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The Preparation of Eye-Preserving Glass for Spectacles

William Crookes

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PHILOSOPHICAL TRANSACTIONS.

I. *The Preparation of Eye-preserving Glass for Spectacles.*

By Sir William Crookes, *O.M., F.R.S.*

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Since March, 1909—in connection with the Glass Workers' Cataract Committee of the Royal Society—I have been experimenting on the effect of adding various metallic oxides to the constituents of glass in order to cut off the invisible rays at the ultra-violet and the infra-red ends of the spectrum. The work has been done chiefly in my own laboratory. I have been aided by Mr. Harry Powell, of the Whitefriars Glass Works, who prepared several pots of coloured glass from my formulæ on a much larger scale than could be made outside a glass works. From these glasses cylinders and sheets were made.

The main object of this research is to prepare a glass which will cut off those rays from highly heated molten glass, which damage the eyes of workmen, without obscuring too much light or materially affecting the colours of objects seen through the glass when fashioned into spectacles, but the work necessitated an examination of the screening properties of glass plates for ultra-violet and luminous light, and therefore the research was enlarged so as to embrace the three forms of radiation.

Radiation from Molten Glass.

In order to ascertain what rays are given off from molten glass I spent some time at the Glass Bottle Works of Messrs. Nuttall and Co., St. Helens, and took many photographs of the spectra of the radiations.

Photo-spectrographic and other examinations were made of the radiation emitted from the molten glass under working conditions. Full details of the experiments and results are given in this paper.

At the time I visited Messrs. Nuttall's works light green bottle-glass was being made; the mixture is composed of silica, sodium sulphate, and calcium carbonate or sulphate. The materials are melted in a large fire-brick tank, heated by a flaming mixture of gas and air playing on the surface. The gas is made some distance from the furnace in a "producer." Gas and air are conducted by separate channels to the upper part of the tank, where they mix and burn, the flame reverberating from the arched roof and heating the glass mixture to the requisite degree.

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The area of the tank of molten glass is about 82 square yards, and it contains from 300 to 350 tons of the mixture. There are several such tanks in the works. The tank is divided by a fireclay partition into two unequal parts. At the lower part is an opening through which the melted glass can flow. The larger portion of the tank, where the materials are melted together at a high heat, has a surface of about 63 square yards. This is called the "melting end"; when the mixture is well fused and homogeneous the molten glass flows through the opening into the "working end" of about 19 square yards, where the heat is less and the glass is in a viscous state. Fireclay rings of 18 inches internal diameter and a foot deep float on the surface of the viscid glass; any scum on the surface of the tank is thereby kept from contaminating the surface of the glass inside the ring. One ring floats opposite each working opening, and the workmen withdraw the requisite quantity of glass for each operation from the inner surface of the ring.

The light from the melting end of the tank, viewed through a working opening, was brilliant white with a tinge of orange; it was with difficulty the unprotected eye could make out any details. Viewed through dark glasses the surface of the metal in the tank appeared as a seething mass in constant commotion. The surface in the working end was more easy to see. It was of a bright yellow incandescence, and comparatively quiet.

It is not certain what the temperatures are at each end of the tank. So far as one could judge, the temperature at the melting end is about 1500° C., and at the working end decidedly less—say, 1200° C.

About each opening, especially at the melting end, thin white vapours rose and settled on the surrounding cooler parts. A piece of paper held in this vapour instantly ignited. Examined with a hand spectroscope the yellow line of sodium was seen to be brilliant in this vapour, but the light from the molten glass showed a continuous spectrum in which the sodium line was visible. On one or two occasions a black line was seen in place of the yellow sodium line, showing a reversal. Some of the condensed vapour was collected from the cool sides of the working opening and chemically examined. It was found to consist principally of sodium and calcium sulphates, with a little sodium chloride.

Photo- and Thermo-graphic Experiments.

The spectrograph used for taking photographs of the radiation from the molten glass is the one I described in 'Roy. Soc. Proc.,' vol. lxv., p. 237, May, 1899. It has two quartz prisms, each made up of two halves, one half being right- and the other half left-handed, according to Cornu's plan for neutralising the effect of double refraction. The collimating and camera lenses and the double condensers are also of quartz cut in the same fashion. The slit jaws are made of two acute-angled quartz wedges, edge to edge. The refracting prisms are of 60 degrees angle, and each face is 35 mm. by 42 mm. The lenses are 52 mm. diameter and 350 mm. focus. The condensers are plano-cylindrical, one being double the focus of the other. In order to ascertain the exact position of any part of the spectrum I might obtain from the radiation from the molten glass, I took photographs on each plate of an alloy of equal molecular weights of zinc, cadmium, tin, and mercury. This alloy gives throughout the photographic region lines, the wave-lengths of which are well known.

The instrument sloped downwards so as to allow the radiation from the surface of the melted glass to enter the condensers, prisms, and slit along the axis. To prevent the great heat injuring the spectrograph Mr. Nuttall allowed the opening to be bricked up, leaving a hole a few inches square in the middle. This was covered with an iron plate with a 2-inch hole in it, and over this a quartz plate was fixed.

Panchromatic films were used. These are sensitive beyond λ 7800 in the ultra-red, and to the highest ultra-violet rays which will pass through quartz (about λ 2100). Flexible films had to be used in preference to glass as they had to follow the curvature of the focal plane. Many preliminary experiments were made to ascertain the extent of spectrum to be recorded, its best position on the films, and the exposures needed. The slit of the instrument was generally placed about four feet from the molten surface, and it was found that from ten to fifteen minutes were required to produce a faint image on development. On each film, immediately before the radiation picture was taken, a photograph of the spark spectrum of the quadruple alloy was impressed on the film in such a position that the two spectra would overlap to a very slight degree.

No. 1 photograph was taken at the working end of the tank, where the temperature was lower than at the other end. An exposure of twenty minutes was given, the width of slit being 0·025 mm.

No. 2 photograph was taken in the same conditions as No. 1, but with an exposure of forty-five minutes.

No. 3 photograph was taken at the melting end, where the heat was fiercest. The width of the slit was reduced to 0·1 mm., and an exposure of half-an-hour was given.

No. 4 photograph, at the melting end, was exposed for one hour.

No. 5 photograph, at the melting end, was exposed for two hours.

No. 6 photograph, also at the melting end, was exposed for three hours.

It was not found practicable to give longer exposures.

Whilst these experiments were in progress, other experiments at another opening at the hottest end were tried to see if X-rays could be detected. Sensitive films were wrapped in black paper and then in lead foil in which designs had been cut. These were exposed for varying lengths of time, as near as it was safe to put them to the radiation from the molten glass, bearing in mind that the heat might affect the films. On development, no image of the stencil designs on any of the films could be detected. These results confirm those previously obtained by Dr. Burch—that X-rays are not emitted by the highly incandescent molten glass.

A careful examination of the six photographs shows a general progressive character, the extent of spectrum photographed extending into the ultra-violet as the length of exposure increases.

