ON THE POLARISATION OF LIGHT SCATTERED BY OPTICAL GLASSES.

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Introduction.

The depolarisation of light scattered by optical glasses was studied carefully by Krishnan (1936) and it was observed by him that in the case of the seventeen specimens of different qualities studied by him ρ_h, the ratio * of the horizontal component H_h to the vertical component V_h of the light scattered in the transverse direction with the horizontal incident light vector was greater than unity. It had previously been shown by Krishnan (1934) that in the case of most of the liquids ρ_h is unity, but in some cases, and especially in the case of some binary liquid mixtures at particular temperatures, ρ_h was greater than unity. This fact was explained by Krishnan by assuming that large molecular aggregates not small compared to the wavelength of light are present in these mixtures at the respective critical temperatures and that these particles scatter according to Mie's (1908) theory. The results obtained in the case of optical glasses were also explained by Krishnan on the same assumption. From the results of X-ray investigations of glasses Warren (1937), however, concluded that there are no crystalline groups in glasses of sizes mentioned above. Hence Krishnan's hypothesis regarding the presence of molecular clusters in optical glasses was not supported by the results of X-ray investigation and if those experimental results be correct, the basis on which Krishnan built his explanation of the scattering of light observed in the case of optical glasses falls to the ground. For this reason, H. Müller (1938) proposed a new theory of the scattering of light in which he reviewed the existing theories and pointed out their inadequacy in explaining the observed scattering in optical glasses. He also discussed the possibility of the explanation of experimental results from his own theory. His theory is based upon the conception of existence of an internal strain which, according to him, is present in all glasses and cannot be removed by annealing. He concluded from a comparison of the results calculated for one set of glasses from his theory with those observed by Krishnan in the case of another set that there was agreement between the observed and the calculated results. But his discussion when examined carefully does not appear to be free from flaws. Further, Müller

* R. S. Krishnan's ρ_h is inverse of ours.

assumed Krishnan's data to be absolutely correct; but the values of ρ_h observed by Krishnan in the case of binary liquid mixtures at their respective critical temperatures did not agree with those observed by Rousset (1935) and Mookerjee (1938). Again, Parthasarathy (1940) criticised Krishnan's results for binary liquid mixtures and pointed out some serious sources of error in his experimental arrangement. Parthasarathy is of opinion that these errors are responsible for the anomalous values of ρ_h observed by Krishnan in the case of binary liquid mixtures. Although Krishnan (1940) has published a reply to the criticism mentioned above, it has not been definitely established thereby that the sources of error mentioned by Parthasarathy did not appreciably affect the results obtained by Krishnan in the case of those mixtures, and a better course would be to repeat the investigations using an ideal arrangement in which the sources of error mentioned by Parthasarathy are scrupulously eliminated.

The present authors, therefore, thought it worth while to repeat the investigations on optical glasses in order to examine how the value of ρ_h changes with the change in some properties of specimens of optical glass. Furthermore, according to Müller's theory the value of ρ_h depends on the product of the ratio of the density of potential energy of the transversal wave to that of the longitudinal wave and some function of the Poisson's ratio. It might be expected that the first factor would depend on the amount of strain present in the specimen. If this assumption be true the value of ρ_h would depend, according to Müller's theory, on the amount of strain present in the glass. In order to test this hypothesis a few samples of optical glass to which different amounts of strain had been purposely imparted were procured by one of the authors (S.P.) from Germany before the outbreak of the present war, and the results of investigation on the scattering of light by these specimens are reported in the present paper.

Experimental Procedure and Results.

The specimens of optical glass kindly supplied by Messrs. Schott and Gen of Jena Glass Works are cubes each having an edge of 3 cm. All the faces of each of these specimens were polished and were free from any scratches. The data supplied by the manufacturers for the four specimens examined are given in Table I.

Table I.

