

**MEASUREMENT OF THE COLOR CHARACTERISTICS
AND BRIGHTNESS OF
FLUORESCENT AND PHOSPHORESCENT MATERIAL**



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NAVAL RESEARCH LABORATORY

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**MEASUREMENT OF THE COLOR CHARACTERISTICS
AND BRIGHTNESS OF
FLUORESCENT AND PHOSPHORESCENT MATERIAL**

by

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ABSTRACT.

The physical basis of color measurement is discussed and an experimental comparison is made of the photoelectric and spectrophotographic method for determining the spectral distribution of energy from fluorescent and phosphorescent material. An R.C.A. photomultiplier tube with a direct-current amplifier is used as the detecting instrument. To demonstrate the practicability of the photoelectric photometer for routine measurements; samples of fluorescent cloth radiating in the visible portion of the spectrum when excited by light from a G. E. S-4 high-intensity mercury arc covered with Kopp ultraviolet transmitting glass No. 41, were examined and the color characteristics measured. The cloth was manufactured and submitted for test by the Continental Lithograph Co. of Cleveland, Ohio. The photoelectric method was simpler, more rapid and accurate than spectrophotographic methods. A comparison is made of the relative merits of the flicker method and "Equality of Brightness" method for measuring fluorescent brightness. The flicker method is more accurate and consistent at high brightness levels when there is a large difference of color between the two fields being compared. At low brightness values and where no large difference of color exists, the "Equality of Brightness" method is probably simpler and is as accurate as the flicker method.

AUTHORIZATION

This investigation was initiated as requested by BuShips in BuShips ltr. JJ-17L18(350) dated 15 December 1942 to NRL, and was assigned NRL Problem No. 37N01-01.

PROBLEM STATUS

This is an interim report. Work on this problem is continuing.

MEASUREMENT OF THE COLOR CHARACTERISTICS
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The present methods of measurement of the brightness and color of phosphorescent and fluorescent materials are cumbersome and difficult, and are in general unsatisfactory. Visual methods are unreliable, principally because of the peculiarities of the human eye. Physical methods have lacked sufficient sensitivity and have been troubled with the difficulties of amplifying photoelectric currents. During the past few years and especially during the war, the increase in the number of uses to which phosphorescent and fluorescent materials have been put has required better, more reliable, and faster methods for determining the luminous properties. During this period the Photometry Section of the Optics Division of the Naval Research Laboratory has been required to make color and brightness measurements of phosphorescent and fluorescent material, and has constantly attempted to devise new methods and improve existing methods of low-luminosity photometry. Some success has attended these efforts, and this report attempts to describe briefly a physical photometer and colorimeter using a photomultiplier tube as the detecting device, and to compare this instrument with color measurements made by spectrophotographic densitometer methods.

To determine the merits of the different methods of measurement of color and brightness which have been investigated and to apply them to cases of color measurement met in practice, several samples of fluorescent and phosphorescent material manufactured by the Continental Lithograph Company have been examined. The color characteristics have been measured by a photomultiplier tube and again by spectrophotometric means, and the two methods are compared for accuracy and ease of manipulation. The brightness has been measured by the "Equality of Brightness" photometer and by the flicker photometer methods. These two methods are compared for accuracy and simplicity.

The luminous material used as a subject for measurement was submitted to the Bureau of Ships by the Continental Lithograph Co. of Cleveland, Ohio in 1942 for tests for information purposes under specifications 17L18(INT) of 15 February 1942. Because of the urgency of war, precedence was given other work and the material was kept in a dry dark space until time was found to carry out the proposed program. Table I lists the luminous material used in this investigation together with the manufacturer's designation, the color, and the type of luminosity.

To specify the luminous characteristics of phosphorescent and fluorescent materials requires a knowledge of their color and brightness under a given excitation. Before describing the experimental procedure of the investigation, a brief discussion of the physics of color is in order.

The phenomenon which the human eye knows as the sense of color may be approached from three aspects, namely, the physiological, the psychological, and the physical. So fundamental to our lives is the sense of color that a set of terms defining the various elements has been built up on the physiological effects on the eye. These

serve their purpose, but because of the great variation in the characteristics of the eye, they cannot be exact definitions. To be exact and explicit, the approach must be a study of the physical characteristics of the radiation. There must be however, some means of translating terms and definitions derived from the physiological aspect to the physical.

TABLE I

Luminous Fabric Manufactured by the Continental Lithograph Co.
and Used to Determine the Brightness and Color Characteristics.