The extent of spectrum into the region of the ultra-violet is conveniently shown in the following tabular form* :—

No. 1	photograph,	exposed	20	minutes,	extends to λ 4520.
,, 2	,,	,,	45	,,	,, λ 4320.
,, 3	,,	,,	30	,,	,, λ 3790.
,, 4	,,	,,	60	,,	,, λ 3640.
,, 5	,,	,,	120	,,	,, λ 3595.
,, 6	,,	,,	180	,,	,, λ 3345.

Taking the ordinary limit of visibility to lie between λ 3900 and λ 7600, it is seen that with an exposure of three hours to the highest heats the strength of impression does not extend much into the ultra-violet. The heat rays are very strong, and if injury to the eye is caused by exposure to radiation from the molten glass, a protective glass should be opaque to the infra-red rays.

These being present in the radiation from molten glass in far greater abundance than the ultra-violet rays, the inference is that it is to the heat rays rather than to the ultra-violet rays that glass workers' cataract is to be ascribed. It is, however, certain that exposure to excess of ultra-violet light also injuriously affects the eye.

That the ultra-violet rays act on the deeper-seated portions of the eye is shown by the intense fluorescence of the crystalline lens induced by these rays.

Besides the invisible rays at each end of the spectrum, the purely luminous rays, if present in abnormal intensity, are found to damage the eye. It therefore would be an advantage if in addition the obscuring glass for the spectacles were to be of a neutral or grey tint.

Synthetic Preparation of Glasses.

It soon became evident that my best, if not only, chance of solving the problem was to make different glasses in my own laboratory, with the addition of known quantities of pure metallic oxides and earths as colouring or absorbing materials. Lapidary

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* In connection with this table the following scale for correlating colours with wave-lengths will be useful :—

Wave-lengths 7230 and below = infra-red.
From λ 7230 to λ 6470 = red.
,, λ 6470 ,, λ 5850 = orange.
,, λ 5850 ,, λ 5750 = yellow.
,, λ 5750 ,, λ 4920 = green.
,, λ 4920 ,, λ 4550 = blue.
,, λ 4550 ,, λ 4240 = indigo.
,, λ 4240 ,, λ 3970 = violet.
,, λ 3970 and above = ultra-violet.

apparatus for cutting, grinding, and polishing was also necessary so that the synthetically made glasses could be cut into plates—polished so as to be tested photographically in the spectrograph already described—and also tested for the percentage of heat rays they obstructed.

Many preliminary experiments were made on the preparation of a clear and colourless glass or flux to serve as a basis for the colouring with the various metallic oxides. Finally, two kinds of soda glass not containing lead were chosen, and Mr. H. Powell, of the Whitefriars Glass Works, who had assisted me in the preliminary trials by supplying me with many kinds of glass of different composition and fusibility, made a quantity of these fluxes and supplied them in a crushed condition. In my earlier laboratory experiments the mixture of colouring matter and granulated flux was put into a small "gold pot" of Morgan's Crucible Co., and gradually heated over a "Meker" gas burner. It is advisable to have one at least of the colouring constituents in the form of nitrate so that its decomposition by heat shall mix and stir the constituents. The decomposition of the nitrate causes a little frothing; therefore it is necessary to add the mixture gradually to the crucible, to avoid frothing over. When all is added and the contents well fritted, the hot crucible is removed to an electic furnace and the temperature slowly raised until the glass is quite fluid. It is stirred at frequent intervals with a stout platinum rod. After an hour the stirring is discontinued, and the temperature kept up for an hour and a-half. The current is then cut off, the openings in the furnace plugged with asbestos to prevent draughts, and the whole allowed slowly to cool to anneal the glass. In some cases the composition of the glass was such that the melting-point had to be raised above 1400° C., and as this temperature was beyond the safe limit with the platinum strip furnace, a blast-furnace fitted with a "Lennox" electric blower was used; with this arrangement larger quantities of glass could be raised with safety to a much higher temperature.

There are two conditions I have endeavoured to secure of the finished glass—each of great importance. One, the most essential, is the absence of all streaks, striæ, and irregularities of density; the other, the absence of air-bubbles. The first is obtained by repeated stirring and perfect admixture; the freedom from air-bubbles is secured by leaving the glass in perfect repose while the heat is at the highest point. On these and other points I have been much aided by reading an early paper by Faraday, "On the Manufacture of Glass for Optical Purposes," the Bakerian Lecture read before the Royal Society in 1829 ('Phil. Trans. Roy. Soc.,' 1830, p. 1). On a small scale it is almost impossible to avoid slight striæ owing to differences of density caused by the long continued heat volatilising some of the soda. Faraday was much harassed by this dilemma in the manufacture of his optical glass, and tried many experiments to ascertain the cause. To get rid of air-bubbles Faraday used spongy platinum in powder sprinkled over or added to the bulk of the melted glass. This was found to act pretty well, making the bubbles rise in the same manner as a piece of bread causes bubbles to rise when thrown into a glass of effervescing liquid. To get the full benefit from this device, however, the glass must be kept perfectly quiet and at the highest temperature for a longer time than in my case was always practicable.

When the crucible has cooled slowly for about twelve hours it is removed from the furnace, and the solid cone of glass removed by breaking the crucible by a few judicious blows with a light hammer. The lump of glass is now taken to the lapidary's table, and slit across the middle and a plate cut from it, which is ground and polished to a determined thickness, usually 2 mm.

Testing Synthetic Glasses for Opacity to Ultra-violet Light.

The plates are now tested for the opacity of the glass to the rays of the ultra-violet end of the spectrum. The spectrograph with complete quartz train, already referred to, was used. By superposing on the radiation from a Nernst lamp the light from a high-tension electric discharge between poles of pure metallic uranium it is possible to produce a practically continuous beam extending from λ 2000 to λ 8000, and the absorption of such a beam of radiation, produced by flat plates 2 mm. thick of all my experimental glasses, has been thereby recorded.

To ascertain the amount of heat obstructed by the plates of glass I first used a MELLONI's thermopile as described in his papers,* but I soon found that modification was needed as the pile responds to the orange and red rays as well as to the infra-red.

Plates of dark smoky quartz 2 mm. thick were tested with the thermopile, and it was found that they transmitted nearly all the heat whilst cutting off 80 or 90 per cent. of the light. Biotite (black mica) exerts a similar effect, and is more easily experimented with than smoky quartz. For many years I have used biotite for cutting off light and transmitting heat; I accordingly investigated the properties of many specimens of black and dark brown mica to find out which would be best for this special purpose.

Selection of Black Mica (Biotite) for Diathermancy.

Samples of dark brown and black mica vary considerably in their power of obstructing light and transmitting the infra-red rays. By the kindness of friends connected with the mining and importation of mica, I have been able to examine a large number of samples from different parts of the world.

