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United States Standard for the Colors of Signal Lights

Handbook 95

United States Department of Commerce
National Bureau of Standards

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(Continued on p. 3 of cover.)

UNITED STATES DEPARTMENT OF COMMERCE • Luther S. Hodges, *Secretary*
NATIONAL BUREAU OF STANDARDS • A. V. Astin, *Director*

United States Standard for the Colors of Signal Lights

Prepared in Collaboration with the
U.S. National Committee on Colors of Signal Lights
by
F. C. Breckenridge

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Foreword

Reliable recognition of signal light colors is an important factor in the safety of modern land, sea, and air transportation. With the growth of international travel, the signal lights of each country are coming to be used more and more by the citizens of other countries, and a need for international standardization has become apparent. The U.S. Standard for the Colors of Signal Lights has been prepared as a recommended standard to help bring specifications used in this country for signal light colors into agreement with international usage as embodied in the recommendations of the International Commission on Illumination (CIE). This standard may also be expected to improve the specifications technically, eliminate wasteful differentiation, and contribute toward maximum reliability in signal-light recognition.

The U.S. Standard for the Colors of Signal Lights was developed by the U.S. National Committee on the Colors of Signal Lights under the sponsorship of the U.S. National Committee of the CIE. The National Bureau of Standards cooperated in this effort by providing the technical data upon which the Standard is based. The Bureau is pleased to have the opportunity to increase the usefulness of the Standard by publishing it as an NBS Handbook.

A. V. Astin, *Director.*

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Preface

This standard has been developed by the U.S. National Committee on the Colors of Signal Lights under sponsorship of the U.S. National Committee of the International Commission on Illumination. This committee is composed of representatives of the following organizations:

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Department of the Air Force
  Headquarters U.S.A.F.
Department of the Army
  Transportation Materiel Command
    Directorate of Engineering
Department of the Navy
  Bureau of Naval Weapons
  Bureau of Ships
Department of Commerce
  National Bureau of Standards
Federal Aviation Agency
  Systems Research and Development Service
Interstate Commerce Commission
Treasury Department
  U.S. Coast Guard

Associations

American Association of Motor Vehicle Administrators
Association of American Railroads, Signal Section
Institute of Traffic Engineers
International Municipal Signal Association
Society of Automotive Engineers

Manufacturers

Corning Glass Works
E. I. du Pont de Nemours & Co.
Kopp Glass, Inc.
Rohm & Haas Company

January 1964.

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January 1, 1964

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Abstract

The standard provides in part I basic chromaticity definitions defining the chromaticities that are considered safe for use as representing the named colors. These are the basis for the selection of the national standard filters and for the tolerances given in part II for duplicating them. The procurement requirements of parts III and IV are based primarily on sets of these filters in combination with prescribed sources although provision is also made for procurement under the basic chromaticity definitions in cases in which it is impracticable to base the procurement on filters. Part V provides guidance in selecting signal colors for new uses, and part VI provides methods for special laboratory tests and serves as a technical interpretation of the practical tests prescribed in parts III and IV.

Contents

Throughout the text Roman numerals are used preceding the numbers of figures, tables, and sections to indicate the part in which these will be found.

Part I. Definitions Underlying the Specification of Colors for Light Signals

Introduction

Part I presents basic definitions for the chromaticities of the signal-light colors included in this standard. As a foundation for the definitive equations, which are stated in sec. 3, pertinent references are given in sec. 1 and general definitions in sec. 2. The chromaticity definitions are not to be considered as purchase specifications but as the boundaries within which procurement specifications are to be held. In addition to part I, procurement specifications will be necessary. Requirements for procurement are given in parts III and IV of the Standard.

1. Reference Publications

The publications cited below define the coordinate systems used in this standard and provide other information for the interpretation of the standard and the procurement specifications based upon it.

1. Proc. Intern. Comm. Illum. (C.I.E.), Eighth Session, Compt. Rend., 1931, pp. 19–29.
2. The 1931 I.C.I. (C.I.E.) Standard Observer and Coordinate System for Colorimetry, D.B. Judd, J. Opt. Soc. Am., **23**, p. 359 (1933).
3. Handbook of Colorimetry, A. C. Hardy, The Technology Press, Massachusetts Institute of Technology, Cambridge, Mass., 1936. Standard Observer is defined on p. 7 et seq.
4. Rectangular Uniform-Chromaticity-Scale Coordinates, F. C. Breckenridge and W. R. Schaub, J. Opt. Soc. Am., **29**, p. 370 (1939).
5. The Psychophysics of Color, Committee on Colorimetry, J. Opt. Soc. Am., **34**, p. 245 (1944).
6. Quantitative Data and Methods for Colorimetry, Committee on Colorimetry, J. Opt. Soc. Am., **34**, p. 633 (1944).
7. Tables for Transforming Chromaticity Coordinates from the I.C.I. System to the R-U-C-S System, NBS Letter Circ. LC–897, May 1948.
8. Colorimetry, NBS Circ. 478 (1950).
9. A Co-ordinated Specification for the Colours of Light Signals, J. G. Holmes, Proc. Intern. Comm. Illum. (C.I.E.) Eleventh Session (Paris) 1948, p. 512.
10. Proc. Intern. Comm. Illum. (C.I.E.) Twelfth Session (Stockholm) 1951, **1**, Sec. 26e; **3**, pp. 70–73.
11. Spectrophotometry (200 to 1000 millimicrons), NBS Circ. 484 (1949).
12. The Science of Color, Committee on Colorimetry of the Optical Society of America (see esp. Definitions, p. 363) 1953.
13. Proc. Intern. Comm. Illum. (C.I.E.) Thirteenth Session (Zurich) 1955, **1**, Sec. 1.3.3.
14. Colours of Light Signals, Publication C.I.E. No. 2 (W–1.3.3) 1959.

2. General Definitions

The following technical terms are used throughout this standard in the senses in which they are defined in this section. (References are to sec. 1 above.)

2.1. Standard Observer and Coordinate System

The standard observer and coordinate system are those adopted by the International Commission on Illumination (C.I.E.) at its Eighth Session at Cambridge, England, in 1931 (ref. 1, 2, 3). The coordinates x and y only are used in this standard. The standard observer is defined for cone vision and normal adaptation. Darkness adaptation with some inclusion of rod vision does not prevent correct recognition of colored lights if the luminance is sufficient for the light to be seen by a light-adapted observer.

2.2. Hue

Hue is that attribute of certain colors which determines whether the color is perceived as red, yellow, green, blue, purple, or as an intermediate color. Colors which have no hue are called neutral colors. A great variety of qualities of light are perceived as neutral under various circumstances. In general, colors represented in the region of the C.I.E. chromaticity diagram near $x=0.333$, $y=0.333$ may be considered as neutral colors under ordinary conditions of observation.

2.3. Saturation

Saturation is that attribute of a color which determines whether the color is perceived as much or little different from neutral, the less prominent the hue, the lower the saturation.

2.4. Chromaticity

Chromaticity is the color-quality of a light as defined by its chromaticity coordinates which in turn are computed from the relative energy distribution of the light in accordance with procedures specified for each system of coordinates. (For the C.I.E. chromaticity coordinates, see ref. 1.) Chromaticity is independent of the luminance, or other quantitative measure of the intensity of light being observed. It correlates with hue and saturation, but since these are subjective quantities, they can not be measured, though they can be estimated with some reliability. Hue and saturation, however, do vary with the luminance of the observed light and its background, and also with the color vision of the observer even when the relative energy distribution of the light itself remains the same. At a given luminance, the chromaticity of a light seen against a black background by a chromatically normal observer determines its hue and saturation. Under favorable conditions, hue and saturation may be estimated by means of curves or tables from the coordinates (x,y or x'',y''), but the relationship is neither simple nor exact. It is necessary to use the terms "hue" and "saturation" when referring to differences in the appearance of two colors, but, on account of the complex and approximate nature of the relationship of these quantities to the spectral energy distribution, it is preferable to express the precise results which may be computed from the relative spectral energy in terms of chromaticity coordinates.

2.5. Luminance

Luminance is luminous flux per unit solid angle emitted per unit projected area (ref. 12, p. 374).

2.6. Transmittance

Transmittance is the ratio of the luminous flux transmitted by the object to the luminous flux incident. (Properly this is "luminous transmittance", but it is customary to use the shortened form when no confusion can result.) (ref. 12, p. 374.)

2.7. Internal Transmittance

Internal transmittance is the ratio of the luminous flux incident upon the second surface of an object to that transmitted by the first surface (ref. 12, p. 372).

2.8. Transmissivity

Transmissivity is the internal transmittance for a unit thickness of a nondiffusing [1] substance (ref. 12, p. 384).

[1] NOTE: The term "transmissivity" is also used for linear transmission through diffusing media.

2.9. Transmittance Ratio

Transmittance ratio is the ratio of the light flux transmitted by a test piece to the light flux transmitted within the same solid angle by a standard piece of the same design made from colorless material of a nature similar to that of the test piece. The light sources in the two cases must be essentially identical. Transmittance-ratio requirements are applicable to all ware, but especially to ware that alters the candlepower distribution (such as lenses or prisms). If the candlepower of a unit with colorless ware is multiplied by the transmittance ratio, the product is approximately the candlepower to be expected with the test ware substituted for the colorless ware. For a plane filter, the transmittance ratio is equal to the internal transmittance, neglecting internal losses in the colorless filter used for reference.

2.10. Color Temperature

Color temperature of a source is the temperature of a complete (Planckian) radiator having the same chromaticity as the source in question (ref. 12, p. 367). Color temperature is usually expressed in degrees Kelvin (°K). The numerical value of a color temperature depends on the value assigned to C_2 in Planck's radiation equation for the complete radiator. For example, with the several values of C_2 indicated the following values of color temperature T all represent the same spectral energy distribution.

C_2	T
14320	2842 °K
14350	2848 °K
14380	2854 °K

In this standard, color temperature is expressed by nominal values given to the nearest 10 °K, based upon C_2=14380.

2.11. Similar Chromaticity Characteristics

A light-transmitting material has chromaticity characteristics similar to a standard material for a given light source over a stated chromaticity range if the chromaticity coordinates, within that range, of the light from the given source transmitted by any thickness of the standard material can be duplicated within stated tolerances by the chromaticity coordinates of the light from the same source transmitted by some thickness of the subject material. As used in this standard and in specifications based upon it the phrase "similar chromaticity characteristics" will be understood to include the range of illuminants to be used with the light-transmitting material in service, and the chromaticity range extends from the chromaticity of the applicable pale limit to that of the second hue limit, or to the chromaticity of such thickness of the subject material as has the minimum acceptable transmittance, whichever gives the lesser range. In this standard the range of illuminants is that specified in part II, table II–1; the minimum transmittance is that stated in table II–2; and the tolerance is that given in table II–3.

2.12. Color Standard

A color standard is a set of two or more filters in combination with a source of designated color temperature which together define one or more limits of acceptable chromaticity for the color represented and provide a basis for controlling the transmittance of ware which is to be used as the filter element of a signal light.

2.13. Basic Color Standard

A basic color standard is a color standard adopted by one, or a group, of the organizations which sponsor the U.S. Standard for the Colors of Signal Lights. The basic standards all include two or more filters having the same chromaticity characteristics for a designated range of color temperatures. With each is associated a set of minimum transmittance requirements. The acceptable region of chromaticity of each standard is designed to provide limits for ware which will give a signal within the basic chromaticity definition for the color represented when the ware is used with any source within a stated range of color temperatures.

2.14. Purchaser's Color Standard

A purchaser's color standard is a color standard adopted by a purchasing authority for a purpose which cannot be adequately accomplished with one of the basic standards.

2.15. Manufacturer's Color Standards

A manufacturer's color standard is a color standard submitted by a bidder and accepted by a procuring agency to control the purchase of ware to be furnished in accordance with a procurement specification on a stipulated order or contract. The chromaticity coordinates represented by a manufacturer's standard should be determined by a laboratory equipped to make such determinations and approved by the procuring agency before the standard is accepted. Filters already furnished by the bidder, or his prospective subcontractor, to the agency requesting the bid, may be designated by a bidder as a manufacturer's standard for a specific quotation.

2.16. National Standard Filter

A national standard filter is one of a set of filters adopted by the U.S. National Committee on Colors of Signal Lights to represent a basic color standard (2.13) and accepted by the National Bureau of Standards for reference and preservation as a national standard. The characteristics of the national standard filters are described in part II of the U.S. Standard.

2.17. Organization Standard Filter

An organization standard filter is one of a set of filters adopted by an organization which sponsors a basic color standard to represent that standard. Organization standard filters may be deposited with the National Bureau of Standards for reference and preservation if they are acceptable to that Bureau.

2.18. Duplicate Standard Filter

A duplicate standard filter is a filter certified as having characteristics duplicating those of a national or organization standard filter within the established tolerances stated in part II.

2.19. Working Standard Filter

A working standard filter is a filter adopted by a purchasing agency, a manufacturer, or a laboratory to represent a chromaticity, range of chromaticities, or a known transmittance.

2.20. Basic Chromaticity Definition

A basic chromaticity definition is a set of boundaries, expressed in terms of a recognized system of chromaticity coordinates, established to control the overall range in chromaticity of a stipulated class of signal lights.