Melting No.	Specimen No.	Refractive Index.	Birefringence.	Remarks.
34906	BK 7 I	1·51763	10$m\mu$ per cm.	Well cooled
34906	BK 7 V	1·51763	150–180$m\mu$ per cm.	Strained
33977	F2 I	1·61987	10$m\mu$ per cm.	Well cooled
33977	F2 V	1·61987	170–200$m\mu$ per cm.	Strained

It is evident from the data given in Table I that the birefringence possessed by the specimens BK 7 V and F2 V is too large to be neglected. It was, therefore, necessary to determine the direction of vibration inside these specimens for light passing normally through their faces. For this purpose the specimens were placed between a pair of crossed Nicol prisms, the direction of vibration of the light coming out through the polariser being vertical. When the polarised beam was allowed to pass normally through a pair of vertical faces of any one of the two specimens and was observed through the analyser crossed with the polariser, bright restoration of light along with a dark cross consisting of a vertical and a horizontal line was observed. These lines were perfectly straight except at the ends, the two ends near the faces of the cube being curved in opposite directions. The same pattern was observed when the polarised beam of light was made normal to the other pair of vertical faces and the two specimens showed exactly the same patterns. The specimens thus behaved in such a way that they possessed an optic axis normal to each of the two pairs of vertical faces, except in the regions very near to the faces parallel to the incident beam of light. The specimens, BK 7 I and F2 I, when examined in the same way exhibited no birefringence which could be detected by the arrangement mentioned above.

It is quite evident from the observations mentioned above that if in the actual experiment the specimens were so placed that the directions of vibrations were respectively horizontal and vertical, then the amplitudes of horizontal and vertical light vectors either of the incident light or of the scattered light would not undergo any change in passing through the specimen especially in regions far away from those faces which were parallel to the direction of the rays. For this reason it was so arranged in the actual experiment that the light was incident normally in the central region of one of these vertical faces of the specimen and the scattered light observed emerged normally through the central region of another vertical face perpendicular to the former.

In order to avoid complications due to the convergence of the incident beam, a parallel beam of light was used as the incident light in the present investigation. A point-o-lite lamp placed in an opaque box provided with an aperture was used as the source of light and the light made parallel with a long focus lens passed through suitable apertures, and was incident normally on one of the surfaces of the specimens. The specimen was placed inside a card-board box having nearly the shape of a cross, two sides of which at right angles to each other were provided with apertures for the entrance of the incident light and the emergence of the scattered light. The ends opposite to these sides were bent in the form of a horn so as to reflect the least amount of light in the forward direction. The inner sides of this box were painted black with 'dull black' paint. The arrangement made for photographing the scattered light is shown diagrammatically in figure 1.

The light scattered in the transverse direction for the incident light along A_1A_2 passed through the double image prism W and the two images

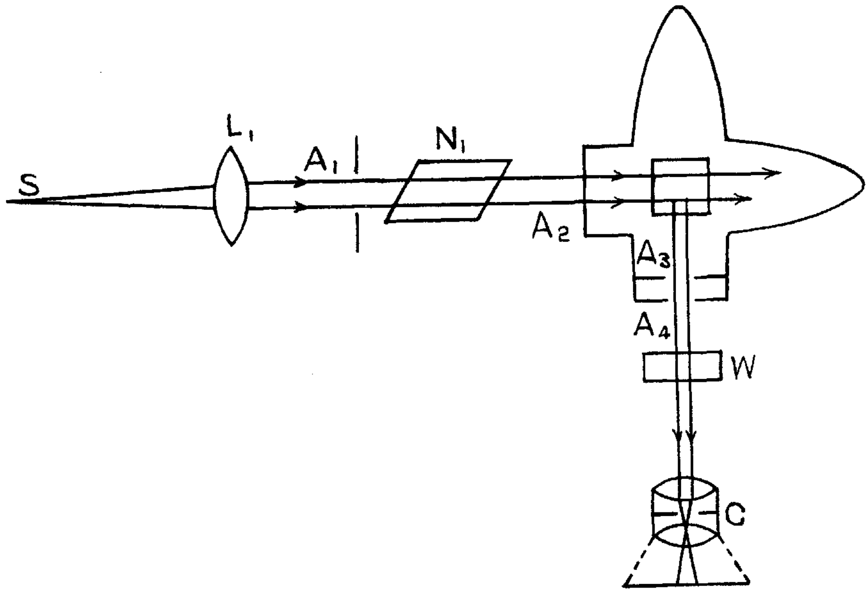

FIG. 1.