Some very fine pieces of black biotite were sent by Messrs. Attwater and Sons, who tell me they were mined by them in the extreme north of Norway from a cleft in a mountain at about 2000 feet. This mica is extremely regular in the thickness of the flakes which can be split from it, and the colour of thin pieces is uniform. A piece

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* "On the Free Transmission of Radiant Heat through Different Solid and Liquid Bodies," 'Ann. de Chim. et de Phys.,' vol. liii., p. 1; TAYLOR'S 'Scientific Memoirs,' vol. 1, p. 1; "New Researches Relative to the Immediate Transmission of Radiant Heat through Different Solid and Liquid Bodies," 'Ann. de Chim. et de Phys.,' vol. lv., p. 337; TAYLOR'S 'Scientific Memoirs,' vol. i., p. 39.

0·07 mm. thick entirely cuts off the luminous rays, and even the sun's disc is only just seen through a flake 0·06 mm. thick.

In addition to specimens from Norway, Messrs. Attwater and Sons sent me black biotite from German South-East Africa, and some fine pieces of "black amber" mica from Africa. The African mica is uniform in colour, and easily splits into flakes of great regularity. The German mica is difficult to split into uniformly regular flakes, and therefore varies considerably in colour.

Messrs. F. Wiggins and Sons allowed me to select some large sheets of dark brown and black biotite from their stock. The sheets when split are uniform in colour, and in thicknesses below about 0·30 mm. are sufficiently transparent to allow the eye to detect a Nernst glower. Mica differs, however, in transparency, one flake from a sheet being opaque at 0·24 mm., while a flake from another part of the same sheet is slightly transparent in a thickness of 0·34 mm. I also received good black mica from Mr. Henson, who gave as its locality Renfrew, Canada.

Many experiments have been carried on with all these kinds of brown mica to find a quality which would cut off the rays which at Kew were called the "scorching rays" (the infra-red rays), and some of the best results were obtained with the Norwegian mica from Messrs. Attwater and Sons, and the black amber African mica from Messrs. Wiggins and Sons.

There is a certain gradation of transmitted rays according to the thickness of the dark brown micas. All of them cut off rays at the blue end of the spectrum, and as the thickness increases the portion of the spectrum obstructed rapidly tends towards the red end, until a mica is found which affects the photographic plate in a narrowed band round the line B, the exposure being from ten to twenty times as long as would be required for this part of the spectrum to impress itself, were no mica to intervene. To increase the thickness of the dark mica soon obstructs all rays in the red visible to the eye.

Examined by the thermometric apparatus, a thermopile, and in the radiometer balance—described below—the dark micas which allow any trace of visible rays to pass are strongly diathermic. As the thickness of mica increases the deflection of the index spot of light gets less and less, until there is very little action at all. Judging from analogy it is most probable that as the thickness increases the heat rays are cut off in regular gradation from the line B in the red to the longest rays of heat which will affect the radiometer balance.

This is only a hypothesis and does not take into account the possibility of there being dark bands in the infra-red portion of the heat spectrum. Still the hypothesis as a working tool has been of considerable use, and has helped me to select dark mica obscuring media—giving good and concordant results.

Were I to take at random a piece of black mica which would cut off all the rays visible to the eye, and not allow any red and ultra-red rays to pass that would affect the panchromatic plate, I should have no certainty that the piece of mica would not cut off some of the heat rays which the glass transmitted. If, on the other hand, I select a piece that allows the red rays near the lines B and C to pass (as shown on the photo-spectrograph), some of the action on the radiometer balance would be due to the luminous red rays, and it is not advisable to entirely cut these off as the residual colour thereby might be affected. The plan ultimately adopted was gradually to increase the thickness of the mica until the photo-spectrograph showed that the visible red had just ceased to affect the plate. After experimenting on some hundred kinds and thicknesses of brown and black mica I succeeded in getting a piece which appeared to satisfy all requirements; the examination of the different kinds of glass made in my laboratory during the last four years has been carried on by help of this specimen.

Measurement of Infra-red Radiation.

Before I had tried many experiments with the thermopile and black mica another difficulty cropped up. The heat radiated from the Nernst glower gradually warmed up the apparatus, and unless a long time was allowed between each observation I never could get the index ray of light to return to zero. This and the little sensitiveness of the instrument used induced me to try a mercurial thermometer in place of the thermopile, all other arrangements being as before. The thermometer was specially constructed with a concave bulb coated with carbon from burning camphor. It was divided into tenths of a degree, the scale being about 9 mm. to a degree.

To test, a selected plate of black mica was permanently fixed in the apparatus between the bulb of the thermometer and the slide containing the glass. First of all, upon lighting the Nernst lamp, the rise in temperature was taken, having only the mica plate between the lamp and the thermometer. The thermometer was observed from a distance through a cathetometer. It was allowed to rise about 1° C., and then with a stop-watch the further rise in sixty seconds was observed. A mean of four observations in this way gave a rise in sixty seconds of—

$$\left.\begin{array}{l}1·75\\1·60\\1·725\\1·675\end{array}\right\}\text{mean } 1·683.$$

In making a determination of diathermancy, glass plates 2 mm. thick were prepared and placed close to the thermometer bulb in a holder having a $\frac{1}{2}$-inch hole; ten observations were made and the mean taken as the value, which was given in percentages of 1·683.

Thus with glass No. 129; mean rise in sixty seconds = 0·26° C.,

$$\frac{0·26 \times 100}{1·683} = 15·4° \text{ C.}$$

A mean of ten similar observations gave a value which was taken as the diathermancy of the glass to dark heat. Its athermancy is obtained by subtracting this value from 100. In this way a multitude of glasses were tested, and recently the results have been plotted on a curve which was found to correspond closely with the result subsequently obtained by the radiometer method.

The Radiometer Balance.

In early papers on "Repulsion Resulting from Radiation,"* I showed that the blackened surface of a radiometer was repelled by all the rays of the solar spectrum, from the ultra-violet to a distance at the red end extending far into the ultra-red, the maximum intensity being a little distance below the spectrum line A.

An instrument was accordingly made based on the principle of the radiometer, and somewhat resembling the apparatus described in a paper read before the Royal Society in 1875: "On Repulsion Resulting from Radiation."† It is a torsion balance in which the beam moves in a horizontal plane. Figs. 1 and 2 show the details of the instrument, the letter references being the same in each figure. AB is a thin glass tube, with a bulb at the end, B, and ground flat at the end, A. To the centre of AB is sealed an upright tube, CD, having an arm, E, blown to it for the purpose of attachment to the pump. FG is a very light arm of aluminium carrying at the end, G, a disc of silver-flake mica coated with lamp-black. At the end, F, is a small counterpoise to allow the arm to hang level. H is a glass stopper to the upper part of the tube, CD, which is widened out to form a cup to hold mercury. The stopper in the cup is accurately ground in the tube, as long a surface as practicable being in contact. The horizontal arm is suspended from the stopper by a bifilar suspension of fine quartz fibres, IJ, which are attached to the arm FG by an aluminium stirrup holding at its upper end a silvered glass mirror of one metre focus. The

