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GLASSES FOR PROTECTING THE EYES FROM INJURIOUS RADIATIONS

BY

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GLASSES FOR PROTECTING THE EYES FROM INJURIOUS RADIATIONS

By W. W. Coblentz and W. B. Emerson

CONTENTS

I. INTRODUCTION

The object in preparing this paper is to meet the demand for general information concerning the protective properties of spectacle glasses, particularly glasses which shield the eye from infra-red or so-called heat rays.

Although it does not appear to be definitely proven that the infra-red rays from incandescent bodies, such as, for example, molten metal, are injurious to the eye, there is, nevertheless, a general feeling that the eye becomes fatigued, if not permanently injured, by prolonged exposure to the intense heat from furnaces containing molten glass, etc.

The researches of Verhoeff and Bell [1] appear to indicate that no artificial source of light used for illuminating purposes contains enough ultra-violet radiation to be injurious to the eye, under practical working conditions, while the infra-red rays have no specific action distinct from thermal effect. However, in view of

[1] Verhoeff and Bell, Science, **40**, p. 452, 1914; Elect. Rev., **75**, p. 503, 1914; Proc. Amer. Acad. Arts and Sci., **51**, p. 630, 1916.

the fact that the infra-red rays are present in far greater abundance than the ultra-violet, the inference is that glassblowers' cataract is to be ascribed to the heat rays rather than to the ultra-violet rays. Exposure to excess of ultra-violet light is injurious, causing conjunctivitis.

However, as just stated, it does not appear to be definitely proven that the infra-red rays have other than a thermic (if any) effect.

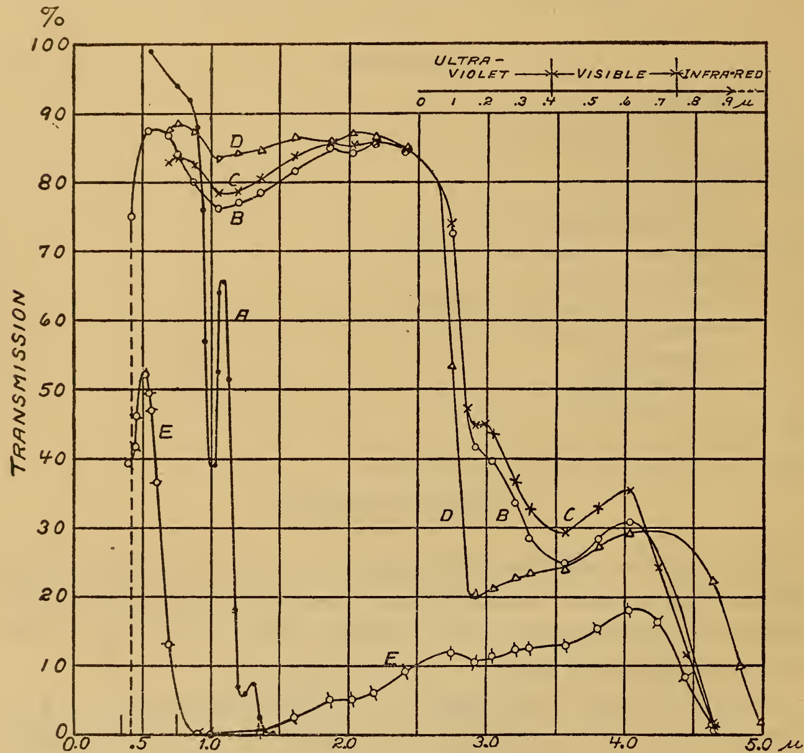

Fig. 1

A, human eye, Corning noviol glasses; *B*, yellow (thickness, t=2.05 mm); *C*, orange (t=2.03 mm); *D*, canary (t=1.85 mm); *E*, Corning G 124 JA, blue-green (t=1.5 mm)

Within the past few years numerous glasses have been produced which differ from the ordinary white crown glass used in spectacles in having a high absorption in (1) the violet, (2) in the infra-red, or (3) in both the ultra-violet and infra-red. (See upper right-hand corner of Fig. 1 for an illustration of the extent of these three spectral regions.) These glasses differ in the amount and color of the light transmitted. It is often desirable to have glasses which transmit a great deal of light and yet are opaque to the extremes of the visible spectrum.

Glasses having a gray or neutral tint are the most agreeable to wear, as they do not alter the color of objects. Hence, for outdoor wear ordinary black glasses, which can be obtained for a few cents, are quite as good as the expensive glasses which one frequently sees advertised.

In connection with the question of injury to the tissue of the eye caused by radiant energy, the question of fatigue caused by the action of the ocular muscles should also be considered. For example, the flashes of light from the small galvanometer mirror into the eye when astatizing a Thompson galvanometer and the flashing of fireflies when photographing the spectrum of their light were found to be very fatiguing, so much so that painful effects were still felt the following day.[2]

TRANSMISSION OF THE OCULAR MEDIA

Before discussing the protective properties of various glasses it is of interest to consider the transparency of the various media (cornea, aqueous humor, crystalline lens, and vitreous humor) which constitute the optical system of the eye. The transmission of the human eye for infra-red rays has been thoroughly investigated by Aschkinass.[3] His transmission curve, not including the energy lost (about 5 per cent) by reflection from the surface, is shown by *A* in Fig. 1. The depth from the surface of the cornea to the retina of the specimen examined was 2.28 cm. The transmission curve of the eye media is the same as that of a corresponding layer of water. From this transmission curve it will be noticed that radiations of wave length greater than 1.4μ can not reach the retina. In fact, because of the presence of water, which is very opaque to infra-red rays, but little radiation of wave lengths greater than 1.5μ ($\mu = 0.001$ mm) passes through the cornea, which is about 0.6 mm in thickness.[4] From this it may be noticed that most of the energy (97 per cent) radiated from a furnace at 1000 to 1200° C (see Figs. 3 and 12, which give the distribution of energy from a porcelain furnace) is absorbed in the outer portion of the eye. Injury caused by infra-red rays, therefore, must occur in the outer portion of the eye. On the other hand, the eye is quite transparent to ultra-violet rays, some wave lengths of which (to 0.35μ) can reach the retina. Moreover, the physiological effect seems to be different. The

[2] Coblentz, A Physical Study of the Firefly, Publication No. 164, Carnegie Institution of Washington, 1912.

[3] Aschkinass, Ann der Phys. (3), 55, p. 401, 1895.

[4] Luckiesh, Elect. World, 62, p. 844, 1913, has computed the transmission of the cornea, aqueous humor, crystalline lens, etc.

infra-red rays appear to produce a thermal effect ("burns"), while the ultra-violet rays (although of a much lower energy value) seem to attack the tissue in a different manner, i. e., their effect is actinic. The cornea is opaque to rays shorter than about 0.32μ.

Instructive papers by Bell and by Luckiesh[5] give data on various glasses (Akopos, Amber, Euphos, Kosma, etc.) for absorbing the ultra-violet.

In the present paper, by absorption (transmission = 100 − absorption) is meant the total reduction in intensity of the incident radiation, including the loss by reflection from the two surfaces. For ordinary glass this reflection amounts to about 9 per cent. The wave-length scale is given in microns, $\mu = 0.001$ mm.

II. YELLOW-COLORED GLASSES

Under this title the general spectral transmission characteristics of yellow and amber colored glasses are discussed. These glasses are intended primarily for absorbing the ultra-violet and are sometimes advertised under the trade names "Akopos," "Noviol," etc. Some of these glasses are quite opaque in the region of 0.4μ. Some may transmit slightly in the region of 0.35μ.

The amber-colored glasses have a high transmission (about 85 per cent) in the visible spectrum, determined by the amount of coloring matter present. In Fig. 1 curve *B* gives the transmission of a lemon-yellow ("Noviol") glass, curve *C* represents an orange, and *D* represents a yellow ("canary") glass, the thickness in all cases being 2 mm. The obstruction to infra-red rays is but little greater than that caused by an equal thickness of colorless glass (*E*, Fig. 2), which transmits uniformly about 91 per cent throughout the region from 1.5μ to 2μ.

