DEPARTMENT OF COMMERCE

TECHNOLOGIC PAPERS

OF THE

BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 119

THE ULTRA-VIOLET AND VISIBLE TRANSMISSION OF EYE-PROTECTIVE GLASSES

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ISSUED JUNE 7, 1919

PRICE. 10 CENTS

Sold only by the Superintendent of Documents, Government Printing Office
Washington, D. C.

WASHINGTON
GOVERNMENT PRINTING OFFICE
1919

PREFACE

Many glasses have been recommended and extensively advertised to absorb injurious radiant energy and so protect the eyes when worn as spectacles or goggles. However, physiologists and oculists desiring to experiment to determine the value of such glasses have little to guide them in their selections except the claims of makers and sales agents. In order to experiment or prescribe intelligently it is obviously necessary that authentic and authoritative data should be available on the spectral transmission of the various glasses which are being commercially promoted as valuable in protecting the eye from harmful radiant energy.

Feeling this need of data, Dr. W. C. Posey, chairman of the committee on hygiene of the eye, American Medical Association, formally requested this Bureau to make an investigation of the spectral transmission of these glasses. The present paper is a report upon the investigation undertaken in response to this request. It deals only with the visible and ultra-violet transmissions, an analogous paper, dealing with infra-red transmissions, having already been published by the Bureau.[1]

Part of the determinations have been made in the physical laboratory at Cornell University. Thanks are due to Prof. E. L. Nichols, of Cornell, for courtesies extended the Bureau in affording facilities to expedite this work, which would otherwise have been greatly delayed.

The authors have had the advice and cooperation of Irwin G. Priest who originally planned and initiated this investigation, but was obliged to lay it aside on account of other duties.

J. T. Filgate has assisted in observing and computing.

[1] Coblentz and Emerson, Bur. Standards Tech. Paper No. 93, May, 1917; 2d edition, April, 1918; 3d edition, February, 1919.

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I. INTRODUCTION

It is well known that ultra-violet radiant energy of certain wave lengths, such as occur in the quartz-mercury arc, the iron arc, and many other sources, is extremely injurious to the eye. Excessive brightness in the visible spectrum may also cause temporary or permanent injury; while the intense heat or infra-red radiant energy coming from molten glass or metal is also considered by some as being dangerous to the eye.

This danger of injury from such sources undoubtedly depends on both the wave length and the intensity of the radiant energy, but in spite of the great amount of work which has been done on this subject [2] quantitative data with few exceptions are not available. It is only recently that accurate data on the transmission

[2] Report of research committee, Trans. I. E. S., 9, p. 307; 1914. W. E. Burge, Trans. I. E. S., 10 [2], p. 932; 1915.

of eye-protective glasses have begun to be published. The following list comprises all the important previous publications which we have found giving data on this subject.

In 1911 the Bureau published the spectral transmissions of a few glasses of well-known trade names as determined by P. G. Nutting at the Bureau.[3]

In 1914 Crookes [4] published the results of an investigation in which he made and tested over 300 specimens in the search for the ideal colorless or neutral glass which should absorb all the ultra-violet and infra-red. Though he failed to find this ideal glass, he did succeed in producing a colorless glass which absorbed much more of the ultra-violet than ordinary colorless glass, and a blue-green glass absorbing about 90 per cent of the radiant heat. In his paper he gives, for plates of each glass 2 mm thick, the "limit of transmission of ultra-violet," the "percentage of heat cut off," the "percentage of luminous rays transmitted," and "the color as registered on a Lovibond tintometer"; but no data are given as to the per cent transmission at different wave lengths.

About the same time Luckiesh [5] measured photographically the per cent transmission from 300 to 500 mμ of nine samples of eye-protective glass—one colorless lead glass, three "smoke" or neutral, one amethyst, two amber, one "Euphos" and one "Akopos"—without, however, giving the thickness. A number of spectrograms of these and other eye-protective glasses are also given, showing approximately the limit of transmission in the ultra-violet, but again the thickness is usually not indicated. The total transmission factors for the visible are given.

In a paper on colored glasses Gage [6] compares the colorless "Crookes" glass with the "Noviol" glass manufactured by the Corning Glass Works. Transmission curves and spectrograms, 400–720 mμ, of "Noviol," "Noglare," "Noviweld," heat-absorbing and railway-signal glasses are given.

A paper by Martin [7] has appeared during the progress of this investigation which gives quantitative data for ultra-violet, visible, and infra-red transmission of various shades of neutral, "Crookes" neutral and green shades, "Fieuzal" and "Hallauer" glasses. The thickness is given in all cases. He made use of the Hilger sector photometer to obtain his ultra-violet data.

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[3] Bur. Standards Circular No. 28, p. 13; March, 1911.
[4] Phil. Trans. Royal Soc., A 214, p. 1; 1914.
[5] Trans. I. E. S., 9, p. 472; 1914.
[6] Trans. I. E. S., 11, p. 1050; 1916.
[7] Trans. Opt. Soc., XVIII; April, 1917.

Coblentz and Emerson[8] have published considerable data on the infra-red transmission of eye-protective and other glasses. The samples studied included yellow-colored, "Crookes" neutral and green glasses, various glasses for absorbing the infra-red, such as gold-plated, blue-green (heat absorbing), greenish-brown, black, and "Noviweld" glasses, the thickness being given in all cases. They have also given the per cent transmission of these samples for the undispersed radiant energy from the gas-filled tungsten lamp, the quartz-mercury arc, and the magnetite arc.

Only the last of these papers supplies extensive data such as are presented herewith for glasses at present on the American market. In some cases comparison of data in this paper with previous data will indicate the degree of agreement obtaining in the spectral transmissions of accidentally selected glasses bearing the same trade name.

II. BRIEF ELEMENTARY DISCUSSION FOR THOSE UNFAMILIAR WITH SPECTROPHOTOMETRY

1. EXPLANATION OF TERMS USED IN THIS PAPER

Radiation is defined as the transference of energy from one point to another by means of vibratory motion in an intervening medium. This medium is caused to vibrate by a source which sends waves out through it with a certain velocity, the number of waves passing a given point per second, or the frequency, being in general the same as the number of vibrations per second of the vibrating source. The greater the frequency the shorter the wave length and vice versa, the relation being given by the formula

$$v = f\,\lambda,$$

where v is the velocity of the waves in centimeters per second, f is the frequency or number of waves passing a given point per second, and λ is the wave length in centimeters. If a suitable receiver is placed in its path, the energy may be detected.

Light, radiant heat, the radiant energy used in wireless telegraphy, ultra-violet radiant energy, and X rays are all forms of radiant energy which, though seemingly greatly different, are essentially alike. They are all generated by some form of electrical oscillations, whether they be vibrations in an electrical circuit or vibrations of atoms or electrons. They are propagated through space as waves by the same medium, the ether, and at the

[8] Loc. cit.

same velocity, approximately 300 000 000 meters (186 000 miles) per second. They differ only as regards their frequencies and the resulting wave lengths.

"Wireless" radiant energy is generated by oscillatory currents in an electrical circuit. It may be detected by other electrical circuits which are properly tuned to vibrate with the same frequency as that of the incident waves. X rays are produced by the bombardment of a piece of metal by electrons moving with high velocities in a vacuum tube. They may be detected by a fluorescent screen or by the photographic plate.

Radiant heat, light, and ultra-violet radiant energy are produced in various ways and usually all at the same time, though in greatly different relative and absolute amounts from different sources. In order to study these forms of radiant energy intelligently, it is desirable to separate from one another those of different wave lengths. They do not travel through material medialike glass with the same velocity as they do through space, but in general with smaller velocity, and the shorter the wave length the smaller the velocity of the radiant energy through the medium. The ratio of the velocity in one medium to that in a second medium is called the refractive index from the first medium to the second. When radiant energy of different wave lengths, such as is emitted from incandescent sources like the sun, the tungsten electric lamp, or the gas flame, is passed through a prism of glass, quartz, or other transparent material, this difference in velocities results in the direction being changed; that is, it is deviated, and in general the shorter the wave length the greater the deviation. If, after passing through the prism, the radiant energy is then focused on a white screen, a spectrum is formed. To the eye this spectrum seems to be composed of the colors red, orange, yellow, green, blue, and violet in that order, the red being deviated least and the violet most. Therefore, the red light is of longer wave length than the orange, the orange than the yellow, etc.

But this is not all. If a thermometer or other sensitive heat-measuring device is placed beyond the red end of the visible spectrum, it will indicate by its rise in temperature that heat waves are being radiated to it, though the eye perceives nothing. This is called infra-red radiant energy or radiant heat and is of longer wave length than red light, since it is deviated less.

Also, if a photograph be taken of this spectrum, it will be found that radiant energy of shorter wave length than the violet light is recorded by the plate, although the eye can not perceive it. This is called ultra-violet radiant energy.

Various units are used to specify wave lengths, depending on the magnitudes involved. The following are in common use, all being derived from the standard of length, the meter (1.093 yards), which is represented by the symbol *m:*

Units	Symbol
1 m=0.001 kilometer	km
1 m=1000 millimeters	mm
1 mm=1000 microns	μ
1 μ=1000 millimicrons	mμ [a]
1 mμ =10 Ångström units	Å

[a] The symbol mμ, to represent the millimicron, is used on the following authorities: C. E. Guillame, Unités et Étalons, p. 7; 1893. Société Française de Physique, Recueil de Constantes Physiques, p. 1; 1913. The millimicron has been commonly represented by the symbol $\mu\mu$, which symbol has now been discarded as being inconsistent with the metric system, the micron μ denoting one millionth.

In the following table is shown the approximate range of wave lengths included in the various forms of radiant energy:

Form	Range of wave length
"Wireless"	12 km (12 x 10^{12}mμ)—1.6 mm (1600μ, 1600000 mμ)
Radiant heat or infra-red	310 μ (310000 mμ)—0.77 μ (770 mμ)
Light or visible	770 mμ —380 mμ
Ultra-violet	380 mμ —60 mμ (600Å)
X rays or Roentgen	12 Å (1.2 mμ)—0.2 Å (0.02 mμ)

It should be understood very clearly that the only difference between the infra-red, the visible, and the ultra-violet radiant energy is that of frequency and wave length. There is no gap in the spectrum between these three forms as there is between "wireless" radiant energy and radiant heat, or as still exists between ultra-violet radiant energy and X rays. The only reason that this classification into infra-red, visible, and ultra-violet exists is because it so happens that the eye is sensitive to radiant energy of a certain range of wave lengths in the middle part of the spectrum. If a source could be found which emitted equal amounts of energy at all wave lengths, then a blackened thermometer or radiometer placed in its spectrum would be affected the same at all wave lengths. It could detect no difference

between ultra-violet of wave length 290 mμ, green light of 540 mμ, or infra-red of 6000 mμ. It would be equally sensitive to them all.

If this equal-energy spectrum were photographed, however, no trace of the red or infra-red radiant energy would be found, unless the plate had been specially sensitized. Green light would be recorded slightly, but the blue, violet, and ultra-violet would affect the plate very easily; that is, the photographic plate has a varying spectral sensitivity.

Now, if this equal-energy spectrum were viewed by the human eye, a still further difference would be noted. Like the photographic plate, the eye is sensitive to radiant energy of certain wave lengths (much different from the plate), which is thus made visible and called light; but by definition the eye can not perceive the ultra-violet or infra-red. But unlike the plate or the radiometer, the eye can perceive a difference in the radiant energy of different wave lengths to which it is sensitive, provided these wave lengths are not too nearly the same; that is, the eye can distinguish light of different wave lengths by its hue—red, green, etc. It can perceive green light easier than that of any other hue, blue and yellow less easily, violet and red least of all, and where the violet and red are no longer perceptible the ultra-violet and infra-red are said to begin. These boundaries are thus somewhat vaguely defined, varying with conditions such as brightness, proximity of other light, different eyes, etc.

This relative sensibility of the eye to light of different wave lengths has been accurately studied. In Fig. 1 (and also Figs. 2–20) the values [9] have been plotted in the form of a curve. This curve is known as the visibility curve of the average human eye for an equal-energy spectrum. It is somewhat different for different observers, and the maximum is shifted to shorter wave lengths for light of very low intensity.

The amount of energy emitted per second, or the radiant power, is well known for many sources. Some sources, like incandescent solids and liquids, where the radiant power is due primarily to temperature, give what is known as a continuous spectrum; that is, all wave lengths over a considerable range are present. The relative spectral distribution of radiant power in a number of such sources is shown in Fig. 1. The radiant powers have all been reduced to 100 at 590 mμ. The maximum radiant power for most

[9] Coblentz and Emerson, Bur. Standards Scientific Papers, No. 303; September, 1917.

of these sources is in the infra-red; but the higher the temperature the shorter the wave length of the maximum until at 5000–6000° C (which is probably about the temperature of the sun) the maximum lies in the visible. The radiant power for all these sources continues to decrease as the ultra-violet region is entered and sooner or later becomes insignificant.

Other sources like the electric arc or spark, in air or in a vacuum, do not in general give a continuous spectrum, but instead the spectrum appears as a number of sharp lines separated by dark regions. Such spectra are termed line spectra and are apt to be very rich in ultra-violet. Each element has its own particular line spectrum different from that of every other element. In Fig. 1 is shown the relative radiant power of the light from the mercury arc, reduced to 100 at 578 mμ. Some of the lines, though plotted as single, are made up of two or more components whose wave lengths are so nearly the same that the radiant power of the group as a whole was of necessity measured.

If the relative radiant power of a source at certain wave lengths is multiplied by the relative visibility of the average human eye at the same wave lengths, a new curve will be obtained which is called the luminosity curve for that source. Like the visibility curve, the luminosity curve for any source is zero in the ultra-violet and infra-red. In fact, the visibility curve is simply the luminosity curve of a source emitting equal amounts of energy at all wave lengths in the visible spectrum. The luminosity curves for the Hefner lamp and blue sky have been thus computed and plotted in Fig. 1. The luminosity "curve" for the mercury arc would consist of a number of vertical lines.

2. ILLUSTRATION OF METHOD FOR COMPUTING THE TRANSMISSION FOR THICKNESSES DIFFERENT FROM THAT MEASURED

If radiant power from any source is passed through media, such as quartz, glass, solutions, etc., the relative spectral distribution may be greatly altered, part of the energy being reflected, part absorbed, and the rest transmitted. The amount absorbed or transmitted may vary greatly with the wave length, but throughout the visible and ultra-violet the amount reflected remains nearly constant. The following brief discussion will make clear the relations existing between reflection, transmission, and absorption, and illustrate the method used in computing the spectral transmissions for thicknesses other than that measured.