of the track of light in the specimen, one due to the scattered light with light vector horizontal and another due to that with light vector vertical, were photographed simultaneously with the help of a camera C of aperture $f/1{\cdot}8$. The aperture of A_3A_4 were used to screen off stray light from the surfaces of the specimen. The Nicol prism N_1 was used just after the aperture A_1 whenever a polarised incident beam was required. As it was mounted on a graduated circle, it could be turned about its axis through known angles. Thus the direction of vibration marked on it was first made vertical with the help of a plumb-line and it was turned through $90°$ to get the incident light with the light vector horizontal. The directions of vibration transmitted through the double image prism had previously been checked for separation in the vertical direction with the help of a Nicol prism. The whole apparatus was set up in a dark room and it was possible to make the alignments by visual observation of the scattered light through the camera so that no stray light might be superposed on the images due to the scattered light. It was observed that a slight displacement of the camera from the position of perfect alignment did not alter appreciably the relative intensities of the two components of the scattered light. Exposures of the order of eight to ten hours were necessary for recording the tracks due to the scattered light on Ilford Golden Isozenith plates which were found to be most suitable for this purpose as the scattered light was blue in colour. Plates of other qualities proved to be much slower. The fluorescent radiation observed by Krishnan in the specimens examined by him was absent in the case of the specimens examined in the present investigation.

Photographs by the scattered light of the track were obtained with the incident light vector horizontal, vertical and unpolarised respectively. Several photographs were obtained for each type of incident light for each specimen, and the results were observed to be reproducible.

In order to calculate the relative intensities of the two components of the scattered light from the blackenings produced on the photographic plate a density-log intensity curve had to be drawn. For this purpose intensity marks were obtained on a Golden Isozenith plate using the same point-o-lite lamp used for studying scattered light as the source of light, and a step filter placed in contact with the plate. The step filter was made by exposing different portions of a process plate for different lengths of time, and then by fully developing and fixing the plate. The relative intensities of white light transmitted through the different blackened portions of this filter with the same intensity of the incident light were measured with the help of a Moll's microphotometer provided with a vacuum thermopile and a Moll galvanometer. The blackenings produced by the light from the point-o-lite lamp of these known intensities on the Golden Isozenith plate were measured by taking microphotometric records of these blackened portions. A density-log intensity curve was drawn with the help of these data. The densities of the tracks of scattered light photographed on the Golden Isozenith plate were also measured, and the relative intensities of the two components were determined with the help of the density-log intensity curve. Since the white light of the tungsten filament lamp of the Moll's microphotometer is not of the same composition as that of the point-o-lite lamp, the relative transmissions through the different steps of the step filter as measured with the help of the microphotometer lamp may not be the same as those for the white light from the point-o-lite lamp. Hence the inclination of the density-log intensity curve drawn with the help of the former lamp may not be accurate for measuring the relative intensities of the two components. On examination of this curve it was found that the maximum uncertainty in the inclination of the curve would lead to an error which is not large. These errors are included in the results which are given in Table II. It may be pointed out, however, that since ρ_h is observed to be

TABLE II.

Specimen No.	Birefringence.	ρ_v	ρ_h	ρ_u
BK I ..	$10m\mu$ per cm.	$0{\cdot}023 \pm {\cdot}006$	0·96	$0{\cdot}06 \pm {\cdot}005$
BK V ..	150–$180m\mu$ per cm.	$0{\cdot}02 \pm {\cdot}006$	0·95	$0{\cdot}06 \pm {\cdot}005$
F2 I ..	$10m\mu$ per cm.	$0{\cdot}11 \pm {\cdot}008$	1·0	$0{\cdot}24 \pm {\cdot}01$
F2 V ..	170–$200m\mu$ per cm.	$0{\cdot}11 \pm {\cdot}008$	1·0	$0{\cdot}25 \pm {\cdot}01$

unity or very nearly equal to unity, any uncertainty in the inclination of the density-log intensity curve does not affect the value of ρ_h at all. The microphotometric records reproduced in figure 2 clearly shows that in both the cases the value of ρ_h is exactly equal to unity.

In Table II ρ_v, ρ_u are factors of depolarisation for incident light vector respectively vertical and unpolarised.

Discussion of Results.