The depth of the absorption band at 2.95μ is determined by the amount of silica in the glass. (See further data, *C*, Fig. 10.)

The amount of infra-red transmitted by these yellow glasses (curve *B* in Figs. 1 and 12) is about 55 per cent of the total radiation from a furnace heated to 1000 to 1100° C.

III. CROOKES'S GLASSES

Under this name one sees most commonly advertised in shop windows certain glasses for absorbing the infra-red, made by Crookes.[6] As a matter of fact, as the result of a very extensive

[5] Bell, Proc. Amer. Acad., **46**, p. 669, 1911; Luckiesh, Trans. Illum. Eng. Soc., **9**, p. 472, 1914.

[6] Crookes, Phil. Trans. Roy. Soc., **213**, p. 25; 1914.

investigation, four classes of glasses were produced by Crookes which were designed, respectively, for (1) absorption of infra-red ("heat") rays, (2) absorption of ultra-violet rays, (3) high transmission of luminous rays, and (4) low transmission of luminous rays for the reduction of the glare of the sun on expanses of snow or reflected from water.

SAGE-GREEN GLASS

The transmission curves of some of these glasses [7] are given in Fig. 2, the thickness in all cases being 2 mm. Curve *C* gives the transmission of Crookes's sage-green glass (marked "Ferrous No. 30"), which represents the type (1), also type (2), just mentioned, having a high absorption of infra-red or so-called heat rays. The transmission in the green is about 45 per cent, while in the infra-red the maximum transmission is only 11 per cent, and this for only a narrow region of the spectrum. This glass transmits only about 5 per cent of the infra-red radiation emitted by a furnace heated to 1000 to 1100° C. (See curve *C*, Figs. 2 and 12.)

Curve *F*, in Fig. 2, gives the transmission of a new blue-green glass (marked "Lab. No. 59"; thickness, 1.93 mm, from the American Optical Co.), which transmits about 43 per cent in the visible. In the infra-red it is more opaque than the sage-green glass just described, and exhibits some characteristics of the bluish-green Corning glass "G 124 JA."

NEUTRAL-TINTED GLASS

The Crookes's glasses, most commonly exhibited in the shop windows under that name, have a smoky, neutral tint, which enables one to perceive objects in their natural colors. They have a high transmission in the visible. In the infra-red they absorb but little more than does ordinary white crown glass (*E*, Fig. 2), although sometimes advertised as having marked opacity in the infra-red. The samples examined represent type (3) just mentioned. Curve *A*, Fig. 2, gives the transmission of a sample which had but little absorption in the visible spectrum, while in the infra-red the absorption differs but little from that of white crown glass of the same thickness (*E*, in Fig. 2; thickness = 2.18 mm) and having a similar silicate composition. Curve *B* gives the transmission of a dark sample of this same kind of glass. Here the increased absorption of the coloring matter extends to 3μ, beyond which there is a slightly higher transparency. Such a variation in trans-

[7] Kindly furnished by the American Optical Co.

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mission was previously observed in red glasses.[8] The absorption band at 0.58μ coincides with that of neodymium. This sample (*B*, Fig. 2, and *D*, Fig. 12) transmits about 54 per cent of the infra-red radiation from a furnace heated to 1050° C. This is not a very marked absorption when compared with the sage-green glass just described. For the effectiveness in absorbing the ultra-violet, see Table 2.

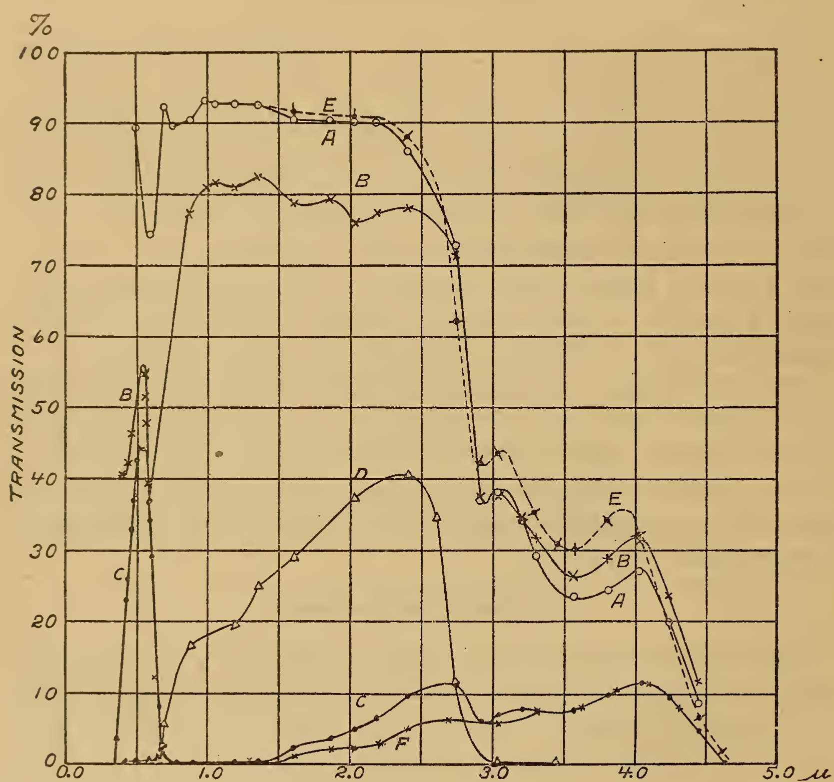

Fig. 2

Crookes's glasses: *A*, light (t=1.96 mm); *B*, dark (t=2.00 mm); *C*, ferrous No. 30, sage-green (t=1.98 mm). *D*, Schott's black glass (t=3.6 mm). *E*, white crown glass (t=2.18 mm). *F*, blue-green glass (A. O. C. Lab. No. 59; t=1.93 mm). (A and B are Crookses's neutral-tint glass.)

Other glasses were produced by Crookes which have a high absorption in the infra-red. They are pale blue, bluish green, or sage green in color. In fact, as will be noticed presently, glasses which absorb highly in the infra-red have either a low transmission throughout the visible spectrum or have the transmission band shifted into the green or blue.

[8] Coblentz, Publication No. 97, Carnegie Institution of Washington, 1908.

IV. VARIOUS GLASSES FOR ABSORBING THE INFRA-RED

GOLD-PLATED GLASSES

Metals are the most opaque substances known for infra-red radiations, while in the visible spectrum (as is well known to all who have handled gold leaf) gold has a region of low reflectivity and great transparency [9] in the region of 0.5μ. This property would naturally suggest itself as a means of eliminating all the infra-red by covering white spectacle glass with a thin layer of gold. The high reflecting power (metallic reflection of 60 to 80 per cent as compared with the vitreous reflection of about 4 per cent from glass) makes it desirable to mount these gold-plated glasses in a hood ("goggles") which prevents reflection of light from the rear surface of the film into the eye.

The effects produced in looking through a sample [10] of gold glass did not appear quite so pleasing as through the sample of Crookes's sage-green ferrous glass (*C*, Fig. 2). In the latter the transmission is twice as great (44 per cent) in the visible with but little addition of infra-red. However, as shown in curve *A*, Fig. 3, the gold-plated glass is an extremely effective means for shielding the eye from infra-red rays. At 1.5μ the transmission is only about 2 per cent, while beyond 2μ the transmission is less than 1 per cent. This sample of gold-plated glass obstructs 99 per cent of the infra-red rays emitted by a furnace heated to 1050° C. (See Fig. 3 and *E*, Fig. 6.) The sample (curve *A*) of gold plate examined was mounted upon Crookes's neutral-tint glass (*B*, Fig 2), thus giving a small absorption band (shown in dotted lines) at 0.58μ. The second sample, curve *C*, was mounted upon crown glass. Beyond 2.5μ it is as opaque as the thicker samples.

