0	−.1	.0
70023	4.0B 3.4/6.2	+.8	−.2	−.4	70078	8PB 1.3/1.6	0	−.2	+.2
70024	2B 2.5/5	−2	+.1	0	70079	3R 5.1/12	0	+.1	−3
70025	8R 7.9/8	−1	.0	−1	70080	5R 4.2/14	0	−.2	−1
70026	10R 7.5/8	0	−.2	−1	70081	4R 3.3/12	0	.0	0
70027	9R 7.5/9	+1	−.1	−1	70082	3R 2.6/10	−1	+.1	0
70028	8R 7.0/10	+1	+.3	0	70083	4.5R 2.0/8.0	−0.1	.0	+1.0
70029	8R 5.6/10	+1	−.1	−1	70084	3.5R 2.0/5.0	+.6	−.1	+1.1
70030	6.5R 4.9/12.0	−0.2	.0	−0.6	70085	7.0PB 3.1/7.5	+.2	−.1	−0.8
70031	5.0GY 7.6/3.6	+1.1	+.1	+.2	70086	7.0PB 2.8/8.0	−.2	−.1	−1.1
70032	10.0GY 6.6/4.0	.0	+.1	+.7	70087	7.7PB 2.2/8.0	+.4	+.1	+0.3
70033	10.0GY 5.2/2.9	−1.2	−.1	.0	70088	6.5PB 2.2/2.8	+.3	+.1	.0
70034	10GY 4.4/1.8	+1	−.2	.0	70089	6.0PB 1.8/2.2	.0	+.1	−.4
70035	10GY 3.4/2.2	−1	+.2	+.5	70090	6PB 1.2/1.2	0	−.2	−.3
70036	10.0GY 2.1/2.2	−1.0	+.1	−.3	70091	9.5YR 7.3/4.0	+.3	−.2	.0
70037	6.0YR 7.1/6.0	−0.4	+.1	−.1	70092	7.5YR 5.2/3.8	+.2	−.2	−.3
70038	2.5YR 7.2/8.5	+.1	.0	−.5	70093	7.5YR 4.7/3.5	+.6	+.1	+.2
70039	9.0R 6.0/10.5	.0	−.2	−.7	70094	5.0YR 3.6/3.6	−.5	−.2	+.3
70040	7.7R 4.9/12.5	+.7	+.1	+.3	70095	5.0YR 2.5/3.2	+.8	.0	−.5
70041	7.5R 4.3/16	0	−.2	+1	70096	6YR 2.1/1.2	+1	−.3	.0
70042	6R 4.0/15	0	.0	0	70097	10RP 6.3/8	+1	−.2	−1.
70043	3.0PB 6.0/4.5	+.5	+.1	−.4	70098	10.0RP 5.1/9.0	+0.5	−.1	−1.3
70044	3.5PB 4.2/4.0	−.8	−.1	−.7	70099	10.0RP 4.1/8.0	+.2	.0	−0.6
70045	2.5PB 4.0/4.5	+.5	+.1	−.2	70100	9.5RP 3.1/8.5	.0	−.2	−.2
70046	4.0PB 3.2/4.3	+.4	+.1	−.4	70101	1.5R 1.7/4.8	+0.2	−0.1	+1.0
70047	3.2PB 2.6/5.5	−.9	−.2	−.4	70102	2R 1.6/2.0	+1.5	.0	0.0
70048	5.0PB 2.2/3.8	−.4	−.1	−.2	70103	1.0Y 6.2/2.5	−0.4	.0	+.2
70049	10RP 4.0/14	+1	+.1	0	70104	9.0YR 5.2/2.4	+.6	−.2	−.6
70050	1.0R 3.1/12	−0.5	−.1	0	70105	9.5YR 4.6/2.5	+.8	−.1	.0
70051	0.5R 3.0/11.0	−.1	−.1	+.6	70106	7YR 3.9/2.0	−1	−.1	+.1
70052	1R 2.6/10	0	.0	−1	70107	8.5YR 2.6/2.5	+0.3	.0	−.2
70053	10RP 2.6/10	−1	−.2	−1	70108	10YR 1.9/2.2	+1	−.2	+.6
70054	10RP 2.1/8	0	−.1	−1	70109	2PB 6.0/1.2	+2	−.2	.0
70055	6.5P 6.1/3.5	+.8	.0	−0.6	70110	2PB 4.9/1.4	−1	+.1	−.1

TABLE 6.—*Visually estimated Munsell book notations of the TCCA color standards, and the differences between these estimates and the adopted book notations*—Con.