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Let radiant power be incident normally upon a plate of glass or other material of thickness b with plane parallel surfaces.[10] Let P_1 be the radiant power incident on the first surface, P_{I} that transmitted by the first surface, P_2 that incident on the second surface, and P_{II} that transmitted by the second surface. At each surface a certain fraction R of the incident power is reflected, this fraction depending on the refractive index n between the two media bounding the surface, i. e.,

$$R=\frac{P_1-P_{\mathrm{I}}}{P_1}=\frac{P_2-P_{\mathrm{II}}}{P_2}=\left(\frac{n-1}{n+1}\right)^2.$$

The transmission T is defined as the fraction of incident radiant power which gets through the specimen, i. e.,

$$T=\frac{P_{\mathrm{II}}}{P_1}$$

and the per cent transmission is 100 T. The transmittance T is defined as the fraction of radiant power transmitted by the first surface which is incident on the second surface, i. e.,

$$\mathsf{T}=\frac{P_2}{P_{\mathrm{I}}}.$$

The law of the variation of transmittance with thickness b is given by the equation $\mathsf{T}=t^b$, wherein t is called the transmissivity of the material composing the specimen and may be defined as the transmittance per unit of thickness.

The relation between T, T, and t may be shown as follows:

Since $P_{\mathrm{I}}=P_1\,(1-R)$

and $P_{\mathrm{II}}=P_2\,(1-R)$

and $P_2=P_{\mathrm{I}}\mathsf{T}=P_{\mathrm{I}}t^b$

$\therefore$ $P_{\mathrm{II}}=P_1\,(1-R)^2\,\mathsf{T}=P_1\,(1-R)^2t^b$

and $\dfrac{P_{\mathrm{II}}}{P_1}=T=(1-R)^2\,\mathsf{T}=(1-R)^2t^b$

In general, this equation is applied only to radiant power of definite wave length. Curves plotted between T or 100 T and λ are called spectral transmission curves or, in case of 100 T, per cent transmission curves. By means of instruments called spectrophotometers (see Sec. VI), values of T may be accurately measured wave length by wave length in the ultra-violet, visible, or infra-red.

[10] The symbols used in this paper are in accord with those to be recommended in another paper now in preparation at the Bureau, A Proposed Basic Nomenclature for Use in Colorimetry, by Irwin G. Priest.

The equation $T=(1-R)^2\mathsf{T}=(1-R)^2t^b$ may be used to compute the transmission for a specimen of different thickness from that observed, or to compute what thickness is necessary to give any desired transmission. The following will illustrate how this may be done:

As noted above, R varies very little with the wave length, being equal to

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

where n is the refractive index between air and glass. For all practical purposes, so far as the glasses in the present investigation are concerned, n may be taken equal to 1.50, making R equal to 0.04 and $(1-R)^2$ about 0.92. Thus the equation may be written

$$\frac{T}{.92}=\mathsf{T}=t^b \text{ (for a given wave length).}$$

For some other thickness b', where the transmission will be T', the transmittance T', and the transmissivity t as before, the equation will be

$$\frac{T'}{.92}=\mathsf{T}'=t^{b'}$$

By taking logarithms, the following equations are obtained:

$$\log \mathsf{T} = b \log t$$
$$\log \mathsf{T}' = b' \log t$$

From these equations the following may be derived:

(1) $$\mathsf{T}'=\mathsf{T}^{\frac{b'}{b}}$$

(2) $$\log \mathsf{T}'=\frac{b'}{b}\log \mathsf{T}$$

(3) $$b'=\frac{\log \mathsf{T}'}{\log \mathsf{T}}b$$

The examples in Table 1 will illustrate how these last equations may be used for numerical computations. The unit of thickness is taken as 1 mm. Logarithms are taken to the base 10. However, the same results will of course be obtained if logarithms to the base e and any other unit of thickness are used.

The computations shown in Table 1 may be much more easily performed graphically by use of the chart shown in Fig. 25, which is a reproduction of the one in use at the Bureau. The legend underneath explains the method of use.

TABLE 1.—Method of Computing Transmission for Different Thicknesses

GIVEN T=0.50 AND b=1.68 mm. TO FIND T′ WHEN b′ EQUALS 3.36 mm OR 2 b, 0.56 mm OR ⅓ b, 5.37 mm, OR 0.73 mm, USING EQUATIONS (1) OR (2)

Problem No.	b′ in mm	T =T/.92 =.50/.92 =.544	Log T =Log .544 =9.736−10 =−.264	b′/b	Log T′ $=\frac{b'}{b}$Log T $=\frac{b'}{b}(-.264)$	T′ $=T\frac{b'}{b}$	T′ =.92 T′
1	3.36 or 2 b	0.544	.....	2	.....	$0.544^2=$ 0.296	0.272
2	.56 or ⅓ b	.544	.....	⅓	.....	$.544^{\frac{1}{3}}=$ .817	.752
3	5.37	.544	−0.264	3.195	3.195(−0.264) =−0.844= 9.156−10	.143	.132
4	.73	.544	− .264	.434	.434(−0.264) =−0.1145= 9.8855−10	.768	.706

GIVEN T=0.50 AND b=1.68 mm. TO FIND b′ WHEN T′=0.30 OR 0.87 USING EQUATION (3)

Problem No.	T′	T′ =T′/.92	Log T′	T =T/.92	Log T	$\frac{\text{Log } T'}{\text{Log } T}$	$=\frac{\text{Log } T'}{\text{Log } T}b$
5	0.30	0.326	9.513−10= −0.487	0.544	−0.264	$\frac{-0.487}{-0.264}=$ 1.84	1.84×1.68= 3.095
6	.87	.945	9.976−10= −0.024	.544	− .264	$\frac{-0.024}{-0.264}=$ 0.091	0.091×1.68= 0.153

III. INSTRUMENTS USED

The data presented in this paper have been obtained partly at this Bureau and partly in the physical laboratory at Cornell University. The determinations by the Hilger sector apparatus and the Lummer-Brodhun spectrophotometer were made at Cor-

nell,[11] those by the Koenig-Martens spectrophotometer and the Martens photometer at the Bureau.

In Table 2, under the heading "Instrument" is indicated for each specimen by an asterisk (*) which instruments were used. With the Hilger apparatus wave lengths were determined photographically in the range 230–500 mμ for per cent transmissions between 1–5 and 100. On the Lummer-Brodhun and Koenig-Martens spectrophotometers, values of the per cent transmission could be obtained from 430 to 710 mμ. In Section VI is given an account of the method of use of the instruments, the agreements between methods, and the estimated accuracy of the results.

IV. SPECIMENS STUDIED

The following dealers or manufacturers have kindly donated samples to the Bureau for examination in this investigation:

Company	Referred to in report as—	Address	Number of samples
American Optical Co	A. O. Co	Southbridge, Mass	47
Chicago Eye Shield Co	C. E. S. Co	2300–2304 Warren Ave., Chicago, Ill	6
Corning Glass Works	Corning	Corning, N. Y	13
F. A. Hardy & Co	Hardy	10 South Wabash Ave., Chicago, Ill	2
Julius King Optical Co	King	12 Maiden Lane, New York	5
Wall & Ochs (through Dr. W. C. Posey).	W. & O	Philadelphia, Pa	9

These specimens[12] are all designated by their trade names. Some of them are of unknown origin, specimens which have been marketed for years under more or less well-recognized trade names. The data given show what may be obtained under one of these names, but, as there are usually so many different shades of the same kind of glass marketed under the single trade name, it can not be expected that duplicates can be obtained merely by ordering by name. However, most of the specimens, especially those of American manufacture, are designated by shade—that is, "A," "B," etc.—as well as by trade name or by number, and in this case it is expected that approximately duplicate samples can be obtained. If accurate reproduction is required, the designation should not be assumed as a sufficient specifica-

[11] Apparatus for the determination of spectral transmissions by this photographic method as well as by the photoelectric (null method) has since been installed at the Bureau, and such determinations are now made here.

[12] It is hoped later to supplement this paper with another giving data on other kinds of eye-protective glasses at present on the market.

tion; but the oculist or buyer, guided by the data given herewith, may now prescribe or order glasses of specified spectral transmissions, acceptance being subject to test.

The surfaces of these specimens were highly polished and with very few exceptions made plane and parallel to 0.01 mm. They are of a thickness ordinarily used in spectacle lenses. They have been labeled and filed at the Bureau for future reference. In Table 2 is given a list of these glasses arranged alphabetically according to their trade names, together with the name of the company, the color, thickness, and other data which will be discussed later.

TABLE 2.—List of Specimens Studied

Specimen, company's designation	Company	Color	Thickness in millimeters	Data, Fig. No. —	Instrument [a]				Total transmission factor
					H	L-B	K-M	M	
Akopos	King	Yellow-green	2.17	13	(*)	(*)	.....	.....	0.36
Amber A	A. O. Co	Yellow	2.13	10	(*)	.....	(*)	(*)	.79
Amber B	...do	....do	2.13	10	(*)	.....	(*)	.....	.57
Amber dark	W. & O	....do	1.85	10	(*)	(*)	(*)	(*)	.555
Amber light	....do	....do	1.93	10	(*)	(*)	(*)	(*)	.805
Amethyst A	A. O. Co	Purple	2.08	15	(*)	.....	(*)	.....	.745
Amethyst B	....do	....do	2.05	15	(*)	.....	(*)	(*)	.70
Amethyst C	....do	....do	2.04	15	(*)	.....	(*)	.....	.55
Amethyst dark	W. & O	....do	1.90	16	(*)	(*)	(*)	(*)	.705
Amethyst light	....do	....do	1.97	16	(*)	(*)	(*)	(*)	.805
Arkweld dark	King	....do.[b]	2.46	21	(*)	.....	.....	.....	0+
Blue A	A. O. Co	Blue	2.10	17	(*)	.....	(*)	.....	.88
Blue B	....do	....do	2.04	17	(*)	.....	(*)	.....	.62
Blue C	....do	....do	2.05	17	(*)	.....	(*)	.....	.35
Blue D	....do	....do	2.11	17	(*)	.....	(*)	.....	.062
Chlorophile	W. & O	Yellow-green	1.98	13, 23	(*)	(*)	(*)	(*)	.65
Chromatic test	A. O. Co	Blue	2.36	18	(*)	.....	(*)	.....	.0075
Cobalt blue AA	....do	....do	2.75	18, 24	(*)	.....	(*)	.....	.033
Cobalt blue A	....do	....do	3.20	18	(*)	.....	(*)	(*)	.026
Cobalt blue B	....do	....do	1.85	18, 24	(*)	.....	(*)	.....	.0085
Cobalt blue C	....do	....do	1.46	18	(*)	.....	(*)	(*)	.0096
Cobalt blue D	....do	....do	1.86	18, 24	(*)	.....	(*)	.....	.0055
Crookes A	W. & O	Neutral	1.79	4	(*)	(*)	(*)	(*)	.84
Crookes B	....do	....do	1.93	4	(*)	(*)	(*)	(*)	.485
Crookes A, Wellsworth	A. O. Co	....do	2.05	3	(*)	.....	(*)	.....	.85
Crookes B, Wellsworth	....do	....do	2.16	3	(*)	.....	(*)	.....	.45
Crown 1.50	....do	....do	1.68	2	(*)	.....	(*)	(*)	.92
Electric smoke red	....do	Red-purple [b]	1.82	21	(*)	.....	.....	(*)	0+
Electric smoke Y	....do	Yellow [b]	2.01	.....	(†)	.....	.....	.....	0+
Euphos	....do	Yellow-green	1.95	11, 24	(*)	.....	(*)	.....	.72
Fieuzal	W. & O	....do	1.98	12, 13, 23	(*)	(*)	(*)	(*)	.835
Fieuzal A	A. O. Co	....do	2.13	12	(*)	.....	(*)	.....	.665
Fieuzal B	....do	....do	2.13	12	(*)	.....	(*)	.....	.51

[a] H=Hilger, L-B=Lummer-Brodhun, K-M=Koenig-Martens, M=Martens. An asterisk (*) indicates which instruments were used. A dagger (†) instead of an asterisk means that no transmission was detected from 230 to 500 millimicrons.

[b] Color very dense.

TABLE 2—Continued

Specimen, company's designation	Company	Color	Thickness in millimeters	Data, Fig. No. —	Instrument [a]				Total transmission factor
					H	L-B	K-M	M	
Hallauer	W. & O.	Yellow-green	1.90	13, 23	(*)	(*)	(*)	(*)	0.48
Laboratory No. 57	A. O. Co.	Neutral	1.90	6	(*)	.....	(*)	(*)	.91
Laboratory No. 58	do.	Yellow	2.02	6	(*)	.....	(*)	(*)	.815
Laboratory No. 59	do.	Blue-green	2.13	14, 24	(*)	.....	(*)	.....	.32
Laboratory No. 61	do.	Yellow-green	2.13	11, 24	(*)	.....	(*)	.....	.65
Luxfel	do.	Yellow	2.00	6	(*)	.....	(*)	(*)	.835
Noviol AA	do.	do.	1.88	9	(*)	.....	(*)	(*)	.88
Noviol A	do.	do.	2.06	9	(*)	.....	(*)	.....	.87
Noviol B	do.	do.	2.10	9, 24	(*)	.....	(*)	.....	.85
Noviol C	do.	do.	2.10	9	.....	.....	(*)	.....	.83
Noviol O	do.	do.	2.03	9, 24	(*)	.....	(*)	.....	.85
Noviol A	Corning	do.	2.00	8, 24	(*)	(*)	.....	(*)	.865
Noviol A_1	do.	do.	2.88	7	(*)	(*)	.....	.....	.87
Noviol A_2	do.	do.	2.84	7	(*)	(*)	.....	.....	.85
Noviol B	do.	do.	1.95	8	(*)	(*)	.....	(*)	.84
Noviol B_1	do.	do.	2.83	7	(*)	(*)	.....	.....	.845
Noviol C	do.	do.	2.00	8, 24	(*)	(*)	.....	(*)	.825
Noviol O	do.	do.	2.01	8	(*)	(*)	.....	(*)	.865
Noviol O	Hardy	do.	1.94	7	(*)	(*)	.....	(*)	.88
Noviweld 4	A. O. Co.	do.	1.89	20	(†)	.....	(*)	(*)	.0315
Noviweld 5	do.	do.	2.16	20	(†)	.....	(*)	(*)	.014
Noviweld 6	do.	do.	2.20	20	(†)	.....	(*)	(*)	.010
Noviweld 7	do.	do.	1.90	20	(†)	.....	.....	(*)	.006
Noviweld 8	do.	do.	2.01	20	(†)	.....	.....	(*)	.0032
Noviweld 12	do.	do.[b]	2.08	.....	(†)	.....	.....	.....	0+
Pfund	do.	Green	(c)	14	(*)	.....	(*)	(*)	.047
Rifleite	King	Yellow	3.14	7	(*)	(*)	.....	.....	.775
Saniweld dark	do.	do.	2.12	13, 21	(†)	(*)	.....	(*)	.0135
Saniweld light	do.	do.	1.82	13	(*)	(*)	.....	(*)	.115
Smoke A	A. O. Co.	Neutral	2.10	5	(*)	.....	(*)	(*)	.75
Smoke B	do.	do.	2.14	5	(*)	.....	(*)	(*)	.38
Smoke C	do.	do.	2.13	5	(*)	.....	(*)	(*)	.265
Smoke D	do.	do.	2.03	5	(*)	.....	(*)	(*)	.092
Special Noviweld No. 8	Hardy	Yellow[b]	1.77	22	(†)	(*)	.....	.....	.00019
Special Welders dark	A. O. Co.	Green[b]	2.54	19, 21	(*)	.....	.....	(*)	0+
Special Welders light	do.	do.	1.68	19, 21	(*)	.....	(*)	(*)	.0105
Welders smoke dark	do.	Neutral	1.42	19	(*)	.....	(*)	(*)	.056
Welding glass 1	C. E. S. Co.	Yellow	1.98	21	(†)	(*)	.....	(*)	.0034
Welding glass 2	do.	do.	2.32	20	(†)	(*)	.....	(*)	.045
Welding glass 3	do.	do.	1.50	21	(†)	(*)	.....	(*)	.00885
Welding glass 4	do.	do.	1.48	21	(†)	(*)	.....	(*)	.00885
Welding glass 5	do.	Red	1.87	21	(†)	(*)	.....	(*)	.0027
Welding glass 6	do.	Yellow	1.97	20	(†)	(*)	.....	(*)	.0705
1.52	A. O. Co.	Neutral	2.33	2	(*)	.....	(*)	(*)	.92
91 B	Corning	do.	1.97	3	(*)	(*)	(*)	(*)	.84
124 IP	do.	Green	2.00	14, 21	(*)	(*)	.....	(*)	.015
124 JA	do.	Blue-green	2.02	14, 24	(*)	(*)	.....	(*)	.61
391 DD	do.	Red[b]	1.90	22	(†)	(*)	.....	.....	.00012
392 F	do.	Blue-green	1.90	14, 24	(*)	(*)	.....	(*)	.72

[a] H=Hilger, L-B=Lummer-Brodhun, K-M=Koenig-Martens, M=Martens. An asterisk (*) indicates which instruments were used. A dagger (†) instead of an asterisk means that no transmission was detected from 230 to 500 millimicrons.