BLUE-GREEN GLASSES

Among the colored glasses [11] available for effectively eliminating the infra-red are several blue-green glasses.

One sample of very light bluish-green glass—Corning G 124 JA; thickness, 1.5 mm—(see *E*, Fig. 1) has a high transmission (52 per cent) in the green and a very low transmission in the infra-red. This sample transmits only 5.5 per cent of the infra-red radiation from a furnace at 1050° C, which is practically the same trans-

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[9] Hagen and Rubens, Ann. der Phys., 8, p. 432; 1902.

[10] Called Pfund's patent gold glass; from the American Optical Co., Southbridge, Mass.

[11] The samples examined were kindly supplied by the Corning Glass Works, Corning, N. Y. Ordinary green glass has a higher transmission in the infra-red than the samples herein described. (See Publication No. 97, p. 56, Carnegie Institution of Washington, 1908.)

mission (4.9 per cent) as Crookes's sage-green glass (*C*, Fig. 2) just described. The color of objects is practically unchanged, so that the choice between these two glasses is a matter of individual taste. The transmission of the bluish-green Corning G 124 JA glass is somewhat higher than Crookes's ferrous sage-green glass at 0.5μ and at 4μ, and the maximum transmission is shifted further toward the blue (from 0.55μ to 0.50μ). (See further data in Fig. 7.)

GREENISH-BROWN GLASSES

Another type of colored glass for protecting the eye from the ultra-violet and to some extent from the infra-red rays is a set of

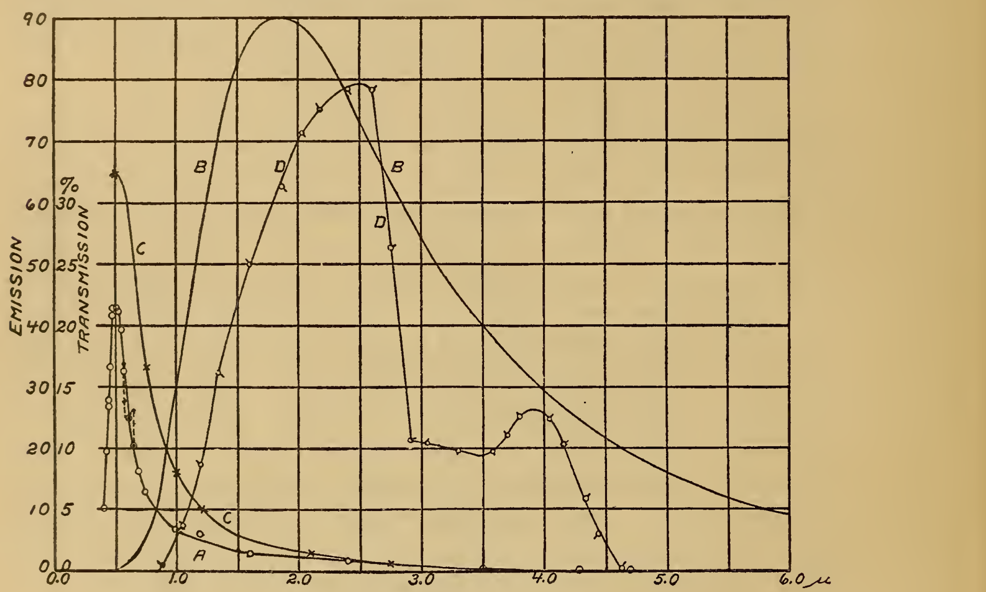

Fig. 3

A, *C*, gold glass: *B*, emission of black body (1050° C); *D*, electric smoke (red) [ordinates=emission scale] (t=2.52 mm)

brownish, greenish-yellow to brownish-yellow colored ("Noviweld") glasses of variable transmission in the visible spectrum. Curve *A*, Fig. 4, gives the transmission of Corning G 124 HL (shade 3; thickness, 1.47 mm). The maximum transmission in the visible is about 27 per cent. The coloring matter is quite effective in its absorption at 1μ, but beyond 3μ the transmission is as high as in uncolored glass.

Curve *B*, Fig. 4, gives the transmission of Corning G 5 CAD (shade 6; thickness, 2.16 mm). The maximum transmission is about 5 per cent in the visible, and the infra-red absorption is more

effective than obtains in curve *A*. Neither of these types of glasses are as effective as the blue-green glass G 124 J, thickness, 2.6 mm (*C*, Fig. 4) for obstructing the infra-red, although they are better adapted for absorbing the visible rays.

A further illustration of this type of glass is shown by *D*, Fig. 4, which gives the transmission of a "Noviweld" goggle. This glass transmitted about 0.7 per cent at the maximum in the visible (thickness, 2 mm). On the other hand, the coloring matter is but little more effective than Corning G 124 HL for obstructing the infra-red. The latter transmits about 38 per cent of the infra-red radiations from a furnace heated to 1050° C. (See *F*, Fig. 12.)

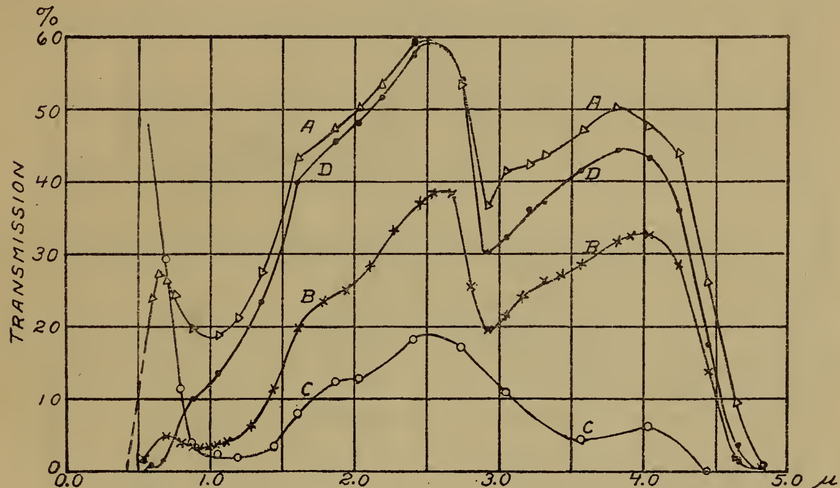

Fig. 4

Corning glasses: *A*, G 124 HL, shade 3 (t=1.47 mm); *B*, G 5 CAD, shade 6 (t=2.16 mm); *D*, G 124 HX, shade 6 (t=2.0 mm). *C*, blue-green glass, G 124 J (t=2.6 mm)

BLACK GLASSES

Black glasses are commonly used for absorbing the visible and the ultra-violet rays. Very dense black glass obstructs the infra-red quite as well as some of the newer, more expensive colored glasses just described. Curve *D* in Fig. 2 gives the transmission [12] of a sample of Schott's black glass ("Rauchglass" 444 III; thickness, 3.6 mm), sometimes used in optical pyrometers. The transmission in the visible spectrum is quite uniform and it amounts to about 0.5 per cent. In the infra-red the transmission is as low as the colored glasses just described. In fact, the sample illustrated in Fig. 2 transmitted but little beyond 3μ, although a lighter

[12] Coblentz, Publication No. 97, Carnegie Institution of Washington, 1908.

colored sample was quite transparent to 5μ. This sample transmits about 18 per cent of the infra-red radiation emitted by a black body heated to 1050°, and for many purposes this kind of black glass would be as effective as more expensive glasses for shielding the eyes from infra-red rays. (See Table 2, which gives the transmission of several smoke glasses from Bausch & Lomb. Shade *C* is slightly darker than the shade *B* of Crookes's neutral tint just described.)