Cable number	Estimated Munsell book notation	Differences (estimated−adopted)			Cable number	Estimated Munsell book notation	Differences (estimated−adopted)		
		Hue	Value	Chroma			Hue	Value	Chroma
STANDARD COLOR CARD OF AMERICA—Continued									
70111	4PB 3.4/1.2	+2	0.0	−0.2	70166	10.0GY 5.6/4.5	+1.2	.0	+.4
70112	4PB 2.9/1.2	+1	−.2	−.6	70167	5.0G 4.6/8.0	+0.9	+.2	−.5
70113	6PB 3.1/1.4	0	+.1	−.4	70168	4G 3.4/8	−1	+.3	0.
70114	8PB 1.9/0.8	+2	.0	−.6	70169	5YR 5.9/0.8	−2.5	−.1	−.4
70115	9.0YR 6.2/5.2	+0.2	−.2	−.5	70170	4R 5.0/0.6	−2.0	.0	−.1
70116	7.2YR 5.8/6.0	.0	−.1	−.8	70171	7.5RP 2.8/0.2	−12.5	−.1	−.2
70117	5.2YR 5.1/5.5	−.9	−.1	−.1	70172	10P 3.4/12	0	+.1	+1
70118	4.5YR 4.1/6.5	+.9	−.2	+.4	70173	9P 2.6/11	+1	.0	+1
70119	4.3YR 2.9/3.8	.0	+.1	−.5	70174	9.0P 2.4/7.5	+0.7	−.2	−0.1
70120	4YR 2.2/4	+1	.0	0	70175	0.5PB 5.0/3.5	−.3	.0	−.7
70121	5.8PB 6.6/2.2	+0.2	0.0	−0.5	70176	7.0B 3.2/4.0	−0.8	−0.2	−0.2
70122	6.0PB 5.4/4.0	.0	−.1	−.7	70177	0.5PB 3.3/4.8	−.9	.0	−.2
70123	5.8PB 4.0/5.0	−.2	−.1	−.2	70178	6R 6.0/12	+1	+.1	−1
70124	7.5R 5.8/4.3	+.4	−.1	−.8	70179	5R 4.0/14	0.0	−.2	0
70125	7.5R 4.7/4.2	+.3	−.2	−.8	70180	5R 3.2/14	.0	+.1	0
70126	9R 2.4/4	+1	−.1	0	70181	6.2R 7.2/4.0	+.1	−.2	−.8
70127	8.8YR 7.9/4.4	+0.2	−.2	−.8	70182	2.5R 5.7/5.5	+.3	.0	−1.0
70128	9.0YR 6.0/4.2	.0	−.1	−.1	70183	7.5Y 6.9/4.8	+.9	−.1	+0.2
70129	9.8YR 4.8/4.0	+.7	.0	−.4	70184	3.0Y 3.7/3.2	+.8	+.2	+.4
70130	2G 4.6/1.8	+2	.0	+.1	70185	10R 6.6/0.4	−5	−.1	−.6
70131	5G 4.0/2.0	−2.5	.0	−.1	70186	2Y 3.5/0.4	+2	.0	+.2
70132	9G 2.0/1.6	−1.6	−.2	−.5	70187	2.0Y 6.9/3.2	+0.3	+.1	−.2
70133	8P 6.6/6	0	−.1	+1	70188	2.0Y 5.6/2.8	+.8	−.1	−.1
70134	7.0P 3.6/5.5	.0	−.1	−0.7	70189	7.0RP 5.0/5.5	+1.0	−.1	−.2
70135	7.0P 2.0/4.2	+.5	−.2	−.1	70190	8.5RP 2.1/3.5	+1.6	−.1	−.1