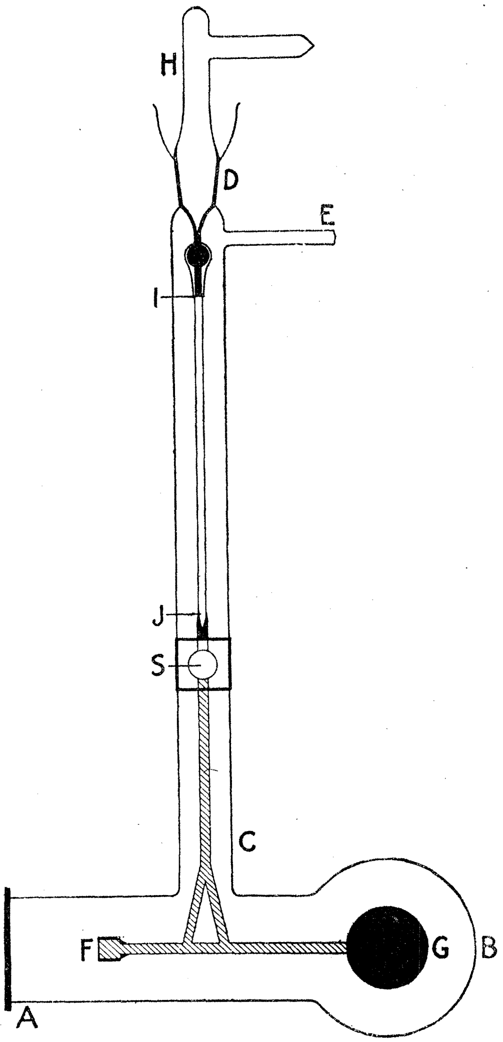

Fig. 1.

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[*] 'Phil. Trans. Roy. Soc.,' 1876, Part II., vol. clxvi., pp. 355–361.

[†] 'Phil. Trans. Roy. Soc.,' 1875, Part II., vol. clxv., pp. 533–4–5.

vertical tube is blown out and the edges ground flat at the part where the mirror hangs; a flat piece of glass is cemented to it, forming a window through which pass the entering and emerging index beams of light. The end A of the horizontal tube is left open to allow of the adjustment of the arm in its stirrup, and then it is sealed with a flat piece of glass cemented on. The stopper, H, is lubricated with drops of burnt indiarubber so that it can be smoothly rotated to allow the arm to be brought accurately to zero.

Fig. 2 shows the arrangement of the appartus fitted for testing the samples of glass. The radiometer balance is enclosed in a wooden box having two holes opposite the mirror and the end of the blackened disc at the torsion arm. Great precautions must be taken to avoid all extraneous radiations from acting on the black disc; a slightly conical card tube, as narrow as the angular movement of the ray of light will admit, is attached to the window at K in front of the mirror, S, and another to the bulb at L opposite the black disc.

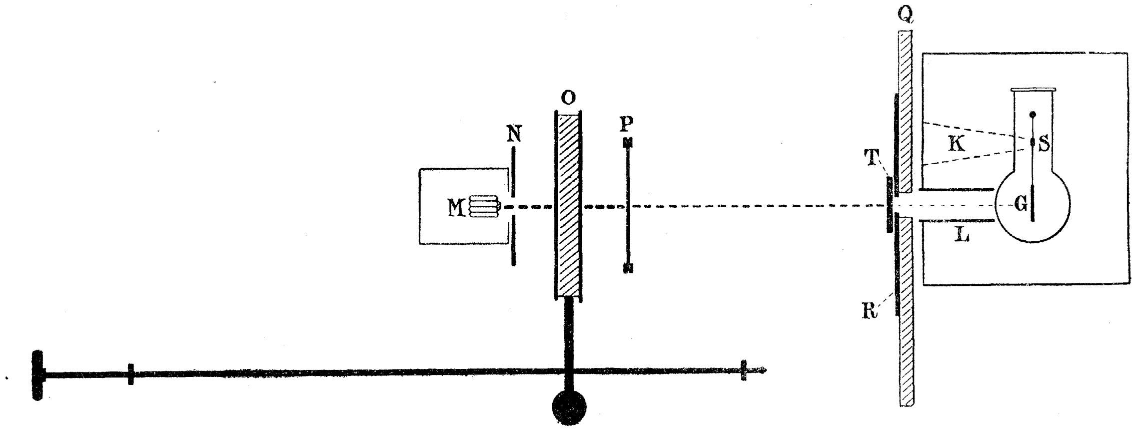

Fig. 2.

A, B, C, D, E.	Case of radiometer. (Fig. 1.)	N.	Aluminium screen.
F, G.	Radiometer arm with blackened mica disc.	O.	Shutter.
H.	Ground glass joint. (Fig. 1.)	P.	Black mica screen.
I, J.	Quartz fibres. (Fig. 1.)	Q.	Carrier for holding glass specimen.
K.	Guard tube in front of mirror S.	R.	Aluminium screen.
L.	Guard tube in front of radiometer disc.	S.	Concave mirror, one metre focus.
M.	Nernst glower.	T.	Glass specimen under examination.

The heat radiation used in these tests is emitted from a Nernst glower, M, enclosed in a metal box with an open end. In front of the glower is an aluminium screen, N, pierced with a centimetre hole. A shutter, O, can be moved up and down by an arm close to the observer. The shutter screen is made of a piece of cork an inch thick, having on each side a plate of polished aluminium. In this way the heating up of the shutter when it is obscuring the ray from the glower is effectually prevented. At P is a frame for supporting the piece of black mica, and at Q is a sliding carrier holding the piece of glass under examination. This is so arranged that it can be drawn out and another piece of glass put in without causing any jar. Behind the glass is an aluminium screen, R, with a hole in it one centimetre in diameter. The vacuum must be a rather high one, about 40 millionths of an atmosphere.*

The whole apparatus is closely packed with cotton-wool, so that no radiation can get to the black disc but that which comes through the window opposite. The box containing the radiometer balance is firmly attached to the main wall of the house, to avoid as much as possible interference from vibration caused by movements in the room. A spot of light reflected by the mirror, S, from another luminous source is received upon a graduated screen one metre distant in the usual manner.

Testing Synthetic Glasses for Diathermancy.

The mode of procedure is thus :—The mica is put in its place and the lamps started. In about ten minutes the zero is adjusted by means of the rotating stopper. When the spot of light is at zero the shutter, O, is raised, and the extent of the deflection noted. At the end of the first half swing the shutter is lowered, and the whole is left at rest until the light is again at zero. The glass under test, T, is now put in its carrier and slid into place, and the extent of deflection of the spot of light noted when the shutter is raised. The amount of deflection with the same piece of mica interposed is thus obtained with many different kinds of glass, and from the data the order of obstruction to heat rays can be calculated for each. It is a necessary precaution to verify the readings once or twice, and to allow the spot of light to come accurately to zero. It is inclined to shift if observations are repeated too rapidly, owing to the retention of heat by the blackened face of the radiometer disc, and the consequent repulsion between it and the front of the bulb B. This effect soon goes off if a little time elapses between the different observations.