C, Fig. 5, shows the transmission curve of a very dark spectacle glass (of unknown composition; thickness, 1.86 mm), which has been in use in this laboratory for a number of years. In the

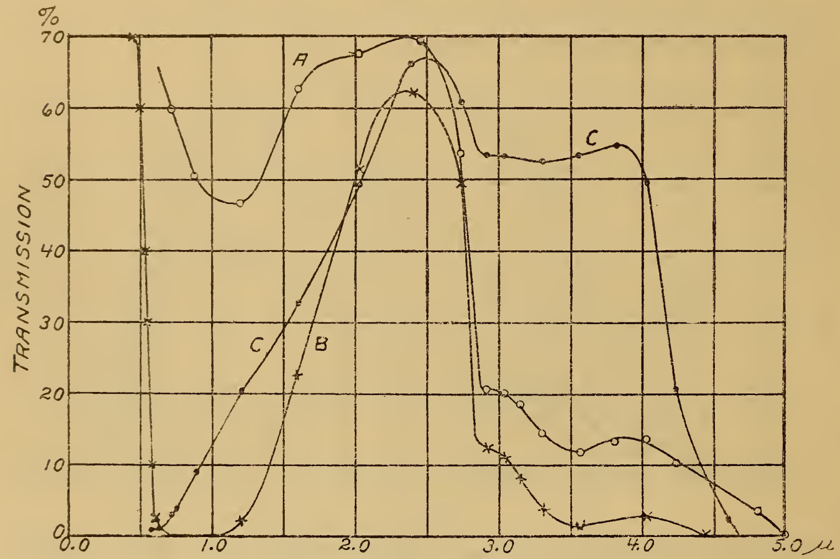

FIG. 5

Corning glass: *A*, orange G 36 (t=5.65 mm); *B*, blue-green G 401 Z (t=6.56 mm). *C*, common black glass (t=1.86 mm)

visible spectrum the transmission is about 0.8 per cent. In the infra-red the transmission is somewhat higher than Schott's black glass just described. However, on the average it obstructs the infra-red rays almost as effectively as some of the newer glasses just described.

NOVIWELD GLASSES

Through the courtesy of Dr. H. P. Gage, of the Corning Glass Works, who provided us with an assortment of colored glasses, the writers are able to include in this (revised) paper the transmission curves of a series of new glasses (known under the trade

name "Noviweld Glasses") which are very opaque to infra-red, as well as visible and ultra-violet rays. The forerunner of these glasses is G 5 CAD (see also G 124 HL, etc.) the transmission of

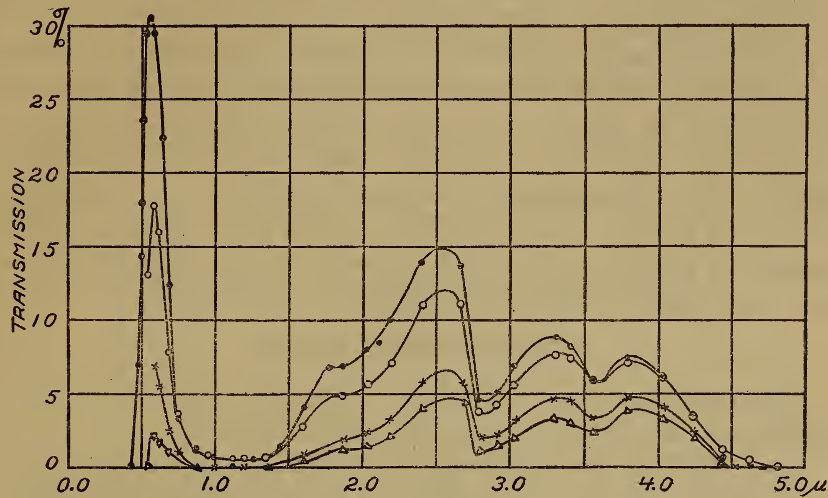

FIG. 6

Corning "New Noviweld" glasses: Top curve=shade 30 per cent; second curve from top=shade 3; next lower curve=shade 4½; bottom curve=shades 6 and 7. Thickness of glasses, 2.2 mm

which is given in Fig. 4. The maker's number of this new noviweld glass is 391 DM (blowing-room designation 39 J).

As illustrated in Fig. 6, the infra-red transmission of the modern

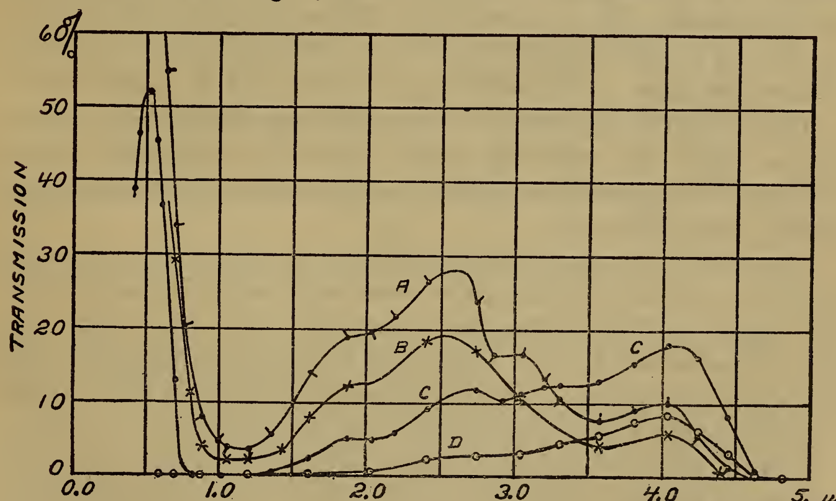

FIG. 7

Corning glasses having marked opacity in the infra-red: *A*, Blue-green, heat absorbing; G 124 J'' and *B*=G 124 J. Curve *C* is G 124 JA; see Fig. 1. Curve *D* is G 124 IP

noviweld glasses is practically suppressed, so that the darkest shades (e. g., shade 6; and shade 7, not illustrated because its

transmission curve coincides with that of shade 6) transmit only about 1 per cent of the infra-red radiation emitted from a furnace heated to 1050° C. These new noviweld glasses are unique for their great opacity to infra-red rays.

The transmission curves of several glasses, made by the Corning Glass Works, and having marked opacity for infra-red rays, are summarized in Fig. 7. The light-colored, greenish-blue glass, G 124 J, is obtainable under the trade name "Heat-absorbing glass." The transmission of another melt of G 124 J (marked G 124 J″) is given in curve *A*, Fig. 7. Curve *D* gives the transmission of a deep brownish-yellow glass, G 124 IP, which is one of the most opaque glasses yet examined. (See Table 2.)

V. MISCELLANEOUS GLASSES

Under this caption are given the transmission spectra of various glasses, representative of what is in present-day use.

In view of the fact that, for most of the glasses described herewith, the transparency (or opacity) in the ultra-violet had already been determined by Bell and by Luckiesh (loc. cit., p. 6), the present investigation has been confined principally to the infra-red. In a few samples the transmission in the visible, and in the ultraviolet, was determined by means of a short-focus spectrometer, which was constructed several years ago especially for such investigations. (It is described in Bureau of Standards Bull. **7**, p. 245, 1911, and illustrated in **10**, p. 38 (Fig. 8, Sp), 1913. A thermopile (also a photoelectric cell) was used as a radiometer.

It seems futile to attempt to determine the transmissive properties of all of the numerous glasses which are obtainable under different trade names, but which have a characteristic color—red, yellow, blue, green, etc.

The color of the same kind of glass may be different for different melts, for different parts of the same melt, and it depends upon the length of time of the heat treatment. However, while this has a marked effect in the visible spectrum, as just noticed in the amber and the yellow ("Noviol") glasses, the effect of the coloring matter usually does not extend far into the infra-red.

Certain colors of glasses are often difficult to match, if one of the set is broken. Moreover, dealers find that spectacle glasses are subject to change on account of "style." It is hoped that the present paper may be of assistance in eliminating this profusion of colored glasses and in standardizing the most useful ones.