Manufacturer's Designation	Color (daylight)	Type of Luminosity
3030	Fire Orange	Fluorescent
30E42	Arc Yellow	Fluorescent
30E53	Signal Green	Fluorescent
3072	Flag Blue	Fluorescent
30E72	Flag Blue	Fluorescent
Permatex No. 10708	Red	Fluorescent
P12 "Glo Sheet"	Green Yellow	Phosphorescent

It has been shown that any color may be produced by a mixture of three primary radiations. Maxwell (1854), Konig and Dieteric (1892), and Abney (1913) carried out measurements of this sort. Ives (1915 and 1923) first pointed out the advantages of the trichromatic system. It remained for Guild (1924) and 1931) and Wright (1928) to lay the experimental foundation for a reliable system of color measurement. Guild examined previous color data and redetermined the color values more carefully using red, green and blue filters. Wright, using pure radiation of wavelengths 650, 530, and 460 millimicrons, independently obtained such values for the three primary radiations. The three quantities used to obtain a given color were given the name of tristimulus values. The tristimulus values obtained by Wright were different from those obtained by Guild, but both found it necessary when matching the purples to add a small amount of at least one of the primaries to the radiation from the source to be matched. These difficulties are not of a fundamental nature since one set of primaries can readily be transformed to another by a linear transformation. The International Commission on Illumination in 1931 adapted a set of primaries with which all colors can be matched by using positive values. The significance of this method for specifying color will be brought out more clearly when the results of the investigation are discussed.

Color may also be described by its "dominant wavelength" and its "excitation purity". The dominant wavelength is defined as that spectrum color which is specified by a wavelength, mixed with white light in the correct proportion, will produce a specified color. Practically, the "white light" is chosen as the I.C.I. source of illumination known as illuminant "C". The "excitation purity" is determined by the amount of white light mixed with the pure spectrum color to produce the unknown color.

To make these methods of specification of color more useful, various graphical methods of representation of colorimetric data have been suggested. To represent a color graphically by the tristimulus values would require a three-dimensional system of coordinates. To overcome this difficulty, three new quantities are defined by the

following equations:

$$x = \frac{X}{X + Y + Z}, y = \frac{Y}{X + Y + Z}, \text{ and } z = \frac{Z}{X + Y + Z}.$$

These are called the trichromatic coefficients. It can be seen that $x + y + z = 1$, thus only two are independent. The color can therefore, be specified by any two of the trichromatic coefficients on a two-dimensional diagram. Figure 1, shows a chromaticity diagram in which y is the ordinate axis and x the abscissa. The solid line is the locus of the trichromatic coefficients of the pure spectrum colors. Point C is the location of the "white light", which for practical purposes is I.C.I. illuminant "C".

Since the color of an object depends upon the type of illumination in which it is observed, it has been necessary to adopt some types of standard illumination. The International Commission on Illumination has adopted three standard illuminants called A, B, and C. Illuminant A is a tungsten lamp operated at a color temperature of 2848°K. Illuminants B and C are produced by filtering the radiation from illuminant A. These sources are easily obtainable and are quite reproducible. Illuminant C is the most important, since this radiation closely approximates daylight.

The procedure to specify a color requires first a knowledge of the distribution of the energy throughout the spectrum emitted by

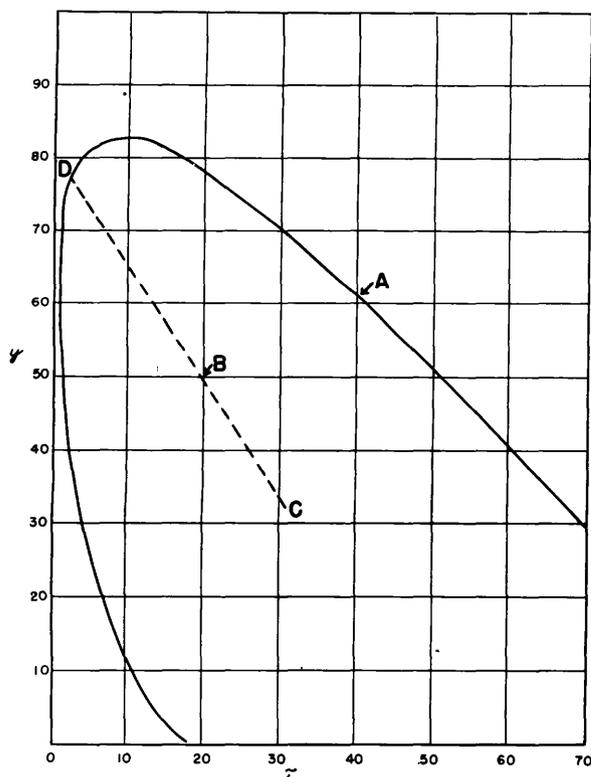


Fig. 1 - Chromaticity Diagram

the source. This source of radiation may be the primary emitter or it may be light passed through an optical filter or reflected from some surface. Since color is a property of the human eye, the data obtained from physical measurements must be transformed into the equivalent stimulus that the eye perceives. This is done by making use of the ICI tristimulus values of the spectrum colors for equal energy values. Multiplying the relative value of the coordinates of the energy distribution curve of the source of light to be studied with the corresponding tristimulus values of the equal energy spectrum colors gives the tristimulus values for the radiation under investigation. The trichromatic coefficients are then readily obtained. The values of the "dominant wavelength" and "excitation purity" may be found most conveniently by locating the trichromatic coefficients on the chromaticity diagram. A straight line drawn through the points on the chromaticity diagram corresponding to a given illuminant (usually Illuminant "C") and the color under investigation and intersecting the curve for the spectrum colors enables one to read the color characteristics. The point of intersection gives the "dominant wavelength". The

ratio of the distance from the point of the unknown color to the point of illuminant "C" to the distance from illuminant "C" to the intersection with the line of pure spectrum colors is called the "excitation purity". An example of this procedure for the determination of the "dominant wavelength" and "excitation purity" will be given in detail for a sample of fluorescent cloth.

