DEPARTMENT OF COMMERCE AND LABOR

CIRCULAR
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 28

THE DETERMINATION OF THE OPTICAL PROPERTIES OF MATERIALS

[1st Edition]
Issued March 1, 1911

WASHINGTON
GOVERNMENT PRINTING OFFICE
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CONTENTS

Many types of screens are employed in the arts for varying the quality, intensity, and distribution of light. The efficiency of such screens depends upon their optical properties. In this circular the properties of the various types of absorbing, diffusing, and standard screens are discussed, the general theory and fundamental principles involved in their action and their testing are outlined, and the actual performance of some good screens of several types is given.

I. FUNDAMENTAL RELATIONS

1. **Reflection.**—Of light incident normally on a polished surface the fraction

$$R=\left(\frac{n-1}{n+1}\right)^2$$

is reflected, n being the refractive index of the reflecting material. Thus, if $n = 1.50$, $R = 4$ per cent; if $n = 1.60$, $R = 5.3$ per cent. Strictly, the refractive index of the air (1.00029) should be taken into account, but its effect on R is negligible in comparison with photometric uncertainty. Again, it is unnecessary to use the more general reflection formula (Drude) involving absorptive index, since it is only in metals and dense dyes that this is large enough to have a measurable effect on the reflection.

If the reflection ocurs at an angle i with the normal to the surface the reflecting power is

$$R=\frac{1}{2}\frac{\sin^2(i-r)}{\sin^2(i+r)}+\frac{1}{2}\frac{\tan^2(i-r)}{\tan^2(i+r)}$$

when r is the angle of refraction computed from $n = \sin i/\sin r$. On glass at angles of incidence up to 30°, the increase of reflection due to the inclination is negligible; at an angle of about 50° the reflection is about double that at normal incidence.

2. **Absorption.**—The logarithmic law of absorption applies generally to homogenous bodies; that is, if a given layer absorbs a certain fraction of the incident light, the following layer will absorb the same fraction of what remains. The absorption coefficient or absorptivity a is the fraction absorbed by a layer of unit thickness. What is transmitted is then $1 - a = T$ say. A layer of thickness x will then transmit a fraction T^x and absorb the fraction $1 - T^x$.

3. **Transmission.**—Let light of intensity I_0 be incident normally on one of the parallel surfaces of a body. Let I_1 be the intensity just inside the first surface, I_2 just inside the second surface, and I the intensity of the light leaving the last surface. We require I in terms of I_0. The first

change in intensity is due to reflection, $I_1 = I_0\ (1-R)$. Then $I_2 = I\ T^x$, x being the thickness and T the transmission of unit thickness. Finally $I = I_2\ (1-R)$ Substituting

$$I = I_0\ (1-R)^2\ T^x$$

I/I_0 is the total transmission measured. To find T we have (for logarithms to any base)

$$\log T = \frac{1}{x} \log \left(\frac{I}{I_0} \frac{1}{(1-R)^2} \right)$$

The relative transmission of two thicknesses x_1 and x_2 of the same material will be simply

$$T^{x_2/x_1}$$

since the loss by reflection is the same in each.

4. **Diffuse Reflection.**—Two distinct kinds of reflection, specular and diffuse, are recognized. In specular reflection the axis of the reflected beam

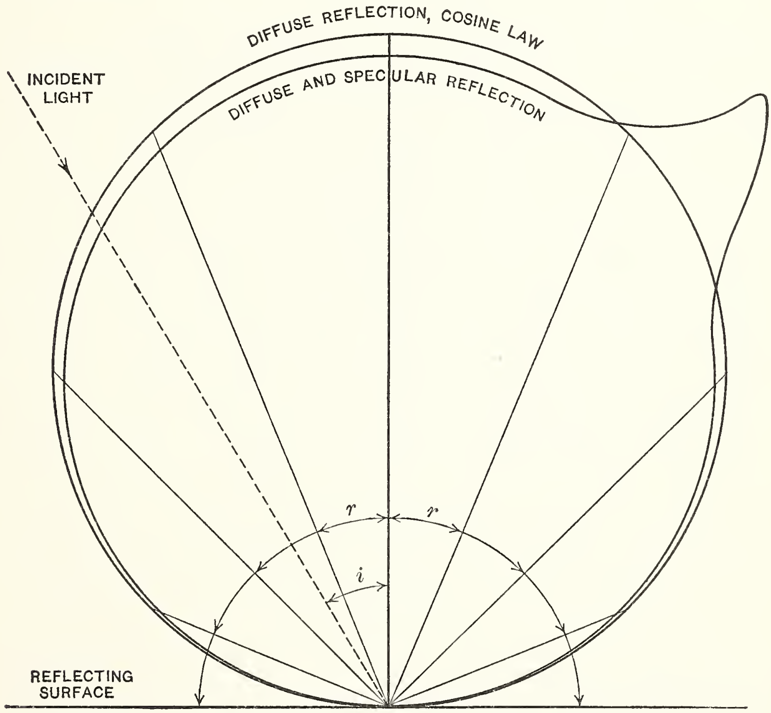

Fig. 1.—*Diffuse and Mixed Reflection.*

lies in the plane of incidence and at an angle with the normal equal to the angle of incidence. In diffuse reflection the incident light is scattered in all directions, the reflected light being distributed according to Lambert's cosine law. The reflection from ordinary surfaces is in general partly specular and partly diffuse, a perfect mirror would itself be invisible, while a perfectly mat surface would show no maximum of reflection at an angle equal to the angle of incidence.