Red glass is sometimes combined with cobalt-blue glass in order to produce a combination which is highly opaque to the whole spectrum. However, from the data cited (footnotes, p. 8 and 9) and from the foregoing data, it is evident that if it is desired to combine a red glass and a blue glass in order to produce a very opaque screen for all radiations, including the visible, a deep blue-

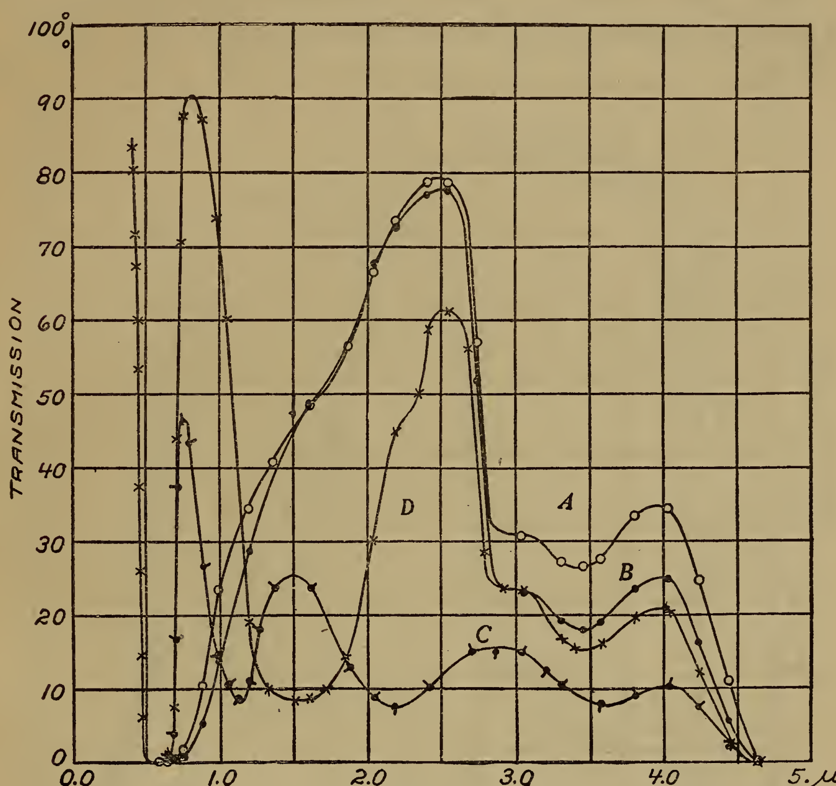

FIG. 8

Purple glasses: Curve *A* (A. O. C., t=1.90 mm); *B*, t=2.40 mm. Corning G 55 A 62 (*C*, t=2.85 mm); blue-purple ultra, G 585 (*D*, t=3.13 mm)

green glass, Fig. 7, must be used instead of the cobalt blue, in order to entirely eliminate the infra-red.

As already mentioned, all the deep-blue glasses are quite opaque to infra-red radiation, but none was found which is so effective in obstructing the infra-red as the bluish-green glass (Corning G 124 JA) illustrated by *E* in Fig. 1. The latter, moreover, is very transparent in the visible part of the spectrum. In that respect it compares favorably with Crookes's darker shade of neutral glass

(illustrated in Fig. 2), with the additional advantage of greater opacity in the infra-red.

Some of these deep-blue glasses (e. g., Corning G 55; Schott's F 3086) transmit 70 to 75 per cent in the blue and violet end of the spectrum, and hence are useful only in obstructing the infra-red rays.

Purple Glass.—Curve *A*, Fig. 8, illustrates the transmission of a deep purple glass (from the American Optical Co.; "electric

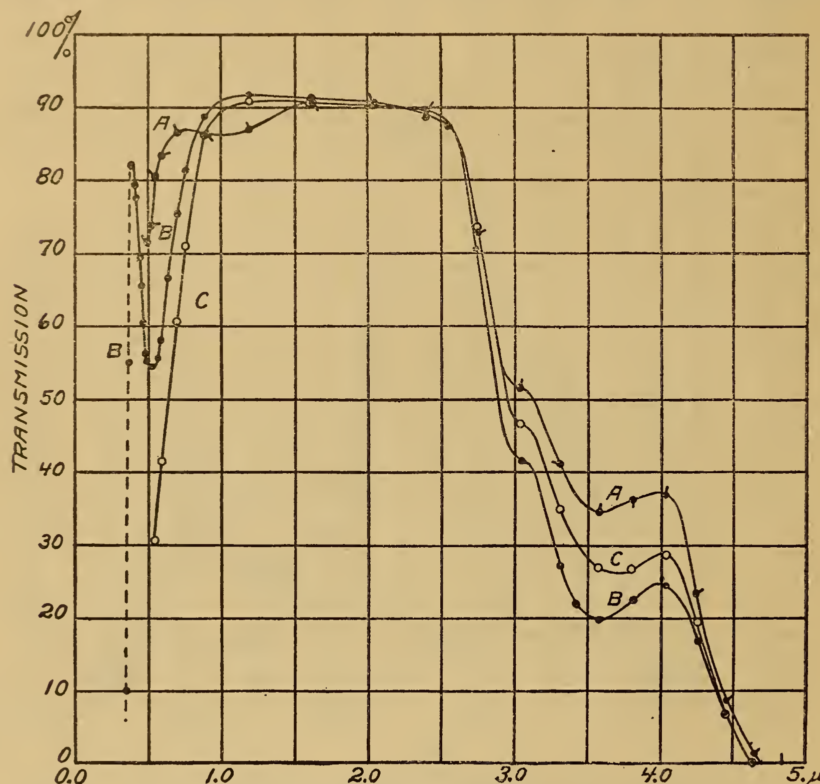

FIG. 9

Amethyst glasses: *B* and *C* (t=2.11 and 1.92 mm). *A*, colorless glass, Lab. No. 58, A. O. C. (t=2.04 mm)

smoke," purple), thickness 1.90 mm. Curve *B* gives the transmission of an "Arcweld" goggle (thickness 2.40 mm.), obtained from a dealer. These two glasses evidently have the same composition. This illustrates the desirability of adopting a definite trade name for a particular kind of glass.

The more opaque samples of "electric-smoke" glass are a deep red. However, the infra-red transmission is the same as for the purple samples as shown in curve *D*, Fig. 3.

An interesting purple glass is Corning G 55A 62, which has a narrow transmission band in the violet and another narrow band of high transmission at 0.8μ. (See curve *C*, Fig. 8; thickness 2.85 mm.) A recent modification of this glass is Corning G 586. This glass, also Corning blue-purple ultra (G 585; curve *D*, Fig. 8), will be useful in producing bands of spectral radiations without using a spectroscope.

Amethyst Glass is sometimes used for spectacles. Only the deep shades appear to absorb appreciably in the violet, hence they are