70136	3Y 7.0/1.3	0	+.2	−.3	70191	6.0YR 5.9/4.5	+0.5	−.1	+.5
70137	10YR 3.1/0.8	−1.0	.0	−.2	70192	2.2YR 3.3/3.8	−.6	.0	+.1
70138	10YR 2.6/0.6	0	−.2	−.3	70193	4Y 6.6/1.0	+1	.0	+.1
70139	9.8YR 6.4/2.0	+.5	+.1	−.4	70194	2.0YR 6.8/3.5	+0.6	+.2	+.1
70140	4.0YR 3.9/3.2	−.2	−.1	+.2	70195	2.0PB 5.4/2.2	−1.6	.0	+.3
70141	4.5YR 2.5/3.2	+.9	+.1	−.3	70196	2.0Y 6.3/4.5	+0.4	−.2	−.4
70142	7.0B 5.2/3.2	−.7	.0	−1.0	70197	10.0GY 7.4/4.2	−.1	+.2	.0
70143	1.5PB 4.1/4.5	+.5	+.1	−0.8	70198	5.5RP 4.8/9.0	+.8	.0	−.3
70144	2.5PB 3.2/4.0	−.6	.0	.0	70199	2Y 7.0/1.4	+1	−.1	−.5
70145	7.0BG 5.5/2.5	−.1	+.1	−.5	70200	2G 6.7/2.2	+1	+.1	+.6
70146	8.0BG 4.0/2.5	−.2	−.2	−.3	70201	7.5YR 6.6/3.2	−0.3	+.3	.0
70147	5.0B 2.8/3.0	−.3	−.1	−.3	70202	2.0RP 6.0/5.8	+1.4	−.1	−.9
70148	4YR 7.6/6	−1	−.2	−1	70203	2.6Y 7.9/8.0	−0.1	.0	+.7
70149	8.0R 5.9/11.5	+0.6	.0	−0.7	70204	1.0B 5.3/2.8	−.8	+.1	−.6
70150	7.0R 4.0/9.2	−.5	+.2	−1.0	70205	5.0Y 8.4/9.5	+.6	+.2	+.6
70151	2Y 5.9/0.4	+2	−.2	−0.2	70206	6R 6.8/11	+1	−.2	−1
70152	10P 5.8/0.3	−10	−.1	.0	70207	9.0BG 5.1/6.0	−0.2	.0	−0.1
70153	5P 4.6/0.3	−2	.0	−.2	70208	10.0Y 7.2/8.2	+1.0	−.2	−.1
70154	3.0GY 5.6/6.0	+0.2	−.1	+.5	70209	4PB 3.5/13	−1	+.1	−1
70155	3.5GY 4.9/5.5	+.5	.0	+.5	70210	2R 4.0/14	−1	+.1	0
70156	3.5GY 3.2/4.5	+.4	+.1	.0	70211	3.0PB 3.6/6.5	+0.1	−.1	−.2
70157	2.5Y 6.0/5.8	+.1	+.1	−.4	70212	2.0P 4.0/8.0	+0.2	−.1	−1.7
70158	2.0Y 5.6/6.0	+.9	+.1	−1.0	70213	4RP 3.9/15	0	+.1	−1
70159	2Y 3.2/4	.0	.0	0	70214	4.7G 5.9/7.2	+.5	−.1	−0.5
70160	1.0YR 4.7/9.2	−.2	−.1	−0.6	70215	4Y 6.2/9	+1	−.1	0
70161	10.0R 3.2/8.0	+.1	.0	.0	70216	8.0PB 2.2/9.5	−0.3	−.2	−.1
70162	10.0R 3.1/6.5	+.2	+.1	+.7					
70163	2.0RP 3.7/4.8	−.5	+.1	−.6					
70164	8.5P 1.7/2.2	.0	−.1	−1.0					
70165	7.5P 1.6/0.8	+.5	−.2	−0.4					