3. Basic Chromaticity Definitions

3.1. General

The basic chromaticity definitions of this section have been adopted by one or by a group of the agencies which sponsor the U.S. Standard for Signal Light Colors. They are stated in the coordinates of the C.I.E. Coordinate System (ref. 2). Since this system does not represent chromaticity differences uniformly, a parallel column has been included in each table giving the approximately equivalent limits in the Rectangular-Uniform-Chromaticity-Scale system (ref. 4). In deriving these approximate equivalents, small deviations for both x'' and y'' have been allowed in some cases in order to keep the equations simple, but the maximum error in the left-hand side of the equation when true values are substituted in the right-hand member will not exceed 0.0015.

3.2. Definition

A light is of the color named if the C.I.E. coordinates representing its chromaticity are within the boundaries stated for that color in table I–1 which follows. The first color defined in each category is designated as signal red, signal yellow, etc., and contains all the chromaticities acceptable for any application coming within the province of this standard. For each of the colors except blue, further restriction is required for one or more applications and provision is made for this by giving the equation of the restricting boundary, and such boundaries are to be used in lieu of the corresponding general boundaries for applications which call for a more restricted range of chromaticities. The remaining boundaries of the more restricted colors are the same as the corresponding boundaries of the signal color. The symbols "$>$" and "$<$" indicate the acceptable side of the boundary.

Figure I–1 shows the boundaries of table I–1 plotted in C.I.E. coordinates and figure I–2 shows these boundaries in RUCS coordinates.

TABLE I–1. *Basic chromaticity definitions**

Colors	Standard Boundaries in C.I.E. Equations	Approximate Equivalents in RUCS Equations
3.3 Signal Red		$\Delta x''=x''-0.075$
Purple boundary	$x+y\geqq 0.992$	$x''\geqq +0.0725$
Yellow boundary	$x-y\geqq 0.330$	$y''\leqq -0.317+0.16\Delta x''$
3.31 Intermediate Signal Red		
†Purple boundary	$x+y\geqq 0.992$	$x''\geqq +0.0725$
Yellow boundary	$x-y\geqq 0.380$	$y''\leqq -0.375+0.4\Delta x''$
3.3.2 Restricted Signal Red		
Purple boundary	$x+y\geqq 0.997$	$x''\geqq +0.0741$
Yellow boundary	$x-y\geqq 0.405$	$y''\leqq -0.407+0.5\Delta x''$
3.4 Signal Yellow		
Red boundary	$y\geqq 0.383$	$y''\geqq -0.225-4\Delta x''$
White boundary	$x+y\geqq 0.872+0.200x$	$x''\geqq +0.068-0.026y''$
Green boundary	$x\geqq 0.550$	$y''\leqq -0.120+3\Delta x''$
3.4.1 Intermediate Signal Yellow		
†Red boundary	$y\geqq 0.383$	$y''\geqq -0.225-4\Delta x''$
†White boundary	$x+y\geqq 0.872+0.200x$	$x''\geqq +0.068-0.026y''$
Green boundary	$x-y\geqq 0.124$	$y''\leqq -0.136+0.5\Delta x''$
3.4.2 Restricted Signal Yellow		
Red boundary	$y\geqq 0.400$	$y''\geqq -0.194-4\Delta x''$
†White boundary	$x+y\geqq 0.872+0.200x$	$x''\geqq +0.068-0.026y''$
Green boundary	$x-y\geqq 0.124$	$y''\leqq -0.136+0.5\Delta x''$
3.5 Signal Green		
Yellow boundary	$x\leqq 0.360-0.080y$	$x''\leqq +0.715y''$
White boundary	$x\leqq 0.650y$	$y''\geqq +0.085-0.600x''$
Blue boundary	$y\geqq 0.390-0.171x$	$x''\geqq -0.150y''$
3.5.1 Intermediate Signal Green		
Yellow boundary	$y\leqq 0.730(1-x)$	$x''\leqq +0.045-0.0075y''$
†White boundary	$x\leqq 0.650y$	$y''\geqq +0.085-0.600x''$
Blue boundary	$y\geqq 0.500-0.500x$	$x''\geqq -0.020y''$
3.5.2 Restricted Signal Green		
Yellow boundary	$y\leqq 0.730(1-x)$	$x''\leqq +0.045-0.0075y''$
White boundary	$x\leqq 0.425y$	$y''\geqq +0.142-0.450x''$
Blue boundary	$y\geqq 0.500-0.500x$	$x''\geqq -0.020y''$
3.6 Signal Blue		
Green boundary	$y\leqq 0.065+0.805x$	$x''\leqq -0.950y''$
White boundary	$y\leqq 0.400-x$	$x''\leqq -0.125+0.350y''$
Purple boundary	$x\leqq 0.100+0.700y$	$y''\geqq -0.370x''$
3.7 Signal White Signal white includes all chromaticities which qualify as any of the four whites defined in sec. 3.7.1 to 3.7.4.		
3.7.1 Variable Source White		
Green boundary	$y-y_0\leqq 0.003$	y_0 being the y-coordinate of the Planckian locus at the point at which x_0 is equal to x.
Purple boundary	$y_0-y\leqq 0.003$	
Yellow boundary	$x\leqq 0.555+0.750(y-0.405)$	$y''\geqq -0.1515$
Blue boundary	$x\geqq 0.325$	$x''\geqq -0.000+0.900(y''-0.009)$
3.7.2 Beacon White Green boundary	$y-y_0\leqq 0.003$	y_0 being the y-coordinate of the Planckian locus at the point at which x_0 is equal to x
Purple boundary	$y_0-y\leqq 0.003$	
Yellow boundary	$x\leqq 0.490+0.500\ (y-0.410)$	$y''\geqq -0.094+0.400\ (x''-0.056)$
Blue boundary	$x\geqq 0.325$	$x''\geqq -0.000+0.900\ (y''-0.009)$

*The recommended uses for the several colors are given in table V–1.
†Same as for corresponding "signal" color.
NOTE: An equation of the form:

$$y=a+b(x-c) \text{ is satisfied if } x=c \text{ and } y=a$$

In those cases in which the boundary definitions have been expressed with this type of equation, the constants a and c are the coordinates of a point close to the Planckian locus and approximate a critical point for the acceptance or rejection of a chromaticity. Since b is the slope, or the reciprocal of the slope, of the boundary (either $\Delta y/\Delta x$ or $\Delta x/\Delta y$), any small correction necessary for an exact value is reduced to the form $\Delta y=b\Delta x$ or $\Delta x=b\Delta y$.

Table I-1. *Basic chromaticity definitions*—Continued

Colors	Standard Boundaries in C.I.E. Equations	Approximate Equivalents in RUCS Equations
3.7.3 Lunar White		
Green boundary	$y \leqq 0.195+0.500x$	$x'' \leqq +0.016-0.571y''$
Purple boundary	$y \geqq 0.170+0.500x$	$x'' \geqq -0.002-0.586y''$
Yellow boundary	$x \leqq 0.445+0.333\ (y-0.405)$	$y'' \geqq -0.060+0.700\ (x''-0.045)$
Blue boundary	$x \geqq 0.325$	$x'' \geqq +0.000+0.900\ (y''-0.009)$
3.7.4 Blue White		
Green boundary		
For $x<0.330$	$y \leqq 0.030+x$ and	$y'' \leqq +0.021-0.844x''$
For $x>0.330$	$y \leqq 0.195+0.500x$	$x'' \leqq +0.016-0.571y''$
Purple boundary		
For $x<0.330$	$y \geqq 0.005+x$ or	$y'' \geqq +0.004-0.794x''$
For $x>0.330$	$y \geqq 0.170+0.500x$	$x'' \geqq -0.002-0.586y''$
Yellow boundary	$x \leqq 0.445+0.333\ (y-0.405)$	$y'' \geqq -0.060+0.700\ (x''-0.045)$
Blue boundary	$x \geqq 0.265-0.250\ (y-0.280)$	$x'' \geqq -0.037+0.700\ (y''-0.040)$

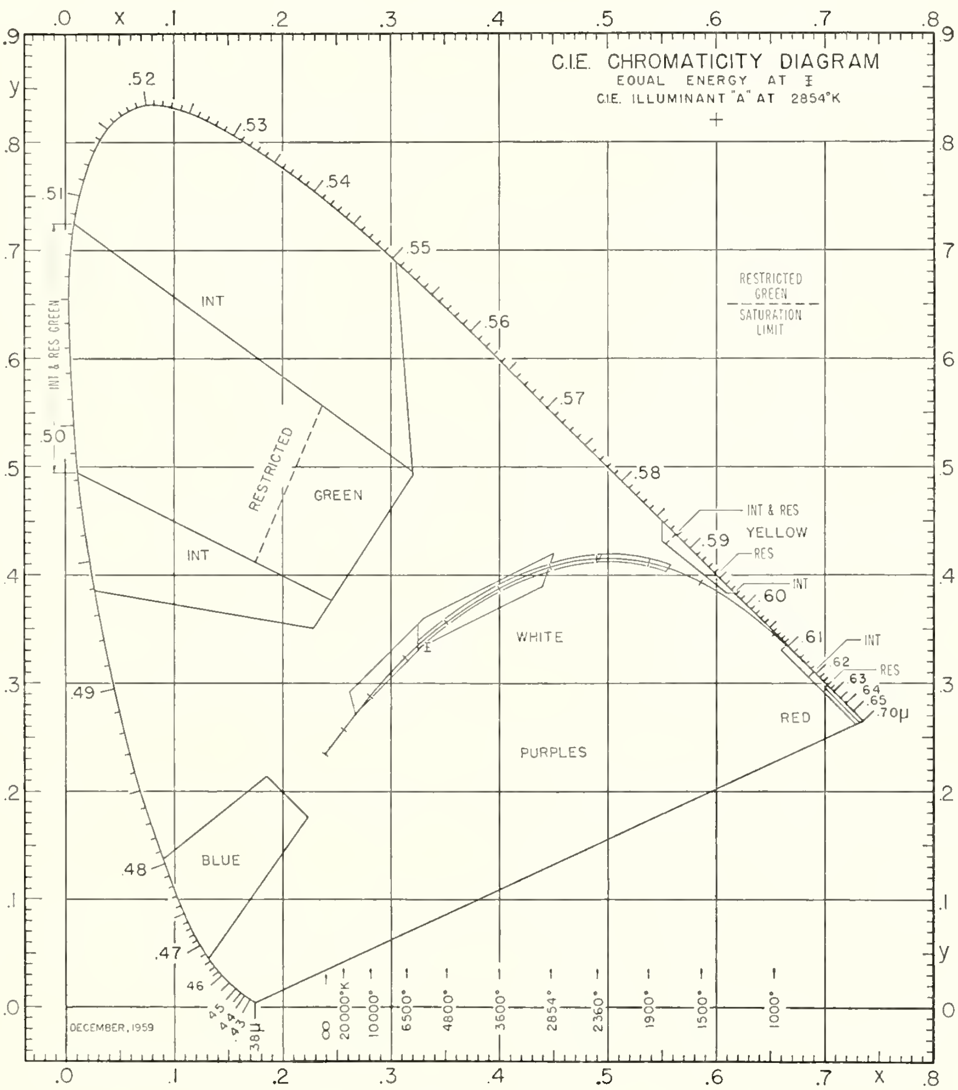

Figure 1-1

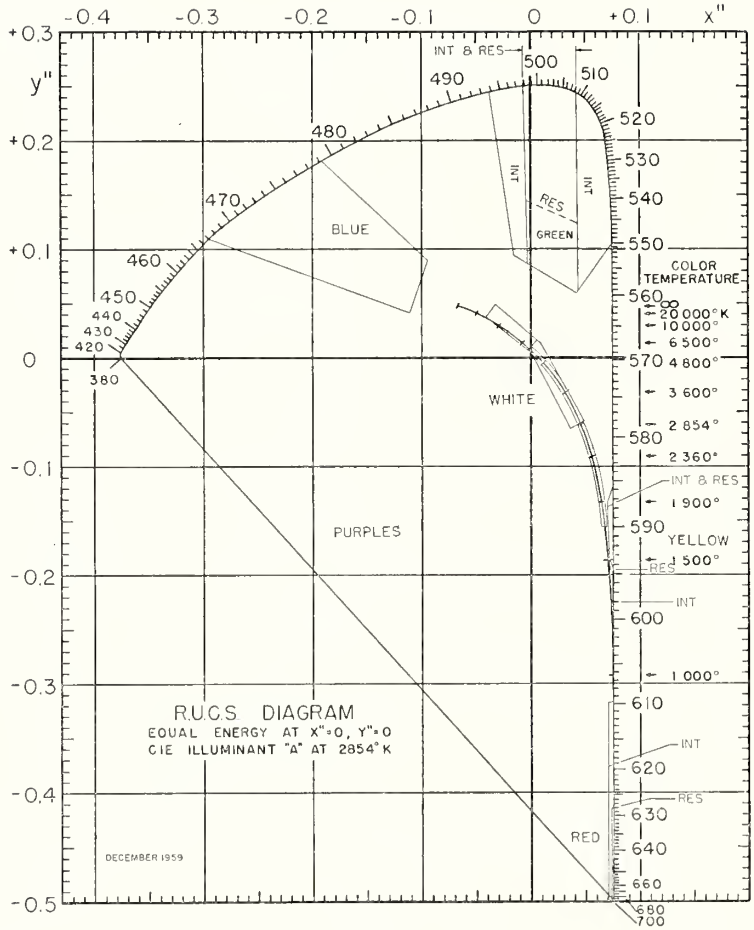
R.U.C.S. DIAGRAM
EQUAL ENERGY AT X"=0, Y"=0
CIE ILLUMINANT "A" AT 2854°K
DECEMBER 1959
BLUE
GREEN
WHITE
PURPLES
YELLOW
RED
COLOR TEMPERATURE
INT & RES
INT
RES
x"
y"

FIGURE I–2

Part II. Master Specifications for Standard Filters for Signal Light Colors

1. Scope and Classification

1.1. Scope

This master specification contains the requirements for limit filters which in combination with designated light sources constitute the basic color standards for signal-light colors.

