Spectral-Transmissive Properties and Use of Eye-Protective Glasses

United States Department of Commerce
National Bureau of Standards
Circular 471

Supplementary Notes on the Spectral Transmittance of Glasses for Driving at Night

(To Accompany National Bureau of Standards Circular 471)

In the course of the preparation of the transmission data on the more than 200 glasses illustrated in the 93 figures of NBS Circular 471 a great amount of care was taken to insure that the reproduced values should not be in error by more than about 1 percent. Interlaboratory checks (see fig. 39 of the Circular), together with duplicate measurements by other laboratory personnel and transmission calculations based on the index of refraction of glass, have indicated that at least, most of the data are accurate to within about 1 percent. The establishment of a higher degree of precision at the time these data were taken (1946 to 1948) would not only have rendered the project impossible with the available instrumentation and funds but such precision would have been meaningless in view of the fact that samples of glass from different melts or from different portions of the same melt are usually found to have measurable differences in relative spectral and absolute transmittance. Differences in shape and condition of surfaces and index of refraction of the glass result in differences of at least a few tenths of a percent in transmittance.

Unfortunately some of the data on the spectral transmittances of certain glasses, in particular Nite-Lite of figure 2 as compared with Light Crown of figure 1, have been misinterpreted by some readers to the extent that indicated differences having a magnitude very much smaller than the recognized precision of the data have been considered significant. This is regrettable. Special letters calling attention to this improper interpretation of the data have been sent out.

In order to establish the precise relative and absolute spectral transmittance of Nite-Lite and Light Crown glasses within the visible spectrum, especially within the spectral limits of 550 to 700 mμ, a number of samples of each have recently been tested at the National Bureau of Standards, employing the best equipment and techniques presently available. Tests on the two types of glass, after having been simultaneously polished in the Bureau's optical shop, were made in three Bureau laboratories. The results of these tests are in close agreement and indicate differences of about 1 to 1.6 percent between the transmittance of Nite-Lite and Light Crown glass at the wavelength of maximum transmittance (ranging from about 580 to 630 mμ among the samples examined) for the Nite-Lite glass. As has been previously pointed out, different melts will have differences in transmittance. This observed difference in transmittance of the two types of glass should be considered only quantitatively true for the particular samples that have been measured.

Table I gives the observed transmittances for the specially polished samples of Nite-Lite and Light Crown glass within the spectral range of 550 to 700 mμ, together with their calculated integrated luminous transmittances.

TABLE I. *Spectral transmittance of Nite-Lite yellow and Bausch & Lomb Light Crown glass from 550 to 700 mμ*

Wavelength	Transmittance: Nite-Lite $t=2.3$ mm	Transmittance: B. & L. Light Crown $t=2.3$ mm
mμ	*Percent*	*Percent*
550	87.7	91.8
560	89.4	91.8
570	89.7	91.8
580	89.9	91.8
590	90.1	91.8
600	90.3	91.8
610	90.3	91.9
620	90.4	91.9
630	90.4	91.9
640	90.4	91.9
650	90.5	91.9
660	90.4	91.9
670	90.4	91.9
680	90.4	92.0
690	90.4	92.0
700	90.3	92.0
Transmittance for incandescent lamp light (CIE source A).	85.8	91.8

A further expansion and the addition of certain explanations relative to the brief remarks included in NBS Circular 471 relating to the use of a yellow glass in night driving is in order. The statement "tests by a number of observers indicate that there is some basis for claims of increased visibility and reduction of glare through the use of this type of glass" referred to reports of personal preference (by 12 people, principally scientists). No objective night-driving tests of yellow glasses were conducted, nor, as far as is known, had any been performed previously. Subjective road tests (expressions of personal preference) of yellow night-driving glasses of Lauer [1], Cole (2) and others since that time result invariably in about 80 percent reporting favorable to the use of such glasses in night driving. However, numerous laboratory and simulated driving tests of an objective nature by Lauer [1], Richards [3], Blackwell [4], Roper [5], and Miles [6] indicate loss in visual acuity, contrast, seeing distance, and certain other factors relating to night-driving efficiency for most observers. For some observers no loss or improvement was found. A minority of observers using yellow glasses found increased efficiencies in most of the tests. Recent objective experiments by Jehu [7] under actual road driving conditions indicate a possible small advantage in the presence of glare in favor of the use of yellow glasses in night driving. In the absence of glare, a more definite advantage in favor of using no glasses is indicated. This is a controversial subject, however, as indicated in a report recently prepared for publication by the American Standards Association [8]. A summary survey of the available literature relating to the use of yellow glasses in night driving has recently been prepared by Judd [9]. Meanwhile, at least for most drivers (quoting from NBS Circular 471) "any gain through their use is small at best and may be overbalanced by the inconvenience of wearing glasses of any kind or by the obscuring effects of the spectacle frames." In considering whether to make yellow glasses a permanent part of his night-driving equipment, each driver has as a guide only his subjective impression of whether they are beneficial, and in making his decision he should take into account the fact that, although about 80 percent of the drivers who try yellow glasses are favorably impressed, objective laboratory tests so far have indicated that use of yellow glasses decreases visual acuity and seeing distance for the great majority of persons tested.

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Washington, November 10, 1955.

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Spectral-Transmissive Properties and Use of Eye-Protective Glasses

by Ralph Stair

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Preface

Conservation of eyesight is one of the foremost problems that confront safety engineers in America today. The eyes must be protected not only from mechanical injury, but from injury resulting from exposure to various sources of radiant energy. The natural protective mechanism of the eye is sufficient to adapt it to ordinary amounts of radiant energy encountered about the home, office, shop, or other place of business or recreation. However, in certain strenuous outdoor activities (snow sports, automobile trips, beach activities, etc.) and in industrial occupations (furnace work, gas and electric welding, etc.) glasses having low transmittancy to harmful radiant energy are required.

At various times during the past three decades, this Bureau has published the results of investigations on the spectral-transmissive properties of various types of colored glasses for protecting the eyes from glare and from injurious amounts of ultraviolet, luminous, and infrared radiant energy. Reprints of these papers are no longer available. Furthermore, a number of new glasses have been developed during the past decade for use in new and old industries.

This Circular is issued to supply the continuing demand for information on the transmissive properties of various makes of tinted lenses for outdoor wear, and on protective glasses for use in industrial operations where the workers operate or are in close proximity with furnaces, cutting and welding apparatus, etc. that emit injurious amounts of ultraviolet, luminous, or infrared radiant energy.

E. U. Condon, *Director.*

Contents

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By Ralph Stair

Abstract

This paper contains spectral-transmissive data on most of the widely distributed brands and types of glasses employed in protecting the eyes from harmful ultraviolet, visible, or infrared radiant energy, which may be encountered in industry, in driving, or while at home or at play. The standardization of shade numbers for protective glasses used in industry, glasses for special welding operations, the use of colored glasses for night driving, and the elimination of glare in sunlight are given considerable attention.

I. Introduction

Man, bird, and beast are endowed with two delicate organs which make vision a reality. The power of acute vision attains its highest development among birds, but nowhere except in man is the eye so expressively beautiful or so exquisitely adapted to its service as an optical instrument [1].[1] Without a doubt, the human eye with its accompanying powers of translation of light energy into nerve stimuli, which are transferred to the brain through the nerve fibers to form true images, is one of the most prized possessions of mankind. Therefore, every possible effort should be made to protect this valuable possession through the use of proper protective glasses wherever injury may possibly occur.

In keeping with industrial progress in this country, protective glasses and goggles have been developed and improved until today there is a glass, or goggle, available for providing adequate protection in each and every occupation or avocation. During the past three decades, a number of publications [2, 3, 4, 5, 6] on the properties or uses of eye-protective glasses have been issued by the National Bureau of Standards. Reprints of these papers are no longer available. Furthermore, during the past decade a number of new glasses have been developed for use with old or new processes in industry. This report is issued to supply the demand for information on glasses available at this time for use in industry and in outdoor wear, such as in driving or in recreation at the seashore, golf links, etc. In its preparation the author has drawn freely upon the previous papers on this subject by Coblentz and Stair [2, 5, 6], retaining much that is applicable to the data and glasses herein described.

Probably second only in importance to the ability of the eye to focus a clear image on the retina, is its power to adjust automatically to the illumination, within a relatively short interval, in order to see objects, under a wide range of illuminations, [46] with practically constant distinctness and comfort. The eye, considered as a physical instrument, automatically changes its sensitivity by a factor of about 1,000,000. Of this amount, the variation in area of the pupil furnishes the factor, 50; and the changes in responsiveness of the retina, the remaining factor, 20,000. Unfortunately this adjustment is not instantaneous when one looks first at a dark and then at a bright or brightly illuminated object, as may be illustrated by walking outside into bright sunlight after having spent some time indoors. This is one example of the need of protecting the eyes with dark glasses.

Another important property possessed by the human eye is the ability to distinguish colors. On the average, 24 out of 25 people [49] possess the power of distinguishing the same range of colors, and to the same degree; but 1 of the 25 is defective in chromatic vision, that is, partially color blind. Even a person with normal color vision is rendered somewhat color blind when looking through colored eye glasses, especially when one or more regions of the spectrum is highly absorbed relative to other spectral regions. Hence, it is very important that the glasses, worn for comfort or protection, shall not seriously impair one's efficiency in color discrimination.

In the field of eye protection in industry, the invisible radiant energy that is always present with the visible (and often to an injurious degree) must be given special attention. When the density of infrared radiant flux is high, the ensuing burning sensation usually gives a quick warning; consequently, it is not so likely to cause injury. But the incidence of ultraviolet (short wave) radiant energy is not felt at the time of exposure; it is only revealed by the discomfort and suffering that develop a few hours after the actual damage

[1] Figures in brackets indicate the literature references at the end of this paper.

has been done. Inasmuch as the incidence of infrared and ultraviolet radiant flux is of no aid to vision, it is wise to minimize the risk of injury, in all cases, by wearing glasses that greatly reduce both the infrared and the ultraviolet as well as cut the flux density of the visible rays to a safe and comfortable value.

1. Elimination of Glare

As commonly used, the term "glare" has various meanings. Here it will be used to signify any brightness within the field of vision of such a character as to cause an unpleasant sensation, a temporary blurring of vision, or eye fatigue. Infrared probably adds nothing to the blurring of vision and under normal conditions little to eye fatigue. However, ultraviolet radiant energy definitely causes blurred vision as the result of flourescence of the eye media.

The elimination of glare from extensive areas of snow, water, sand, roadways, and city streets in bright sunlight by the use of tinted lenses, is easy and satisfactory; and there is no problem in making a selection, by trial, of a glass that will adequately serve the purpose.

Through the continued use of dark lenses, it has been found that the eye becomes more or less accustomed to a lower illuminance, or level of illumination, so that glare may result when the eye is exposed to a certain higher level of illumination to about the same extent as if no glasses had ever been worn at all. On the other hand, if a person spends a major part of the time out of doors in sunlight, the eye becomes accustomed to the higher illuminances so that it may be possible to see comfortably without any glasses at all. However, most of us require protection during those times when we are outside in bright sunlight, because the greater part of our lives is spent indoors under a lower level of natural or artificial illumination. This "habit forming" characteristic of the eye can be controlled to a certain extent by guarding against the use of shaded lenses of any kind (except possibly in certain pathological cases) while indoors or under conditions of similarly low illuminance. In most homes and offices the level of illumination is so low that the normal eye requires all the available light for comfortable seeing. The best lens, with the usual light covering of dust, oil, etc., reduces the light flux density about 10 percent. The use of a tinted lens would reduce the visibility of objects even more. Hence the practice of prescribing corrected tinted lenses for use in the home or office is probably erroneous in most cases, since most inside working conditions now have illumination levels too low for best results [48 ,53].

For use in sunlight there is oftentimes a need for corrected lenses, since eye fatigue may be caused by lack of proper refraction corrections as well as by glare. This is especially the case on long automobile trips when the eyes are kept constantly "fixed" on the highway for hours at a time. For persons requiring corrected lenses, two alternatives are possible, namely, the use of commercially available "clip on" protective sun glasses, and prescription ground tinted lenses. If the refractive corrections are small for distant vision, corrected lenses made from tinted sun glass stock are preferable, since the wearing of two sets of glasses over the eyes has a number of disadvantages. If, on the other hand, the refractive corrections are large, an excessive variation in shade over the area of the lens will result (unless the lens is very thick). As most corrective glasses are converging, the resulting glass will be dark in the center and light around the edge—a condition just the opposite of that desired for most efficient reduction of glare.

There are several possible solutions to this problem of nonuniform density. The use of a metalized coating on the finished corrective lens that is made from clear glass will produce a tinted sun glass of uniform density, which may be of any shade depending upon the amount of metal deposited on the glass. The use of polaroid between clear glass plates will give a neutral glass having a luminous transmittance[2] of about 35 percent (see fig. 15). In this case most of the absorption is within the polarizing layer, which is not disturbed in the grinding and polishing operations. Clear glass may be "flashed" to give any color or density by coating one side with colored glass. The glass may then be polished on both sides. If ground and polished slightly concave on the flashed side, a lens may be obtained that is of light shade or clear in the center with increasing density toward the edge. The green glass of figure 32 represents the dark edge of such a glass recently examined [32]. Any refractive corrections would then be ground on the clear surface of the glass.

In industry, the refractive correction must be handled in a different manner. It is out of the question to modify the protective filter glasses in any way. Their density and thickness must not be disturbed by any grinding or polishing operations. Both the strength and the radiant absorbance are reduced, especially in the case of heat treated lenses [35, 36]. There are, however, two satisfactory solutions. Corrective clear glass lenses may be mounted within the goggles just inside the filter glass. This is, however, usually an expensive and not too practical solution. The more satisfactory solution is the use of special goggle frames that will fit over the operators regular glasses. These are commercially available, and, while not so neat as regular goggles,

[2] In this paper, consistent with the terminology adopted in LC857 for Bureau use, *transmittance* is defined as the ratio of transmitted to incident radiant energy. This has formerly been designated as *transmission*.

they allow the workman to use his regular glasses in their regular (and correct) position over his eyes, so that he performs the same visual adjustments in his work as when not wearing a protective goggle. Their use should be recommended where the worker normally wears glasses, not only for the comfort of the individual, but for his safety and efficiency.

2. Use of Glasses for Driving at Night

When one is driving at night, the eye is partially dark-adapted and, hence, is near its maximum sensititivity. This may be readily appreciated by recalling the relatively low brightness of a headlight during the day as compared with its brightness at night.

Because of the serious risks involved, the use of dark glasses for relieving glare in night driving demands special attention. Without shaded glasses, the blinding effects of the passing automobile headlights tend to place the right-of-way in momentary obscurity, similar to the effect of going from a brightly lighted room into the dark. Although this blinding effect may be minimized by keeping the oncoming headlights out of the direct line of sight, these lights are still very fatiguing and may finally induce a painful condition. On the other hand, if the driver attempts to eliminate the glare by wearing dark glasses, his entire field of view is correspondingly darkened, and the right-of-way is placed in continuous obscurity, since the eye is not able to detect the roadway contour from retinal images of such low luminous flux density.

In a summary report of a survey by the National Safety Council [14] the various authorities questioned were unanimous in the belief that the advantage of reducing glare from automobile headlights, by wearing dark glasses, is more than counterbalanced by the extra hazard arising from the decreased visibility of objects.

Numerous suggestions have been offered for eliminating or reducing the glare from approaching automobile headlights. The use of a dark strip (glass or plastic) on the upper part of the windshield, or a composite goggle, the upper half of dark glass with the lower of clear glass, was suggested at least two decades ago. A modification of this suggestion was the suggested use of a "dipped" glass, wherein, after grinding, the glass center was clear but surrounded with a graduated blending into a darker shade, for example, the green glass of figure 32 referred to above. A recent suggestion is the use of a "photochemical" glass (see Glare Rid glasses in fig. 34), wherein a rectangular area of each lens to the left of forward vision is darkened by a photochemical treatment. The dark area of the glass is placed in such a position that it shields the eye from approaching automobile headlights.

The use of polarizing headlight lenses, together with polarizing windshields, has been suggested and seriously considered by some persons. There are three major difficulties involved. First, because of the low luminous transmittance of any available polarizing material (about 35%), the candlepower of headlights would have to be increased severalfold. This would be possible, but even if accomplished, would produce dangerous conditions in cases where the motorist or pedestrian was caught in the light beam unprotected by a polarizing windshield. Second, the natural illumination of the sides of the roadway (by moon, stars, street lights, etc.) would be effectively reduced to such an extent that one would be unable to follow the road outlines as is done at present in country and city driving. Although the normal eye is capable of functioning under conditions of extremely low illuminance (at a level of about 15 millionths of a footcandle—5 to 15 micromillilamberts [46])—its efficiency drops very importantly before this extremely low level of illumination has been reached. Third, the delay in adoption of new devices by owners of present usable equipment would prohibit any sudden change-over in the type of illumination employed in night driving. The appearance of new cars with excessively bright headlight beams would be an extreme hazard to the drivers with present-day equipment and would, no doubt, result in a marked increase in night traffic accidents for a number of years.

Recently the use of a yellow glass has been suggested for night driving. Tests by a number of observers indicate that there is some basis for claims of increased visibility and reduction of glare through the use of this type of glass. A yellow glass (see glasses H, N, and S of fig. 1, glasses C and N of fig. 2, and glass C of fig. 18) no doubt increases visual acuity through the elimination of the blue, violet, and ultraviolet regions of the spectrum, thus reducing the chromatic aberration of the eye [7, 8, 9, 10, 11] as well as reducing the veiling effect of scattered short-wave light. There is some evidence that the scattering of light by the ocular media is spectrally selective, being higher for short-wave than for long-wave light [12]. Therefore, one is able to distinguish finer details, with the result that a hazy day may well be turned into what appears to be a clear day with observed objects standing out in sharper relief. The same situation continues, but with diminishing character, through dusk and into the evening until the level of illumination reaches such a low value that there is insufficient light to see the roadway clearly either with or without glasses. The glare from approaching automobile headlights is also reduced slightly by these glasses.

The fact that short-wave energy is scattered more than the long-wave by haze has been known for a long time by the aviation or landscape photographer who obtains, through haze, clear-cut pictures of distant scenes by placing a yellow, amber, red, or infrared filter over his camera lens to exclude the short-wave portion of the spectrum. However, the application of this principle to the use of yellow glasses for night driving should not be given too much emphasis. Any gain through their use is small at best and may be overbalanced by the inconvenience of wearing glasses of any kind or by the obscuring effects of the spectacle frames.

3. Distortion of Colors of Objects

The lighter shades of tinted lenses show relatively little selective absorption in the visible spectrum, and therefore do not alter colors appreciably. Neither do the lighter shades give much protection against glare.

Glasses that are sufficiently opaque to give the eye reasonable protection from glare (that is, those having incandescent-lamp-light [3] transmittances within the range of about 10 to 60 percent) usually exhibit a considerable amount of selective absorption and may appreciably alter the colors of objects [52]. The neutral shade and smoke glasses have a roughly uniform absorption throughout most of the visible spectrum and consequently cause the least distortion of color (see figs. 9 to 15).

From their transmittance curves (figs. 5 to 8) it is readily seen that the darker shades of amethyst, Roseite, Soft-Lite, and similar glasses, possessing a strong absorption in the blue region of the spectrum, modify colors by making the greens and blues appear darker, while yellow, orange, and red tints are accentuated. Similarly, blue glasses (figs. 36 and 37) reduce the brightness of green, yellow, orange, and red objects, while blue objects appear brighter.

Amber and brown glasses absorb within the short-wave region of the spectrum. They reduce the brightness of violet, blue, and green objects but brighten reds.

The blue-green, green, and greenish-yellow glasses absorb both the violet and red ends of the spectrum, and, hence accentuate the green in vegetation. The darkest shades convert purple and red flowers to dark brown or almost black. White flowers may appear tinged with blue, green, or yellow.

As the maximum of the visual response is in the yellow-green, for wear outdoors, it has been suggested that a filter lens of colored glass having a hue in the yellow-green or greenish-yellow portion of the visible spectrum be used [13]. Glasses of this color are finding favor in aviation, automobile driving, and in recreation. The slight distortion in object color, that is, the reduction in brightness of the blues and reds, appears to be of less importance than other gains through the elimination of radiant energy, which serves no useful purpose.

The use of a vivid green glass—for example, one of the type used for aluminum welding (see figs. 32, 63, and 65), or a bright green plastic lens—should be avoided for such purposes as driving, since they may almost completely obscure a red traffic light. Similarly, an amber glass may greatly reduce the visibility of a blue-green light.

The question of confusion in colors of traffic signals by persons having defective chromatic vision (color blindness) has received extensive consideration in the summary report of the National Safety Council [14] on the use of colored glasses by motor vehicle drivers.

The most common form of defective chromatic vision is red-green blindness, that is yellow-blue vision. When it is considered that an average of about 4 persons out of 100 are color-blind (a much higher percentage among men than women), the importance of avoiding confusion of traffic signals by persons with defective color vision is evident. Because of this fact, the standard green traffic signal recommended by the American Standards Association is green to bluish-green. However, since bluish-green glass, and its position relative to the red in traffic lights, is not in universal use, the hazard of confusion of colored signals does not seem to be entirely eliminated, unless care is taken in selecting colored lenses that do not strongly absorb the blue part of the spectrum [6, 14].