[b] Color very dense.

[c] Gold film.

V. RESULTS OF THE INVESTIGATION

1. TRANSMISSION CURVES

The results of the investigation are shown by curves in Figs. 2–22, in which the per cent transmissions for different wave lengths are plotted against the wave lengths. By per cent transmission is meant that per cent of the incident radiant energy which gets through the specimen. The curves are drawn in heavy lines as far as the actual observations were carried. Estimated values are indicated by the dotted parts. In each figure (except Figs. 21 and 22) is also plotted the relative visibility curve of the average human eye for a source emitting equal amounts of energy at all wave lengths in the visible spectrum. In each figure (except Figs. 21 and 22) is also given the transmission curve of a specimen of crown glass 1.68 mm thick (specimen "Crown 1.50," Fig. 2) so that one may see at a glance in what respect the various glasses protect the eye better than ordinary colorless glass. Of course in comparing the transmission curves of two specimens, any difference in thickness must be allowed for. (See Sec. II and Fig. 25.)

Little need be said in discussion of the curves, as the information desired may be obtained by inspection of them, together with Table 2. It must be remembered that conclusions reached apply only to the particular glasses herein listed.

Of the specimens studied, the five kinds which are most efficient as protection against the ultra-violet, while being at the same time nearly colorless in the thicknesses examined, are "Crookes A" (Figs. 3–4), Corning "91B" (Fig. 3), A. O. Co. "Lab. No. 57" (Fig. 6), A. O. Co. "Lab. No. 58" (Fig. 6) and "Noviol O" (Figs. 7–9). Of these, "Noviol O" and A. O. Co. "Lab. No. 58" are the best, but are not so truly colorless as the other three. Of the slightly colored glasses, by far the best seem to be "Noviol A" (Figs. 8–9) and "Noviol A_1" (Fig. 7), as they absorb completely below 410 mμ while transmitting about 87 per cent of the incident light. It is not thought that the slight color would be at all objectionable for ordinary use.

A combination of "Noviol A" (Figs. 8–9) and Corning "124JA" (Fig. 14) is very efficient for eye protection, as it absorbs all the ultra-violet and most of the infra-red, and still has high visible transmission. The color is a very light green, and the colors of objects viewed through it are distorted practically none at all.

A gold film on "Noviol A" glass would also be very efficient, though transmitting less of the visible than the combination just mentioned.

The yellow and yellow-green glasses (Figs. 7–13) of a deeper shade are usually good protection against the ultra-violet. The green and blue-green glasses of Fig. 14 are used primarily to protect the eye from the infra-red. The "Pfund" specimen is a gold film between two pieces of what seems to be "Crookes" glass. "Smoke" (Fig. 5), amethyst (Figs. 15–16), and blue (Figs. 17–18) or purple glasses are liable to be little better than clear glass as a protection against the ultra-violet. Of the welding glasses (Figs. 19–22), yellow seems to be the safest, as the green or neutral shades are liable to have transmission bands centering near 395 mμ, which may extend a considerable distance into the ultra-violet.

In Fig. 11 is plotted the transmission curve for a specimen called "Fieuzal" obtained from a retail store. By comparison with the curves of Figs. 11 and 12, it is seen to resemble A. O. Co. "Euphos" and "Lab. No. 61" much more than the "Fieuzal" specimens from W. & O. or A. O. Co. The resemblance between W. & O. "Chlorophile" (Fig. 13) and A. O. Co. "Fieuzal A" and "Fieuzal B" (Fig. 12) is also very great, much more than that between the latter specimens and W. & O. "Fieuzal" (Fig. 12). The resemblance between "Hallauer" and "Akopos" (Fig. 13) is very striking; also that between "Noviol C" (Figs. 8–9) and "Rifleite" (Fig. 7).

As may be noted from the curves, the transmissions of many of the glasses herein examined, especially the yellow or yellow-green, decrease to less than 1 per cent somewhere from 480 to 340 mμ, depending on the specimen, and so far as can be detected do not increase at shorter wave lengths. Transmissions of probably one-tenth the lowest value measured could be detected on the photographic negatives. Therefore, when in the figures the curves are drawn as if there were zero transmission below 500 mμ, it should be understood merely that the transmission, if there be any, is less than 0.3 or 0.4 per cent if 2.5 per cent were the lowest value measured and less than 0.1 or 0.2 per cent if 1.0 per cent were measured. Specimens one-half or one-third the thickness of those examined might show slight transmission in the ultra-violet.

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2. TOTAL TRANSMISSION FACTORS

In Table 2, last column, are given the total transmission factors for light of equal energy at all wave lengths. These factors were computed as follows: At every 10 mμ from 400 to 720 mμ, the value of the relative visibility of the average human eye (which is the luminosity of a source emitting equal amounts of energy at all wave lengths in the visible spectrum) was multiplied by the fraction of incident light transmitted by the specimen at that same wave length. With these values a new curve was plotted to the same scale as the visibility curve. This new curve would show the relative luminosity of the equal energy source after the light had passed through the specimen. Then the areas under these two luminosity curves were measured with a planimeter, and the ratio of these two areas gives the total transmission factors for light of equal energy at all wave lengths. Any error in the transmission curves, of course, enters into the total transmission factors. Assuming the transmission curves to be correct, the total transmission factors given in Table 2 are considered accurate to at least one unit in the second figure.

It should be understood that the total transmission factor of any specimen depends on the relative luminosity (relative visibility times relative radiant power—see Fig. 1) of the source emitting the light which is viewed through the specimen. To compute the total transmission factor for a source whose relative spectral distribution of radiant power is known, the values of the relative luminosity of the source should be used instead of the values of the relative visibility, as was done in the computations described above. The total transmission factors for sunlight do not, in general, differ much from those for a source emitting equal amounts of energy at all wave lengths, but for the tungsten lamp and other artificial sources the difference may be considerable.

VI. METHODS, AGREEMENTS, AND ACCURACY ATTAINED

1. HILGER APPARATUS FOR ULTRA-VIOLET

The Hilger sector apparatus with the Hilger quartz spectrograph, type C, was used practically unchanged as set up by H. E. Howe.[13] The slit of the spectrograph was 0.15 mm. The source was a high-tension aluminum spark under water, which gives a continuous spectrum throughout and beyond the range 500–230

[13] Phys. Rev., N. S., VIII, p. 674; 1916.

mμ. This photographic method is greatly superior to any other and compares favorably in speed and accuracy with any visual method. It consists essentially in simply determining, for any per cent transmission desired, at what wave length two contiguous spectra are of equal density; and so far as known this value, by this method, is independent of the kind, the law, the chromatic sensitivity, or the length of development of the plate, as well as independent of the kind of developer, the variations in intensity of the source, and the length of exposure. The per cent transmission is determined arbitrarily by the ratio of sector openings, which may be set anywhere from 1.00 to 0.01, the wave length being the dependent variable.

Due to certain contrast effects on the negatives, these wave lengths can be determined more accurately where the transmission curve is steep than where it is nearly horizontal, and where the per cent transmission is low than where it is high. The varying dispersion makes determinations increasingly accurate as the spectrum is traversed from 500 to 230 mμ. The method was limited at 500 mμ by the lack of sensitivity of the plates used.

Other things being equal, the uncertainty of determinations on the steep parts of the curves is 1–8 mμ from 500 to 460 mμ, 1–4 mμ from 460 to 400 mμ, and 1–2 mμ from 400 to 230 mμ. Around the peaks of transmission bands or on the parts of curves where the slope is small, this uncertainty is increased. In this as in the other methods, a number of determinations were made and the average used.

2. LUMMER-BRODHUN SPECTROPHOTOMETER

The Lummer-Brodhun spectrophotometer was used practically the same as in a previous investigation,[14] the acetylene flame, the carbon lamp, and the gas-filled tungsten lamp being used as sources, the last one being the most satisfactory. The slits of the telescope and first collimator were kept constant at 0.60 mm, while the slit of the second collimator was varied about from 0.06 to 1.00 mm. The ratio of the readings of this second slit when the specimen was placed in front of the first slit and then removed gave the fraction of incident light transmitted, except that 0.02 mm was subtracted from all readings of this second slit before computing this ratio.[15] This correction is made necessary probably by a loss of light due to reflection or diffraction at the edges of

[14] K. S. Gibson, Phys. Rev., N. S., VII, p. 194; 1916.
[15] Nichols and Merritt, Phys. Rev., XXXI, p. 502; 1910.

the slit, which is equivalent to a shift in the zero point of the screw by 0.02 mm.

When the transmission was so low as to bring the reading of the second slit below 0.06 mm and thus make the correction of 0.02 mm inaccurate, a specimen of known transmission was placed before the second slit, necessitating widening it, and making it possible to obtain values as low as 0.1 per cent with considerable accuracy. This method was used, for instance, in obtaining the curves in Fig. 21 for those specimens measured on the Lummer-Brodhun spectrophotometer.

In the case of the two specimens whose curves are shown in Fig. 22, the slits of both collimators were varied and glasses of known transmission used before them until the proper combination was obtained to make the values fairly accurate.

Except for subtracting 0.02 mm from all slit readings, no corrections were made for slit widths. In spite of the wide and varying slits used, however, the agreement with other methods shows that the error is very small except in case of a glass like "Crookes A," where the narrow bands near 580 mμ could not be accurately measured as they were on the Koenig-Martens instrument.

3. KOENIG-MARTENS SPECTROPHOTOMETER

The Koenig-Martens polarization spectrophotometer [16] was used in the usual way. Two beams of light from the same source are polarized mutually perpendicular by means of a Wollaston prism and brought together to form the two halves of a photometric field. This field is viewed through a nicol prism and the adjustment is such that the two halves of the field are brought to equality by the analyzing nicol somewhere near 45° on the scale. The specimen was placed first in one beam and then in the other, and the analyzing nicol rotated in each case until a photometric match was obtained. The tangent of the angle in one case multiplied by the cotangent in the other gives the fraction of incident light transmitted. The slit was 0.10 mm in width. A 500-watt gas-filled tungsten lamp was used as a source. Color screens were used over the eyepiece when needed to cut out stray light. On this instrument measurements were made down to 1 per cent transmission.

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[16] Ann. d. Phys., Series 4, 12, p. 985; 1903.

4. MARTENS PHOTOMETER

The Martens polarization photometer,[17] working on the same principle as the Koenig-Martens spectrophotometer, but without a dispersing prism, was used with a mercury arc lamp and colored glass screens by which light of wave lengths 406, 436, and 578 mμ could be isolated. Values of transmission could be obtained accurately as low as 0.1 per cent. This method served as a valuable means of checking the other results when discrepancies appeared and also gave definite results in some cases where no other method could be used. For example, in Fig. 21 are plotted curves for specimens having weak transmission bands near 400 mμ. The wave length of maximum transmission and the approximate width of band could be obtained from the negative, also an indication as to whether or not the transmission was nearly 1 per cent. The Martens photometer gave a definite value at 406 mμ, and with these data the curves were drawn. It was also useful in giving low values at 436 mμ as in the curves of Fig. 21, and at 578 mμ as in the case of A. O. Co. "Noviweld No. 7," "Noviweld No. 8," and "Special Welders Dark."

5. AGREEMENTS BY THE DIFFERENT METHODS

In Figs. 23 and 24, a number of curves are drawn with all points plotted to indicate the kind of agreements and disagreements met with in the instruments used in this investigation. In all cases the black circles represent values obtained photographically with the Hilger sector apparatus, the white circles those obtained visually with the Lummer-Brodhun spectrophotometer, the crosses those with the Koenig-Martens spectrophotometer, and the squares those with the Martens photometer when it was used.

Between 500 and 650 mμ, values obtained by the two visual spectrophotometers seldom disagree by more than 3 units of per cent and usually agree within 1 unit, especially at the lower transmissions. Beyond 650 mμ, the discrepancies are sometimes larger, occasionally reaching 5 to 10 units around 700 mμ. Also from 500 mμ into the blue the same large discrepancies occasionally appear, especially at 440 or 450 mμ, but values obtained on the Hilger apparatus and on the Martens photometer at 406 and 436 mμ help remove doubt as to where the curve should be drawn.

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[17] Phys. Zeit., I, p. 299; 1900.

6. ESTIMATED ACCURACY OF THE TRANSMISSION CURVES

It is difficult to estimate the accuracy of curves of such varying types, especially when the range of wave lengths and transmission values is so great. But a careful study of these and many others measured on the same instruments indicates the following accuracies in the curves as drawn: In all figures (except Figs. 21 and 22), from 230 to 400 mμ and from 500 to 650 mμ the curves are considered accurate to 0–2 units of per cent, and from 400 to 500 mμ and from 650 to 710 mμ to 0–5 units of per cent. In Fig. 21 the curves are considered accurate to 0–3 units, the unit being 0.1 of 1 per cent, and in Fig. 22 to 0–5 units, the unit being 0.001 of 1 per cent.

VII. SUMMARY

Eighty-two samples of eye-protective glass have been studied in regard to their transmission of ultra-violet and visible radiant energy. For each specimen is given:

1. The trade name under which it is marketed,
2. The company from which it may be obtained,
3. The approximate color,
4. The thickness, the samples being from 1.42 to 3.20 mm thick, that ordinarily used in spectacle lenses.
5. The per cent transmission curve from 230 mμ to 710 mμ, in each figure being given for comparison the transmission curve of a sample of colorless crown glass and the visibility curve for the average human eye,
6. The total transmission factor for light of equal energy at all wave lengths.