TABLE 6.—*Visually estimated Munsell book notations of the TCCA color standards, and the differences between these estimates and the adopted book notations*—Con.

Cable number	Estimated Munsell book notation	Differences (estimated—adopted)			Cable number	Estimated Munsell book notation	Differences (estimated—adopted)		
		Hue	Value	Chroma			Hue	Value	Chroma
				UNITED STATES ARMY COLOR CARD					
65001	2Y 7.2/10	+1	−0.1	−1	65011	7.0PB 2.1/3.5	−0.2	−0.2	−0.5
65002	7.5YR 6.6/11	+0.5	+.1	−1	65012	6PB 1.8/0.1	+1	+.2	−.2
65003	3.5YR 5.9/11.5	+0.4	.0	−0.5	65013	2R 3.2/11	0	.0	−1
65004	9R 5.0/13	0	−.2	−1	65014	8.0B 5.0/2.2	+.7	−.2	−0.7
65005	4Y 8.7/1.5	+1	−.1	−0.2	65015	10.0YR 7.0/5.0	+.4	−.1	−.4
65006	6R 3.3/12	0	.0	−1	65016	5.0YR 3.0/3.5	.0	+.2	.0
65007	2.0G 3.0/3.2	+.2	−.1	−0.1	65017	5.5R 2.1/3.5	+.8	.0	+1.0
65008	3Y 5.9/0.4	+2	−.1	.0	65018	N 1.8/	-------	+.1	−0.1
65009	2P 2.6/8	0	.0	−1	65019	5.5PB 2.0/3.5	−0.3	−.1	+.6
65010	7.0PB 2.2/10.0	−.5	.0	−1.6	65020	7.5R 2.8/10	0	+.3	0
					65021	2.5Y 6.8/7.0	−.4	.0	+.4
					65022	5.0GY 5.0/6.5	+.4	+.1	+.9

The sources of error discussed in the previous section may combine to yield a rather large possible discrepancy between the adopted book notation and the corresponding visual estimate in table 6. A review of the hue and value differences recorded there, however, indicates that these possibilities have not been realized. There are only five samples (70028, 70096, 70168, 70201, 65020) yielding a value discrepancy as large as 0.3, and the discrepancies in hue greater than one step are ascribable to uncertainties arising from low chroma, extrapolation, or local irregularities in the spacing of the Munsell standards. It may be of interest, however, to review the sources of error that have caused the two outstanding discrepancies in chroma, 3 steps each for Cornflower Blue (70074) and Geranium (70079).

Both of these samples are strongly fluorescent, and the adopted chromas are therefore based entirely upon a comparison with Munsell standards by means of the chromaticity-difference colorimeter. As was often done for samples yielding poor agreement, these comparisons were repeated several times by two observers (GBR, DBJ) and for different Munsell standards with closely agreeing results. From the degree of agreement obtained the uncertainty of the chroma is estimated at 0.4 for Cornflower Blue and 0.3 for Geranium. Cornflower Blue formed a noticeably metameric combination with the neighboring Munsell standards and may have yielded poorer agreement on that account. A correction (eq 4) was then applied for the greater amount of surface-reflected light characteristic of observation before a window. This correction is applied because of the average disparity in angular conditions between the standardized conditions of measurement and the somewhat uncontrolled conditions of use of the samples. From the tristimulus specifications so found (Y, x, y) the Munsell book notations were read by extrapolation with an uncertainty of about 0.5 chroma step for Cornflower Blue and 1.5 for Geranium.

