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THE ULTRA-VIOLET AND VISIBLE TRANSMISSION OF VARIOUS COLORED GLASSES

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I. INTRODUCTION

During the last three years the spectral transmissions of a great number and variety of glasses have been measured by the Bureau of Standards throughout the ultra-violet, visible, and infra-red. The transmissions throughout the infra-red, and extending into the visible, have already been published,[1] as well as the transmissions for the visible and ultra-violet of glasses particularly classed as eye-protective.[2]

In the present paper are given the transmissions for the visible and ultra-violet of a large number of glasses, mostly colored, which are not used primarily for eye protection, but which are useful for various other purposes. These data have been accumulating for the last three years; and it was thought worth while to publish those which might be of value or interest to others, without,

[1] Coblentz and Emerson, B. S. Technologic Paper No. 93; May, 1917; 3d ed., February, 1919. Coblentz, Emerson, and Long, B. S. Scientific Paper No. 325; August, 1918.

[2] Gibson and McNicholas, B. S. Technologic Paper No. 119; June, 1919.

however, trying to make an exhaustive report on all the possible glasses obtainable.[3]

The glasses listed in this and the other papers mentioned, however, are representative of what may be obtained to-day on the American market, and include also some of foreign make which could be obtained before the war. It is thus possible to make comparison of the relative merits of foreign and American glass and see in what respects the latter may duplicate or improve upon the former.

Although many transmission data are on file on substances other than glass, these are not included in this paper, being reserved for the future, when more complete data can be presented. Moreover, certain kinds of glasses, such as "Lovibond tintometer" glasses, artificial-daylight glasses, and present-day standard railway-signal glasses, are not included in this paper, inasmuch as such data are to appear in separate papers on these particular subjects.

Very little previous work on the ultra-violet transmission of colored glasses, excepting those classed especially as eye-protective, has been published. Previous publications of transmissions throughout the visible include a paper by Gage,[4] of the Corning Glass Works, in which the principal coloring constituents of many of the glasses herein listed are given, and papers by Gibbs [5] and Gibson,[6] in which the change in the transmission with temperature is given for many glasses similar to those of this paper.

II. METHODS AND ACCURACY

Photographic, photoelectric, and visual methods were used in obtaining the data herein presented. Some of the photographic and visual determinations were made in the physical laboratory of Cornell University in 1917, and thanks are due to Prof. E. L. Nichols, of Cornell, for placing the facilities of that laboratory at the Bureau's disposal.

Photographic determinations were made by the Hilger sector-photometer method with a quartz spectrograph. At Cornell the apparatus was used as set up and described by Howe [7] (width of slit of spectrograph = 0.15 mm). During 1917 a duplicate of the

[3] The authors have had the assistance of J. M. Hyatt, J. T. Filgate, and H. E. Cole in obtaining part of the data herewith given. The tracings were made by C. L. Snow.

[4] Trans. I. E. S., 11, p. 1050; 1916.

[5] Phys. Rev., 31, p. 463; 1910.

[6] Phys. Rev. (2), 7, p. 194; 1916.

[7] Phys. Rev. (2), 8, p. 674; 1916.

sector photometer was constructed in the Bureau's instrument shop, and since February, 1918, measurements have been made here by this method (slit width = 0.10 mm). Certain minor changes and refinements have been made in the method, however. These are described in the Appendix.

The photoelectric method is the null method described in a recent paper [8] (slit width = 0.20 mm) and has been in operation since April, 1918.

Three visual methods were employed. At Cornell the Lummer-Brodhun spectrophotometer was used. Only a few of the specimens were measured on this instrument.

By far the greater part of the visual data given in this paper were obtained on the König-Martens spectrophotometer [9] at the Bureau (slit width = 0.10 mm). This has been in use here since 1912. The apparatus at present employed for illumination of the König-Martens spectrophotometer field may be described as follows: [10]

1. The light sources are inclosed in a white-lined diffusing box. There are receptacles in the box for ten 500-watt, gas-filled, tungsten lamps and space for three large mercury lamps.

2. The spectrophotometer is so placed as to "look into" this box through suitable diaphragmed apertures in one end of it, so that the illumination of the field is obtained from diffusely reflecting surfaces on the inside of the opposite end.

3. In measuring transmission the surfaces illuminating the field are both white (magnesium oxide or carbonate) and the sample intercepts the light from one of the surfaces in the space between the slits and the outside of the box.

4. In measuring reflection the sample is substituted for one of the white surfaces.

5. Both reflection and transmission measurements are made by the method of interchanging sample and standard before the two slits, and means are provided for doing this quickly and conveniently.

6. The illumination box is cooled by the circulation of water in an inclosing jacket.

In addition to the above methods the Martens photometer [11] is used considerably at the Bureau, with a mercury arc as source.

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[8] K. S. Gibson, B. S. Scientific Paper No. 349; October, 1919.

[9] Ann. d. Phys. (4), 12, p. 985; 1903.

[10] Design by Irwin G. Priest and H. J. McNicholas. To be described in detail later in B. S. Technologic Paper.

[11] Phys. Zeit., 1, p. 299; 1900.

By means of suitable selective ray filters (Fig. 23), the violet, blue, green, and yellow lines can be isolated and accurate check readings taken at these wave lengths.

A brief description of the method of use of the Hilger sector photometer, the Lummer-Brodhun spectrophotometer, the König-Martens spectrophotometer, and the Martens photometer is given in Bureau of Standards Technologic Paper No. 119. For further details, the original papers should be consulted.

All of the glasses, so far as it was possible to get values, were measured photographically and visually, and in most cases photoelectrically. The methods overlap to such an extent that when all are used extremely reliable transmission curves may be obtained. The photographic method may be used from 230 to 500 millimicrons (mμ), the photoelectric from 380 to 600 mμ, and the visual from 436 to 720 mμ. This overlapping is sufficient to eliminate the uncertainty which always appears as the limiting regions for any method are reached.

With possibly a few exceptions, therefore, the curves as given in this paper are considered accurate within 2 units, considering the transmission scale of 0.00 to 1.00 as being divided into 100 units; and in many cases, especially at low transmissions and in the better specimens, the uncertainty is definitely less than this. The actual values have not been plotted, inasmuch as the purpose of the paper is to give information as to the transmission rather than to compare methods, and the values, if plotted, might cause considerable confusion.

III. TRANSMISSION DATA

1. DEFINITION OF TERMS

The transmission of a specimen is defined as that fraction of radiant energy incident on the first surface which gets through the second surface. In a comparison of the transmissions of different samples, due account must be taken of the variation of transmission with thickness. This may be done, at least approximately, by means of the following equation:

$$\mathrm{T}=\frac{T}{(1-R)^2}=t^b,$$

wherein T is the transmission as already defined, R is the fraction of radiant power reflected at each surface of the specimen, T is the transmittance or the transmission corrected for reflection, b

RATIO OF THICKNESSES b'/b
REQUIRED TRANSMITTANCE T
0.10
0.20
0.30
0.40
0.50
0.60
.50
.60
.80
.80
.70
.60
.50
.40
.30
.20
.15
.10
.08
.07
.06
.05

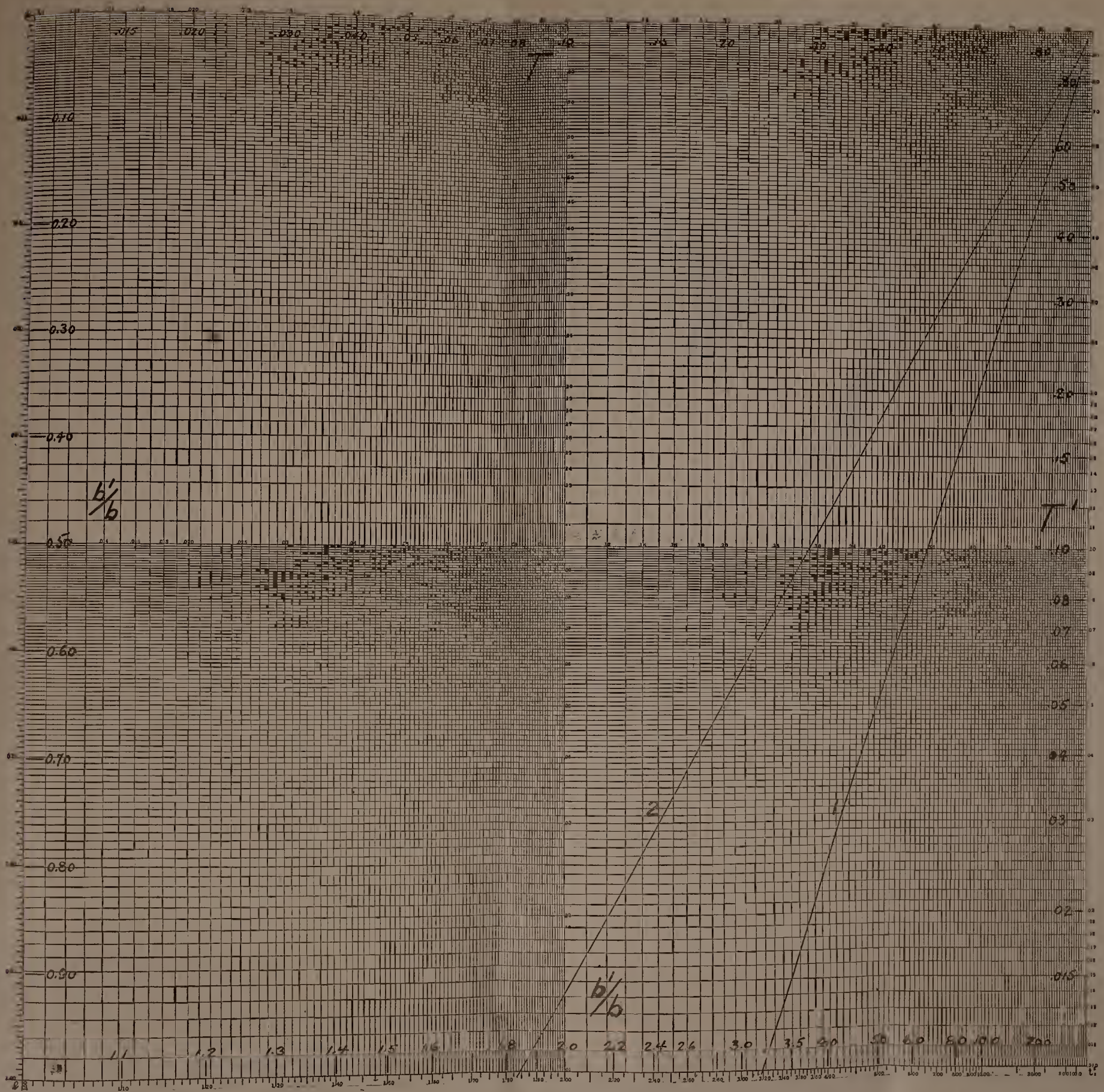

FIG. 1—*Reproduction of chart used at Bureau of Standards for computing transmissions for different thicknesses and vice versa*

Method of use.—To find T' when b', T, and b are given: Lay a straight edge from origin in upper right-hand corner to value of b'/b found on left-hand or lower scale. Find T ($=T/0.92$) on upper scale and follow it down to intersection with the straight edge. The value of T^1 on right-hand scale corresponding to this intersection is the required transmittance and $T'=0.92\ \mathrm{T}'$. Example (Line 1): Given $T=0.50$ and $b=1.68$ mm; to find T' when $b'=5.37$ mm.