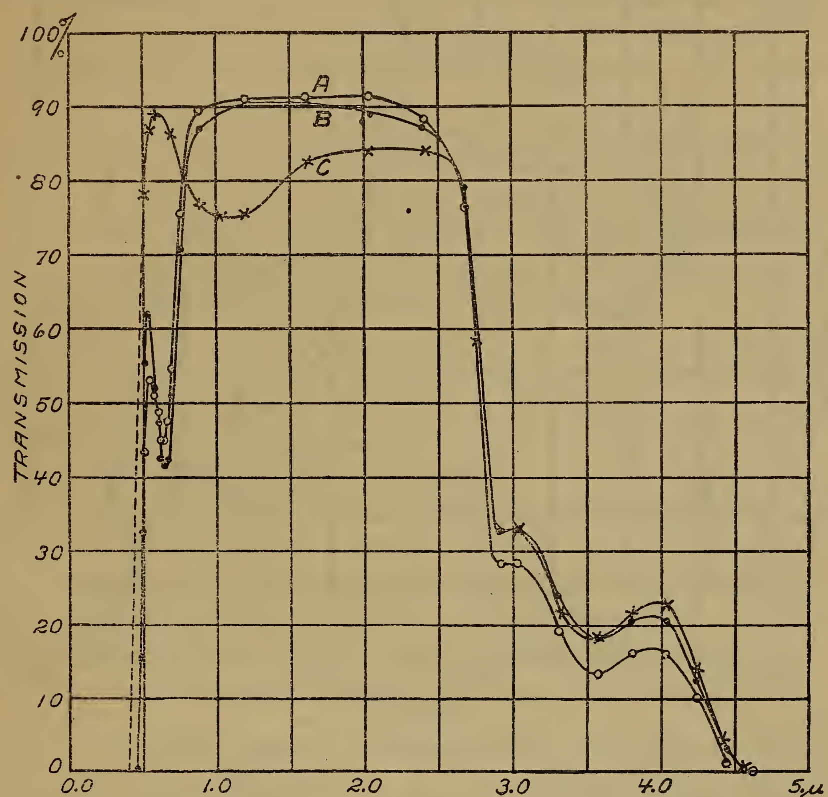

FIG. 10

Noviol, shade B, *C* (t=2.88 mm). Euphos, shade B, *B*, from Bausch & Lomb (t=3.1 mm); *A* (B. S. scrap material, t=3.30 mm)

useless as an eye-protective glass. As shown in Fig. 9, the absorption in the infra-red is the same as that of white crown glass. Curve *B*, Fig. 9, gives the transmission of a dark sample of amethyst ("shade C," from the American Optical Co.). The dotted part of curve *B* in the ultra-violet represents data taken from a paper by

Luckiesh (loc. cit., p. 6). Curve *C* illustrates the transmission of a deep wine-colored glass, of unknown origin.

Noviol Glass (Corning shade B) is a yellow glass described in a preceding page. (See Fig. 1.) A further illustration is given in curve *C*, Fig. 10; thickness 2.88 mm.

Orange-Colored Glass.—The transmission of a deep orange-colored glass (Corning G 36; thickness, 5.65 mm.) is illustrated in curve *A*, Fig. 5. All glasses of this thickness absorb heavily

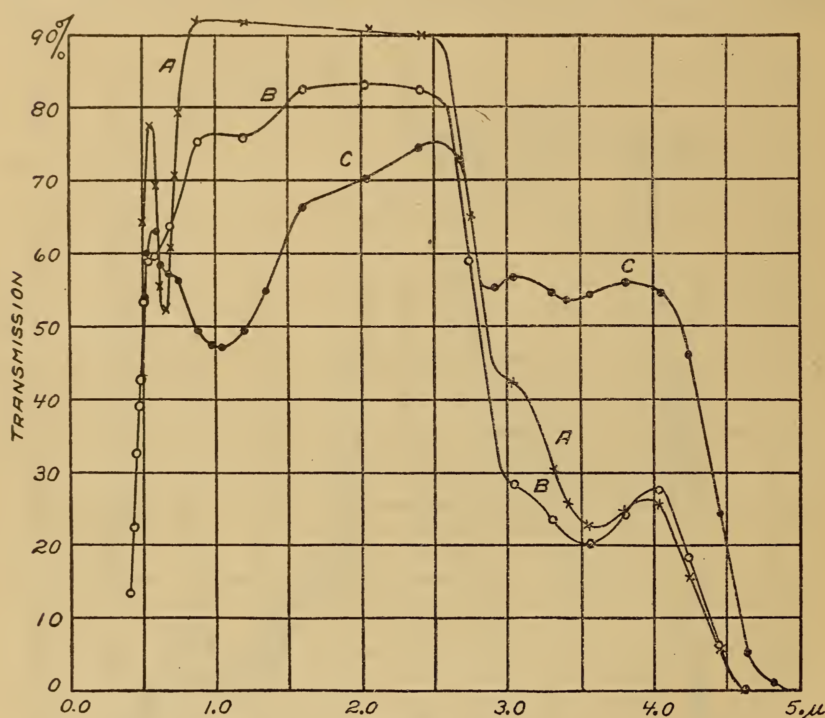

Fig. 11

A, Lab. No. 61, A. O. C. (t=2.09 mm); *B*, Fieuzal glass, shade B (t=2.04 mm); *C*, Hallauer glass (t=1.41 mm)

beyond 3μ. "Orange G 34" made by the Corning Glass Works is a reddish-yellow glass, having a rather marked absorption band at 1.1μ.

Euphos Glass is of German origin. It has a slightly more greenish tint than the Fieuzal glass. As shown in curve *A*, Fig. 10 (thickness 3.30 mm.), the absorption band at 1.1μ is absent and the band at 0.62μ is more sharply defined than in the Fieuzal glass (Fig. 11). Curve *B*, Fig. 10, gives the transmission of a sample of Euphos glass (shade B, thickness 3.1 mm.), which was obtained from the Bausch & Lomb Optical Co. The transmission

is practically the same as that of the preceding sample, the source of which is unknown. (See Table 2.)

Lab. No. 58, of the American Optical Co., is a colorless glass which has a strong absorption in the ultra-violet. As shown in curve *A*, Fig. 9, the absorption (thickness of sample, 2.04 mm) in the infra-red is the same as that of white crown glass.

Akopos Glass (greenish tint). The sample examined (thickness 1.58 mm) had practically the same transmission characteristics as the Euphos glass just described; except that at $\lambda = 0.54\mu$ the transmission was 77 per cent, and at $\lambda = 3.8\mu$ it was 51 per cent.

Lab. No. 61, of the American Optical Co., is a light yellowish-green glass having a narrow absorption band at 0.65μ. (See curve *A*, Fig. 11; thickness 2.09 mm.)

Fieuzal Glass, shade B, thickness 2.04 mm, from the American Optical Co., is a dark greenish-yellow glass of French origin. As shown in curve *B*, Fig. 11, it has the characteristic absorption band of the yellow, "Noviol," glasses at 1.1μ and the didymium band at 0.6μ. This glass (also the Euphos and the Hallauer) is used for absorbing the ultra-violet. (See Table 2.)

Hallauer Glass (thickness of sample 1.41 mm) is of German origin. It has practically the same tint as the Fieuzal glass. However, as shown in curve *C*, Fig. 11, its transmission is quite different in the infra-red.

In Table 1 is given a short summary of the most important glasses investigated. Column 3 gives the maximum transmission in the visible spectrum, and column 4 gives the per cent transmitted of the total radiation from a furnace heated to 1000 to 1100° C. (See also Table 2, which gives data for sources of radiation having a different spectral-energy distribution.)

TABLE 1.—Glasses which are Well Adapted for Protecting the Eyes from Infra-Red Rays

Kind of glass	Thickness	Maximum trans-mission in visible spectrum	Total infra-red transmitted
	mm		Per cent
Gold plated	.....	22	0.8
Crookes's ferrous No. 30, sage green	1.98	44	4.9
Corning bluish-green (heat absorbing):			
G 124 JA	1.50	52	5.5
Noviweld, 391 DM, Shade 6	2.17	2	1.1

Curve *I* in Fig. 12 gives the relative intensities in the spectrum of a black-body furnace at 1050° C. The various curves (*A*, *B*, *C*, etc.) in this illustration give the relative intensities of the radiation from the furnace after passing through the glasses described in this paper. The ratio of the area under the curve when the glass is interposed (e. g., curve *C*) to the total area under the curve *I* (extended beyond 10μ) gives the amount of energy transmitted through the glass in question. In the case of the gold-plated glass curve *E*, this area is only about 0.8 per cent of the area under the curve *I*.

In conclusion, it is of interest to call attention to several minerals which are very opaque to infra-red rays; for example, beryl and garnet[13] [$Ca_3(FeMg)_3Al_2(SiO_4)_3$] are very opaque in the region of 1 to 2μ. If a glass can be made that contains the constituents of garnet there is a possibility of obtaining a material which has almost complete absorption in the infra-red.

