U. S. DEPARTMENT OF COMMERCE

DANIEL C. ROPER, Secretary

NATIONAL BUREAU OF STANDARDS

LYMAN J. BRIGGS, Director

CIRCULAR OF THE NATIONAL BUREAU OF STANDARDS C421

SPECTRAL-TRANSMISSIVE PROPERTIES AND USE OF COLORED EYE-PROTECTIVE GLASSES

By W. W. Coblentz and R. Stair

[Issued June 1, 1938]

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1938

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents

PREFACE

Conservation of eyesight is one of the foremost problems that confronts safety engineers. The natural protective mechanism of the eye is sufficient to adapt it to ordinary intensities of illumination. However, with the increase in strenuous outdoor activities (e. g., snow sports, long automobile journeys, etc.) and in industrial occupations (furnace work, gas and electric welding) spectacle glasses of various colors are being worn as an additional protection from harmful radiation.

At various times during the past two decades this Bureau has published the results of researches on the spectral-transmissive properties of various types of colored glasses for protecting the eyes from glare and from injurious amounts of ultraviolet and infrared radiation.

Since reprints of these papers are no longer available, 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 deeply colored lenses, made especially for protecting the eyes of industrial workers who are employed near or operate furnaces, cutting and welding apparatus, etc., that emit injurious amounts of ultraviolet and infrared radiation.

LYMAN J. BRIGGS, *Director.*

SPECTRAL-TRANSMISSIVE PROPERTIES AND USE OF COLORED EYE-PROTECTIVE GLASSES

By W. W. Coblentz and R. Stair

ABSTRACT

In response to the continuing demand for information on colored glasses for protecting the eyes from glare and from injurious amounts of ultraviolet and infrared radiation, this Circular gives the spectral-transmissive characteristics of various colored lenses that are marketed under a variety of trade names, such as Amethyst, Avitint, Azurlite, Bluelite, Calobar, Cerulite, Cruxite, Diantho-Lite, Kalichrome, Noviol, Noviweld, Polaroid, Roselite, Soft-Lite, Solarex, Viopake, etc. For convenience in exposition of the data, the various tinted lenses are grouped under the color that predominates in transmission—amber, green, blue, etc. Introductory to the presentation of the data, various important incidental questions are discussed, including elimination of glare, distortion of colors, confusion of traffic signals, the hazard in wearing colored glasses when driving at night, the importance of having standard shades, etc.

CONTENTS

I. INTRODUCTION

Data on the spectral transmissions of various makes of tinted lenses and eye-protective glasses have been given in two technical papers published within the last decade [1, 2].[1] Reprints of these papers are no longer available. This Circular is issued to supply the continuing demand for information on tinted lenses for outdoor wear; and on more deeply shaded lenses designed to protect the eyes of industrial employees who work near or operate furnaces or metal-cutting and welding machines that emit injurious amounts of ultraviolet and infrared radiation.

There is also need for a wider dissemination of information on the hazards associated with the indiscriminate wearing of colored glasses and on any important modification in brightness or brightness-contrast which may result from the wearing of such glasses. This question has attained sufficient importance to automobile drivers to receive the attention of the National Safety Council, which has issued a summary of opinions submitted by manufacturers, oculists, medical practitioners, scientists, and illuminating engineers [11].

It is desirable also to correct some misconceptions regarding the advantage, disadvantage, enduring benefits, or injuries resulting from wearing tinted lenses. These misconceptions seem to be traceable largely to shortcomings in advertising—a subject discussed in reference [1]. In spite of the fact that there has been great improvement in recent years in the advertising claims, numerous inquiries are still received regarding their reliability.

To supply a background of information as an aid in making a discriminatory use of the technical data on colored glasses, summarized in sections II and III, a brief review is given of the more pertinent optical and physiological questions involved.

Probably second only in importance to the ability of the eye to focus a clear image on the retina, is its power to automatically adjust the illumination, within a relatively short interval of time, so as to see objects, under a wide range of light intensities, 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 responsivity of the retina, the remaining factor, 20,000. Unfortunately, this adjustment is not instantaneous, as we strikingly perceive on entering a brightly illuminated room after being outside on a dark night; and on going into the dark from a brightly lighted room. Hence, there is need of a means of quickly shielding the eye from sudden exposure to high intensities of illumination, such as are encountered in driving at night.

The magnitude of this range in adjustment of the eye raises a question as to whether a reduction of only a few percent in the luminosity of one's surroundings could possibly induce any appreciable feeling of relief. This question is pertinent and can be settled only by trial. A glass that transmits 80 percent (shade *A*, fig. 1) of the visible rays may perhaps eliminate discomfort when used, in ordinary surroundings, by a neurasthenic person with eyes so sensitive that an intensity higher than the light of the sky shining through a window cannot be

[1] Numbers in brackets refer to references and notes at the end of this Circular.

tolerated; but, for this same person, it would not be dark enough to safely ascend or descend a light-colored stairway in bright summer sunlight (illumination 9,000 foot candles). For these latter conditions a shade *B* or even *C* would be needed.

It is the purpose of this Circular, however, to deal with the use of shaded glasses for the average, relatively healthy eye (not necessarily free from errors of refraction) as differing from the albino and the diseased eye, which requires special consideration for each individual—see abstract No. 10 of reference [11] and textbooks on diseases of the eye [14].

Another important property possessed by the human eye is the ability to distinguish colors. On the average, 19 out of 20 people are found to possess the power of distinguishing the same range of colors, and to the same degree; but 1 of the 20 is defective in chromatic vision—partially color blind. But even a person with normal color vision is rendered somewhat color blind when looking through colored eyeglasses. Hence, it is important that the glasses, worn for comfort or protection, shall not seriously impair one's efficiency in color discrimination.

Finally, in the field of eye protection, the invisible radiation which is always present with the visible (and often to an injurious degree) must be given special consideration. When intense infrared radiation is present, the ensuing burning sensation gives a quick warning; consequently, it is not so likely to cause injury. But, the presence of ultraviolet (short-wave) radiation is not felt at the time of exposure; it is only revealed by the discomfort and suffering which develops a few hours after the real damage is done. Inasmuch as the presence of infrared and ultraviolet radiation is of no aid to vision, it is wise to minimize the risk of injury, in questionable cases, by wearing glasses which eliminate both infrared and ultraviolet.

1. ELIMINATION OF GLARE

The term "glare," as commonly used, has various meanings. Here it will be used to signify an unpleasant sensation and a temporary blurring of vision caused by a high luminosity of the field of view, either as a whole or in part; and does not, contrary to some early advertising literature on tinted lenses, include ultraviolet light as contributing to the effect.

The elimination of glare from extensive areas of snow, water, sand, 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 the glass that will serve the purpose. But, if choice is to be made in some other way, for example, from a catalog, it is well to remember that many tinted lenses on the market are of such light shades (transmission 80 to 88 percent, fig. 1) that they cannot give relief. The light shades which show no color except when viewed edgewise are no better than common window glass (see figs. 2 and 9), which appears greenish when viewed edgewise and is even better for removing the infrared than some of the others given in figure 2.

It is relevant to add that there is little or no scientific foundation to serve as a basis for claims made for many of the colored glasses recommended and sold for outdoor wear [11, 20]. Personal appearance and adornment enters into the wearing of tinted lenses [1], and the cosmetic appeal ("a tint that matches the complexion") may outweigh the consideration of eye comfort.

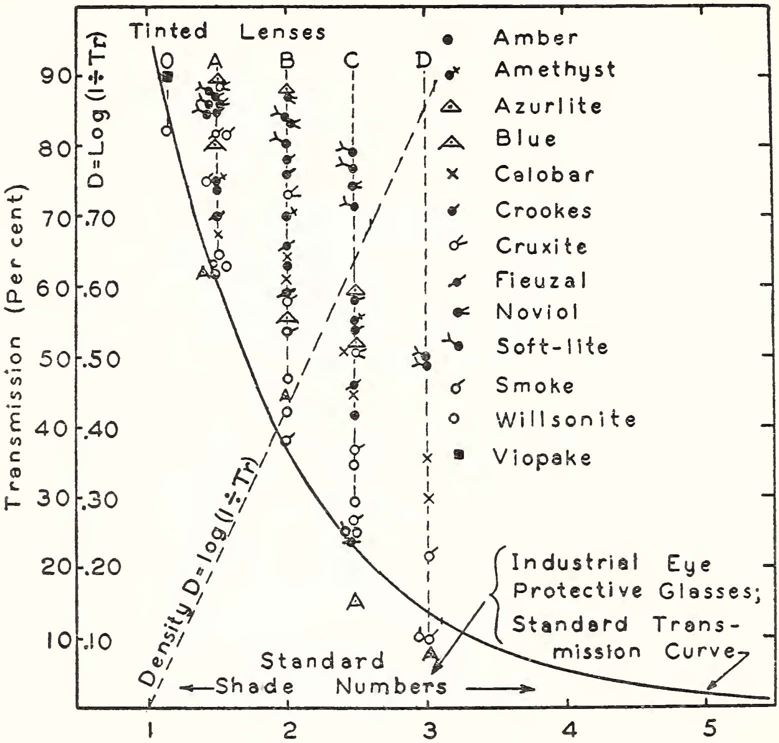

FIGURE 1.—*Comparison of transmissions of total visible radiation by shades O, A, B, C, and D of different makes of tinted lenses.*

2. GLASSES FOR DRIVING AT NIGHT

When one is driving at night the eye is partially dark-adapted and, hence, is near its maximum sensitivity. This may be readily appreciated on 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 consideration. Without shaded glasses the blinding effects of the passing automobile headlights tends 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 ameliorate the glare by wearing dark glasses, his entire field of view is correspondingly darkened, and the right-of-way is placed in continuous obscurity.