The deflection of the spot of light when the dark mica alone is interposed gives the effect of the total heat ray, and the lessened deflection when the glass under test is also interposed is a measure of the heat it cuts off. By dividing the scale divisions traversed by the luminous index when both glass and mica are in the path of the heat ray by the number of scale divisions traversed when the mica alone is interposed, the result gives the amount of heat obstructed.

Addition of Absorbing Media to the Soda Flux.

The first point to be settled is the effect of dissolving various metallic oxides by fusion in the clear colourless glass. The metal is added in the form of oxide, nitrate, or other salt, according to which is easiest to obtain pure. Unless oxidation of other ingredients is to be avoided the nitrate is preferred, as the copious liberation of gas during the fusion stirs up the fused mixture and assists in making it homogeneous in a much shorter time.

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* 'Phil. Trans. Roy. Soc.,' 1876, Part I., p. 301 (the Bakerian Lecture), and 'Roy. Soc. Proc.,' vol. xxv., p. 305.

To be generally useful, it is desirable to obtain a glass which will absorb rays of longer wave-length than about λ 7200, and so cut off dark heat radiation. It should also be opaque to wave-lengths shorter than about λ 3550, thus cutting off the most chemically active rays, and also those which give rise to ionisation, *i.e.*, cause the air through which they pass to conduct electricity.

Working in a vacuum and with sensitive plates of emulsion containing no gelatine, Dr. SCHUMANN succeeded in photographing ultra-violet rays as short as λ 1000. In a paper recently read before the French Physical Society by MM. KARL STOCKHAUSEN and FRITZ SCHANZ, it is stated that the harmful action of light on the eye is due to the ultra-violet rays. It is also shown that the cornea is opaque to rays shorter than λ 3200.

The crystalline lens is opaque to rays shorter than λ 3500, and rays of longer wave-lengths than this reach the retina. As the transparency of ordinary spectacle glasses is limited to λ 3000, it follows that a considerable amount of ultra-violet radiation may reach the cornea through ordinary spectacles.

Method of Testing Glass.

Single metals were at first tried in varying quantities to see if from the colour and properties communicated to the glass they were worth further examination. Each specimen is cut and polished into a plate 2 mm. thick. The plate so prepared is first tested in the spectrum apparatus to ascertain the upper limit of transmission of the ultra-violet rays. It is next put into the radiometer balance to see the percentage of heat cut off, then tested in CHAPMAN JONES's opacity balance* to see the percentage of luminous rays transmitted, and finally the colour is registered in a LOVIBOND's tintometer.†

A large proportion of the known metallic elements were tested in this manner, and a considerable number were proved to be unsuitable. After experiments extending over several months the following elements were selected as likely to be worthy of further experimentation by combining the metals two, three, or four at a time in one glass so as to enable the advantages of one to make up for the shortcomings in another:—

- Cerium.
- Chromium.
- Cobalt.
- Copper.
- Iron.
- Lead.
- Manganese.
- Neodymium.
- Nickel.
- Praseodymium.
- Uranium.

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* "An Opacity Balance," by CHAPMAN JONES, 'The Photographic Journal,' vol. xxiii., p. 99.

† The tintometer is an instrument devised by Mr. Lovibond (Messrs. Gallenkamp and Co.). Any colour can be matched by a combination of three sets of glasses, coloured respectively red, yellow, and blue, and numbered in order of depth of colour, increasing with the magnitude of the numbers.

I will now take the metals selected for further trials, and give the results of the preliminary test of the glasses so as to ascertain their behaviour in the four instruments above described.

Cerium.

One of the most important additions to soda flux is ceria, which gives a practically colourless glass. Cerium nitrate was generally used, and occasionally cerium borate and ceric oxide. Trial glasses were made, the proportion of metal varying from 1 per cent. to 7·5 per cent. The conclusion arrived at on tabulating and considering the results shown by this series of glasses, is that cerium is of value in cutting off the ultra-violet rays. The glasses are very slightly coloured, and allow nearly all the luminous rays to pass. The heat absorption is about 30 per cent., and does not vary much with the amount of cerium present.

Chromium.

This metal, in quantities of less than 1 per cent. in the glass, exerts a strong action on the ultra-violet rays, cutting them off down to the blue (λ 4550). In larger proportions, either singly or mixed with other metals, the absorption extends as far as λ 5600 (about the middle of the green). Its heat obstructing power is not on a par with that of uranium, being about 30 per cent. for 1 per cent of chromium metal. The luminous rays transmitted by chromium glass containing 0·85 per cent. of metal are 37 per cent. of the total light, the colour of the glass being green.

Cobalt and Nickel.

Cobalt colours glass a rich blue, and then transmits ultra-violet rays of shorter wave-length than about λ 3200. It cuts off 40 per cent. of the heat, and unless in very small quantity obstructs too much light to be of use. Nickel colours glass brown. In glass its absorption of ultra-violet light is about the same as cobalt. It obstructs a little more heat and is more transparent to light. These two metals separately are of no use for the present purpose, but united they have the valuable property of neutralising each other's colour and giving the glass a neutral grey tint.

It is noteworthy that the colours of nickel and cobalt in aqueous solution are green and pink, whilst in solid solution in glass they are brown and blue, in each case complementary to one another.

Solutions of nickel and cobalt sulphates, containing 5 gr. to 100 c.c. of water, mixed together in the proportion of 2·5 c.c. Ni to 1 c.c. of Co, gave a mixture of a neutral grey colour. The mixture was divided into two parts; one was gradually heated to the boiling-point, while the other was left for comparison at the temperature of the laboratory (16° C.). Compared with the cold solution, the one at the boiling point was decidedly pink, and it required a further addition of nickel solution to restore the neutrality of colour at the boiling-point, raising the proportion of nickel to cobalt 3·5 to 1 at 100° C. against 2·5 to 1 at 16° C. As the hot solution cooled the neutral tint gradually changed until it became decidedly green.

The same mixed solution, neutral tinted in the cold, was acidified with sulphuric acid. It immediately assumed a very faint tinge of pink, but not so decided a tint as the same neutral coloured solution took when heated to the boiling-point.

A solution was prepared containing nickel and cobalt in the proportion of 2·5 to 1; it was evaporated to dryness and ignited. The mixed oxides were then added to the hard soda flux, and the whole melted together at a high temperature; the glass resulting was cut and polished into a plate 2 mm. thick. It was decidedly blue, although the metals were in the proportion to give neutrality at the ordinary temperature when in aqueous solution. More nickel was added in small proportions at a time, and it was not until the proportion in the glass was 1 cobalt to 5 nickel that a neutral grey glass was obtained.

As a colouring agent cobalt is stronger than nickel. It is not easy to get an exact proportion, as the neutral point is difficult to hit with accuracy. If 4 of nickel instead of 5 are used with 1 of cobalt the glass is of a decided bluish tint, while if 6 of nickel are added the colour is brown.

Copper.

Copper by itself as a constituent of glass is not of much advantage. It colours the glass blue, has not much action on the ultra-violet rays, but cuts off three-fourths of the heat rays. It forms a useful addition to other colouring agents in tending to neutralise those of the orange-yellow colour.

