DISPERSION OF FARADAY ROTATION IN SOME OPTICAL GLASSES

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Abstract

The dispersion of magneto-optic rotation has been studied in a set of eight optical glasses of known composition from λ 5780 to λ 3650 Å. Dispersion formulæ for optical refraction have been proposed for these glasses using two mean absorption wavelengths. In all the glasses λ 600 Å is assumed to be one absorption wavelength and the other varied with the composition of the glass. But the experimental data on magnetic gyration in each glass has been fitted up into a dispersion formula by using only the near ultraviolet absorption wavelength that is responsible for refractive dispersion and it is found that the absorption wavelength in the far ultraviolet, *i.e.*, λ 600Å is practically ineffective towards magnetic gyration. The value of the anomaly factor in the glasses containing Al_2O_3, B_2O_3, BaO is noticed to be low compared to the glasses containing the oxides of lead and zinc. It has been possible to establish that the network forming ions like boron, aluminium, barium, etc., diminish the value of γ thereby indicating the presence of covalent binding between the ions in them.

1. Introduction

The magneto-optic rotation in many substances is expressible by a formula of the Becquerel type, *viz.*,

$$V = \gamma \cdot \frac{e}{2mc^2} \lambda \frac{dn}{d\lambda}$$

where γ is the anomaly factor, and V is the Verdet constant. Though Darwin and Watson (1927) attempted to verify the correctness of this formula in many substances in the solid, liquid and gaseous states, they make no reference to glasses. Most of our present knowledge regarding the Faraday effect in glasses is due to Du Bois (1903), Ingersoll (1917), Ramaseshan (1946) and Cole (1950). Du Bois has reported measurements on several optical glasses only for the sodium yellow line. Ingersoll measured the magneto-optic rotation of a few glasses for several wavelengths in the infrared, but the Becquerel formula could not be tested out, as the refractive dispersions of these glasses were not known. More recently Ramaseshan measured the Verdet constant and refractive indices of 18 optical glasses whose composition were approximately known, for the three wavelengths

λ 5893, λ 5461 and λ 4358 Å. He was able to show that γ was very nearly the same for the three wavelengths and he drew some general conclusions regarding the magnitude of anomaly factor and the chemical composition of glasses. Since the measurements were made only at three wavelengths, it was not possible to establish definitely whether γ was constant for different wavelengths or not.

Earlier studies in calcite and sodium chlorate (Ramaseshan and Sivaramakrishnan. 1956) have indicated that the anomaly factor for different absorption frequencies responsible for refraction, may be different. However, the accuracy of measurement in the case of these crystals was not as high as desirable. But in the case of these glasses. the Verdet constant could be measured to a very great degree of accuracy due to their excellent optical quality and also due to the sensitivity of the photoelectric polarimetry technique used here. Therefore, it occurred to the author that a sure test could be made as to whether the magneto-optic anomaly factor was actually a constant or not and to investigate whether the anomaly factor is different for different absorption frequencies that are characteristic of the substance. For this the Verdet constant of a set of eight glasses of varying compositions was measured accurately for various wavelengths from λ 5780 Å to λ 3650 Å. Dispersion formulæ for both optical refraction and magnetic gyration have been proposed assuming reasonable absorption frequencies in the ultraviolet. It is found that, of the two frequencies that contribute to dispersion only one is magneto-optically effective. Also an attempt has been made to relate the magneto-optic properties of glasses with their chemical composition.

2. Materials and Methods

The specimens studied formed a set of eight optical glasses, supplied by the firm Chance Brothers Ltd. They were all cut into small rectangular blocks and polished in this laboratory. The thickness of the specimens were between 2 and 2·2 cm. While grinding and polishing the specimens, care was taken to see that the faces of the blocks were perpendicular to each other. The photoelectric polarimetry method described in detail by the author (1956) in an earlier publication was employed for the measurement of rotations from λ 5780 Å to λ 3650 Å. The rotations were determined accurately to $\frac{1}{2}$%.