Reflecting surfaces are tested by determining their reflecting power for each wave-length and each angle of reflection. The departure of the distribution of the reflected light from the cosine law gives the ratio of regular to diffuse reflection, i. e., the matness of the surface. The departure of the spectral curve of the reflected light from that of the incident light gives the hue and shade of the surface.

5. **White Light.**—A mat, non-selective surface of high reflecting power, illuminated at the earth's surface by the midday sun is "white" as nearly

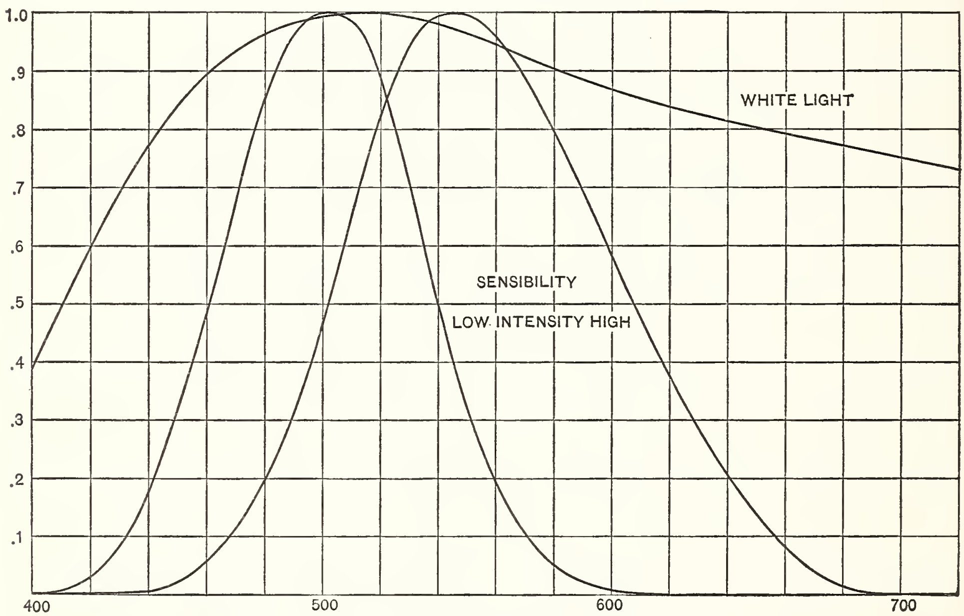

Fig. 2.—*White Light Visual Sensibility.*

as the term can be defined. Sky light varies greatly in composition, even direct noon sunlight varies considerably, but we can do no better than to define the composition of white light as that of mean direct sunlight. In the figure and table are given data for midday, clear sky, Washington sunlight reduced from the 1905 data of Abbot and Fowle.[1]

[1] Annals Astroph. Observatory II, p. 105.

Wave-length,	.40	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60
White light,	.39	.59	.78	.90	.97	.99	1.00	.98	.94	.97	.87
Wave-length,	.62	.64	.66	.68	.70	.72	.74	.76	.78	.80	
White light,	.84	.82	.79	.77	.75	.73	.71	.69	.67	.65	

The approximate values of some illuminations useful for reference are: Solar disk 1.5 x 10^9 meter candles, normal zenith sunshine 100 000 m. c., cloudy December midday sky light on horizontal plane 3000 m. c., sunset sky light ditto 2000 m. c., lunar disk 1200 m. c., midday sky 1000 m. c.,