1.2. Classification

1.2.1. Types of Filters. Four types of standard filters are recognized in this specification, namely:

National standard filters
Organization standard filters
Duplicate standard filters
Working standard filters

These are defined in part I of the U.S. Standard for the Colors of Signal Lights as follows:

2.16. *National Standard Filter*

A national standard filter is one of a set of filters adopted by the U.S. National Committee on Colors of Signal Lights to represent a basic color standard (2.13) and accepted by the National Bureau of Standards for reference and preservation as a national standard. Their characteristics are described in Part II of the U.S. Standard.

2.17. *Organization Standard Filter*

An organization standard filter is one of a set of filters adopted by an organization which sponsors a basic color standard to represent that standard. Organization standard filters may be deposited with the National Bureau of Standards for reference and preservation if they are acceptable to that Bureau.

Those presently so deposited are described in the appendix to part II, table II–6.

2.18. *Duplicate Standard Filter*

A duplicate standard filter is a filter certified as having characteristics duplicating those of a national or organization standard filter within the established tolerances stated in part II.

2.19. *Working Standard Filter*

A working standard filter is a filter adopted by a purchasing agency, a manufacturer, or a laboratory to represent a chromaticity, range of chromaticities, or a known transmittance.

1.2.2. Colors. The requirements of this specification apply to standards for the following colors:

- Red
  - Signal red
  - Intermediate signal red
  - Restricted signal red
- Yellow
  - Signal yellow
  - Intermediate signal yellow
  - Restricted signal yellow
- Green
  - Signal green
  - Intermediate signal green
  - Restricted signal green
- Blue
  - Signal blue
- White
  - Signal white
  - Variable-source white
  - Beacon white
  - Lunar white
  - Blue white

2. Applicable Documents

Part I of the U.S. Standard for the Colors of Signal Lights contains definitions applicable to this specification.

National Bureau of Standards Circulars 478 (Colorimetry) and 484 (Spectrophotometry) contain information with reference to chromaticity testing that is applicable to this specification.

3. Requirements

3.1. Composition of Standards

Each color standard consists of a set of two or more filters and an illuminant of designated color temperature (part I, 2.12). One filter designated as the "pale-limit" represents the minimum coloration that is acceptable. In general this filter is both a hue limit and a saturation limit. In the cases of yellow and green, it is necessary to have a second hue limit. In all cases, at least one filter designated as a "transmittance standard" is provided to serve as a basis for measuring the transmittance of ware that is near the minimum acceptable transmittance for its grade. The same filter may be designated as both a chromaticity limit and a transmittance standard if it meets the requirements for both.

TABLE II-1. *Range of light-source color temperatures for determining compliance with similar chromaticity requirements*

	°K (C_2=14380)
Aircraft Lights:	
Formation lights	2100–2300
Indicator lights	1800–2300
Instrument lights	1800–2300
Position lights	2500–2800
Aviation Ground Lights:	
Approach lights	1550–3250
Beacons	2850–3000
Code beacons	2850–3000
Course lights	2850–3000
Obstruction lights	2100–2850
Runway and threshold lights:	
Low intensity	1550–3100
Medium intensity	1550–3100
High intensity	1550–3100
Traffic projectors, portable	2350–2850
Automotive Signals:	
Brake lights	2950–3150
Tail lights	2350–2600
Turn signals	2350–2850
Highway Traffic Lights:	
All types	2350–2850
Marine Lights:	
Lights, acetylene	2360
Lights, battery operated	1900–2350
Lighthouses, electric power	2850–3000
Post lanterns, electric power	2350–2850
Ships running lights, electric	1900–3050
Ships running lights, kerosene	1900–2100
Railroad Signals:	
Electric Power, pressed ware	2350–2850
Battery Operated, pressed ware	1900–2350
Oil Wick Flame, pressed ware	1900–2100
Electric Power, polished disk	2350–2850
Battery Operated, polished disk	1900–2350
Hand Lanterns, Oil Wick Flame	1900–2100

TABLE II-3. *Tolerances for similar chromaticity characteristics*

The following table contains the tolerances for similarity of chromaticity as defined in I-2.11. In this table Δx, Δy, $\Delta x''$, and $\Delta y''$ are the numerical values (neglecting the sign) defined by the equations:

$$\Delta x = x - x_0, \text{ for } y = y_0$$
$$\Delta y = y - y_0, \text{ for } x = x_0$$
$$\Delta x'' = x'' - x_0'', \text{ for } y'' = y_0''$$
$$\Delta y'' = y'' - y_0'', \text{ for } x'' = x_0''$$

in which x_0 and y_0 (also x_0'' and y_0'') are the coordinates of the chromaticity of light from a source of the specified color temperature transmitted through any thickness of the standard material, within the required chromaticity range, and x and y (also x'' and y'') are the coordinates of the chromaticity of the same light transmitted through the optimum thickness of the material under consideration.

Color	Limits		Approximate Equivalents	
	Δx max	Δy max	$\Delta x''$ max	$\Delta y''$ max
Red	----------	0.0015	0.0005	----------
Yellow	----------	.002	.0007	----------
Green	----------	.010	.004	----------
Blue	0.010	----------	----------	0.014

TABLE II-2. *Minimum transmittance values for determining compliance with similar chromaticity requirements*

Illuminant is 2854 °K

For aeronautical and marine standards

Grade	Signal red	Signal yellow	Signal green	Signal blue
A	0.184	0.552	0.207	0.024
B	.161	.460	.184	.020
C	.138	.368	.161	.015
D	.120	.276	.138	.007

For railroad and highway standards

Grade	Restr. red	Interm. red	Interm. yellow	Signal yellow	Interm. green	Signal blue	Lunar white
E	0.064	----------	----------	----------	0.183	0.021	----------
F	.047	0.127	0.300	----------	.200	.021	0.290 [k] .162
G	.047	.095	----------	0.440	.200	----------	----------
H	.078 [e] .079	----------	.452	----------	.169	.0159	----------

NOTE. In general the several grades are considered suitable for the following uses:

A—For ware in which the highest possible transmittance is essential.
B—For pressed ware of uniform thickness not more than 6 mm (0.2 in.) throughout the working area.
C—For blown ware.
D—For thick-sectioned pressed ware.
E—For thin cones and polished disks to be used in searchlight-type signals.
F—For lenses, roundels, and slides for wayside signals and train markers.
G—For traffic signal cover glasses.
H—For lantern globes, generally blown ware.
[k] Alternate for kerosene illuminant.
[e] Alternate for electric lanterns.

(See table V-3 for antecedent specifications)

3.2. Similarity of Material

All the filters of a standard shall have similar chromaticity characteristics (part I, 2.11), table II-3.

3.3. Ranges of Illuminants

In qualifying filters for standards, the ranges of color-temperature given in table II-1 will be assumed for the illuminants in the lighting units indicated.

3.4. Range of Transmittance

In qualifying filters for standards, the ranges of transmittance given in table II-2 will be assumed according to the application of the standard.

3.5. Chromaticity

No standard shall be qualified unless it is feasible to produce ware having chromaticity characteristics similar to its paler limit and also a transmittance equal to the minimum permissible for the grade of ware to be furnished under the standard, and the chromaticity of such ware shall remain within the boundaries of the appropriate basic chromaticity definition of table I-1, for the applicable range of illuminants as given in table II-1, and the applicable variation in transmittance allowed in table II-2.

Each standard shall contain at least one filter, to be used as a transmittance standard, which shall conform to the following additional chromaticity requirements with illuminant 2854 °K:

Color	Limit
red	$y<0.310$
yellow	$y<0.435$
green	$x<0.210$
blue	$y<0.086$

This requirement is for the purpose of insuring that the chromaticity difference between minimum transmittance ware and the transmittance standard will not be so great as to interfere with checking the acceptability of the ware for transmittance.

3.6. Physical Requirements

3.6.1. Material. Standard filters shall be made of material similar to that from which the ware is to be made (part I, 2.11).

3.6.2. Uniformity of coloring. The coloration shall be uniformly distributed throughout the material. Flashed material consisting of a thin layer of highly selective material attached to a clear body shall be avoided.

NOTE: This is not only because of probable nonuniformity from spot to spot but also because slight scratches may alter the chromaticity significantly.

3.6.3. Dimensions. The standard filters shall be cut square, not more than 5.05 centimeters (1.99 in.) nor less than 4.90 centimeters (1.93 in.) on each side, and shall not be less than 1.5 millimeters (0.059 in.) thick.

NOTE: These dimensions are required in order to make the various standard filters applicable to testing equipment already available. The minimum thickness is to avoid unduly fragile standards.

3.6.4. Optical quality. Standard filters shall have sufficiently plane, parallel, and well-polished faces, and shall be sufficiently free from bubbles, striae, scratches, and other defects to be suitable for use as standards. Any defect sufficient to alter appreciably the judgment of an inspector in his use of the specimen as a standard shall be avoided.

3.7. National Standard Filters

The national standard filters that have been adopted by the U.S. National Committee on the Colors of Signal Lights are listed in table II–4 and their chromaticities for five illuminants are listed in table II–6 (appendix).

3.8. Duplicate Standard Filters

Duplicate standard filters shall have similar chromaticity characteristics within the tolerances given in table II–3, to the national standard filters which they represent for the applicable range of color temperatures listed in table II–1

TABLE II–4. *Tolerances for duplicates of national standard filters*

Illuminant 2854 °K

x, y, coordinates uplicate; x_0, y_0, coordinates of standard; $\Delta x=x-x_0$, $\Delta y=y-y_0$

Red Filters

For all red filters one lateral boundary is the spectrum locus and the other is: $x+y\geqq 0.9995$. All terminal boundaries have slope $\Delta y/\Delta x=1$. Location of terminal boundaries is fixed by defining tolerance on line $x+y=1.0000$.

Chromaticity definition in part I	Purpose of standard	Filter No.	Chromaticity with 2854 °K source		Tolerances for min. Δy for max. Δy
			Accepted value		$\Delta y=y-y_0$
			x_0	y_0	
Restricted (special)	Trans. std	3.086T	0.7224	0.2776	$\Delta y=-0.0025$ $\Delta y=+.0010$
Restricted (special)	Yellow limit	3.154	.7132	.2867	$\Delta y=-.0010$ $\Delta y=+.0007$
Restricted	Trans. std	3.154T	.7132	.2867	$\Delta y=-.0030$ $\Delta y=+.0007$
Restricted	Yellow limit	3.126	.7050	.2949	$\Delta y=-.0010$ $\Delta y=+.0005$
Intermediate	Trans. std	3.126T	.7050	.2949	$\Delta y=-.0035$ $\Delta y=+.0005$
Intermediate	Yellow limit	3.075	.6927	.3072	$\Delta y=-.0010$ $\Delta y=+.0005$
Signal	Trans. std	3.075T	.6927	.3072	$\Delta y=-.0040$ $\Delta y=+.0005$
Signal	Yellow limit	3.640	*.6687	*.3310	$\Delta y=-.0010$ $\Delta y=+.0010$

*Replacement for 3656A, values to be adjusted when measurements have been completed, see corrigendum.

Table II–4. *Tolerances for duplicates of national standard filters*—Continued

Yellow Filters

For all yellow filters one lateral boundary is spectrum locus and the other is given in table as min $(x+y)$=const. All terminal boundaries have slope $\Delta y/\Delta x=1$. Location of terminal boundaries is fixed by defining tolerance on lines $x+y=x_0+y_0$.

Chromaticity definition, part I	Purpose of standard	Filter No.	Chromaticity with 2854°K source Accepted value x_0	y_0	Tolerance for min $(x+y)$ $(x+y)$	Tolerance at $x+y=x_0+y_0$ Min Δy	Max Δy
Signal and intermediate	Red limit*	4.200	0.5889	0.4073	0.9960	−0.0005	+0.0015
Restricted	Red limit*	4.199	.5762	.4226	.9975	−.0010	+.0010
Restricted and intermediate	Green limit	4.166	.5635	.4349	.9970	−.0010	+.0010
Signal	Green limit	4.261	.5515	.4454	.9965	−.0025	+.0003

*Red limits also serve as transmittance standards.