In a recent summary report of a survey by the National Safety Council [11] the various authorities are 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 which, at best, is of a low order. For use on the highway, colored glasses should be standardized for driving in the daytime, and abolished at night [20]. This traffic hazard is probably greatest to drivers making long hauls with freight trucks and busses. In this case, goggles are usually worn for protection from wind as well as from eyestrain. When darkness comes on they often continue to wear the colored glasses instead of changing to goggles provided with colorless glass. The alternative is a dark strip on the windshield or a composite goggle, the upper half of dark glass for protection from oncoming automobile headlights and the lower half of clear glass (transmission not less than 90 percent) for good seeing and for protection from wind [11].

3. INCREASE IN VISIBILITY

"Visual acuity" signifies sharpness of vision in respect to the ability to distinguish fine details. Theoretically at least, visual acuity may be increased by using monochromatic illumination to eliminate the effect of chromatic aberration of the eye; but this cannot be accomplished by using colored glasses, for these transmit broad bands of radiation instead of spectral lines.

In the National Safety Council survey [11] the opinion is expressed that visual acuity, in the usual sense, is not nearly so important as brightness-contrast in ordinary seeing.

As used in connection with tinted lenses for increasing the visibility of distant objects, the term "visual acuity" is a misnomer. What is accomplished, if anything, is an increase in visibility ("apparent distinctiveness") of objects by the elimination of scattered light of short wave lengths. This is well-known to the landscape photographer, who obtains clear-cut pictures of clouds and distant scenes by placing over his camera lens an amber glass, which excludes the short waves of the spectrum. The aviation photographer obtains sharp photographs of enormous stretches of landscape by using an optical filter which excludes all but the infrared rays. These devices function largely by removing the veiling effect of the short-wave light scattered by the intervening atmosphere; but they do not improve vision in a fog or dust-laden atmosphere, which scatters the longer waves as well.

So-called visual acuity tests were made by two observers, having normal color vision, through various herein-described lenses, on a hot day, in bright sunshine, with a hazy atmosphere that obscured the details of large objects (buildings and tall, light-colored smokestacks) situated 1 to 3 miles away. Observations were made also on a nearby traffic sign (white on black background), on nearby buildings of red brick laid on contrasting mortar, and on the underbrush of a neighboring forested hillside. From these observations it was concluded that the visibility of objects, near and far, viewed through light shades of azure-blue glass was either unchanged or decreased—never enhanced.

Light shades ("*O*," "*A*," figs. 1 and 2) of glasses that absorb the violet end of the spectrum, yet transmit 85 to 88 percent of daylight, do not increase the visibility of objects partially obscured by haze; but dark shades of amber and greenish-yellow glasses improve the visibility of partially obscured objects.

4. DISTORTION OF COLORS

The light shades (fig. 2) of all tinted lenses show relatively little selective absorption in the visible spectrum, and consequently the claim that they do not appreciably alter colors is substantially correct. Such glasses are of little use to protect the eye from glare.

But glasses which are sufficiently opaque (shades *B* and *C*) to protect the eye from glare usually exhibit selective absorption and may appreciably alter the colors of outside objects (flowers and vegetation). The smoke glasses have a fairly uniform absorption throughout the visible spectrum (fig. 3) and consequently cause the least distortion of color.

From their transmission curves (figs. 10 and 11), it is readily seen that shades *B* and *C* of Amethyst and Soft-Lite glasses, possessing a strong absorption in the blue region of the spectrum, modify colors; greens and blues appear darker, while yellow, orange, and red tints are accentuated.

Amber and brown glasses absorb the blue and violet, and, hence, flatten the yellows and intensify the reds.

The dark blue-green and greenish-yellow glasses (Willsonite, Calobar, etc.) 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 bluer or be tinged with yellow.

Since the maximum of the visual response is in the yellow-green, for wear outdoors with the least distortion of colors, if a colored glass is to be worn at all, a filter lens having a dominant hue in the yellow-green or greenish-yellow portion of the visible spectrum has been suggested [20]. Such a glass, having a transmission of about 50 percent, was found to eliminate the glare from the large expanse of blue sky and to prevent discomfort in seeing. As noted on a subsequent page, such glasses, especially the smoky, greenish-yellow glasses, having a transmission of about 60 percent (shade 1.5), are finding favor in aviation. For sports wear, where colored glasses are worn only during the brightest part of the day for protection from glare, the question of distortion of colors appears to be of secondary importance.

The question of confusion of 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 [11].

The most common form of defective chromatic vision is red-green blindness—yellow-blue vision. When it is considered that an average of 5 persons out of 100 are color-blind (a higher percentage of men than women), the importance of avoiding confusion of traffic signals by persons with defective color vision is evident. For this purpose, the standard green traffic signal recommended by the American Standards Association is bluish-green. However, since bluish-green glass, and its position relative to the red, is not in universal use, the hazard of confusion of traffic 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 [11].

Another thing that is to be guarded against is the use of strongly colored, especially green, filters (e. g., the deep-green celluloid eye-shades and windshield overlays), which may obscure almost completely a red traffic light, thus having practically the same effect as color blindness (11).

5. ARE TINTED LENSES HABIT-FORMING?

The term "habit-forming" is rather vague. Some years ago it had a sinister meaning, at least by inference, that an atrophy of the color sense (color blindness) might result from prolonged use of certain kinds of tinted lenses. In recent discussions, "habit-forming" has been used to characterize a temporary loss of the power of adaptation to brightness [11].

The question of possible loss of color sense, by excluding from the retina certain wave lengths that excite vision, must be answered in the negative. Suitable color tests on two subjects, reported a few years ago [1], revealed that years of exclusion of the blue-violet rays, by means of amber-colored glasses, had not rendered them color-blind. In the meantime (since 1934), one of these subjects has been wearing colorless lenses, with no feeling of discomfort, showing that the prolonged use of amber glasses has not been detrimental. In the report [11] of the National Safety Council, the opinion is expressed that colored glasses are not likely to cause color blindness.

A temporary loss of the power of accommodation, induced by wearing colored glasses on long automobile drives, is occasionally reported [11]. This may be relieved by wearing specially prepared glasses which are gradually increased in transmission until the eye can tolerate a normal intensity. This trouble can be avoided by wearing the colored glasses only during the brightest period of the day.

Before leaving this subject, it is desirable to mention that eye fatigue on automobile trips is not necessarily caused by glare. A case has been cited [8] where wearing a shade 3 glass failed to give relief, and yet this was obtained by wearing clear glasses that properly corrected a slight inequality in refraction of the two eyes (anisometropia). This instance is cited to show the narrow limits that may exist between eye comfort and discomfort, and how the latter sometimes may be avoided by taking into consideration small factors that ordinarily may be neglected, as, for example, in this case where clear glasses are worn for near vision (reading) and, generally, none are worn for distant vision.

6. STANDARDIZATION OF SHADE NUMBERS

The purpose of wearing colored glasses is to secure eye comfort without producing a hazard from reduction in visibility [11]. The various shades used are based on experience and not necessarily on laboratory observations of the visual response (reduction in brightness sensation) of the eye. However, until within very recent times, there has been no attempt to standardize the various shades of tinted lenses for outdoor wear, although the transmissions for glasses used in the industries have been fixed for some time. The multiplicity of the kinds of tinted lenses and of trade names, some of which apply to the same type of glass, add to the dealer's confusion. For example, amethyst-colored glass is marketed under different trade names: Soft-Lite, Roselite, Roseite, Old Rose, etc.

59187—38——2

The great need of ophthalmologists, opticians, and dealers in tinted lenses is a reduction in trade names, and in the number of shades of tinted lenses. This will simplify the problem of prescribing tinted lenses, and it will reduce the expense of carrying them in stock. Probably the most objectionable feature of the present situation is the sudden change in style, which may leave the dealer with a stock of unsold lenses [1].

As an illustration of the need of standardization of shade numbers, in figure 1 is shown the great variation, ranging from 30 to 50 percent, observed several years ago [1] in the transmission of visible radiation through the same nominal shade (*A*, *B*, or *C*) of different brands of tinted lenses. While in recent productions there seems to be a better uniformity, there is need for still closer agreement in the transmissions of the various brands with the standard shades.

In order that the oculist may know what he is prescribing, it is imperative that manufacturers agree upon a standard set of shades and corresponding percentage transmissions and adhere to them. It is recommended that the number of shades be reduced to three (*A*, *B*, and *C*) having transmissions easily remembered. In round numbers, corresponding with the shades *A*, *B*, and *C*, the recommended transmissions are 60, 35, and 25 percent, respectively.[2]

The corresponding numerical values suggested for the shades *A*, *B*, and *C* fall within the tolerances in the transmissions proposed in the Federal specification [10]. The revised Federal specifications include shade numbers 1.5, 2.0, and 2.5 (with corresponding transmissions of 62, 37, and 24 percent, respectively) instead of the shades *A*, *B*, and *C*. The use of the letters *A*, *B*, and *C* simplify prescription records and should be continued because they are in common use among ophthalmologists. Furthermore, the use of letter designations will distinguish tinted lenses for outdoor wear from the colored glasses used for protecting the eyes from injurious amounts of ultraviolet and infrared rays.

Since shades *A*, *B*, and *C* are intended for outdoor wear, the special requirement for protection from ultraviolet and infrared rays, as prescribed in the Federal specification [10] does not seem vital. If shade *C* is not adequate (for example, for use in ultraviolet therapy with artificial sources, that emit radiation of wave lengths shorter than 280 mμ [9]) the physician may prescribe a darker shade from among those of industrial eye-protective glasses.