DETERMINATION OF THE RELATIVE DISTRIBUTION OF ENERGY IN THE RADIATION UNDER INVESTIGATION

Two methods were used to determine the relative distribution of energy in the spectrum of fluorescent radiation: first, by means of a photomultiplier tube, and, second, by photographic means. The most common method for obtaining the distribution of radiant energy of relatively low luminosity has been photographic densitometry since ordinary detecting devices like the thermocouple have insufficient sensitivity, and photoelectric cells with their amplifying circuits are complicated and unstable. Photographic methods, however, leave much to be desired, since the analysis of the densitometer trace is long and tedious and the exposures may be inconveniently long. The photomultiplier tube eliminates both difficulties, since it does not necessitate complicated amplifying circuits with all of their difficulties of instability and high background-noise levels.

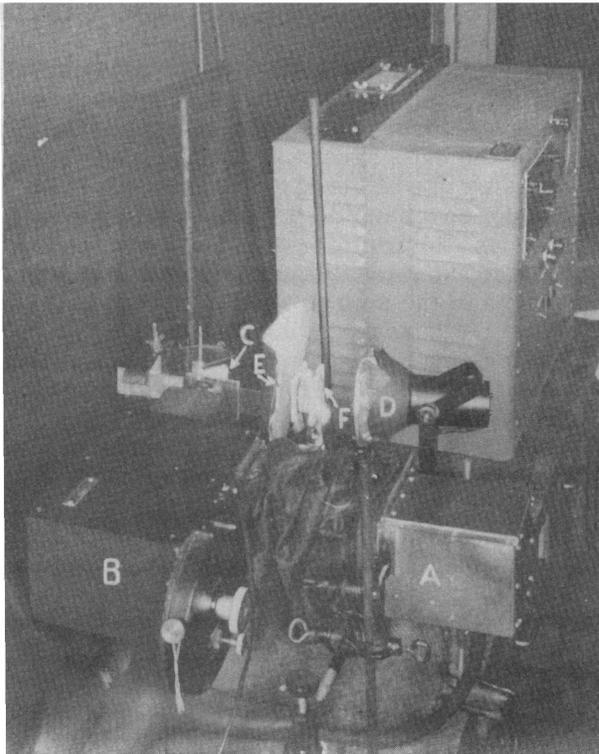


Fig. 2 - Photograph of Phosphoroscope

Figure 2 shows the arrangement of the apparatus which makes use of the photomultiplier tube to measure the luminous characteristics of fluorescent cloth. The instrument may be called a phosphoroscope or phosphorometer. In Figure 2, (A) is a light-tight box containing an RCA 1P22 photomultiplier tube. This box is mounted in front of the exit slit of a Gaertner L234-HT monochromatic illuminator (B) and is fitted with a shutter to admit light at the will of the operator. Since the radiation from phosphorescent and fluorescent material is in general of low intensity it was necessary to use a high light-gathering-power instrument. This is shown at (B). The fluorescent cloth (C) to be examined is mounted in a plane at 45 degrees to the optical axis of the instrument and was illuminated at right angles to the axis by radiation from a quartz mercury arc (D) fitted with an ultraviolet-transmitting glass filter (E). The water cell (F) protects the filter from heat.

Since a photoelectric detecting device has a spectral sensitivity peculiar to the type of surface used, it is necessary to determine the response curve, or to compare the emission of the unknown source

with that from a known source. In the present investigation, a tungsten filament lamp radiating at a known temperature was used as a standard comparison. The procedure for comparison of the two sources was to determine the readings on the phosphoscope for a series of wavelengths at intervals of 200 Å throughout the visible spectrum. Since the energy distribution for the tungsten lamp is known, the distribution of energy in the radiation from the fluorescent cloth was readily determined. The energy distribution curves for a black body and tungsten are well known and can be found in tables.

After determining the energy distribution of the radiation from fluorescent cloth, there remains to compute the trichromatic coefficients by multiplying, at each wavelength, the tristimulus values of the spectrum colors by the relative values of energy distribution. A table of tristimulus values weighted for the fluorescent radiation is obtained. These values are \bar{x} , \bar{y} and \bar{z} . The sum for each gives the three tristimulus values X, Y and Z for each color. The trichromatic coefficients x, y and z are then defined by the equations

$$x = \frac{X}{X + Y + Z}, y = \frac{Y}{X + Y + Z}, \text{ and } z = \frac{Z}{X + Y + Z}.$$

Defining x, y and z in this manner results in the equation $x + y + z = 1$, thus, knowing any two values defines the third. A color may then be represented graphically in two dimensions.