To find b' when T', T, and b are known: Lay a straight edge from upper right-hand corner through the intersection of T and T' ($=T/0.92$ and $T'/0.92$, respectively). The intersection of this straight edge on the lower scale gives b'/b, from which b' can be found. Example (Line 2): Given $T=0.50$ and $b=1.68$ mm; to find b' when $T'=0.30$.

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is the thickness between surfaces, and t is the transmissivity or transmittance per unit of thickness. This computation of the transmissions for different thicknesses or the thicknesses corresponding to different transmissions may be easily carried out

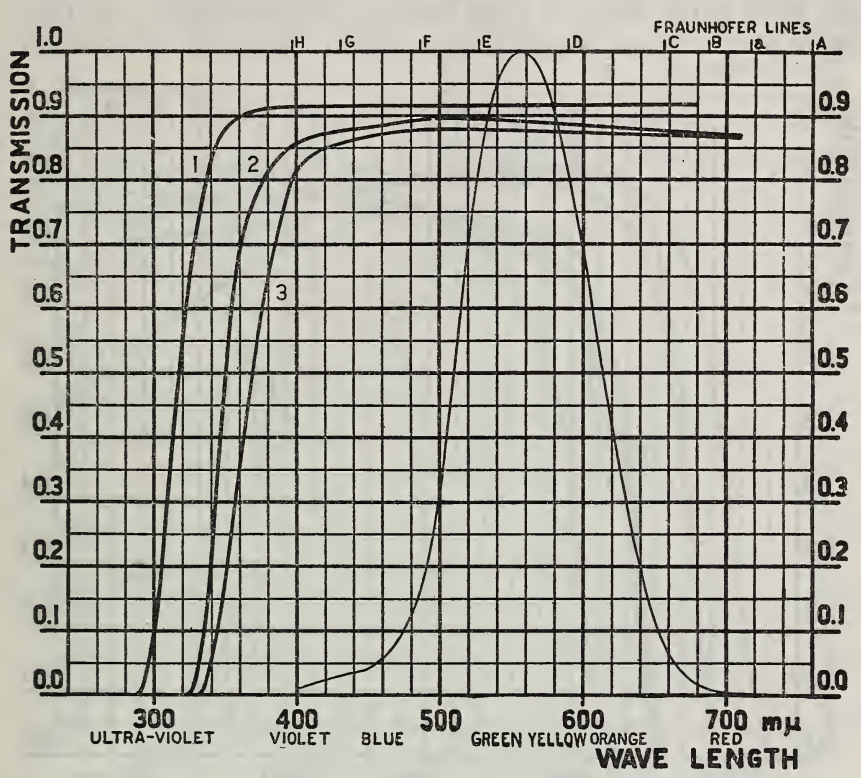

FIG. 2.—*Nearly neutral glasses*

1="Crown 1.50," 1.68 mm; A. O. Co. 2="G111CD," 8.30 mm; 3="122BR," 8.04 mm; C. G. W.

graphically, as illustrated in Fig. 1, which is a reproduction of the chart in use at the Bureau.[12]

The transmission data are shown by the curves in Figs. 2 to 21, the specimens and curves being numbered (from 1 to 87) for convenient reference. For each specimen, the maker or dealer,[13] the trade name or designation, and the thickness are given in the

[12] Same chart as that in B. S. Tech. Paper No. 119, Fig. 25. The original of this chart was designed at the Bureau in 1915 for this particular kind of work. The chart from which this published figure was copied was ruled by Keuffel & Esser according to this design. It was subsequently called to our attention that Luckiesh and Cady (Trans. I. E. S., IX, p. 853, 1914) had used a somewhat similar chart; but in its published form this is too small to be of practical value to the reader, except as an illustration of the method. The large reproduction of the Bureau's chart has been given in the hope that the reader could actually use it in the solution of problems similar to those illustrated.

[13] A. O. Co.=American Optical Co., B. & L.=Bausch & Lomb Optical Co., C. G. W.=Corning Glass Works, Jena=Schott & Gen., Glaswerk, Jena.

legends. In many cases curves are given for more than one thickness of glass of a given name. In the case of the Jena precision samples and others, these different thicknesses were cut from the same part of the same glass, but in some cases different samples of the same name were cut from entirely different stock. In each figure also is given the relative visibility curve for the average

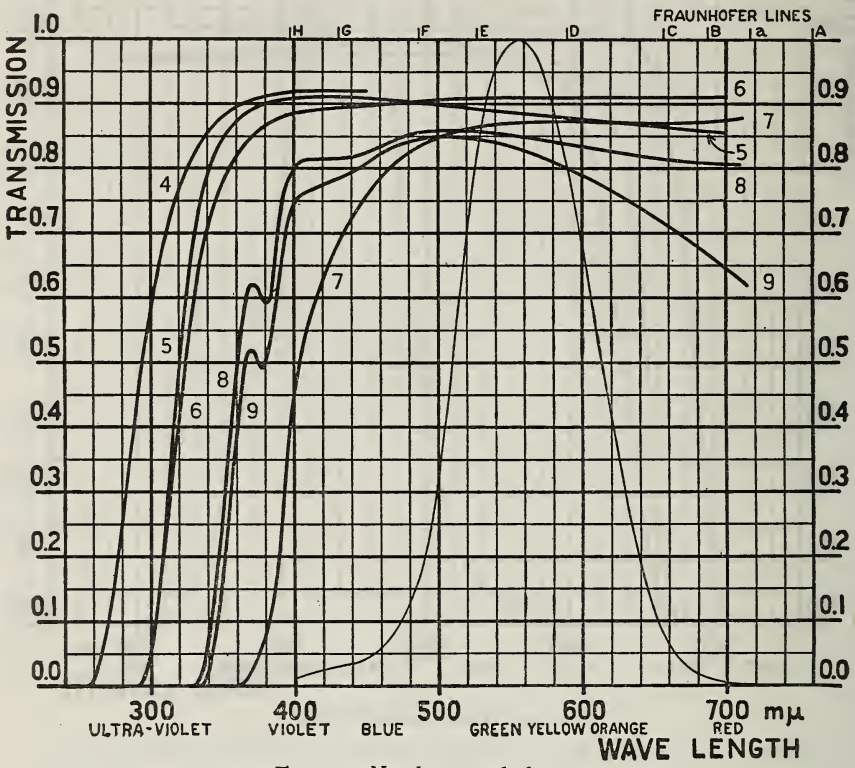

FIG. 3.—*Nearly neutral glasses*

4="G174S Ultra," 0.39 mm; 5=same, 3.49 mm; 6="Pyrex," 0.77 mm; 7="G123N Nultra," 4.84 mm; C. G.W. 8 and 9=mirror glass, 21.01 mm and 19.54 mm; B. & L.

human eye as obtained at the Bureau.[14] Inasmuch as an inspection of the curves will give practically all the information desired, little need be said in discussion except to call attention to certain points of special interest or importance.

2. NEARLY NEUTRAL GLASSES

The Corning "Ultra" glass, curves 4 and 5, is of special interest, for it transmits farther into the ultra-violet than any other neutral glass so far examined. Its ultra-violet transmission is very

[14] Coblentz and Emerson, B. S. Scientific Paper No. 303; September, 1917.

similar to that of the blue glasses shown by curves 64 and 68, the thin sample transmitting about 1 per cent even at 260 mμ. The sample "G123N Nultra" has practically the same transmission as the "Noviol O" samples, whose curves are given in Bureau of Standards Technologic Paper No. 119. The "Pyrex" glass is

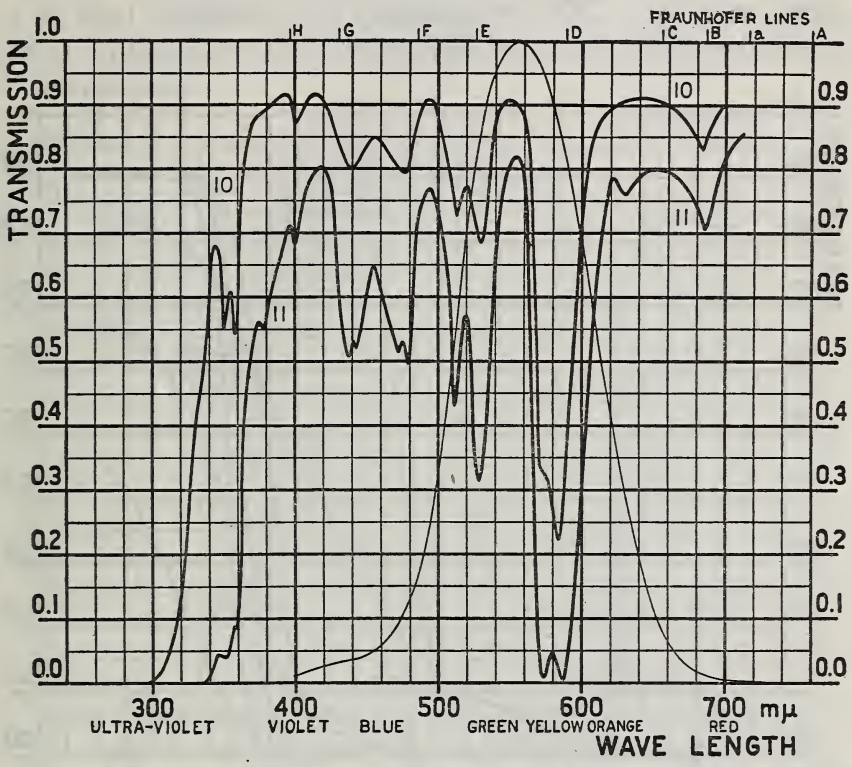

FIG. 4.—*Didymium glasses*

10="3728," 3.22 mm; Jena. 11="G555P," 3.02 mm; C. G. W.

notable for its low thermal expansivity and its extensive use in chemical and cooking glassware.