For any one controlled set of angular conditions the visual estimates of chroma for these samples are uncertain by about 1.0 chroma step, the estimate for Geranium because it is obtained by extrapolation, that for Cornflower Blue by more than the usual 0.5 chroma step because of a local irregularity in the spacing of the Munsell standards. This local irregularity consists of two factors: first, the hue interval from 7.5PB 4/10 to 10PB 4/10 is unusually large making interpolation difficult, and second, the two samples 10PB 4/8 and 10PB 4/10 are nearly alike, making the uncertainty seem more important in terms of book-notation chroma than it really is. The uncertainty introduced by using simple observation before a window rather than controlled angular and spectral distributions is estimated at 0.7 chroma step for both samples. And, finally, Cornflower Blue is one of the few TCCA colors giving significant evidence of impermanence (see table 4). Recent measurements of the unmounted sample indicates that it has decreased in chroma by about 1.0 since the original measurement. The estimate of maximum discrepancy for Cornflower Blue is therefore $0.4+0.5+1.0+0.7+1.0=3.6$ chroma steps, and that for Geranium is $0.3+1.5+1.0+0.7=3.5$. That the observed discrepancies, three steps each, for these colors come so close to the estimate of maximum possible discrepancy is an indication that nearly the maximum of the possible component errors has been realized in each case, and furthermore that the directions of the component errors have agreed so that the effects are cumulative.

This analysis of possible discrepancy serves also to bring out the fact that a large part of it for these two samples (1.5 out of 3.6 for Cornflower Blue, 2.5 out of 3.5 for Geranium) arises from the limitations of the Munsell standards, themselves, their limited range and local irregularities. Samples that can be given a Munsell book notation by interpolation would, of course, generally yield a considerably smaller estimate of maximum possible discrepancy. Furthermore, for the purpose of controlling the color of redyeings of the TCCA standards, the ICI specification, (Y, x, and y) could be used and would have an uncertainty corresponding only to the first component (0.4 chroma step for Cornflower Blue, 0.3 for Geranium).

In conclusion, it may be stated that this measurement in fundamental terms (Y, x, and y) of a set of material color standards widely used in commerce may well mark the beginning of an important new era in the utilization of dyestuffs. Just as the modern automobile with interchangeable parts is made possible by fundamental standards of length combined with accurate and practical secondary length standards, so also may we expect American industry to find important, and as yet largely unforeseen, ways to make use of these sets of secondary standards of color. Only through their relation to a fundamental standard of length do micrometer calipers and gage blocks reach their full usefulness, and likewise the textile color cards require a fundamental colorimetric calibration in order to acquire permanent meaning. The immediate gain to government agencies in simplifying their statements of color requirements through correlation between the Standard Color Card of America and the American War Standard ASA–Z44–1942 can be fairly well assessed now, but the full worth of this work to the textile industry and the consumer will not become known for many years. By sponsoring and supporting this necessary forward-looking step, the Textile Color Card Association has performed a service not only to the textile industry but to all color technology.

VII. SUMMARY

The colors of the samples of the Standard Color Card of America and those of the U. S. Army Color Card have been measured either by means of the recording spectrophotometer or, for fluorescent samples, by colorimetric comparison with standards previously so measured. The resulting color specifications serve as a record against which future dyeings of textile standards may be checked whenever it is desired to know whether they conform under the conditions of use to those measured. These color specifications are given in the three different ways recommended by American War Standard Z44–1942; they are therefore in a form convenient for correlation with existing color specifications so that extension of the already wide use of the TCCA color standards will be facilitated.

It has been shown that although the spectrophotometric technic recommended by Z44–1942 is often inapplicable to fluorescent samples, themselves, colorimetric comparison with nonfluorescent standards previously calibrated by that technic is a practical way of following the provision in Z44–1942 which states that the "spectrophotometer shall be recognized as the basic instrument in the fundamental standardization of color."

The uncertainty ascribable to the various known sources of error (metamerism, variation in angular conditions, variation from sample to sample, errors of interpolation and extrapolation along the Munsell color scales) has been evaluated. It has been shown that the angular condition of the recording spectrophotometer (approximately normal-diffuse) accords somewhat better for these textile samples with the customary condition of viewing before a window than those (45°-normal) recommended by the International Commission on Illumination [30]. And, finally, the reliability of the adopted values has been established by detailed cross-checks and by a comprehensive closing check under the conditions of use. The TCCA standards comprise the first extensive series of material color standards to receive a calibration that has been thus cross-checked in detail. Furthermore, they cover important color ranges not adequately covered by any other set of material color standards calibrated for ICI standard illuminant *C* (average daylight).

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