For driving in bright sunlight, Coblentz and Stair, among others, find that shade 3 (shade *D* in fig. 1; transmission 14 percent) is none too dark; but as already noted for night driving, it is impracticable to wear even shade *B* or *C* for protection from headlight "glare" [1, 11]. The lightest shade, *O*, in figure 1, having a transmission of 85 to 88 percent, which gives a reduction in brightness sensation of less than about 5 percent, offers no adequate protection from glare, and should have no place in the eye-protective market.

In concluding this discussion it is relevant to note that, in recent years, some of the lighter shades of tinted lenses, sold for outdoor wear, are being made of the same kind of glass that is used in the darker shades of lenses for protecting the eyes of industrial workers. The extension of this practice will reduce the plethora of tinted lenses,

[2] From physiological tests it appears that if the shades *A*, *B*, and *C* have transmissions of 60, 36, and 21.5 percent, respectively, they reduce the brightness sensation by equal steps.

cheapen the product by quantity production, and simplify their prescription through standardization.

II. SPECTRAL TRANSMISSIONS OF TINTED LENSES

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

As shown in figure 2, which gives the spectral transmissions of various makes of glasses, and also the visual response curve of the eye, the lighter shades of tinted lenses, which contain only a small amount of coloring matter, are practically colorless except when viewed edgewise.

The color in the glass may be caused by an extension of a band of absorption (a) from the ultraviolet, (b) from the infrared, or (c) from both the ultraviolet and the infrared, into the visible spectrum. Spectacle lenses having marked selective absorption in a narrow band of the visible spectrum are principally Crookes (didymium) glasses, which, in the darkest shades, absorb heavily in the region of maximum visibility (at about 550 mμ), the resultant color being approximately neutral.

In view of the large number of kinds of tinted lenses, some of which, as already noted, appear to be differences only in trade name for the same type of glass, in this Circular the various types of colored glasses are classified according to their dominant hue—amber, yellow-green, sage-green, etc.

The data presented herewith consist of some of the measurements made by Gibson and McNicholas [3] on glasses marketed some years ago (marked "*T.119*" in the illustrations); also data obtained by the writers, with the assistance of J. M. Hogue [1] and new data on recent productions of tinted lenses. Additional data on infrared transmissions and other details pertaining to most of these glasses are published elsewhere [2, 4, 5]. The thickness of samples examined was close to that commonly used in lenses, namely, 2 mm. The material examined was obtained from various sources, principally from the following firms: American Optical Co., Azurlite Lens Co., Bausch & Lomb Optical Co., Corning Glass Works, Arthur Frank & Co., and The Willson Products, Inc.

1. COLORLESS GLASSES

By "colorless" is meant an absence of tint in the glass when viewed through a 2 mm thickness as commonly used in spectacles. Viewed edgewise a sheet of practically colorless glass may show a distinct color.

The most representative example of colorless ("water white") glass, commonly used in spectacles, is called light crown (fig. 2). It is a soda-lime glass (refractive index, $n=1.523$), prepared from relatively pure materials (including sand) containing a low concentration of iron oxide, which imparts a greenish tint to common window glass (figs. 2 and 9) when viewed edgewise. On the other hand, one of the most useful materials, intentionally added to the batch to produce a colored eye-protective glass, is ferrous oxide.

The greenish tint that would otherwise appear in glass used in windows, bottles, lamp chimneys, etc., is sometimes neutralized by adding a small amount of manganese or selenium to the melt. On solarization, the glass that is decolorized with selenium, shows a brownish tint, and the glass decolorized with manganese appears pink or deep amethyst. Good illustrations of amethyst-colored glass are chimneys inclosing carbon arcs and Welsbach gas mantles used in street lighting, and discarded bottles that have been exposed to sunlight.

There is no marked difference in the spectral transmission of solarized (amethyst-colored) bottle glass and the hereindescribed intentionally colored amethyst spectacle glasses [21].

The light shades of Bluelite, Cruxite (figs. 2 and 3), Viopake (figs. 2 and 4), and of a cerium oxide glass (fig. 2; sample prepared by A. N. Finn, of the National Bureau of Standards) are practically colorless, except when viewed edgewise.

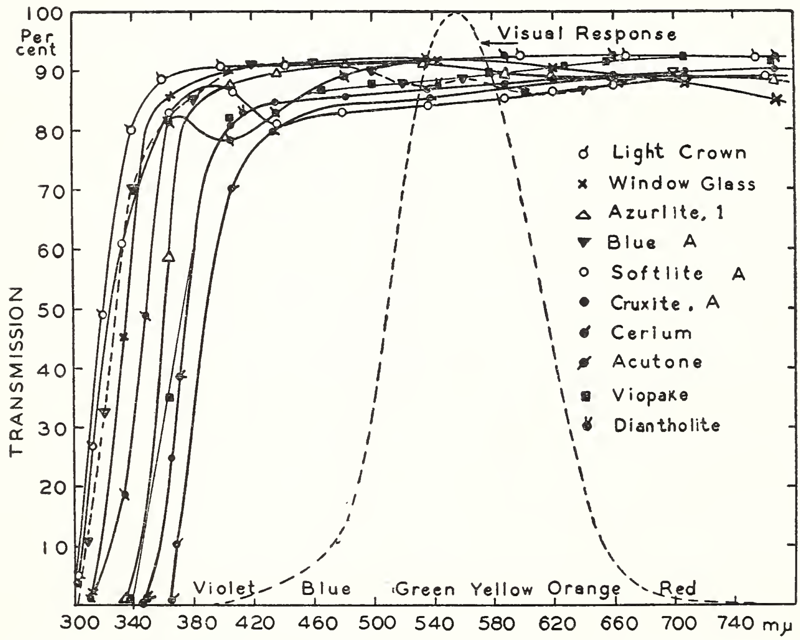

FIGURE 2.—*Spectral transmissions of a number of so-called tinted lenses, and the visual-response curve of the eye.*

Filtray [2], Diantho-Lite (fig. 2), and Avitint *A* seem to be other trade names for glasses having a composition similar to Cruxite *A*. The sample of Avitint *A* examined was found to be opaque at 334 mμ and to exhibit a strong blue fluorescence, the same as Cruxite *A*, when exposed to ultraviolet radiation.

As already stated, all the light shades of the hereindescribed tinted lenses are practically colorless, except when viewed edgewise. The spectral transmissions of the various types (trade names) throughout the visible spectrum (see fig. 2) are fairly uniform, ranging from about 83 percent for the darker shades to 90 percent for the lighter shades. The transmission of total visible radiation (fig. 1) of many of these glasses is above 80 percent, and consequently, they offer little or no protection against glare.

2. NEUTRAL-TINT GLASSES

The most representative examples of this type of lens used in spectacles are smoke (fig. 3) and Crookes glasses (fig. 4). The data for smoke glasses are from various sources. Curve *A* is taken from the paper by Gibson and McNicholas [3]; curve *C* represents the transmission of a sample of unknown make; and curve *W* depicts the transmission of a newly developed Willsonite smoke lens.

The smoke glasses and the darker shades of Cruxite (fig. 3) are characterized by a wide, fairly uniform absorption band throughout the visible spectrum. The darker shades of Cruxite appear to be smoke glasses with cerium oxide added (fig. 2) to absorb the ultraviolet.

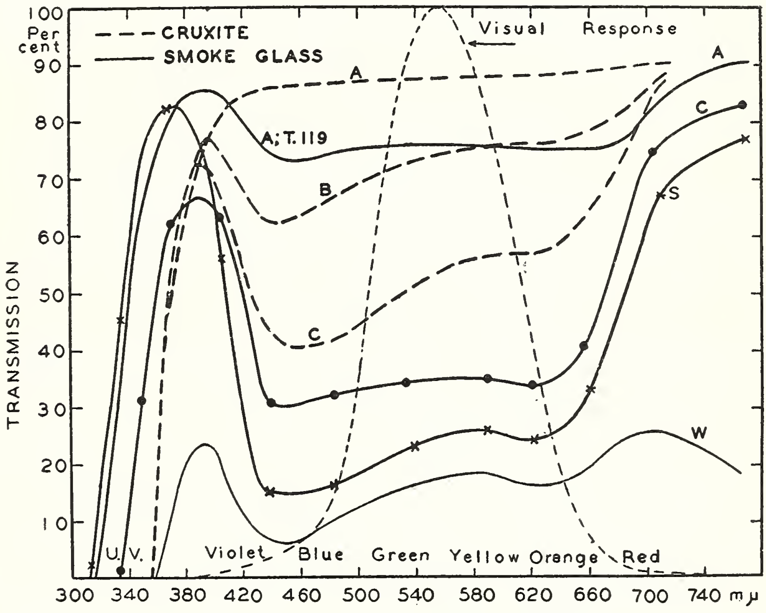

FIGURE 3.—*Spectral transmissions of neutral-tinted (smoke) glasses and the spectral visual-response curve of the eye.*

The Umbral glasses 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 wave lengths shorter than about 350 mμ and has considerable selective absorption in the region of 1,000 mμ. The spectral transmission of Umbral glass differs from smoke (see fig. 3) in the suppression of the band of relatively high transparency at 380 mμ; and also at 700 mμ, similar to curve *W* in figure 3.

Owing to the low radiation sensibility of the eye in the deep blue-violet, requiring a high intensity to excite vision, the high transparency at 380 mμ in the smoke glasses has but little effect upon the color of objects viewed. In the deep shades, as a result of the increased relative transparency in the red, objects, like the sun, viewed through them have a reddish tinge, but as a whole, the smoke glasses are of a neutral tint.

