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THE SCATTERING OF LIGHT IN AMORPHOUS SOLIDS

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1. INTRODUCTION

Recent investigations have shown that when light traverses a dust-free liquid, an observable fraction of the energy is laterally scattered and that this effect is due to the local fluctuations of density and to the random orientations of the molecules which cause the fluid to be optically inhomogeneous.[1] In the case of a mixture of liquids, we have in addition a scattering due to the local fluctuations of composition which cause corresponding local variations of refractive index. Since the transverse scatterings due to density and composition fluctuations are fully polarized, while that due to the random orientation of the molecules is almost entirely unpolarized, the resultant scattering in a fluid is usually only partially polarized. When the temperature of a liquid is lowered, its compressibility usually diminishes and with it also the local fluctuations of density. Thus we may expect that when the liquid is cooled to such an extent that it passes into the amorphous solid condition, the density scattering would become very small. On the other hand, in liquid mixtures, the local fluctuations of *composition* usually tend to increase rather than to diminish with fall of temperature. Thus they should certainly tend to persist or even increase when the mixture congeals into an amorphous solid. The effect due to random molecular orientations would certainly remain in the amorphous solid condition. Thus, we may anticipate that an amorphous solid such as glass consisting of a mixture of anisotropic molecules would exhibit when light traverses it, a partially-polarized internal scattering or opalescence of an order of intensity not greatly inferior to that ordinarily observed in liquids or liquid mixtures.

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[1] C. V. Raman, Molecular Diffraction of Light, Calcutta University Press, 1922.

An internal scattering of light in common glasses and also in optical glasses has actually been noticed.[2] Its nature has been a subject of debate,[3] and owing to our insufficient knowledge of the amorphous state, is not fully understood at present. Judging, however, from such observations as are available, it is the opinion of the writer, that the effect observed in optical glasses is a true molecular scattering arising from local fluctuations of composition and of molecular orientation, being thus of the same general nature as the opalescence observed in binary liquid mixtures such as phenol-water, carbon disulphide-methyl alcohol and so on. In support of this view, it is proposed in this paper to give the results of the study of the light-scattering in a series of 14 different optical glasses manufactured by the firm of Schott in Jena.[4] If the light-scattering in glass were due to accidental inclusions or incipient crystallizations occurring within it as has been suggested by some writers, we should expect the intensity of the scattered light to show large and arbitrary variations depending on the circumstances of the particular melting from which the specimen was taken. On the other hand, if the phenomenon has a true molecular origin, we should expect to find the intensity of scattering to be definitely correlated with the refractivity and chemical constitution of the glass.

TABLE 1. *List of classes examined.*

	Melting	Type	Composition	Refractive index μ	$\nu=1/\omega$
No. 1	18165	0.6781	Fluor crown	1.4933	69.9
2	4927	U. V. 3199	U. V. crown	1.5035	64.4
3	15189	0.144	Borosilicate crown	1.5100	64
4	16564	0.3832	Prism crown	1.5163	64
5	15065	0.3453	Silicate crown	1.5191	60.4
6	16740	0.3439	Telescopic flint	1.5286	51.6
7	16397	0.7550	Baryta light flint	1.5694	56
8	14657	0.211	Densest Borosilicate crown	1.5726	57.5
9	17538	0.340	Ordinary Light flint	1.5774	41.4
10	18023	0.1266	Baryta light flint	1.6042	43.8
11	11095	0.103	Ordinary flint	1.6202	36.2
12	10259	0.748	Baryta flint	1.6235	39.1
13	8988	0.102	Dense flint	1.6489	33.8
14	16889	0.198	Densest flint	1.7782	26.5

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[2] Lord Rayleigh, Proc. Roy. Soc., *95*, p. 476, 1919, and C. V. Raman, "Molecular Diffraction of Light," p. 85.

[3] R. Gans, Ann. der Phys., *77*, p. 317; 1925.

[4] The specimens were presented by Messrs. Schott to Prof. P. N. Ghosh, who kindly placed them at the writer's disposal for the work.

2. THE SPECIMENS EXAMINED

Table 1 gives a list of the glasses examined and their description as furnished by the manufacturers, arranged in order of increasing refractive index. The samples were furnished in the form of slabs 7 cm × 7 cm × 2 cm, with one pair of end-faces polished. For the purpose of the observation of light-scattering, the slabs were immersed in a trough containing benzene and a beam of sunlight focused by a lens was admitted through a side-face, the necessity of polishing the latter being thus avoided. The track of the beam as seen through the end-faces was perfectly uniform and appeared of a beautiful sky-blue color.

3. EXPERIMENTAL RESULTS

When the scattered light was viewed through a double-image prism held so that the direction of vibrations in the two images seen were respectively perpendicular and parallel to the direction of the beam traversing the glass, it was seen that these were of very different intensities, showing that the scattered light was strongly but not completely polarized. The color of the stronger image was always a sky-blue. The color of the fainter image in the ordinary flint glasses was blue, but in the other specimens varied very considerably. The total intensity of the scattered light in the glasses was determined by comparison with that of the track in a bulb containing dust-free benzene immersed in the same trough as the block of glass under examination and traversed by the same beam of light. A rotating-sector photometer was used for the purpose. The ratio of the intensities in the parallel and perpendicular components of vibration in the laterally scattered light was also determined with the help of a double-image prism and nicol (Cornu's method) in the usual way. The measurements give us the ratio of the intensity of the faint image to the bright image seen through the double image prism, and this expresses the degree of depolarization of the scattered light.