It can be seen from Table II that the value of ρ_h, which is defined as equal to H_h/V_h, is observed to be equal to unity or very nearly equal to unity in the case of all the specimens examined. According to Krishnan's measurements, however, ρ_h was found to be greater than unity. Hence the results observed in the present investigation are not in agreement with those reported by Krishnan. It may be pointed out that the large amount of birefringence possessed by two of the specimens did not affect the values of ρ_h, ρ_v and ρ_u, because the incident as well as the scattered beam passed along the optic axes inside the specimens. It has not been mentioned by Krishnan, however, whether the specimens examined by him possessed any birefringence or not.

Since there are some experimental errors lying within certain limits in the values of ρ_v and ρ_u, attempt has not been made to calculate ρ_u from the observed values of ρ_v and ρ_h and to compare these values with the observed values of ρ_u, as has been done by Krishnan. But definite conclusions can be drawn from these results regarding the relation between ρ_v or ρ_u and the refractive index of the specimens. The results show that ρ_v and ρ_u are smaller in the case of the specimens BK 7 I and BK 7 V having smaller refractive index than in the case of the other two specimens having larger refractive index. The difference between the value of ρ_u for the specimen BK 7 V and that for F2 V is clearly demonstrated by the microphotometric records reproduced in figure 3. Figure 2 shows that the value of ρ_h does not depend at all on the amount of strain possessed by the specimen. As regards the intensity of scattering by the specimen, it may be mentioned that although accurate determination of the absolute intensities of light scattered by the specimens was not made, the densities of the vertical components in the case of ρ_v observed for approximately the same time of exposure for the different specimens with the steady source of incident light indicated that the intensities of the vertical components were nearly equal in the case of the four specimens studied.

According to Müller's Theory

$$\rho_h = \frac{H_h}{V_h} = \frac{U_L}{U_T} \cdot \frac{1-2\sigma}{1-\sigma} \qquad \ldots \quad \ldots \quad \ldots \quad (1)$$

where U_L and U_T are densities of potential energy stored in a single longitudinal and transversal wave respectively and σ is the Poisson's ratio. Müller could

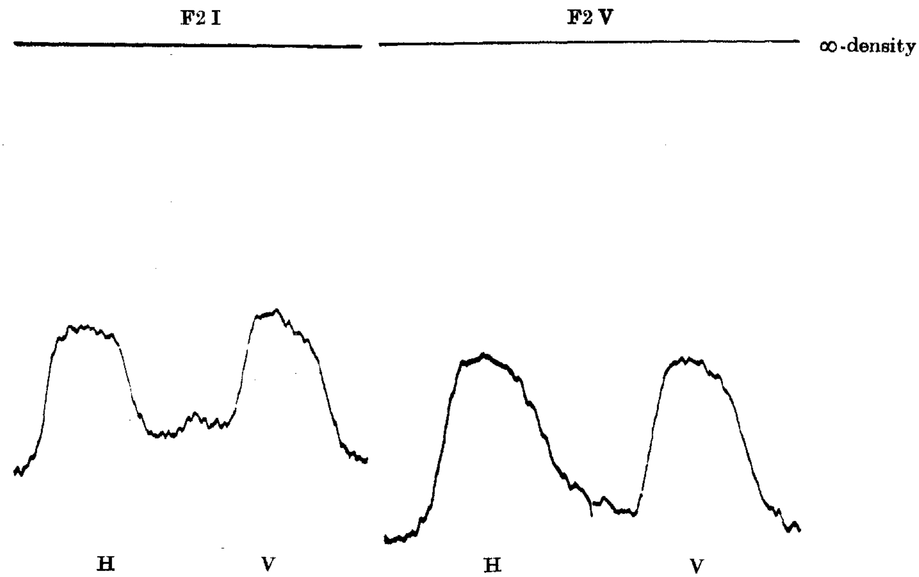

Fig. 2.—Microphotometric records of the horizontal and vertical components of light scattered with incident vector horizontal.