3. DIDYMIUM GLASSES

These glasses, Fig. 4, are remarkable for the large number of strong and narrow absorption bands. The Corning and Jena samples are very similar, although, as may be noted at wave lengths 350–390, 570–590, and 630 mμ, they are not exactly alike. This glass is of special value as a ray filter for use with the mercury arc, for it absorbs the yellow lines very strongly, while transmitting the green quite freely. Its absorption of the helium, sodium, and other yellow lines is also of value in special cases.

4. RED GLASSES

The curves of Fig. 5 show the transmissions of two kinds of Jena red glass at different thicknesses. These and the other Jena glasses, except specimens 10, 48, 64, and 65, comprise a set of standard precision glasses kept on file at the Bureau for the purpose of comparing methods. They are especially fine specimens, both as to material and finish, and any discrepancies in the values of the trans-

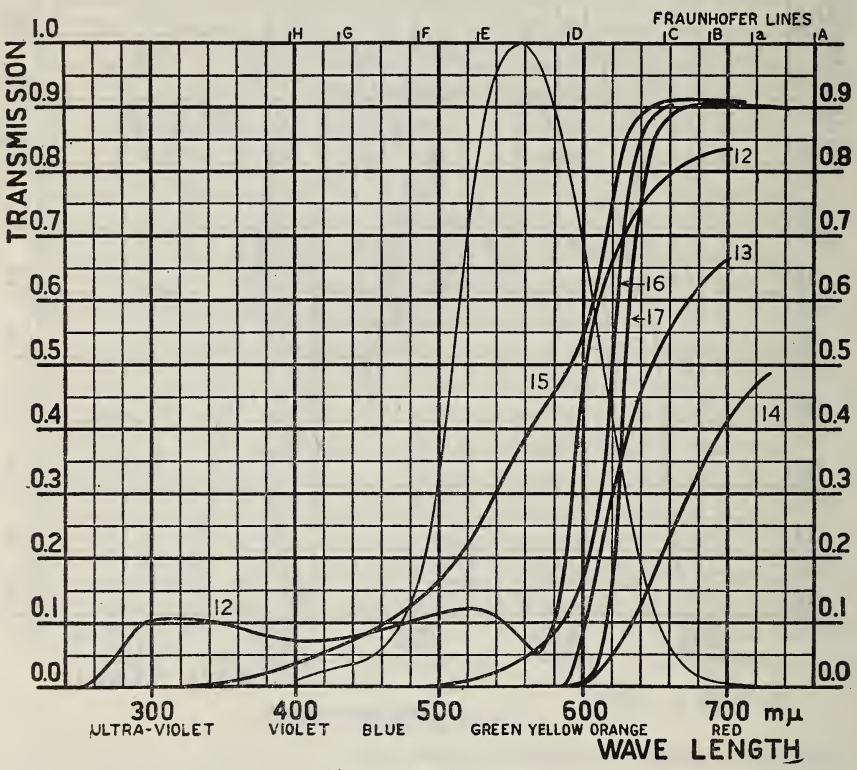

FIG. 5.—*Red glasses*

12="2745," 0.32 mm; 13=same, 1.03 mm; 14=same, 2.99 mm; 15="4512," 0.30 mm; 16=same, 1.02 mm; 17=same, 2.99 mm; Jena.

mission by different methods can be laid entirely to the method, and not to the specimen. Specimen 12 is remarkable for its transmission of the ultra-violet, though nominally a red glass, and the curve illustrates how little can be told regarding the transmission of thin specimens from that of a thicker one of the same kind.

The Corning glasses of Fig. 6 are similar to Jena "4512". They do not have as high transmission in the red, but the transmission is much more sharply reduced to an inappreciable amount than in the Jena glasses. For most purposes, the Corning red

would probably be more desirable than the Jena. It is understood that Corning red glass can now be obtained of higher transmission than that found for these samples.

5. ORANGE AND YELLOW GLASSES

In Fig. 7 are given curves for different shades of Corning "G34" and "G38 Noviol". Curves for a large number of other "Noviol" glasses are given in Bureau of Standards Technologic Paper No. 119.

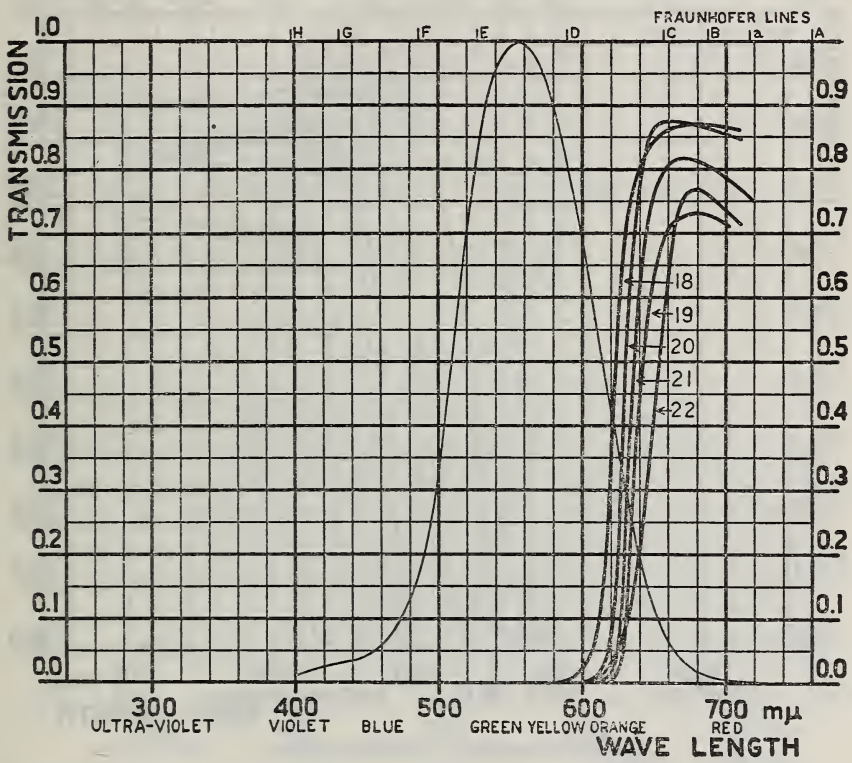

FIG. 6.—*Red glasses*

18="G24," 0.88 mm; 19=same, 5.97 mm; 20="Ruby 100%," 0.90 mm; 21=same, 4.18 mm; 22="G20," 7.2 mm; C. G. W.

Most of these glasses are characterized by the sharp transition between high transmission and strong absorption, and are used to absorb ultra-violet, to eliminate haze and thus improve visibility both in visual and photographic work, and, in general, as selective ray filters. Different samples of this kind vary greatly in the sharpness of the transition between absorption and transmission and in the value and shape of the curve where the transmission is high.

In Figs. 8 and 9 are given curves for other samples of orange and yellow glass, these being the usual shades of the different kinds, while the various shades of "G34" in Fig. 7 were made on a special order.

The Jena glass of Fig. 10 is similar in appearance to the deep shades of "Noviol," but has a more uniformly high transmission in the red, yellow, and green, and a very gradual decrease in

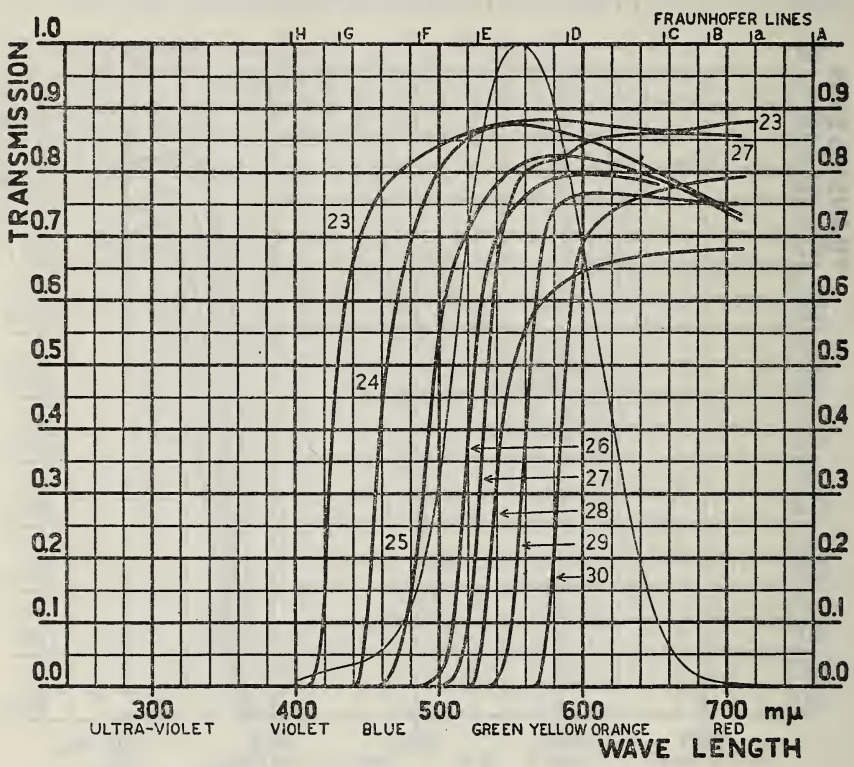

FIG. 7.—*Orange and yellow glasses*

23="Noviol A," 2.00 mm; 24="G38 Noviol B," 3.22 mm; 25="G38 Noviol C," 4.23 mm; 26 to 30=special shades of "G34;" 26=2.25 mm; 27=0.93 mm; 28=3.68 mm; 29=3.45 mm; 30=3.16 mm; C. G. W.

transmission through the violet and ultra-violet. It therefore has not the value for most purposes that the "Noviol" has.

The glasses of Fig. 11 are fluorescent. This kind is quite commonly called "canary" glass and fluoresces with a greenish light. The Jena and Corning samples seem to be practically the same.