The visual sensation evoked by selectively absorbing the yellow rays, by means of didymium, as in Crookes' glasses (fig. 4) and in Neophan glasses, is a fair representation of "neutral tint." In this connection it is relevant to add that, as noted earlier [1], if there were atrophy of the color sense as a result of practically the entire absence of a narrow band of wave lengths (as obtains in glasses containing didymium), then contrary to known facts, the eye should be insensitive (color-blind) to the violet (*H* and *K*) and to the yellow (*D*) Fraunhofer lines in sunlight.

3. AMBER AND YELLOW GLASSES

Typical examples of amber-colored glasses are Amber (fig. 5); and of a more brilliant yellow are Noviol (figs. 4 and 10) and Kalichrome (fig. 4). Acutone (fig. 2) is made in but one shade that shows only a faint uranium yellow.

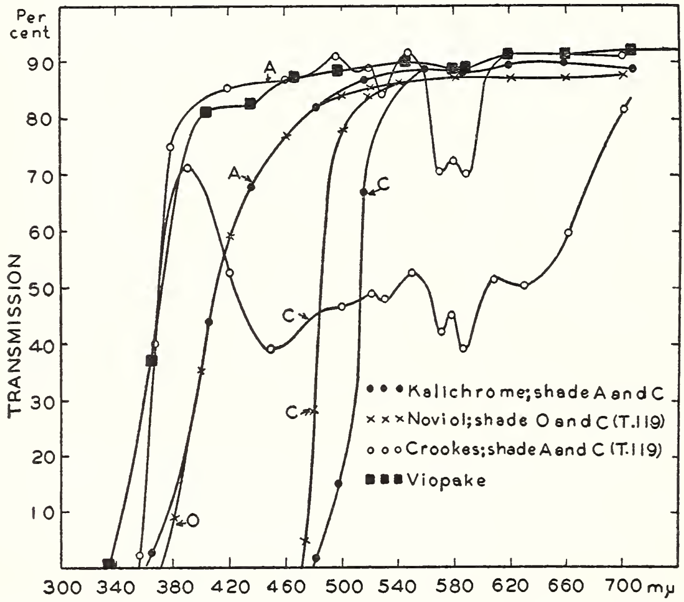

FIGURE 4.—*Spectral transmissions of neutral-tinted, amber, and yellow glasses.*

In the amber glasses, the absorption is relatively high in the ultraviolet, and in the darker shades, the blue and violet rays are absorbed. In the infrared, the transmission of the older productions of amber glasses is high and similar to that of clear window glass [5], which contains a small amount of iron oxide as an impurity. A recent production of Willsonite Amber, shade *B*, (transmission of visible radiation 38 percent) was found to transmit only 5 percent of the total infrared radiation from a Mazda tungsten lamp.

Because of the high selective absorption in the blue and violet, deep-colored amber glasses are likely to cause traffic signals [11] to be confused; especially since the recommended bluish-green light, and its position relative to the red light, is not in universal use.

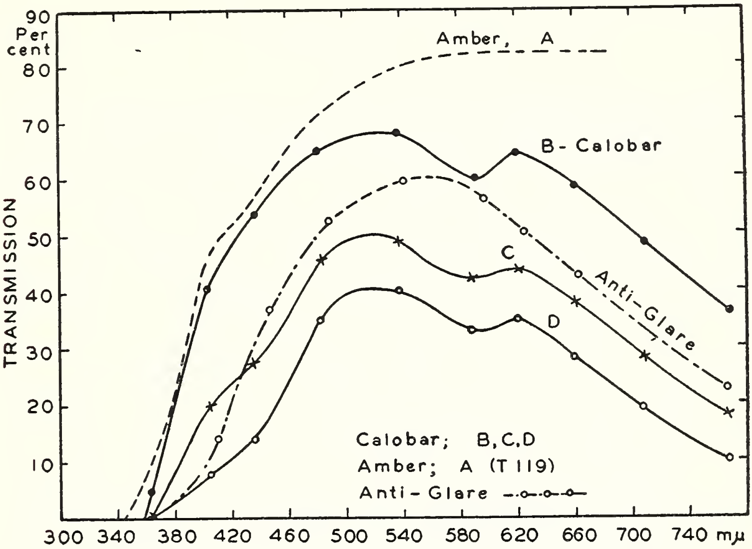

FIGURE 5.—*Spectral transmissions of sage-green, amber, and of blue-green glasses.*

4. YELLOW-GREEN GLASSES

Typical examples are Euphos, Fieuzal, Chlorophile, Hallauer, and Akapos (fig. 6). The glasses in this group differ from the yellow and the amber glasses described under the preceding caption in that, superposed upon the ultraviolet absorption which is common to both types, there are bands of selective absorption in the visible spectrum producing a smoky-greenish yellow in Fieuzal, and a chlorophyl green, "sea green," or yellowish-green in the various glasses sold under the trade names Chlorophile, Euphos, Hallauer, and Akopos (transmissions in fig. 6). The last three glasses appear to be different shades of the same kind of material.

The infrared transmission of these glasses is high and similar to that of light crown glass containing iron impurities [5].

5. SAGE-GREEN AND BLUE-GREEN GLASSES

Typical examples are Calobar (fig. 5), Antiglare (fig. 5), Willsonite blue-green (fig. 7), and Noviweld (fig. 12).

The Antiglare and Willsonite glasses, especially in the darkest shades, have a smoky bluish-green tinge. All are characterized by practically complete opacity in the ultraviolet [3] and in the infrared [2]. Hence, they are practically the only type of glass that can comply with the Federal specifications for eye-protective glasses [2, 6, 10]. Since glasses of this type are not worn continuously, it would seem that atrophy of the color sense of the retina need not be considered [1, 11].

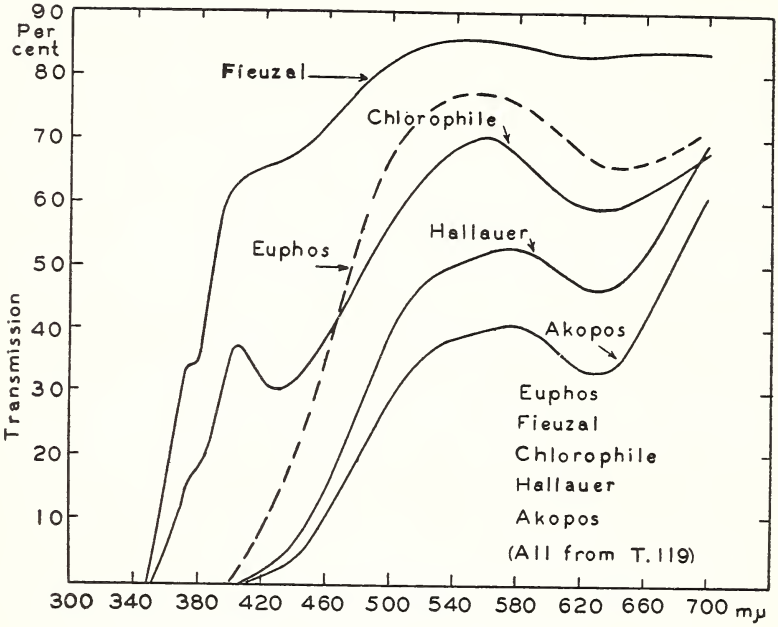

FIGURE 6.—*Spectral transmissions of yellow-green glasses.*

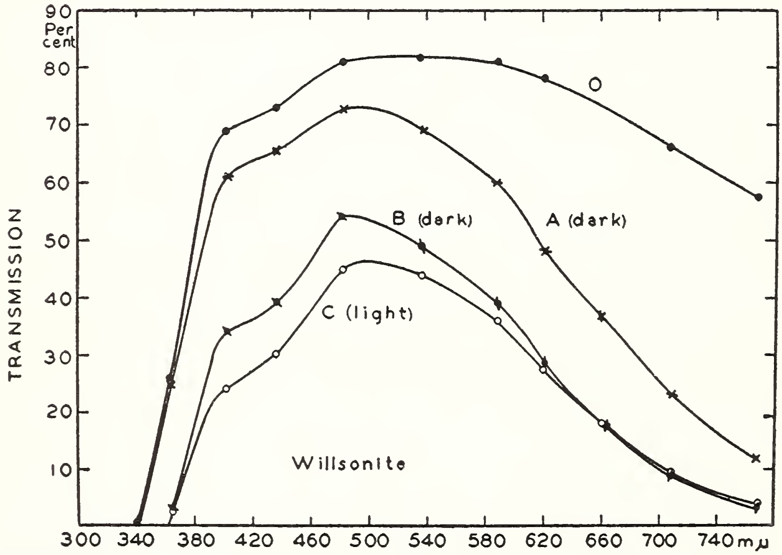

FIGURE 7.—*Spectral transmission of various shades of a bluish-green glass.*

A recent addition to the list of tinted lenses ("sun glasses") is Solarex, which, in the lightest shades, is tinged a bluish-smoke. This glass is opaque to the ultraviolet of wave lengths shorter than about 334 mμ; and it is very opaque to the infrared. The absorption in the deep red distorts the color of red flowers. However, as already stated, this distortion of colors, which is a shortcoming of all types of lenses, is not very marked.

6. BLUE GLASSES

Typical examples are the deep cobalt-blue glasses (fig. 8) and the pale-blue, Azurlite (Azurine), glasses (fig. 9). The latter type is similar to the pale-blue glass, Corning, *G171* (fig. 9), previously described [5].