4. Standardization of Sun Glass Shade Designations

The establishment of any set of shade number designations for sun glasses must of necessity be based on experience rather than upon laboratory study of the visual response (reduction in brightness sensation) of the eye. The luminance (photometric brightness) of objects or scenes under scrutiny should be such as to yield eye comfort without producing a hazard because of reduction in visibility. It is only within recent times that there has been a real attempt to standardize the various shade numbers of tinted lenses for outdoor wear, although the transmittances for glasses used in industry have been fixed for some time. Because of the multiplicity of the kinds and types of tinted lenses on the market, the shade number is often forgotten by both the dealer and consumer. However, many of the leading manufacturers of sun glasses are producing more or less standardized shades of glasses (A, B, and C, or 1, 2, and 3, with shade D or 4 sometimes added) having luminous transmittances of about 75, 50, and 25 percent (with about 10 percent for a fourth shade in some cases). The manufacturers are to

[3] Incandescent-lamp light transmittance has often been referred to in the literature by the less explicit term *total visible transmission*. In this paper, in accordance with National Bureau of Standards Letter Circular LC857, the term *luminous transmittance* is ordinarily used [51].

be complimented for this voluntary standardization.

Some of the manufacturers produce the lighter sun glass shades from the same glass as employed for the industrial glasses. The extension of this practice should result in a better and cheaper product through quantity production, and should simplify the establishment of shade numbers and prescription of sun glasses.

In the identification of shade numbers of sun glasses, it has been suggested [6] that sun glasses be designated as shades A, B, and C rather than as numbers 1, 2, and 3 in order to prevent confusion between the sun glass and industrial glass shade number designations. It was also suggested at that time that the shade A have a transmittance of 60 percent, shade B 35 percent, and shade C 25 percent. These values correspond roughly with industrial shade numbers 1.5, 2.0, and 2.5 (with corresponding transmittances of 62, 37, and 24 percent, respectively). The use of the letters A, B, and C simplifies prescription records and customer selection, and should be continued because they are in common use among ophthalmologists, oculists, optometrists, and opticians.

Since sun glasses are intended for outdoor wear, the special requirements for protection from ultraviolet and infrared rays, as prescribed in the Federal specification for industrial glasses [15], does not seem vital. If shade C does not offer sufficient protection in the ultraviolet spectrum (for example with artificial sources used in ultraviolet therapy), a suitable shade from among the industrial eye-protective glasses may be selected. Sun glasses are not intended to be worn in industrial situations and should not be used for such purpose except under qualified professional guidance. In their use for outdoor wear, any of them offers all needed protection from the ultraviolet or infrared rays of the sun. Only protection from visible rays usually need be considered, since any glass that has sufficient optical density to protect against glare usually reduces the ultraviolet and infrared radiant flux somewhat proportionally. Through the long ages during which man has lived in sunlight, the human eye has become adapted to the energy distribution of the solar spectrum. It is only when he wanders away from his usual pursuits, or location, that he gets into difficulty in seeing and requires dark glasses.

In the Commercial Standard Specifications [16] for sun glasses, the luminous transmittance is specified as follows: "The finished lenses shall transmit not more than 67 percent of the total visible light rays from a high-powered, gas-filled tungsten lamp operated at its rated voltage."

This specification rules out all light-shade sun glasses having a luminous transmittance greater than the specified 67 percent. It is, therefore, in line with the original suggestion that shade A shall have a luminous transmittance of about 60 percent.

II. Spectral Transmittances of Tinted Lenses

The various tints of lenses on the market result from the kind and amount of colorant intentionally added to the glass-forming constituent, generally a soda-lime batch.

The color of a glass may be caused by one or more absorption bands centered within the visible spectrum, or within either or both the near ultraviolet and near infrared region of the spectrum.

In view of the large number and kinds of tinted lenses covered in this report, some of which differ but little or none in transmission characteristics, the various types of colored glasses are classified according to hue—blue, blue-green, yellow-green, amber, etc.

The ultraviolet, visible, and near infrared spectral transmittances of these glasses (except in the few cases noted in the legends to the illustrations) were obtained with a Beckman quartz spectrophotometer [17, 18]. The accuracy of the instrument was carefully checked through the use of samples standardized by the photometry and colorimetry section of this Bureau. A comparison between the values obtained in the radiometry laboratory with those obtained as a mean of several methods by the photometry and colorimetry sections is displayed in figure 39.

The spectral transmittances in the infrared spectrum from 1 to about 4.5 μ were obtained by using a fluorite-prism mirror spectrometer in conjunction with a Nernst glower and a vacuum thermopile [19, 37]. All data were obtained by the point by point method.

1. Colorless Glasses

In this discussion a glass is classed as "colorless" if there is no apparent tint in the glass when viewed through a single standard thickness of about 2.00 mm.[4] If the lens is viewed edgewise, a practically colorless glass may show a distinct color.

The most representative example of colorless glass, commonly used in spectacles, is called light crown (see fig. 1). It is a soda-lime glass (refractive index $n=1.523$), prepared from relatively pure materials (including sand) containing a very low concentration of iron oxide, which imparts a greenish tint to common window glass (fig. 3). On the other hand, one of the most useful materials

[4] Although there is no specification covering thickness for sun glasses, 2.00 mm has been considered standard by many people. If the glass is much thicker, the spectacles are heavy. If appreciably thinner, the glass has insufficient strength and may become a hazard because of danger of shattering into the eyes.

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intentionally added to the batch to produce a colored eye-protective glass, is ferrous oxide [20, 21, 22].

Commercially produced soda-lime glass usually contains a greenish tint, which may be neutralized by the addition of a small amount of manganese or selenium to the melt if it is desirable that the manufactured product, for example a food jar or a milk bottle, be free of the green coloring. On solarization, the glass that is decolorized with selenium shows a brownish tint similar to a light smoke, and the glass decolorized with manganese appears pink or deep amethyst (see figs. 5 to 8). Good illustrations of amethyst-colored glass are certain globes inclosing carbon arcs used in street lighting, and discarded bottles that have been exposed to sunlight. Because of this color change upon solarization, selenium is more commonly employed, since it changes more slowly in color upon exposure to ultraviolet radiant energy.

The light shades of Viopake (fig. 2), Cruxite fig. 4), Crookes (figs. 9, 10), Roseite (fig. 6), Soft-lite (fig. 7), Velvet-Lite (fig. 8), and Azurlite (fig. 38), and the glasses identified as Acutone, Di-antholite, Avitint (fig. 1), Filtray [2], and Thermi-non (fig. 3), are practically colorless in a thickness of 2.00 mm and may be considered colorless for all practical purposes as sun glasses. The spectral transmittances of these glasses throughout the visible spectrum are fairly uniform and in most cases well above 80 percent, so that they offer little or no protection from glare. Some of them contain cerium oxide, or other constituents that render them more opaque to the shorter wave-lengths of the ultraviolet spectrum than light crown glass, so that they may be useful where one is working around artificial sources.

2. Amethyst Glasses

Typical examples of this type of glass are Amethyst (fig. 5), Roseite (fig. 6), Soft-Lite (fig. 7), and Velvet-Lite (fig. 8). Old Rose, Roselite, Sportone, and Kromatone are other glasses (or other trade names) belonging to this same classification. Rose Smoke (fig. 17) is a slight modification.

In the early days of glass manufacture, amethyst glasses were common in the form of solarized windows, gas light chimneys, etc., before the manufacture of true amethyst glass. It is reported that the celebrated oculist, Dr. William Thompson of Philadelphia, in the latter part of the past century, suggested the use of amethyst-tinted glasses in cases of asthenopia [33]. Optical glass of that color being obtainable only with difficulty at that time, the opticians secured material through removing old window-panes. It was difficult to distinguish the difference between real amethyst glass and amethyst-colored solarized glass. However, upon heating, the solarized material returns to the clear state, whereas the truly amethyst material changes little in color.

3. Neutral-tint Glasses

Representative examples of this type of lens used in spectacles are Smoke (figs. 11 to 14), Crookes [41] (figs. 9, 10), Cruxite (fig. 4), and Polaroid (fig. 15) glasses. The smoke glasses were obtained from various sources and have slightly different compositions, which alter their spectral transmittances and degree of neutrality of shade. All of these glasses, especially Polaroid, are characterized by a roughly constant spectral transmittance throughout most of the visible spectrum. The Cruxites differ from the smoke glasses in having much greater absorbance (or optical density) in the ultraviolet as a result of the addition of cerium oxide. The Crookes glasses have additional absorption bands resulting from the incorporation of didymium (didymium is a mixture of the elements neodymium and praseodymium, see reference [19]) as well as cerium oxide. The darker shades of the Crookes glasses are apparently obtained through the use of a smoke glass as a base. If only a small amount of didymium oxide is added, only the stronger absorption bands appear in the transmittance curves. If sufficient didymium oxide is added to a glass, a relatively neutral tint may be obtained by the use of this material alone in what would otherwise be a colorless glass (see fig. 69). The Germans produced a neutral sun glass for use on submarines through the addition of didymium to what would otherwise have probably been a light smoke glass (see fig. 72).

The Umbral glasses [6] made by Zeiss are smoky-brown in color. The three shades transmit about 25, 50, and 75 percent, respectively, of the visible rays. The darkest shade is opaque to ultraviolet of wavelengths shorter than about 350 mμ and has considerable selective absorption in the region of 1,000 mμ. The spectral transmittance of Umbral glass is lower in the ultraviolet and in the near infrared than the ordinary smoke glasses and is similar to Willsonite Neutral (see fig. 14).

The high transparency at 400 to 430 mμ in the smoke glasses has but little effect upon the colors of objects viewed in daylight. In the case of the dark shades, as a result of the increased relative transparency in the red (see figs. 11 and 12) objects, like the sun,[5] viewed through them have a slightly reddish tinge. The dark shades of smoke are finding favor for use by aviators, especially in the U. S. Navy, because they distort colors but little.

The Polaroid glasses examined consist of films of light-polarizing material (fine imbedded crystals) between glass plates of clear or light colored glass. Spectral transmittance curves for these

[5] In no case should the sun be observed through any of the available sun glasses—use a shade 10 to 12 welding glass for this purpose.

are given in figure 15. The neutral sample, which consisted of polarizing material between light blue-green glass plates is the best example of a neutral filter of any examined for this report. The degree of protection in the ultraviolet and infrared offered by these filters depends entirely upon the composition of the glass used in their manufacture. The infrared transmittance of the samples examined was high.

Plastic Polaroid lenses have similar transmittances in the visible spectrum. The degree of protection in the ultraviolet and infrared depends on the properties of the plastic used in their construction.

The use of polaroid glasses (or plastic lenses) for the reduction of reflected glare from roadways, water, sand, snow or ice, automobile surfaces, etc. where a large component of the reflected light is polarized is found to be helpful. Although the luminous transmittance for these glasses is of the order of 30 to 40 percent for nonpolarized light, the transmittance for the light reflected from surfaces may be much lower due to its partially polarized character. These glasses are often worn for eye-protection in driving or in sports, to mitigate the glare reflected from surfaces. Because of the greatly reduced light flux from specularly reflecting surfaces, the wearing of these glasses appears to turn a bright sunlight scene into that of a cloudy day. Visual acuity is increased as the result of this diminution of light from reflecting surfaces within the field of view.

During World War II, a submarine search goggle incorporating single rotatable polaroid lenses was employed by the U. S. Navy to reduce the effect of sunlight glare from water surfaces, thus enabling the seamen to spot submarines even though they chose to approach the surface in direct line with the solar reflections on the water surface. By the use of a variable density double polaroid goggle, it was possible for gunners to follow tracer ammunition in the daytime. The optical density was made variable by the rotation of one pair of lenses relative to another.

4. Amber Glasses

The spectral transmittance curves of amber glasses are shown in figure 16. In these glasses, there is considerable absorption in the ultraviolet, and especially in the darker shades the blue and violet rays are strongly absorbed. The infrared transmittances of these glasses is ordinarily relatively high, being but little less than that for the colorless glasses.

Because of the high selective absorption in the blue and violet, deep-colored amber glasses are likely to dim bluish traffic signals [14] and cause confusion in driving. In no case should a person, having defective chromatic vision (any degree of color blindness) wear amber or yellow glasses while driving, because they may cause the green and red traffic signals to be confused.

5. Yellow Glasses

Among the yellow glasses are the Noviols (fig. 18), Kalichromes, Night-Lite, Willson Gold (fig. 2), and Yellow Shooting, Night Driving or sun glasses (fig. 1), having spectral transmittances similar to that of Noviol C. These glasses are yellow because they either reduce or eliminate the blue and violet regions of the spectrum.

The use of yellow glass for night driving and in increasing visual acuity was discussed in the introductory statements. They should never be worn in driving (day or night) by a person having defective color vision; but may be found quite useful by persons having normal vision for wear on cloudy days or when blue haze or fog is present. Their high luminous transmittance renders them of little use in protecting the eyes against glare on bright sunny days.

For the same reasons that yellow glasses are sometimes helpful in night driving, they may serve a useful purpose around industrial operations carried on by night wherein bright lights are encountered, for example, by the field personnel at airports who handle the loading, unloading, towing, refueling of planes, etc.

6. Yellow-Green Glasses

Typical examples of yellow-green glasses are Euphos, Fieuzal, Chlorophile, Hallauer, and Akapos [3, 42, 43] (see figs. 19 and 20). These glasses not only have high absorption in the ultraviolet, violet, and blue, but have selective absorption within the visible spectrum, which produces a smoky-greenish yellow, a chlorophyl green, or a sea green color. Their infrared transmittance is high, as would be expected from the general trend of the transmittance curve in the longer wavelengths of the visible spectrum. They have been replaced by the nonuranium [6] glasses wherein color characteristics are obtained through the use of ferrous iron oxide, which usually results in a glass having a bluish green tint. If, however, a large part of the iron is reduced to the ferric oxide state, the glass shifts in color toward the yellow so that a greenish-yellow or yellowish-green glass may result [21, 34]. Early Noviweld glasses [6, 40] had a transmission maximum in the yellow region of the spectrum. Early productions of Willson-Weld [6] were yellowish-green in color.

7. Blue-Green Glasses

Typical examples of blue-green glasses are Antiglare, Aviation glass, Calobar, Contra-Glare,

[6] Uranium compounds formerly used in the manufacture of some of the yellow-green glasses have been reserved for governmental atomic work.

Cool-Ray, Ray-Ban, Willsonite, etc. (see figs. 21 to 33).

These glasses are characterized by practically complete opacity in the ultraviolet and in the infrared. Although they distort colors slightly through a relatively greater absorption in the red and blue ends of the spectrum, they do not tend to cause confusion in distinguishing colored traffic signals. They are similar in character to the darker shades used in industry. In fact, in a number of cases they are manufactured from lighter melts of the same type of glass.

Glasses in this color range have become the most popular of all colors for general outdoor sunlight protection.

Among similar glasses which are greenish yellow, blue-green or sage green in color and on which transmittance curves are not given in this report are Sun Rest, Opti-Ray, Sun Ray, Noglair, Screen Star, Absorb-o-Ray, Retna-Ra, Sunmaster, Olivette, Emerlite, Green-Ray, Ma-Lite, Mildray, Idealite, Glare-Bar, etc. It is not expected that the spectral transmittance curves of these would be appreciably different from those displayed in the illustrations to which reference is made above.

8. Blue Glasses

Typical examples are the deep cobalt-blue glasses (figs. 36 and 37) and the pale-blue Azurlite (Azurine), glasses (fig. 38). The latter type is similar to the pale blue Corning glass, G171 (see fig. 28).

The cobalt-blue glasses absorb selectively in the green, yellow, and orange-red. The pale-blue glasses, prepared from copper oxide, have an absorption band in the infrared that extends into the visible spectrum, giving it high absorption in the red.

The cobalt-blue glasses have a characteristic absorption band at 1,500 mμ in the infrared [19, 20]. The pale-blue glasses have a characteristic maximum of absorption at about 900 mμ, followed by high transparency at 2,000 mμ in the infrared [19]. Hence, neither glass would be useful for completely absorbing the infrared.

Other trade names of glasses having practically the same color as azurlite are Pittsburgh Blue and Bluelite.

The blue glasses, in the lighter shades, offer little or no protection from glare or from ultraviolet or infrared radiant energy. As a matter of fact, the high transmittance in the near ultraviolet and blue, together with the lower transmittance values in the green to yellow region of the spectrum where the luminosity values are high mitigate against the use of this type of glass in driving or in other outside activities.

III. Eye-Protective Glasses for Use in Industry

When glasses are worn for protection of the eyes in industry, a number of things must be taken into consideration, such as possible injury from flying particles, moving machinery or other obstructions encountered in moving about, radiant energy emitted by equipment operated by others, etc., as well as the ultraviolet, visible, and infrared energy emitted by the operator's equipment. This paper is devoted primarily to eye-protective glasses from the standpoint of protection through absorption of the ultraviolet, visible, and infrared rays.

The elimination of harmful ultraviolet rays in industrial operations must be given first attention, because they will produce great injury without a warning of any kind. It is only after the damage has been done (some 4 to 6 hr later) that their effects begin to appear in the form of a "sand in the eyes effect" (conjunctivitis). Although a small amount of ultraviolet may not produce permanent injury to the eyes, the only safe procedure to follow in writing specifications is to exclude completely all harmful ultraviolet rays. The infrared rays are given second consideration, because, their action being thermal, the worker is generally forewarned by the burning sensation that is felt immediately on viewing sources emitting intense infrared radiation. Although there is less danger of injury in this case, and in many industrial operations there is not sufficient infrared to produce permanent injury, nevertheless, no risk should be taken. Hence, the Federal Specifications [15] for eye protection of industrial workers are very stringent in requiring the elimination of both the ultraviolet and infrared rays from harmful sources of radiant energy.

The Federal Specifications require that a filter glass almost completely absorb both the ultraviolet and infrared rays. In order to conform with these specifications, there must be high absorption also in the blue and red ends of the visible spectrum. Hence, the resulting glass must have its maximum of transmittance somewhere within the spectral region of bluish-green to greenish-yellow. If the glass has a relatively low spectral transmittance elsewhere, it would have nearly the maximum possible luminous transmittance relative to the radiant energy reaching the eye. For most industrial operations, the resulting bluish-green to greenish-yellow color is satisfactory. In other operations where, for example, a special blue or green glass is required, special considerations must be given to the absorption of ultraviolet and infrared radiant energy.

The luminous transmittance of a glass determines its suitability for a particular operation (after its ultraviolet and infrared characteristics are taken care of). The relation between mean optical density, luminous transmittance, and shade number of eye-protective glasses is given by the following formula [2, 5, 6]:

$$\text{Optical density} = 3/7\ (\text{shade number} - 1) = \log^{10}\left(\frac{1}{\text{transmittance}}\right).$$

In this formula the optical density has the usual meaning, being the logarithm of the opacity; that is, the logarithm of the reciprocal of the transmittance. For example, shade No. 8 (see table 1) has a density of 3.000, and (since 3 is the logarithm of 1,000) consequently a transmittance of 0.100 percent.

TABLE 1. *Transmittances and tolerances in transmittance of various shades of filter lenses*

The values given apply to class I filter glass. For class II filter lenses the transmittances and tolerances are the same with the additional requirement that the transmittance at 589.3 mμ shall not exceed 15 percent of the luminous transmittance. Some of the headings in this table have been changed to conform with NBS Letter Circular LC857)

Shade Number	Optical density			Luminous transmittance			Maximum infrared transmittance	Maximum spectral transmittance in the ultraviolet and violet			
	Minimum	Standard	Maximum	Maximum	Standard	Minimum		313 mμ	334 mμ	365 mμ	405 mμ
				Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1.5	0.17	0.214	0.26	67	61.1	55	25	0.2	0.8	25	65
1.7	.26	.300	.36	55	50.1	43	20	.2	.7	20	50
2.0	.36	.429	.54	43	37.3	29	15	.2	.5	14	35
2.5	.54	.643	.75	29	22.8	18.0	12	.2	.3	5	15
3.0	.75	.857	1.07	18.0	13.9	8.50	9.0	.2	.2	0.5	6
4.0	1.07	1.286	1.50	8.50	5.18	3.16	5.0	.2	.2	.5	1.0
5.0	1.50	1.714	1.93	3.16	1.93	1.18	2.5	.2	.2	.2	0.5
6.0	1.93	2.143	2.36	1.18	0.72	0.44	1.5	.1	.1	.1	.5
7.0	2.36	2.571	2.79	0.44	.27	.164	1.3	.1	.1	.1	.5
8.0	2.79	3.000	3.21	.164	.100	.061	1.0	.1	.1	.1	.5
9.0	3.21	3.429	3.64	.061	.037	.023	0.8	.1	.1	.1	.5
10.0	3.64	3.857	4.07	.023	.0139	.0085	.6	.1	.1	.1	.5
11.0	4.07	4.286	4.50	.0085	.0052	.0032	.5	.05	.05	.05	.1
12.0	4.50	4.714	4.93	.0032	.0019	.0012	.5	.05	.05	.05	.1
13.0	4.93	5.143	5.36	.0012	.00072	.00044	.4	.05	.05	.05	.1
14.0	5.36	5.571	5.79	.0004	.00027	.00016	.3	.05	.05	.05	.1

The formula is simple and correlates the densities of the different shade numbers in such a way that if the sum of the densities of any two shade numbers is taken, it will be that for a shade number one less than the sum of the two shade numbers concerned. For example, take the denstities of shades 3 and 8, which are 0.857 and 3.000 and whose sum is 3.857, the density of shade No. 10 (3+8−1=10). In a similar manner, the transmittance of a given shade number is 1/1,000, or 0.1 percent of that for a glass seven shade numbers lighter.

1. Purpose of Goggles

The general function of protective goggles as covered by Federal Specifications, when fitted with the proper filter lenses and cover glasses, is to protect the eyes of the wearer from ultraviolet and infrared radiant energy, to reduce the luminous flux (rate of flow of visible radiant energy) to the proper level to view in comfort the operation at hand, and to protect against injury from flying particles, molten metal, etc. The use of proper goggles should offer ample protection in gas welding and cutting, and in electric cutting and welding up to 30 amperes.

According to the Federal Specification [15],[7] "shade numbers 1.5 to 3.0, inclusive, filter lenses are intended for stray light from cutting and welding.

"Shade number 4 filter lenses are intended for the same use as shades 1.5 to 3.0, inclusive, under conditions of greater light flux.