6. GREEN GLASSES

In Fig. 12 Jena and Corning green glasses are compared. They are very similar, although the transmission band of the latter is at slightly shorter wave length than that of the former.

7. BLUE-GREEN GLASSES

Various types and shades of blue-green glasses (green by yellow light) are shown in Figs. 13 and 14. This type of glass usually gives very good protection against the infra-red.

8. BLUE GLASSES

Three kinds of Jena blue glass are shown in Figs. 15 and 16. Specimens "8780" and "3653" have not been duplicated in any

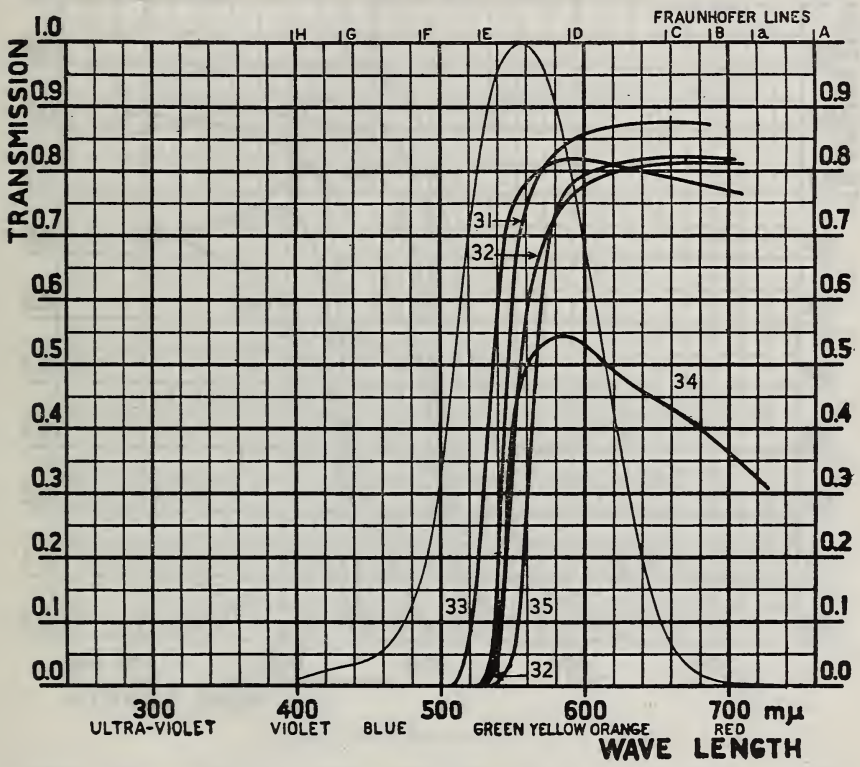

FIG. 8.—*Orange and yellow glasses*

31="G_{34}," 1.50 mm; 32=same, 3.68 mm; 33="$G_{34}B$ 143%," 1.13 mm; 34=same, 6.40 mm; 35="$G_{341}F$," 2.12 mm; C. G. W.

of the glasses examined. The thick sample of "3653" transmits farther into the ultra-violet than any other glass ever examined, if the curves for these others be reduced to that for a thickness of 5.45 mm. However, the thin specimen transmits no farther than the various other thin specimens which go to about 1 per cent at 260 mμ.

In Figs. 17, 18, and 19 are shown a number of different kinds of Corning blue glass, some of them appearing purple if viewed by

yellow light. "G585", curves 68 and 69, seems to be a duplicate of Jena "3654," Fig. 16.

9. PURPLE GLASSES

Purple glasses of lighter and darker shades are shown in Figs. 20 and 21. Those of Fig. 21 are of special interest and value. They are the best obtainable for demonstrating fluorescence, they

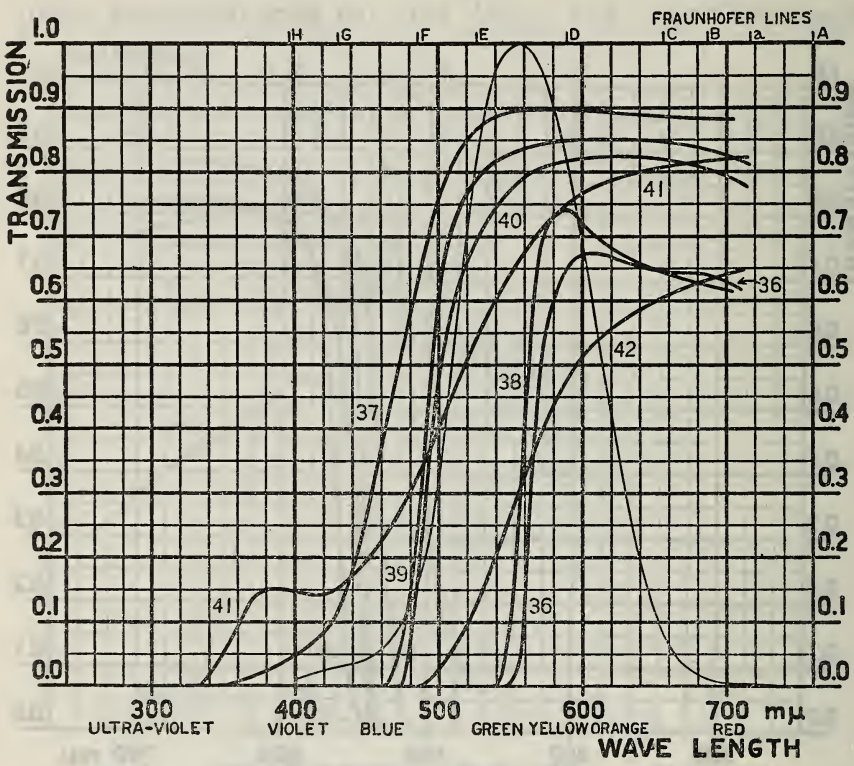

FIG. 9.—*Orange and yellow glasses*

36="G36," 5.16 mm; 37="G36 190%," 0.60 mm; 38=same, 6.81 mm; 39="G361CE," 3.04 mm; 40=same, 6.00 mm; 41="Yellow 100%," 1.12 mm; 42=same, 3.79 mm; C. G. W.

are of value as selective ray filters, and may be put to other uses. "G586J" and others very similar have been used in ultra-violet signaling.[15] The red and infra-red transmission of this glass is too small to measure. "G586N" transmits considerably more red than "G586J." It will be noted that the maximum trans-

[15] "Confidential Report (to the Navy Department, Bureau of Steam Engineering) on the Possibility of Using Ultra-Violet Position Lights and the Applicability of Ultra-Violet Radiation to Signaling," by Irwin G. Priest and K. S. Gibson, Mar. 5, 1918. "Report on the Applicability of Ultra-Violet Rays to Signaling," by Irwin G. Priest and K. S. Gibson, Paper communicated to American Physical Society; Apr. 25–26, 1919.

mission varies from 370 mμ in the lightest shade to 360 mμ in the darkest.

10. APPLICATIONS

There are many practical uses to which these glasses may be put, in addition to those already mentioned. Some of them, or somewhat similar glasses, are used in railway signaling; others, alone or in combination, are used to isolate certain parts of the spectrum; and various other ways in which the different types

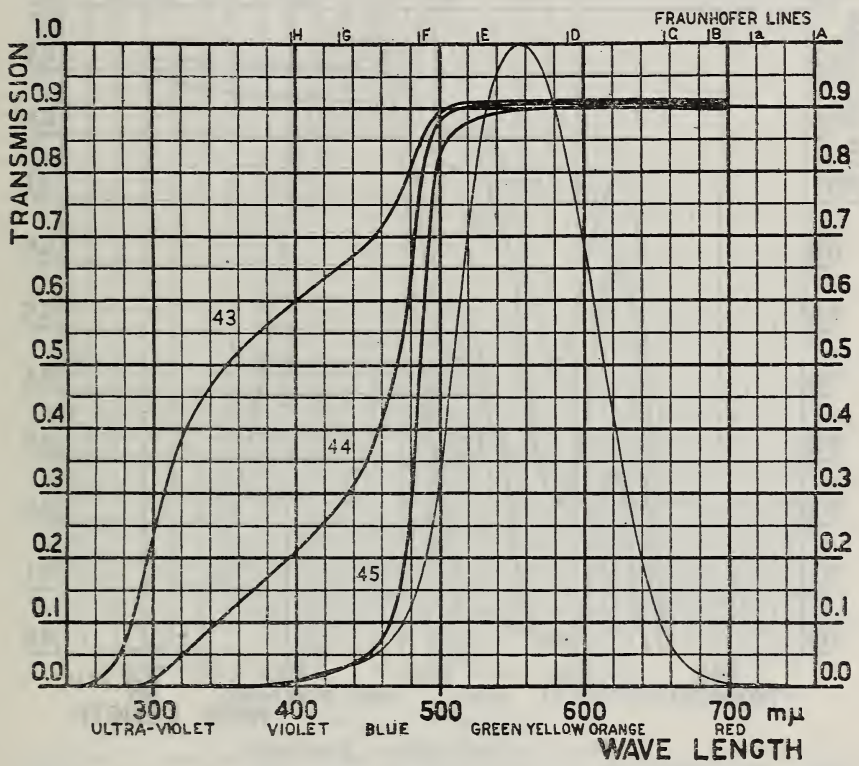

FIG. 10.—*Yellow glasses*

43="5560," 0.30 mm; 44=same, 1.02 mm; 45=same, 3.01 mm; Jena.

might be used will occur to those interested. Those labeled "Ruby 100%," "Yellow 100%," "Green 100%," "Blue 100%," and "Purple 100%" are samples from old railway-signal glasses, but were not measured through the original surfaces. A paper is now in preparation giving the transmission in the visible of present-day standard railway-signal glasses, precision measurements being made both through the original surfaces and through the same specimens planed and polished, the specimens being cut from the center of the roundel.