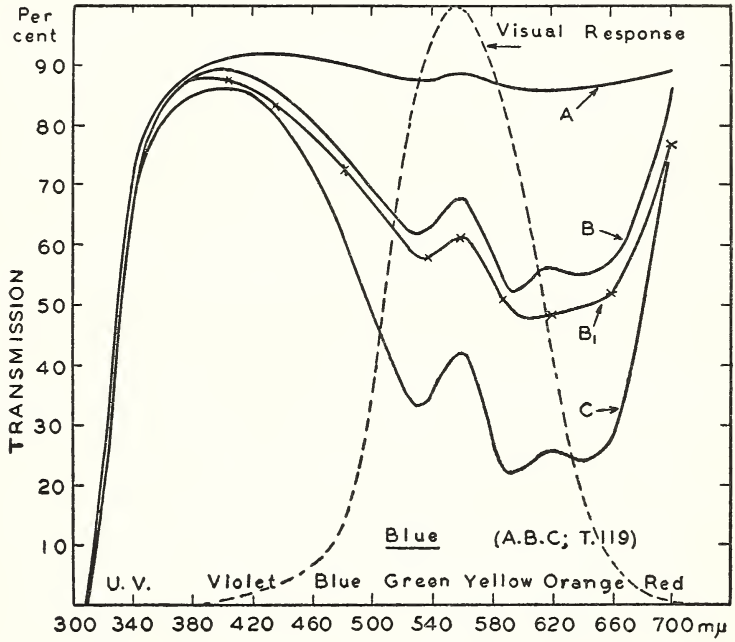

FIGURE 8.—*Spectral transmissions of various shades of cobalt-blue glass, and the visual response of the eye.*

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

The cobalt-blue glasses have a characteristic absorption band at 1,500 mμ, in the infrared. 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 [2, 5]. Hence, neither glass would be useful for completely absorbing the infrared.

As shown in figure 9, the lightest shade (No. 1) of Azurlite is colorless, and in the deep red it absorbs less than a sample of window glass having the same thickness.

Other trade names of glasses having practically the same color as Azurlite are Pittsburgh Blue and Bluelite. The samples of Bluelite, shades *A*, *B*, and *C*, examined were close matches of shades 1, 2, and 3 of Azurlite; and, like the latter, the shades *A* and *B* offer little or no protection from glare or from infrared radiation.

A recent production of Willsonite Blue having a spectral transmission of 57 to 58 percent at 408 to 436 mμ had a total infrared transmission of 3.5 to 5.7 percent for different samples of the same thickness (t=2.3 m).

Cerulite is an imported blue glass. The sample (t=1.4 mm) examined transmitted 34 percent of the total visible and 4.5 percent of the total infrared. It was too thin to meet the Federal specifications [10].

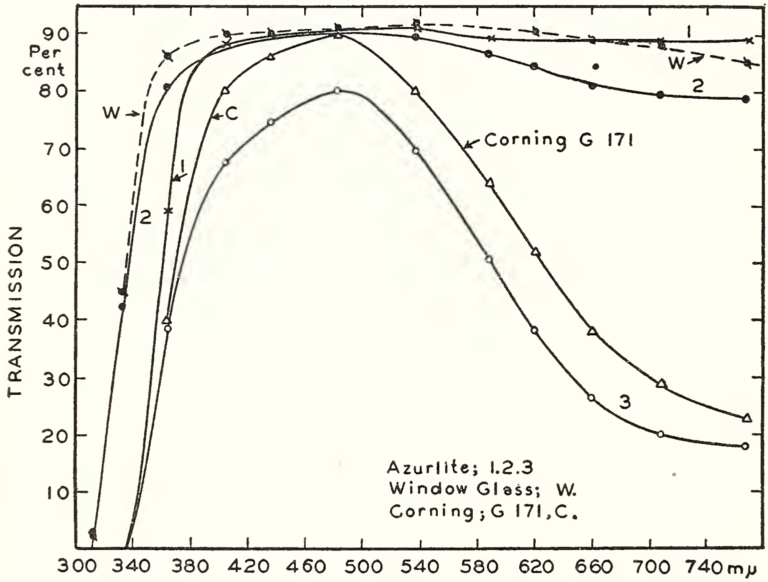

FIGURE 9.—*Spectral transmissions of pale-blue glasses and window glass.*

7. AMETHYST GLASSES

Typical examples of this type of glass are Amethyst (fig. 10) and Soft-Lite (fig. 11). Judging from their descriptive names, "Roselite," "Roseite," and "Old Rose" belong to this classification (fig. 11).

Aside from the fact that Soft-Lite has a slightly more reddish tint than Amethyst glass, the spectral-transmission curves of these two glasses for the same shades, are practically the same. Both glasses are characterized by an absorption band in the blue-green which almost disappears in the lightest, shade *A*, (shade 1) lens which transmits 85 to 88 percent of the total visible radiation (see fig. 1). The transmission in the ultraviolet and in the infrared [2, 5] is high, and not markedly different from light crown glass.

In concluding this presentation of data on tinted lenses for outdoor wear, reference is made to a discussion of glasses for protecting the eye

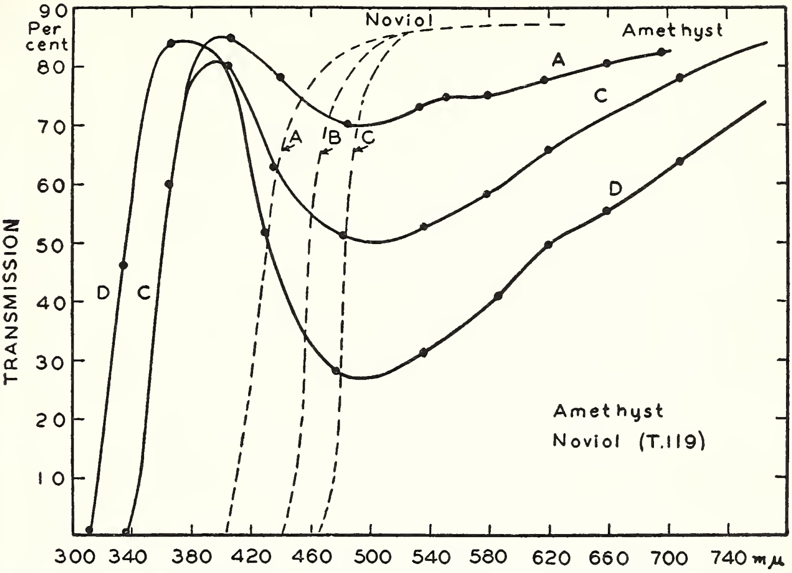

FIGURE 10.—*Spectral transmissions of Amethyst and Noviol yellow glasses.*

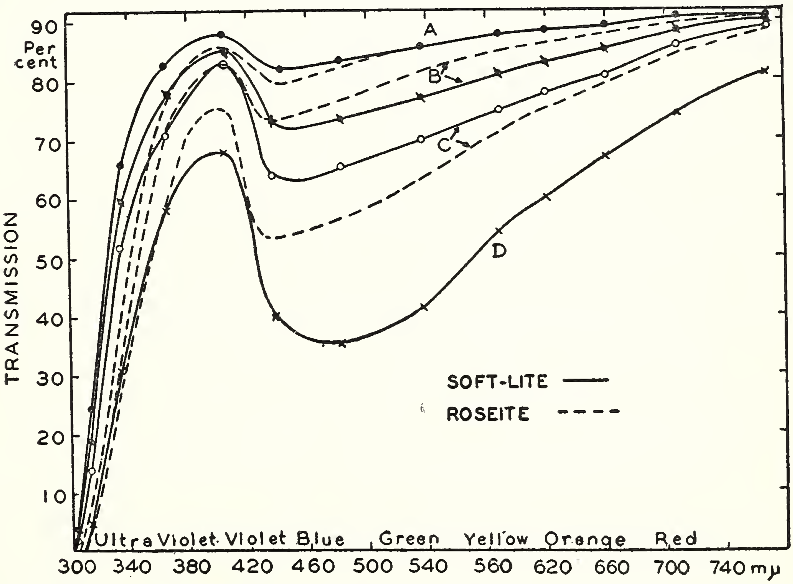

FIGURE 11.—*Spectral transmissions of Amethyst colored ("Soft-Lite," "Roseite") glasses.*

from glare [7, 8] in which it was shown (as repeatedly emphasized in this circular) that only the darkest shades of tinted lenses can shield the eye from the intense glare of visible radiation, and that protection of the eye from ultraviolet solar radiation reflected from average surroundings is of secondary importance.

On the other hand, in the presence of artificial sources of ultraviolet light, such as are used for healing purposes, dark glasses, which are opaque to the ultraviolet, should be worn to avoid injury. We have tested a number of such glasses, having a mahogany or wine color, which were found suitable for wear by persons taking ultraviolet irradiation treatments. However, this is not to be construed as indicating that any lens, having this color, will necessarily protect the eyes from injurious ultraviolet radiation. For example, deep-colored amber glasses are usually found to be opaque throughout the ultraviolet. Nevertheless, the writers have examined samples that had a band of selective transmission at 365 mμ, also samples of (imported) dark welding glasses that transmitted an appreciable amount of ultraviolet at 310 mμ.

From this it appears that the wearing of nondescript colored glasses, when near artificial sources, is advisable only when one has competent assurance that they protect the eyes from injurious amounts of ultraviolet and infrared radiations.

