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GLASSES FOR PROTECTING THE EYES FROM INJURIOUS RADIATIONS

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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 infrared 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 the fact that the infra-red rays are present in far greater abundance than the ultra-violet, the inference is that glassworkers' cataract

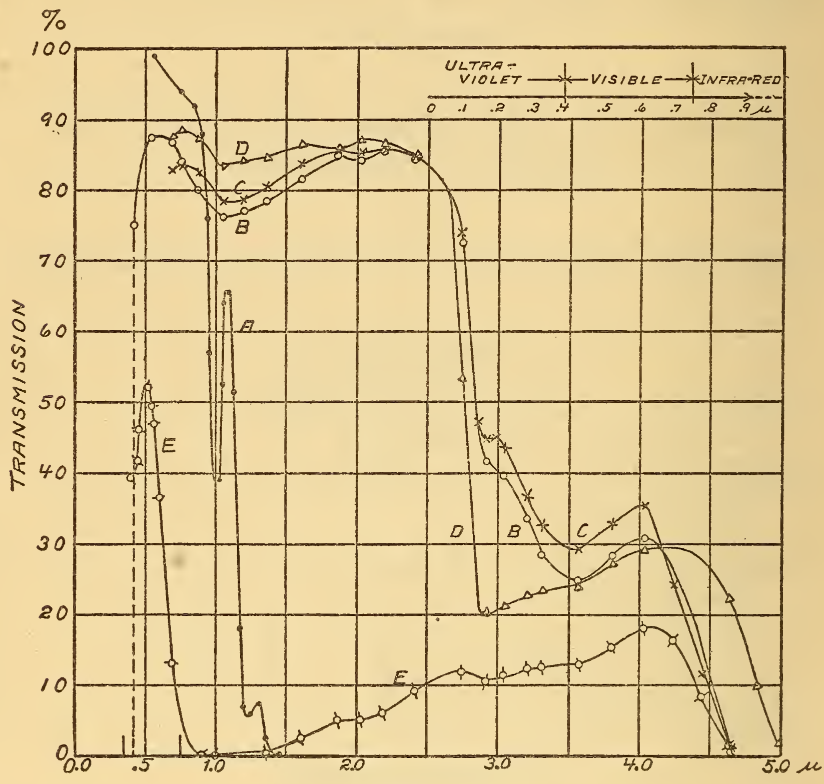

FIG. 1

A, human eye; *B*, yellow glass (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)

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.

Within the past few years numerous glasses have been produced which differ from the ordinary white crown glass used in spec-

[1] Verhoeff and Bell, Science, 40, p. 452, 1914; Elect. Rev., 75, p. 503, 1914.

tacles 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

[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.

that most of the energy (97 per cent) radiated from a furnace at 1000 to 1200° C (see Figs. 3 and 6, 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 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.

An instructive paper by Luckiesh[5] gives 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. AMBER-COLORED GLASSES

Under this title the general spectral transmission characteristics of "canary" 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. These glasses are quite opaque in the region of 0.45μ to 0.48μ with a slightly higher transmission 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 an amber-yellow ("Noviol") glass, curve *C* represents an orange, and *D* represents a yellow ("canary") glass, the thickness in all cases being 2mm. 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.

[5] Luckiesh, Trans. Illum. Eng. Soc., 9, p. 472; 1914.

The amount of infra-red transmitted by these amber glasses (curve *B* in Figs. 1 and 6) 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 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 6.)

Curve *F*, in Fig. 2, gives the transmission of a new blue-green glass (marked "E. D. T.," 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 the 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.

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[6] Crookes, Phil. Trans. Roy Soc., 213, p. 25; 1914. [7] Kindly furnished by the American Optical Co.