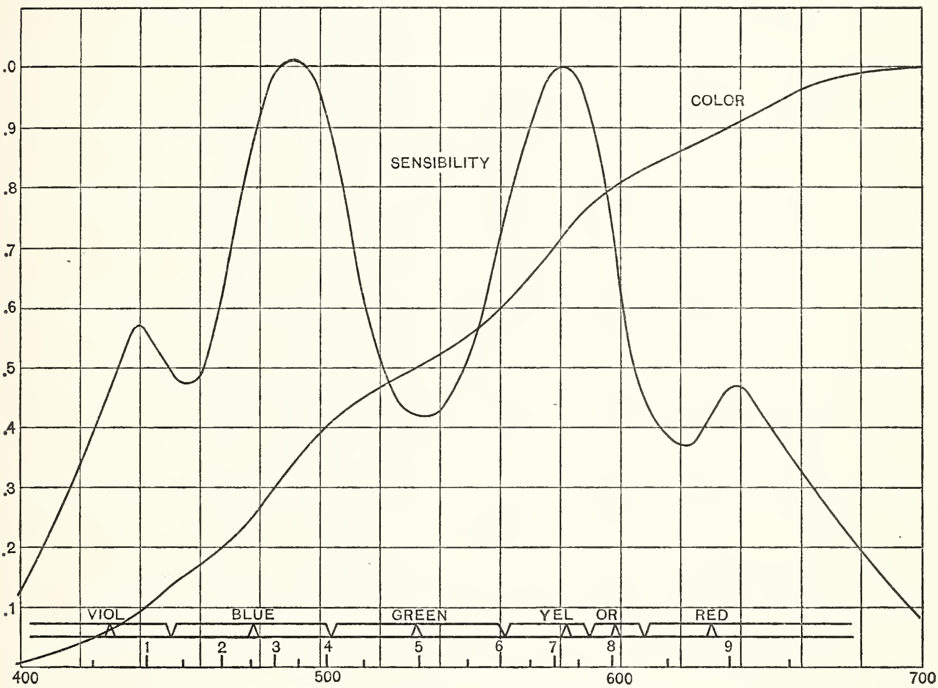

Fig 3.—*Color Sensibility. Color Scale.*

good working artificial illumination 50 m. c., visual comfort 10 to 1000 m. c., minimum for reading 0.1 m. c., moonlight 0.1 m. c., threshold red 0.002, green 0.0001, white 0.00002, blue and violet 0.000003 m. c.

6. **Visual Sensibility.**—The ratio of light to energy (the visual sensibility of the eye) varies with the wave-length and in the range 1 to 10 m. c. (roughly) with the intensity as well. This ratio depends upon the sensibility of the eye, the so-called visibility of radiation. Visibility curves

67604°—11——2

for intensities over 10 m. c. (cone vision) and below 1 m. c. (rod vision) are plotted in Fig. 2 below. The corresponding data are given below.

Wave-length,	.42	.44	.46	.48	.50	.52	.54	.56	.58	.60	.62	.64	.66	.68
Visibility High I,		.01	.08	.25	.48	.82	.99	.95	.80	.59	.40	.20	.07	.01
Visibility Low I,	.01	.12	.51	.82	1.00	.88	.53	.20	.05	.01	.005	.001		

These are reduced to maximum ordinate unity. The value of the maximum ordinate is about 60 candles per watt for high intensities and is unknown for low.

Photometric sensibility (least perceptible increment of intensity) is about 1.5 to 2 per cent for all moderate and high intensities and all wave-lengths, but decreases at low intensities down to the threshold of vision.

7. **Color.**—A body appears colored when its transmissivity or reflectivity varies throughout the visible spectrum, otherwise it is white, gray,

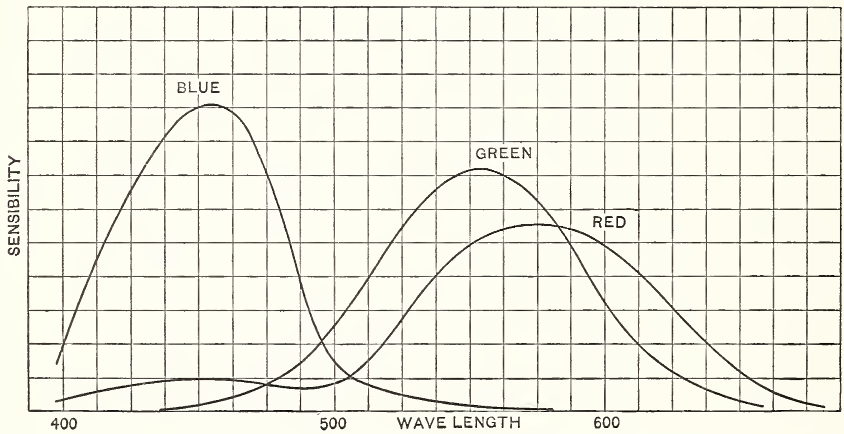

Fig. 4.—*Primary Sensibilities.*

or black. If the departure from uniformity is great the body is highly colored, if the departure extends through but a narrow spectral region the color or absorption is pure.

The empirical specification of color utilizes the extreme sensibility of the eye to color (hue and shade) differences. In Ridgway's system, mat cards are dyed a series of about 30 spectral hues, showing just perceptible color difference. The six principal hues and the wave-lengths of these reflection maxima are: Violet 430, blue 473, green 520, yellow 577, orange 598, and red 632 $\mu\mu$. Violet is shaded off through purple back to red. Each hue is then shaded off to white and to black in three equal steps, making seven shades of each hue and 210 just perceptibly different colors in all. Mixtures of these standards give several thousand substandards against which colors may be matched.

In the Ives system [1] red, green, and blue light, from transmission filters placed over slits, are mixed in variable proportions to match the sample. The transmissivities of the red, green, and blue primaries correspond with the three fundamental retinal sensibilities, but need not be coincident with them since they merely determine a point in the color triangle.