VI. SUMMARY

The object of the present paper is to give the general characteristics of certain newly developed glasses sometimes used for protecting the eye from radiant energy, especially the infra-red or so-called heat rays. Because of the difficulty in reproducing the same color in different melts, no attempt is made to give specific data on the transmission for a given thickness of glass. In order to obtain exact data it is necessary to examine samples from each melt.

These data are representative of an extensive group of glasses available for protecting the eye from (1) the ultra-violet, (2) the visible, and (3) the infra-red rays.

For protecting the eye from ultra-violet light, black, amber, green, greenish-yellow, and red glasses are efficient. Spectacles made of white crown glass afford some protection from the extreme ultra-violet rays which come from mercury-in-quartz lamps and from electric arcs between iron, copper, or carbon. The vapors from these arcs emit but little infra-red radiation in comparison with the amount emitted in the visible and in the ultra-violet.

For shielding the eye from infra-red rays deep-black, yellowish-green, sage-green, gold-plated, and bluish-green glasses are the most serviceable. For working near furnaces of molten iron or glass if considerable light is needed a light bluish-green or sage-green glass is efficient in obstructing the infra-red rays. For

[13] Publication No. 65, p. 59, Carnegie Institution of Washington: 1908.

working molten quartz, operating oxyacetylene or electric welding apparatus, searchlights, or other intense sources of light, it is

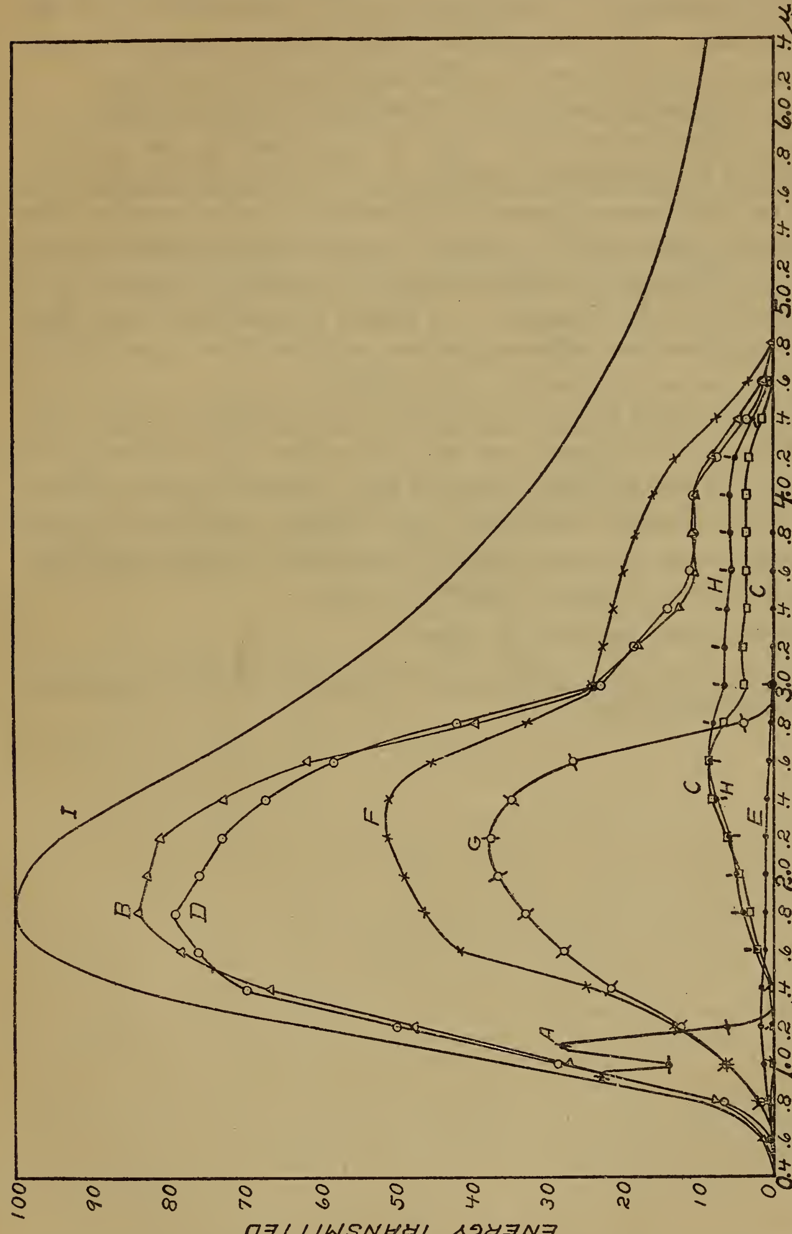

FIG. 12

A, eye media (Fig. 1, *A*); *B*, yellow glass (Fig. 1, *B*); *C*, sage green (Fig. 2, *C*); *D*, neutral tint (Fig. 2, *B*); *E*, gold plate (Fig. 3, *A*); *F*, greenish-brown (Fig. 4, *A*); *G*, black glass (Fig. 2, *D*); *H*, blue-green (Fig. 1, *E*); *I*, black body (1050° C)

important to wear the darkest glasses one can use, whether black, green (including gold-plated glasses), or yellowish-green, in order to obstruct not only the infra-red but also the visible and the ultra-violet rays.

One can easily decide upon the kind of glasses to use to protect the eye from the visible rays. The question is not so easily settled concerning the elimination of the ultra-violet and the infra-red rays. The data presented herewith give some clue as to what can be accomplished in eliminating the infra-red rays.

Data are given showing that of the infra-red rays emitted by a furnace heated to 1000 to 1100° C (1) about 99 per cent are obstructed by gold-plated glasses, (2) about 95 per cent by sage-green or bluish-green glasses, (3) about 60 to 80 per cent by very deep-black glasses, and (4) about 60 per cent by greenish-yellow glasses. The dark shades of the new "Noviwelds" absorb 95 to 99 per cent of the infra-red. At higher temperatures these data would be somewhat different, but not sufficiently so to modify the rough estimates dealt with in this paper.

Tabulated data are given also of the transmission of the radiation from (1) the quartz mercury vapor lamp, (2) the magnetic arc, and (3) the gas-filled tungsten lamp through various glasses.

A very complete bibliography on harmful radiations and eye protection is to be found in the Transactions, Illuminating Engineering Society, volume 9, page 311, 1914.

WASHINGTON, January 18, 1919.[14]

[14] The first edition of this paper, dated Nov. 14, 1916, was issued May 5, 1917; the second edition, dated Oct. 5, 1917, was issued Apr. 4, 1918.

APPENDIX

TRANSMISSION DATA OF VARIOUS GLASSES [15]

The quartz mercury vapor lamp is one of the most common sources of injury to the eye, from ultra-violet rays. Injurious effects result even after these rays are reflected from fabrics, etc. The ultra-violet rays are very insidious in that the inexperienced and unsuspecting experimenter does not feel the effects until several hours after exposure to these rays. The milder cases of injury consist of granulation of the eyelids and pain through the optic nerve. This may continue for several days. Reports have come to the writers' notice of the deleterious effects of ozone and nitrous oxide upon the bronchial tubes, etc., which gases are formed by the ultra-violet rays from quartz mercury vapor lamps.[16]

It is extremely important to protect the eyes from ultra-violet rays by means of colored glasses, the most efficient ones being amber, yellow, and greenish-yellow glasses. The most efficient glass, used singly, for absorbing the infra-red and the ultra-violet is the Corning new "Noviweld," as shown in Table 2, which gives the per cent of total radiant energy transmitted by various glasses, some of whose spectral transmission curves are given in the foregoing pages.

The radiations from the quartz mercury vapor lamp are mostly in the visible and in the ultra-violet, only a few weak emission lines being in the infra-red. A new Cooper-Hewitt, also an R. U. V. quartz mercury lamp, were used in making these determinations. These lamps become red-hot. Hence, in order to eliminate the radiations of hot quartz from these transmission data, the bismuth-silver thermopile, which was used to measure the radiation intensities, was covered with a 1 cm cell, having thin quartz windows and containing distilled water, both of which substances are very transparent to ultra-violet rays, but which are very opaque to infra-red rays. As shown at the bottom of Table 2, white crown glass and mica absorb much of the extreme ultra-violet radiation.