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

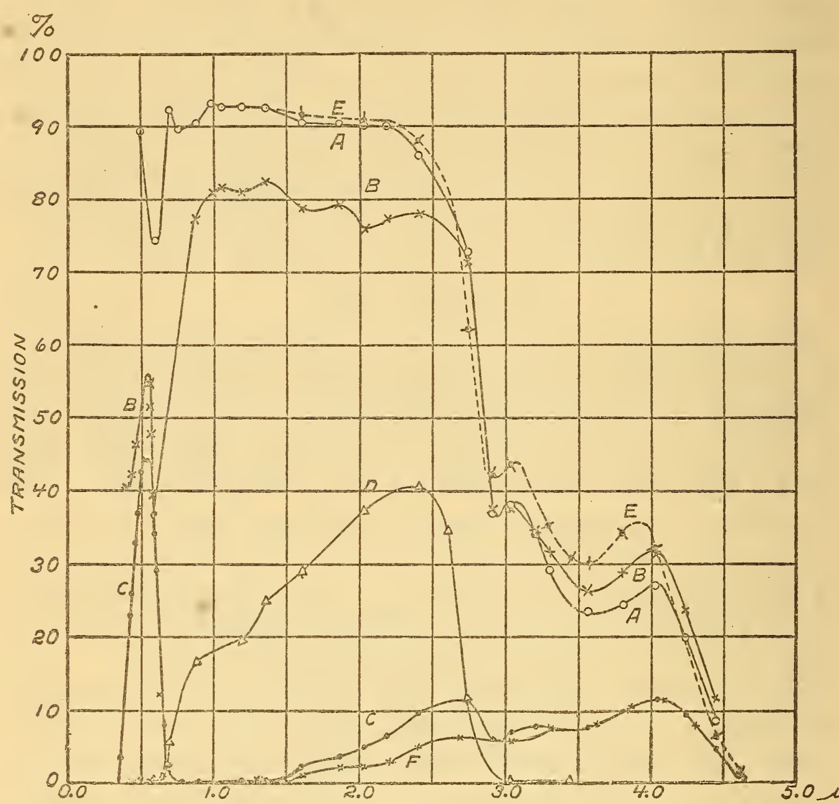

FIG. 2

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 (E. D. T.; t = 1.93 mm).

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 transmission 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. 6) transmits about 54 per cent of the infra-red radiation from a furnace heated to 1050° C. This is not a very

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

marked absorption when compared with the sage-green glass just described.

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.

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 the most effective means yet produced 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.

[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.

GREEN GLASSES

Among the colored glasses[11] available for effectively eliminating the infra-red are several 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 6.4 per cent of the infra-red radiation from a furnace at 1050° C, which is practically the same transmission (4.9 per cent) as Crookes's sage-green glass (*C*, Fig. 2) just

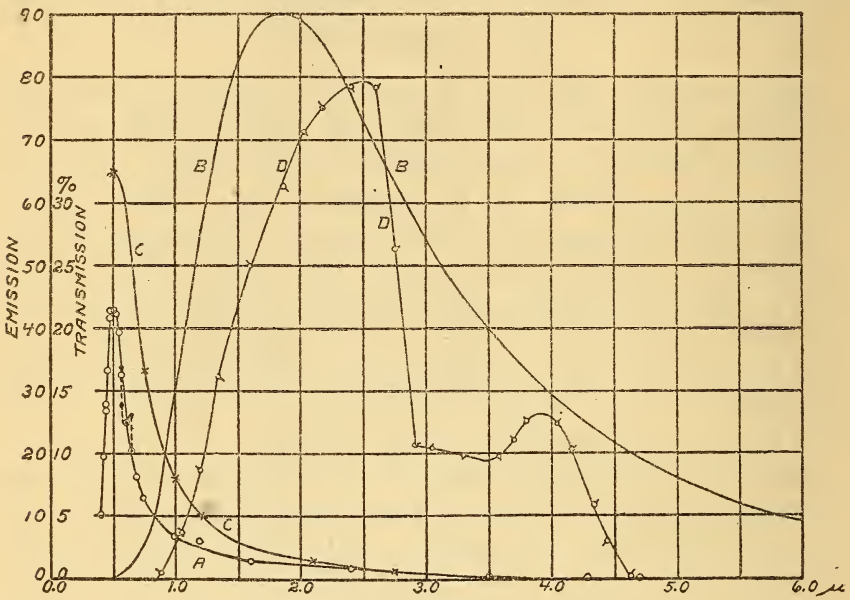

FIG. 3

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

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).

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

[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.)