Green Filters

Chromaticity definition, part I	Purpose of standard	Filter No.	Chromaticity with 2854 °K source Accepted value x_0	y_0	Tolerance* for min x for max x $\Delta x=x-x_0$ Δx	Tolerance* for min y for max y $\Delta y=y-y_0$ Δy
Signal and intermediate	Yellow limit	7.134	0.2448	0.4145	−0.0015 +.0015	$-0.0010+0.25\Delta x$ $+.0010+0.25\Delta x$
Signal and intermediate	Yellow limit	7.137	.2324	.4116	−.0015 +.0015	$-.0020+0.3\Delta x$ $+.0010+0.3\Delta x$
Signal and intermediate	Yellow limit blue	7.087	.2084	.4016	−.0020 +.0020	$-.0020+0.5\Delta x$ $+.0020+0.5\Delta x$
Signal and intermediate	Blue limit	7.322	.1909	.3891	−.0015 +.0015	$-.0020+0.6\Delta x$ $+.0020+0.6\Delta x$
Signal	Blue limit	7.136	.1753†	.3795†	−.0015 +.0015	$-.0020+0.8\Delta x$ $+.0020+0.8\Delta x$

Blue limits also serve as transmittance standards.
*For diagram interpreting equations, see figure II-1.
The constants given in the columns headed Δx and Δy are represented in the figure by C_x, C_y, K_x, and K_y. The coefficients of the Δx terms are the m_y ratios of the figure.
†New standard, values to be adjusted when measurements have been completed, see corrigendum.

Blue Filters

Chromaticity definition, part I	Purpose of standard	Filter No.	Chromaticity with 2854 °K source Accepted value x_0	y_0	Tolerance* for min x for max x $\Delta x=x-x_0$ Δx	Tolerance* for min y for max y $\Delta y=y-y_0$ Δy
Signal	Green and white limit	8.047	0.1530	0.1221	$-0.0010+0.25\Delta y$ $+.0010+0.25\Delta y$	$-0.0025-0.25\Delta x$ $+.0005-0.25\Delta x$
Signal	Green and white limit	8.141	.1575	.1212	$-.0010+0.25\Delta y$ $+.0010+0.25\Delta y$	$-.0030-0.25\Delta x$ $+.0010-0.25\Delta x$
Signal	Trans. std	8.057	.1440	.0862	$-.0005+0.10\Delta y$ $+.0020+0.10\Delta y$	$-.0100-0.10\Delta x$ $+.0020-0.10\Delta x$
Signal	Trans. std	8.131	.1474	.0728	$-.0010+0.10\Delta y$ $+.0010+0.10\Delta y$	$-.0020-0.10\Delta x$ $+.0100-0.10\Delta x$

*For diagram interpreting equations see figure II-1. The constant terms listed in the columns under Δx and Δy are shown in the diagram as C_x, C_y, K_x, and K_y, and the coefficients of Δy and Δx are shown as m_x and m_y, respectively.

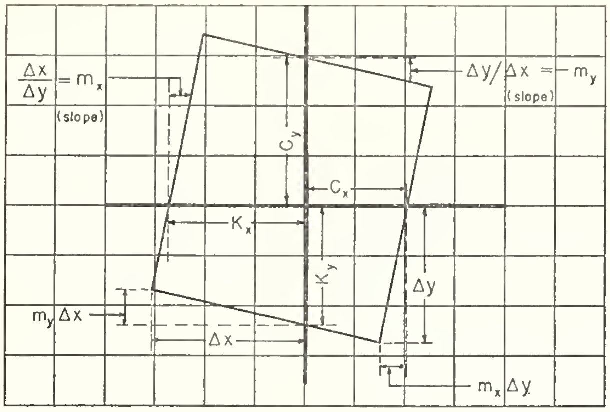

FIGURE II–1

TABLE II–5. *Computed values for critical points of tolerances for national standard filters**

Illuminant 2854 °K

Red filters, intercepts at $x+y=1$		
Filter No.	Apparent value	
	x	y
3.086T	0.7249	0.2751
	.7214	.2786
3.154	.7143	.2857
	.7126	.2874
3.154T	.7163	.2837
	.7126	.2874
3.126	.7061	.2939
	.7046	.2954
3.126T	.7086	.2914
	.7046	.2954
3.075	.6938	.3062
	.6923	.3077
3.075T	.6967	.3032
	.6922	.3077
3.640	.6697	.3300
	.6677	.3320

Yellow filters, intercepts at $x+y=x_0+y_0$		
Filter No.	Apparent value	
	Min y	Max y
4.200	0.4068	0.4088
4.199	.4216	.4236
4.xxx	.4340	.4360
4.261	.4429	.4457

x_0 and y_0 are chromaticity coordinates for the National Standard Filter.

*These values are given to facilitate comparison with antecedent specifications. They are computed on the basis of the currently accepted values for the national standard filters. Should any occasion arise to revise the values assigned for the coordinates of any of these filters the corresponding values in this table would have to be changed accordingly.

Apparent values at tolerance corners

Green filters				
Filter No.	x	Max y Min y	x	Max y Min y
7.134	0.2433	0.4151 .4131	0.2463	0.4159 .4139
7.137	.2309	.4122 .4092	.2339	.4130 .4100
7.087	.2064	.4026 .3986	.2104	.4046 .4006
7.322	.1894	.3902 .3862	.1924	.3920 .3880
7.136				

Blue filters				
Filter No.	Min x Min x	Max y Min y	Max x Max x	Max y Min y
8.047	0.1522	0.1228	0.1541	0.1223
	.1515	.1200	.1534	.1195
8.141	.1568	.1224	.1587	.1219
	.1559	.1186	.1577	.1181
8.057	.1437	.0882	.1462	.0880
	.1425	.0764	.1450	.0761
8.131	.1474	.0828	.1494	.0826
	.1462	.0709	.1482	.0707

and transmittances listed in table II–2, and they shall conform in chromaticity and transmittance to the applicable tolerances stated in table II–4. (See also table II–5.)

3.9. Approval of Working Standards

It is important that the filters of a standard be made from the same type of material as is to be used for the manufacture of ware to be controlled by the standard. In cases where an established practice does not exist, manufacturers should ascertain in advance of bidding whether or not the material they desire to use in supplying ware on any contract which they may receive under any procurement specification based on the U.S. Standard for the Colors of Signal Lights has similar chromaticity characteristics to those of the primary standard filters described in tables 3 and 4. If the proposed material does not meet this requirement, the manufacturer may, with the consent of the purchasing agency, submit duplicate sets of limit filters to that agency with the request that such filters be tested and if found satisfactory be accepted as a working standard for that contract. If found satisfactory, one of the duplicate sets will be returned to the manufacturer and the other will be delivered to the inspection staff of the purchasing agency.

NOTE: If new standards for plastics are required they will be added to table II–4. In the meantime sec. 3.9 is available to provide for their present uses.

Appendix

TABLE II–6. *Organization standard filters*

The filters listed below have been deposited with the National Bureau of Standards by the Signal Section of the Association of American Railroads. Those identified by 4 digit numbers with a decimal point have been adopted as national standard filters, the others have the status of organization standards. The chromaticity and transmittance values given below for source color temperatures 1904 °K, 2365 °K, and 2854 °K are from NBS Research Paper RP1688.

Filter no.	Illuminant 1500 °K			Illuminant 1904 °K			Illuminant 2365 °K			Illuminant 2854 °K			Illuminant 3250 °K		
	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T
Red:															
3.075	0.7000	0.2999	0.3084	0.6967	0.3032	0.2431	0.6944	0.3055	0.1989	0.6927	0.3072	0.1698	0.6917	0.3082	0.1538
3.086	.7241	.2759	.1337	.7234	.2766	.0944	.7228	.2772	.0711	.7224	.2776	.0572	.7223	.2777	.0499
3.126	.7094	.2905	.2711	.7074	.2925	.2072	.7060	.2940	.1655	.7050	.2949	.1388	.7044	.2955	.1244
3.154	.7161	.2839	.2106	.7148	.2852	.1564	.7138	.2862	.1222	.7132	.2867	.1009	.7128	.2872	.0895
Yellow:															
4.199	.6238	.3754	.7632	.6036	.3955	.7137	.5878	.4111	.6692	.5762	.4226	.6334	.5692	.4295	.6106
4.200	.6329	.3661	.7295	.6147	.3836	.6708	.6000	.3972	.6210	.5889	.4073	.5823	.5820	.4133	.5584
4.261	.6127	.3859	.7998	.5873	.4107	.7669	.5669	.4306	.7358	.5515	.4454	.7095	.5422	.4545	.6922
Green:															
7.087	.3217	.5366	.1150	.2684	.4976	.1492	.2316	.4472	.1784	.2084	.4016	.2013	.1965	.3719	.2155
7.134	.3798	.5164	.1699	.3197	.4944	.2106	.2749	.4550	.2442	.2448	.4145	.2698	.2286	.3866	.2856
7.137	.3610	.5245	.1487	.3025	.4974	.1872	.2602	.4542	.2193	.2324	.4116	.2440	.2175	.3828	.2592
7.322	.2896	.5437	.0928	.2415	.4942	.1236	.2099	.4376	.1502	.1909	.3891	.1712	.1813	.3586	.1845
Blue:															
8.047	.2328	.2915	.0157	.1783	.2049	.02216	.1595	.1521	.02909	.1530	.1221	.03556	.1510	.1070	.0401
8.057	.1590	.2029	.0072	.1458	.1387	.01164	.1436	.1051	.01669	.1440	.0862	.02155	.1447	.0770	.0251
8.131	.1830	.1788	.0056	.1543	.1187	.00876	.1482	.0889	.01252	.1474	.0728	.01626	.1476	.0649	.0190
8.141	.2610	.2945	.0160	.1916	.2070	.02173	.1665	.1522	.02789	.1575	.1212	.03372	.1545	.1058	.0378

Filter no.	Illuminant 1500 °K			Illuminant 1904 °K			Illuminant 2365 °K			Illuminant 2854 °K			Illuminant 3250 °K		
	x	y	T	x	y	T	x	y	T	x	y	T	x	y	T
Red:															
126	0.7094	0.2905	0.2711	0.7074	0.2925	0.2072	0.7060	0.2939	0.1655	0.7050	0.2949	0.1389	0.7044	0.2955	0.1244
201	.7074	.2926	.2862	.7051	.2948	.2205	.7036	.2963	.1771	.7025	.2974	.1493	.7018	.2981	.1340
211	.7189	.2811	.1778	.7178	.2822	.1300	.7171	.2829	.1004	.7165	.2835	.0823	.7161	.2838	.0726
400	.7125	.2875	.2515	.7108	.2891	.1898	.7096	.2904	.1502	.7088	.2912	.1251	.7083	.2917	.1116
Yellow:															
141	.6221	.3748	.5901	.5963	.3976	.5571	.5740	.4157	.5296	.5560	.4291	.5082	.5445	.4370	.4949
142	.6326	.3658	.4609	.6113	.3861	.4262	.5934	.4026	.3978	.5794	.4151	.3762	.5705	.4228	.3629
271	.6328	.3667	.7029	.6151	.3843	.6456	.6014	.3979	.5967	.5913	.4078	.5584	.5853	.4138	.5346
Green:															
139	.4001	.5141	.1640	.3407	.5025	.2002	.2951	.4721	.2294	.2634	.4376	.2515	.2458	.4126	.2649
140	.3494	.5385	.1099	.2949	.5138	.1397	.2555	.4742	.1645	.2295	.4348	.1835	.2154	.4078	.1952
Lunar white:															
45	.5259	.4029	.2041	.4395	.3981	.2173	.3651	.3664	.2306	.3122	.3279	.2421	.2832	.3004	.2497
73	.5361	.4030	.2505	.4556	.4032	.2643	.3840	.3772	.2779	.3308	.3426	.2895	.3007	.3166	.2972
74	.5024	.3958	.1285	.4005	.3766	.1394	.3216	.3308	.1509	.2711	.2852	.1612	.2456	.2559	.1682
124	.5520	.4027	.3614	.4822	.4106	.3755	.4169	.3953	.3891	.3654	.3688	.4004	.3346	.3468	.4077
Yellow:*															
359	.6093	.3887	.7856	.5822	.4148	.7590	.5601	.4358	.7334	.5432	.4517	.7115	.5329	.4614	.6970

*Deposited by Institute of Traffic Engineers.

Part III. Specification for Color of Ware for Use in Producing Signal Light Colors [1]

1. Scope and Classification

1.1. Scope

This specification defines the color requirements for light-transmitting ware. Equipment in which the coloring element and the light source are inseparable is not included.

1.2. Classification

1.2.1. Colors. The following colors are included in this specification:

Signal red	Intermediate signal red	Restricted signal red
Signal yellow	Intermediate signal yellow	Restricted signal yellow
Signal green	Intermediate signal green	Restricted signal green
Signal blue		
Signal white	Variable source white	Lunar white
	Beacon white	Blue white

1.2.2. Grades. This specification covers the transmittance requirement of eight grades of light-transmitting ware designated as grades *A* through *H*.

1.2.3. Classes. This specification covers transmittance requirements for two classes of ware.

1.2.3.1. Refracting ware. Refracting ware is ware intended to alter significantly the candlepower distribution of the light source.

1.2.3.2. Nonrefracting ware. Nonrefracting ware is ware which is not intended to alter the candlepower distribution of the source significantly.