The fluorescent cloth manufactured by the Continental Lithograph Co. and called by them "Conti-Glo Arc Yellow" is used as an example to demonstrate the method for computing the characteristics of a given radiation. A complete calculation is given in Table II.

TABLE II
Measurement of "Dominant Wavelength" and "Excitation Purity" of "Conti-Glo Arc Yellow"
Fluorescent Cloth

Wavelength in mμ	D _λ Reading of Indicating Instrument	C _{λc} Reading of Instrument Corrected for Sensi- tivity of Photocell	*D _{λc} (%) Relative Distribution of Energy	X	Y	Z
420	0.6	2.4	4.9	0.658	0.020	3.165
440	3.6	13.1	27.0	9.366	0.621	46.985
460	6.9	23.3	48.0	13.963	2.880	80.126
480	11.7	38.1	78.0	7.457	10.842	63.398
490	14.0	48.1	99.0	3.168	20.592	46.045
500	14.7	48.6	100.0	0.490	32.300	27.200
510	13.8	47.2	97.0	0.902	38.791	15.345
520	12.2	43.0	88.5	5.602	62.835	6.921
530	10.2	35.1	72.0	11.916	62.064	3.031
540	8.1	28.7	59.0	17.134	56.286	1.204
550	6.3	23.0	47.0	20.374	46.765	0.414
560	4.8	18.0	37.0	21.996	36.815	0.141
570	3.5	14.0	29.0	22.104	27.608	0.161
580	2.6	11.1	23.0	21.073	20.010	0.034
590	1.8	8.2	17.0	17.452	12.869	0.020
600	1.3	6.54	13.0	13.806	8.203	0.010
620	0.7	4.12	8.5	7.262	3.238	
640	0.4	2.87	6.0	2.687	1.050	
				197.410	453.789	294.102

$$X + Y + Z = 945.301$$

* D_{λc} is corrected reading based on the distribution of energy of tungsten lamp at 2860°K color temperature.

$$x = \frac{X}{X + Y + Z} = 0.2088 \text{ Dominant Wavelength **}$$

**Dominant Wavelength and Purity are obtained from the Chromaticity Diagram (Figure 2).

$$y = \frac{Y}{X + Y + Z} = 0.4800 \text{ Purity 37 Percent **}$$

Column 1 gives the wavelength; column 2 gives the readings of the microammeter registering the photoelectric current generated in the photomultiplier tube when excited by the radiations from the fluorescent cloth. The fluorescent cloth was excited by a General Electric S-4 high-pressure mercury arc covered with ultraviolet-transmitting glass, Corning No. 5860. The ultraviolet energy fell on the cloth at the rate of 51 ergs/mm² per second. This was determined by means of the effect of ultraviolet radiation upon a solution of uranyl sulphate and oxalic acid. The method was described by Anderson and Robinson¹ in 1925.

Column 3 of Table II gives the reading of the indicating instrument when corrected for the dispersion of the monochromator and for the characteristic sensitivity of the photomultiplier. The values in column 3 are given by

$$D_{\lambda} = D_{\lambda} \frac{J_{\lambda}}{D_{\lambda}''}, \quad (1)$$

where D_{λ} is the corrected value of D ,

D_{λ} the reading of the recording meter of the phosphorometer,

J_{λ} the energy distribution of the color standard,

D_{λ}'' the reading of the phosphorometer when the photomultiplier is activated by the radiation from the color standard.

Column 4 gives the values of column 3 reduced to relative values by taking the value at 500 m μ as 100. This column is then the relative distribution of energy in the radiation from the fluorescent cloth excited by mercury light.

The visual characteristics of the eye are introduced through the tristimulus values of the pure spectrum colors. These values are the relative effects upon the eye at each wavelength of the pure spectrum colors and have been obtained experimentally by a number of observers, particularly Wright and Guild². At each wavelength there are three values representing the blue, green, and red regions. The values given in column 4 are multiplied by each of the tristimulus values of the pure spectrum colors to give the tristimulus values X, Y and Z of columns 5, 6 and 7 of Table II. As indicated in Table II the trichromatic coefficients x, y are obtained from the sums of the columns X, Y and Z. Figure 2 is the chromaticity diagram. The curve A is the locus of the trichromatic coefficients of the pure spectrum colors. Illuminant C is located at C and the yellow fluorescent cloth at B, the coordinates being the values of x and y from Table II. A line from B through C intersecting the locus of pure spectrum color enables the "dominant wavelength" and "excitation purity" to be determined. The wavelength at which the line intersects the locus is the "dominant wavelength". If the intersection is called D, then the "excitation purity" is the ratio $\frac{CB}{CD}$.