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 1; 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 4; 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

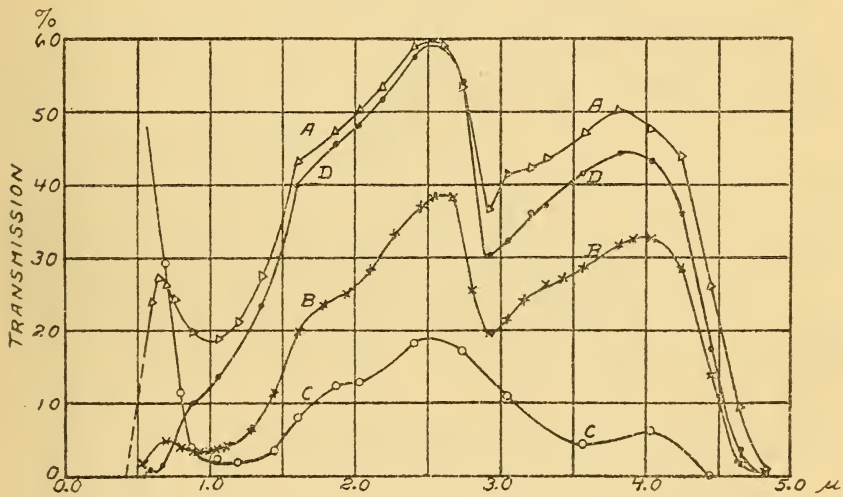

FIG. 4

Noviweld glasses: *A*, G 124 HL, shade 1 (t=1.47 mm); *B*, G 5 CAD, shade 4 (t=2.16 mm); *D*, shade 6 (t=2.0 mm). *C*, blue glass, Corning G 124 J (t=2.6 mm)

are as effective as the blue glass G 124 J, thickness, 2.6 mm (curve *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, 2mm). 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. 6.)

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 illus-

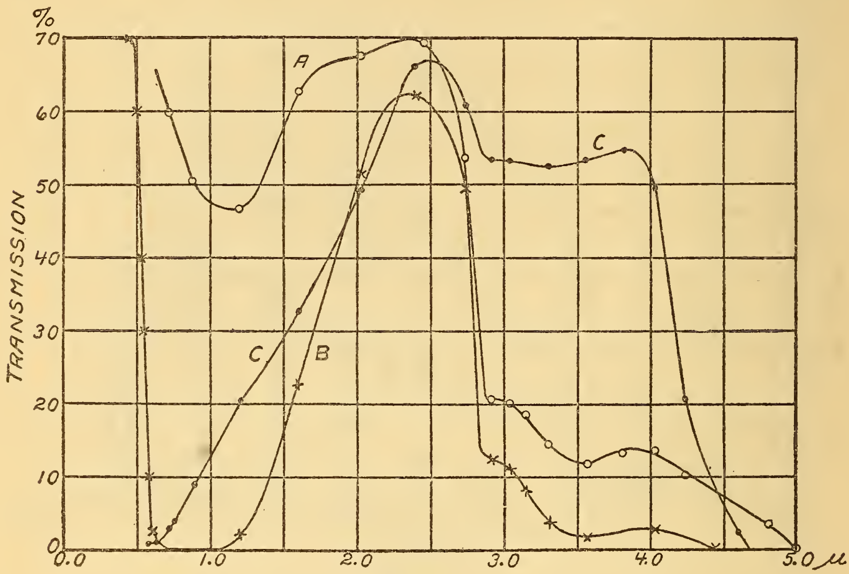

FIG. 5

Corning glass: *A*, orange G 36 A[1] (t=5.65 mm); *B*, blue G 401 ZA[1] (t=6.56 mm). *C*, common black glass (t=1.86 mm)

trated in Fig. 2 transmitted but little beyond 3μ, although a lighter 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.

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 visible spectrum the transmission is about 0.8 per cent. In the

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

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.

D, Fig. 3, gives the transmission curve of a very deep red glass (from American Optical Co., marked "electric smoke red"; thickness, 2.52 mm). This sample has a very high transmission (about 80 per cent) at 25μ, and therefore would be useful in experimental investigations in which it is desired to obtain radiations of these wave lengths without using a spectroscope.

V. MISCELLANEOUS GLASSES

Several glasses having interesting transmission spectra are given in Fig. 5. Curve *A* gives the transmission of an orange-colored glass (Corning G 36 A_1; thickness, 5.65 mm). All glasses of this thickness absorb heavily beyond 3μ.

Curve *B* gives the transmission of a Corning blue glass (G 401 ZA_1; thickness 6.56 mm). Schott's blue-violet glass No. F 3086 was found[12] to have practically the same transmission in the infra-red and in the violet as the sample illustrated by *B* in Fig. 5.