The results of the work are gathered together in Table 2.

4. DISCUSSION OF RESULTS

From a scrutiny of the figures in Table 2, several interesting facts emerge. In the first place, it will be seen that the crown glasses show uniformly a smaller intensity of light-scattering than the other varieties of glass. Both the ordinary flints and the baryta flints scatter light strongly, the latter more so than ordinary flints of equal refractive index. It will be seen also that considering each species of glass separately, there is a progressive increase of the intensity of light-scattering with increasing refractive-index. The colors shown by the fainter components of the scattered light in the first four glasses in Table 2 are obviously due to a species of weak fluorescence, probably of the same kind as has been met with in investigations on light-scattering in liquids.[5] This fluorescence being unpolarized, the large values of the depolarization found in the case of these glasses stands self-explained. If the fluorescent light had been excluded by the introduction of suitable color-filters, the depolarization for these glasses would have been much smaller. It is interesting to notice that in glasses Nos. 6, 7, and 8, we have a low value for the depolarization in spite of the obvious presence of a weak fluorescence; this is obviously due to the greater intensity of polarized scattering appearing in the last column of Table 2 of these glasses.

TABLE 2. *Experimental results.*

	Glass	Refractive index	Color of bright component	Color of faint component	Depolarization	Intensity relative to benzene = 1
No. 1	Fluor crown	1.4933	Blue	Yellow	0.180	0.18
2	U. V. crown	1.5035	"	Pink	0.158	0.12
3	Borosilicate crown	1.5100	"	"	0.295	0.11
4	Prism crown	1.5163	"	"	0.285	0.14
5	Silicate crown	1.5191	"	Blue	0.123	0.18
6	Telescopic flint	1.5286	"	Purple	0.068	0.40
7	Baryta light flint	1.5694	"	"	0.053	0.44
8	Densest borosilicate crown	1.5726	"	"	0.045	0.37
9	Ordinary light flint	1.5774	"	Indigo-blue	0.067	0.30
10	Baryta light flint	1.6042	"	Indigo	0.067	0.41
11	Ordinary flint	1.6202	"	Blue	0.079	0.42
12	Baryta flint	1.6235	"	Indigo-blue	0.085	0.57
13	Dense flint	1.6489	"	Blue	0.062	0.52
14	Densest flint	1.7782	"	"	0.065	0.63

The several regularities to which attention has been drawn above, particularly the fact that the intensity of scattering is very clearly a function of the refractive-index and chemical composition of the glass, render it extremely improbable that the effect can arise from accidental inclusions or imperfections in the structure of the glasses. It is, in fact, clear from the data that the effect arises from the ultimate molecular structure of glass.

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[5] K. S. Krishnan, Phil. Mag., *50*, p. 697; 1925.

It would be very interesting to study the light-scattering in amorphous solids having a relatively simple chemical constitution, e.g., transparent quartz-glass. Experiments on the scattering of light in liquids which can first be rendered dust-free and then supercooled into the amorphous solid state may also be expected to furnish important information. Further work on these lines is in progress.

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Statics and the Dynamics of a Particle. By William D. MacMillan, Professor of Astronomy at the University of Chicago. xviii+430 pages. The McGraw-Hill Book Company. New York. $5.00.

According to the preface, this is the first of a series of volumes in this general field, the present volume being "designed as a text-book in mechanics for . . . . students in our colleges and universities, particularly those students who are interested in astronomy, physics, or mathematics" and for "that relatively small group of engineers who wish to extend their knowledge beyond the mere rule of thumb into the deeper foundations of general theory."

The book is divided into three parts: I, The Fundamental Concepts of Mechanics; II, Statics; III, The Dynamics of a Particle. Each part is divided into chapters, sixteen in all, which have such chapter headings as Vectors; Velocity; Acceleration; Mass and Force; Work and Energy; The Statics of a Particle; Moments of Vectors; Virtual Work; Elastic Solids; Gravity and Acceleration; Curvilinear Motion; Constrained Motion; The Generalized Coordinates of Lagrange; Hamilton's Equations; etc.

While the book is best suited to the student of Mathematics, Physics or Astronomy who is well past elementary courses, the presentation is most admirable—in that it starts from the elementary and proceeds rapidly, but with adequate though concise discussion, to the more advanced. Thus, it is a long journey from the problem (page 33) "A stone dropped over a cliff strikes the ground in 5 sec. With what speed did it strike . . . . ?" to the problem (page 344) "Find the time required for a body to slide down the curve

$$\frac{x^2}{a^2} = \frac{4}{9}\left(\frac{z}{a} - 1\right)^3$$

assuming . . . . ."
The author, however, very skillfully directs the student along the road.

Incidentally, the book contains very many excellent problems—a feature which, in conjunction with the well written text, should recommend the book for general use.

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