"Shade number 5 filter lenses are intended for light gas cutting and welding and for light electric spot welding.

"Shade numbers 6 and 7 filter lenses are intended for gas cutting, medium gas welding, and for arc welding up to 30 amperes.

"Cover glasses are intended as a protection against pitting of the filter lenses."

In table 1 are given the transmittances and tolerances in transmittance (also densities and tolerances in density) of the various shades of eye-protective glasses. These values have been revised slightly from the original Federal Specifications and are under consideration for inclusion in the new revision to bring the optical density and transmittance data into precise line with the density-transmittance formula and to include all optical density and transmittance values within

[7] Material under this, and the two sections following enclosed within quotation marks, has been copied from the Federal Specifications without significant change in wording.

some shade value, thus insuring against the waste of material in manufacture. The maximum optical density for a particular shade must not exceed a certain value, which in turn must be exceeded by the next higher shade number. Hence glass of all densities within the range between shades 1.5 and 14.0 falls into a definite shade classification.

In addition to the general protective goggles for welding and associated industries, special goggles are available for other purposes. Among these are the chipper's goggle, combustion goggle, flying goggle, sun goggle, contrast goggle, the variable optical-density goggle, the single rotatable submarine search goggle, and the dark adaptation goggle. The chipper's goggle is not considered in this report, since it has no selective optical characteristics that have any particular significance in its use. The variable optical-density and the submarine search goggle are for use in the reduction of solar glare and are discussed under the heading of neutral-tint glasses. The dark adaptation goggle is for use in producing a condition of dark adaptation of the eye, so that one may be enabled to see better at night or under very low levels of illumination. It was used during World War II by the armed forces engaged in night fighting, such as antiaircraft crews, night pilots and gunners, and by the commandos. It was found that if the eyes were kept shielded from radiant energy of all wavelengths shorter than about 580 mμ, the observer possessed "cat" eyes at night.

2. Purpose of Welders' Helmets and Hand Shields

The general function of the welders' helmet and hand shield, when fitted with the proper filter lenses and cover glasses for the operation at hand, is to protect the eyes, face, head, and neck from heat and injurious radiant energy encountered in any gas or electric welding or cutting. The use of the hand shield often makes the work more accessible while offering sufficient protection and is preferred for some operations. It is sometimes employed by inspectors and supervisors where their work does not require the use of both hands.

According to the present Federal Specifications [15], "shade No. 8 filter glasses are intended for heavy gas welding and for arc welding and cutting when using over 30, but not exceeding 75 amperes.

"Shade No. 10 filter glasses are intended for arc welding and cutting over 75, but not exceeding 200 amperes.

"Shade No. 12 filter glasses are intended for arc welding and cutting over 200, but not exceeding 400 amperes.

"Shade No. 14 filter glasses are intended for arc welding and cutting over 400 amperes.

"Cover glasses are intended as a protection against pitting of the filter glasses." They are sometimes coated with a plastic to reduce the effect of weld splatter.

Although shade numbers 9, 11, and 13 are not mentioned in this list of intended uses in the Federal Specifications, it is not the intention of the Safety Equipment Committee to rule against them in any way. For certain persons and uses they may be found more suitable than one of the even-number shades for use in the job at hand.

Recent experience in high-amperage arc welding indicates that the shade numbers suggested in the Federal specifications are about 1 to 2 shades too dark for the operation at hand. Based on tests made by the author, and as the result of consultations with other members of the staff of this Bureau, the Safety Equipment Committee for the Federal Specifications, and the Navy Department, it appears that for arc welding within the range of 200 to 500, shade 9 or 10 welding glass should be suitable in most cases. There appears to be little difference in the requirement for a large change in amperage. This is probably due partially to the fact that as a heavier current is employed the metal temperature rises relatively little but the hot spot simply extends over a greater surface area. Furthermore, with the heavy currents, more heat is radiated so that the operator usually moves a little farther away from his work, which is equivalent to increasing the density of the protective glass. Two other factors, namely, the type of rod employed (or no rod at all in some of the new welding processes wherein argon or helium is employed to enclose the welding operation), and the operator's individual eye requirements govern to a certain extent within at least one shade number the density of glass required for a given operation.

With the advent of didymium glasses in the darker shades (see figs. 53 to 62), the type of welding rod has little effect upon the light reaching the eye, since its strong sodium lines are highly attenuated. In these cases it may be possible to use a glass several shades lighter if a didymium glass is employed. This becomes an advantage in that the operator has a higher visibility of conditions surrounding the center of the welding operation. The above statements may be summarized by saying that within reasonable limits the privilege should be left to the individual to choose the desired shade of protective glass for his particular pair of eyes and operation.

The transmittances and tolerances in transmittance (also densities and tolerances in density) of the various shades of helmet windows are given in table 1.

3. Radiant-Energy Tests for Filter Lenses

The Federal Specifications [15] require that al filter glasses shall be tested for their transmission qualities according to the following methods:

(a) Ultraviolet

"The source of radiant energy for determining the ultraviolet spectral transmittance shall be a quartz mercury arc or other source emitting an intense and preferably discontinuance spectrum. The intense emission lines of the quartz mercury arc at 313, 334, 365, and 405 mμ are conveniently distributed and well adapted for making these measurements. If other sources are used, the wavelengths closest to the above values of the mercury arc may be used.

"If a high-powered (2,000- to 3,000-w) gas-filled tungsten lamp (which is especially strong in infrared radiant energy) is used as a source of ultraviolet radiant energy, then special precautions shall be taken to eliminate the effect of scattered visible and infrared energy from the measurement in the ultraviolet.

"If a spectroradiometer is used, its optical parts should be of quartz or other material transparent to the extreme ultraviolet. To eliminate the effect of scattered radiant energy, especially in the extreme ultraviolet, the shutter used in admitting the radiant energy of the source into the spectroradiometer while taking the zero readings should be of red or yellow glass that is opaque to ultraviolet energy." With the use of a quartz ultraviolet spectrophotometer, for example, the Beckman [17, 18], the effect of scattered radiant energy may be almost completely eliminated through stepping from one filter glass to another in density steps not exceeding 1.000. This method was employed in obtaining the transmittance curves (for the darker shades) displayed in this report.

In place of a spectroradiometer for determining the opacity of filter lenses at different wavelengths in the ultraviolet, suitable photoelectric cells and filters may be employed to compare the transmittance (given in table 1) in wide bands of the ultraviolet [6, 15].

The apparatus for this work consists of a quartz mercury-arc lamp as a source, in front of which is placed a photoelectric cell (with or without a filter) and a shutter to admit radiant energy to the photoelectric cell. By interposing, in succession, the unknown and the same shade of a standard sample, a measurement is obtained of the protective property of the unknown glass. For example, a photoelectric cell of Cd, or of Ti, which is insensitive to radiant energy of wavelengths longer than 320 mμ connected with a high-resistance galvanometer, with an amplifier and microammeter, or with a Rentschler "impulse" ultraviolet meter [23] may be used to compare the transmittance of the unknown filter lens with that of the same shade of a standard sample to energy of wavelengths shorter than 320 mμ. This is the most important part of the spectrum to be eliminated, because radiant energy of wavelengths shorter than about 320 mμ causes conjunctivitis, coagulation of albumin, and ("sunburn") erythema.

By using a photoelectric cell of cerium [24], which is sensitive to wavelengths shorter than 410 mμ, covered with a filter glass, Corning No. 5860 [25], which has a maximum transmittance at 365 mμ, a measurement is obtained of the transmittance of the unknown sample relative to that of a standard sample, at the wavelengths 334 and 365 (principally 365) mμ in the quartz mercury arc.

By covering the Ce cell with a filter of shade *O* Noviol glass (fig. 18), which is opaque to 365 mμ, a measurement is obtained of the transmittance of the unknown sample relative to that of the standard sample at 405 mμ, which is used as the long wave end point in specifying the spectral transmittance in the ultraviolet (table 1).

Most of the filter glasses manufactured in recent years absorb the ultraviolet so completely that it is possible to obtain the information desired on an unknown sample by a single measurement with the cerium cell, with and without the use of the Noviol filter. If a further analysis is required, the photoelectric cell can be covered with the Corning filter No. 5860, and a measurement made of the transmittance in the region of 365 mμ. Only as a last resort is it necessary to make a measurement with a Cd or Ti cell to test the transmittance at 320 mμ and shorter wavelengths.

(b) Visible

"The standard source of radiant energy used in the measurement of the luminous ('light') transmittance of filter lenses shall be a 500-watt (or other high powered) gas-filled tungsten filament electric incandescent lamp operated at rated voltage. The luminous transmittance shall be determined photometrically by an observer having normal color vision, as determined by the Holmgren test for color vision; or with a physical photometer consisting of a thermopile (or other radiometer) with a luminosity solution" or filter in a combination such that the spectral response of the photometer shall coincide closely with the luminosity curve of the average eye; or by means of a spectrophotometer and calculation of the luminous transmittance through the use of spectral luminosity data [26] for a lamp operated at rated voltage (temperature near 2,848° K). "Class No. II filter lenses (those for welding with sodium fluxes) shall have the transmittance at the sodium line measured by means of a suitable spectroradiometer and a sodium arc lamp, or other lamp producing spectrally homogenous light at 589.3 mμ."

(c) Infrared

"The same standard source of radiant energy used in determining luminous transmittance shall be used also in the measurement of the infrared transmittance.

"The infrared transmittance shall be determined either by observing the infrared spectral-energy-distribution curves of a gas-filled lamp with and without the lens placed before the entrance slip of the spectrometer, and integrating the area under each of the two curves between the spectral limits 700 and 4,000 mμ; or by covering the radiometer receiver with a deep-red glass" (e. g., Corning glass 2404), which has a high and fairly uniform transmittance through the infrared spectrum and transmits less than 5.0 percent of the visible radiant energy (see fig. 91). The use of Corning red glass 2404 is recommended by the National Bureau of Standards. Samples having transmission characteristics closely approximating that shown in figure 91 may be obtained from the Bureau.

IV. Spectral-Transmittance Data on Special Filter Glasses

The stringent requirements of the Federal Specification for eye protection [15] has reduced the number of colored glasses that are suitable for use in protecting the eyes of industrial workers. Many of the sun glasses (tinted lenses) described in this paper are unsuitable for use in industry because of high ultraviolet or infrared transmittances or because of poor mechanical or optical characteristics. Only those glasses that generally conform in mechanical and optical properties with the Federal Specification will be considered in this discussion.

Glasses suitable for welding and associated operations are necessarily very opaque to both the ultraviolet and infrared regions of the spectrum. In the accompanying illustrations the spectral transmittances are given within the range of 300 to 900 mμ, and for some of the lighter shades through the infrared to about 4,500 mμ.

Since the optical densities of the darker shades are very high (transmittances very low), it was necessary to use special methods to obtain accurately the spectral transmittances in the visible spectrum and the corresponding luminous transmittances. For this purpose, and with the cooperation of E. L. Hettinger (of Willson Products, Inc.), sets of transmittance standards have been established for all shade numbers.

The establishment of standards of optical density was first attempted a number of years ago through the use of density wedges [2] with measurements being made by a number of observers. Several defects in this method soon became apparent. It was found that individuals who presumably possessed normal color vision obtained different readings [39] with a photometer; also that the same individual obtained variable readings depending upon previous activities, time of day, etc. The whole process became confused—including the use of density wedges—so that the entire idea was discarded in favor of using spectral transmittance measurements, together with luminosity data for a standard of color temperature [26, 38].

Samples of welding glass having transmittances near the minimum and maximum densities (or percentage transmittances) for the various shade numbers were selected and their spectral transmittances accurately determined with a Beckman quartz spectrophotometer [17, 18] at 10-mμ intervals within the spectral range of 400 to 760 mμ. These values were then transformed into luminous transmittances through the application of luminosity factors [26] for a complete radiator (black body) at a color temperature of 2,848° K (which value is near the normal for a 500-watt gas-filled lamp).

In establishing these standards, a group of three primary standards was set up through intercomparisons within a group of about 25 glasses ranging in density from shade No. 1.5 to 6.0. That is, in this work, first a group of light shade glasses was measured on a Beckman quartz spectrophotometer and then each compared with a dark sample of Calobar, identified as *DK*, which became standard No. 1. Next, a second group of glasses having densities near the values for shades 2.5 and 3.0 was compared with standard No. 1 and with a certain Willson-Weld shade No. 3 glass, identified as 3*A*, which became standard No. 2. Finally, a third group of glasses having densities ranging from the values for shade 5 to shade 6 was compared with standard No. 2 and with a certain Bausch and Lomb shade 6 glass, identified as 6*A*, which became standard No. 3.

In order to verify the accuracy of this work, a check measurement was made by the photometry and colorimetry section of this Bureau on standard No. 3 (identified as 6*A* in fig. 39), by measuring its spectral transmittance at various wavelengths from 390 to 740 mμ on two Beckman photoelectric spectrophotometers (directly and through the use of other standards) and on a Koenig-Martens spectrophotometer [27] at the same wavelengths from 435.8 to 660 mμ. The values indicated by dots (see fig. 39) were obtained by the photometry and colorimetry section, and those indicated by circles were observed by the author. The very close agreement (at 4 points the values coincide exactly) between the two laboratories is gratifying.

Using the three standards (Nos. 1, 2, and 3) identified as *DK*, 3*A*, and 6*A*, the samples of welding glass having transmittances near the minimum and maximum density values of the various shade numbers were accurately measured with the Beckman spectrophotometer. The lighter shades were determined directly, shades between 1.7 and

3.0 by comparison with standard *DK*, those between 3.0 and 6.0 by comparison with 3*A*, and those above 6.0 by comparison with standard 6*A*. Supplementing these measurements, comparison checks were made between the different samples and with the group of 25 glasses used in standardizing the three standards. Hence we have a group of standards representing values near the minimum and maximum densities of the different shade numbers. These standards serve a useful purpose in establishing the shade number of welding glass by simple photometric comparisons. For further information regarding these standards, reference should be made to a paper on that subject [50].

1. General-Purpose Welding Glasses

Under this heading may be classed the standard (class I) welding glasses, Arc-Ban, (figs. 40 to 43) Cescoweld (figs. 44 and 45), Filterweld (fig. 46), Noviweld (figs. 47 and 48, and Willson-Weld (figs. 49 to 52). These glasses are similar in characteristics except for small variations in color. The Noviweld samples have their maximum transmittance at slightly longer wavelengths, giving that glass a distinct yellow-green or greenish-yellow tint as compared with a blue-green for Arc-Ban, Cescoweld, Filterweld, and Willson-Weld. All of these glasses have very low transmittances in the ultraviolet and infrared, even for the lighter shades, and when properly selected for shade number meet the requirements of the Federal Specifications on filter glasses for use in goggles, helmets, and hand shields for use in welding and associated industries.

The high opacity of the class I welding glasses for the ultraviolet and infrared regions of the spectrum insures complete protection of the eyes when working with any source of radiant energy encountered in industry, provided the proper shade number for clear seeing is employed. Since there are differences between individuals, the exact shade number for a particular operation must be chosen through trial by the operator himself for best results in his work. However, the shade numbers are well established, and once an operator has determined the right density of glass for his eyes, replacement may be made without further tests.

In some cases the lighter shades of welding glasses are used, with adjusted thickness, in the manufacture of sun glasses, for example Ray-Ban (compare figs. 25 and 40) and Willsonite (compare figs. 26, 27 and 49). Similarities between the transmittance curves for Contra-Glare (fig. 24), Aviators glass (figs. 3 and 28) Antiglare (figs. 3 and 23), Cool-Ray (fig. 22), Calobar (fig. 21) and the lighter shades of class I welding glass indicate either identical or similar compositions and source of supply.

2. Special Glasses for Sodium Light and Aluminum Welding

In operations, such as welding with coated rods or in aluminum or magnesium welding, producing high radiant flux at the wavelengths of the sodium lines at 589.3 mμ, the use of glasses containing didymium (class II filter lenses) has been found very useful. Recently, glasses of this type in shades ranging from No. 3 to No. 10 (see figs. 53 to 62) have been developed. These glasses are similar to class I filter glasses in ultraviolet, visible, and infrared characteristics, except that they contain in addition sufficient didymium to reduce their transmittance in the region of 589.3 mμ to a relatively low value. Other absorption bands characteristic of didymium are present but add or detract little from the usefulness of the glass. It appears that all of these glasses contain about the same amount of didymium, as judged from the relative depths of the absorption bands, the darker shades being obtained simply through the use of the denser base glass.

These glasses remove almost completely the bright sodium glow surrounding welding or cutting operations, enabling the operator to view his work clearly. A further improvement is usually possible through the use of a lighter shade thus gaining added visibility of details surrounding the center of operations. However, oftentimes, the operator has trouble in adapting his welding operations to the use of these glasses, since they alter the orange and red values so that he may overheat the metal or weld it to his work table until he has become accustomed to their use.

Other glasses previously developed for use in aluminum welding are shown in figures 63, 64, and 65. All of these reduce the sodium (589.3 mμ) and lithium (670.8 mμ) radiant flux to a low value and will be found useful, and in many cases preferable to the special didymium welding glasses, in aluminum or magnesium cutting and welding because they have also high absorbance in the red. Alubro-Weld is available in three special shades and offers ample protection in the infrared. The lighter shades give insufficient protection in the ultraviolet. The Burt-Weld and G–1 Aluminum welding glasses offer complete protection in the ultraviolet, but have high transmittances in the infrared. None of these glasses conform with the Federal Specifications as now written. It is possible that slight modifications in their composition would result in increased opacity to the invisible rays without appreciably changing their optical characteristics in the visible spectrum. As effort should be made along this line, since these glasses are preferred to the special didymium welding glasses (see figs. 53 to 62) by many workers in aluminum welding operations because they cut out the red more effec-

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tively and appear to offer a higher degree of visual acuity.

In view of the fact that in aluminum welding infrared radiant energy is low as a consequence of the relatively low melting temperature of the metal coupled with its low emissivity, it follows that the required infrared protection in this type of work is less important than is the case with the ferrous metals. Since this is true, and no case of injury from infrared radiant energy in aluminum welding has come to the attention of this Bureau, it is the author's opinion that the provisions of the Federal Specifications referring to infrared as applied to glasses for aluminum welding might well be reconsidered to allow a higher infrared transmittance. Even when using a glass of the types illustrated in figures 63 to 65 for aluminum welding, less radiant heat will reach the eye than when one is welding at high amperages on steel while using a standard shade 10 glass, because the shade 10 glass will itself heat up from the arc and steel and will thus reradiate an appreciable part of the absorbed energy onto the eye.

3. Melters' Blue Glasses

Special blue glasses known by various names as Melters' Blue, Cobalt Blue, Pugh Glass, and Ohio Blue, are available in as many as six to eight slightly different densities, usually according to thickness. Representative samples were examined and their transmittance curves reproduced in figures 65, 66, and 67. This type of glass is demanded by operators of open-hearth furnaces, etc., in the particular shade with which the operator is familiar, because of the contrast in brightness that is obtained between the molten metal and the interior of the furnace. Viewed through these glasses, green vegetation (leaves, grass, etc.) in sunlight appears red on the lower surfaces. These cobalt glasses have high transmittances in both the ultraviolet and infrared regions of the spectrum. The addition of cobalt does not reduce the ultraviolet transmittance of a glass. The presence of a small amount of stannous chloride (added intentionally or as an impurity) increases the permeability of a glass to ultraviolet radiant energy by reducing the ferric iron to the ferrous state [28]. In view of the usefulness of this glass in furnace work, experiments were conducted at the Bureau [29] some years ago by adding cerium oxide to eliminate the ultraviolet and ferrous iron to absorb the infrared. Copper is sometimes employed to absorb the infrared and red. With the resulting blue glass, a red object appears to be black. Some German glasses having high red opacity are shown in figure 37.

The special blue glasses as now manufactured do not contain cerium and ferrous iron oxides (or other possible materials) to absorb the harmful ultraviolet and infrared rays and therefore cannot be classed as fully protective. However, when used for only a short time each day, as is usually the case in furnace work, the requirements for protection from invisible radiant energy should be less stringent than applies in prolonged welding operations. There is therefore a need for a special specification on Melters' Blue glasses for furnace work. Until such is available, all operators should be cautioned against prolonged use of present blue glasses.

4. Bessemer Furnace Glass

The Bessemer lens (see figs. 68 and 89) is a dichromatic filter having transmittance bands in the green, near 560 mμ, and in the red above 650 mμ. This lens was developed [30] to replace combination yellow, blue, and red imported glasses, and blue-amber domestically produced glasses for use by the Bessemer blower in estimating certain color changes of the flame in the Bessemer steel making process.

During the production of steel and cast iron by the Bessemer process, metal containing various impurities (primarily silicon, magnesium, and carbon) is loaded into a vessel and a blast of air shot through it for a period of 15 to 20 minutes. This oxidizes and then burns off the impurities in the order listed with a distinctive color for each oxide. As the "blow" progresses, the temperature of the material increases because of the rapid oxidation. The operator depends upon a photoelectric and visual observation of the colors of the burning gases in determining the proper point at which to stop the "blow" and to pour the metal.

5. Glass-Blowing Lenses

In view of the fact that ordinary glass contains large amounts of sodium, it gives off an intense yellow flare when heated. Because of this bright light (at 589.3 mμ) the operator has difficulty, without special glasses, in seeing the glass to bend or shape it into the desired article. It has become the practice of glass blowers to wear didymium glasses that have a high luminous transmittance yet high absorbance at 589.3 mμ and some absorbance in the ultraviolet and infrared regions of the spectrum (see figs. 69, 70, 71, and 90). Special glasses of this type do not come under the considerations of the present Federal Specifications.

The art of glass blowing is old, and through the ages has left many sufferers from eye injury. Although the prevalence of cataract among glass workers has been high, it exact cause has been disputed. According to an investigation by Clark [47], ultraviolet radiant energy (300 to 310 mμ) denatures the protein molecule within the eye (in the presence of dilute calcium salts), which then enters into a reaction with water at a raised temperature followed by flocculation between the light and heat denatured molecules to form a visible coagulum (cataract of the eye lens). If such is the case, the wearing of didymium glasses should do much toward reducing glass blowers' cataract.