The rational specification of color is based upon the wave-length scale (the pure spectrum) and the sensibility to differences in wave-length of the average human eye.[2] In Fig. 3 are plotted sensibilities (reciprocal limens) of the mean of twelve subjects.[3] The general integral of this latter curve

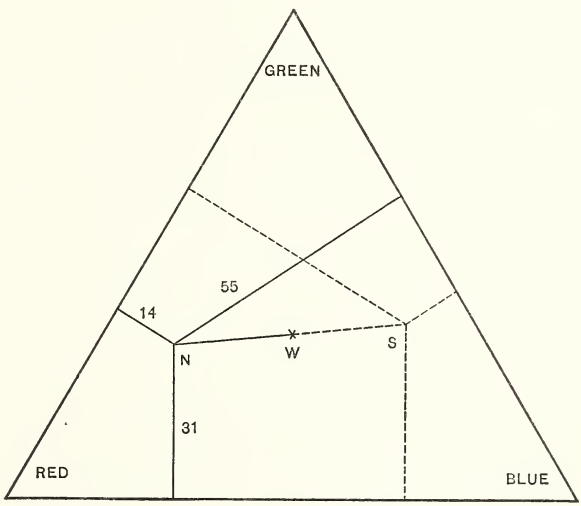

Fig. 5.—*Color Triangle.*

is the color curve or scale of equal color differences. This may be subdivided in any convenient manner; in the figure it is divided into 10 steps corresponding nearly with the accepted spectral hues.

The three primary sensation curves are somewhat as shown in Fig. 4 when reduced [4] to equal areas. The actual relative luminosities are (instead of being equal) according to Abney [5]

Red	Green	Blue
65.73	33.83	0.44

[1] Trans. Ill. Eng. Soc. **3**, p. 627.

[2] Bull. B. S. **6**, 89, 1909.

[3] Sitz. A. K. Wiss. Wien, 115, IIa, Jan., 1906.

[4] Exner. Sitz. Ak. Wiss. Wien **3**, 857, 1902.

[5] Phil. Trans. Roy. Soc. **193**, 286, 1900.

the resultant being the visibility curve for high intensities given in Fig. 2. Where the three primaries are most inclined to each other, sensibility to color differences (Fig. 3) is greatest; where least inclined, color sensibility is least.

A light which analyzes r per cent red, g per cent green and b per cent blue ($r+g+b=100$) may conveniently be represented by a Maxwell color triangle (Fig. 5) in which r, g, and b are measured from the sides opposite the apices representing red, green, and blue, respectively. Such a light may be made up of white (center) plus a dominant hue.

II. PROPERTIES OF SCREENS

TYPES OF SCREENS

1. White-light screens for reducing to white light the light from an artificial source.
2. Spectacle glasses for protecting the eye and for enhancing or reducing contrast.
3. Photographic screens for three-color photography, for enhancing or reducing contrast; dark-room, monochromatic and ultra violet screens.
4. Signal glasses for colored signals. Fog penetration.
5. Optical glass.
6. Colorimeter standards; trichromatic colorimeter plates, tintometer plates, mat standards, special standards.
7. Mat surfaces.
8. Diffusing screens.

The properties of screens depend upon the intensity, quality, and distribution of the reflected and transmitted light, hence the testing of screens is largely spectrophotometry. In absorbing screens it is the net transmission of a given plate at each wave-length that is measured. In some cases no more is required, in others it is the net transmission or the absorption per unit thickness that is required. It the latter, then the refractive index must also be measured in order to correct for reflection. In testing mat standards and diffusing screens, the intensity of the reflected or transmitted light must be determined at each angle and specular reflection determined or eliminated.

The limit of photometric and of spectrophotometric precision under favorable circumstances is ½ to ⅓ the photometric sensibility of the eye (½ per cent). Photographic photometry is less certain and radiometers still less in the visible spectrum with the intensities available.

1. **White Light Screens.**—Artificial light sources depart more or less widely in quality from daylight. It is frequently very desirable to obtain

white light from these sources, for instance, in microscope illumination, testing photographic plates, or where acute and precise color discrimination is required. This may be accomplished in general in three different ways: (*a*) By screening off the excess over white light, (*b*) by screening out the dominant hue, and (*c*) by balancing up with an illuminant of the comple-