III. COLORED GLASSES FOR PROTECTING THE EYES OF INDUSTRIAL WORKERS FROM INJURIOUS RADIATION

The action of ultraviolet rays is very insidious because the effects (conjunctivitis, etc.) are not felt until some 5 or 6 hours after exposure. Hence, the first thought in writing specifications for eye-protection is to exclude the ultraviolet rays. The action of the infrared rays is thermal, and the worker is generally forewarned by the burning sensation that is felt immediately on viewing sources emitting intense infrared radiation. But even in this case no risk should be taken that may result in injury. Hence, the Federal specifications for eye protection of industrial workers are very stringent in requiring the elimination of both the ultraviolet and infrared rays from harmful sources of radiation.

These specifications [10] require a filter glass that almost completely absorbs the ultraviolet and the infrared rays. The color of the light transmitted through the filter glasses that meet these requirements ranges from a bluish-green to greenish-yellow, or greenish-brown. While in some glasses the maximum of the spectral-transmission curve coincides closely with the maximum of the spectral visibility response of the eye, this is not essential; the color of the glass is of minor importance also in gas and electric-welding operations.

The question has arisen whether there is a safe distance at which spectators can view arc welding, or at which individuals can work near an operator engaged in arc welding, without injury to the eyes [18]. Atmospheric absorption is relatively low for the ultraviolet rays of wave lengths between 240 and 290 mμ, which are strongly emitted by electric arcs and, hence, are most effective in producing conjunctivitis. Hence, the chief protection from injury (if any) is owing to reduction in intensity, which varies inversely with the square of the distance. In addition to this factor is the length of time of exposure, the susceptibility of the individual, the kind and size of the arc, etc. Hence, no definite minimum safe distance can be specified at which one can work without shielding the eyes from possible injury from welding arcs. Before the introduction of modern safety goggles, injury to the eyes sometimes resulted from watching a demonstration of electric arc-welding. In one particular case [19] out of 30 observers, only 2, who wore thick dark glasses, escaped injury.

Coblentz and Stair [2, 6] have given a formula for specifying the shade numbers of eye-protective glasses. By use of this specification good uniformity in the shades of various makes of colored glasses is now obtained. The formula is

$$\text{Density}=3/7\ (\text{shade number}-1)=\log_{10}\left(\frac{1}{\text{transmission}}\right).$$

In this formula the density has the usual meaning, being the logarithm of the opacity; that is, the logarithm of the reciprocal of the transmission.

1. PURPOSES OF GOGGLES

The general function of the goggles covered by the Federal specifications, when fitted with proper filter lenses and cover glasses, is to protect the eyes of the wearer from intense visible light, from ultraviolet and infrared rays, and from mechanical injuries such as spatter from molten metal.

Shades of filter lenses 1.5 to 3.0, inclusive, are intended for protection from the glare of sunlight reflected from snow, water, roadbeds, roofs, sand, etc.; also stray light from cutting and welding, and for protection in metal pouring and furnace work.

Shade 4 is intended for the same use as shades 1.5 to 3.0, inclusive, under conditions of greater intensity.

Shade 5 is intended for wear in light gas cutting and welding and for light electric spot welding.

Shades 6 and 7 are for wear in gas cutting, medium gas welding, and for arc welding up to 30 amperes.

The cover glasses are used as a protection against pitting of the filter lenses.

In table 1 are given the transmissions and tolerances in transmissions of these various shades of eye-protective glasses.

2. PURPOSE OF WELDERS' HELMETS AND HAND SHIELDS

The general function of the helmet is to protect the face, head, and neck from heat and injurious radiant energy encountered in gas or electric welding and cutting, while that of the shield is to protect the face and head.

Shade 8 of filter glasses is for heavy gas welding and for arc welding and cutting when using over 30 but not exceeding 75 amperes.

Shade 10 is for arc welding and cutting when using over 75 but not exceeding 200 amperes.

Shade 12 is for arc welding and cutting when using over 200 but not exceeding 400 amperes.

Shade 14 is for arc welding and cutting when using over 400 amperes.

The cover glasses are used as a protection against pitting of the filter glasses.

TABLE 1.—*Densities and transmissions (in percent); also tolerances in densities and transmissions of various shades of glasses for protection against injurious rays*

[Shades 1.5 to 7, inclusive, are for use in goggles; shades 8 to 14, inclusive, for welders' helmets and handshields]

Shade No.	Density for visible radiation			Transmission of total visible			Maximum total infrared	Maximum ultraviolet spectral transmission			
	Minimum	Standard	Maximum	Maximum	Standard	Minimum		313 mμ	334 mμ	365 mμ	405 mμ
1.5	0.17	0.21	0.25	67	62	56	25	0.2	0.8	25	65
1.7	.26	.30	.36	55	50	44	20	.2	.7	20	50
2.0	.37	.43	.52	43	37	30	15	.2	.5	15	35
2.5	.53	.64	.74	29	24	18	12	.2	.3	5	15
3.0	.75	.857	1.06	17.9	13.9	8.70	9.0	.2	.2	.5	1.0
4.0	1.07	1.286	1.49	8.51	5.18	3.24	5.0	.2	.2	.5	1.0
5.0	1.50	1.714	1.92	3.16	1.93	1.20	2.5	.2	.2	.2	.5
6.0	1.93	2.143	2.35	1.18	.72	.45	1.5	.1	.1	.1	.5
7.0	2.36	2.572	2.78	.44	.27	.17	1.3	.1	.1	.1	.5
8	2.79	3.000	3.21	.162	.100	.062	1.0	.1	.1	.1	.5
9	3.22	3.429	3.63	.060	.037	.023	.8	.1	.1	.1	.5
10	3.64	3.857	4.06	.0229	.0139	.0087	.6	.1	.1	.1	.5
11	4.07	4.286	4.49	.0085	.0052	.0033	.5	.05	.05	.05	.1
12	4.50	4.715	4.92	.0032	.0019	.0012	.5	.05	.05	.05	.1
13	4.93	5.143	5.35	.00118	.00072	.00045	.4	.05	.05	.05	.1
14	5.36	5.571	5.78	.00044	.00027	.00017	.3	.05	.05	.05	.1

The transmissions and tolerances in transmissions of the various shades of helmet windows are given in the lower part of table 1.

3. RADIANT-ENERGY TESTS FOR FILTER LENSES

The Federal specifications require that all filter glasses shall be tested for their transmission qualities according to the following methods:

(a) ULTRAVIOLET SPECTRUM

The source of radiant energy for determining the ultraviolet spectral transmission shall be a quartz mercury arc or other source emitting an intense and preferably discontinuous 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 wave lengths closest to the above values of the mercury arc may be used. The wave length 405 mμ is included in this specification principally as a guide in establishing the maximum transmission in the blue-violet part of the visible spectrum.

If a high-powered (2,000 to 3,000 watts) gas-filled tungsten lamp (which is especially strong in infrared radiation) is used as a source of ultraviolet radiation, then especial precautions shall be taken to eliminate the effect of stray visible and infrared radiation from the measurements in the ultraviolet.

If a spectroradiometer (with a thermopile or photoelectric cell) is used, its optical parts should be of quartz or other material transparent to the extreme ultraviolet. To eliminate the effect of stray radiation, especially in the extreme ultraviolet, the shutter which is used in admitting the radiation of the source into the spectroradiometer while taking the zero reading should be of red or (Noviol) yellow glass that is opaque to ultraviolet radiation.

In place of a spectroradiometer for determining the opacity of filter lenses at different wave lengths in the ultraviolet, suitable photoelectric cells and filters may be employed to compare the integrated ultraviolet transmission of an unknown filter lens with that of a standard sample of known spectral transmission (given in table 1) in wide bands of the ultraviolet.

The apparatus 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 radiation on 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 wave lengths longer than 320 mμ (connected with a high-resistance galvanometer, with a balanced amplifier and microammeter [22], or with a Rentschler "impulse" ultraviolet meter [23]) may be used to compare the opacity of the unknown filter lens with that of the same shade of a standard sample to wave lengths shorter than 320 mμ. This is the most important part of the spectrum to be eliminated, because radiation of wave lengths 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 wave lengths shorter than 410 mμ, covered with a filter glass, Corning *No. 586* [25], which has a maximum transmission at 365 mμ, a measurement is obtained of the opacity of the unknown sample relative to that of a standard sample, at the wave lengths 334 and 365 mμ, in the quartz mercury arc.

By covering the Ce cell with a filter of shade O Noviol glass (fig. 4) which is opaque to 365 mμ, a measurement is obtained of the transparency of the unknown sample relative to that of the standard sample at 405 mμ, which is used as the long wave length end point in specifying the spectral transmission in the ultraviolet (table 1). Hence, judging from the filter glasses now manufactured, close agreement of the opacity of the unknown sample with that of the standard sample at 405 mμ is unnecessary in order to insure complete elimination of the rays of shorter wave lengths known to be injurious.

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. 586*, and a measurement made of the transparency in the region of 365 mμ. Only as a last resort is it necessary to make a measurement with Cd or Ti cell to test the opacity at 320 mμ and shorter wave lengths.

(b) VISIBLE RADIATION

The standard source of radiant energy used in the measurement of the transmission of visible radiation ("light") of eye-protective glasses shall be a 500-watt (or other high-powered) gas-filled tungsten-filament electric incandescent lamp operated at rated voltage.

The transmission of visible radiation ("total visible") is to be determined photometrically by an observer having normal color vision, as determined by the Holmgren test for color vision. A physical photometer, consisting of a thermopile and a luminosity solution having a special transmission curve which coincides closely with the spectral luminosity curve of the average eye, or a photronic cell covered with a filter that gives the device a spectral response that coincides with spectral luminosity reponse of the average eye may be used to determine the transmission of visible radiation.