Four different methods were used to obtain the data, part of the work being done in the physical laboratory of Cornell University and part at this Bureau.

Sample transmission curves are given with all values plotted, illustrating the kind of agreements and disagreements obtained on the different instruments.

A brief summary is given of the good or bad qualities of the various kinds of glass in comparison with colorless glass as regards protection against ultra-violet radiant energy.

A brief elementary discussion is given, explaining the meaning of terms used in spectrophotometry and illustrating how to compute the transmissions for thicknesses other than that measured.

APPENDIX

FORMS SUITABLE TO BE USED IN THE SPECIFICATIONS OF EYE-PROTECTIVE GLASSES

It is desirable that those who wish to specify eye-protective glasses should have at hand certain standard type forms for such specifications. The following forms, separately or in combination, as the case in hand may require, will be found, in general, suitable and adequate for this purpose:

1. *For Protection from Ultra-Violet.*—"The transmission shall not be greater than 0.01 for radiant energy of any wave length less than 406 millimicrons."

2. *For Protection from Heat.*—"The total transmission for radiant energy from a source having the spectral energy distribution of a complete radiator ('black body,' Wien equation) at 1500° absolute shall not be greater than . . . . . ."

3. *For Protection from Intense Light while Allowing Sufficient Light for Work.*—"The total light transmission for light of equal energy at all wave lengths shall not be more than . . . . . nor less than . . . . . ." This would approximate closely the total light transmission for sunlight. In some cases it might be desirable to make the specification in terms of the known spectral energy distribution of the standard acetylene flame or other source.

The blank spaces in the above forms should be filled as found desirable in particular cases. Satisfactory glasses should be selected by trial under service conditions. The measured transmissions of these selected glasses will then serve as data for filling the blanks in the above forms.

WASHINGTON, July 25, 1918.

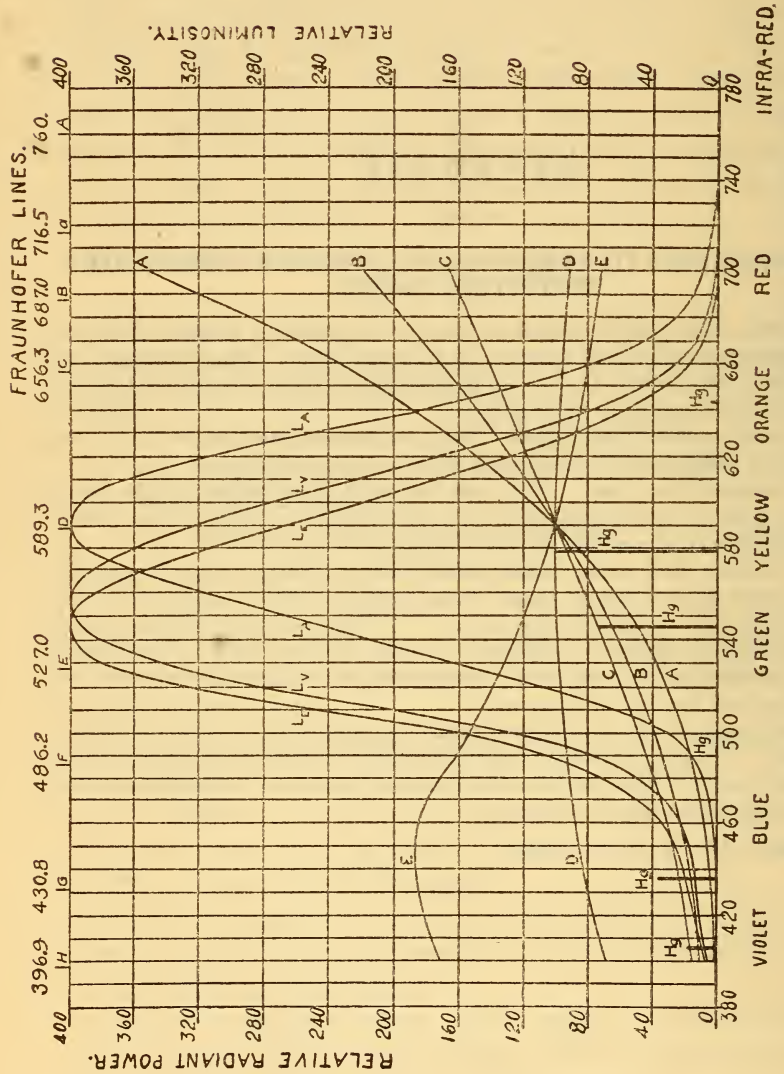


FIG. 1

Relative spectral distribution of radiant power in various sources: A=Hefner lamp, H. E. Ives, Trans. I. E. S., 5, p. 208, 1910; B=acetylene flame, Coblentz and Emerson, B. S., 13, p. 363, 1916; C=tungsten (gas) incandescent lamp (No. 1717) at 15.6 lumens per watt, data by Coblentz; D=black body at 5,000° absolute—approximately sunlight, computed from Planck equation; E=blue sky, H. E. Ives, Trans. I. E. S., 5, p. 208, 1910; Hg=Heraeus quartz-mercury lamp, 81 watts, W. W. Coblentz, B. S., 9, p. 97, 1913. Relative visibility: L_V=Relative visibility curve for the average human eye (or luminosity of a source having constant radiant power throughout the visible spectrum), Coblentz and Emerson, B. S., 14, p. 192, 1917.

Relative luminosity=relative radiant power times relative visibility: L_A=luminosity of Hefner lamp; L_E=luminosity of blue sky.

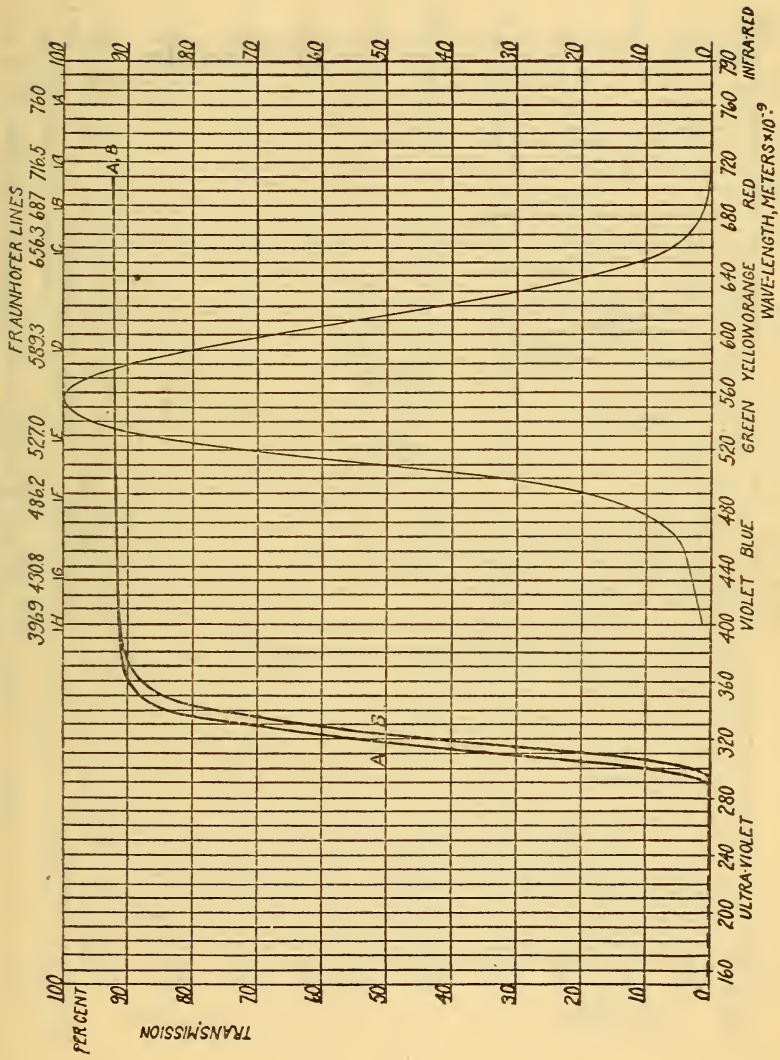


FIG. 2.—A = "Crown 1.50," 1.68 mm; B = "1.52," 2.33 mm; A. O. Co.

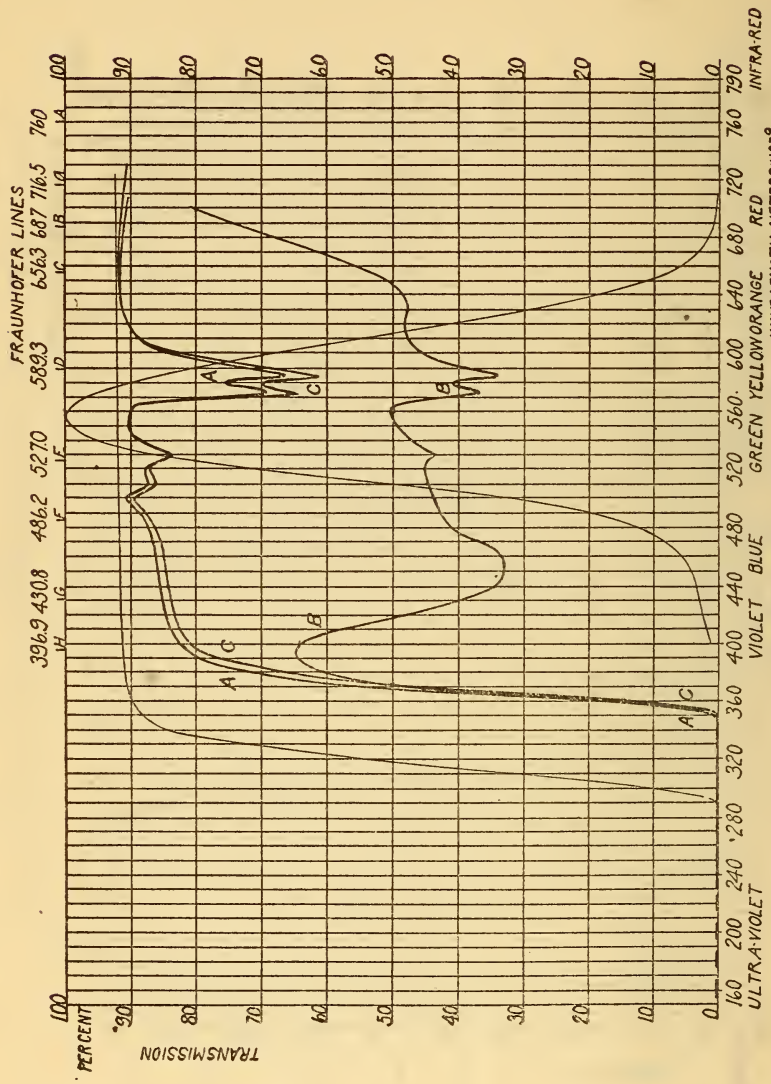


FIG. 3.—A = "Crookes A, Wellsworth," 2.05 mm; B = "Crookes B, Wellsworth," 2.16 mm; A. O. Co. C = "91 B," 1.97 mm; Corning

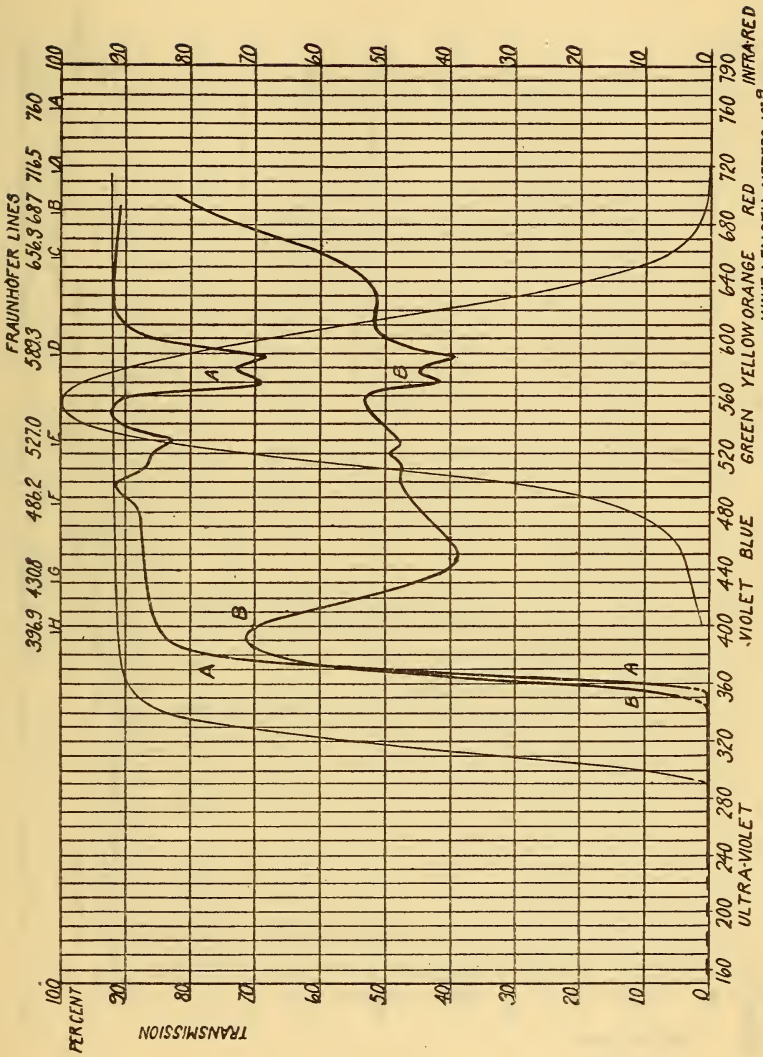


FIG. 4.—*A*="*Crookes A*," 1.79 *mm*; *B*="*Crookes B*," 1.93 *mm*; *W*. & *O*.