The color characteristics of six colors of fluorescent cloth manufactured by the Continental Lithograph Co. were measured under two conditions: first, when the cloth was excited by a General Electric High-Pressure Mercury S-4 Lamp (covered with an ultraviolet-transmitting glass Corning No. 5860) which allowed no visible light to pass,

1. Anderson and Robinson - The Oxalic Acid Uranyl Sulphate Ultraviolet Radiometer - Jour. Am. Chem. Soc. 47, 718, 1925.

2. I. Guild Trans, Opt. Soc, 26, 95, 1924 and 26, 139, 1924. I. Guild Phil. Trans. Roy. Soc. A. 230, 149, 1931. W. D. Wright, Trans. Opt. Soc. 30, 141. 1928.

and second, when the cloth was illuminated by I. C. I. illuminant "C" which closely matches the daylight from the north sky. These latter measurements are called the "reflection" characteristics. Table III lists the color characteristics of the cloths before they were subjected to exposure in an accelerated weathering unit and again after exposure.

TABLE III

Color Characteristics of Six Fluorescent Cloths Manufactured by the Continental Lithograph Company

Manufacturers Designation	Before Exposure in the National Weatherometer				
	Color	Reflection		Fluorescence	
		Reflection Dominant Wavelength	Excitation Purity Percent	Dominant Wavelength	Excitation Purity Percent
No. 10708	Permatex	515 $c m\mu$	53	606 $m\mu$	100
3030	Fire Orange	589	46	585	87
30E42	Arc Yellow	568	26	501	34
30E53	Signal Green	534	24	522	56
3072	Flag Blue	566	11	480	70
30E72	Flag Blue	472	62	456	98

After 25 Hours Exposure in the National Weatherometer					
No. 10708	Permatex	496 $m\mu$	38	599 $m\mu$	100
3030	Fire Orange	598	21	502	10
30E42	Arc Yellow	574	11	479	64
3072	Flag Blue	580	3	480	59

Figures 3 and 4 show the spectral distribution of the fluorescent radiation from the six samples before weathering when excited by radiation from the mercury arc, and --

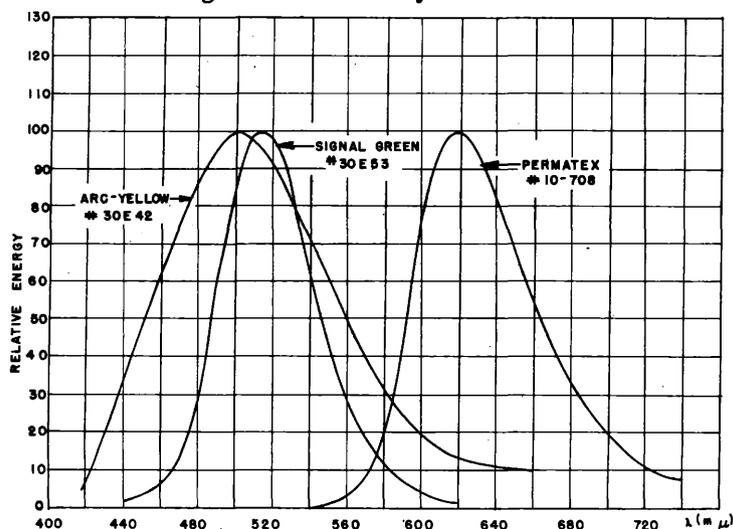


Fig. 3 - Spectral Distribution of Radiation from Samples of Fluorescent Cloth

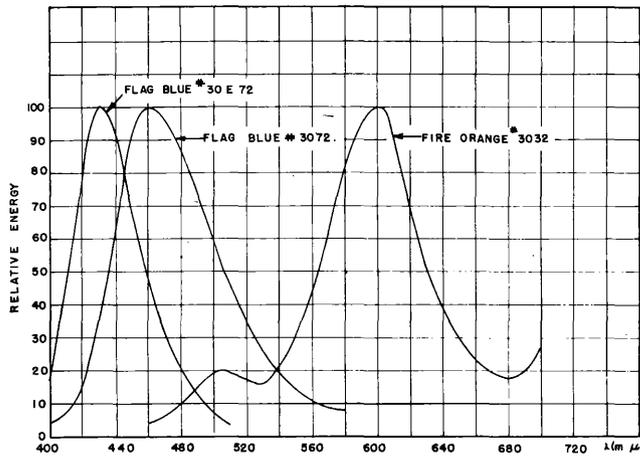


Fig. 4 - Spectral Distribution of Radiation from Samples of Fluorescent Cloth

Figures 5 and 6 show the spectral reflection characteristics when illuminated by Illuminant "C". It must be understood that the intensity and spectral character of the so-called reflected radiation from the fluorescent material, when illuminated by daylight or illuminant "C", is made up of the light reflected by the fluorescent material plus the radiation due to fluorescence. It may be possible to obtain a spectral distribution where the relative energy at given wavelengths may be greater than 100 percent. An example of this occurs in the curve called "Fire Orange No. 3030" of Figure 5. Table III lists the "dominant wavelength" and "excitation purity" of the six samples for the fluorescent radiation and reflection color. Table III also gives the color characteristics of four of the samples after they have been exposed in the National Weatherometer for 25 hours.