2. Applicable Specifications and Publications

2.1. U.S. Standard

Parts I, II, and V of the U.S. Standard for Colors of Signal Lights are applicable to this specification.

3. Requirements

3.1. Transmittance

The transmittance ratio or apparent transmittance [2] of the ware shall not be less than the appropriate value given in table III–1 for the class and grade of ware stipulated. If neither the detail drawings, the equipment specifications,

TABLE III–1. *Minimum transmittance values for different grades of ware*

Illuminant is 2854 °K

For aeronautical and marine standards					For railroad and highway standards							
Grade	Signal red	Signal yellow	Signal green	Signal blue	Grade	Restr. red	Interm. red	Interm. yellow	Signal yellow	Interm. green	Signal blue	Lunar white
A	0.184	0.552	0.207	0.024	E	0.064				0.183	0.021	
B	.161	.460	.184	.020	F	.047	0.127	0.300		.200	.021	0.290 .162k
C	.138	.368	.161	.015	G	.047	.095		0.440	.200		
D	.120	.276	.138	.007	H	.078 .079e		.452		.169	.0159	

NOTE. Unless otherwise stipulated in this specification or in the procurement order, the several grades are applicable to the following types of ware:
- A, For ware in which the highest possible transmittance is essential.
- B, For pressed ware of uniform thickness not more than 6 mm (0.2 in.) throughout the working area.
- C, For blown ware.
- D, For thick-sectioned pressed ware.
- E, For thin cones and polished disks to be used in searchlight-type signals.
- F, For lenses, roundels and slides for wayside signals and train markers.
- G, For traffic signal cover glasses.
- H, For lantern globes, generally blown ware.
- k, Alternate for kerosene illuminant.
- e, Alternate for electric lanterns.

(See table V–3 for antecedent specifications.)

[1] This specification may be used as a procurement specification or the pertinent sections may be revised as required and incorporated into a specification for equipment. Procurement orders should state the color and grade, and may also state the national standard or organization standard filters to be used as hue limits. In any case, color and grade designations should be consistent with this specification.

[2] For a discussion of the relationship between "apparent" and "true" transmittance, see footnote to sec. 4.6.3.2.

nor the order stipulates the grade or class of the ware, the inspector shall classify it according to the definitions of 1.2.2 and 1.2.3.

3.2. Chromaticity

When ware or equipment using such ware is procured in accordance with this specification, the light transmitted in every direction that is to be utilized in service shall conform with the following requirements at every color temperature within the range specified in table III–2, for the type of equipment which is to be procured. This requirement must be met at physical temperatures characteristic of service conditions and if the colorant is subject to fading, this requirement must be met after an appropriate fading test. The procurement order will state the physical temperatures, if they are other than normal room temperature, and specify the fading test if one is required. The chromaticity limits of the following requirements are those of the applicable chromaticity standard realized by transmitting light from a source of color temperature 2854° K through standard filters supplied or designated by the procurement authority. If no filters are supplied or designated, duplicates of the national standard filters will be used.

3.2.1. Red ware. The light transmitted by the the ware furnished shall not be yellower nor less saturated than the light transmitted by the applicable yellow limit.

3.2.2. Yellow ware. The light transmitted by the ware furnished shall not be redder than the light transmitted by the applicable red limit, nor greener nor less saturated than the light transmitted by the applicable green limit.

3.2.3. Green ware. The light transmitted by the ware furnished shall not be yellower nor less saturated than the light transmitted by the applicable yellow limit, and shall not be bluer than the light transmitted by the applicable blue limit.

3.2.4. Blue ware. The light transmitted by the ware furnished shall not be greener, nor less saturated, than the light transmitted by the green limit, and when light transmitted by the ware is transmitted in turn through a duplicate of National Standard red filter 3.086, the transmittance of the red filter for the blue light shall not be more than 0.015.

3.2.5. "White" lights.

3.2.5.1. Colorless ware. When colorless ware is specified, as for variable-source white or beacon-white signals, the light transmitted by the ware furnished shall not be noticeably different in chromaticity from that of the illuminant.

3.2.5.2. Lunar-white and blue-white ware. The light transmitted by the ware shall not be yellower than the light transmitted by the applicable yellow limit, nor bluer than the light transmitted by the applicable blue limit, and it shall not be greener nor more purple than the light transmitted by these limits to an extent that interferes with these judgments.

3.2.6. Similarity of chromaticity characteristics. In all cases the ware shall be made from material having the same chromaticity characteristics (part I–2.11) as the applicable standard filters unless the order notes that an accepted manufacturer's color standard has been substituted (part I–2.15).

4. Sampling, Inspection, and Test Procedures

4.1. General

General methods of sampling, inspection, and test are given below. Procurement specifications for the various types of equipment will specify any deviations from or additions to these methods.

4.2. Facilities

Contractors not having laboratory facilities adequate for carrying out the tests of this section shall engage the services of a testing laboratory equipped with such facilities.

4.3. Inspection of Parts

The acceptance or approval of material during the course of manufacture shall in no case be construed as a guaranty of the acceptance of the finished product.

4.4. Sampling

Note: The degree of variability characteristic of the different types of ware which may be procured under this Standard is so great that it is not practicable to include a definite requirement for sampling. Instead of such a requirement, the following principles are presented as guides for prescribing sampling procedures appropriate to different types of ware.

Signal lights are used for purposes of safety and for this reason the acceptability of a small random sample does not give adequate assurance that unsatisfactory ware will not be put into service since the user has no way of distinguishing between acceptable and unacceptable chromaticities. The sampling procedure should be one that virtually assures that no ware outside of the limits will go into service.

Whenever practicable, each piece should be inspected for conformity to the color requirements. Whenever it is not practicable to inspect each piece in accordance with the procedures prescribed in this Standard, the next recourse is to select as samples the pieces departing most widely in color from that of the majority of the pieces in the critical directions. In general, these departures are characterized by paleness, that is, low saturation accompanied by high transmittance on the one hand, and by high saturation accompanied by low transmittance on the other hand. If other deviations independent of these are present, separate samples of such deviations should also be selected. The selection of these samples for complete inspection is made by viewing the pieces in pairs against a white surface illuminated with daylight or the light from ordinary incandescent lamps. Each piece is compared in turn with the palest and most saturated pieces found up to that point of the comparison, the pale and saturated comparison pieces being replaced by others whenever paler or more saturated pieces are found. The sample obtained in this way should include not less than five pale and five saturated specimens. The failure of a single piece among samples selected in this manner need cause the rejection of only the failing piece, but the failure of two or more pieces may be considered an indication of unsatisfactory control by the producer and therefore grounds for requiring that the entire quantity be retested or replaced by the vendor.

If the entire quantity covered by an order is so large as to make the foregoing sample selection method impracticable, and if it is established that production is under statistical control, then a random sampling procedure may be used. The consumer and producer should agree upon the lot size to determine inspection level in accordance with inspection by attributes as defined in Military Standard 105A. Agreement should also be reached on sample size and acceptable quality level as defined in Military Standard 105—consistent with end use as signal lights for purposes of safety. It is important to note that the use of any random sampling procedure will also require the adoption of more conservative inspection limits than those represented by the national standard filters, since those were established for use with the procedures outlined in the preceding paragraphs.

4.5. Test Equipment

4.5.1 Calibrated equipment. When calibrated test equipment is required, the contractor shall provide equipment calibrated within the preceding 12 months by a laboratory generally recognized as competent.

4.5.2. Color standards. Standard filters furnished by the National Bureau of Standards for testing such equipment, or other standards approved by the procuring agency, shall be used in testing the ware.

4.5.3. Comparison lamp. A calibrated seasoned lamp, that has been standardized for color temperature 2854 °K, and such other color-temperatures as are required for the inspection, shall be used.

4.5.4. Test lamp. A calibrated test lamp of the same type as is used in the equipment, standardized for 2854 °K and/or such other color temperatures as are required for the inspection, shall be used.

4.5.5. Electric meter. A calibrated voltmeter or ammeter suitable for the purpose shall be used for controlling the lamps unless a suitable potentiometer and standard cell are available.

4.5.6. Comparator. A suitable color comparator and photometer, which may be a photoelectric cell with microammeter, or a combination of such instruments, shall be used foi testing the chromaticity and transmittance.

4.5.7. Power supply. The power supply for lighting the comparison and test lamps shall be of sufficiently constant voltage to permit satisfactory testing.

4.6. Test Methods for Chromaticity

4.6.1. Special equipment. If a special color comparator or other special equipment is to be used, the instructions will be furnished with the equipment; otherwise the inspector shall proceed as outlined hereinafter.

4.6.2. Standard procedure. The standard chromaticity test procedure consists of the following steps:

4.6.2.1. The test lamp, comparison lamp, and comparator are so mounted that each lamp illuminates one field of the comparator. If a colorless piece of the same design as the test ware is to be used, it is to be placed between the lamp and comparator in such a manner as to be in its normal relation to the lamp. The distance between the test source and the comparator should be large enough so that the test field of the comparator receives light from as large a part of the ware as is effective in service. For condensing lenses and units containing parabolic reflectors, this may require a test distance 100 times the aperture diameter. This distance may be shortened to 20 times the diameter if a colorless translucent diffusing surface is interposed midway between the ware and the comparator.

4.6.2.2. The current or voltage is adjusted for each lamp to the value required to obtain a color temperature of 2854 °K.

4.6.2.3. The comparator is adjusted to equalize the luminance (brightness) of the two fields and the fields are compared for color match. If the fields do not very nearly match, one of the lamps has changed and should be replaced.

4.6.2.4. One of the hue limits is placed [3] between the comparison lamp and its comparator field, care being used to see that it intercepts at right angles all the light reaching the field.

4.6.2.5. The pieces of test ware are now placed between the test lamp and its field in the manner described above (4.6.2.1).

4.6.2.6. The inspector compares the fields for hue and saturation and if the chromaticity of the test field is beyond the limit represented by the comparison field, the test ware is rejected. If the test field is within the limit, the test should be repeated with different samples of transmitted light until the inspector is satisfied that the ware when in service will give a true color in all directions of use. If the inspector finds color differ-

[3] In placing filters for chromaticity tests and transmittance measurements they should be located in the coolest available location, since the chromaticity and transmittance of red filters are altered by high temperatures and any filter, especially one of low transmittance, is liable to break if heated unduly.

ences which are not readily classified as within or without the limit, such pieces will be separated from the others and typical samples of them submitted for laboratory tests for similarity of chromaticity characteristics. If these tests indicate that the ware does not conform to the requirements for similarity of chromaticity characteristics, the entire lot of ware may be rejected. If the test for similarity of chromaticity characteristics is satisfactory, these samples will be compared with the hue limits. If these samples are all within the hue and saturation limits, the group which they represent will be accepted. If all the samples are outside the hue limits in the same direction, the group will be rejected. In any other case, the entire group will be reinspected, either at the manufacturer's plant or at a colorimetric laboratory if the procuring agency deems that desirable.

NOTE: Pieces having the same chromaticity characteristics form a series which may be represented on the mixture diagram essentially as a line so that any piece which does not match a standard lies definitely to one side or the other of this standard. A piece which does not have the same chromaticity characteristics may lie in any direction from the standard and the standard would not constitute a definite limit for such a piece.

4.6.2.7. After the ware has been tested with respect to the first hue limit, the test is repeated with the second hue limit if the color is one having a second chromaticity limit.

4.6.3. Test methods for transmittance.

4.6.3.1. Special instruments. If a special photometer or a light collecting device is to be used, the instructions for its use are to be furnished with the instrument and the inspector shall follow those instructions. Otherwise the inspector shall proceed in accordance with the following instructions.

4.6.3.2. Formulas. Since most of the ware which is to be inspected under this specification causes some refraction as well as absorption of the incident light, the only procedure that is generally applicable is the substitution of a test piece for a standard piece of the same design which gives the relative transmittance of the two pieces in accordance with formula (1). If the photometer does not give readings that are proportional to the illuminance on its test surface, the photometer readings are to be reduced to values proportional to the illuminance before substituting them in the formula.

$$T_{\mathrm{rel}}=T_t/T_s=R_t/R_s \qquad (1)$$

T_{rel} = relative transmittance of the test piece in relation to the standard piece
T_t = transmittance of the test piece
T_s = transmittance of the standard piece
R_t = reading of photometer for test piece
R_s = reading of photometer for standard piece

If the standard piece is colorless, the relative transmittance is the transmittance ratio.

Since neither the human eye nor the photoelectric cell can be trusted to give reliable results for two illuminations that differ markedly in spectral composition, it is necessary to introduce a standard filter of known transmittance to reduce the error to a negligible value. If a colorless filter is used in the place of the standard filter for those measurements for which the standard filter is not required, the resulting values should be called "apparent transmittance."[4]

Since a standard filter is to be used, formula (1) must be modified to include its effect. For photoelectric photometry, the filter is placed between the photometer and the standard piece when it is being measured. This causes the reading of the standard to be reduced in proportion to the transmittance of the standard filter, and R_s must be divided by the transmittance of this filter to restore the equality. Thus:

$$T_r=R_t/(R_s/T_f) \text{ or } T_r/T_f=R_t/R_s \qquad (2)$$

T_r = transmittance ratio of test piece
T_f = transmittance of duplicate representing standard filter (see report of test on duplicate).