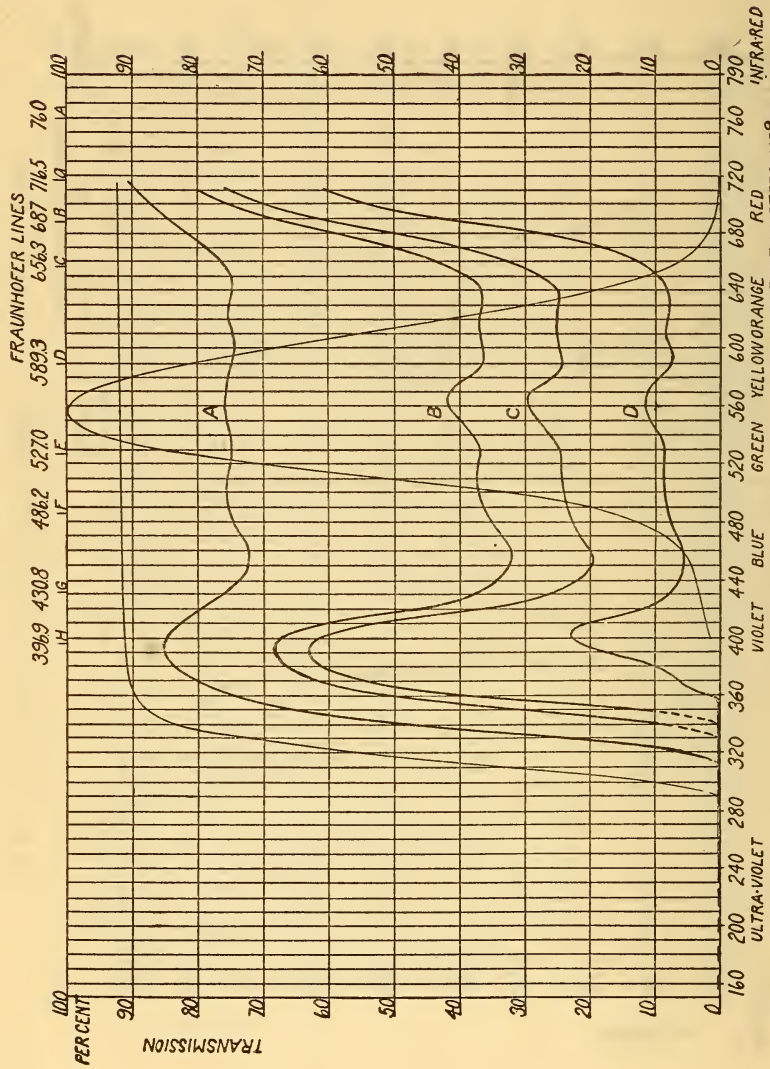


FIG. 5.—A="Smoke A," 2.10 mm; B="Smoke B," 2.14 mm; C="Smoke C," 2.13 mm; D=Smoke D," 2.03 mm; A. O. Co.

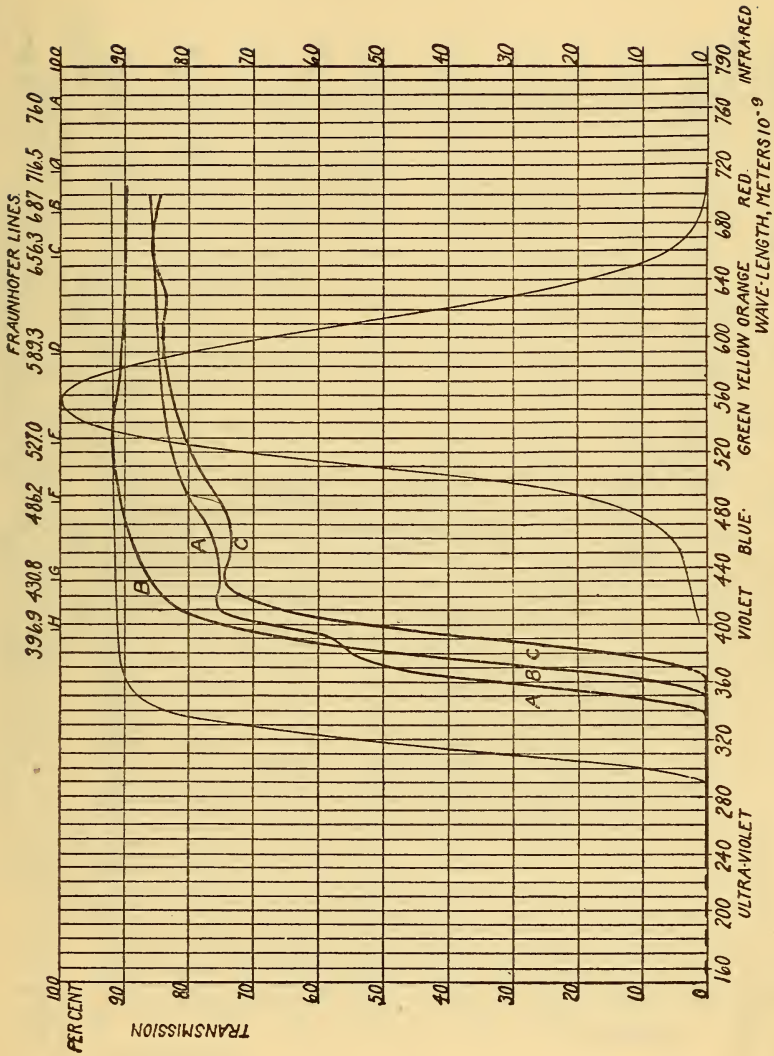


FIG. 6.—A = "*Luxfel*," 2.00 *mm*; B = "*Lab. No.* 57," 1.90 *mm*; C = "*Lab. No.* 58," 2.02 *mm*; A. O. Co.

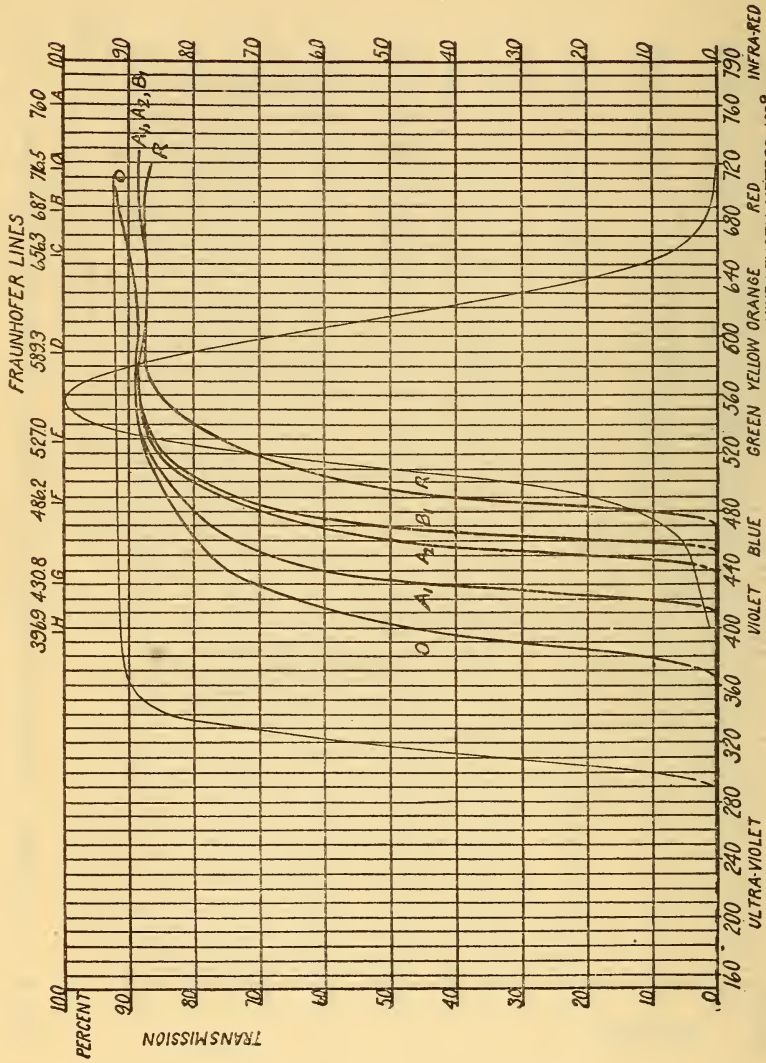


FIG. 7.—O="Noviol O," 1.94 mm; Hardy. A_1="Noviol A_1," 2.88 mm; A_2="Noviol A_2," 2.84 mm; B_1="Noviol B_1," 2.83 mm; Corning. R="Rifleite," 3.14 mm; King

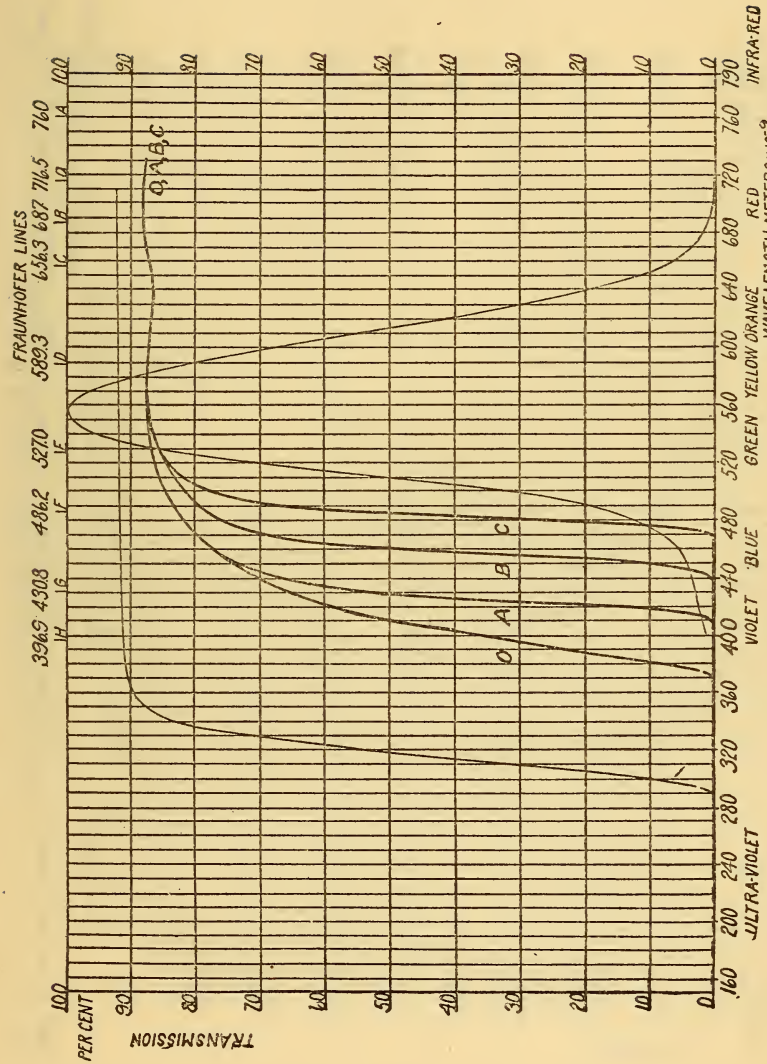


FIG. 8.—O="Noviol O," 2.01 mm; A="Noviol A," 2.00 mm; B="Noviol B," 1.95 mm; C="Noviol C," 2.00 mm; Corning

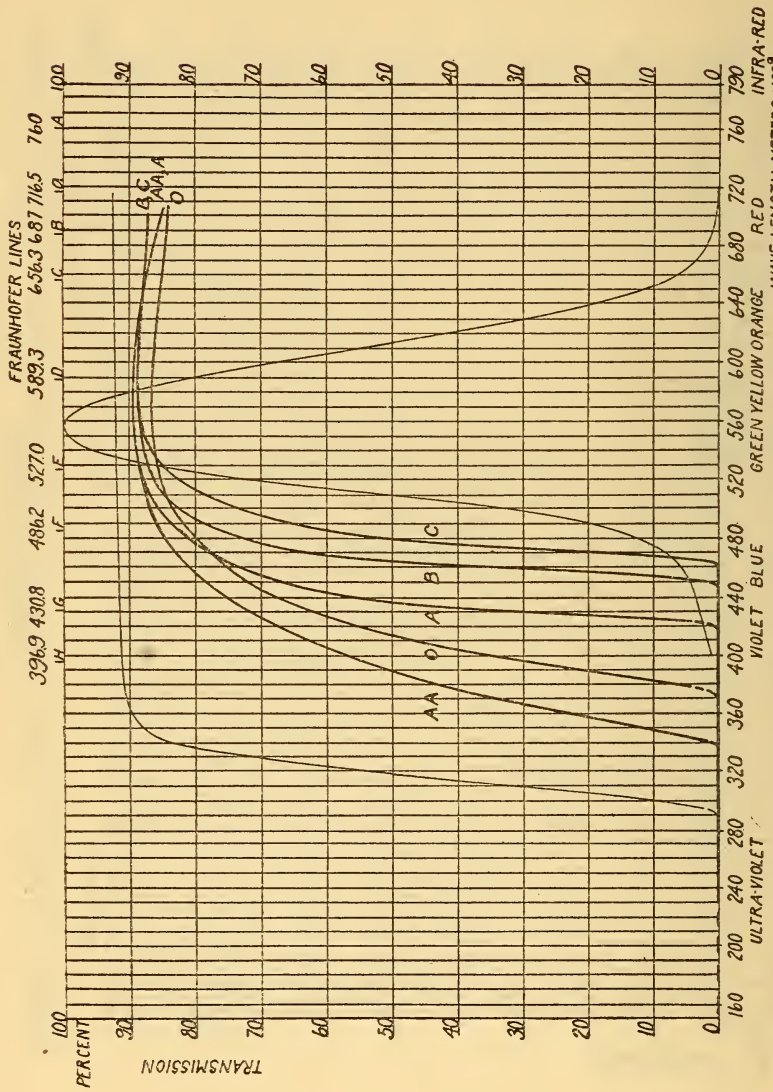


Fig. 9.—*AA*="*Noviol AA*," 1.88 *mm*; *O*="*Noviol O*," 2.03 *mm*; *A*="*Noviol A*," 2.06 *mm*; *B*="*Noviol B*," 2.10 *mm*; *C*="*Noviol C*," 2.10 *mm*; *A. O. Co.*

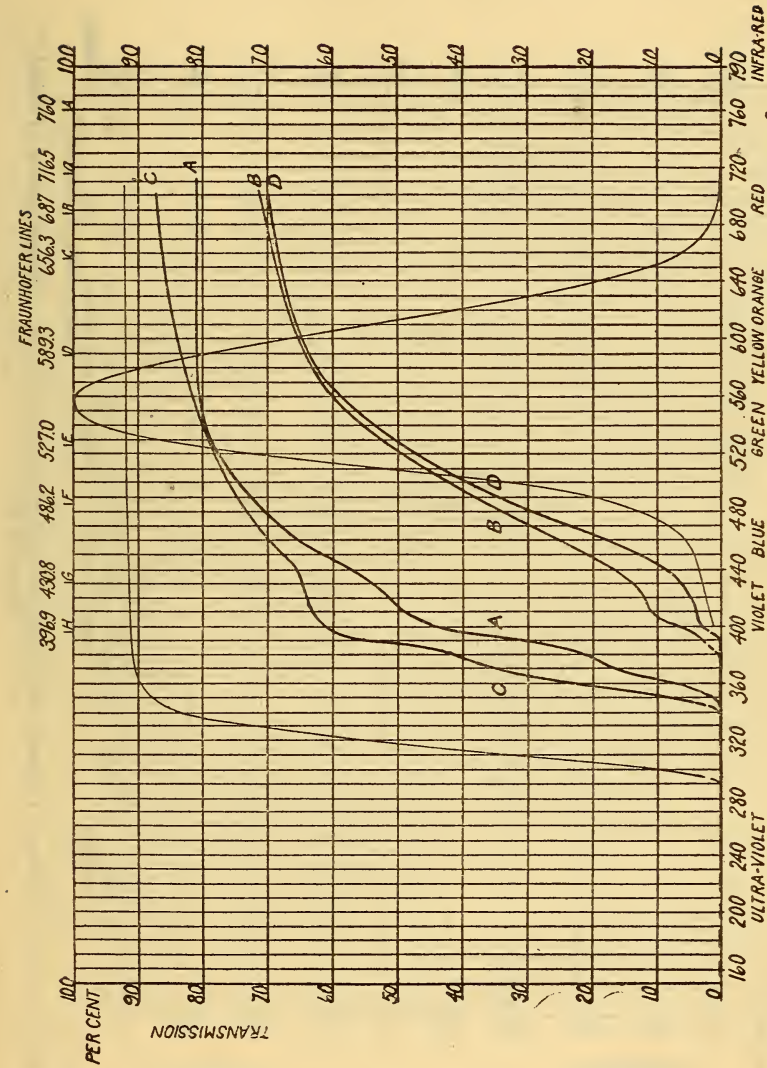


FIG. 10.—A="Amber A," 2.13 mm; B="Amber B," 2.13 mm; A. O. Co. C="Amber, light," 1.93 mm; D="Amber, dark," 1.85 mm; W. & O.