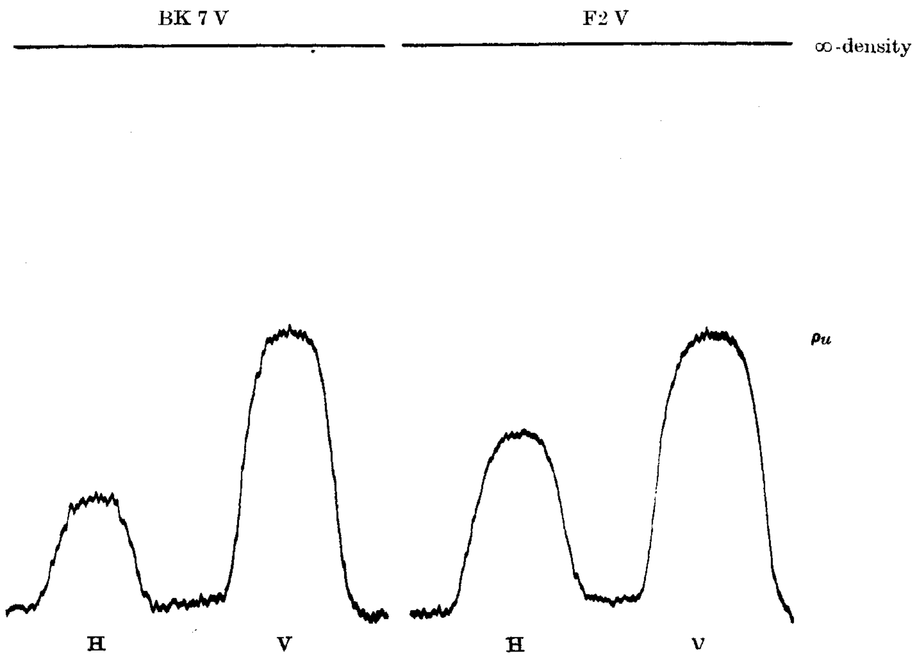

Fig. 3.—Microphotometric records of the horizontal and vertical components of light scattered with incident light unpolarised.

not verify equation (1) with the values of ρ_h published by Krishnan, because the values of σ for the specimens studied by Krishnan were not known. He, however, calculated the values of $(1-2\sigma)/(1-\sigma)$ for a few specimens of glass for which the values of the elasto-optic constants p and q and of σ had been reported by Pockels (1906). It was found that the values of $(1-2\sigma)/(1-\sigma)$ ranged from 0·62 to 0·77 and were of the order of half the values of ρ_h observed by Krishnan for optical glasses. Hence he concluded that U_T was much smaller than U_L for all optical glasses. It is not necessary, however, to have $\rho_h > 1$ in order to get the values of U_L/U_T greater than unity, because even with ρ_h equal to unity U_L/U_T lies between 1·3 and 1·5. Since we do not know whether σ varies with the amount of strain present in the glass, it cannot be stated definitely from these experimental results whether U_L/U_T varies with the strain in the glass.

According to Müller the real criterion for testing the validity of his theory is the value of $\rho_v \cdot \rho_h$ which depends only on the elasto-optic constants p and q. He showed that the values of $\rho_v \cdot \rho_h$ calculated for Pockels' glasses for which the values of p and q had been given by Pockels lay within the range of the values of $\rho_v \cdot \rho_h$ observed by Krishnan for optical glasses. From this he concluded that the observed values of $\rho_v \cdot \rho_h$ supported his theory. He was, however, not justified in drawing such a conclusion, because although the lower and upper limits of the values calculated from the theory were 0·0018 and 0·052 respectively and those for the values observed by Krishnan were 0·007 and 0·16, Müller's theory might as well be contradicted by the observed values if a certain low value of $\rho_v \cdot \rho_h$ corresponded to a glass having elasto-optic constants giving a very high value calculated from Müller's theory. Hence in order to test the theory, the values of p, q and σ of the specimens for which the values of $\rho_v \cdot \rho_h$ are known are to be determined. The results of such investigations will be reported in a future communication.

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SUMMARY.

The values of ρ_h, ρ_v and ρ_u of light scattered by four cubes of optical glass having different amounts of inherent strain have been determined using a parallel beam of incident light and avoiding errors due to birefringence exhibited by the specimens having larger amounts of strain. It has been observed that H_h/V_h is very nearly equal to unity and its value does not depend on the amount of inherent strain possessed by the specimen. Thus the effect observed by Krishnan, e.g., that $H_h/V_h > 1$ is not exhibited by these specimens of optical glass.

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