As already noted, glasses having a type of curve given in Figs. 6 and 7 are very valuable as photographic ray filters, for improving visibility, or for protecting the eyes from the ultra-violet while transmitting highly in the visible. By varying the thickness it is possible to have the steep part of the curves—that is, the transition between high and low values of transmission—occur at any wave length. The glasses of Figs. 6 and 7 make this possible

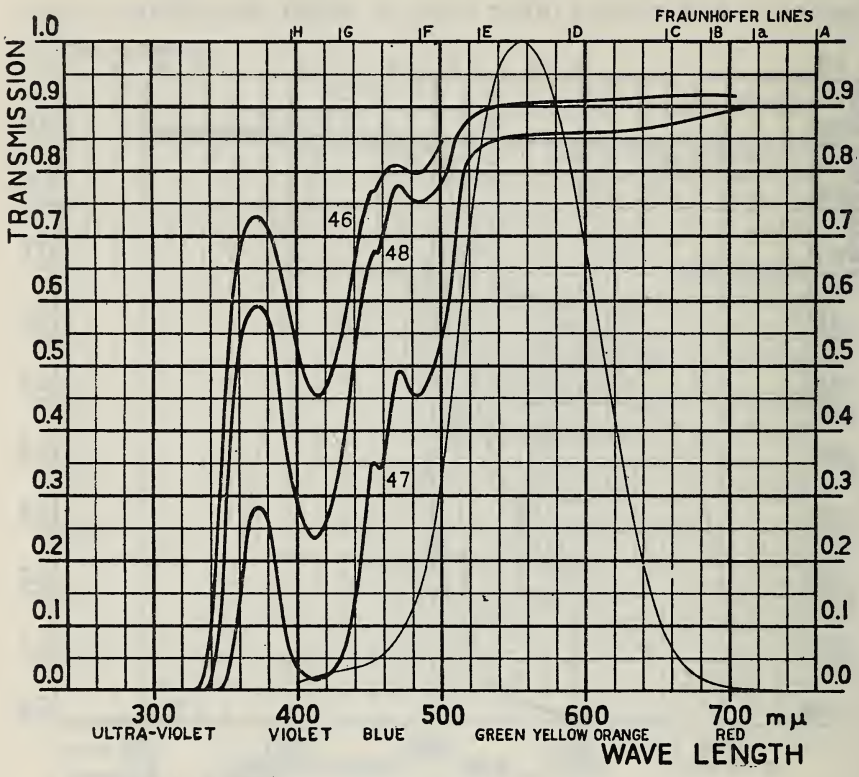

FIG. 11.—*Yellow glasses, fluorescent*

46="G371," 0.99 mm; 47=same, 5.79 mm; C. G. W. 48="3757," 1.97 mm; Jena.

anywhere from 400 to 660 mμ. By the use of different thicknesses of various neutral glasses, as illustrated in Figs. 2 and 3, this type of curve may be extended into the ultra-violet below 300 mμ. By combining the glasses of Fig. 6 with glasses like 69, 74, and 83, the same type of curve may be obtained from 670 mμ toward the infra-red.

The inverse type of curve—that is, low transmission at long wave lengths and high transmission at shorter wave lengths—may be obtained by some of the glasses shown in Figs. 13 to 21, though

the transition is usually much more gradual. However, if frequencies instead of wave lengths be plotted, this difference is not so apparent.

Some of the glasses of Figs. 12, 14 (curve 58), 15, 16, 17, 18, 20, and 21 make it possible to isolate certain more or less narrow regions of the spectrum, the various maxima occurring at 360, 370, 390 (69×81), 410, 450, 490, and 525 mμ. By combining the glasses

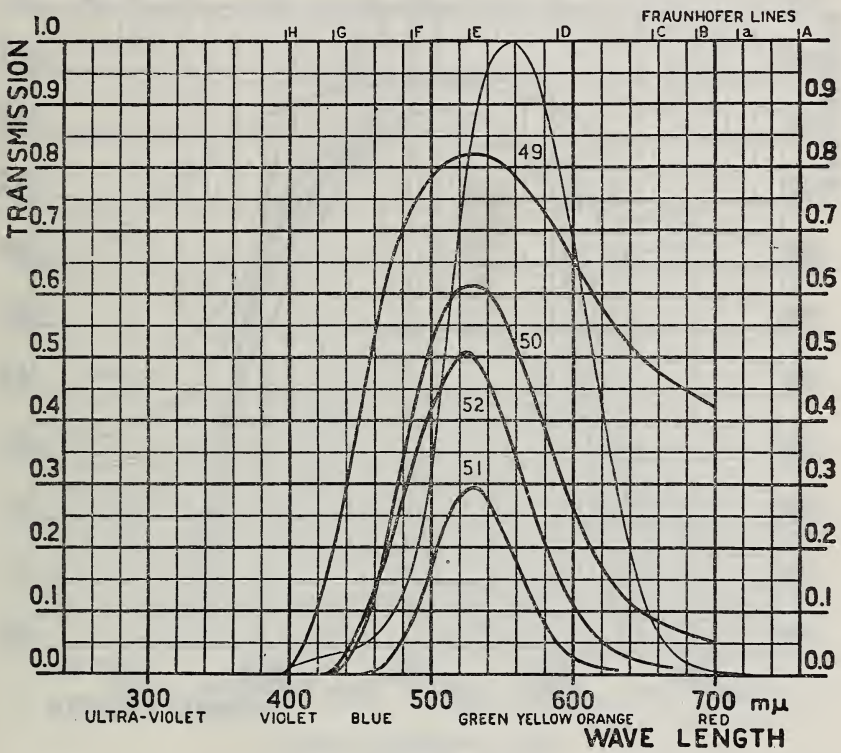

FIG. 12.—*Green glasses*

49="4930," 0.28 mm; 50=same, 1.03 mm; 51=same, 2.99 mm; Jena. 52="Sextant Green," 1.66 mm; C. G. W.

of Figs. 6 and 7 with those of Figs. 12, 13, and 14 and certain of the glasses of Figs. 16 to 19, fairly narrow regions of the spectrum may be isolated, the values of the transmission and wave length at the maximum being more or less controllable. This isolation of narrow regions of the spectrum is of value in various visual and photographic work.

A combination of glasses similar to 25 and 69 gives a low-transmission, dichromatic, red-blue screen which has proved of value in the detection of camouflage.

The combination of glasses 35 and 11 has been proposed[16] as a means of protecting the eyes from the intense radiation from accidental arcs between copper parts in electrical installations, while transmitting sufficient light to permit of its being worn in goggles by the workmen under ordinary illumination. Protection is required not only against the ultra-violet, but also against the

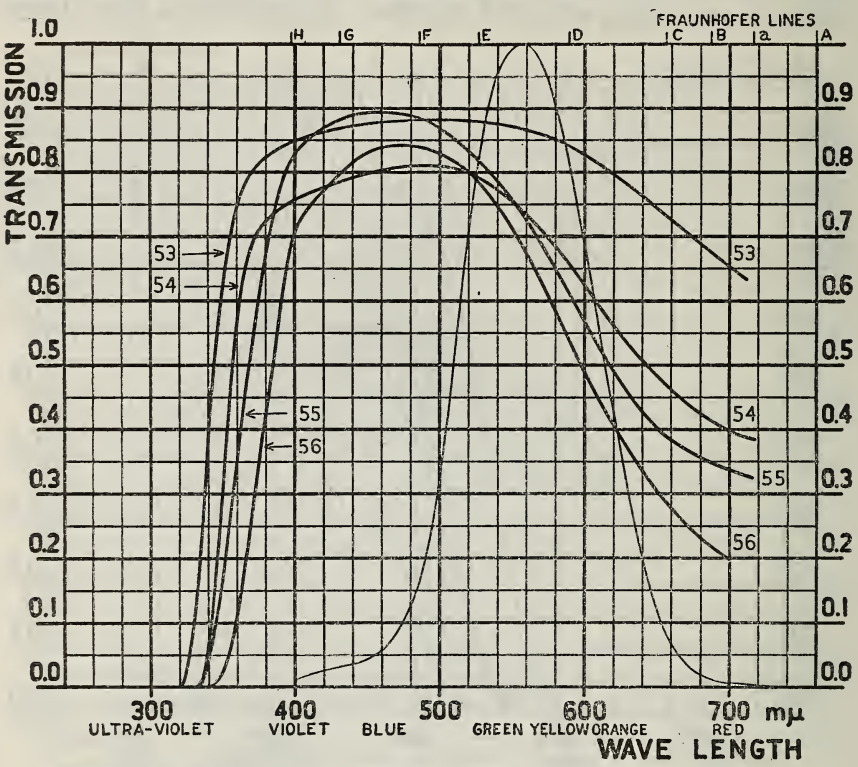

FIG. 13.—*Blue-green glasses*

53="G124J," 1.04 mm; 54=same, 3.09 mm; 55="G171IZ," 3.12 mm; 56=same, 4.62 mm; C. G. W.

blinding flash of light from the arc. The principal visible lines in the copper arc are shown in Fig. 22, in which is also plotted the transmission curve for the combination of glasses above mentioned. Most of the light is due to the yellow lines and the many lines below 530 mμ. As may be noted from the figure, these lines are all largely absorbed, as well as those in the ultra-violet, but a considerable amount of daylight or light from any other source having a continuous spectrum is transmitted.

[16] Letter of I. G. Priest to E. B. Rosa; Mar. 12, 1918. A combination of glasses 31 and 11 would be considerably more efficient than the filter here proposed. Glass 31 was not available at the time this proposal was made.