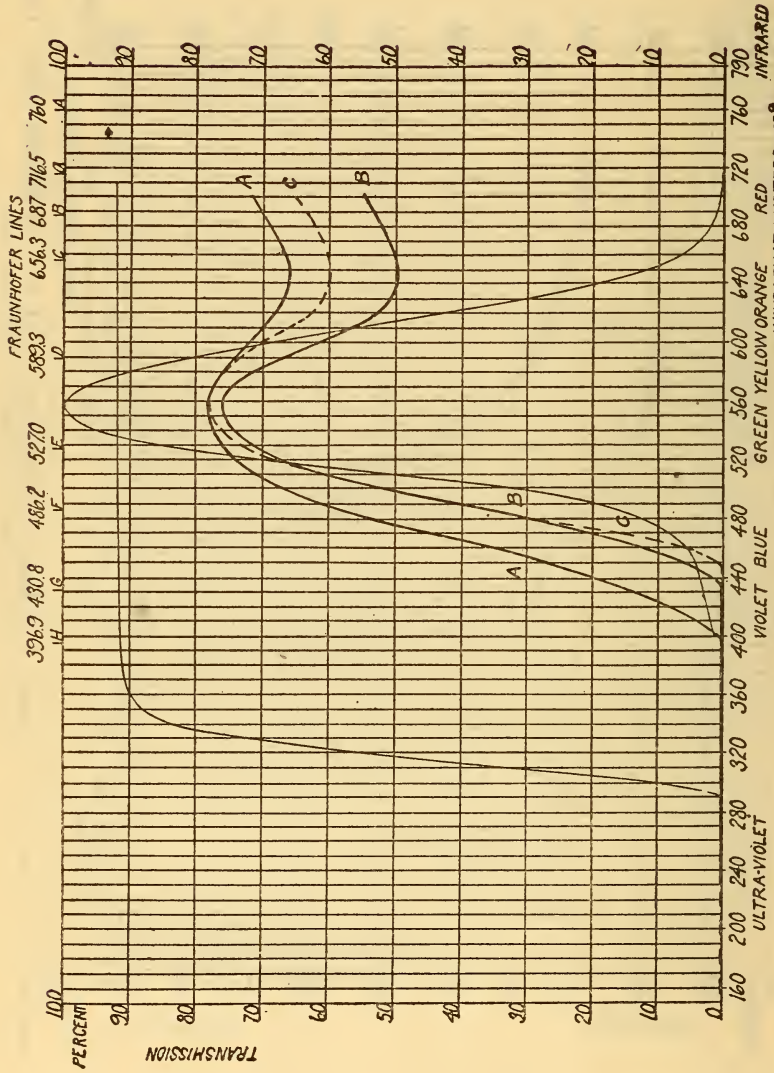


FIG. 11.—A = "Euphos," 1.95 mm; B = "Lab. No. 61," 2.13 mm; A. O. Co. C = glass labeled "Fieuzal," bought in store

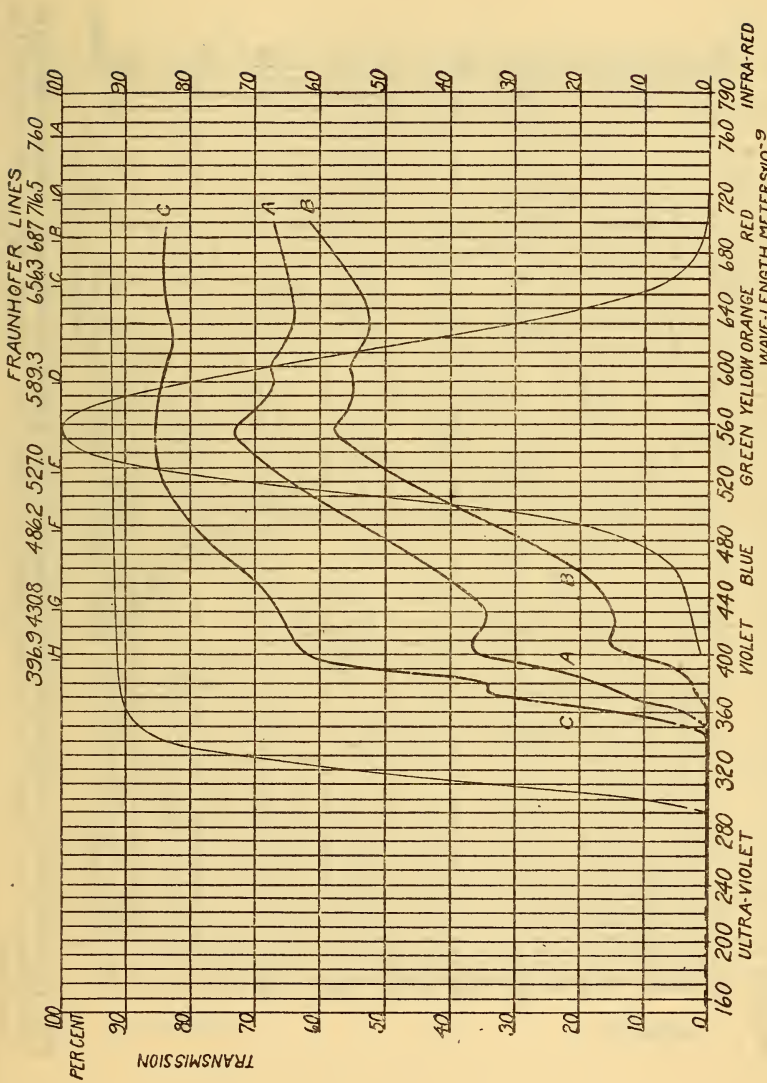


FIG. 12.—*A*="*Fieuzal A*," 2.13 *mm*; *B*="*Fieuzal B*," 2.13 *mm*; *A. O. Co.* *C*="*Fieuzal*," 1.98 *mm*, *W. & O.*

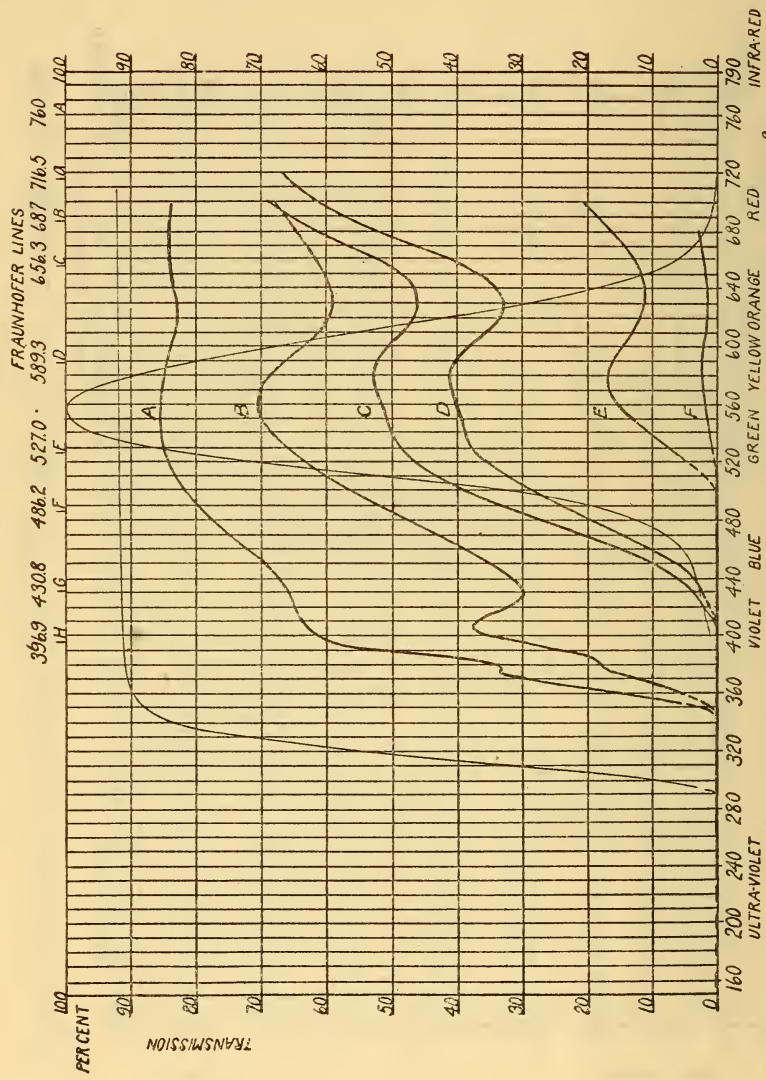


FIG. 13.—A="Fieuzal," 1.98 mm; B="Chlorophile," 1.98 mm; C="Hallauer," 1.90 mm; W. & O. D="Akopos," 2.17 mm; E="Saniweld, light," 1.82 mm; F="Saniweld, dark," 2.12 mm (see Fig. 21); King

FIG. 14.—*A*="392 F," 1.90 mm; *B*="124 JA," 2.02 mm; *C*="124 IP," 2.00 mm (see Fig. 21); Corning. *D*="Lab. No. 59," 2.13 mm; *E*="Pfund," gold film between plates of "Crookes" glass, total 2.89 mm; A. O. Co.

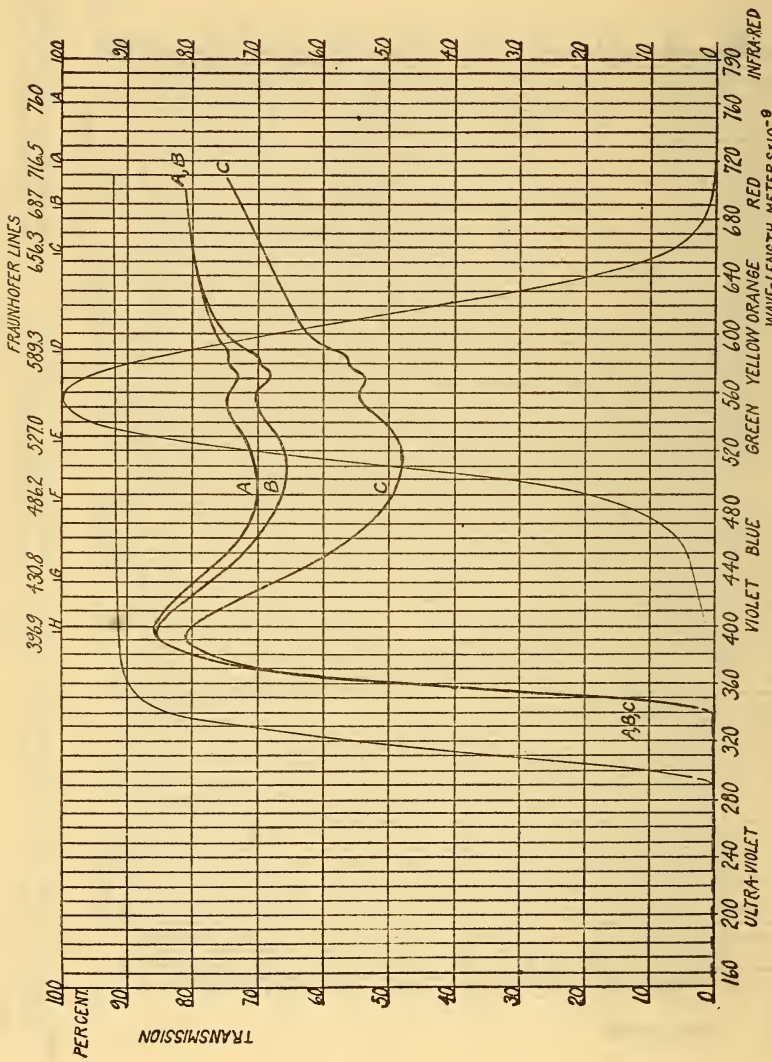


FIG. 15.—A = "Amethyst A," 2.08 mm; B = "Amethyst B," 2.05 mm; C = "Amethyst C," 2.04 mm; A. O. Co.