Iron (FeO).

Iron is introduced into the glass as ferrous sulphate, care being taken to avoid all oxidising agents. The fused mass is stirred with a carbon rod, and a little powdered charcoal added to the melt in the crucible. In quantities from 1 to 2·5 per cent. the obstruction to heat radiation is great, and increases with the quantity of metal present. One per cent. of iron cuts off about 65 per cent. of the heat, and 2·3 per cent. cuts off about 89 per cent. The action on the ultra-violet end is but slight, the photographs extending to λ 3467 with the lowest amount of iron, and to λ 3560 with the largest amount experimented with. The light transmitted by the 2 mm. plate is 71 per cent. with the least amount of iron and 50 per cent. with the largest amount. The colour of the glass is greenish blue. Iron in the ferrous state, therefore, will prove useful on account of its communicating adiathermic property to the glass.

Iron (Fe_2O_3).

In this state of oxidation iron glass cuts off ultra-violet light to a limited extent. When small proportions only are present, such as 0·25 per cent., the rays are transmitted from λ 3500 (far in the ultra-violet), and it is only when the amount of iron in the per state rises to about 2 per cent. that the glass becomes opaque to the rays near λ 4000 (about the limit of visibility in the violet). A glass of this composition cuts off about 63 per cent. of the total heat. The colour is almost pure yellow. The glass transmits about 75 per cent. of the incident light. Iron in the per state, therefore, is another metal useful in combination.

Lead.

A plate 2 mm. thick was cut from a block of FARADAY'S "heavy glass" (boro-silicate of lead) prepared by himself, and tested as a sample of lead glass. It is practically colourless and transparent, and is opaque to the ultra-violet above λ 3800. Its action on the heat rays is slight, only cutting off about 38·5 per cent.

Manganese.

Glass containing manganese is of a reddish purple colour. In respect to obstruction to the ultra-violet and heat rays manganese has no special action. It has, however, been experimented with to obtain a neutral coloured glass by adding it to glass containing a greenish colouring agent.

Neodymium and Praseodymium.

These two bodies would be useful in the quest for a suitable glass were they to be obtained at a price which would not be prohibitive. In aqueous solutions praseodymium salts are greenish yellow, and those of neodymium are of a violet-rose colour. Mixed together in the proportion of five parts of praseodymium to one of neodymium the mixture is of a neutral grey. In solid solution in glass the colours are—praseodymium greenish yellow, and neodymium lilac. Melted together in glass in the same proportion as in aqueous solution, the resulting colour is also neutral grey. In this respect these two elements differ from nickel and cobalt, inasmuch as the colours remain constant either in aqueous solution or melted in glass, and the proportion required to obtain neutrality of tint appears to be the same in each case.

Uranium.

Glasses were prepared containing from half a per cent. of uranium to over 4 per cent. The colour of the glasses with smallest quantity of metal is very faint brown, and with the highest proportion it is yellowish brown. The opacity for ultra-violet light increases as the glass is richer in metal, the one with about 4 per cent. uranium being opaque to the indigo and violet down to the blue. The heat absorbed at most is about 55 per cent. These results show that uranium is a metal likely to be useful in combination.

Composition of Glasses Specially Selected for Practical Use.

Whilst bearing in mind that the chief object of this research is to find a glass that will cut off as much as possible of the heat radiation, I have also attacked the problem from the ultra-violet and the transparency points of view. Taking each of these desiderata by itself I have succeeded in preparing glasses which cut off over 90 per cent. of heat radiation, which are opaque to the invisible ultra-violet rays, and are sufficiently free from colour to be scarcely noticeable when used as spectacles. But I have not been able to combine in one specimen of glass these three desiderata in the highest degree. The ideal glass which will transmit all the colours of the spectrum cutting off the invisible rays at each end, is still to be discovered.

As far as transparency, however, is concerned it will not be an unmixed advantage for the sought-for glass to be quite clear and colourless. The glare of a strong light on white cliffs, expanses of snow, electric light, &c., is known to be injurious to the eye, and therefore a tinted glass combining good obstruction to the heat radiation and ultra-violet rays is the best to aim for.

Grey or neutral tints are the most pleasant to wear. They do not appreciably alter the natural colours of objects, and are a great relief to the eye. Many glasses are met with in commerce of different colours which are found by experience to suit the public demand for tinted spectacles. They are of various tints of yellow, green, blue, and neutral, and therefore I do not think it will be wrong to select the tints of my glasses, suitable in other respects, no darker than those which appear to suit the public taste.

As a basis for the preparation of the coloured glasses, Mr. Powell prepared for me a quantity of hard soda-flux mixture of the following composition :—

Sand	61·00
Sodium carbonate, anhydrous	25·50
Sodium nitrate, recrystallised	5·00
Calcium carbonate, precipitated	7·20
Borax	0·75
Arsenic trioxide	0·55
	100·00

This mixture whilst melting loses about 25 per cent. in weight. When first melted, it is colourless; on second melting it acquires the usual faint greenish tint of sodalime glass. The contents of a large potful of the melted flux was poured into cold water. The broken-up mass was sent to my laboratory and has been used in the preparation of the test glasses. The object of pouring the molten flux into water is to break it up and render it easy to powder for convenience of adding other ingredients. In this state I call it "Fused Soda Flux."

Sometimes it is found advisable to use the flux in its raw state without previous melting, and when working upon the large scale this is the best plan. I then call it "Raw Soda Flux."

Without counting numerous preliminary experiments, I have made and fully tested over 300 tinted glasses, the quantitative composition of each being known. From these glasses I have selected a certain number which possess valuable qualities in respect of athermancy, adiactinity, and transparency.

I will now give the composition of these glasses, and the special properties in respect to the desired results.

Glass 150.

Fused soda flux	90·00
Cerium borate	8·13
Nickel sulphate, crystallised	0·07
Uranoso-uranic oxide	1·80
	100·00

In Glass 150 a small amount of nickel has been added to the cerium and uranium. The colour is pale yellow, and it is opaque to ultra-violet radiation, the limit being λ 3613. It cuts off 37 per cent. of the heat radiation and transmits 73 per cent. of the incident light. The tintometer numbers are:—Red, 4·0; yellow, 3·5; blue, 0·5.

Glass 158.

Fused soda flux	89·75
Cerium borate	8·18
Ferroso-ferric oxide	2·03
Chromic oxide	0·09
	100·00

This glass is pale greenish yellow. It is quite opaque to all the ultra-violet rays, the limit being λ 3700. It cuts off 63 per cent. of heat radiation, and transmits 54 per cent. of the light.

The glass has a pale greenish yellow colour. Its tintometer numbers are:—Yellow, 2·75; blue, 3·5.

Glass 165.

Raw soda flux	87·56
Cerium borate	8·00
Ferrous sulphate, crystallised	3·00
Uranic oxide	0·55
Nickel oxide	0·09
Chromic oxide	0·80
	100·00

This glass cuts off practically all the ultra-violet rays shorter than λ 3680, and 38 per cent. of the heat radiation. It transmits 48 per cent. of the light. Its colour is a pale yellowish green. Its tintometer numbers are :—Yellow, 4·0 ; blue, 2·50.