6. Plastic Eye Protectors

The increased use of plastics as eye protectors has raised a number of questions regarding their adequacy and applicability for use in industry. Many of these questions have been answered by the Battelle Memorial Institute [31] through an investigation sponsored by the National Safety Council.

In this work, a study of plastic eye protectors was made from the standpoint of four types of hazards, namely, mechanical, heat, chemicals, and light. Since the mechanical hazards are probably the greatest source of eye injuries and are prevalent in all industries, they are given major importance and consideration. Most of the plastics compare favorably with glass and in certain cases are far superior. No attempt will be made in this report to summarize the work of the Battelle Memorial Institute, but rather to supplement it by giving ultraviolet and visible spectral transmittance data on some of the types of material available.

Transmittance data are given in figures 92 and 93 for clear samples of eight commercially available materials. No attempt has been made to include data on colored samples having possible value for use in welding or other operations requiring protection from ultraviolet and infrared radiant energy. Many of the colored samples that have been examined had high ultraviolet and infrared transmittances and would not for that reason conform with the requirements of the Federal Specifications on welding glasses.

In general, plastics are much softer than glass, and the surface is readily injured by scratching, pitting, etc. Also since these materials are molded or pressed (rather than polished or drawn in the case of glass) they are subject to having distorted surfaces, which may give them poor optical qualities. High temperatures often soften the surfaces and lead to rapid deterioration of their optical qualities. Some of them age rapidly in atmospheres of high or low humidity and often turn brown or otherwise discolor when used in the presence of certain fumes around chemical laboratories or explosive manufacturing plants. Colored plastics often change in color or in optical density upon exposure to radiant energy or to certain chemical atmospheres. Most of these subjects are covered in the Battelle report [31].

It is to be understood that these remarks regarding the use of plastics refer only to specialized devices for eye protection that are subjected to extremely severe conditions of heat, abrasion, corrosion by chemicals, and mechanical strain, in various industrial environments. There is no reference to the fabrication and use of molded optical elements of plastic materials for other purposes.

This work has been made possible through the generous cooperation of a large number of people, representing the firms and individuals listed below, who have not only supplied material but have given many suggestions relative to its property and uses. In this connection, E. L. Hettinger of Willson Products, Inc., Wilson Sterling of Bausch & Lomb Optical Co., and E. D. Tillyer and Thomas Walsh of the American Optical Co. were especially helpful.

The author expresses special thanks to E. L. Hettinger for furnishing a large collection of samples of welding glass having various optical densities from which the minimum and maximum shade standards were selected, and to James Shea for assistance in obtaining some of the spectral infrared transmittance data.

American Optical Co., Southbridge, Mass.
American Optical Co., New York 18, N. Y.
American Optical Co., Honolulu 2, T. H.
Azurlite Lens Co., New York, N. Y.
Bausch and Lomb Optical Co., Rochester 2, N. Y.
R. C. Burt Scientific Laboratories, Pasadena 5, Calif.
Chicago Eye Shield Co., Chicago 12, Ill.
Cobalite Optical Laboratories, Waltham 54, Mass.
Corning Glass Works, Corning, N. Y.
Dechau Optical Co., Inc., Providence, R. I.
Fulkerson-Keely-Sheley, Wshington 4, D. C.
May Manufacturing Co., New York, N. Y.
Mitchell Optical Co., Waynesville, Mo.
Robert C. Morris, New York 6, N. Y.
National Bureau of Standards, Washington 25, D. C.
New Era Optical Co., Chicago, Ill.
Polaroid Corporation, Cambridge 39, Mass.
Quality Lens Co., Southbridge, Mass.
Superior Goggle Co., Houston 6, Tex.
Titmus Optical Co., Petersburg, Va.
Willson Products, Inc., Reading, Pa.
Philip Wolman and Co., Los Angelse 13, Calif.

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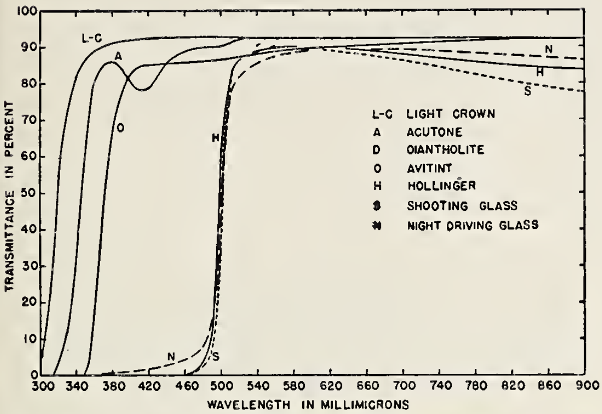

FIGURE 1. *Spectral transmittances of colorless, lightly tinted and yellow glasses.*

Light Crown, t(thickness) = 2.81 mm, National Bureau of Standards; Acutone, t=1.88 mm, Arthur Frank & Co.; Avitint, t=1.93 mm, source unknown; Dianthotite, t=1.75 mm, Quality Lens Co.; Hollinger yellow glass, t=2.09 mm, Joseph Hollinger & Co.; Shooting Glass, t=2.20 mm, and Night-driving glass t=1.88 mm, Willson Products, Inc. The ultraviolet transmittances of Avitint and Diantholite are similar to that of Cruxite *A*, (fig. 4). The three yellow glasses are similar to Kalichrome *C*, (fig. 2), and Noviol *C*, (fig. 18), except that they have a much higher transmittance through the yellow and red of the visible spectrum than Noviol *C*.

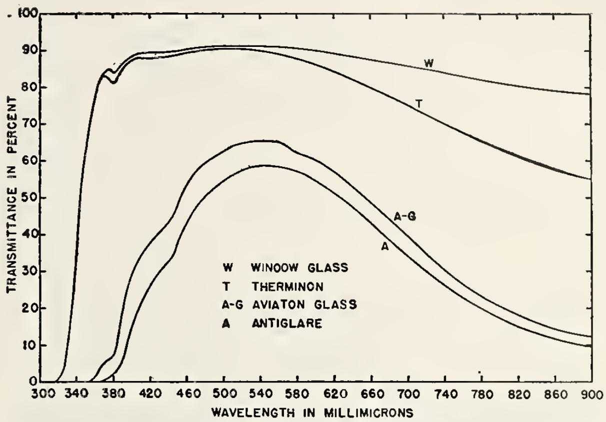

FIGURE 3. *Spectral transmittances of light blue-green glasses.*

Window glass, t=1.60 mm, source unknown; Therminon glass, t=2.02 mm, and Aviation glass, t=2.30 mm, American Optical Co.; Antiglare, t=1.86 mm, Bausch & Lomb Optical Co. These light blue-green glasses are similar except for varying degrees of opacity as more ferrous iron oxide is added to the batch. Therminon is a light blue-green glass having absorbing properties principally in the red and infared wavelengths. The Aviation and Antiglare glasses are similar to some of the blue-green glasses of figures 21 to 33, Antiglare being the earlier trade name of Ray-Ban 2, shown in figure 25. See figure 73 for the spectral infrared transmittance of window glass and Therminon glass.

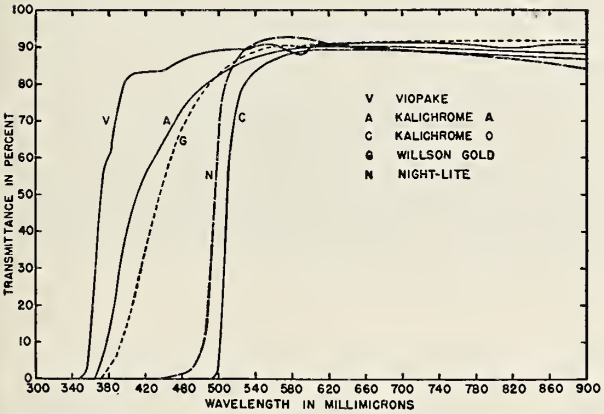

FIGURE 2. *Spectral transmittances of lightly tinted and of light yellow glasses.*

Viopake, t=2.00 mm, Viopake Co., Kalichrome *A*, t=1.96 mm, and Kalichrome *C*, t=2.08 mm, Bausch & Lomb Optical Co.; Willson Gold, t=2.70 mm, Willson Products, Inc.; Nite-Lite, t=2.25 mm, Mitchell Optical Co. The transmittance of Viopake is similar to that of Cruxite *A*, except for the presence of small absorption bands, which gives it a slight yellow tint. The three yellow glasses, together with those of figure 1, are used in sun glasses (since they absorb the short-wave energy) to increase visibility by target and field shooters.

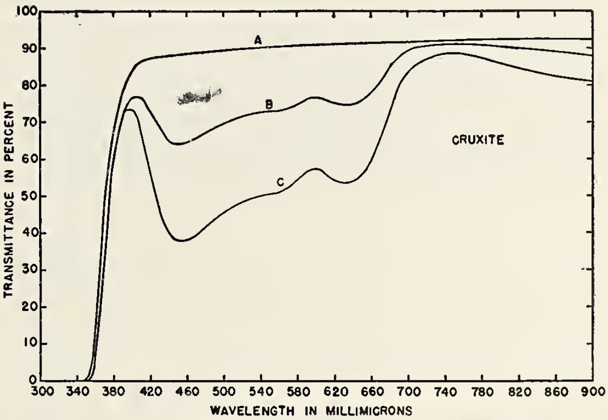

FIGURE 4. *Spectral transmittances of Cruxite glasses.*

Cruxite *A*, t=1.97 mm, Cruxite *B*, t=2.07 mm, and Cruxite *C*, t=2.04 mm, American Optical Co. The similarity between the transmittance curves of the darker Cruxites and those for the Crookes and smoke glasses indicates that Cruxite *B* and *C* are simply smoke glasses containing cerium oxide, see figures 9 to 12 inclusive.

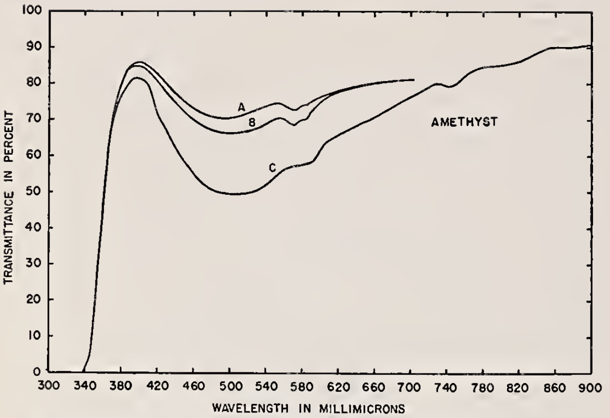

Figure 5. *Spectral transmittances of Amethyst glasses.*

Amethyst *A*, t=2.08 mm, Amethyst *B*, t=2.05 mm, and Amethyst *C*, t=2.11 mm, American Optical Co. Similarities between these glasses and those of figures 6, 7, and 8 may be noted. The curves for shades *A* and *B* are from BS Tech. Paper 119.

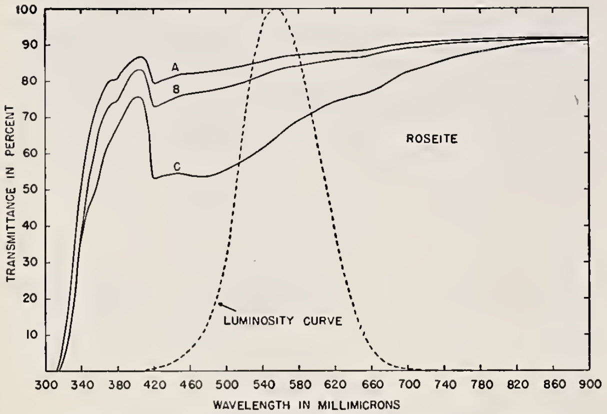

Figure 6. *Spectral transmittances of Roseite glasses.*

Roseite *A*, t=2.98 mm, Roseite *B*, t=2.99 mm, and Roseite *C*, t=2.98 mm.

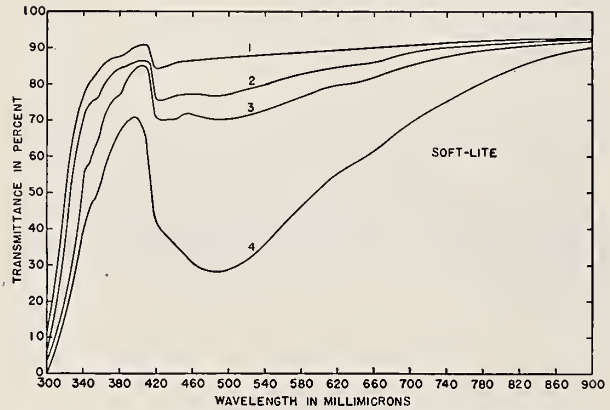

Figure 7. *Spectral transmittances of Soft-Lite glasses.*

Soft-Lite No. 1, t=1.49 mm, Soft-Lite No. 2, t=1.72 mm, Soft-Lite No. 3, t=1.78 mm, and Soft-Lite No. 4, t=1.79 mm, Bausch & Lomb Optical Co.

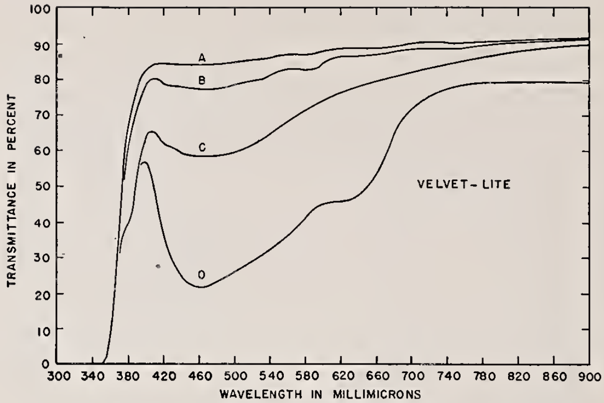

Figure 8. *Spectral transmittances of Velvet-Lite.*

Velvet-Lite *A*, t=2.24 mm, Velvet-Lite *B*, t=2.15 mm, Velvet-Lite *C*, t=2.15 mm, and Velvet-Lite *D*, t=2.16 mm, Titmus Optical Co.

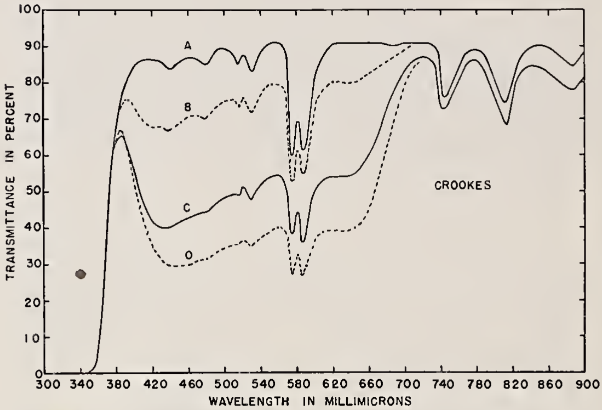

Figure 9. *Spectral transmittances of Crookes glasses.*

Crookes A, t=2.00 mm, Crookes *B*, t=2.10 mm, Crookes *C*, t=2.24 mm, and Crookes *D*, t=2.09 mm, Titmus Optical Co. These glasses are similar to Crookes shades No. 1, 2, and 3 (fig. 10). The shape of the transmittance curves indicates that Crookes glasses are smoke glasses containing didymium and cerium oxides (figs. 11 and 12).

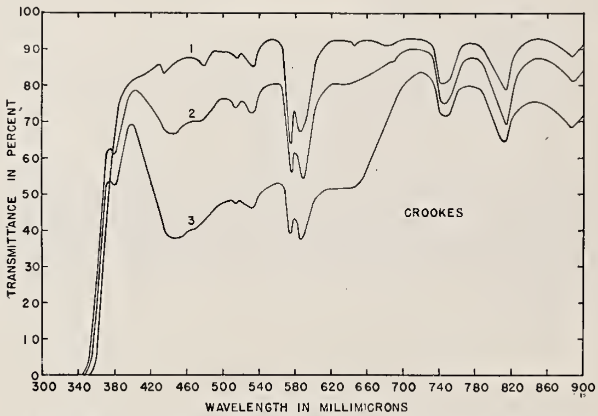

Figure 10. *Spectral transmittances of Crookes glasses.*

Crookes No. 1, t=2.10 mm, Crookes No. 2, t=2.07 mm, and Crookes No, 3, t=2.07 mm, Bausch & Lomb Optical Co.

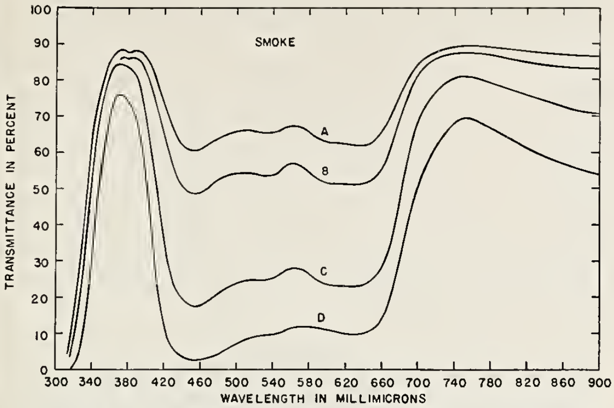

FIGURE 11. *Spectral transmittances of Smoke glasses.*

Smoke *A*, t=2.16 mm, Smoke *B*, t=2.01 mm, Smoke *C*, t=2.11 mm, and Smoke *D*, t=2.12 mm, American Optical Co. (See figure 74 for tbe spectral infrared transmittance of Smoke *D*.

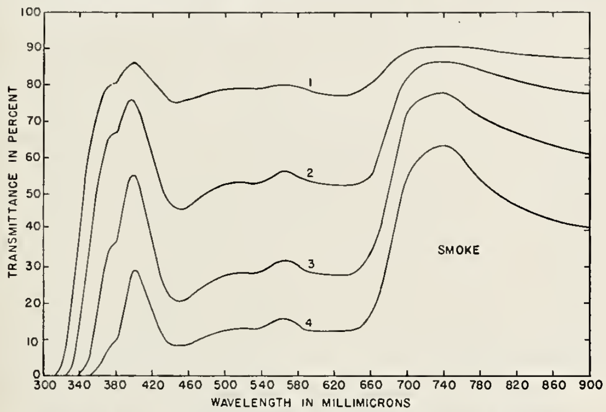

FIGURE 12. *Spectral transmittances of Smoke glasses.*

Smoke No. 1, t=2.08 mm, Smoke No. 2, t=2.07 mm, Smoke No. 3, t=2.04 mm, and Smoke No. 4, t=2.08 mm, Bausch & Lomb Optical Co. These smoke glasses are similar to those of figure 11 except for bigher opacities in botb the ultraviolet and infrared spectral regions. These glasses are also known as Neutral, *N*1, *N*2, *N*3, and *N*4. *N*4 is of particular importance because of its use by the U. S. Navy in flying sun glasses. See figure 74 for the spectral infrared transmittance of smoke glasses.

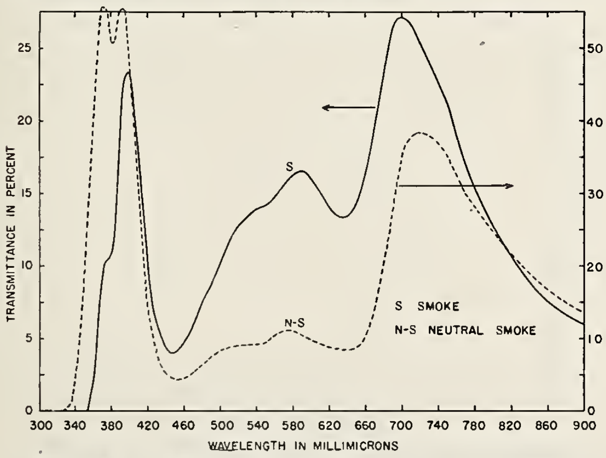

FIGURE 13. *Spectral transmittances of Smoke glasses.*

Willsonite Smoke t=2.03 mm, Neutral Sbade Smoke, t=2.17 mm, Willson Products, Inc. These smoke glasses are interesting in that their composition bas been modified, probably, through the addition of ferrous and ferric iron oxides (maybe other materials also) to reduce tbe infrared transmittances.

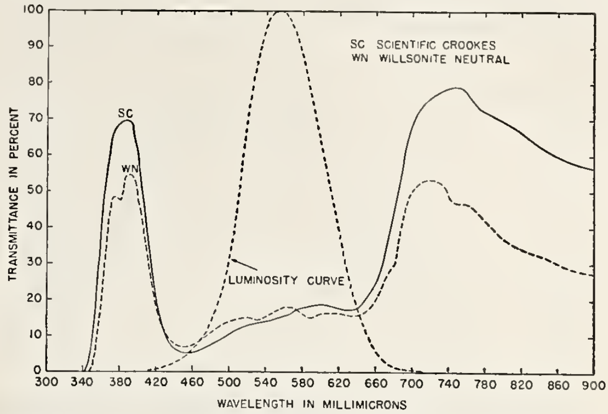

FIGURE 14. *Spectral transmittances of smoke glasses; also the luminosity curve of the eye.*

Scientific Crookes, t=1.41 mm, G. C. Murphy Co.; Willsonite Neutral, t=1.83 mm, Willson Products, Inc. The sample of "Scientific Crookes" is a smoke glass, and similar in characteristics to Willsonite Neutral. No didymium bands are present.