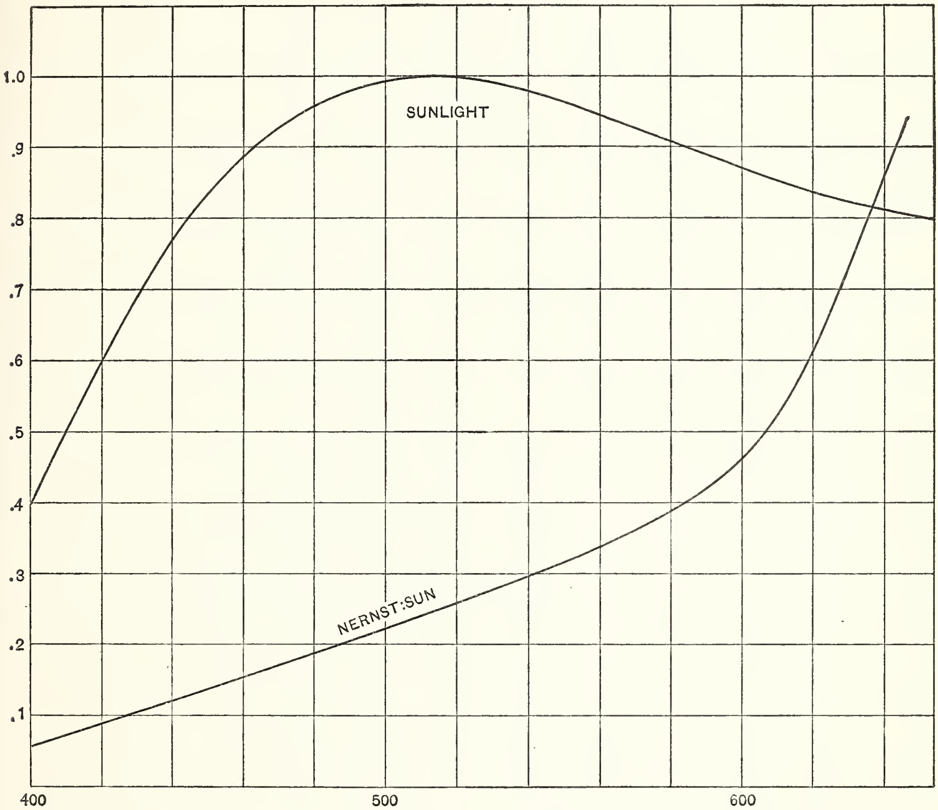

Fig. 6.—*Colored Source.*

mentary dominant hue. For color discrimination the second method is in general unsatisfactory.

As an example, consider the case of the Nernst lamp. Fig. 6 shows roughly the curves of relative spectral energy for sunlight, Nernst light, and the ratio Nernst/sun. We might first trim off the Nernst spectrum, starting at 450, by using a light-blue screen. Again, reference to the three primaries of Fig. 5 gives for the composition of Nernst light 55 per cent red, 31 per cent green, and 14 per cent blue. The color triangle (Fig. 5) indicates a dominant hue of 580 in the yellow. To screen down to white would require a removal of 74 per cent of the red and 55 per cent of the green.

A thickness x of a screen will reduce lamplight to sunlight at each wave length if

$$\text{constant} \times \text{lamp/sun} = 1/(1-R)^2 T^x$$

determines T for each wave length, the notation being that of the first equation under "Transmission."

A screen to merely absorb the excess of dominant hue from the Nernst light would have a dominant absorption at 580 in the yellow. White light after passing through it would show 12 per cent red, 30 per cent green, and 58 per cent blue. The specifications for such a screen are indeterminate, as many different screens might show this color characteristic.

2. **Spectacle glasses.**—Comfortable vision requires (*a*) specific luminosity and (*b*) contrast that is adequate but not excessive, and (*c*) the elimination of radiation that fatigues the eye but does not aid vision. Spectacles of various absorbing glasses may materially aid vision in many cases.

The *specific luminosity* (or brilliancy) of the objects viewed should not be less than about 0.003 nor over 0.3 candles per sq. cm or, respectively, 10 and 1000 meter candles in terms of the illumination of white paper, and should be steady. Inadequate illumination produces strain and fatigue; too great is dazzling and injurious to the retina. The photometric sensibility of the retina (to slight differences in intensity) is greatest between the above limits. Uniformly absorbing "smoke" glasses may be advantageously employed by persons exposed to dazzling sun or arc light. The intensity accommodation of the iris is about 1:10 and of the lids 1:10, making 1:100 in all. The sun may be viewed directly through glass whose transmission is (by measurement) 0.000002. Absorption in protective glasses, if non-selective, does not affect contrast and may reduce the low lights below the limit of visibility.

Contrast in specific luminosity is best for vision at about 1:10 in intensity and without limit as regards color. Intensity contrast should not be less than 1:3 nor greater than 1:100. If either the objects viewed or the screen through which they are viewed are non-selective, the screen will not affect the contrast; but in special cases selective screens may be a great aid to vision. A light-yellow screen is very effective in eliminating a purple haze in viewing distant objects and thus heightening contrast in an otherwise "flat" field. The extreme contrast produced by the direct reflection of sunlight on water can not be avoided (being nearly non-selective), but the maximum intensity may be reduced at the sacrifice of the low lights, or the glare may be "softened" with a yellow or orange screen which eliminates the more fatiguing blue and violet.