Glass 187.

This glass and the next are both cerium glasses. No. 187 is composed of :—

Fused soda flux	83·0
Cerium nitrate, crystallised	17·0
	100·0

The heat rays cut off by this glass are only 27 per cent., but its other qualifications are important. It is practically opaque to ultra-violet radiation, the limit being λ 3650, and it transmits 99 per cent. of the light.

In the tintometer and opacity meter no colour or want of transparency can be detected, although against white paper in a good light a faint tinge of yellow is perceptible.

Glass 197.

Fused soda flux	79·00
Cerium nitrate, crystallised	20·50
Nickel sulphate, crystallised	0·30
Cobalt sulphate, crystallised	0·05
Uranoso-uranic oxide	0·15
	100·00

Nickel and cobalt are here mixed in the proportion to make a neutral tinted glass, the other ingredients only slightly modifying the colour. The colour is a pale neutral. It is opaque to ultra-violet rays of shorter wave-length than λ 3799, and cuts off 41 per cent. of the heat rays. It is transparent to 45 per cent. of the incident light. The numbers in the tintometer are :—Red, 2·00 ; yellow, 3·00 ; blue, 5·50.

Glass 202.

I have obtained a neutral tinted glass by neutralising the orange-yellow colour communicated to glass by iron in the ferric state, by adding to it a little cobalt, which colours it blue. The composition is :—

Soda flux	95·15
Fe_2O_3	4·75
$CoSO_4, 7H_2O$	0·10
	100·00

The resulting glass is opaque to ultra-violet of shorter wave-length than λ 3830, it cuts off 83 per cent. of the heat radiation, and transmits 25 per cent. of light. The tintometer numbers are :—Yellow, 2·5 ; blue, 5·5.

Glass 210.

Fused soda flux	89·0
Ferrous sulphate, crystallised	8·9
Chromic oxide	1·3
Carbon, in fine powder	0·8
	100·0

Glass 210 is of a bluish-green colour, the blue colour communicated by the ferrous oxide making the colour of the chromium not so pure a green. It cuts off all ultra-violet rays of shorter wave-length than λ 3620. It obstructs 87 per cent. of the heat radiation, and transmits 30 per cent. of light. The tintometer numbers are :—Yellow, 2·0 ; blue, 16·0.

Glass 217.

A further attempt was now made to get the iron in the ferrous state, and a glass was prepared of the following composition :—

Fused soda flux	96·80
Ferroso-ferric oxide	2·85
Carbon	0·35
	100·00

A few percentages of finely powdered carbon are added to this mixture before fusion to keep the iron in the proto-state. Any excess of carbon rises to the top of the fuzed mass and prevents oxidation of the iron. This glass is of a pale blue colour, and cuts off the ultra-violet rays shorter than λ 3550. It cuts off 96 per cent. of the heat radiation, and transmits 40 per cent. of light. Spectacles made of this glass are very pleasant. The glass is bluish with a tinge of green. In the tintometer the numbers are :—Yellow, 2·0 ; blue, 8·0.

Glass 221.

Fused soda flux	80·0
Cerium nitrate, crystallised	13·4
Uranoso-uranic oxide	6·6
	100·0

In this glass the action of uranium on the ultra-violet rays is added to that of cerium. The colour is faint yellow. It practically cuts off all the ultra-violet radiations, the limit being λ 3685, and it also cuts off 39 per cent. of the heat rays. Its transparency is 60 per cent. In the tintometer the number is :—Yellow, 8·0.

Glass 238.

Raw soda flux	77·0
Cerium nitrate, crystallised	23·0
	100·0

Glass 238 is similar in composition to Glass 187, but it contains more cerium. Like 187 it is practically opaque to ultra-violet light, the limit being about λ 3610, the injurious rays being beyond this wave-length. It cuts off 34 per cent. of the heat, and transmits 71 per cent. of the luminous rays. In the tintometer the numbers are :—Red, 0·375 ; yellow, 0·375 ; blue, 1·500.

Glass 240.

Further experiments with biotite showed that its special property was due to the iron protoxide it contained, and another glass was therefore made in which the iron could be introduced in the form of a definite salt of known composition. Ferrous oxalate was chosen, the proportions being as follows :—

Raw soda flux	90
Ferrous oxalate, $FeC_2O_42H_2O$	10
	100

The glass made from this material does not cut off quite so much of the heat rays as the one prepared from biotite, the rays obstructed being 88 as against 94 per cent. But the ultra-violet is entirely intercepted, the limit being λ 3950. It transmits 36 per cent. of the luminous rays. It is of a smoky green colour. The tintometer numbers are :—Yellow, 4·0 ; blue, 4·0.

Glass 246.

This is a glass made on a larger scale at the Whitefriars Glass Works, and of the same composition to start with as Glass 240, namely, 10 per cent. of ferrous oxalate with raw soda flux. At the suggestion of Mr. Harry Powell a small quantity of red tartar and powdered wood charcoal was added to prevent oxidation; the resulting glass is sage-green in colour, a plate 2 mm. in thickness cuts off ultra-violet rays down to λ 3800, its opacity to heat radiation is 98 per cent., and it transmits 27·6 of the incident light. The tintometer numbers are :—Yellow, 5·5; blue, 11·0.

A plate of this glass 1 mm. thick cuts off the ultra-violet rays down to λ 3550, its opacity to heat radiation is 83 per cent., and it transmits 47·9 per cent. of the incident light. The tintometer numbers are :—Yellow, 2·25; blue, 5·0.

Glass 247.

Raw soda flux	92·00
Cerium borate	6·30
Nickel oxide	0·04
Ferric oxide	1·60
Chromic oxide	0·06
	100·00

Glass 247 has a faint green tint and is practically opaque to the ultra-violet rays, the limit being λ 3620. It obstructs 29 per cent. of the heat radiation, and transmits 71 per cent. of the luminous rays. The tintometer numbers are :—Yellow, 2·0; blue, 2·0.

Glass 248.

Fused soda flux	94·60
Cerium nitrate, crystallised	4·72
Uranic oxide	0·30
Nickel oxide	0·30
Cobalt sulphate, crystallised	0·08
	100·00

Glass 248 is similar in composition to the one described in (197), p. 18, but is of a darker neutral tint. It is opaque to ultra-violet rays shorter than λ 3550, and cuts off 47 per cent. of the heat radiation. It transmits 30 per cent. of the incident light. Its tintometer numbers are :—Red, 2·0; yellow, 2·5; blue, 7·5.

Glass 249.

Fused soda flux	88·47
Ferric oxide	1·50
Cobalt sulphate, crystallised	0·03
Cerium nitrate, crystallised	10·00
	100·00

Glass 249 is of a pale blue tint almost opaque to the ultra-violet rays, the limit of wave-length being λ 3550 ; to all rays of shorter wave-length it is opaque. It cuts off 51 per cent. of the heat radiation, and transmits 63 per cent. of the luminous rays. Its tintometer numbers are :—Yellow, 0·5 ; blue, 2·0.