11. MONOCHROMATIC LIGHT FILTERS.

For various kinds of work it is highly important to have available filters which will transmit monochromatic light from the mercury arc or the hydrogen or helium vacuum tube. The filters whose curves are given in Fig. 23 are advised, many of them having been in use for some time at the Bureau. Usually a combination

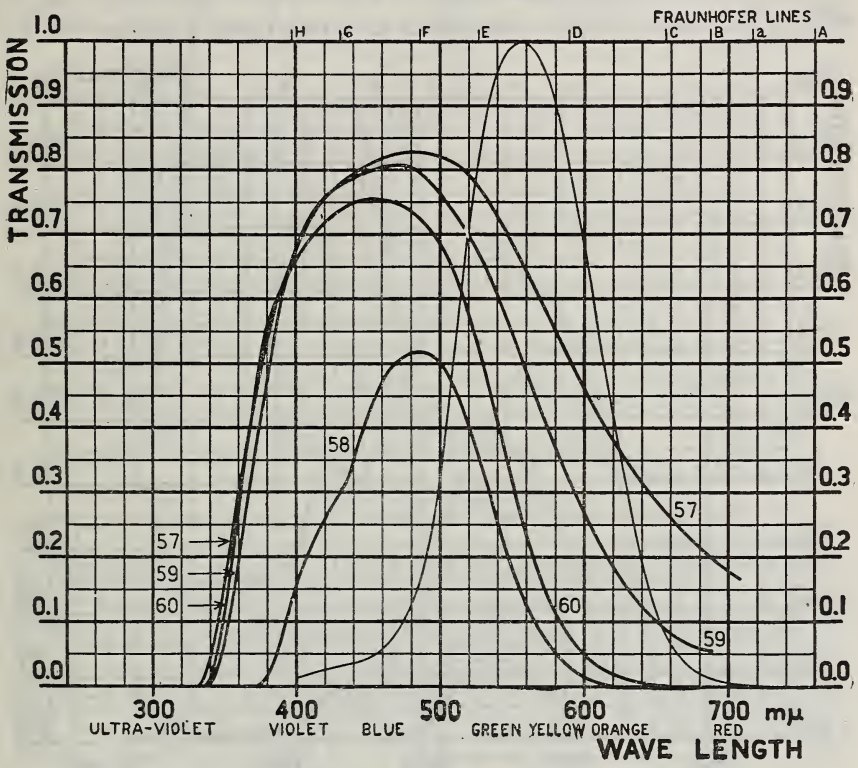

FIG. 14.—*Blue-green glasses*

57="Green 100%," 0.92 mm; 58=same, 5.55 mm; 59="401Z," 2.22 mm; 60="G584" (old "GT14B"), 4.1 mm; C. G. W.

of glasses is necessary for this purpose, although in some instances a single one is sufficient. In choosing these filters the attempt is made, of course, to obtain as high transmission as possible of the particular line desired, with as high absorption as possible of all remaining lines in the visible spectrum.

In the case of the mercury arc, the filters are so chosen as to absorb even the faint line at 491.6 mμ. The faint red lines are also absorbed by the filters transmitting the blue and violet lines, but they are so faint in comparison with the green and yellow lines that

they need not be absorbed by the filters transmitting these lines. Care must be used in making measurements if the specimen has a strong red or yellow fluorescence.

No trouble is experienced in separating the hydrogen lines. The lines in the extreme violet beginning at 410.2 mμ are absorbed in all cases.

Only the red and yellow lines of the helium spectrum can be efficiently used, as the blue lines are too close together to be

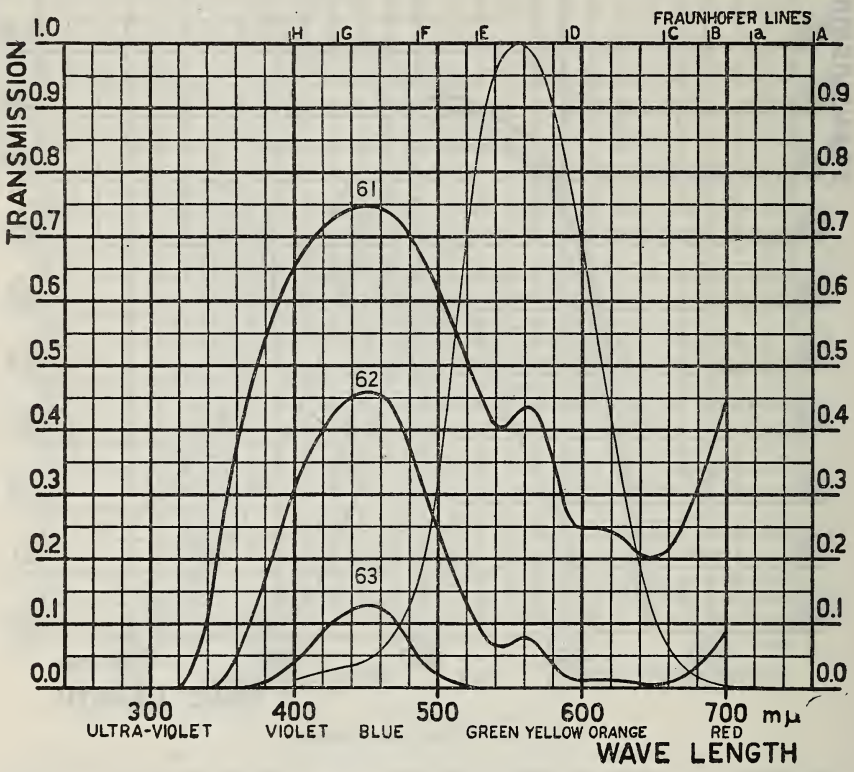

FIG. 15.—*Blue glasses*

61="8780," 0.31 mm; 62=same, 1.03 mm; 63=same, 2.99 mm; Jena.

separated. The transmission of the far red line at 706.5 mμ by the filter used to transmit the strong line at 667.8 mμ does not introduce error unless the sample being examined transmits the former very highly relative to the latter.

IV. SUMMARY

1. Spectral transmission curves for 87 samples of glass representing over 50 different kinds, mostly colored, are given in this paper. These curves extend from about 710 mμ throughout the visible

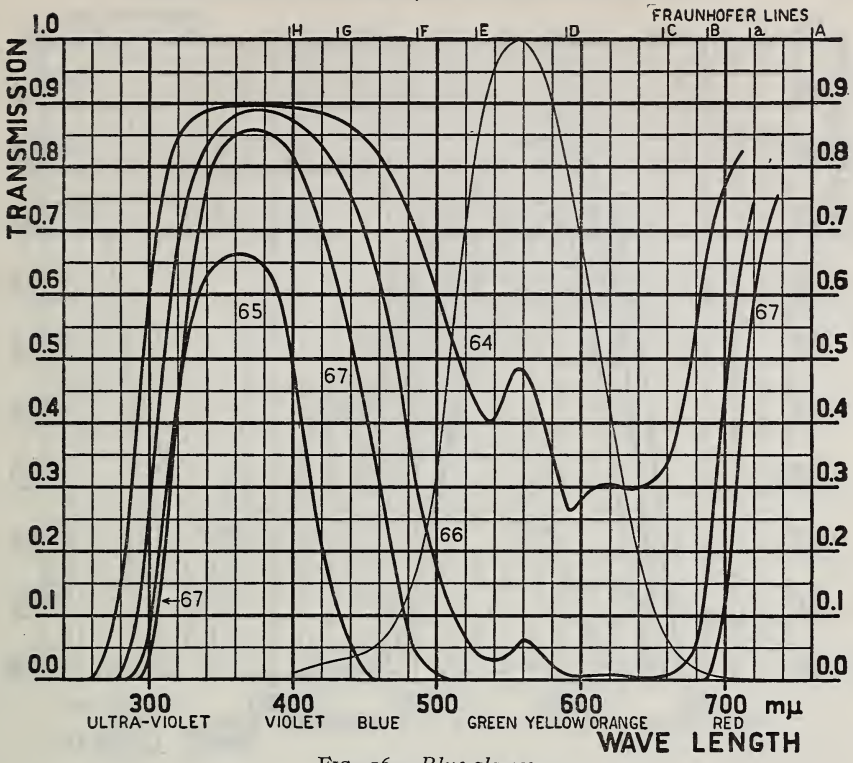

FIG. 16.—*Blue glasses*

64="3653," 0.27 mm; 65=same, 5.45 mm; 66="3654," 1.04 mm; 67=same, 3.00 mm; Jena.

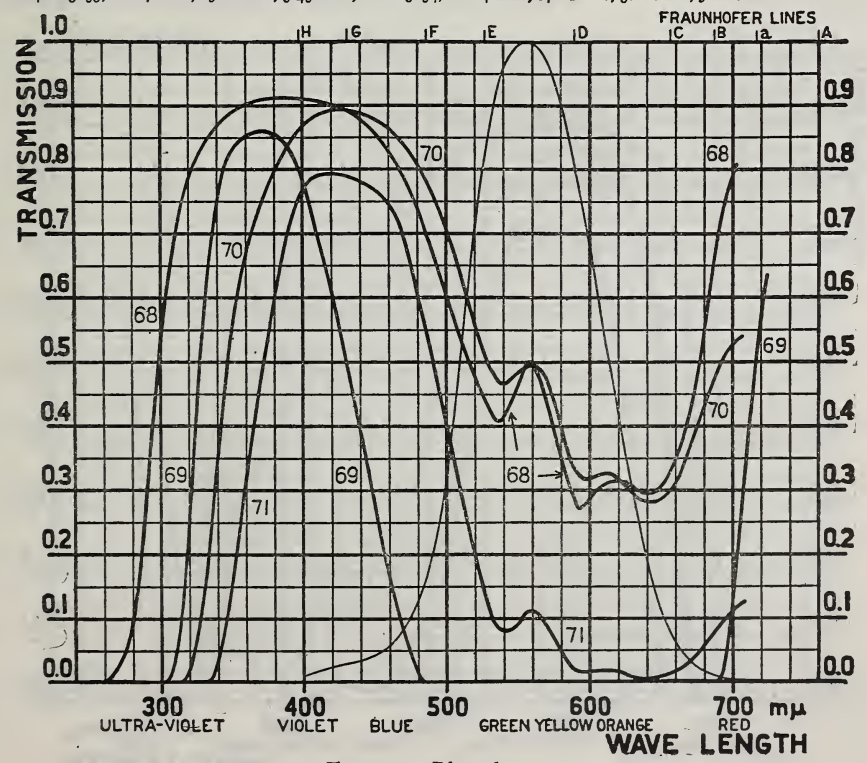

FIG. 17.—*Blue glasses*

68="G585" (old "GT11E"), 0.28 mm; 69=same, 4.62 mm; 70="G50 77%," 0.98 mm; 71=same, 3.39 mm; C. G. W.