(c) INFRARED RADIATION

The same standard source of radiant energy used in determining the transmission of visible radiation shall be used also in the measurement of the transmissions of the total infrared radiation.

The total infrared radiation shall be determined either by observing the infrared spectral-energy distribution curves of a gas-filled lamp, with and without the glass interposed before the entrance slit 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 Sextant Red [2] or Schott's 2,745 or 4,512) which has a high and uniform transmission through the infrared spectrum and transmits less than 0.5 percent of visible radiation.

4. SPECTRAL-TRANSMISSION DATA OF SPECIAL FILTER GLASSES

The stringent requirements of the Federal safety code for eye protection [10] has reduced the number of glasses that are suitable for protecting the eye from injurious radiation. In these glasses the opacity in the ultraviolet and in the infrared is so great that only for the lighter shades is it of interest to give the spectral transmissions. In the following pages a brief description is given of the transmissive properties of some of the glasses used in industrial work.

(a) NOVIWELD

Until recently, the Noviweld glasses (American Optical Co.), described in earlier papers [2, 4], were unique for their completeness in obstructing practically all the ultraviolet and the infrared through the whole range of shades from the lightest to the darkest.

The color of the transmitted light is greenish-yellow. The transmission [13] in the visible spectrum is illustrated in figure 12, and the measurements throughout the visible and the infrared are depicted in figure 13. Recently, a new Noviweld glass has been developed, greenish in color, with a transmission curve closely the same as the Willson-Weld and the B&L Green illustrated in figure 12. The infrared transmissions are much lower than shown in figure 13.

(b) WILLSON WELD

This is a greenish or faintly bluish-to-yellowish-green colored glass from the Willson Products, Inc. As may be noted in figure 14, the darker shades of this glass are entirely opaque to the ultraviolet and to the infrared.

A somewhat similar brownish-green Belgian glass imported by the Mattice Engineering Co. was found to have good protective properties in the ultraviolet, but the infrared transmission was too high to meet the specifications.

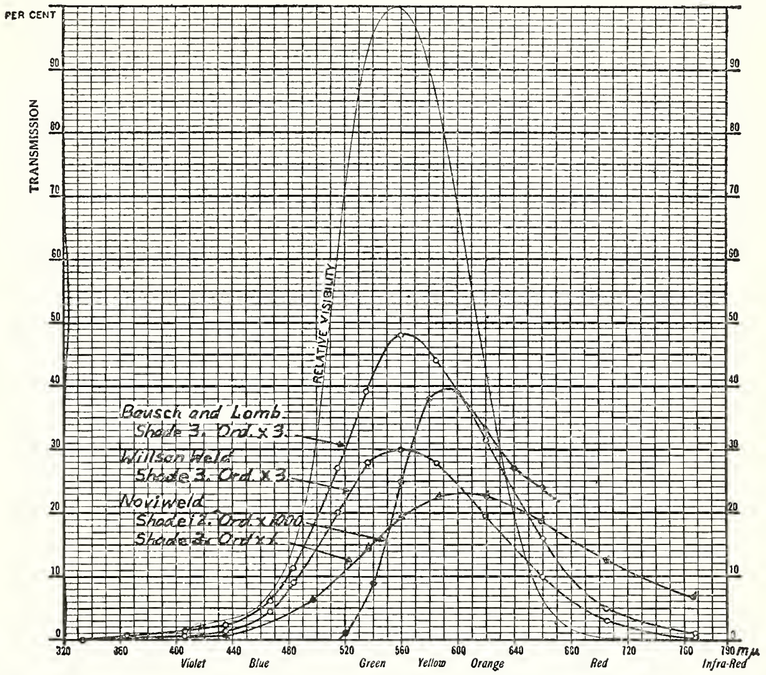

FIGURE 12.—*Transmissions in the visible spectrum of several standard industrial eye-protective glasses.*

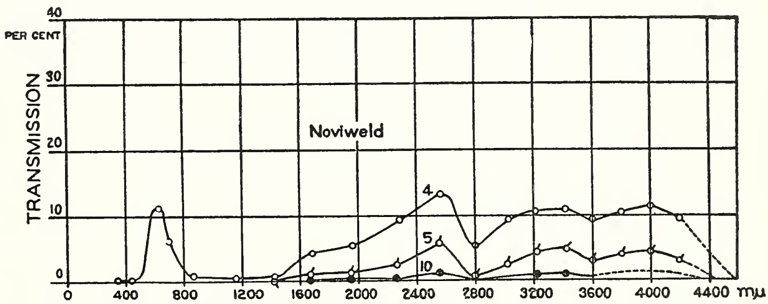

FIGURE 13.—*Spectral transmissions in the visible and in the infrared of several shades of a yellowish-green glass.*

(c) WILLSONITE SMOKE

This is a newly developed smoky, faintly yellowish-green, colored glass, with a low transmission in the red (see fig. 3) that seems to aid in producing a neutral tint.

In this connection, it is relevant to note that some years ago the writers improved the uniformity of the spectral transmission of their optical-pyrometer filters (Schott's neutral tint smoke glasses, which have a high transmission in the deep red) by combining with them a light blue-green heat-absorbing glass, Corning *G124J*, that absorbs the red and infrared.

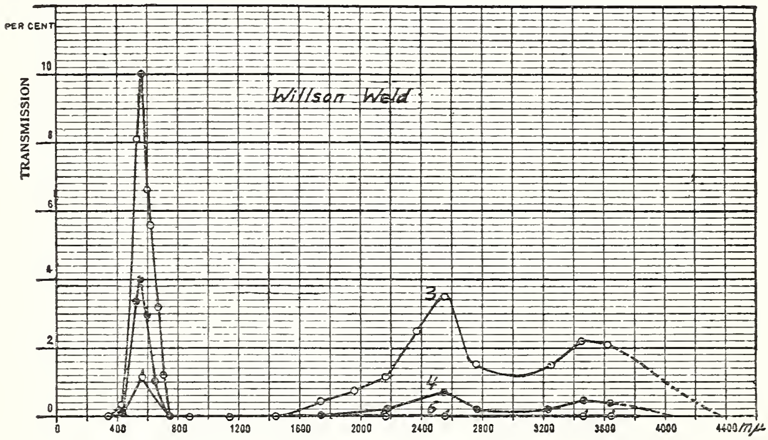

FIGURE 14.—*Spectral transmissions in the visible and in the infrared of a bluish-green glass.*

(d) BAUSCH & LOMB GREEN

A recent addition to eye-protective glasses is a greenish-colored, or, in the lighter shades, a faintly yellowish-green glass, made by the Bausch & Lomb Optical Co. The darker shades of this glass are entirely opaque to the ultraviolet and to the infrared. The transmission of a light shade of the B&L filter glass is illustrated in figure 12; and of various shades, throughout the infrared, in figure 15.

It is to be noted that owing to the great opacity of the darker shades of all makes of colored glasses (for example, American Optical Co., No. 2120) in the infrared, the transmissions cannot be conveniently depicted.

(e) CALOBAR

The spectral transmission of this glass (from the American Optical Co.) depicted in figure 16 is similar to that of Crookes' ferrous sage-green glass previously described [4].

Shade 1.5 (shade *A*; *tr*=62 percent) of blue-green and sage-green glasses seems to be gaining favor for outdoor wear, especially by aviators.

(f) IMMUNITE

This is a greenish glass (from Strauss and Buegeleisen). The sample of "Immunite III" tested had a dark-green color. It is notable for its relatively high transmission in the visible spectrum and great opacity in the ultraviolet and in the infrared. Other samples having the same name, which were more grayish in color, were not so satisfactory as regards opacity in the infrared [2].

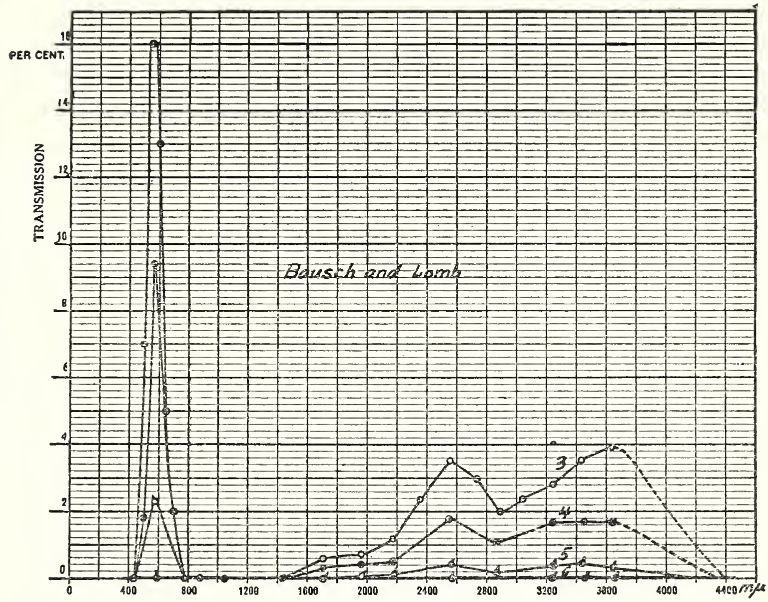

FIGURE 15.—*Spectral transmissions in the visible and in the infrared of a yellowish-green glass.*

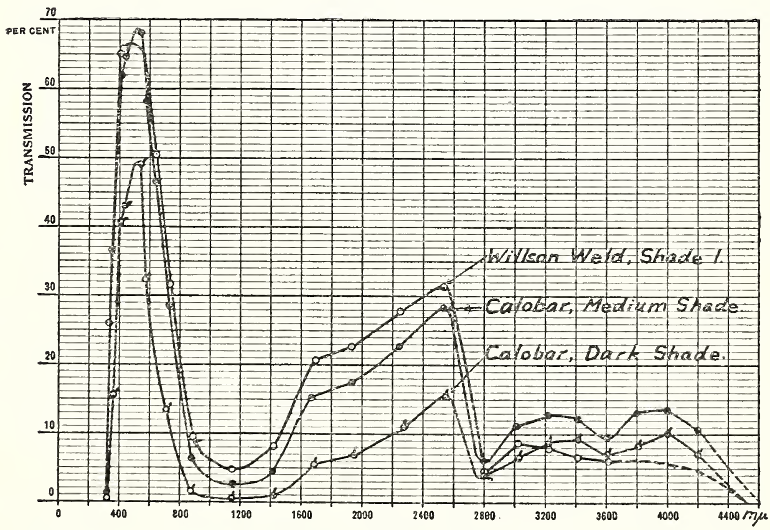

FIGURE 16.—*Special transmissions of several shades of a sage-green glass.*

(g) EXCELOLITE X

This is a greenish-colored glass (from the Sellstrom Manufacturing Co.). The sample tested was about shade 12. It was very opaque to the ultraviolet and the infrared. Another sample of "Excelolite" did not have such good absorptive properties for injurious radiation [2].