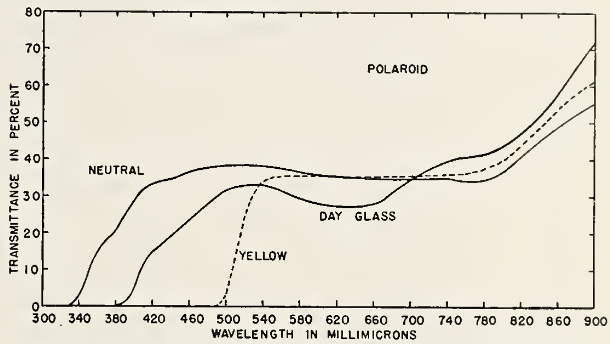

FIGURE 15. *Spectral transmittances of Polaroid glasses.*

Neutral Polaroid, t=5.20 mm, Polaroid Day Glass, t=2.28 mm, and Yellow Polaroid, t=5.65 mm, Polaroid Corp. Tbe samples consisted of polarizing films between plates of light bluish-green glass. Most of the color of the samples appears to be determined by tbe presence of a dye within the polarizing layer.

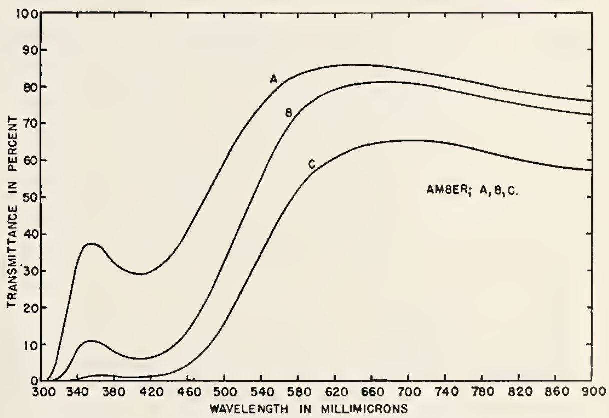

FIGURE 16. *Spectral transmittances of Amber glasses.*

Amber *A*, t=2.10 mm, Amber *B*, t=2.12 mm, and Amber *C*, t=2.13 mm, American Optical Co. These glasses are characterized by baving a single wide absorption band in tbe violet, leaving tbem a relatively low ultraviolet but a bigb infrared transmittance.

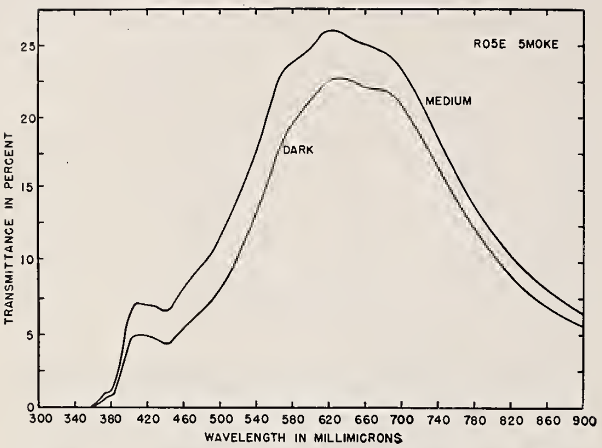

FIGURE 17. *Spectral transmittances of Rose Smoke glasses.*

Medium Rose Smoke, t=1.92 mm, Dark Rose Smoke, t=1.90 mm, American Optical Co. See figure 75 for the spectral infrared transmittance of Medium Rose Smoke.

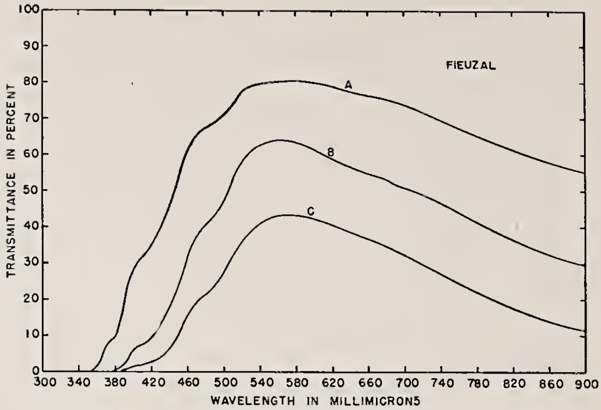

FIGURE 20. *Spectral transmittances of Fieuzal glasses.*

Fieuzal *A*, t=1.90 mm, Fieuzal *B*, t=1.82 mm, and Fieuzal *C*, t=1.82 mm, American Optical Co.

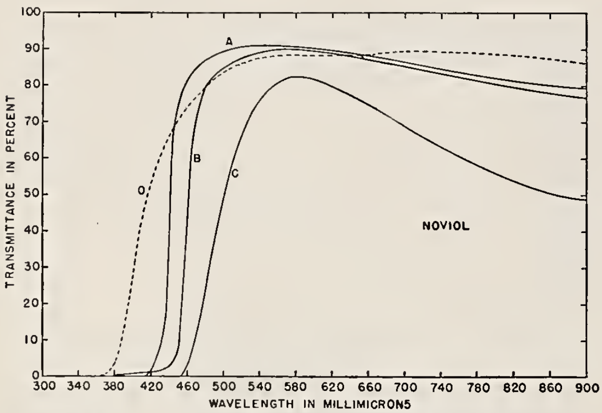

FIGURE 18. *Spectral transmittances of Noviol glasses.*

Noviol *O*, t=2.63 mm, Noviol *A*, t=1.90 mm, Noviol *B*, t=2.89 mm, and Noviol *C*, t=3.05 mm, Corning Glass Works.

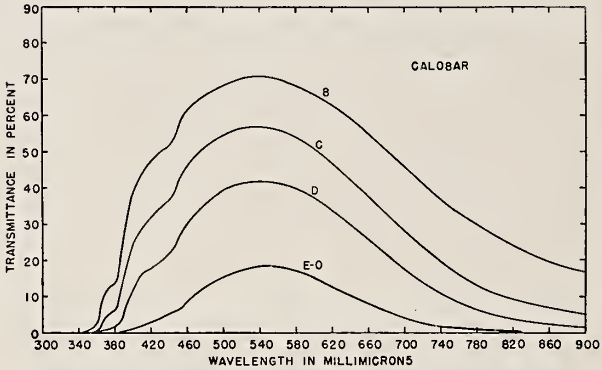

FIGURE 21. *Spectral transmittances of Calobar glasses.*

Calobar *B*, t=1.91 mm, Calobar *C*, t=1.91 mm, Calobar *D*, t=1.93 mm, and Extra Dark Calobar, t=3.67 mm, American Optical Co. See figure 76 for the spectral infrared transmittance of Calobar *B*.

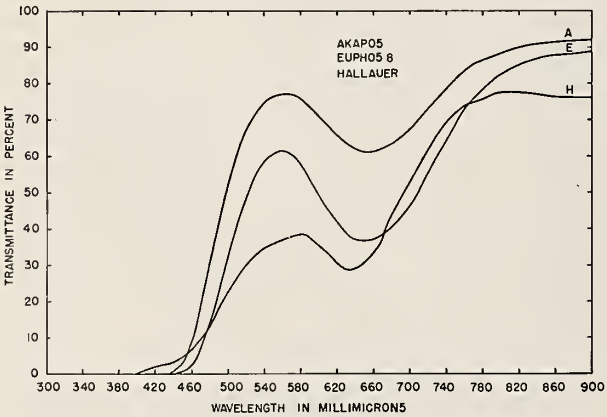

FIGURE 19. *Spectral transmittances of yellowish-green glasses.*

Akapos t=1.58 mm, Euphos *B*, t=3.10 mm, and Hallauer, t=2.36 mm, source unknown. These glasses are very similar in characteristics and are no doubt of similar composition. See reference [3] for additional information.

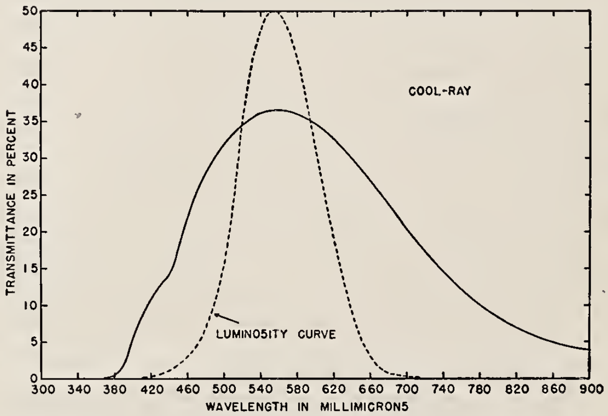

FIGURE 22. *Spectral transmittance of Cool-Ray glass; also the luminosity curve of the eye.*

Cool-Ray, t=1.92 mm, American Optical Co. The similarity of the spectral transmittance curves between Cool-Ray and other blue-green glasses such as Calobar, Ray-Ban, Willsonite, etc., is interesting.

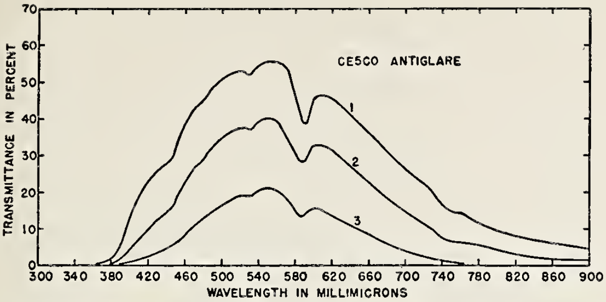

FIGURE 23. *Spectral transmittances of Cesco Antiglar glasses.*

Cesco Antiglare No. 1, t=3.60 mm, Cesco Antiglare No. 2, t=3.59 mm, and Cesco Antiglare No. 3, t=3.58 mm, Chicago Eye Shield Co. These are hardened (heat treated) lenses. Their spectral transmittances resemhle those for the other hlue-green glasses, such as Calohar, Ray-Ban, Willsonite, etc., except for the superimposed narrow ahsorption hands, (possihly caused hy traces of didymium within the glass) especially at ahout 580 mμ. See figure 77 for the spectral infrared transmittance of Cesco Antiglare No. 2.

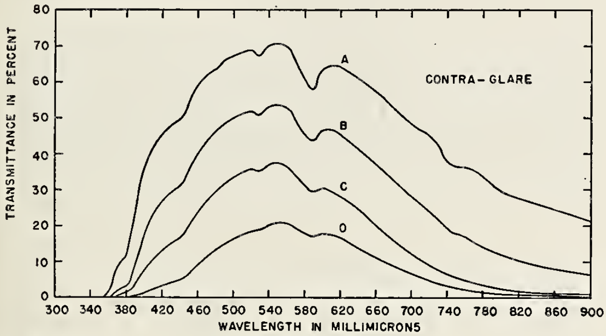

FIGURE 24. *Spectral transmittances of Contra-Glare glasses.*

Contra-Glare *A*, t=2.18 mm, Contra-Glare *B*, t=2.10 mm, Contra-Glare *C*, t=2.18 mm, and Contra-Glare *D*, t=2.19 mm, Titmus Optical Co. An examination of the transmittance curves of these glasses indicates that they are identical with the Cesco Antiglare glasses of figure 23.

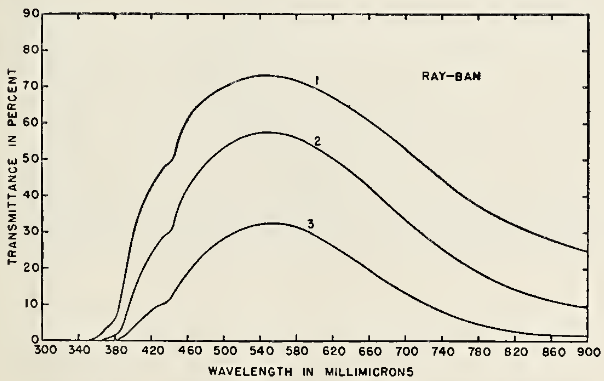

FIGURE 25. *Spectral transmittances of Ray-Ban glasses.*

Ray-Ban No. 1, t=1.99 mm, Ray-Ban No. 2, t=1.93 mm, and Ray-Ban No. 3, t=2.10 mm, Bausch & Lomh Optical Co. Ray-Ban is made in three shades, which are uniformly graded in density such that if the thickness be douhled, the resulting density is that of the next higher shade numher. See figure 78 for the spectral infrared transmittance of Ray-Ban No. 1.

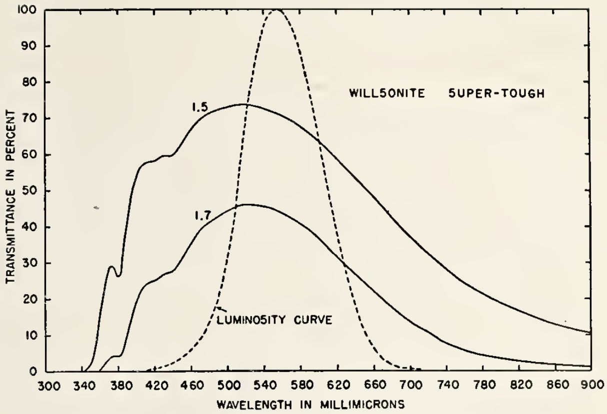

FIGURE 26. *Spectral transmittances of Willsonite Super-Tough glasses.*

Willsonite Super-Tough No. 1.5, t=3.60 mm, and Willsonite Super-Tough No. 1.7, t=3.45 mm, Willson Products, Inc. These are hardened (heat treated) lenses. They have transmission characteristics identical with those of Willson-Weld (see fig. 49).

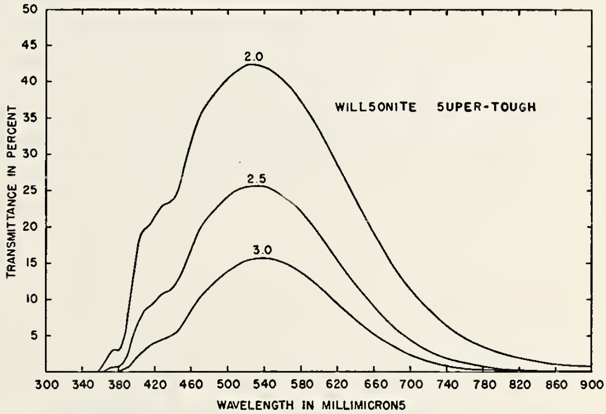

FIGURE 27. *Spectral transmittances of Willsonite Super-Tough glasses.*

Willsonite Super-Tough, No. 2.0, t=3.78 mm, Willsonite Super-Tough No. 2.5, t=3.65 mm, and Willsonite Super-Tough No. 3.0, t=3.39 mm, Willson Products, Inc. These are darker shades of the same series as those of figure 26.

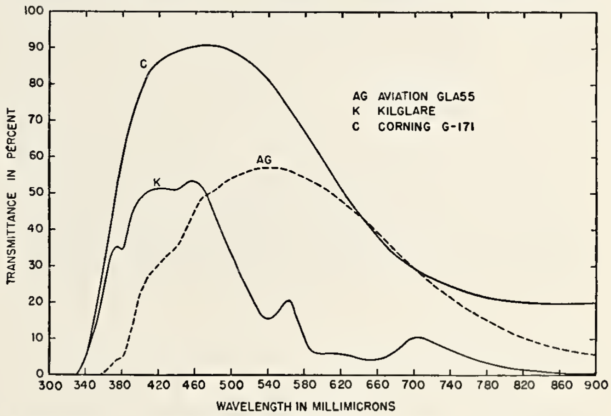

FIGURE 28. *Spectral transmittances of blue and blue-green glasses.*

Willsonite Aviation Glass, t=2.04 mm, and Kilglare glass, t=1.94 mm, Willson Products, Inc. Corning Glass, G-171, t=3.22 mm, Corning Glass Works. The Willsonite aviators glass has transmittance characteristics approximating those of Calohar and Ray-Ban.

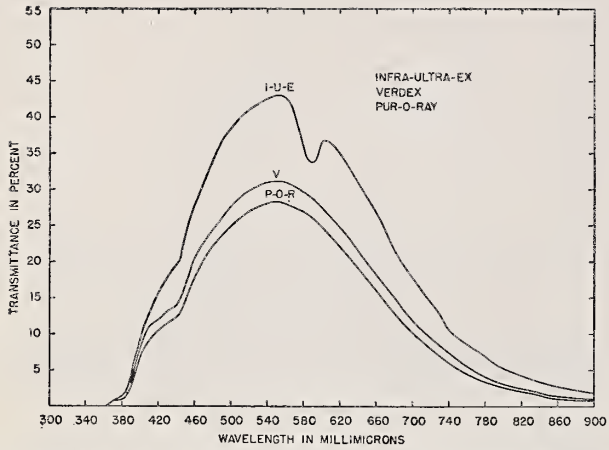

FIGURE 29. *Spectral transmittances of blue-green glasses.*

Infra-Ultra-Ex, t=2.30 mm, Verdex, t=2.12 mm, and Pur-O-Ray, t=2.12 mm, all obtained from local sources.

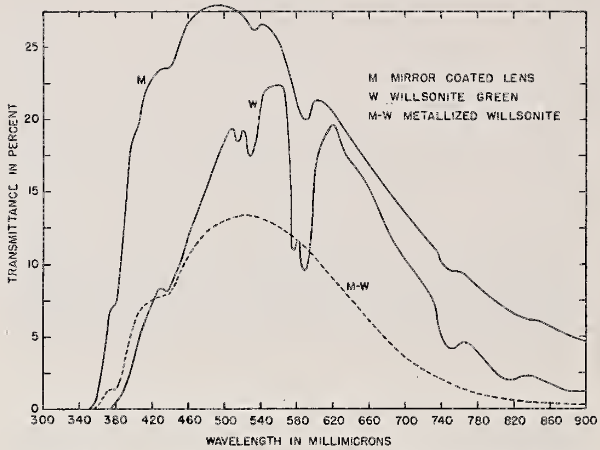

FIGURE 31. *Spectral transmittances of blue-green glasses.*

Mirror-coated Lens, t=1.91 mm, Philip Wolman Co. Metallized Willsonite, t=2.10 mm, and Willsonite Green, t=1.25 mm, Willson Products, Inc. These lenses apparently contain didymium in varying degree. The mirror-coated lens has a light blue-green glass as base. The metal coating has a relatively high reflecting power, so that it becomes to a certain degree a "one way" glass. The transmission peak in the Willsonite green is shifted toward the longer wavelength, and it has a higher opacity in the ultraviolet and infrared.

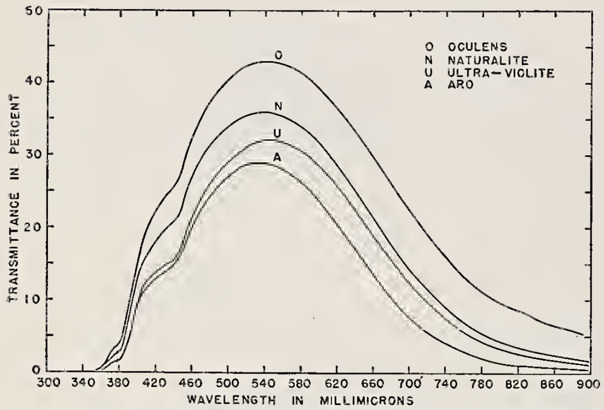

FIGURE 30. *Spectral transmittance of blue-green glasses.*

Oculens, t=1.54 mm, Naturalite, t=1.64 mm, Ultra-violite, t=2.01 mm, and Aro, t=2.44 mm, all obtained from local sources.

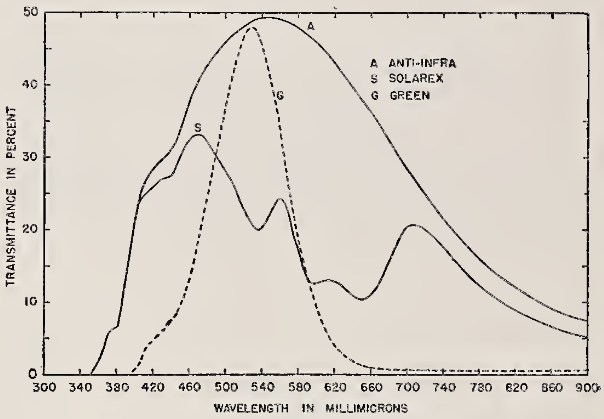

FIGURE 32. *Spectral transmittances of blue-green and green glasses.*

Anti-Infra, t=1.24 mm, and Solarex, t=1.25 mm, obtained from local stores; Green, t=2.17 mm, Robert C. Morris. The Anti-Infra sun glass transmittance curve resembles those for Calobar, Ray-Ban, Willsonite, etc. Solarex is a smoky or "dirty" blue-green resulting from numerous absorption bands within the visible spectrum. The green glass has a vivid color and transmits a very narrow spectral range.

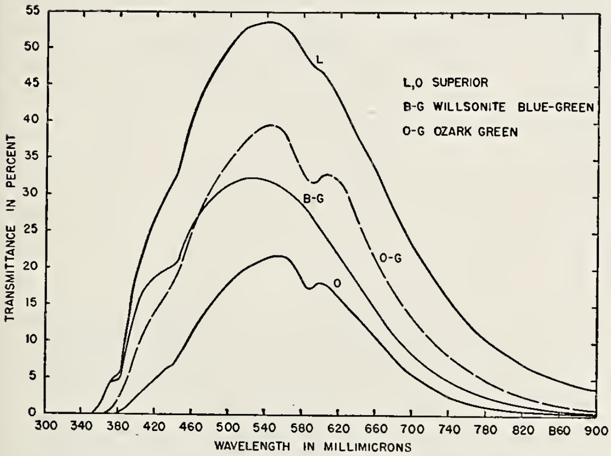

FIGURE 33. *Spectral transmittances of blue-green glasses.*

Light Superior, t=2.01 mm, and Dark Superior, t=1.92 mm, Superior Goggle Co.; Willsonite Blue-Green, t=2.03 mm, Willson Products, Inc.; Ozark Green, t=2.04 mm, Mitchell Optical Co. The light and dark Superior glasses were joined to form the lower and upper parts, respectively, of a goggle lens.