Ultra violet radiation fatigues the eye much more than white, green, or red. Fatigue is a minimum in the green, increases rapidly toward the violet, and then still more rapidly in the ultra violet. At about 320 the eye media become opaque and shorter waves may affect the surface of the cornea or even the pupil, but can not reach the retina. For the red and infra red the fatigue is not very different from that for the green and yellow, and just beyond the visible the eye media become opaque. Clear glass of all kinds becomes gradually opaque in the region 330–300 and continue so

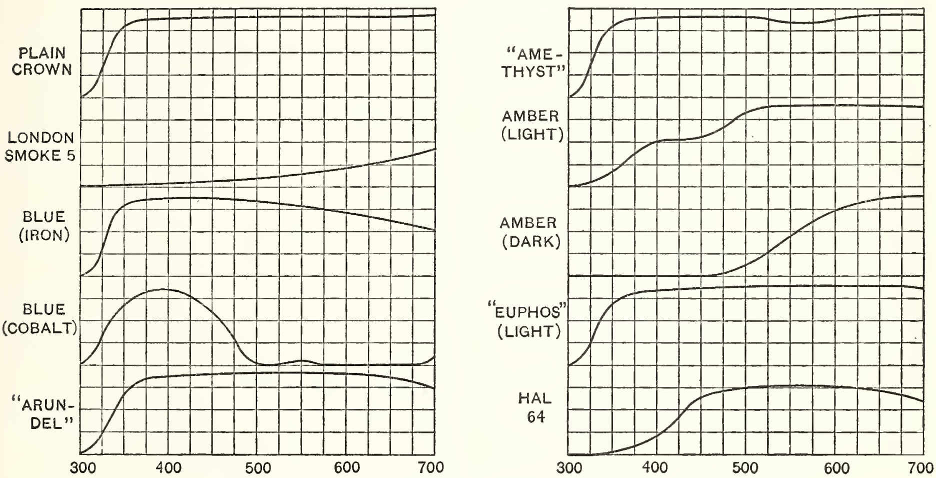

Fig. 7.—*Transmission of Spectacle Glasses.*

farther out, so that spectacles of clear glass would only partially protect the retina from such short wave-length radiation as reaches it.

The spectrum of daylight falls off rapidly from 420 in the visible out into the ultra violet. At 293 the solar spectrum ends and the whole invisible portion is too faint to be injurious unless perhaps the sun were viewed directly through a screen transmitting only ultra violet. What is true of sunlight is even more true of the light from any incandescent solid.

The light from electrically conducting vapors like the arc flame, the electric spark, the vacuum tube, and mercury are, however, frequently very rich in violet and ultra violet, the mercury arc in a quartz tube particularly so. Where these are used as illuminants the eyes should be protected by glasses absorbing all radiation down to 400 or 440. No colorless glass is known which absorbs just down to 400, although it should be possible to produce one. There are several of a light olive tint which absorb down into the visible violet and blue.

In Fig. 7 are given the transmission curves of several well known glasses determined with a spectrophotometer in the visible spectrum and photographically with an iron spark and spectrograph, in the ultra violet.

3. **Photographic Screens.**—Screens of various tints are used in photography to enhance or reduce contrast as well as for many special purposes. So far as known, all ordinary photographic plates are about

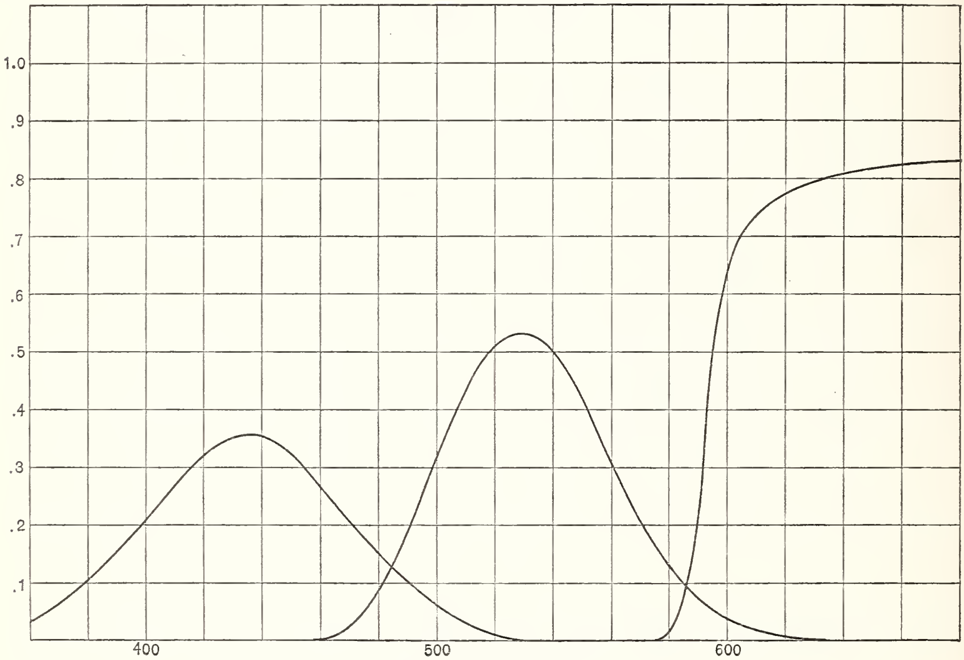

Fig. 8.—*Color Filters.*

uniformly sensitive from wave length 200 in the extreme ultra violet to about 480 in the visible blue; but from that wave length to the red they vary widely in sensibility with wave length and kind of plate, hence the wide departures from visual contrast obtainable in photography.