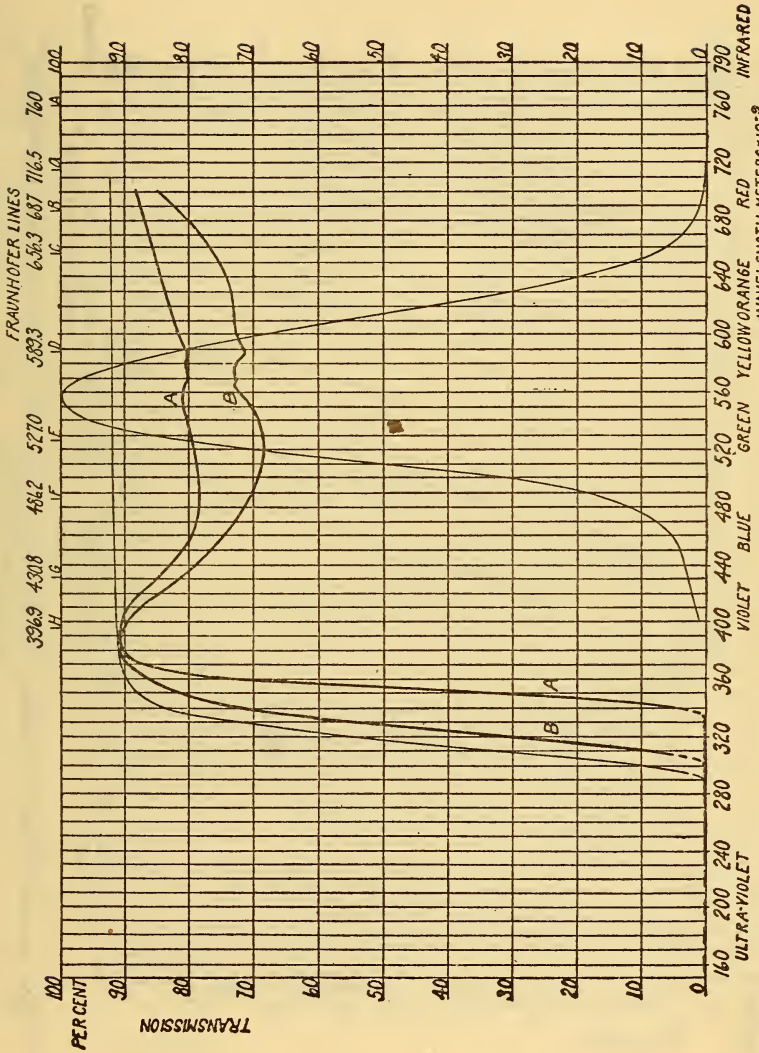


FIG. 16.—*A*="*Amethyst, light,*" 1.97 *mm*; *B*="*Amethyst, dark,*" 1.90 *mm*; *W. & O.*

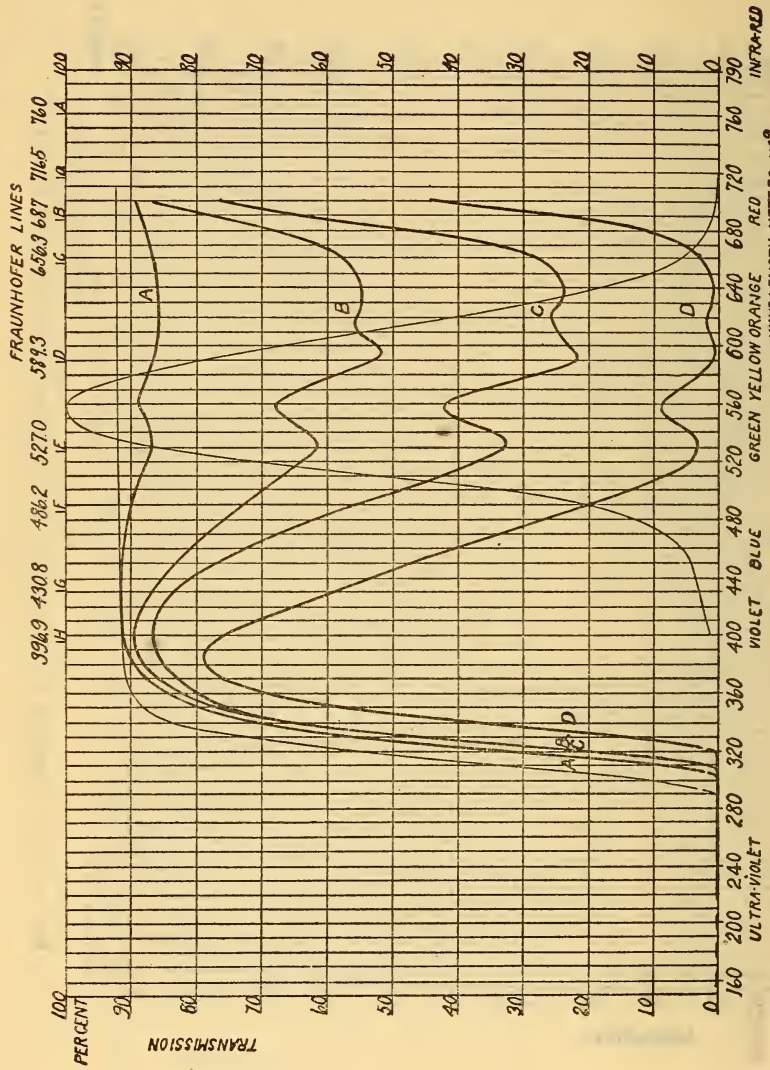


FIG. 17.—A="Blue A," 2.10 mm; B="Blue B," 2.04 mm; C="Blue C," 2.05 mm; D="Blue D," 2.11 mm; A. O. Co.

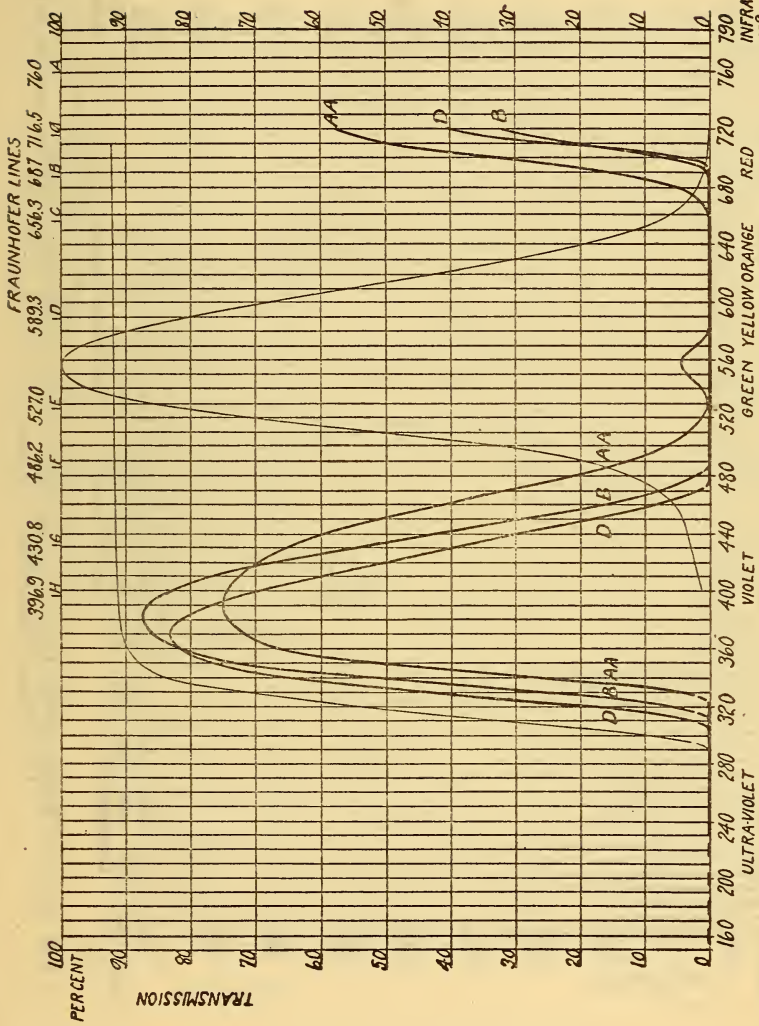


FIG. 18.—*AA*="*Cobalt Blue AA*," *2.75 mm; B*="*Cobalt Blue B*," *1.85 mm; D*="*Cobalt Blue D*," *1.86 mm; "Cobalt Blue A," 3.20 mm nearly same as curve AA; "Cobalt Blue C," 1.46 mm nearly same as curve B; "Chromatic Test," 2.36 mm similar to curve B, but slightly lower in value; A. O. Co.*

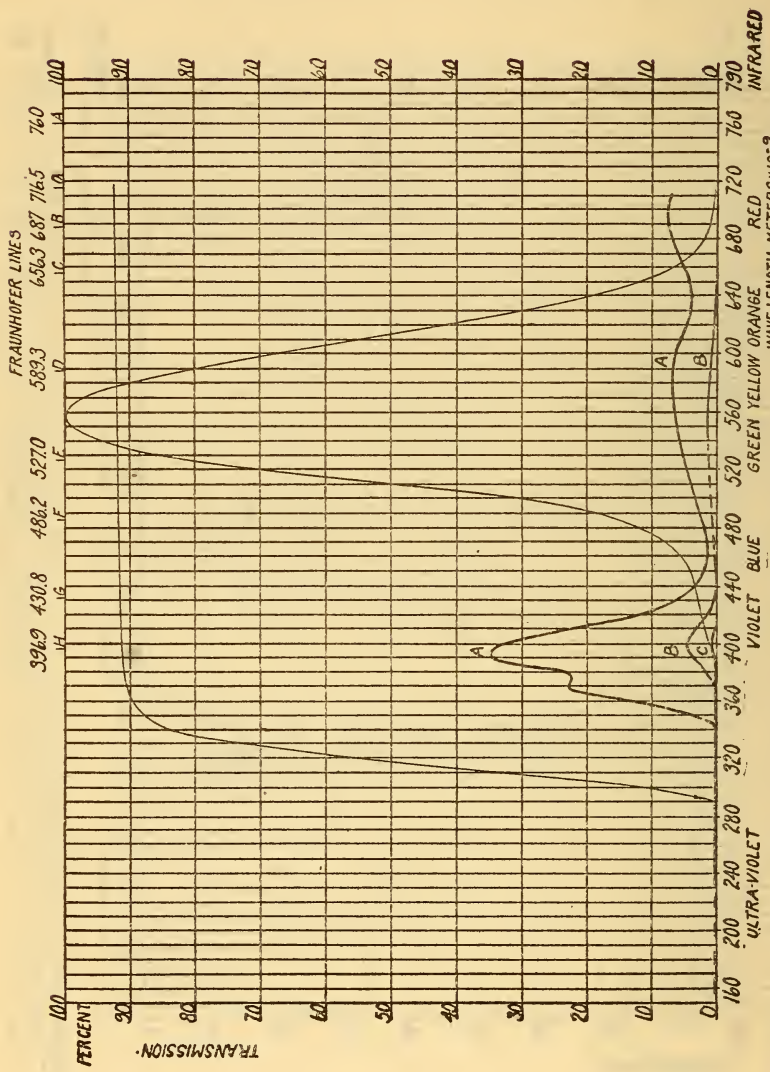


FIG. 19.—A = "Welders Smoke Dark," 1.42 mm; B = "Special Welders Light," 1.68 mm (see Fig. 21); C = "Special Welders Dark," 2.54 mm (see Fig. 21); A. O. Co.

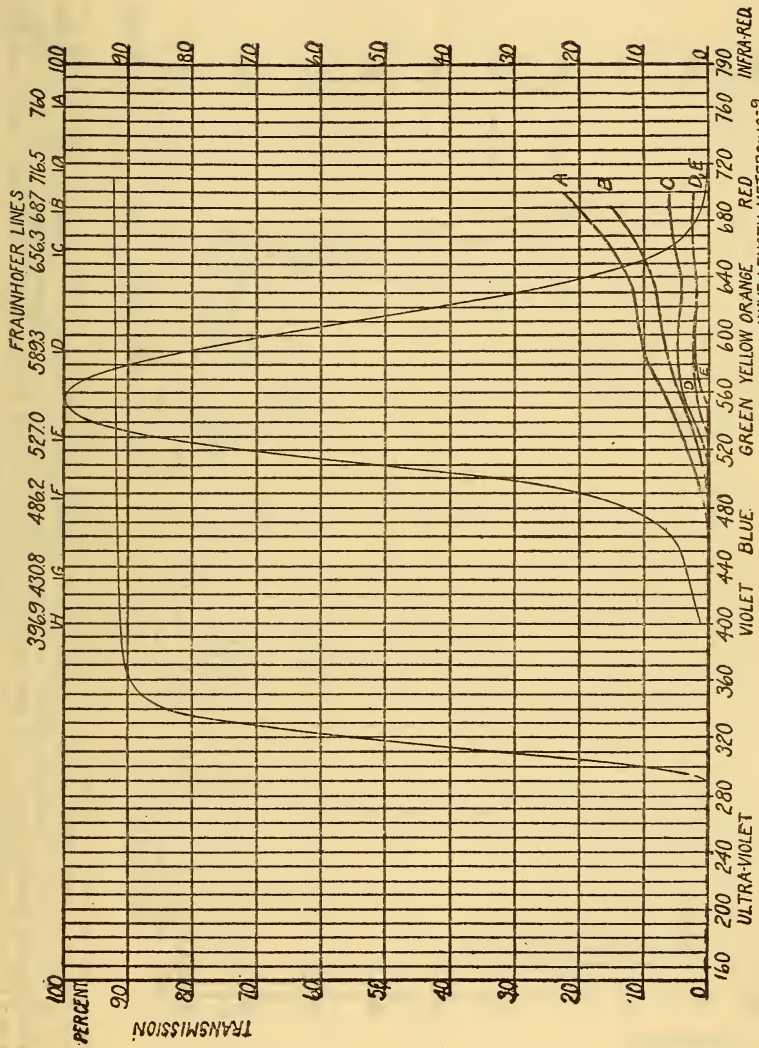


FIG. 20.—*A*="*Welding glass 6,*" *1.97 mm; B*="*Welding glass 2,*" *2.32 mm; C. E. S. Co. C*="*Noviweld 4,*" *1.89 mm; D*="*Noviweld 5,*" *2.16 mm; E*="*Noviweld 6,*" *2.20 mm;* "*Noviweld 7,*" *1.90 mm 1.02% at 578;* "*Noviweld 8,*" *2.01 mm 0.517% at 578; A. O. Co.*

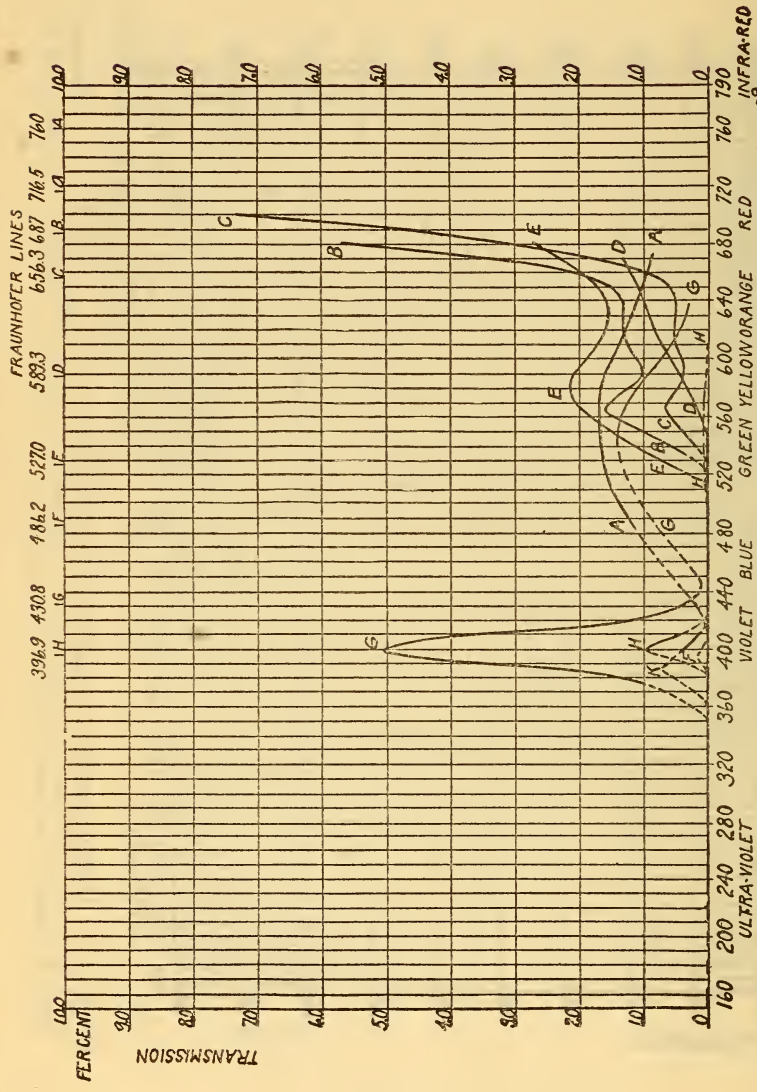


FIG. 21.—*Note scale of ordinates. A="124 IP," 2.00 mm (see Fig. 14); Corning. B="Welding glass 3," and "Welding glass 4," 1.48 mm (identical); C="Welding glass 1," 1.98 mm; D="Welding glass 5," 1.87 mm C. E. S. Co. E="Saniweld, Dark," 2.12 mm (see Fig. 13); F="Arkweld," Dark," 2.46 mm; King. G="Special Welders Light," 1.68 mm (see Fig. 19); H="Special Welders Dark," 2.54 mm, 0.061% at 578 (see Fig. 19); K="Electric Smoke Red," 1.82 mm; A. O. Co.*