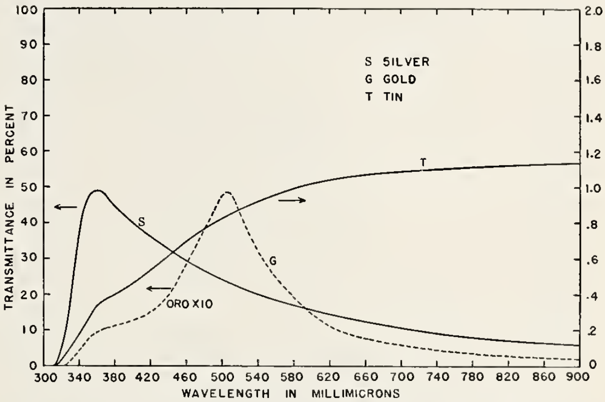

FIGURE 35. *Spectral transmittances of metal films on glass.*

The metal films are of undetermined thickness on clear glass, and only illustrate what may be obtained through the use of metals having varying degrees of relative spectral absorption. In general the "white" metals, e. g., aluminum, platinum, chromium, cadmium, rhodium,etc., would be expected to show but little selective spectral absorption with total density depending on the amount of metal deposited on the glass.

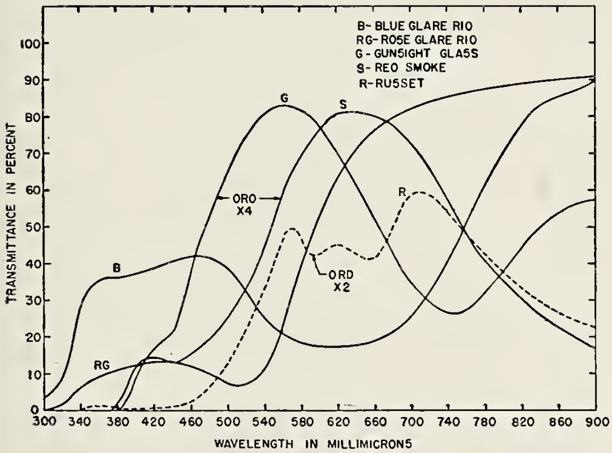

FIGURE 34. *Spectral transmittances of miscellaneous sun glasses.*

Blue Glare Rid, t=2.16 mm, Rose Glare Rid, t=2.37 mm; Dechau Optical Co. Gunsight Glass, t=4.06 mm, Red Smoke, t=2.03 mm, and Willsonite Russet, t=2.14 mm, Willson Products, Inc.

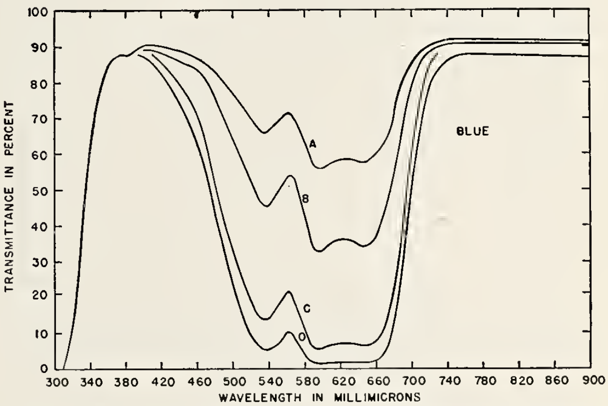

FIGURE 36. *Spectral transmittances of cobalt blue glasses.*

Blue A, t=2.10 mm, Blue B, t=2.05 mm, Blue C, t=2.12 mm, and Blue D, t=2.15 mm, American Optical Co.

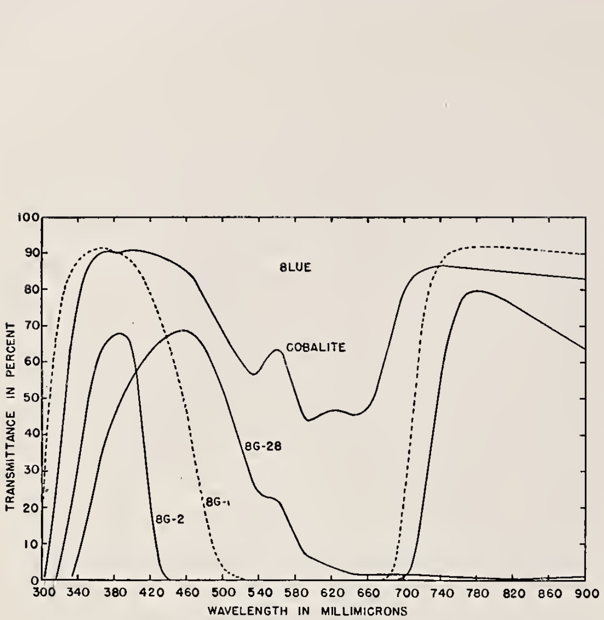

FIGURE 37. *Spectral transmittances of blue glasses.*

Cobalite, t=2.63 mm, Cobalite Optical Laboratories; BG–28, t=1.03 mm, BG–1, t=2.04 mm, BG–2, t=1.99 mm, imported German glasses.

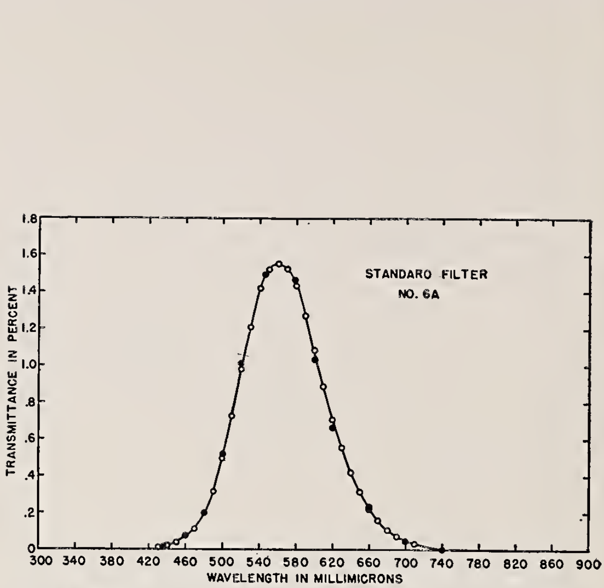

FIGURE 39. *Spectral transmittance of NBS Standard Filter No. 6A.*

This is the darkest one of the standard filters used as comparison standards in this investigation. The values represented by the open circles were obtained in the Radiometry Laboratory by the author; those represented by the solid circles by the Photometry and Colorimetry Section.

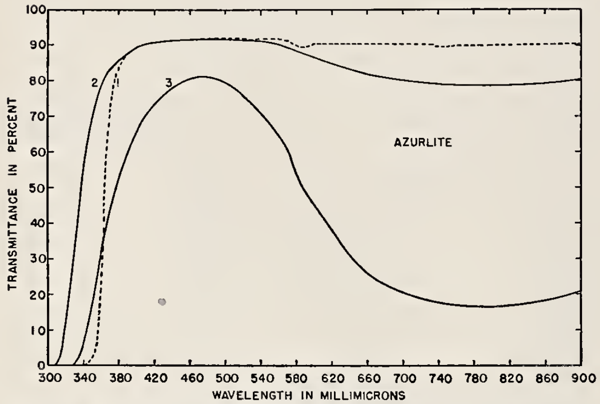

FIGURE 38. *Spectral transmittances of light blue glasses.*

Azurlite No. 1, t=1.24 mm, Azurlite No. 2, t=1.64 mm, and Azurlite No. 3, t=1.68 mm, Azurlite Lens Co.

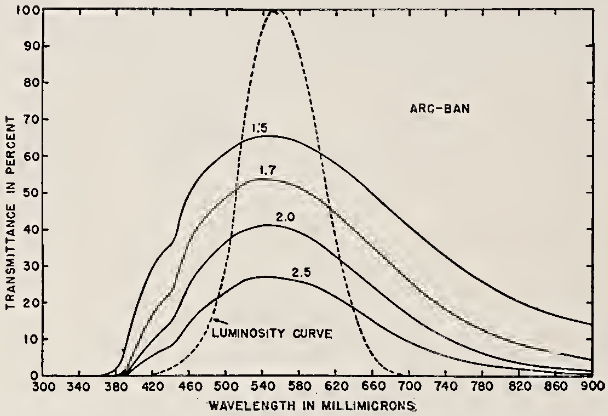

FIGURE 40. *Spectral transmittances of Arc-Ban welding glasses; also luminosity curve of the eye.*

Arc-Ban shade No. 1.5, t=2.92 mm, Arc-Ban shade No. 1.7, t=3.97 mm, Arc-Ban shade No. 2.0, t=3.28 mm, and Arc-Ban shade No. 2.5, t=2.46 mm, Bausch & Lomb Optical Co. See figure 80 for the spectral infrared transmittances of Arc-Ban shade Nos. 1.5 and 2.0.

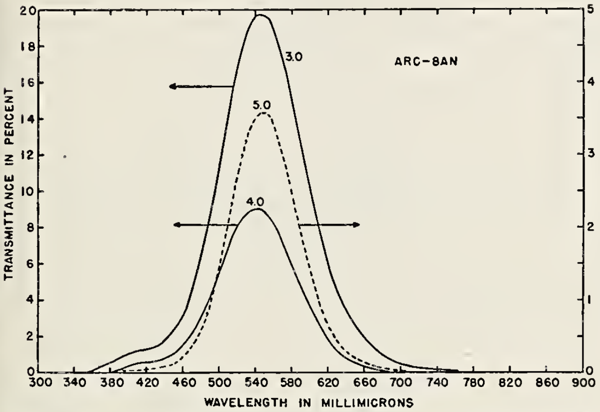

FIGURE 41. *Spectral transmittances of Arc-Ban welding glasses.*

Arc-Ban shade No. 3.0, t=2.51 mm, Arc-Ban shade No. 4.0, t=2.83 mm, and Arc-Ban shade No. 5.0, t=2.47 mm, Bausch & Lomb Optical Co.

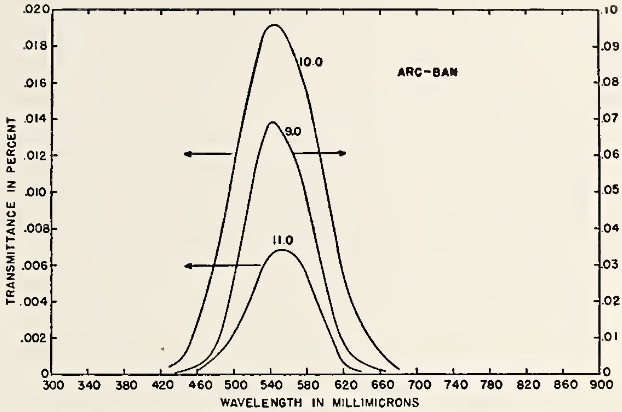

FIGURE 43. *Spectral transmittances of Arc-Ban welding glasses.*

Arc-Ban shade No. 9.0, t=3.00 mm, Arc-Ban shade No. 10.0, t=2.62 mm, and Arc-Ban shade No. 11.0, t=2.64 mm, Bausch & Lomb Optical Co.

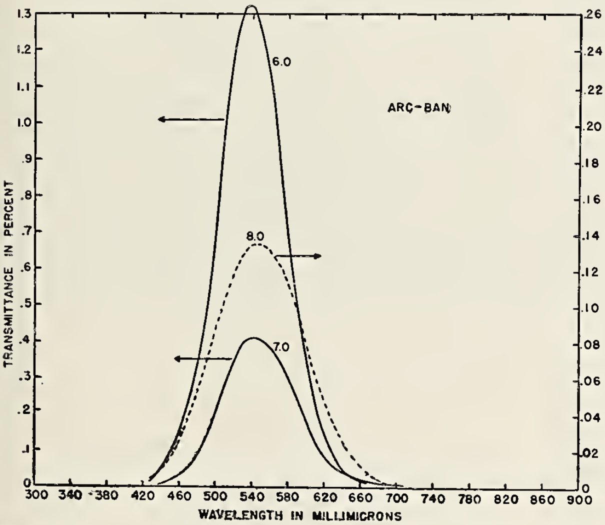

FIGURE 42. *Spectral transmittances of Arc-Ban welding glasses.*

Arc-Ban shade No. 6.0, t=2.71 mm, Arc-Ban shade No. 7.0, t=2.27 mm, and Arc-Ban shade No. 8.0, t=2.07 mm, Bausch & Lomb Optical Co.

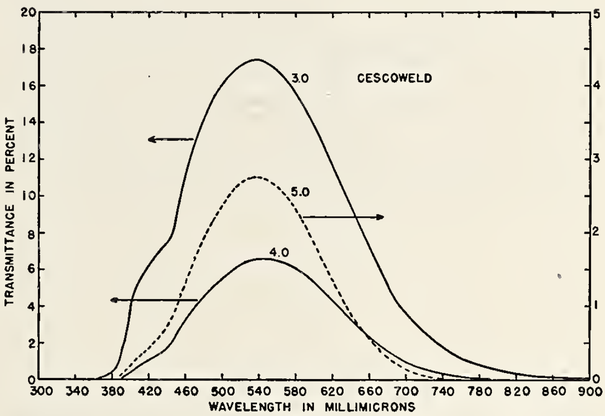

FIGURE 44. *Spectral transmittances of Cescoweld welding glasses.*

Cescoweld shade No. 3.0, t=2.59 mm, Cescoweld shade No. 4.0, t=2.38 mm, and Cescoweld shade No. 5.0, t=2.40 mm, Chicago Eye Shield Co. See figure 77 for the spectral infrared transmittance of Cescoweld shade No. 2.0.

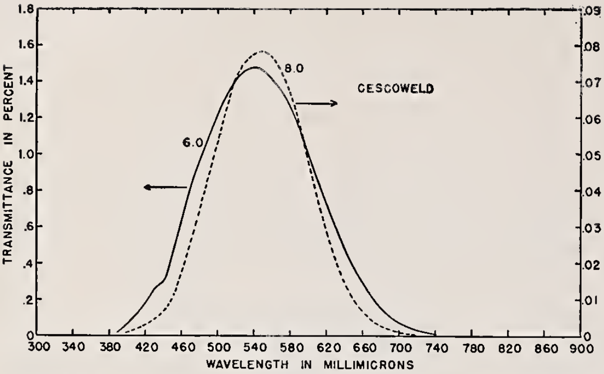

Figure 45. *Spectral transmittances of Cescoweld welding glasses.*

Cescoweld shade No. 6.0, t=2.56 mm, and Cescoweld shade No. 8.0, t=2.15 mm, Chicago Eye Shield Co.

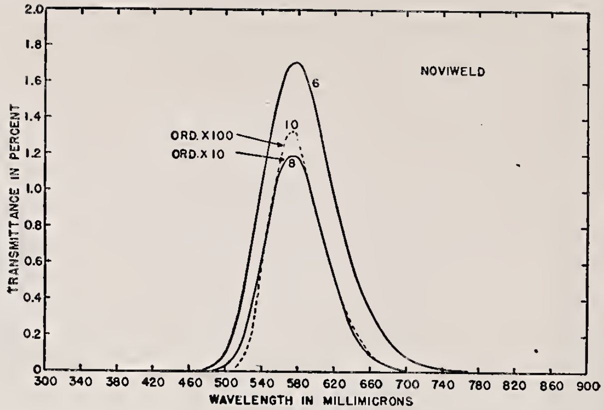

Figure 48. *Spectral transmittances of Noviweld welding glasses.*

Noviweld shade No. 6.0, t=1.95 mm, Noviweld shade No. 8.0, t=2.28 mm, and Noviweld shade No. 10.0, t=2.55 mm, American Optical Co.

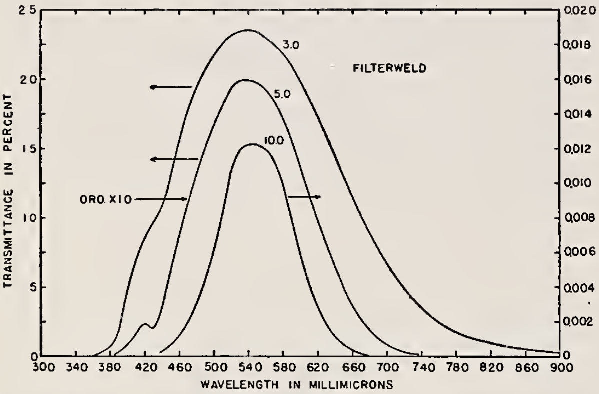

Figure 46. *Spectral transmittances of Filterweld welding glasses.*

Filterweld shade No. 3.0, t=2.03 mm, Filterweld shade No. 5.0, t=2.46 mm and Filterweld shade No. 10.0, t=2.03 mm, American Optical Co. See figure 81 for the spectral infrared transmittance of Filterweld shade No. 3.0.

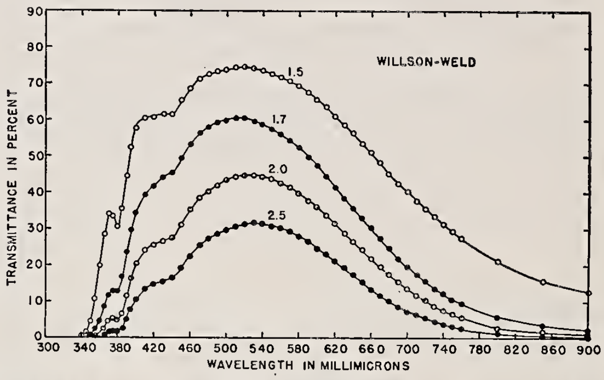

Figure 49. *Spectral transmittances of Willson-Weld welding glasses.*

Willson-Weld shade No. 1.5, t=3.38 mm, Willson-Weld shade No. 1.7, t=3.12 mm, Willson-Weld shade No. 2.0, t=3.42 mm, Willson-Weld shade No. 2.5, t=3.25 mm. Willson Products, Inc. See figure 83 for the spectral infrared transmittances of some of these glasses.

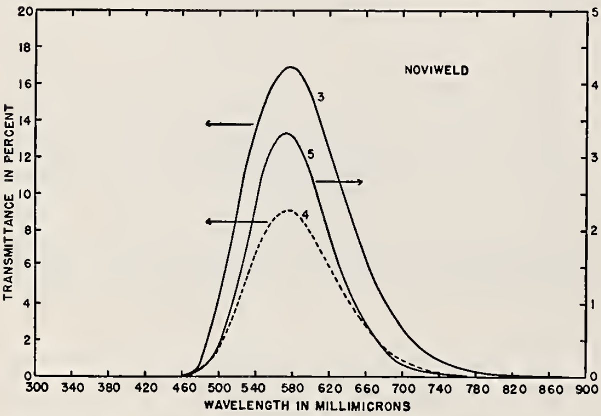

Figure 47. *Spectral transmittances of Noviweld welding glasses.*

Noviweld shade No. 3.0, t=2.49 mm, Noviweld shade No. 4.0, t=2.31 mm, and Noviweld shade No. 5.0, t=2.15 mm, American Optical Co. See figure 82 for the spectral infrared transmittance of Noviweld shade No. 3.0.

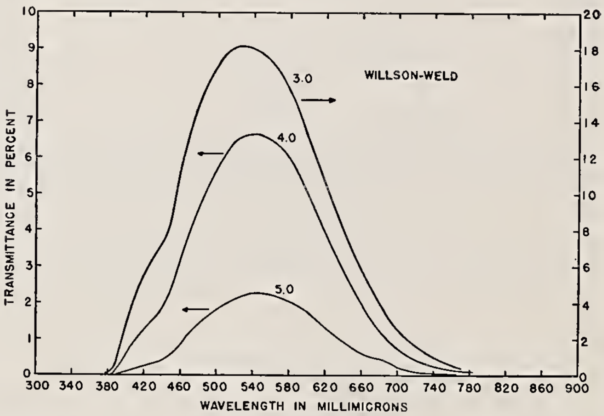

Figure 50. *Spectral transmittances of Willson-Weld welding glasses.*

Willson-Weld shade No. 3.0, t=3.22 mm, Willson-Weld shade No. 4.0, t=2.50 mm, and Willson-Weld shade No. 5.0, t=2.44 mm, Willson Products, Inc.

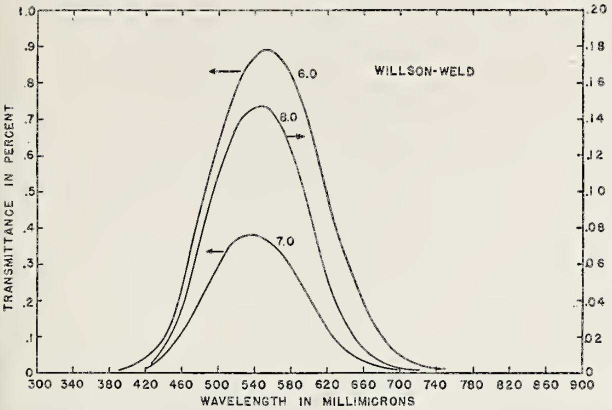

FIGURE 51. *Spectral transmittances of Willson-Weld welding glasses.*

Willson-Weld shade No. 6.0, t=2.90 mm, Willson-Weld shade No. 7.0, t=3.04 mm, and Willson-Weld shade No. 8.0, t=2.61 mm, Willson Products, Inc.

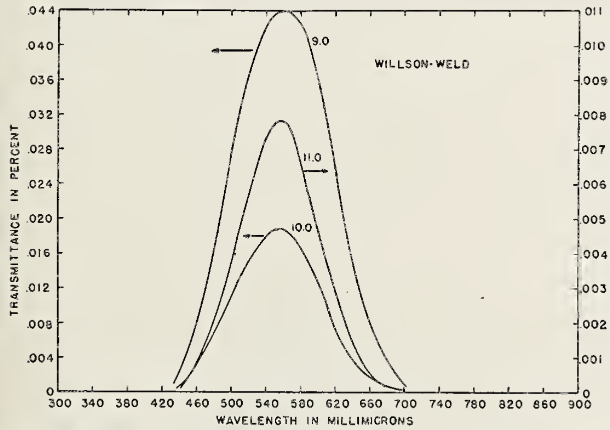

FIGURE 52. *Spectral transmittances of Willson-Weld welding glasses.*

Willson-Weld shade No. 9.0, t=2.25 mm, Willson-Weld shade No. 10.0, t=2.47 mm, and Willson-Weld shade No. 11.0, t=2.78 mm, Willson Products, Inc.