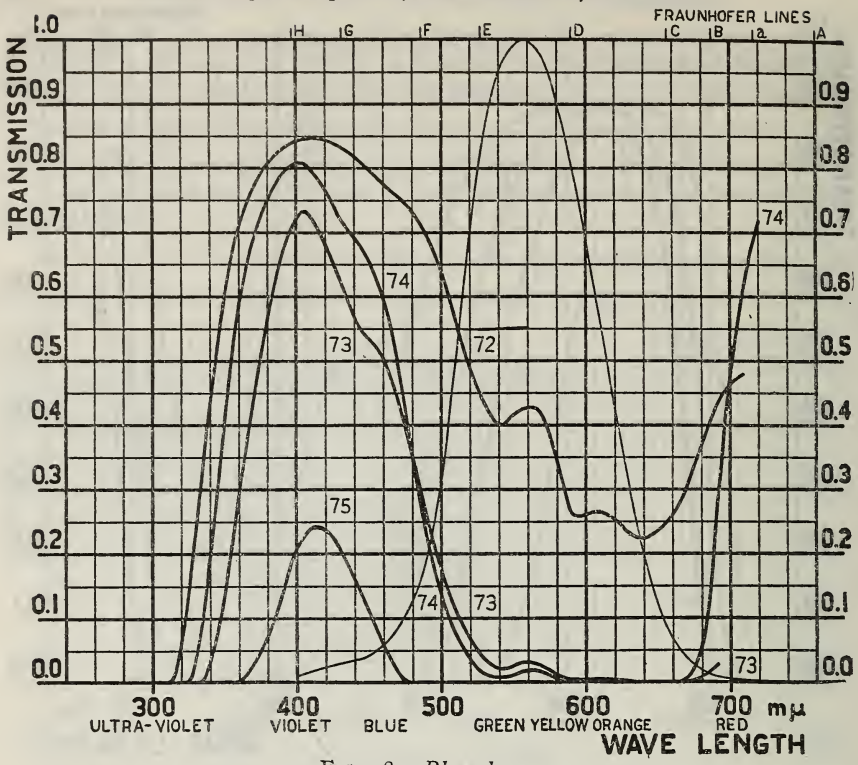

FIG. 18.—*Blue glasses*

72="Blue 100%," 0.92 mm; 73=same, 4.36 mm; 74="Purple 100%," 5.03 mm; 75="G_{53}," 2.59 mm; C. G. W.

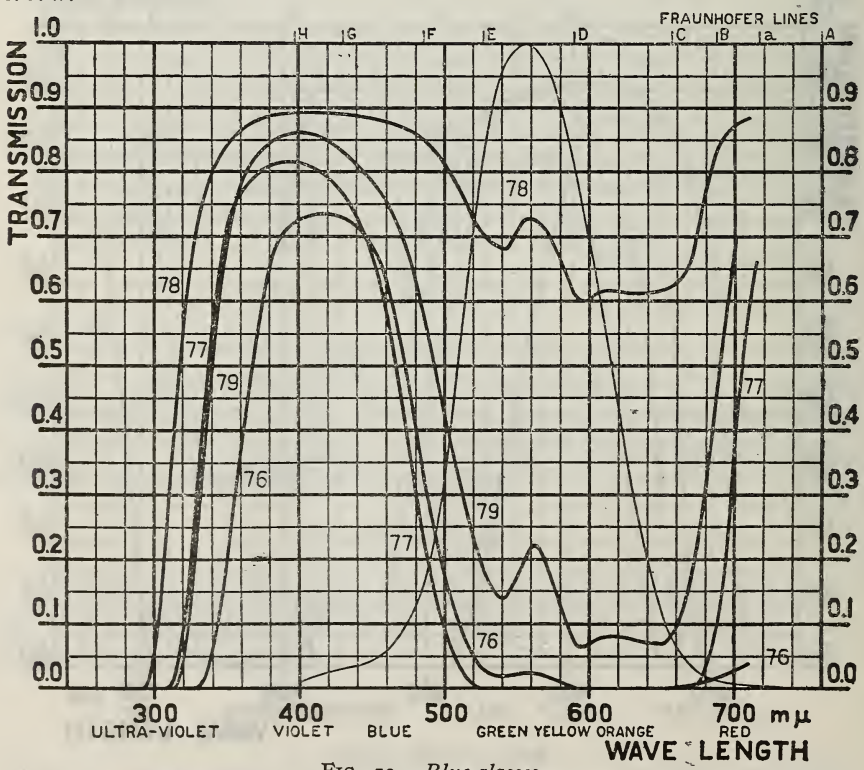

FIG. 19.—*Blue glasses*

76="G_{55}," 5.7 mm; 77="$G_{55}A$ 80%," 5.64 mm; 78="$G_{55}D$ 70%," 0.97 mm; 79=same, 6.22 mm; C. G. W.

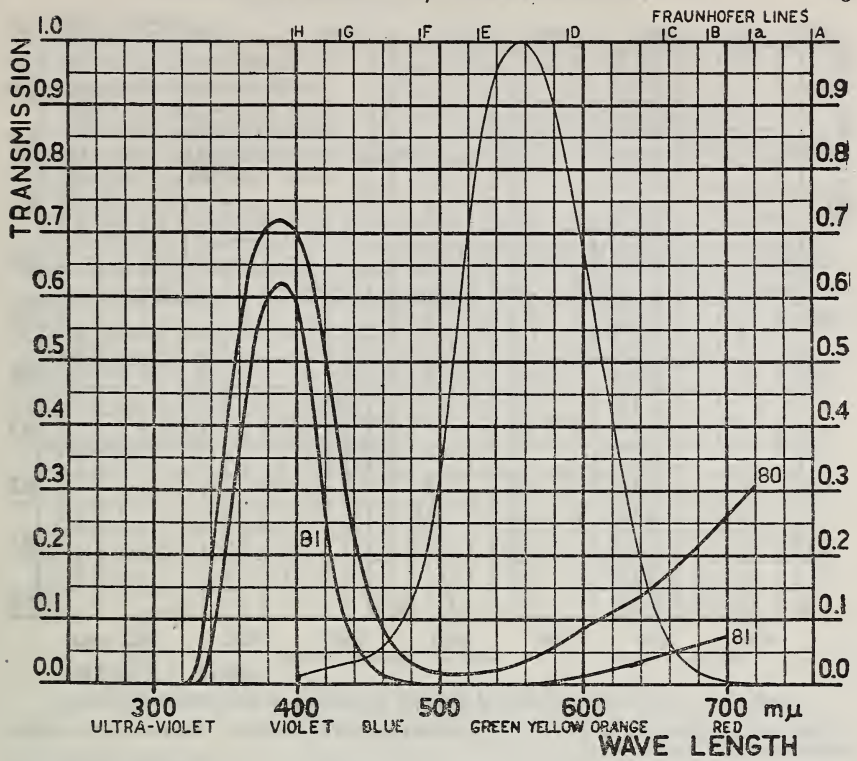

FIG. 20.—*Purple glasses*

80="G172BW5," 5.27 mm; 81='G554 CP," 5.48 mm; C. G. W.

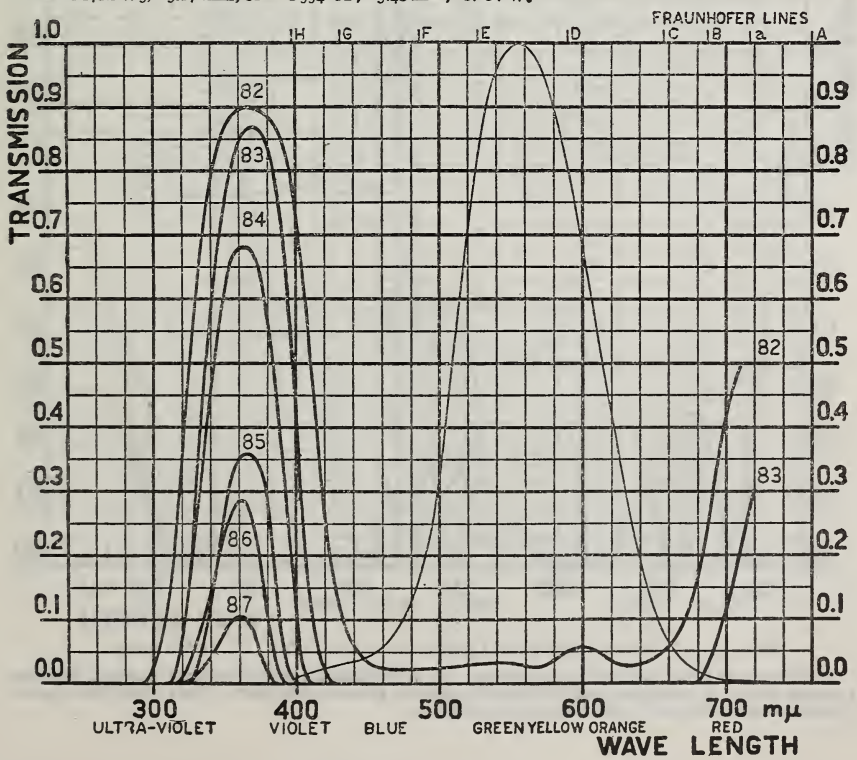

FIG. 21.—*Purple glasses*

82="G586A " (old "G55A62"), 1.03 mm; 83=same, 3.20 mm; 84="G586C," 4.05 mm; 85="G586J 2.68 mm; 86="G586N," 3.15 mm; 87="G586P," 4.37 mm; C. G. W.

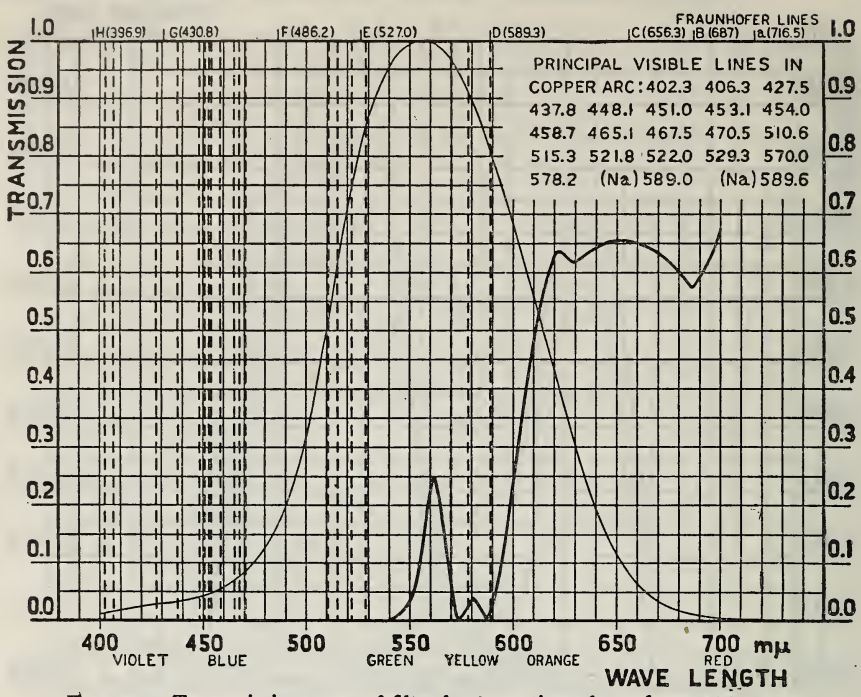

FIG. 22.—*Transmission curve of filter for protection of eyes from copper arcs*

The principal visible spectral lines of the copper arc are given in the figure. The curve is the product of previous curves 11 and 35.