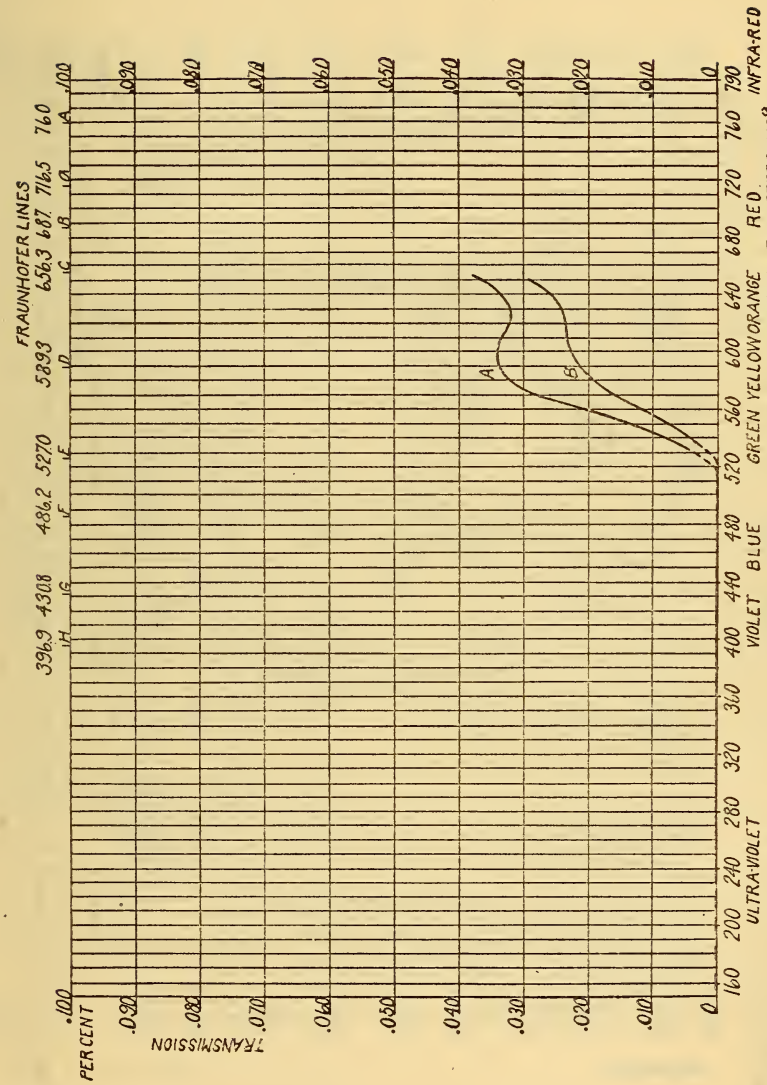


FIG. 22.—*Note scale of ordinates. A = "Special Noviweld No. 8," 1.77 mm; Hardy. B = "391 DD," 1.90 mm; Corning.*

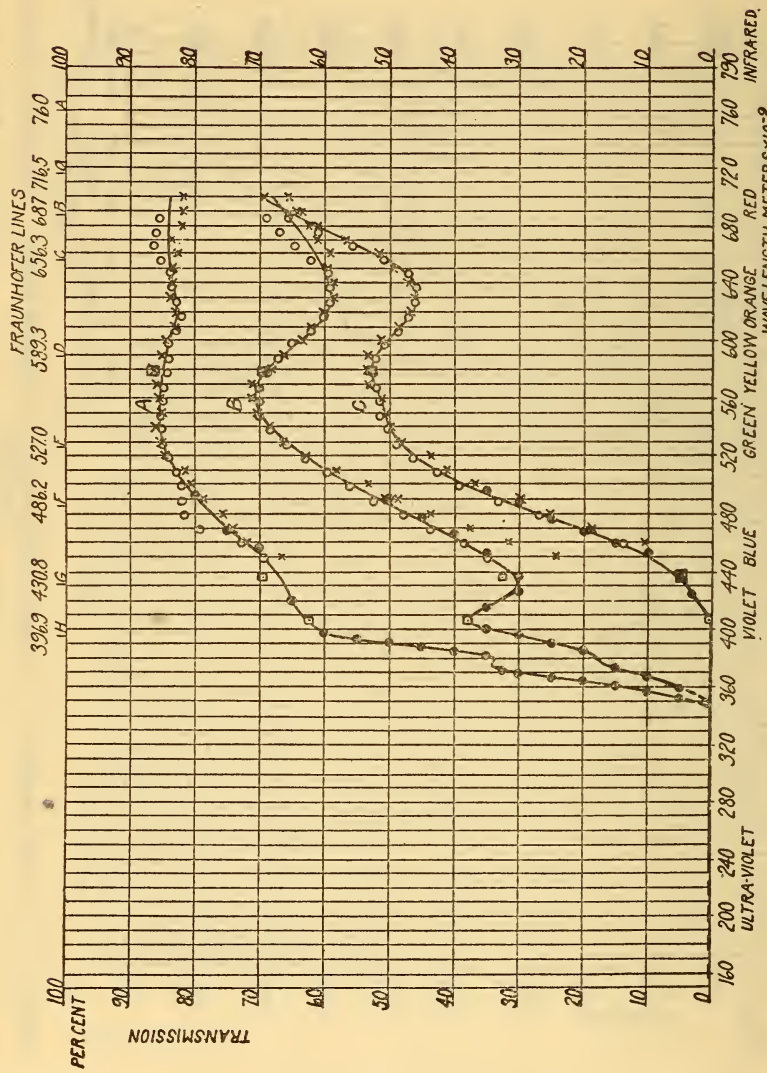


FIG. 23.—A="Fieuzal," 1.98 mm; B="Chlorophile," 1.98 mm; C="Hallauer," 1.90 mm (see Fig. 13); W. & O.

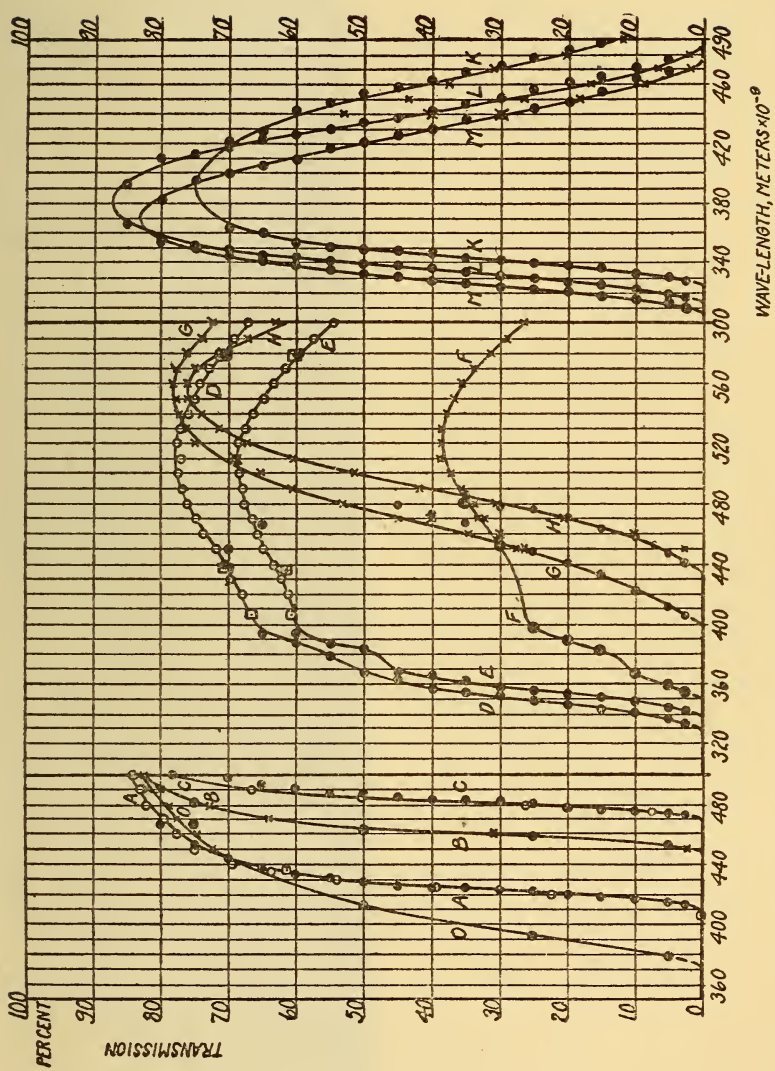
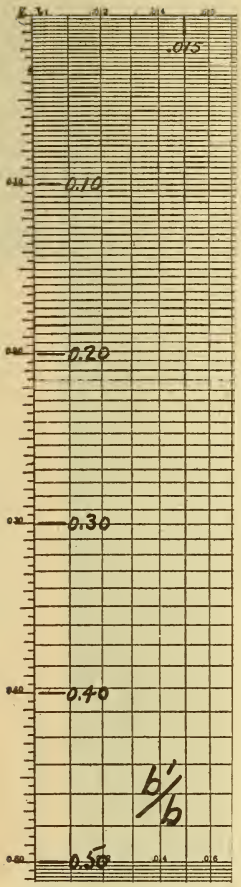


FIG. 24.—O="Noviol O," 2.03 mm; B="Noviol B," 2.10 mm (see Fig. 9); A. O. Co. A="Noviol A," 2.00 mm; C="Noviol C," 2.00 mm (see Fig. 8); Corning. D="302 F," 1.90 mm; E="124 JA," 2.02 mm (see Fig. 14); Corning. F="Lab. No. 59," 2.13 mm (see Fig. 14); G="Euphos," 1.95 mm; H="Lab. No. 61," 2.13 mm (see Fig. 11); A. O. Co. K="Cobalt Blue AA," 2.75 mm; L="Cobalt Blue B," 1.85 mm; M="Cobalt Blue D," 1.86 mm (see Fig. 18); A. O. Co.


.015
0.10
0.20
0.30
0.40
b'/b
0.50

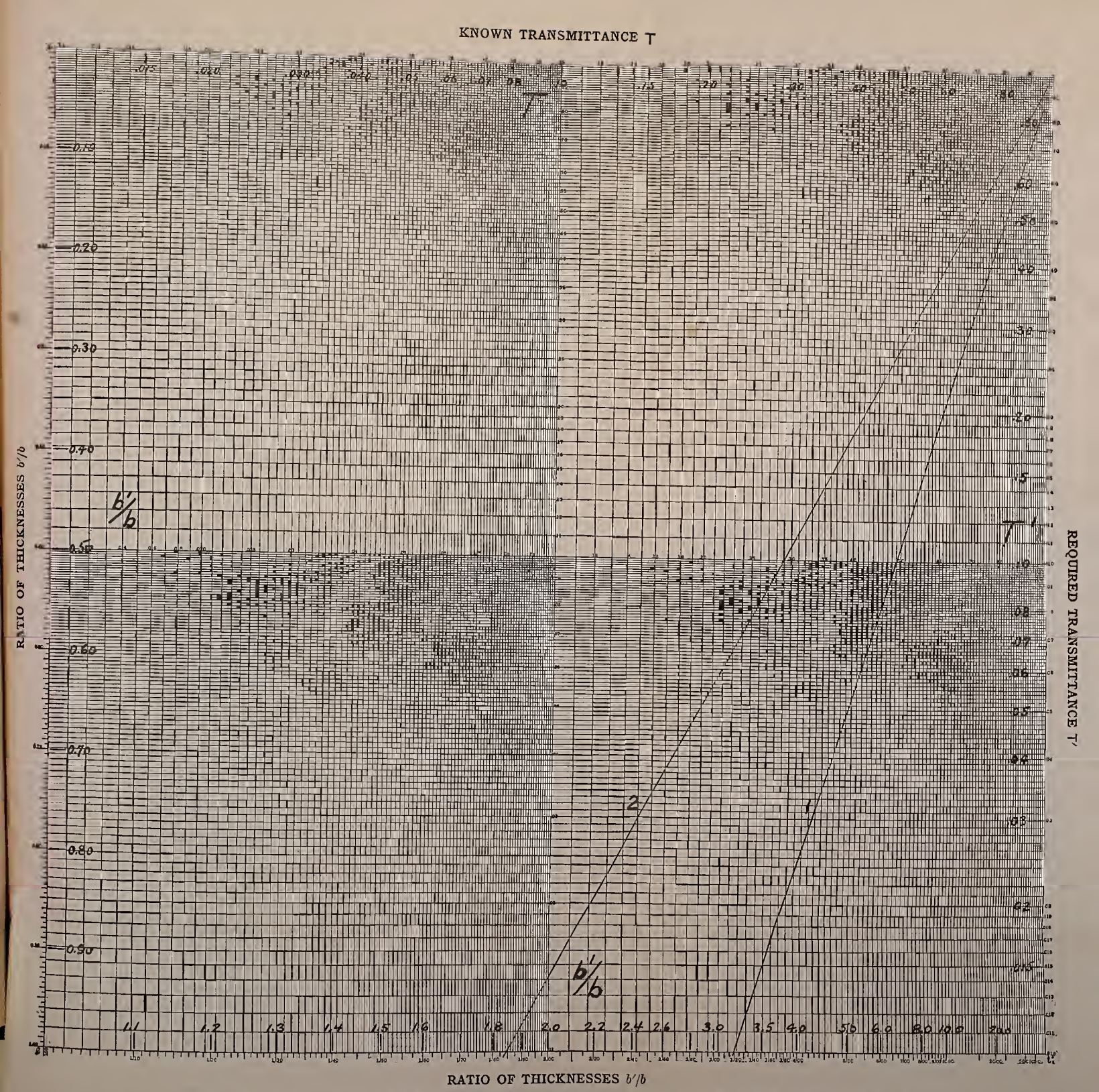


FIG. 25.—*Reproduction of chart used at Bureau of Standards for computing transmissions for different thicknesses and vice versa*

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′ on right-hand scale corresponding to this intersection is the required transmittance and $T'=0.92$ T′. Line 1 illustrates the solution of problem 3 in Table 1.

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. Line 2 illustrates the solution of problem 5 in Table 1.

89784°—19. (To follow page 47.)