If the sensibility of a photographic plate were identical with that of the retina (Fig. 2) no screen would be required to reproduce visual (intensity) contrast in a negative. If a plate were uniformly sensitive at all wave lengths, a color screen whose transmission curve was the same as the visual sensibility curve would give normal contrast. An orange screen with ordinary plates (not sensitive to red) gives roughly this result by absorbing the blue. But since plate sensibility varies so widely in the most luminous part of the spectrum, to obtain good results it is necessary to balance up with each of the three primary sensibilities separately to obtain normal contrast.

In Fig. 8 are given the transmission curves of a set of good modern ray filters. These may be compared with the visual primaries (Fig. 4).

In copying and photoengraving, the source of light, the filter, or the plate are varied in photographing any shade of any hue as either white or black. When contrast is to be reduced, objects are brought toward the same hue or hues for which the plate is equally sensitive; if it is to be enhanced, toward different hues or hues for which the plate is of different sensibilities. For example, in copying a blueprint, a yellow light or a yellow screen is used. A typewritten page, in purple type ink, on which corrections have been made in blue pencil and red ink spilled, is copied to eliminate the blot by using a red screen and red sensitive plates.

Three color photography requires screens with transmissions corresponding to the primary visual sensibilities. *Dark room* or "safe-light" screens should transmit chiefly those wave lengths for which the plates are not sensitive. *Selective screens* may be prepared transmitting narrow portions of the spectrum ranging from 326 in the ultra violet (silver on quartz) to the red beyond 760 (a combination of red, green, and blue screens).

4. **Signal Glasses.**—Red, green, and blue signal glasses in planes, cylinders, and lenses are in common use. The chief requirements are a rather pure hue and high transmission of that hue. If the hue is not pure but merely dominant, the transmitted light will vary greatly with the light used and with the observer. The screen should transmit 50 to 85 per cent of the hue desired, otherwise a great deal of light (frequently not strong at best) is wasted.

A *red* signal glass may transmit from 600 on to the extreme red. Its maximum transmission should be 80 per cent (at about 620) and total transmission (ordinary oil flame) at least 5 per cent. Gold ruby is a pleasanter color than copper, but transmits considerable blue. *Green* should transmit chiefly between 500 and 580 and at least 50 per cent of the total light. *Blue* should transmit all on the violet side of 500, but can not transmit more than 2 or 3 per cent of the total light of ordinary sources. An arc or acetylene flame is much better than an oil or ordinary gas flame for a blue signal, because the latter are very deficient in blue light.

The fog-penetrating power of light is nearly independent of color and no screening of the source can be of any advantage comparable with that of slightly increasing the intensity of the source. But if the foreground is a diffuse white or gray, as where an observer is on a well-illuminated vessel in a fog, a distant signal light may, by contrast, be more visible if colored than if white.

5. **Optical Glass.**—Crown and flint glasses for lenses and prisms should have a minimum of absorption throughout the whole visible spectrum, since all such absorption means a dead loss of illumination in the image formed by an optical instrument. The ordinary unit of thickness for lens and prism glasses is 10 cm. The absorption in this path should not exceed 10 per cent and is as low as 1 per cent in the best glasses for the C, D, and F lines. It is sufficient to know three decimal places of the refractive index to make the necessary correction for reflection. In measuring the transmission of a thick block of glass it is, of course, of the utmost importance that the beam of light be neither convergent or divergent in passing through the glass.

6. **Color Standards.**—Standard plates, screens, or solutions are used in many forms of colorimeters as standards of hue or standards of density or both. Colorimeters utilize the extreme sensibility (about 2 per cent in each case) of the eye to slight differences in shade and dominant hue.

Trichromatic colorimeters mix pure red, green, and blue light in variable proportions until the mixture matches the unknown sample. The three primary beams are obtained by the use of color screens. These should have transmissitivities corresponding roughly with the three primaries of vision, but need not be in the same proportion since intensities are variable independently.

Monochromatic colorimeters or "tintometers" make use of a separate series of standards for each hue and match the shade by using different combinations of plates in a series or by varying the length of a column of solution. In order to fully utilize the high sensibility of the eye in tintometry (*a*), the resultant illumination should be ample (20–100 m. c.), (*b*) the two fields should be of precisely the same dominant hue, (*c*) losses by reflection and general absoprtion (e. g., by surface films) should be corrected for or eliminated, (*d*) the absorbing media should be homogeneous, and (*e*) the standard transmissions should be accurately known from spectrophotometric study.

Mat reflection colorimeters make use of dyed cards as reference standards. Secondaries of two or three hues or shades are either mixed in varying proportions on a rotating disk to match the unknown or else the unknown is placed by interpolating between tertiary standard samples prepared by using the variable rotating disk. This form of colorimetry is sensitive and may be precise if the secondaries are nearly monochromatic, are known in terms of the natural primary scale and do not fade.

7. **Mat Surfaces** reflect from 0.5 per cent (black velvet) to about 80 per cent (paper, snow, zinc oxide) of the light falling upon them. Since the reflecting powers (albedo) of mat surfaces are so easy to compare and so difficult to measure, known mat surfaces are useful as reference standards. The standard surface is tested for both matness and selectivity as regards color.