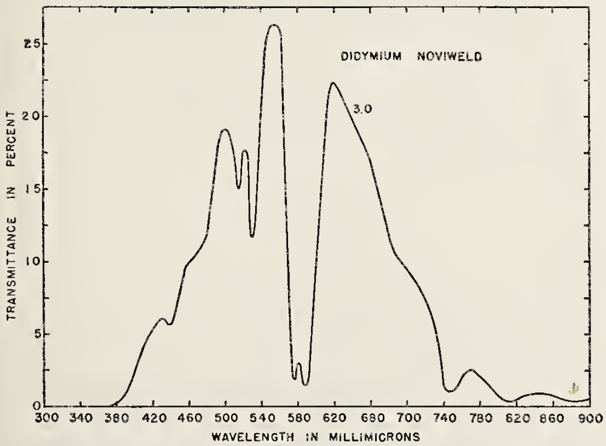

FIGURE 53. *Spectral transmittance of Didymium Noviweld Welding glass.*

Didymium Noviweld shade No. 3.0, t=3.56 mm, American Optical Co. See figure 84 for the spectral infrared transmittance of this glass.

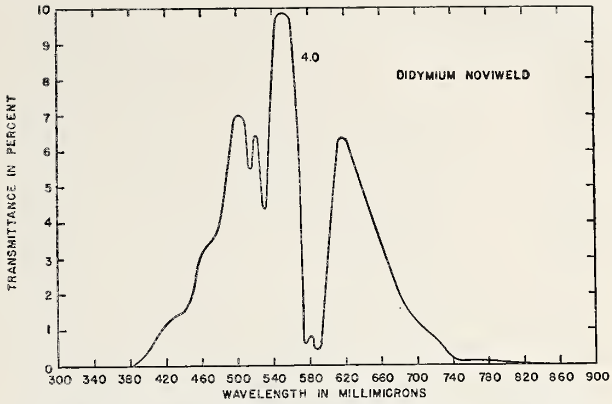

FIGURE 54. *Spectral transmittance of a Didymium Noviweld welding glass.*

Didymium Noviweld shade No. 4.0, t=3.66 mm, American Optical Co.

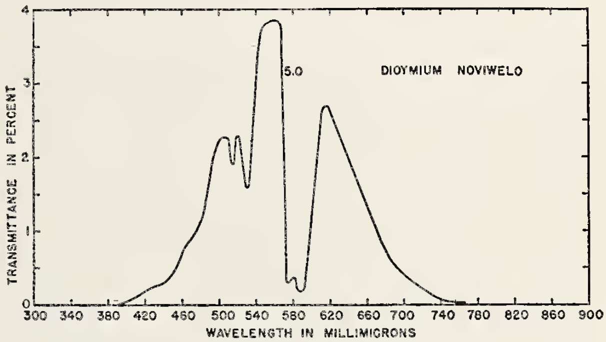

FIGURE 55. *Spectral transmittance of a Didymium Noviweld welding glass.*

Didymium Noviweld shade No. 5.0, t=3.61 mm, American Optical Co.

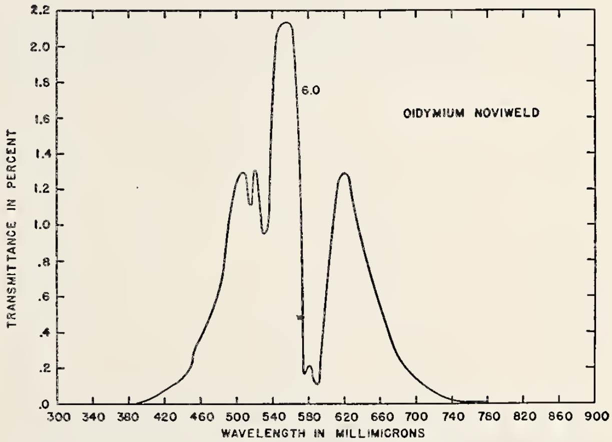

FIGURE 56. *Spectral transmittance of a Didymium Noviweld welding glass.*

Didymium Noviweld shade No. 6.0, t=3.51 mm, American Optical Co.

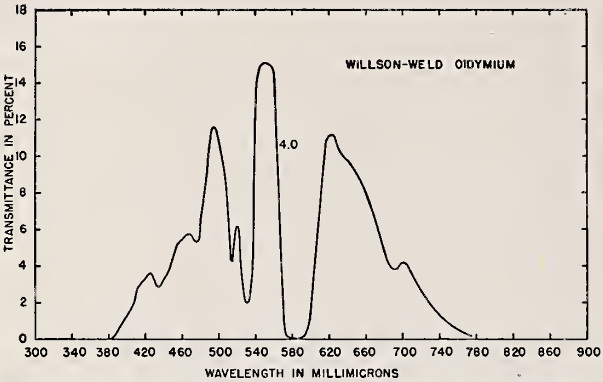

FIGURE 57. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 4.0, t=3.58 mm, Willson Products, Inc.

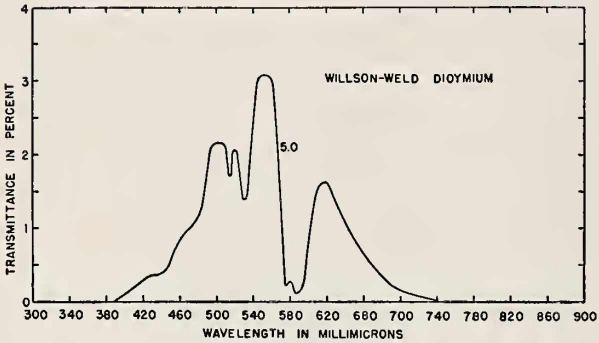

FIGURE 58. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 5.0, t=3.54 mm, Willson Products, Inc.

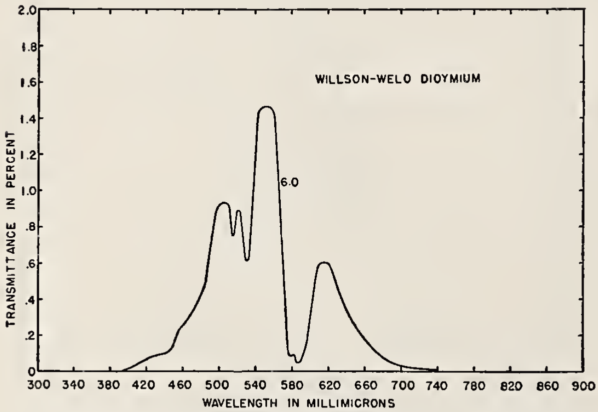

FIGURE 59. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 6.0, t=3.54 mm, Willson Products, Inc.

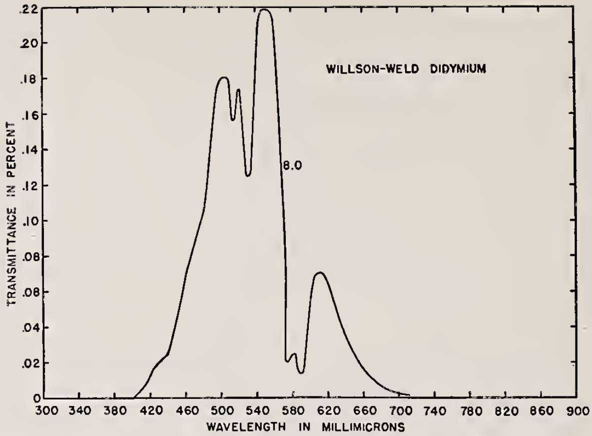

FIGURE 60. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 8.0, t=3.44 mm, Willson Products, Inc.

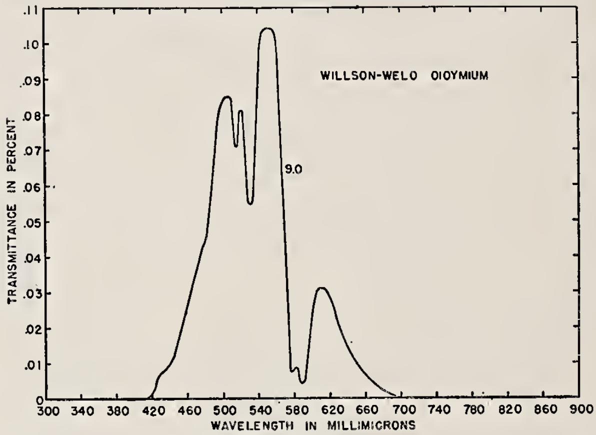

FIGURE 61. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 9.0, t=3.85 mm, Willson Products, Inc.

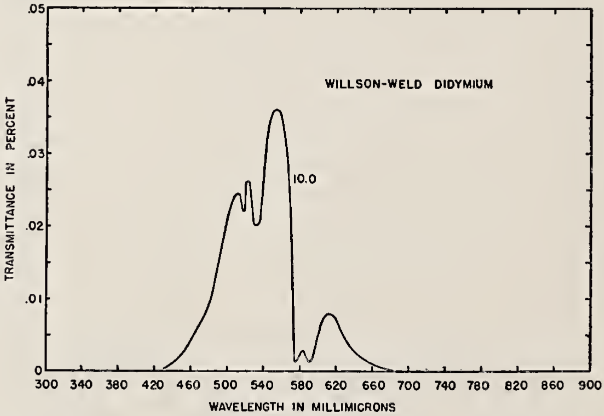

FIGURE 62. *Spectral transmittance of a Willson-Weld Didymium welding glass.*

Willson-Weld Didymium shade No. 10.0, t=3.51 mm, Willson Products, Inc.

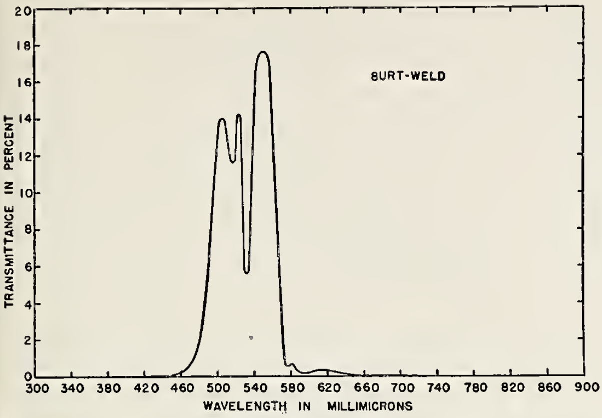

FIGURE 63. *Spectral transmittance of Burt-Weld aluminum welding glass.*

Burt-Weld, t=3.54 mm, B. F. McDonald Co. This glass is shade No. 4 (luminous transmittance about 5 percent). See figure 87 for the spectral infrared transmittance of this glass.

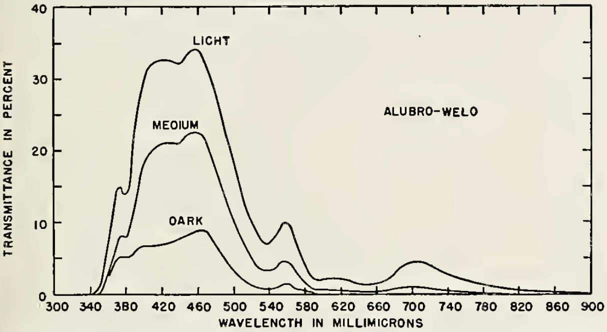

FIGURE 64. *Spectral transmittances of Alubro-Weld aluminum welding glasses.*

Light Alubro-Weld, t=3.01 mm, Medium Alubro-Weld, t=3.54 mm, and Dark Alubro-Weld, t=2.25 mm, Willson Products, Inc. See figure 85 for the spectral infrared transmittance of Light Alubro-Weld.

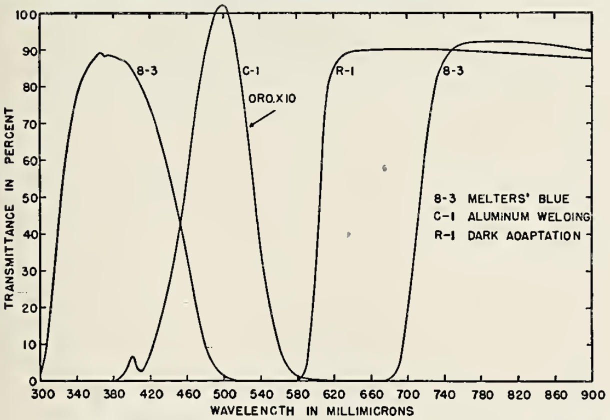

FIGURE 65. *Spectral transmittance of (G–1) Aluminum welding glass; also Melters' Blue glass, and a red Dark Adaptation glass.*

The Aluminum welding glass (t=3.20 mm) is made with a high density for wavelengths longer than about 580 $m\mu$ for absorbing the sodium and lithium flares in aluminum welding. The luminous transmittance is that of a light shade No. 5.0. The Melters' Blue (B–3), t=4.00 mm, is one of eight shades of blue (thickness range 3.6 to 4.3 mm of the same glass) varying slightly in density with thickness. See figures 66 and 67 for similar glasses. The Red glass (R–1), t=2.97 mm, is a dark adaptation glass. All glasses are from the Bausch & Lomb Optical Co. See figure 86 for the spectral infrared transmittance of the Aluminum welding glass.

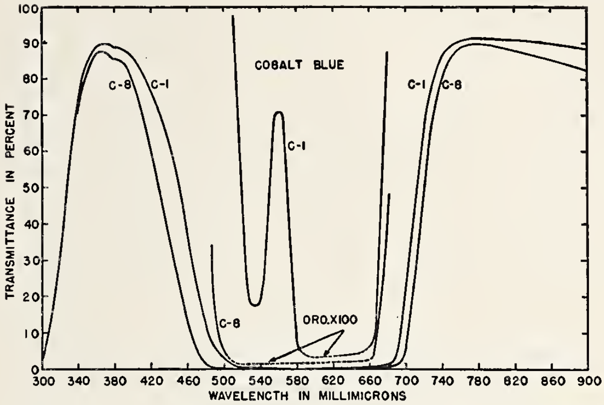

FIGURE 66. *Spectral transmittances of deep-blue cobalt glasses.*

Cobalt Blue, C–1, t=3.02 mm, and Cobalt Blue, C–8, t=3.96 mm, American Optical Co. These cobalt blue glasses are the lightest and darkest of a series of eight shades of blue. See, also, figures 65 and 67 for similar glasses (or the same glass under other designations). See figure 88 for the spectral infrared transmittance of one of these glasses.

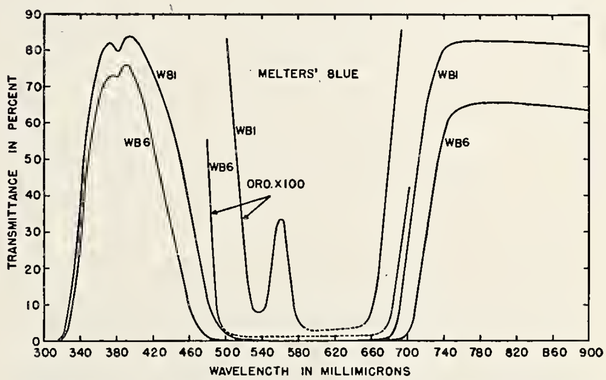

FIGURE 67. *Spectral transmittances of deep-blue cobalt glasses.*

Melters' Blue (WB1), t=3.05 mm, and Melters' Blue (WB6), t=3.04 mm, Willson Products, Inc. These cobalt blue glasses are the lightest and darkest of a series of six shades of blue. See, also, figures 65 and 66.

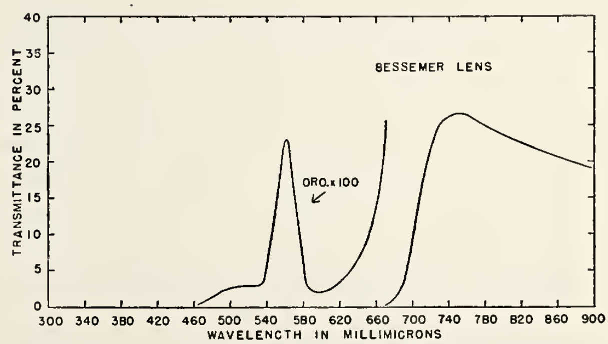

FIGURE 68. *Spectral transmittance of a Bessemer Lens.*

Bessemer Lens, t=3.03 mm, Bausch & Lomb Optical Co. See figure 89 for the spectral infrared transmittance of this glass.

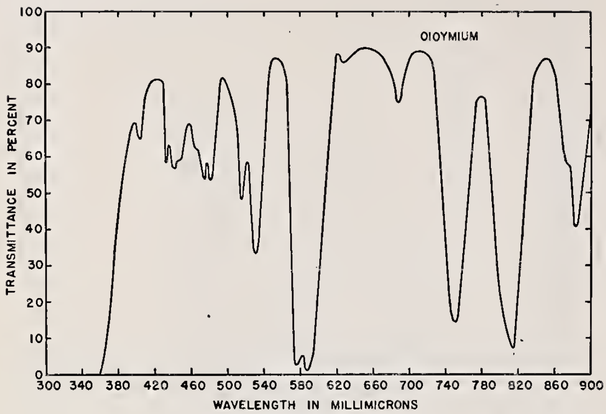

FIGURE 69. *Spectral transmittance of a light didymium glass.*

Didymium glass, t=3.17 mm, American Optical Co., and Willson Products, Inc. This transmittance curve indicates the quality of work possible with the instrument employed in the present investigation. See figure 90 for the spectral infrared transmittance of this glass.

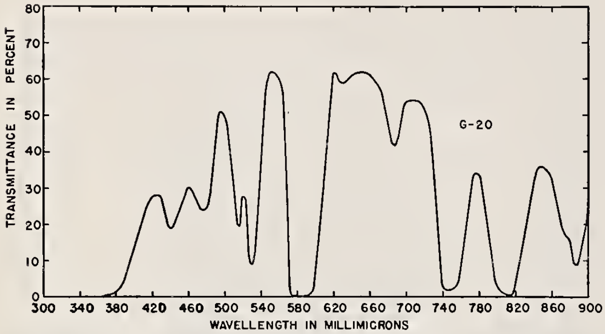

FIGURE 70. *Spectral transmittance of a didymium glass.*

Didymium glass, G–20, t=2.99 mm, Bausch & Lomb Optical Co. This lens was designed for glass blowing. It has a high density for the short wavelengths in the ultraviolet, and a reduced infrared transmittance. The transmittance at the sodium line is less than 0.5 percent. See figure 90 for the spectral infrared transmittance of this glass.

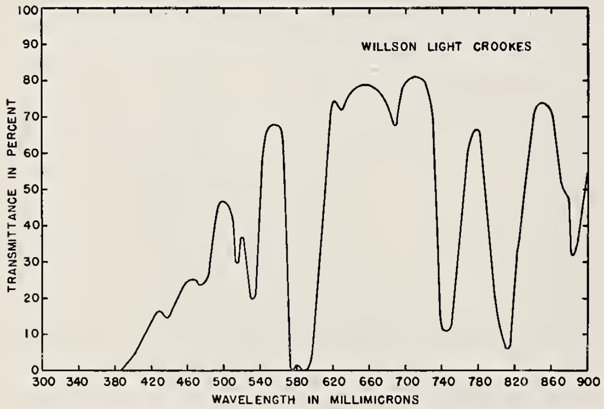

FIGURE 71. *Spectral transmittance of Willson Light Crookes glass.*

Willson Light Crookes, t=1.87 mm, Willson Products, Inc. This glass has a high opacity in the ultraviolet and a density in the visible intermediate between the two didymium glasses illustrated in figures 69 and 70.

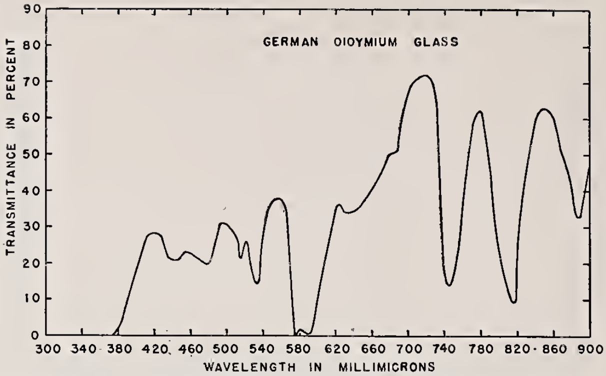

FIGURE 72. *Spectral transmittance of a German didymium smoke glass.*

German didymium glass, t=1.95 mm. This glass was used in the German Navy by submarine crews during World War II.

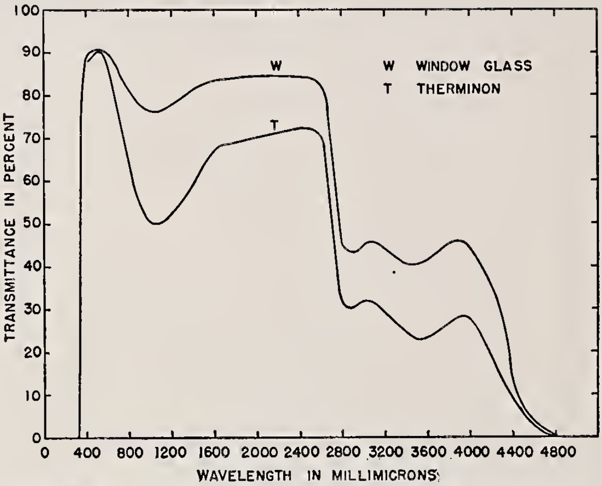

FIGURE 73. *Spectral infrared transmittances of light blue-green glasses.*

Window glass, t=1.60 mm; Therminon glass, t=2.02 mm. See figure 3.