C, Fig. 4, gives the transmission curve of a blue glass (Corning G 124 J; thickness, 2.6 mm). This kind of glass is very opaque in 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.

In the following table 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.

Glasses which are Well Adapted for Protecting the Eyes from Infra-Red Rays

Kind of glass	Thickness	Maximum transmission 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:			
G 124 JA	1.50	52	6.4
G 124 HL	1.47	27	38
Schott's black glass 444 III	3.6	0.5	18

Curve *I* in Fig. 6 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.

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

For protecting the eye from ultra-violet light, black, amber, green, greenish-yellow, and red glasses are efficient. Spectacles

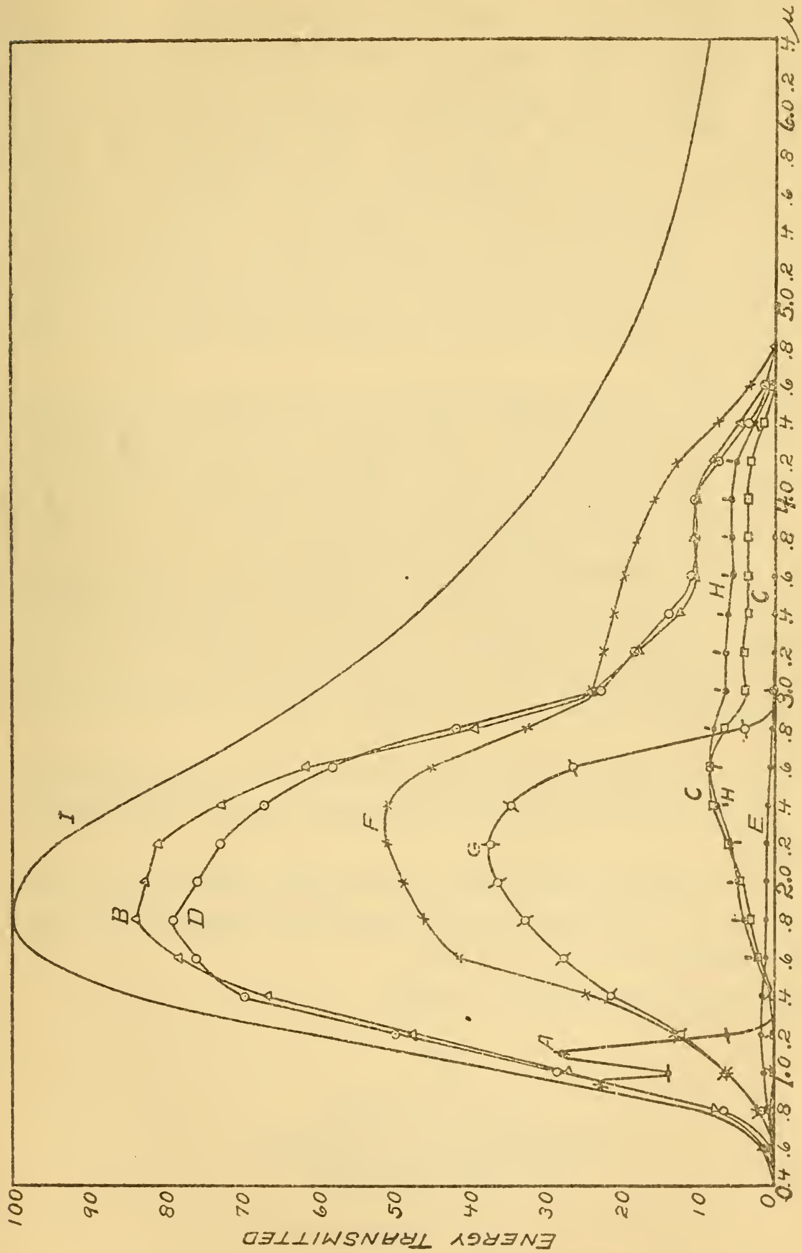

FIG. 6

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*, Noviweld (Fig. 4, *A*); *G*, black glass (Fig. 2, *D*); *H*, blue-green (Fig. 1, *E*); *I*, black body (1050° C)

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

At higher temperatures these data would be somewhat different, but not sufficiently so to modify the rough estimates dealt with in this paper.

A very complete bibliography on harmful radiations and eye protection is to be found in the Transactions, Illuminating Engineering Society, vol. 9, p. 11, 1914.

WASHINGTON, November 14, 1916.

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