Glass 250.

Raw soda flux	88·00
Cerium borate	5·00
Ferrous sulphate, crystallised	4·15
Uranoso-uranic oxide	2·75
Chromic oxide	0·10
	100·00

Glass 250 has a yellow colour with a faint tinge of green. It cuts off ultra-violet light, being opaque to radiation shorter than λ 3685. It only obstructs 25 per cent. of the heat rays, and is transparent to the extent of 74 per cent. In the tintometer the numbers are :—Yellow, 7·00 ; blue, 1·25.

Glass 251.

Raw soda flux	92·0
Ferrous sulphate, crystallised	8·0
	100·0

During the fusion the iron is partially peroxidised. Glass 251 is of a faint yellow colour ; it is opaque to ultra-violet rays shorter than λ 3550, it obstructs 37 per cent. of the heat radiation, and it transmits 89 per cent. of the incident light. Its tintometer number is :—Yellow, 1·25.

Glass 252.

Raw soda flux	72·60
Cerium nitrate, crystallised	24·90
Copper sulphate, crystallised	2·10
Nickel oxide	0·40
	100·00

The colour of Glass 252 is faint bluish green. In it copper is introduced to counteract the yellow-brown tint given by the cerium and nickel, and to obtain a tint approaching neutral. It is opaque to ultra-violet rays of shorter wave-length than λ 3680, cuts off 47 per cent. of the heat radiation, and transmits 45 per cent. of light. The tintometer numbers are :—Yellow, 2·0 ; blue, 4·5.

Glass 253.

I have already explained that black mica (biotite) is almost perfectly transparent to heat radiation, and at the same time opaque to the luminous rays. I thought it would be interesting to see what would be the effect of melting up some pieces of highly diathermanous biotite with soda flux. After many experiments it was found that a glass of a neutral tint could be made by melting biotite at a high temperature and fusing the result with flux. The proportions are—

Raw soda flux	88·5
Black biotite, fused	11·5
	100·0

On testing the resulting glass it was found that it had remarkable properties in respect to the heat rays, but in exactly the opposite way to what was expected. It offers an almost complete obstruction to the invisible heat rays, and it cuts off 94 per cent. of the heat radiation, and allows 30 per cent. of the incident light to pass through. It is opaque to ultra-violet rays of shorter wave-length than λ 3610. It is of a sage-green colour, and its tintometer numbers are :—Yellow, 4·0 ; and blue, 7·0.

Discussion of the Foregoing Results.

I have already said that the progress of this research has widened since I commenced investigations three years ago. Then my object was to find a glass which would cut off the heat so as to preserve the eyes of those engaged in glass works. I soon found it difficult, even if it were advisable, to confine the research to the action on heat rays alone. Thus the glasses now described include specimens suitable for spectacles adapted to all requirements—from Eyes of Youth to Eyes of Age.

The first necessity therefore is to find a glass which will cut off as much as possible of the heat radiation. Glass 246—sage-green in colour—is almost perfect in this respect, as it cuts off 98 per cent. of the heat. Glass 217—of a pale blue tint—is opaque to 96 per cent. of heat radiation. Next comes Glass 253—of a neutral tint—which cuts off 94 per cent., and then comes Glass 240—of a neutral tint—cutting off 88 per cent., Glass 210—of a green tint—cutting off 87 per cent. heat radiation, and Glass 158—of a pale greenish yellow—cutting off 63 per cent. of the heat radiation.

If more light is desired to enable the workers to see better at the expense of a little athermancy, Glass 249 is commendable. It is a very pale blue and transmits 63 per cent. of luminous rays while cutting off 51 per cent. of the heat rays. Spectacles of this glass scarcely appear to obstruct light at all, and the colours of objects are practically unchanged.

For ordinary use, when no special protection against heat radiation is needed, the choice will rest on whether the ultra-violet or the luminous are most to be guarded against; or whether the two together are to be toned down. To begin with I will take into consideration glasses most effective in cutting off ultra-violet rays. Ordinarily the visible spectrum is assumed to end at the Fraunhofer line K, λ 3933, but light can easily be distinguished some distance beyond by the naked eye. For instance, about fifty years ago, with a quartz spectroscope with solar rays, I could see L, λ 3820, and M, λ 3727, though now I cannot see above K. It may therefore be considered that the ultra-violet rays which are to be cut off on account of their probable injurious action are those of shorter wave-lengths than, say, λ 3700. The most effective glasses for this purpose are 158, 150, 240, 246, 202, and 197, all of which are opaque to rays shorter than 3700. The colours are pale green, yellow and neutral, they transmit ample light so that a choice of tints is available to suit individual taste.

If much transparency is required there is a choice between glasses 187, 150, 251, 250, 247, and 238, which transmit from 99·5 to 70 per cent. of the incident light. The choice between this range of glasses will depend on the conditions required, *i.e.*, on the absolute transparency or the colour. The colours are pale tint of yellow, green, and neutral.

If only a moderate degree of transparency is desired Glasses 158, 249, and 221 may be selected; the light transmitted ranges from 70 to 60 per cent., and the tints are of pleasant green, blue, and orange.

When glasses are required which are restful to the eyes in the glare of the sun on chalk cliffs, expanses of snow, or reflected from the sea, Glasses 249, 197, 252, 165, 210, and 248 are most suitable, the tints being yellow, green, and neutral. Moreover, they have the advantage of cutting off practically all the ultra-violet rays and also a considerable amount of the heat radiation.

For convenience of reference all the glasses above described are arranged in the following four tables:—

I. Absorption of Heat Rays.
II. Absorption of Ultra-violet Rays.
III. Transmission of Luminous Rays.
IV. Reduction of Glare.

This latter property is the most valuable for general use in brilliant light.

TABLE I.—Absorption of Heat Rays.

Glass No.	246	cuts off	98	per cent.
„	217	„	96	„
„	253	„	94	„
„	240	„	88	„
„	210	„	87	„
„	158	„	63	„

TABLE II.—Absorption of Ultra-violet Rays.

Glass No.	240	opaque to rays	of shorter	wave-length than	3950.
„	202	„	„	„	3830.
„	246	„	„	„	3800.
„	197	„	„	„	3800.
„	158	„	„	„	3700.
„	221	„	„	„	3685.
„	150	„	„	„	3620.

TABLE III.—Transmission of Luminous Rays.

Glass No.	187	transmits	99	per cent.
„	251	„	89	„
„	250	„	74	„
„	150	„	73	„
„	247	„	71	„
„	238	„	71	„

TABLE IV.—Reduction of Glare.

Glass No.	Absorption of heat.	Absorption of ultra-violet.	Transmission of light.	Colour.
	per cent.		per cent.	
249	51	3550	63	Pale blue.
197	41	3800	45	Pale neutral.
252	47	3680	45	Faint blue-green.
165	38	3680	42	Pale yellow-green.
210	87	3620	30	Blue-green.
248	47	3550	30	Dark neutral.