(h) COBALT-BLUE GLASS

A particular shade of cobalt-blue glass, known as the Pugh glass, is demanded by operators of open-hearth furnaces, etc., because of the contrast in brightness that is obtained between the molten metal and the interior of the furnace. Viewed through a Pugh glass, green vegetation (leaves, grass) appears red. On the Lovibond system of color grading, the Pugh glass is closely matched by a No. 15 red and No. 20 blue.

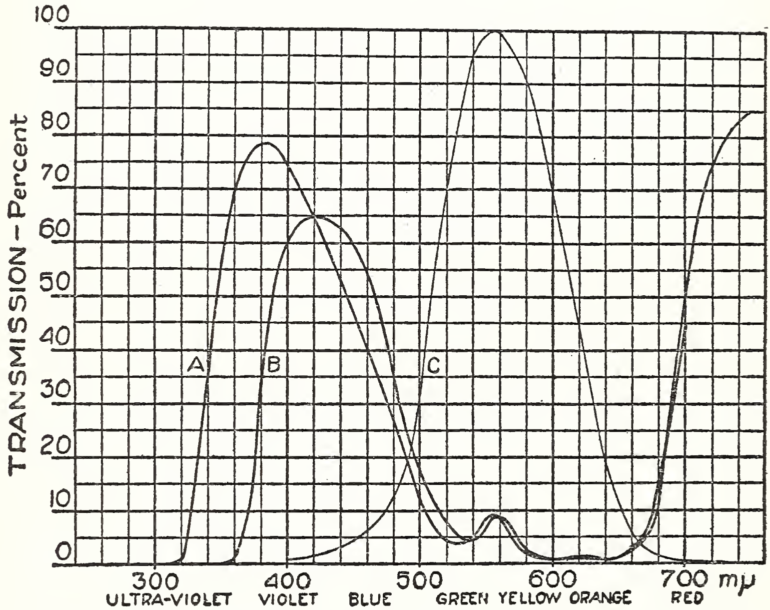

Figure 17.—*Spectral transmission of ordinary cobalt-blue glass, A, and of a similar glass containing cerium oxide, B.*

Ordinary cobalt glass has a high transmission for ultraviolet rays and a relatively high transmission for infrared rays. In view of the usefulness of this glass in furnace work, some years ago improvements were made [12] in the optical properties; first, by adding cerium oxide to eliminate the ultraviolet and, later on, by adding ferrous iron, to absorb the infrared. For further data on this glass, reference is made to the original papers [2, 12].

In figure 17, curve *A* shows the spectral transmission of ordinary cobalt glass, curve *B* shows the elimination of the ultraviolet by means of cerium oxide, and curve *C* shows the spectral luminosity response of the average eye. From these curves it may be seen that, owing to the almost complete absorption of the green, yellow, and orange rays, great contrast is obtained between different parts of the interior of a furnace and the container of the molten metal when viewed through a deep cobalt-blue glass.

In places where the Pugh glass is used for only a short time each day, the requirements for protection from infrared radiation appear to be less stringent than in prolonged usage, day after day, as for example, in welding and cutting with the electric arc.

(i) POLAROID

This recently devised light-polarizing material, consisting of fine crystals imbedded in a thin film of cellulose or other transparent flexible material, is worn for eye protection in winter sports, to mitigate the glare reflected from snow and ice. It has been proposed as a means for reducing the glare of automobile headlight lamps.

The samples of polaroid lenses examined consisted of a lamination (green or brownish in color) between plates of relatively colorless glass. In both kinds (colors) the transmissions were about 0.3 percent at 365 mμ, and much lower for shorter wave lengths. The transmission of unpolarized visible radiation (determined with a physical photometer, since a polarization photometer is inapplicable) was 26 percent. The total infrared was high (81 percent), but this could be reduced by using a sage-green glass as a mounting. As noted on a preceding page, the transmission (26 percent) of visible radiation through this type of tinted lens is too low for use as a spectacle lens for night driving.

IV. REFERENCES AND NOTES

[1] W. W. Coblentz, *The transmissive properties of tinted lenses.* Am. J. Ophthalmol. **15,** 932 (1932).

[2] W. W. Coblentz and R. Stair, *Transmissive properties of eye-protective glasses and other substances.* Tech. Pap. BS **22,** 555 (1928) T369 (out of print).

[3] K. S. Gibson and H. M. McNicholas, *The ultraviolet and visible transmission of eye-protective glasses.* Tech. Pap. BS **6,** (1919) T119 (out of print).

[4] W. W. Coblentz and W. B. Emerson, *Glasses for protecting the eyes from injurious radiations.* Tech. Pap. BS (3d ed. 1919) T93 (out of print).

[5] W. W. Coblentz, W. B. Emerson, and M. B. Long, *Spectroradiometric investigation of the transmission of various substances.* BS Sci. Pap. **14,** 653 (1918) S325.

[6] W. W. Coblentz and R. Stair, *Correlation of the shade numbers and densities of eye-protective glasses,* J. Opt. Soc. Am. **20,** 624 (1930).

[7] W. W. Coblentz, *Glasses for protecting the eye from glare.* J. Am. Med. Assn., **95,** 593 (1930).

[8] W. W. Coblentz, *Tinted lenses, the present deal.* J. Am. Med. Assn. **102,** 1223 (1934).

[9] Council on Physical Therapy: *Regulations to govern advertising of ultraviolet generators to the medical profession,* J. Am. Med. Assn. **102,** 841 (1934); *To the public only,* J. Am. Med. Assn. **98,** 400 (1932); *Acceptance of sun lamps,* J. Am. Med. Assn. **102,** 42 (1934).

[10] Federal specifications for welders' goggles and welders' hand shields are for sale by the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. These specifications (Nos. GGG–G–541 and GGG–H–191a) are undergoing revision, hence the new numbers cannot be given here and inquiry should be addressed to the Superintendent of Documents.

[11] The Use of Colored Glasses by Motor Vehicle Drivers. Summary opinions in reply to questionnaire. Mimeograph report issued in January 1937, by Edw. R. Granniss, safety engineer, National Safety Council, 20 North Wacker Drive, Chicago, Ill.

[12] W. W. Coblentz and A. N. Finn, *A nonactinic cobalt-blue glass.* J. Am. Ceramic Soc. **9,** 423 (1926).

[13] The transmission measurements were made in the colorimetry section of this Bureau.
[14] Charles H. May, Manual of the Disease of the Eye. 14th ed. (1934).
[15] Frank W. Law, *Protection of the eyes during light treatment.* British J. Phys. Med. (August 1937).
[16] A. R. Bauer, *An experimental study of glare susceptibility.* Am. J. Optometry, **13,** No. 6 (June 1936).
[17] E. C. Albers and Charles Sheard, *The tolerance of light in nonphotophobic individuals.* Am. J. Ophthalmol. **19,** No. 5, (May 1936).
[18] The Physical Effects of Radiant Energy from Electric Arc; Some Suggested Protective Measures. Mimeographed report compiled by Roy S. Bonsib, Standard Oil Co. (N. J.), 30 Rockefeller Plaza, New York, N. Y. (September 1937).
[19] *Effect of ultraviolet rays on the eye.* Report in Gen. Elec. Rev. **23,** 893 (1920).
[20] Matthew Luckiesh and Frank K. Moss, The Science of Seeing (D. Van Nostrand Co., Inc., 250 4th Ave., New York, 1937).
[21] W. W. Coblentz and R. Stair, *Data on ultraviolet solar radiation and the solarization of window materials.* BS J. Research **3,** 629 (1929) RP113. (Available from Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 15 cents.)
[22] W. W. Coblentz and R. Stair, *A portable ultraviolet intensity meter, consisting of a balanced amplifier, photoelectric cell, and microammeter.* BS J. Research **12,** 231 (1934) RP647. (Available from Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 5 cents.)
[23] H. C. Rentschler, *An ultraviolet light meter.* Proc. Am. Inst. Elec. Engrs. **49,** 113 (1930); Trans. Illum. Eng. Soc. **25,** 406 (1930).
[24] H. C. Rentschler, D. E. Henry, and K. O. Smith, *Photoelectric emission from different metals.* Rev. Sci. Instr. **3,** 794 (1932).
[25] Glass Color Filters, p. 8 (Corning Glass Works, Corning, N. Y., 1937).

WASHINGTON, December 29, 1937.

O