The National Weatherometer is an accelerated-weathering chamber built by the National Carbon Company. It is so constructed that the samples are continually exposed to radiation from a carbon arc burning the National Carbon Company "Sunshine" carbons enclosed in clear Corex A glass. The samples are bathed with clear water for approximately 20 minutes out of every two hours. The temperature of the samples during this exposure is about 120° to 130°F. A determination of the ultraviolet energy falling on the samples by means of an oxalic acid-uranyl sulphate ultraviolet radiometer shows ultraviolet energy to be about 1350 ergs/mm²/sec.

MEASUREMENT OF COLOR CHARACTERISTICS OF FLUORESCENT CLOTHS BY SPECTROPHOTOGRAPHIC DENSITOMETRY

To examine the nature of the agreement between the color characteristics as determined by the photomultiplier tube and by spectrophotometric methods, the spectral energy distribution of the fluorescent radiation from a sample of the "Conti-glo Arc Yellow" cloth when excited by a G. E. S-4 mercury arc was determined by spectrophotometric methods. A Bausch and Lomb constant-deviation glass-prism spectrograph was pointed at the sample of glowing yellow cloth. A camera attachment enabled the investigator to take photographs of the spectrum. The distribution of energy in the fluorescent spectrum was determined by comparing the intensity at each wavelength with the intensity of the spectrum of known distribution. The known source was a 500-watt tungsten lamp burning at 2860°K color temperature. The method of comparison consisted of photographing the fluorescent spectrum with an exposure sufficient to give

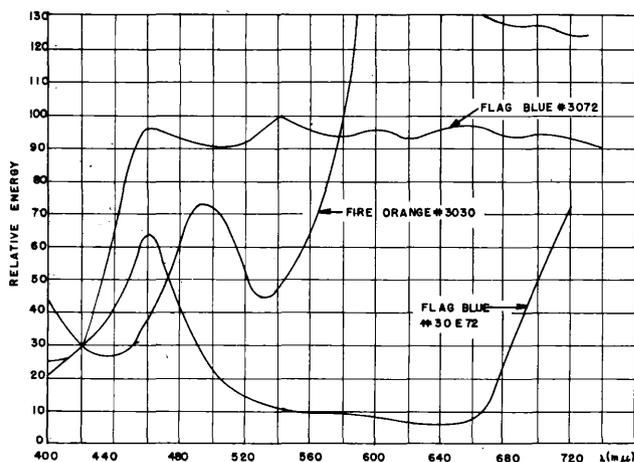
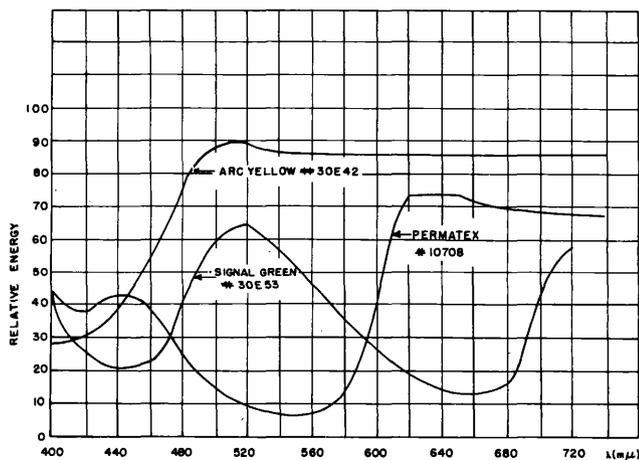


Fig. 5 - Spectral Distribution of Reflected Radiation from Samples of Fluorescent Cloth

Fig. 6 - Spectral Distribution of Reflected Radiation from Samples of Fluorescent Cloth



densities within the densitometer range. Then with the same exposure time, a series of spectra of the tungsten lamp was taken, reducing the photographic density successively by means of screens of known transmission placed in front of the slit of the spectrograph. The density at any given wavelength of the unknown was then interpolated in the series of known spectra. Although the same exposure time for each spectrum is desirable, different exposure times may be used provided the reciprocity law of photographic exposure is recognized and the work kept within its limitations. Thus, when the spectral distribution of energy of the tungsten lamp and the relative intensities of the fluorescent spectrum to the tungsten at any given wavelength are known, the distribution of energy in the unknown may be determined. How well this method agrees with the measurements made by the photomultiplier tube is shown in Figure 7, where A is the distribution of energy determined spectrophotometrically and B is determined by the photomultiplier tube.