8. **Diffusing Screens** such as ground glass, opal glass, prism glass, and many patent varieties are widely useful in breaking up images, throwing light in a particular desired direction, or in lowering the specific luminosity of sources. Their testing consists in a determination of the amount and direction of both reflected and transmitted light and the total absorption. From this data the properties of a plane screen may be obtained by computation.

III. REFRACTOMETRY

For the *identification* of optical glass, fluids, crystals, and the like a determination of the refractive index for yellow light to the fourth decimal place is often sufficient. Such tests are easily made with a simple refractometer of the total reflection type requiring but a few square millimeters of plane face or but a few drops of fluid.

For computing lenses and prisms it is necessary to know the refractive indices for a number of wave lengths to the fifth decimal place. The following wave lengths are the ones generally used:

Color.	Line.	Source.	Wave length.	
Red	A′	Potassium	0.7682	(Middle of double line.)
Red	C	Hydrogen	0.6563	
Yellow	D	Sodium	0.5893	(Middle of double line.)
Blue	F	Hydrogen	0.4861	
Violet	G′	Hydrogen	0.4341	

These determinations are made on small 60° prisms with a spectrometer.

Refractive indices may be determined to the sixth decimal place with a spectrometer of high precision provided with means of temperature control, monochromatic slit illumination, ocular slit (or slit wire), a divided circle reading to 2″ and very plane prism faces. This degree of precision is required for determining temperature coefficients of refractive index (which are of the order of 0.000002 per degree C) and indices of standard check samples of glass. Inhomogeneity of the glass generally occurs in the sixth or seventh decimal place and uncertainties in determining deviations and circle errors are of about the same order. Temperature coefficients from $-10°$ to $50°$ C should be known for glass to be used for telescope objectives, from $10°$ to $300°$ C for investigating the properties of glasses.

IV. TESTS OF MATERIALS

The following optical tests of materials will be made as desired:

1. *Identification* of glasses, crystals, and fluids by a determination of the refractive index to the fourth decimal place. A polished plane surface of 20 mm^2 on a solid or a few drops of a fluid are sufficient.

2. *Refractive index* and dispersion of glasses, crystals, and fluids through the visible and ultra-violet spectra to the fifth decimal place. A $60°$ prism of the glass with two well-worked plane surfaces at least 5 mm across or 10 cc of the fluid are required.

3. *Refractive indices of gases* in the visible spectrum.

4. *Temperature coefficients* of refractive index, $-10°$ to $50°$ C, or $10°$ to $300°$ C for C, D, and F lines.

5. Prism *angles* and goniometry of crystals.

6. *Curvature* of lens, prism, and other surfaces.

7. *Homogeneity* of glass and freedom from strain of prisms.

Other tests of a similar nature will be undertaken by special arrangement.

V. REGULATIONS CONCERNING TESTS

(*a*) **Application for Test.**—The request for the examination of any material should state explicitly the points at which test is to be made and the temperature or any other conditions which it is desired should be observed. When ever possible, the request should be accompanied by the fee as shown in the appended schedules.

(*b*) **Identification Marks.**—Instruments and the packages in which they are shipped should both be plainly marked to facilitate identification, preferably with the name of the manufacturer or shipper, and a special reference number given to the article.

(*c*) **Shipping Directions.**—Instruments should be securely packed in cases or packages which may be used in returning them to the owner. Tops of cases should be screwed down whenever possible. Transportation charges are payable by the party desiring the test, and should be prepaid. Unless otherwise arranged, articles will be returned by express "collect."

(*d*) **Address.**—Articles should be addressed simply, "Bureau of Standards, Department of Commerce and Labor, Washington, D. C." Delays incident to other forms of address will thus be avoided.

Articles delivered in person or by messenger should be left at the office of the Bureau and should be accompanied by a written request for the verification.

(*e*) **Remittances.**—Fees may be remitted by money order or check drawn to the order of the "Bureau of Standards." Delays in forwarding fees will involve corresponding delay in the completion of tests, as the articles are not returned until all fees due thereon have been received.

(*f*) **Breakage.**—Although all possible care is taken in testing and packing, the Bureau does not assume any responsibility for breakage or other damage to instruments or materials submitted for test.

VI. FEES

SCHEDULE 47.—OPTICAL PROPERTIES OF MATERIALS

(*a*) Spectrophotometric determinations are uniformly for the visible and the same for the ultra-violet spectrum	$1.00
(*b*) Determination of the coefficient of diffuse reflection or transmission	1.00
(*c*) Determination of the distribution of diffusely reflected or transmitted light	2.00
(*d*) Determination of *refractive indices* to the fourth decimal place	1.00
(*e*) Determination of *refractive indices* to the fifth decimal place	1.50
(*f*) Determination of *temperature coefficient* of refractive index	$2.00 to 10.00
(*g*) Determination of indices of standard samples to the sixth decimal place	.50 to 2.00
(*h*) Color tests	.50 to 5.00

Fees for special tests and tests of the same kind in large number given upon request.

S. W. STRATTON,
Director.

Approved:

BENJ. S. CABLE,
Acting Secretary.