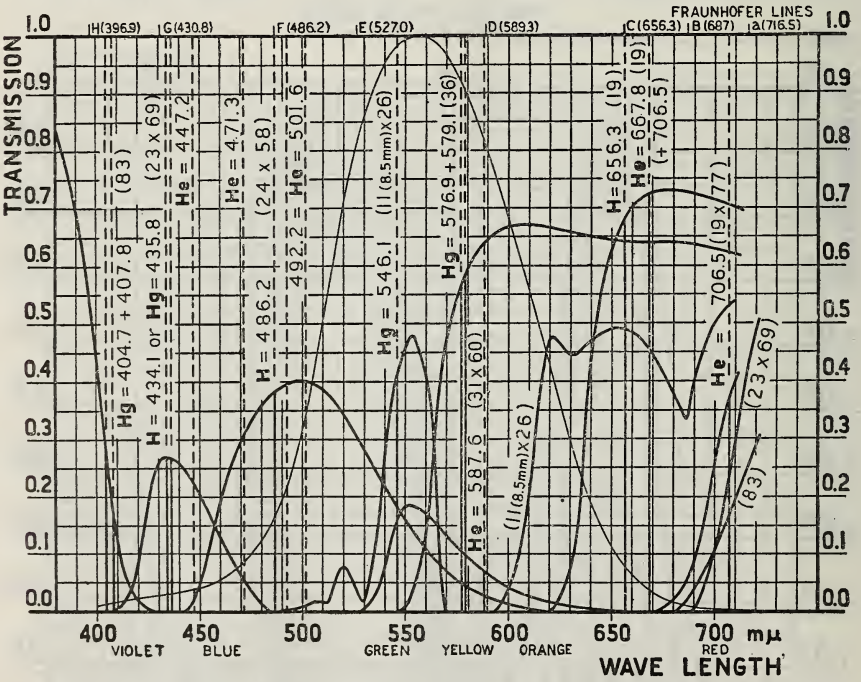

FIG. 23.—*Monochromatic light filters for use with Hg, H, or He lamps*

The principal visible spectral lines are shown. In parentheses are given the curve numbers, from the previous figures, of the glasses used to obtain the curve as given in this figure. The spectral line is made continuous up to the curve of the filter used to isolate it.

and ultra-violet as far as the specimens have any appreciable transmission.

2. Most of these glasses are of American manufacture, but a comparison is afforded with some samples of Jena glass obtained before the war.

3. Various practical uses to which these glasses may be put are indicated, such as ultra-violet signaling, railway signaling, improvement of visibility both for visual and photographic work, protection of the eyes, and selective ray filters. Of special value is their use as filters to obtain monochromatic light from the mercury, helium, or hydrogen lamps.

WASHINGTON, June 30, 1919.

APPENDIX

By E. P. T. Tyndall

The source for the ultra-violet spectrophotometer was set up at the Bureau at first as described by Howe.[17] It was soon found, however, that an exceedingly small movement of the electrodes caused the two comparison spectra, taken first and last on the plate, to become unequal. It was almost impossible to get reliable data, as this movement very often occurred during a series of exposures. This trouble was always present in the Cornell set-up, but in less degree than the Bureau apparatus showed. To remedy the difficulty, a trial was made of putting the electrodes perpendicular to the position formerly used; that is, with the spark length parallel to the slit of the spectrograph. The expected ease and permanence of adjustment were realized, and, in addition, another improvement was noted.

This improvement may be seen by examining Figs. 24, 25, and 26. Fig. 24 shows a print from a negative taken with the apparatus at Cornell (horizontal spark). Fig. 25 is one taken at the Bureau on the original set-up. It will be noted that in both cases the two spectra, for any exposure, are only in contact in the middle region of the spectrum. In the extreme ultra-violet and in the visible region there is considerable spread, enhancing the difficulty of making photometric observations for a considerable range. Fig. 26 is a print from a negative taken with the spark length parallel to the slit (vertical spark). The spectra here make contact throughout their whole length, and the ease and accuracy of determining points of equal density are greatly increased.

Several other minor changes have been made. Brass rods about 1.2 mm in diameter have been substituted for the aluminum ones used by Howe, as the former do not disintegrate so fast under the mechanical shock of the spark. The gap under water is generally about 1.5 cm, so that there are no lines superposed on the continuous spectrum. This necessitates the photographing of a known spectrum (aluminum spark in air) at least twice on each plate. The spark is placed directly in front of the slit and can be swung out of the way while not in use.

[17] Loc. cit.

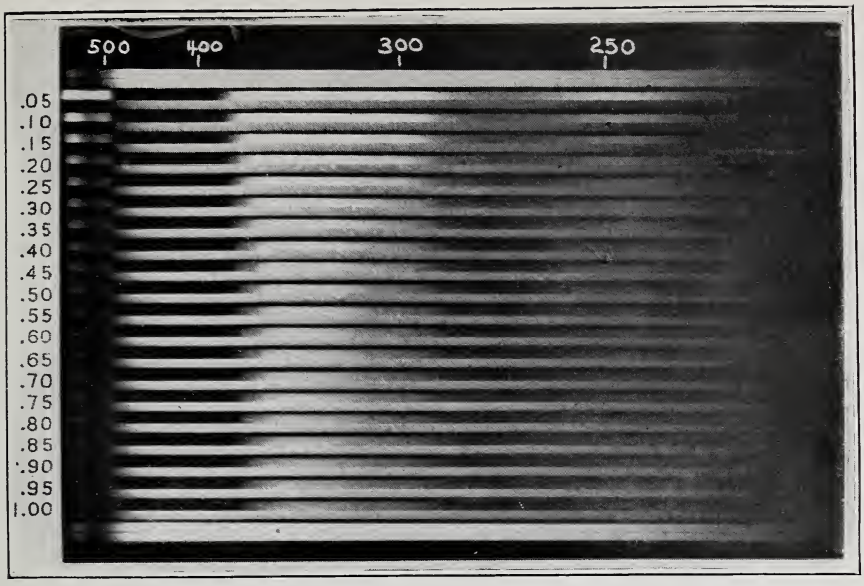

FIG. 24.—*Paranitrosodimethylaniline, 0.000034 g per cubic centimeter of distilled water, 1 cm layer, February 24, 1917, K. S. G. at Cornell University*

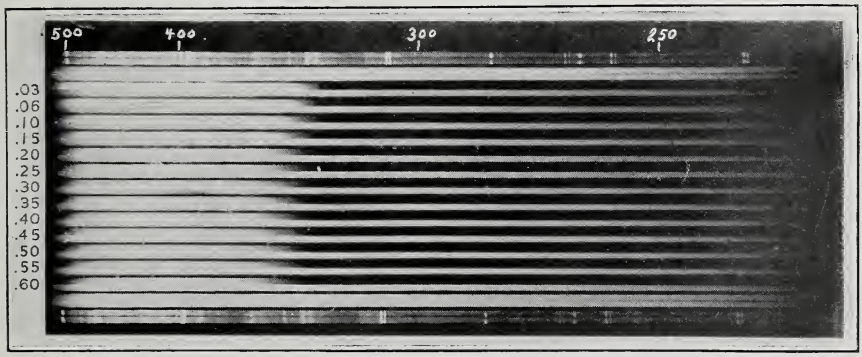

FIG. 25.—*Corning "Blue 100%" (curve 73, Fig. 18), August 17, 1918, E. P. T. T. at Bureau of Standards*

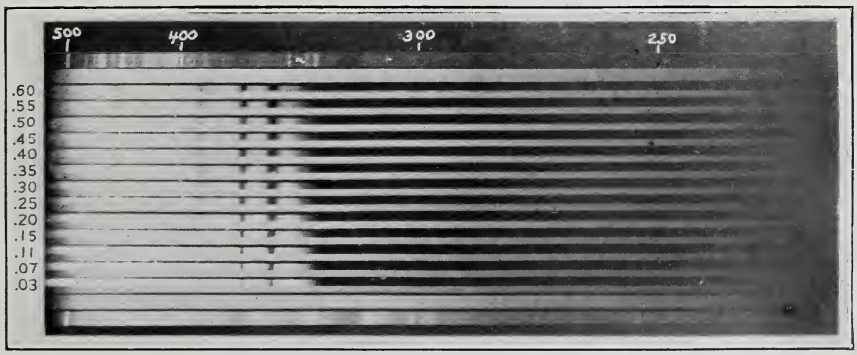

FIG. 26.—*Holmium nitrate (impure), 0.282 g of nitrate to 1 g of solution (distilled water), 1 cm layer, December 20, 1918, E. P. T. T. at Bureau of Standards*

Electrode holders have been made which are quite independent of any movements of the distilled-water jar. By means of scales and verniers the vertical and horizontal positions of the two electrodes may be read to 0.1 mm. This facilitates adjustments when they are necessary, though, except for an occasional shortening of the gap, readjustments need seldom be made during the whole life of a pair of electrodes.

Howe's method has up to the present been used in obtaining the transmission curves from the negatives. In most cases, however, the plates have been "spotted" on the glass side several times and corresponding readings averaged. This is a slow process, and to save time and to increase the accuracy of locating the points of equal density a comparator has just been completed. In this comparator the negative is placed over a sheet of milk glass in a brass frame. This frame moves from left to right on roller bearings in a second frame, which moves to and from the observer. The first motion permits of any pair of spectra being moved parallel to their length under a fixed bilateral slit until the point of equality is reached. The position is read by means of a scale on the second frame and vernier on the first. Reference to a calibration curve or table gives the wave length or frequency for the point of match for that particular setting of the sector. The motion of the second frame then allows another pair of spectra to be brought into view. The slit is made adjustable in width, as it is necessary to increase the slit width when the density gradient of the spectrum transmitted through the absorbing substance is gradual. A simple convex lens ($f = 30$ mm) is used to view the slit. All of the above is mounted on a metal box containing an incandescent lamp placed directly below the slit.

WASHINGTON, June 30, 1919.