Although the agreement is not all that could be desired, the possible sources of error which enter into spectrographic densitometry make high accuracy difficult. One has more confidence in the comparison measurements made with the photomultiplier tube, since the measurements are more direct and involve fewer chances for error than does the photographic process.

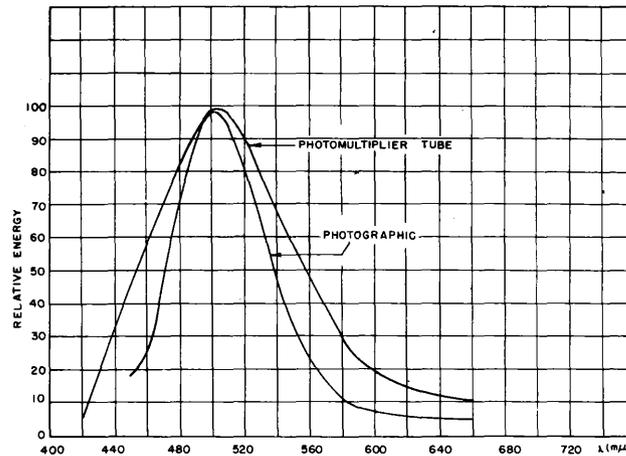


Fig. 7 - Agreement of Photoelectric and Spectrophotometric Methods for Determining the Spectral Distribution of Radiation from Fluorescent Cloth

A few words may be said in regard to the errors entering photographic densitometry and the precautions that are necessary to reduce these errors to a minimum. Photographic materials are variable and may show differences in sensitivity at different points on a single plate or from plate to plate. To reduce this possibility, the spectrum of which the spectral radiation is to be measured and the series of known spectra of varying densities should be taken on a single plate. This procedure also has the advantage that the spectrograms will undergo identical development procedure. Brushing the plate during development with a fine camels hair brush assists this uniformity by evenly distributing the developer over the surface of the plate. Care should be taken to employ the same time of exposure for each spectrum thus eliminating any question about the applicability of the reciprocity law of photographic exposure. Sometimes all exposures cannot be equal because of the different intensities of the radiating sources. If this is the case, care must be taken to stay on that portion of the characteristic H and D curve to which the reciprocity law is applicable, that is, the straight-line portion. The most reliable method for reducing the density of the known comparison spectrum is the use of neutral screens placed in front of the source. These eliminate the questionable characteristics of so-called neutral-glass filters and the intermittency effect of rotating sectored disks. However, the photographic measurements of radiation are reliable, fairly accurate and reproducible if the operator has an intimate knowledge of the factors entering into the processes.

The process of computing the tristimulus coefficients from the energy distribution curve of the fluorescent radiation obtained by spectrophotometric measurements is exactly like that used in computing them from data obtained with the photomultiplier tube.

MEASUREMENT OF BRIGHTNESS

The measurement of the brightness of fluorescent and phosphorescent radiation involves the difficulties of both low luminosity and hetero-chromatic photometry. The samples of fluorescent cloths manufactured by the Continental Lithograph Co. have been taken as subjects to investigate the relative merits of "Equality of Brightness" method and the "flicker" photometer. In the region of photopic vision with small fields it has been shown that the "flicker" photometer gives more consistent results for a number of observers than does the "Equality of Brightness"; however, as the brightness decreases and there is a large difference of color, neither method is satisfactory.

With fluorescent and phosphorescent colors, the level of brightness lies in the low photopic and continues down through the Purkinje region to the color threshold. The fields of the few commercially obtainable "flicker" photometers are too small to be satisfactory at the lower brightness so it was necessary to construct a laboratory model with a larger field angle.

The comparison field was the radiation from a tungsten lamp, operating at about 2300°K, illuminating a diffusing disk. The illumination on the disk could be varied at will by varying the distance from the lamp to the disk. The comparison field and the field of the luminous cloth were brought adjacent to each other by a series of prisms. Care was taken that no dividing line separated the images. The flicker arrangement consisted of a plane mirror about $1\frac{1}{2}$ inches by $\frac{3}{4}$ inches high, oscillating about a vertical axis and mounted so that the image of the comparison and unknown field were visible alternately to the eye of the observer. It has been found at certain critical speeds of oscillation that when the two fields are of the same brightness the flicker disappears. This phenomenon takes place even for large color differences. With the present apparatus at a speed of approximately five oscillations a second the apparent flicker could be made to disappear when the fields were of equal brightness. The "Equality of Brightness" measurements were made by stopping the mirror at which time the observer saw the two fields adjacent to each other.

To determine which of the two methods of visual photometry is the more satisfactory and consistent in its operation, measurements of the brightness by each method were made of four samples of fluorescent cloth made by the Continental Lithograph Co. These are listed in Table IV.