The transmission of the radiation from a magnetite arc lamp, through some of these protective glasses, is given in the last column of Table 2. A 1 cm cell of water (just described) eliminated the radiation from the electrodes. In making these measurements the electrodes were mounted in a hand-operated mechanism to control the steadiness of the arc. These data are of interest to workmen doing arc welding.

The transmission of these glasses (Table 2, column 5) was determined also for the radiations from a (500-watt, stereoptican) gas-filled tungsten lamp which emits considerable visible and infra-red radiation. In this test no water cell intervened between the thermopile and the sample under examination. The data are instructive in comparison with the spectral transmission curves already described.

Instructive data on the ultra-violet component in various artificial lights have been published by Bell,[17] who concluded that no commercial illuminant radiates, for any ordinary working value of illumination, enough ultra-violet energy to be at all harmful, provided one exercises ordinary discretion in keeping unpleasantly bright visible light out of the eyes.

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[15] These data were obtained in collaboration with M. B. Long.

[16] For a thorough discussion of the injurious effects of radiant power upon the eye, the following papers should be consulted: Verhoeff and Bell, Proc. Amer. Acad. Arts and Sci., **51**, p. 630, 1916. Birge, Trans. Ilum. Eng. Soc., **10**, p. 932, 1915. Amer. Jour. Physiol, **36**, p. 21, 1914; **39**, p. 335, 1916.

[17] Bell, Proc. Amer. Acad. Arts and Sci., **48**, p. 1, 1912.

The last column of Table 2 gives the transmission of solar radiation through various glasses. In making these measurements a single thermojunction was exposed, through a rock salt window, to the solar radiation, on a very clear day (Mar. 16, 1918, Q=1.1 gr. cal. per cm [2] of horizontal surface).

TABLE 2.—Transmission of the Radiations from a Gas-Filled Tungsten Lamp, the Sun, a Magnetite Arc, and from a Quartz Mercury Vapor Lamp (no Globe) Through Various Substances, Especially Colored Glasses

Color	Trade name	Source [a]	Thickness in mm	Transmission, per cent			
				Gas-filled tungsten	Quartz mercury vapor	Magnetite arc	Solar radiation
Greenish-yellow	Fieuzal, B	A. O. C.	2.04	71.6	26.9	46.0	63
Do	Fieuzal, 63	F. H. E.	1.80	75.5	34.3	55.0	72
Do	Fieuzal, 64	F. H. E.	1.65	50.7	22.0		
Do	Euphos	B. S.	3.27	78.9	25.0		
Do	Euphos, B	B. & L.	3.12	78.8	24.7	53.0	64
Do	Akopos green	J. K.	1.58	84.6	29.5	59.0	74
Do	Hallauer, 65	B. S.	2.36	70.3	17.7		
Do	Hallauer, 64	F. H. E.	1.35	58.7	25.9		55
Smoky green	G 124, IP	C. G. W.	2.81	.4	.2		
Yellow-green	Noviweld, 30%	C. G. W.	2.14	5.1	7.8		9
Do	Noviweld, shade 3	C. G. W.	2.20	3.4	4.2	2.7	
Do	Noviweld, shade 4½	C. G. W.	2.20	1.6	1.2	.8	
Do	Noviweld, shade 6	C. G. W.	2.17	.9	.4	.2	.9
Do	Noviweld, shade 7	C. G. W.	2.17	.8	.2		
Amber	No. 213	P. W. G.	5.57				43
Do		B. S.	3.12	51.6	15.2		
Do	Bottle	B. S.	2.2				49
Do	Saniweld, dark	J. K.	1.32	78.1	10.6	43.0	50
Orange	G 34	C. G. W.	3.57	56.9	17.0		47
Yellow	Noviol, shade A	C. G. W.	2.00				81
Do	Noviol, shade B	C. G. W.	2.88	74.1	32.2	56.0	75
Do	Noviol, shade C	C. G. W.	2.00				72
Sage green	Ferrous No. 30	A. O. C.	1.95	5.3	17.5		17
Yellow-green	No. 61	A. O. C.	2.10	82.7	28.6		72
Blue-green	Lab. No. 59	A. O. C.	1.93	3.7	17.3	11.5	
Do	G 124JA	C. G. W.	1.53	5.3	21.5	12.5	19
Black	Smoke, C	B. & L.	2.26	65.3	31.2	52.0	60
Do	Smoke, D	B. & L.	2.45	50.9	16.0	39.0	43
Neutral tint	Crookes, A	A. O. C.	1.97	85.3	46.1		89
Do	Crookes, B	A. O. C.	2.00	75.7	32.0	64.0	69
Gold plate	Pfund	A. O. C.		2.6	7.2	1.2	12
Do. (darker)	Pfund	A. O. C.			1.3		
Colorless	Lab. No. 58	A. O. C.	1.58	83.3	40.0	66.0	88
Do	Lab. No. 57	A. O. C.	2.00		51.9		
Amethyst	Shade C	A. O. C.	2.11	82.8	44.3		79
Purple	Electric smoke	A. O. C.	1.89	36.6	2.2		11
Do	G 55 A 62	C. G. W.	2.85	17.4	17.0		16
Blue	Shade D	B. & L.	2.09	37.6	20.7	39.0	
Blue, dark	G 53	C. G. W.	2.51	2.9	3.9		

[a] A. O. C., Amer. Optical Co., Southbridge, Mass.; C. G. W., Corning Glass Works, Corning, N. Y.; B. & L., Bausch & Lomb, Rochester, N. Y.; J. K., Julius King Optical Co., New York City; F. H. E., F. H. Edmonds, Optician, Washington, D. C.; P. W. G., Penna. Wire Glass Co., Philadelphia, Pa.; B. S., Bureau of Standards; scrap material, source unknown.

TABLE 2—Continued

Color	Trade name	Source	Thickness in mm	Transmission, per cent			
				Gas-filled tungsten	Quartz mercury vapor	Magnetite arc	Solar radiation
Blue-green	G 171-IZ	C. G. W.	3.21	46.6	41.7		
Blue, pale	G 584	C. G. W.	3.75	24.9	25.2		
Red-purple	G 172 BW 5	C. G. W.	4.93	72.4	26.5		
Blue-purple	G 585	C. G. W.	3.13	35.8	34.0		41
Red	Selenium	C. G. W.	2.90	67.8	7.9	48.0	48
Do		Schotts'	3.22	69.4			46
Do	Flashed	B. S.			4.8		
Colorless	Window	B. S.	1.85		59.5		82
Do	Crown	B. S.	1.56		64.9		92
Do	Aqueduct	P. W. G.	4.75				81
Brown	Mica	B. S.	1.30		35.4		
Colorless	do	B. S.	.09		43.1		
Clear	Water	B. S.	10.00	34.2	[a] 56.0		
Do	do	B. S.			[b] 83.0		[b] 76

[a] Transmission of 1 cm cell having glass windows.
[b] Using a 1 cm cell having thin quartz windows. The transmission of this cell, for the total radiation from the quartz mercury vapor lamps, no water cell intervening, was 36 per cent.

The results of the foregoing investigation show that, in glasses which have a high absorption in the violet and ultra-violet (thus producing yellow and amber colored glasses), the effect of the coloring matter does not, as a rule, extend into the infra-red. Such glasses usually absorb but little more than colorless glass in the infra-red.

Glasses which have a wide absorption band in the red and yellow (blue-green glasses) usually have a marked absorption in the infra-red.

In view of the diversity of glasses on the market and the uncertainty of their protective properties, the foregoing brief summary will give the reader a rough estimate of the protective properties that may be expected when purchasing untested glasses whose origin is unknown.