In visual photometry, the standard filter may be introduced in the same way as for photoelectric photometry if a suitable filter is kept on the comparison side for all the measurements. It is also possible in visual photometry to introduce the standard filter on the comparison side of the instrument after the standard colorless piece has been measured. This causes the readings obtained for the test ware to be increased and it is necessary to multiply these readings by the transmittance of the standard filter to obtain their true value; thus (1) becomes:

$$T_r=(R_t\times T_f)/R_s \text{ or } T_r/T_f=R_t/R_s \qquad (3)$$

which is identical with (2).

It is not customary to make any correction in the formula when a colorless filter is substituted for the standardized filter, but the specification requirements are set proportionately lower to allow for the lower ratios which are obtained from the formula.

For the special case in which the test piece is one having the minimum transmittance ratio, or apparent transmittance, allowed by the specification (2) becomes:

$$T_m/T_f=R_m/R_s \text{ or } R_m=R_s(T_m/T_f) \qquad (4)$$

[4] The "apparent transmittance" is sometimes treated as a true transmittance, which is defined in par. I-2.6. True transmittance includes all the transmitted light without regard to refraction or scattering. Both transmittance ratio and "apparent transmittance" assume an equivalence of refractive and scattering effects in the colored and the colorless pieces, and thus undertake to evaluate the effect of the colorant alone. The "apparent transmittance" is the ratio of the transmittance ratio to the transmittance of the colorless filter used in its measurement. Numerically it is approximately 0.92× transmittance ratio.

R_m = the minimum reading that is acceptable for test ware.

T_m = the minimum acceptable transmittance ratio or apparent transmittance from table III–1.

4.6.3.3. Procedure. If a photoelectric photometer is used, it shall be fitted with a spectrally corrected photoelectric cell or barrier layer cell of the type commonly called "color-corrected." If visual photometry is used, only observers known to have normal color vision should operate the photometer. The test lamp is adjusted to the voltage required for light of color temperature 2854 °K. If a comparison lamp is used, its voltage is adjusted to make the test and comparison fields match without any filter on either side, or with the standard filter on the test side and a comparison filter on the comparison side, according to the type of photometry to be used. The colorless standard piece having the same optical design as the test pieces is then placed over, or in front of, the lamp as it would be in service, and an initial reading is taken with the photometer. This is R_s of formula (4). From this value and the known values of T_f and T_m which are given in the report for the duplicate used and in table III–1 respectively, or otherwise provided to the inspector, the inspector computes the value of the minimum acceptable reading according to formula (4). The standard filter is then removed from the test side, or if the initial reading was made with a visual photometer using white light, the standard filter is inserted on the comparison side. If the specification is expressed in terms of apparent transmittance instead of transmittance ratio, the standard filter is replaced by a colorless filter, or put in place of a colorless filter, according to the type of photometry being used. The standard piece is then replaced by each of the test pieces in turn and these are accepted or rejected depending on whether the photometer readings are larger or smaller than R_m.

Two precautions are necessary to insure reliable inspection. The distance of the test piece from the photometer must be large enough to insure that the sample of light intercepted by the test plate or cell is typical of that which would be seen by the eye of an observer. For condensing equipment this may require a test distance 100 times the aperture of the test unit. If the ware is to be used with a condensing system composed of colorless lenses and/or reflectors, a set of these should preferably be used for the inspection. The set so used should be regarded as a standard set and should be reserved for inspection purposes so that the same set will always be used.

With condensing equipment it is customary to test the transmittance only on the axis of the beam since testing at other angles would require multiple values of R_m associated with the several directions of test. With noncondensing systems and semicondensing systems, which produce a distribution of luminous intensity that is nominally independent of angle in one plane, the inspection test should be repeated at different angles to insure that the ware will give satisfactory performance as seen from directions typical of those from which it will be viewed in service. The number of directions from which the test is made will vary according to the design, the way in which the equipment is used, and the importance of the equipment from the standpoint of safety. This problem should be studied by the inspectors with their supervisors and a customary practice developed for each type of ware that is to be inspected.

Part IV. Specification for Color Signals Produced with Autochromatic Equipment[1]

1. Scope and Classification

1.1. Scope

This specification defines the color requirements for signal lighting in which the coloring element is integral with the light source so that for this reason, or any other, it is not feasible to have the coloring element separately tested. Such equipment is referred to in this specification as autochromatic.

1.2. Classification

1.2.1. Colors. The following colors are included in this specification: (Each agency should delete the names of colors which are not to be purchased.)

Signal red	Intermediate signal red	Restricted signal red
Signal yellow	Intermediate signal yellow	Restricted signal yellow
Signal green	Intermediate signal green	Restricted signal green
Signal blue		
Beacon white		Lunar white

1.2.2. Grades. For the purpose of specifying the colors, all autochromatic lighting units are considered to constitute one grade.

1.2.3. Classes. This specification covers three classes of equipment.

1.2.3.1. Gaseous discharge units. Gaseous discharge units include all units in which the initial source of radiant energy is a volume of ionized gas conducting an electrical discharge.

1.2.3.2. Integrated incandescent units. Integrated incandescent units include all autochromatic units in which the initial source of radiant energy is a metallic filament heated to incandescence by an electric current.

1.2.3.3. Electroluminescent units. Electroluminescent units include all signal lighting units in which a luminous area is produced by applying electric potential differences to substances which fluoresce when subjected to such potential differences.

[1] Since this specification is designed to provide for different applications, it contains more provisions than are required for any one application. Sections which are not pertinent may be omitted.

2. Applicable Specifications and Publications

2.1. Standard

Parts I, II, V, and VI of the U.S. Standard for Colors of Signal Lights are applicable to this specification.

3. Requirements

3.1. Intensity or Luminance

The equipment specifications should contain requirements for the luminous intensity or the luminance applicable to the colored light as emitted by the unit, since it is impracticable to measure transmittance in the case of autochromatic equipment.

3.2. Chromaticity

The chromaticity of the light emitted in every direction that is to be utilized in service shall conform with the following requirements under every condition of ambient temperature and operating voltage that is to be expected in normal service including deterioration in service for 2,000 hours. The chromaticity limits of the following requirements are those of the applicable chromaticity standard realized by transmitting light from a source of color temperature 2854 °K through standard filters supplied or designated by the procurement authority. If no filters are supplied or designated, duplicates of the national standard filters will be used.

3.2.1. Red units. The light emitted by the units furnished shall not be yellower nor less saturated than the light transmitted by the applicable yellow limit.

3.2.2. Yellow units. The light emitted by the units furnished shall not be redder than the light transmitted by the applicable red limit, nor greener nor less saturated than the light transmitted by the applicable green limit.

3.2.3. Green units. The light emitted by the units furnished shall not be yellower nor less saturated than the light transmitted by the applicable yellow limit, and shall not be bluer than the light transmitted by the applicable blue limit.

3.2.4. Blue units. The light emitted by the units furnished shall not be greener, nor less saturated, than the light transmitted by the green limit, and when light emitted by the unit is transmitted in turn through a duplicate of National Standard Filter 3.086, the transmittance of the red filter for the blue light shall not be more than 0.015.

3.2.5. White units. The light emitted by the units furnished shall conform to the basic chromaticity definitions for beacon white lights as given in section 3.7.2, part I of the U.S. Standard for the Colors of Signal Lights.

3.2.6. Lunar white. The light emitted by lunar white units shall not be yellower than the light transmitted by the applicable yellow limit, nor bluer than the light transmitted by the applicable blue limit, and it shall not be greener nor more purple than the light transmitted by these limits to an extent that interferes with these judgments.

3.2.7. General requirement. If no standards are available, units shall conform to the basic chromaticity definitions for the colors stipulated as given in section 3 of part I of the U.S. Standard for the Colors of Signal Lights.

4. Sampling, Inspection, and Test Procedures

4.1. General

General methods of sampling, inspection, and tests are given below. Procurement specifications for the various types of equipment will specify any deviations from or additions to these methods.

4.2. Qualification Tests

Every new type of unit shall be given a qualification test. This may be done either before the contract is awarded or after one or more production units have been completed, but before any routine inspection for acceptance of units. Qualification tests shall be made by a colorimetric laboratory to be designated by the procuring agency. The testing shall be carried out in accordance with the principles outlined in part VI of the U.S. Standard for Signal Light Colors and shall be sufficiently comprehensive to determine whether the sample unit emits light that is in accordance with the basic chromaticity definitions and the standard limits, if any have been designated. The laboratory making the qualification tests shall review the instructions given below for inspection testing and designate the currents or voltages at which the test units are to be checked with each standard. If the qualification tests are made after the production of units has been completed and the samples used for these tests are selected in accordance with the provisions of sec. 4.4, the laboratory making the type approval tests may recommend the waiving of further tests if the results of the qualification tests indicate that all the units must conform to the chromaticity requirements.

4.3. Inspection of Parts

The acceptance or approval of material during the course of manufacture shall in no case be construed as a guaranty of the acceptance of the finished product.

4.4. Sampling

Whenever practicable, each lighting unit shall be inspected for conformity to the color requirements. When this is not practicable, a number of lighting units shall be operated at one time in such a manner as to facilitate a comparison of the light emitted by the several units. The units will generally be too bright for direct viewing, but a set of screens may be used so that each lamp can be used to illuminate an independent area of a white screen. If no differences in the chromaticities of the light are found, samples may be selected at random. If differences are found, the inspector shall select the extreme variants as samples. This may be done by comparing each piece with the extreme variants thus far found and substituting more extreme variants as they are found.

4.5. Facilities

Contractors not having laboratory facilities adequate for carrying out the tests of this section shall engage the services of a testing laboratory equipped with such facilities.

4.6. Test Equipment [2]

4.6.1. Calibrated equipment. When calibrated test equipment is required, the contractor shall provide equipment calibrated within the preceding 12 months by a laboratory generally recognized as competent.

4.6.2. Color standards. Standard filters furnished by the National Bureau of Standards for testing signal lights, or other standards approved by the procuring agency, shall be used in testing the units.

4.6.3. Comparison lamp. A calibrated seasoned lamp, that has been standardized for color temperature 2854 °K, shall be used.

4.6.4. Electric meter. A calibrated voltmeter or ammeter suitable for the purpose shall be used for controlling the lamps unless a suitable potentiometer and standard cell are available.

4.6.5. Comparator. A suitable color comparator and a photometer, which may be a photoelectric cell equipped with suitable filters and a microammeter, or a combination of such instruments, shall be used for testing the chromaticity.

4.6.6. Power supply. The power supply for lighting the comparison and test lamps shall be of sufficiently constant voltage to permit satisfactory testing.

[2] If special testing equipment is to be used, this section should be replaced by a description of that equipment.

4.7. Test Methods for Chromaticity

4.7.1 Special equipment. If a special color comparator or other special equipment is to be used, the instructions will be furnished with the equipment; otherwise the inspector shall proceed as outlined hereinafter.

4.7.2. Visual procedure. The visual chromaticity test procedure consists of the following steps:

4.7.2.1. The test unit, comparison lamp, and comparator are so mounted that each lamp illuminates one field of the comparator. The distance between the test source and the comparator should be large enough to insure that the test field of the comparator receives light from as large a part of the ware as is effective in service.

4.7.2.2. The current, or voltage, is adjusted for the comparison lamp to the value certified for 2854 °K and one of the hue limits is placed[3] between the comparison lamp and its comparator field, care being used to see that it intercepts at right angles all the light reaching the field.

4.7.2.3. The current or voltage of the test unit is then adjusted to the minimum or maximum value to be expected in normal service operation, or both, and the comparator is adjusted to equalize the luminance (brightness) of the two fields. This may be done by changing one of the lamp distances, by the use of a variable sector, with a polarization photometer, or by any other means that does not change the chromaticity of either of the fields. The fields are then compared for color match and the direction of the difference suitably recorded. This procedure is then repeated with other combinations of voltage, or current, and limit standard until all the combinations prescribed by the laboratory which made the qualification tests have been tested. If the comparator field for the test unit is on the acceptable side of, or matches, the comparator field of the limit standard in every prescribed combination, then the test unit is acceptable with respect to its chromaticity.

4.7.2.4. If no standards are available for carrying out the provisions of sec. 4.7.2.3, or if the inspector encounters color differences of such a nature that he is unable to determine whether the test field is on the acceptable side of the standard field, then sample units selected as prescribed in sec. 4.4 shall be referred to a colorimetric laboratory to be designated by the procuring agency and the tests will be carried out in accordance with the procedures of part VI of the U.S. Standard for the Colors of Signal Lights.

4.7.3. Photoelectric procedure. Units emitting only red light may be checked for chromaticity by the use of a photoelectric photometer in some cases. A photometer calibrated for light of the desired chromaticity is used to measure the emitted light and assure that the unit is of the required intensity or luminance. A second measurement of the unit is then made with a prescribed type of red filter between the unit and the photometer, and the ratio of the second reading to the first must not fall below a stipulated value which must be determined in such a manner as to take account of the spectral distribution of light from the unit, the spectral transmittance of the filter, and the spectral response of the photoelectric cell.