TABLE IV

Color Characteristics of Four Samples of Fluorescent Cloth and a Comparison of the "Direct Comparison of Fields" and "Flicker" Methods for Measuring Brightness Values

Color	Trichromatic Coefficient		Dominant Wavelength	Excitation Purity	Average Deviation from the Mean		Ratio Col. 5 Col. 6
	X	Y			Flicker	Direct Comparison	
Flag Blue	.1455	.1574	480 m μ	70%	5.2%	7.6%	1.45
Signal Green	.2088	.4800	501 m μ	34%	5.4%	6.9%	1.28
Fire Orange	.4750	.4809	585 m μ	87%	2.5%	3.3%	1.29
Permatex No. 10708	.6510	.3490	606 m μ	100%	3.7%	12.0%	3.22

In most cases the observations were made by four different observers who were more or less experienced in this type of measurement, and who had approximately normal vision. In most cases, twenty separate settings of the photometer were made in each measurement. The average percent deviation was computed for each observer and the mean entered in Table IV. Column 1 gives the manufacturer's name for the luminous cloth, column 2 the trichromatic coefficients, column 3 the dominant wavelength, column 4 the excitation purity, column 5 the average percent deviation with the flicker photometer, column 6 the average percent deviation with the direct comparison field photometer, and column 7 the ratio of column 6 to column 5. The greatest differences of readings between the flicker and contrast field instruments occur at the two extremes of the visible spectrum. The difference at the red end of the spectrum is more than twice that at the blue end.

The brightness of the four samples of fluorescent cloth was measured by means of the flicker photometer when they were activated by radiation from a G. E. S-4 high-pressure mercury-vapor arc covered with a Kopp ultraviolet transmitting glass No. 41. This glass transmits the region of the ultraviolet spectrum from approximately 400 m μ to slightly below 320 m μ . The energy falling on the cloth was 51 ergs/mm²/sec. Table V gives the value of the brightness of the unexposed fluorescent cloths and of the material after specimens had been exposed for 25 hours in a salt spray chamber and also in the National Weatherometer.

TABLE V

The Brightness of "Conti-Glo" Fluorescent Cloth When Irradiated with Ultraviolet Light

Manufacturers Designation	Brightness in Microlamberts				
	Before Exposure	After 25 hours in Salt Spray Chamber		After 25 hours in National Weatherometer	
		color	color	o/o decrease	color
Permatex No. 10708	710 ml	1180 ml orange	166*	600 ml orange red	15
3030 Fire Orange	2150 ml	1980 ml yellow	8	1450 ml pink	33
30E42 Arc Yellow	1590 ml	818 ml yellow green	49	600 ml greenish blue	62
3072 Flag Blue	840 ml	200 ml gray	76	264 ml pale blue	69

* This increase in brightness is probably due to the fact that the color of the sample has changed to a region of the spectrum in which the eye is relatively more sensitive.

These exposures give some indication as to the ability of the luminous material to withstand exposure out-of-doors, especially on shipboard. In the salt spray, the specimens were subjected alternately to exposures of a fine spray of five percent salt solution for fifteen minutes and a stream of air heated to about 120° F for fifteen minutes. They were continually irradiated with approximately 290 ergs/mm²/sec of ultraviolet light from four G. E. S-4 high-intensity mercury arcs. In the National Weatherometer the specimens were continually subjected to radiation from a carbon arc, burning the

National Carbon Co. "Sunshine" carbons which give a spectral distribution somewhat similar to daylight. For about twenty minutes out of every two hours the specimens were subjected to a spray of clean fresh water. The total ultraviolet radiation falling on the luminescent cloth over a series of eight observations average 1375 ± 154 ergs/mm²/sec. The measurement of the total ultraviolet radiation was made by determining the change produced by the light in an oxalic acid-uranyl sulphate solution. The results are given in Table V. In general the ultraviolet light produced changes in the character of the fluorescent cloth and reduced its fluorescent brightness.

Included with the samples of fluorescent cloth was one sample of fabric-backed phosphorescent sheet. The luminous material was calcium sulphide which radiated in the blue region of the spectrum. Since the color difference between the laboratory standards of brightness and the phosphorescent material was not great, all measurements of brightness were made by the direct comparison of fields. The decay of phosphorescent brightness after activation by tungsten radiation of 600 foot candles for one minute was measured. The effect of exposure to ultraviolet light, humidity and high temperature was determined by exposing the sample in a salt-spray chamber for 100 hours. In this chamber, ultraviolet light from a G. E. S-4 high intensity mercury arc continually irradiated the specimen during the exposure. The rate at which the total ultraviolet fell on the material was 250 ergs/mm²/sec. The material was exposed alternately for fifteen minutes to a blast of air at 120°F and to a five-percent salt spray at the same temperature. The brightness after decay was as follows:

Time after Irradiation	Brightness in Microlamberts
1 min	15.0
30 min	0.5
60 min	0.4
180 min	0.04

The decrease in brightness after exposure in the salt spray chamber was about 50 percent. The material complied with specification 17L18(INT).