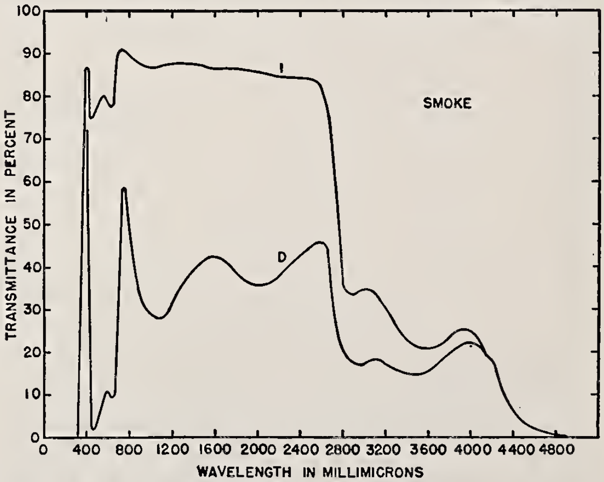

FIGURE 74. *Spectral infrared transmittances of Smoke glasses.*

Smoke No. 1, t=2.08 mm, and Smoke D, t=2.12 mm. See figures 11 and 12.

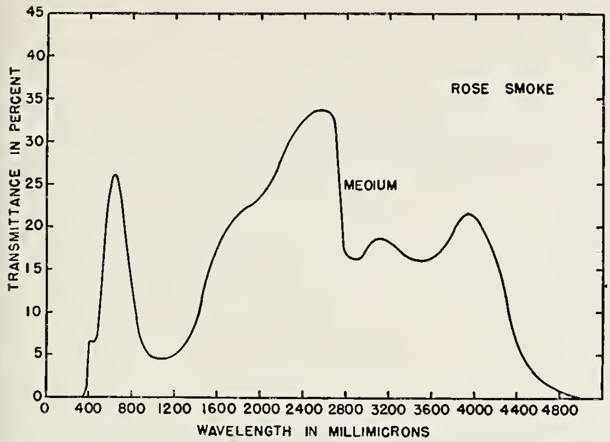

FIGURE 75. *Spectral infrared transmittance of a Rose Smoke glass.*

Medium Rose Smoke, t=1.92 mm. See figure 17.

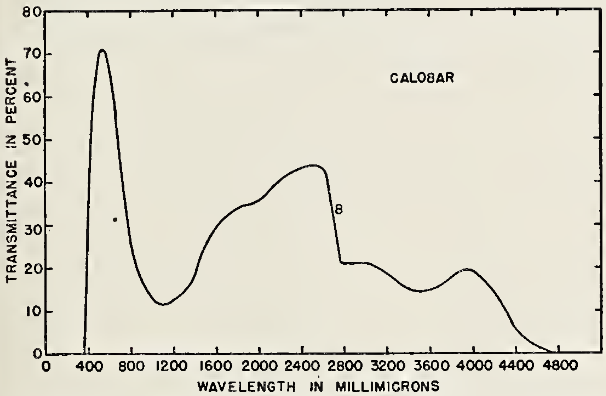

FIGURE 76. *Spectral infrared transmittance of a Calobar glass.*

Calobar *B*, t=1.91 mm. See figure 21.

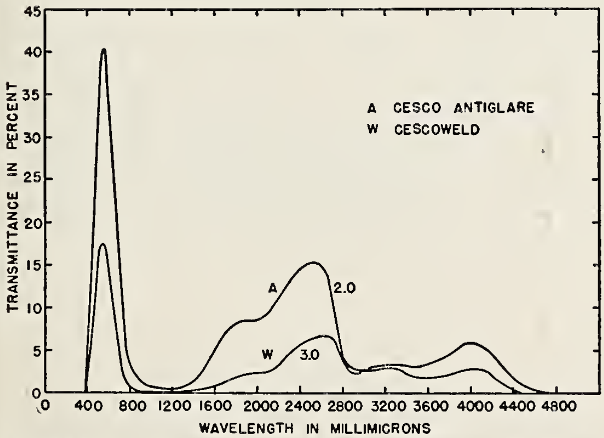

FIGURE 77. *Spectral infrared transmittance of Cesco Antiglare glass; also Cescoweld welding glass.*

Cesco Antiglare shade No. 2.0, t=3.59 mm, and Cescoweld shade No. 3.0, t=2.59 mm. See figures 23 and 44.

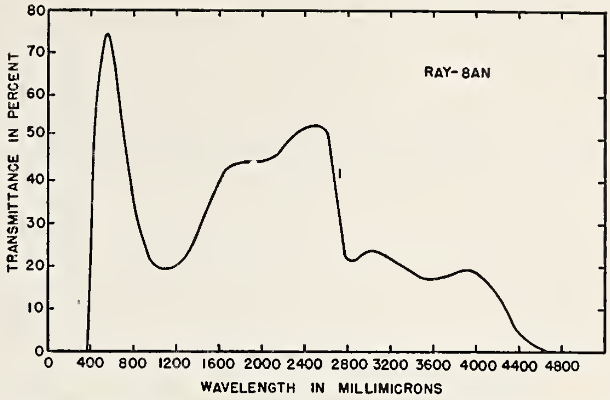

FIGURE 78. *Spectral infrared transmittance of a Ray-Ban glass.*

Ray-Ban No. 1, t=1.99 mm. See figure 25.

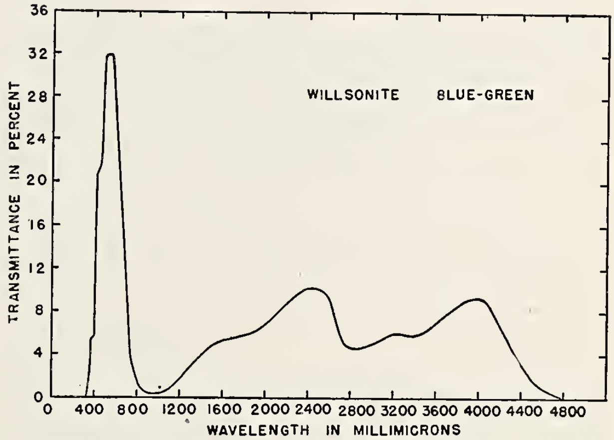

FIGURE 79. *Spectral infrared transmittance of a Willsonite glass.*

Willsonite blue-green, t=2.03 mm. See figure 33.

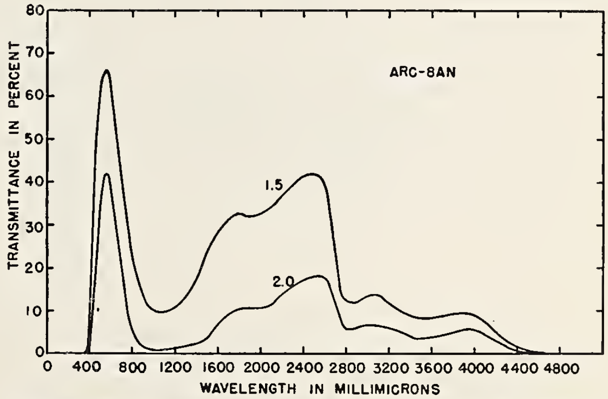

FIGURE 80. *Spectral infrared transmittances of Arc-Ban welding glasses.*

Arc-Ban shade No. 1.5, t=2.92 mm, and Arc-Ban shade No. 2.0, t=3.28 mm. See figure 40.

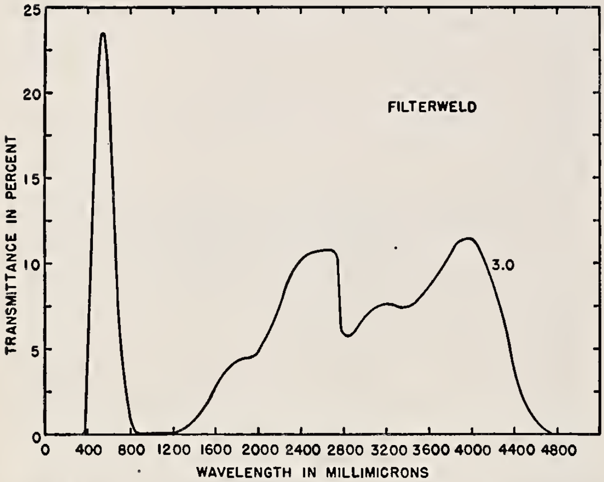

Figure 81. *Spectral infrared transmittance of a Filterweld welding glass.*

Filterweld shade No. 3.0, t=2.03 mm. See figure 46.

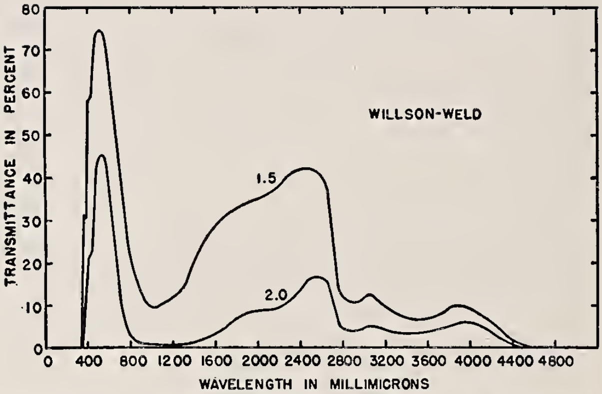

Figure 83. *Spectral infrared transmittances of Willson-Weld welding glasses.*

Willson-Weld shade No. 1.5, t=3.38 mm, and Willson-Weld shade No. 2.0, t=3.42 mm. See figure 49.

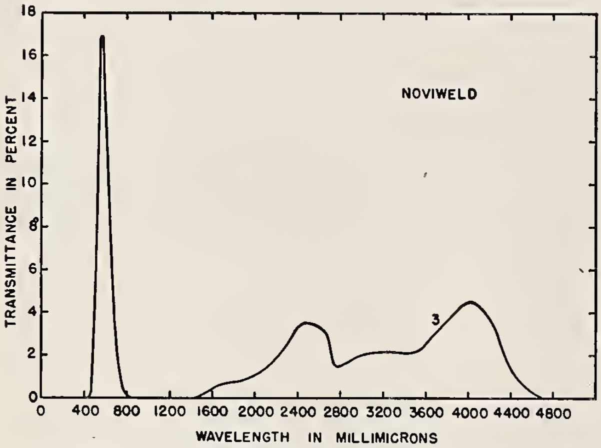

Figure 82. *Spectral infrared transmittance of a Noviweld welding glass.*

Noviweld shade No. 3.0, t=2.49 mm. See figure 47.

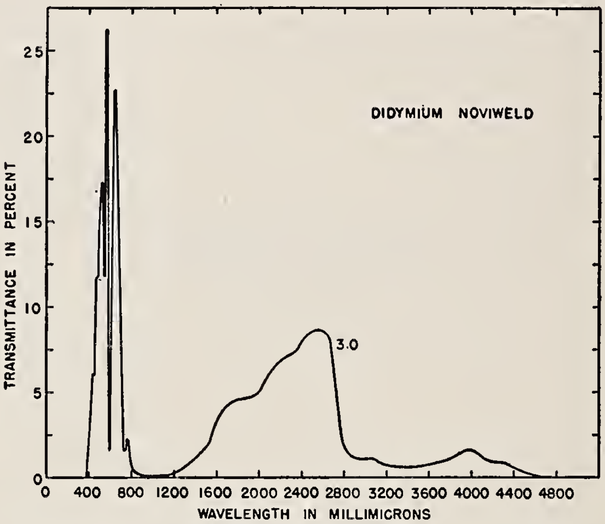

Figure 84. *Spectral infrared transmittance of a Didymium Noviweld welding glass.*

Didymium Noviweld shade No. 3.0, t=3.56 mm. See figure 53.

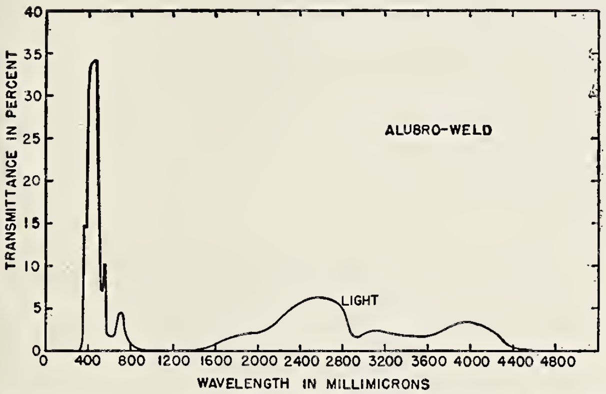

FIGURE 85. *Spectral infrared transmittance of an Alubro-Weld aluminum welding glass.*

Light Alubro-Weld, t=3.01 mm. See figure 64.

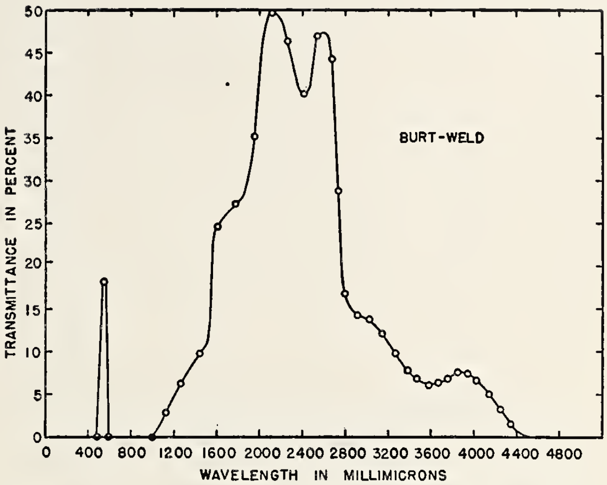

FIGURE 87. *Spectral infrared transmittance of Burt-Weld aluminum welding glass.*

Burt-Weld, t=3.54 mm. See figure 63.

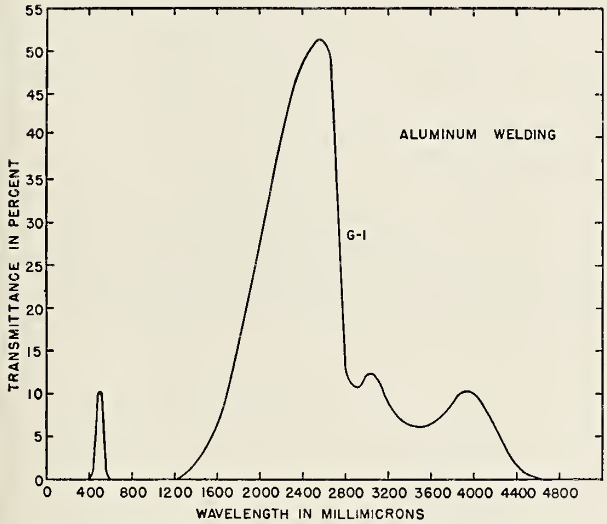

FIGURE 86. *Spectral infrared transmittance of (G–1) Aluminum welding glass.*

Aluminum Welding, G–1, t=3.20 mm. See figure 65.

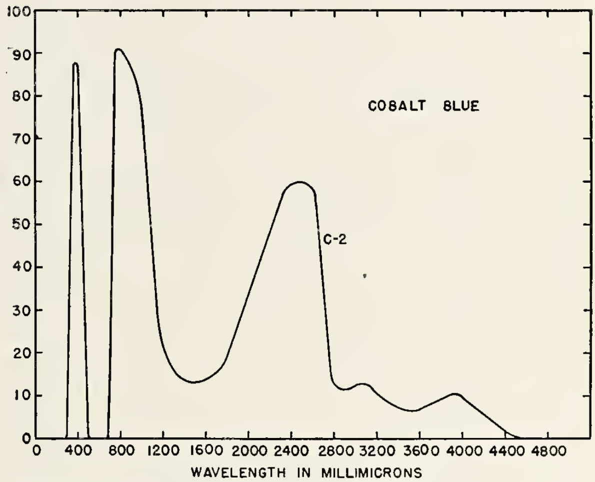

FIGURE 88. *Spectral infrared transmittances of a deep-blue cobalt glass.*

Cobalt Blue, C–2, t=3.50 mm. See figures 65, 66, and 67.

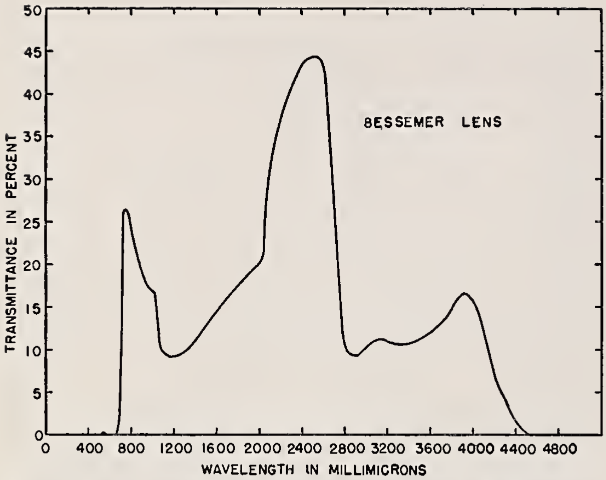

FIGURE 89. *Spectral infrared transmittance of a Bessemer Lens.*

Bessemer Lens, t=3.03 mm. See figure 68.

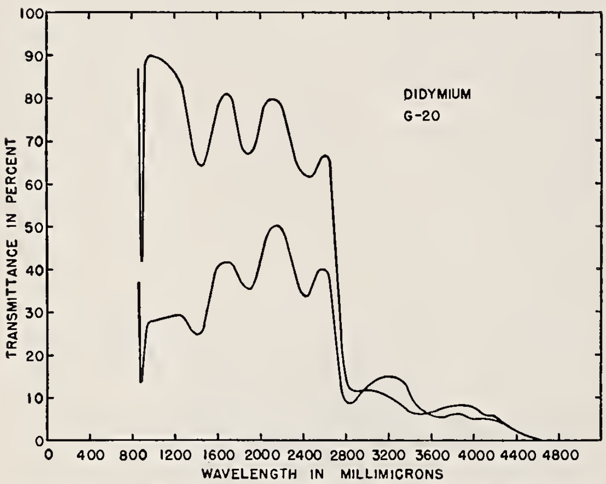

FIGURE 90. *Spectral infrared transmittances of didymium glasses.*

Didymium, t=3.17 mm, and Didymium glass, G–20, t=2.99 mm. See figures 69 and 70.

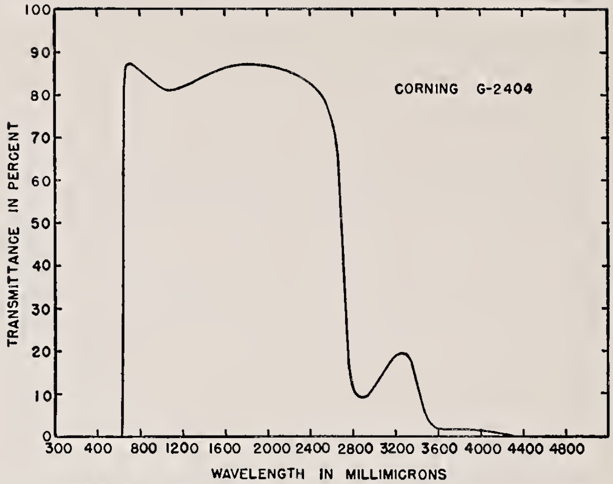

FIGURE 91. *Spectral infrared transmittance of NBS Standard Infrared Filter.*

Corning Glass, G–2404, t=2.90 mm, Corning Glass Works.

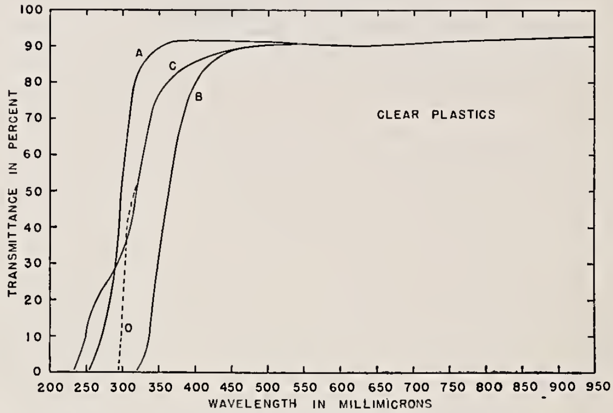

FIGURE 92. *Spectral transmittances of clear plastics.*

A, Methyl methacrylate, t=1.47 mm; *B*, allyl alcohol, t=3.05 mm; *C*, cellulose acetate butyrate, t=0.41 mm; *D*, cellulose acetate, t=0.50 mm.

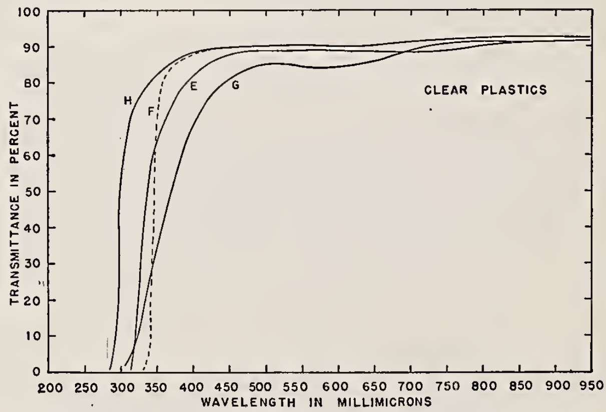

FIGURE 93. *Spectral transmittances of clear plastics.*

E, cellulose nitrate, t=0.80 mm; *F*, cellulose propionate, t=0.23 mm; *G*, ethyl cellulose, t=0.79 mm; and *H*, polystryene, t=0.45 mm.

WASHINGTON, February 25, 1948.

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