4.8. Stability of Color

The light emitted by gaseous discharge lamps may change both in intensity and chromaticity with the use of the lamp. Lamps tested for qualification should be retained and subjected to a life test, and the measurements of intensity and chromaticity should be repeated at intervals of 1,000 or 2,000 hours until the lamps fail or fall below the requirements in some respect. The chromaticity should remain within the basic chromaticity definitions as long as the lamp is considered a useful lamp.

[3] In placing filters for chromaticity tests they should be located in the coolest available locations since the chromaticity and transmittance of red filters are altered by high temperatures and any filter, especially one of low transmittance, is liable to break if heated unduly.

Part V. Use of Colors for Signal Lights

Part V contains information for those responsible for establishing and operating signal-light systems including officials responsible for the use of such systems. It is not a complete discussion of the problems involved in the design and use of systems involving colored lights. It is intended only to serve as an introduction to these problems. References and notes are provided to facilitate further study if needed.

1. Recognition of Colors

Signal lights are given distinctive colors in order to convey important information to the users. It is necessary to know, therefore, under what conditions the user may be expected to recognize the colors. At least 10 elements contribute to those conditions. These are: (1) the number of colors in the system, (2) the user's familiarity with the colors of the system, (3) the opportunity to compare colors through simultaneous or successive observations, (4) the degree of concentration which the user can devote to the recognition of the color, (5) the normality of the user's vision, (6) the state of his visual adaptation, (7) the luminance of the background, (8) the solid angle subtended by the signal at the user's eye, (9) the illuminance, or fixed light equivalent illuminance, at his eye, and (10) the spectral composition of the light. Of these, only the first and last are entirely under the control of the designers of the system, but some of the others will be very greatly affected by the design and installation of the system.

With the exception of such systems as may be designed entirely for indoor use, it should be assumed that a system will sometimes be required to operate as close to the limit of its visibility as is possible. For aviation and marine beacons and for ships' running lights and airplane position lights, operation at the limit of visibility is frequently brought about by reason of distance alone. For these and other types of signals, such operation may become necessary because of fog or other forms of poor visibility. Since the use of signals at the limit of color recognition constitutes one of the measures of a system's usefulness, it is important to recognize the manner in which this limitation affects the system.

When a light is just visible it is nearly colorless. Some observers state that red lights are recognizable as such even at threshold, but not all observers have found this to be true. We must conclude that the recognition of red lights at threshold is too uncertain for signal purposes, and hence at threshold we have only one signal color. As the intensity of the light is increased, or the observer approaches closer to it, red lights may be distinguished from lights of other colors, but lights of other colors continue to look alike. At still higher levels of illumination, green lights become recognizable, giving us the common three-color system composed of red, green, and an intermediate color which at still higher illuminances becomes differentiable into yellow, white, and blue. To get a sixth color with point sources, it is necessary to use dichroic purple lights which usually appear as red lights surrounded by blue rays since the lenses of the eyes cannot focus for both colors at once. With sources of appreciable size, trained observers, and favorable conditions of observation, it would be possible to use additional intermediate colors, but, since the use of such colors for outdoor signals would reduce the dependability of the system, this standard does not provide for such colors.

The effect of fog on the recognition of signal-light colors has been studied very little. The principal effect of fog is to attenuate the light which comes directly from the signal to the observer by scattering it. This is equivalent to reducing the intensity of the light itself and this reduces the useful range of the signal both for visibility and color recognition. Some of the light scattered from the beam is rescattered toward the observer's eye but comes to him from a slightly different direction than the light which travels in a single straight line. This scattered light builds up the luminance of the background and tends to obscure the signal. At the same time light scattering into the beam generally dilutes the color and makes the color less saturated. In a true aqueous fog, all colors are scattered about equally so that the hue is not changed. In a haze of smoke or dust, the blue light is scattered more than the red and this may make white and yellow lights somewhat reddish, but mainly it reduces the intensity of a good blue or green signal.

It should be noted that a difference of intensity is not a desirable means of differentiating between signals unless the signals are always seen under the same conditions of distance, atmosphere, and background luminance because changes in these conditions may easily obscure differences in intensity.

2. Number of Colors

The more colors used in any system the greater the risk that the user will confuse them. In the extreme case of a single color there would be no possibility of color confusion. On the other hand, the larger the number of colors in a system, the smaller will be the chromaticity differences which can be used to separate them. The number of colors, therefore, should be kept to the minimum that will serve the needs of signaling. Moreover, a system of signal lights should not depend solely upon colors to differentiate the signal lights from other lights that may be in the field of view if this can be avoided. To do so would make the colors of all the stray lights in effect parts of the system for they must be rejected upon the basis of color difference.

3. The Primary Signal Colors

Most signal-light systems are based on three primary signal colors, red, green, and an intermediate color which may be either yellow or signal white. The basic reason for the choice of these colors is apparent at once from their locations on an RUCS diagram. The red and green areas are as far apart as two colors can be, and the area including yellow and white is approximately midway between them. It might be thought that some color composed of a mixture of both red and blue might be more easily distinguished from both red and green, but such colors are not used because they can be obtained only by the use of filters of very low transmittance.

Comparing colors of equal intensity, the further apart the areas on the RUCS diagram which represent them, the more dependable will be their recognition. In practice it does not follow, however, that dependability is indefinitely increased by contracting the permitted areas around the top and bottom of the diagram. With a fixed amount of light available from the lamp, and a given type of filter, there is an optimum filter density for recognition at maximum distance.

Starting with filters of very low density, the transmitted light is almost white; increasing the density of the filter increases the saturation, making the color more recognizable. When the density is increased beyond the optimum, further increases reduce the transmittance, and hence the intensity, so rapidly that the further gains in saturation cannot compensate for the loss in illuminance at the observer's eye. For a signal system used under conditions that do not require its full intensity to insure visibility, the certainty of recognition can be increased by requiring a higher saturation and accepting, in consequence, filters of lower transmittance.[1] Accordingly, the specification limits should be adjusted to place the optimum signal chromaticity midway between the pale limit and the computed chromaticity of the minimum acceptable transmittance.

4. Yellow-White Discriminations

The close proximity of the regions representing signal yellow and signal white on the RUCS diagram makes it evident that these two colors are not to be considered as independently identifiable. Furthermore, the lights most often classed as "white lights" have a chromaticity which most people would classify as yellow if they saw a disk of that color in the daytime. At night these same lights seem whiter because of the effects of dark adaptation, their small apparent size, and the fact that most of the lights we see are of this same chromaticity. In view of this, the convention by which they are called white is not unreasonable, especially as it is necessary to have a name by which to distinguish them from the lights equipped with yellow filters.

Both the proximity of some chromaticities that are defined as white for signal-light purposes to some that are defined as yellow, and the fact that some of these chromaticities are seen as white under some conditions, and as yellow under other conditions, make it necessary to observe precautions in the use of yellow and white signal lights. The required precautions have been stated in the "International Standards and Recommended Practices for Aeronautical Ground Lights and Surface Marking Colours" adopted by the International Civil Aviation Organization[2] and quoted below.

2.2. Discrimination between Yellow and White Lights.

2.2.1. Recommendation. If yellow and white are to be discriminated from each other, they should be displayed in close proximity of time or space as, for example, by being flashed sucessively from the same beacon.

NOTE.—The limits of yellow and white have been based on the assumption that they will be used in situations in which the characteristics (colour temperature) of the light source will be substantially constant.

2.2.2. Recommendation. The colours variable-yellow and variable-white are intended to be used only for lights that are to be varied in intensity, e.g., to avoid dazzling. If these colours are to be discriminated from each other, the lights should be so designed and operated that:

[1] J. G. Holmes has investigated the characteristics of the optimum green in his paper on "The Recognition of Coloured Light Signals" in the Transactions of the Illuminating Engineering Society (London) *6*, 91 (1941).

[2] Annex 14 to the Convention on International Civil Aviation, Part IV, p. 16.

a) the chromaticity of the yellow lights will be represented by coordinates such that y is not greater than $x - 0.160$ at any time when the chromaticity of the white lights is represented by coordinates of which x is greater than 0.470; and

b) the disposition of the lights will be such that the yellow lights are displayed simultaneously and in close proximity to the white lights.

To clarify the application of the above limitations on the use of yellow and white signal lights in the same system, consider three typical cases.

(1) Seadrome beacons flash alternately yellow and white. The yellow acceptable for this use is the restricted yellow and the white is beacon white. The chromaticity difference between a light of the color of the common gas-filled, incandescent beacon lamp and the green limit of restricted yellow is comparable with the separation between signal green and signal white, and the alternation of the colors in the successive flashes facilitates recognition of the color difference.

(2) Both yellow and white lights have been used on some airport runways, the yellow being used to indicate that the pilot is running out of runway. In this case it is necessary to use signal yellow and variable-source white because the large range of intensities required by different weather conditions can only be obtained by accepting a large range of chromaticities. But these two colors have boundaries which almost adjoin each other over a part of their length. It was for this case that the I.C.A.O. requirement of 2.2 was written. If this precaution is observed, the difference in chromaticities is preserved during the dimming, the yellow lights becoming redder as the white lights become yellower. While this difference is not as large as would be required for two independent primary signal colors, it is sufficient so long as the pilot can see lights of both colors at the same time, to enable him to distinguish the change of color.

(3) The third case is that of the railroads which use both yellow and white lights, but in this case a blue filter is used on the white lights the chromaticities of which are required to be lunar white. This improves the chromaticity separation between the white and the yellow, has little effect upon the difference in chromaticity between the white and the green used by the railroads, but brings the white closer to the blue. Since, however, both lunar white and blue are secondary signal colors intended for use at relatively shorter ranges and slower speeds than those at which the primary signals are generally used, the chromaticity difference is adequate.

Even though a signal system does not contain white as a signal color, difficulty can arise if lights are installed without reference to background lights on the assumption that the yellow color of yellow signals will make them distinguishable from ordinary lights. If the yellow lights are displayed only with lights of another color, if they are flashed, or if they do not have to be recognized at more than 25 yards and are exhibited in distinctive fixtures which can be recognized at that distance, then they should constitute trustworthy signals.

5. Blue Signal Lights

Blue signal lights as developed to date are of relatively low intensity. A satisfactory signal blue can only be obtained from incandescent lamps by absorbing nearly all the light of other colors. It follows that blue filters are low in transmittance and heat more than red, green, or yellow filters with the same lamps. Blue signal lights can be obtained with the use of fluorescent or gaseous discharge lamps, but in this case the luminance is low and fairly large units are required to produce moderate intensities. In both cases the light is better suited for a secondary signal than for a primary signal requirement. If blue signals are included in any system of signal lights, it is important to use blue light which contains no appreciable red light. Some filters which look blue transmit light that contains a considerable red component and in this case there is the possibility that the signal may, under some conditions of observation, appear red.[3]

6. Signals for Color-Deficient Users

In many applications it would be desirable to use signal-light colors which could be recognized even by colorblind users. There might be a possibility of selecting a saturated yellow green, a lunar white, and a color midway between red and blue which could be distinguished by all except the totally colorblind. The filter for the red-blue light would be low in transmittance, however, and subject to the risk of confusion for normal users when the red and blue components became separated by chromatic aberration. Another possibility is to use a saturated blue, a lunar white, and a signal red. Here again the saturated blue would require a filter of very low transmittance.

Since very few persons are totally colorblind whereas a substantial number who can distinguish yellow from blue have difficulty in distinguishing red from green, a system of colors designed to be usable by this latter group has been designed by D. B. Judd [4] and tested by Sloan and Habel.[5]

[3] This may be the result of selective scattering of the blue light either by the atmosphere or eye media, or of chromatic aberration of the lens of the eye as the result of which the longer-wave, red component is brought to a focus while the shorter-wave, blue component is blurred.

[4] D. B. Judd, "Standard Color Filters for Electronic Equipment," Report of Armed Forces-National Research Council Vision Committee, July 1, 1952.

[5] L. L. Sloan and A. Habel, "Recognition of Red and Green Point Sources by Color-Deficient Observers," J. Opt. Soc. Am. 45, 599 (1955).

This system consists of lights which would meet the requirements given in this standard for signal red, signal blue, and signal green with its yellow boundary moved to $y=0.667(1-x)$. It was developed primarily for use with electronic equipment which is seen at short range so that the lights subtend an appreciable angle at the eye and the luminances and illuminances can be kept within comfortable limits. The tests under these conditions were moderately satisfactory.

7. Backgrounds

The background of a signal light can have a very considerable effect on its conspicuity and recognition. A signal light of normal intensity which would be amply conspicuous in its usual background may become so inconspicuous against some backgrounds as to be difficult to find even for one who is looking for it. Exposure to bright red or green lights can interfere with the normal adaptation in such a way as to change the apparent color of a signal for a person who has been exposed to the colored lights. Red and green signal lights with adequate intensity for daylight recognition at a distance of several hundred yards may be much too glaring at night for optimum recognition. It is recommended that, where possible, signal light fixtures should be designed to present as much black background as is practicable, that if there is any choice of location for installing a signal light, avoidance of competition from background lights be given as much weight as possible, and that the problem of further reducing the hazard of competing lights through both cooperation and control be given study.

8. Application of the Colors

In this standard the names used for the colors defined in part I have been chosen so as not to imply any particular application, since in many cases the same definitions are suitable for two or more applications. Table V–1 indicates the definitions recommended for different applications, and table V–2 lists the National Standard Filters and shows the recommended basis for selecting filters for different applications. Table V–3 is a comparative listing of the transmittance requirements of the antecedent specifications. In comparing the values shown in this table, and in selecting transmittance limits for new applications, consideration must be given not only to the range of chromaticities which are acceptable but also to the type of ware, its design, and even to the number of pieces to be produced, a closer control being practicable on larger orders. Whenever possible, it is preferable to control the transmittance by specifying minimum intensities, i.e., candlepower, since this controls at one time variations in colorant density, colorant efficiency, ware thickness, surface quality, and design. When circumstances do not permit control of the intensity, the next preference should be for transmittance ratio (for definition, see part I–2.9) which allows for the effects of design and surface quality by using a colorless specimen of the same design as a basis for comparison. It is not possible to measure transmittance directly except in the case of filters which cause very little refraction as in the case of flat filters and some cylindrical filters. Nevertheless, some laboratories prefer to introduce a colorless filter into the path of the light from the test piece when measuring transmittance ratios and thereby obtain a quasi-transmittance value in cases in which specifications have specified "transmittance." (Tables II–2 and III–1 are based on table V–3.)

Table V–1. *Recommended application of chromaticity definitions of part I to different transportation services*

Service	Red	Yellow	Green	Blue	White
Aircraft lights:					
Exterior	Signal	Intermediate	Signal		Beacon
Warning	Signal	Signal			
Formation	Restricted	Restricted	Restricted	Signal	Blue white
Aeronautical ground lights	Signal	Signal and Restricted	Signal	Signal	Variable source and beacon
Highways* traffic lights	Intermediate and Restricted	Intermediate and Signal	Intermediate		
Highways vehicles	Intermediate	Intermediate			Beacon
Marine aids	Signal		Signal		Beacon
Marine ship	Signal		Signal		Beacon
Railroad	Restricted	Intermediate	Intermediate	Signal	Lunar white
All services, indicator lights**	Restricted	Restricted	Restricted	Signal	Lunar white

*Includes railroad crossings on highways.
**In cases where high ambient brightness requires more conspicuity, the signal color may be used in place of the restricted color.

Table V-2. *Recommended basis for selection of national standard filters for different applications*

Yellow limit	Transmittance standard	Red signals
		Restricted Type
3.154	3.086T	Signals requiring maximum chromaticity contrast, such as aircraft formation lights and railroad wayside and train signals.
3.126	3.154T	Signals requiring high conspicuity among other lights with relatively short range, such as railroad lanterns and urban traffic signals.
		Intermediate Type
3.075	3.126T	Signals requiring maximum conspicuity and intermediate range, such as through highway-highway and highway-railroad crossings and tail lights and brake lights on vehicles.
		Signal Type
3.640*	3.075T	Signals for which maximum range is paramount, such as aviation and marine lights.

Red limit	Green limit	Yellow signals
		Restricted Type
4.200	4.199	Signals having source color temperatures between 2450 °K and 3100 °K for which the narrowest chromaticity variation is desirable, such as railroad disks and cones for wayside signals.
		Intermediate Type
4.200	4.261	Signals having source color temperatures between 1904 °K and 2500 °K in systems not using either signal or intermediate red, such as hand lanterns on railroads and in most other applications.
4.200	4*	Signals having source color temperatures between 1904 °K and 2854 °K including most applications not otherwise classified.
		Signal Type
4.199	4.261	Signals having source color temperatures between 2050 °K and 2900 °K in systems showing yellow only in conjunction with green or not requiring a distinction between yellow and green, such as highway traffic signals.
4.199	4.166*	Signals having source color temperatures between 1650 °K and 3250 °K for signals which must operate on a maximum of voltage variation and for which a minimum chromaticity difference is satisfactory, such as aviation runway lights.

Table V-2. *Recommended basis for selection of national standard filters for different applications*—Continued

Yellow limit	Blue limit	Green Signals
		Restricted Type
		Used only for aviation formation lights and no National Standard Filters have been selected for this purpose.
		Intermediate Type
7.134	7.087	Signals having source color temperatures between 1904 °K and 2854 °K provided high expansion glass is satisfactory, such as most railroad wayside and train signals, highway traffic signals, and some aviation and marine signals.
7.137	7.135*	Signals having source color temperatures between 1904 °K and 2650 °K for which low expansion glass is required, such as railroad and other hand lanterns.
		Signal Type
7.137	7.135*	Signals having source color temperatures between 1800 °K and 3200 °K for which low expansion glass is required, such as aviation and marine beacons and some other lights in these applications.
7.087	7.136*	Signals having source color temperatures between 1550 °K and 3050 °K for which low expansion glass is required, such as aviation threshold lights.

Green limit	Transmittance standard	Blue Signals
8.047	8.057	Signals having source color temperatures 1904 °K and above and not requiring low expansion glass, such as railroad wayside and train signals and some aviation taxiway lights.
8.141	8.131	Signals having source color temperatures between 1904 °K and 2854 °K and requiring low expansion glass, such as railroad hand lanterns and some aviation taxiway lights.

*New filter.

Table V-3. *Comparative table of minimum transmittances* (T_{2854}) *from antecedent specifications*

Grade	Organization	Type of ware	Red			Yellow		Green		Blue	Lunar white
			Restr.	Inter.	Signal	Inter.	Signal	Inter.	Signal		
A	U.S. Av	Special			0.184	0.414	0.552		0.207	0.024	
E	A.A.R	Thin disks and cones	0.064			([a])		0.183		.021	0.29
B	U.S. Av	Thin, pressed (6mm)			.161	.368	.460		.184	.020	
F	A.A.R	Lenses, roundels, slides	.047	0.127		[b] (.30)		.20		.021	.29 [c].162
G	I.T.E	Cover glasses	.047	.095			[d].440	.200			
C	U.S. Av	Blown filters			.138	.322	.368		.161	.015	
H	A.A.R	Blown lantern globes	.078 .079	([e])		.452		.169		.0159	
D	U.S. Av	Thick, pressed			.120	.276	.276		.138	.007	

Notes:
[a] No specified minimum for yellow disks and cones which are partially diffusing.
[b] Colorant selected to prevent excessive transmittance relative to other signal colors.
[c] Alternate requirement for ware used with kerosene illuminants.
[d] Colorant selected to insure high transmittance for conspicuity.
[e] Requirement for glasses used with electric hand lanterns.

Specifications from which values are taken.
A.A.R.—Association of American Railroads, Signal Section, Specifications 69–59 and 59–61. See also NBS Research Paper 2849.
I.T.E.—Institute of Traffic Engineers, Technical Report No. 1, A.S.A. D-10.1–58 and supplement.
U.S. Av.: Federal Standard No. 3 and Military Specifications MIL–C–25050 computed to equivalent transmittances instead of transmittance ratios for comparison with other specifications.

Part VI. Procedures for the Determination of the Color of Light Signals by Referee Laboratories

In view of the lack of precedents for referee tests and the necessity for basing many tests on subjective judgments, it has not been considered practicable to prescribe exact procedures for such tests. The procedures described below have been used at the National Bureau of Standards. These procedures are recommended for the use of colorimetric laboratories equipped for carrying them out. They include procedures for testing for compliance with basic chromaticity definitions in cases in which no chromaticity standards are applicable.

1. Certification of Standard Filters

Standard filters are spectrophotometered and their characteristics computed from the spectrophotometric values by the procedures described in NBS Circular 484, Spectrophotometry, or equivalent procedures.

Duplicate limit filters and transmittance standards for issuance by the National Bureau of Standards are either spectrophotometered and their characteristics computed or measured by color difference colorimetry and photometry as described in NBS Circular 478, Colorimetry, section III, or by such improved methods as may have been introduced.

When filters are submitted by a manufacturer for certification and acceptance by a procuring agency as a manufacturer's color standard, they must be tested to determine if ware having similar chromaticity characteristics to the filters of that standard will transmit light conforming to the basic chromaticity definitions when such ware is used with a source of any color temperature within the range to be encountered in service. In general, this is the range shown in table II–1, part II, for the types of equipment which are to be made from the material represented by the color standard submitted. When specific applications are not included in table II–1, part II, the color temperature range should be stipulated by the procuring agency. The testing for conformity with the basic chromaticity requirements is done by spectrophotometering the filters of the standard and computing the chromaticity coordinates for different thicknesses of the same material for sources representing the extremes of the required range, and for such intermediate temperatures as may be necessary to make certain that the chromaticity throughout this range of thicknesses and temperatures remains within the defined boundaries. To ascertain that an adequate range of thicknesses has been considered, the transmittance of the maximum thickness is compared with the minimum transmittance allowed in table II–2.

2. Similarity of Chromaticity

Similarity of chromaticity is determined by computations based upon the spectral transmissivity of the material from which the ware is made. If the test is to be made on a sample other than a filter with plane parallel faces, it will generally be necessary to cut a piece from the sample and grind and polish it to uniform thickness to obtain reliable transmissivity values.

3. Compliance With Hue and Saturation Limits

Referee tests for compliance with hue and saturation limits, in cases in which the ware meets the requirement for similarity of chromaticity characteristics, may be made in the same manner as inspection tests (part III), except that at least three experienced observers will be used.

4. Compliance With Basic Definitions

4.1. General

In the case of autochromatic units, the requirements for which are given in part IV, and of ware which must be tested without standards having the same chromaticity characteristics, it is necessary to make a direct determination of the chromaticity of the light emitted by the unit or transmitted by the ware. If a colorimeter suited to this type of measurement is available, the determination may be made directly. Most colorimeters, however, are not suitable for such measurements and consequently in most other cases the procedure described below (4.2) is used, notwithstanding that it relies upon subjective methods involving a degree of professional judgement.

4.2. Basic Principle of the Method

The chromaticity of the light emitted by the equipment or transmitted by the ware under test may be determined by comparing the chromaticity of the emitted or transmitted light with light of known chromaticity provided the directions and amounts of the hue and saturation differences are such as to indicate definitely whether the light conforms, or does not conform, to a specific color requirement. For example, if we have available a lamp-filter combination known to have a chromaticity close to the blue boundary of green (e.g., at $x=0.180$, $y=0.360$), it can be used to judge the conformity to aviation green of light which is either a close chromaticity match to it or of a chromaticity perceived as yellower and not more than slightly more or less saturated than this comparison standard. The tested equipment or ware would, in this case, be found to conform to the blue limit of aviation green. But this source-filter combination would not warrant a decision to be made regarding equipment yielding chromaticities perceived as substantially less saturated, because the observer would have no basis for judging whether the chromaticity departure is, or is not, great enough to indicate that the chromaticity of the equipment being tested has coordinates that fall below the white boundary for green. A source-filter combination represented by a point just within the corner at which the blue boundary intersects the white boundary is only satisfactory for accepting equipment with chromaticities which are both yellower and more saturated than the light from the working standard. If, however, the light is considerably on the safe side with respect to one of these attributes, and questionable, or apparently slightly outside, with respect to the other, the observer could not be certain whether it should be accepted or rejected. The solution of this difficulty is to find another source-filter combination which is a closer match for the light being tested, or differs in such a way as to resolve the question.[1]

Two difficulties restrict the application of this method. Notwithstanding that the chromaticity boundaries in the present basic definitions have been made to follow lines of constant hue and saturation as nearly as practicable, differences in adaptation or natural eyesight may cause observers to see the color relationships abnormally. Large differences in any aspect of a color make it difficult for an observer to make reliable judgments with respect to other aspects. For this reason it may be necessary to use three or more source-filter combinations to make certain that equipment under test is, or is not, within the boundaries of the definition. This makes it desirable to have an adequate assortment of calibrated filters available in order to carry out tests by this method.

[1] It would facilitate this type of determination to have the coordinates of both the source-filter combinations and the chromaticity boundaries of the colors expressed in the RUCS system since both the nature and importance of the chromaticity differences are more easily estimated in this system.

4.3. Procedure for Chromaticity Tests

4.3.1. One side of a test field is illuminated with light from the equipment under test. If this equipment is light-transmitting ware, an incandescent light source of a color temperature corresponding to one of the extremes of color temperature specified in table II–1 will be used.

4.3.2. The other side of the photometric field is illuminated with a standardized source-filter combination of the approximate chromaticity of the light to be tested, and the equipment will be adjusted to make the luminances of the test and comparison fields approximately equal. There is no necessary relationship between the color temperature of this lamp and any lamp that may be used in the equipment under test, and it may be advantageous to use the same filter with its light source at several color temperatures if the chromaticity coordinates for the combinations are known. The direction and magnitude of the color difference are then noted for each case. This process should be repeated with a sufficient number of different combinations of sources, filters, and observers to be certain as to whether the light being tested is within, or outside of, the limits.

4.3.3. If the unit tested is required to conform to the basic definitions throughout a range of color temperatures, the operations of 4.3.2 are repeated with a light source for the test piece corresponding to the other extreme of color temperature. If the test piece passes the chromaticity requirements for both upper and lower extremes of color temperature as specified in table II–1, it may be assumed that it is within the limits for the intermediate color temperatures.

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THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

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