A small difficulty was encountered in these measurements. When the specimen was kept exactly normal to the incident light, it was not possible to cross the two nicols perfectly when the magnetic field was put on. This was due to the fact that light which comes to the analyser after two reflections at the surface of the glass was rotated through a greater angle than that which comes through without any reflection. To avoid this the glass was kept at a small angle about 1° from the normal position. This increase in effective thickness for a 2 cm. specimen was about 0·02% and hence quite negligible. Therefore, it appears to the author that this simple technique is very much superior to the rather tedious corrections that are often made (Borel, 1903) for successive reflections. This method, however, cannot be used when studying the rotations of birefringent crystals along the

optic axis. For the fitting up of the dispersion formula for refraction, the refractive indices data for different wavelengths, supplied by the manufacturers, was made use of.

3. Results

Table I gives the chemical composition of the glasses. In Table II are given the values of constants A, B, λ_1, λ_2 and K in the dispersion formulæ for optical

TABLE I

Chemical Composition of the Glasses

No.	Glass type	Chemical composition									
		SiO_2 %	B_2O_3 %	K_2O %	CaO %	Al_2O_3 %	As_2O_3 %	Na_2O %	BaO %	ZnO %	PbO %
1	B.S.C.	69·6	6·7	20·5	2·9	0·3	0·1	..	..	..	..
2	H.C.	72·0	..	10·1	11·4	0·3	0·2	6·1	..	..	..
3	L.B.C.	57·1	1·8	13·7	0·3	0·2	0·1	..	26·9	..	..
4	L.F.	52·5	..	9·5	0·3	0·2	0·1	..	..	..	37·6
5	B.L.F.	45·2	..	7·8	..	..	0·4	..	16·0	8·3	22·2
6	D.B.C.	36·2	7·7	0·2	0·2	3·5	0·7	..	44·6	6·7	..
7	D.F.	46·3	..	1·1	0·3	0·2	0·1	5·0	..	..	47·0
8	E.D.F.	40·6	..	7·5	0·2	0·2	0·2	0·1	..	..	51·5

refraction and magnetic gyration, *viz.*,

$$n^2 - 1 = \frac{A\lambda^2}{(\lambda^2 - \lambda_1^2)} + \frac{B\lambda^2}{(\lambda^2 - \lambda_2^2)};$$

$$V_n = \frac{e}{2mc^2} \frac{K\lambda_2^2\lambda^2}{(\lambda^2 - \lambda_2^2)^2}$$

where $K = B\gamma_2$ and V and λ are in radians and in microns respectively. Table III gives the values of magneto-optic constants of these glasses along with their density and the refractive index for λ 5893. The values of Verdet constant, V in mintues/cm./oersted and also the calculated values of magneto-optic anomaly factor $\bar{\gamma}$ are given in this table for five wavelengths. $\bar{\gamma}$ corresponds to the value of mean anomaly factor obtained by assuming that both the absorption frequencies are equally active towards magnetic gyration, *i.e.*, $\gamma_1 = \gamma_2 = \gamma$. The value of γ_2 is found out from the dispersion formulæ for magnetic gyration which is proposed on the

TABLE II

The Values of the Constants in the Dispersion Formulæ for Refraction and Magnetic Gyration

Glass No.	A	B	λ_1 in μ	λ_2 in μ	K	γ_2
1	0·3935	0·85192	0·0600	0·1077	0·72247	0·848
2	0·43793	0·83243	0·0600	0·1138	0·71731	0·862
3	0·46436	0·8696	0·0600	0·1151	0·76351	0·883
4	0·86226	0·5692	0·0600	0·1692	0·5234	0·924
5	0·88582	0·6286	0·0600	0·1619	0·5901	0·943
6	0·67961	0·8726	0·0600	0·1234	0·7338	0·846
7	0·93485	0·61684	0·0600	0·1807	0·5626	0·917
8	0·9679	0·6798	0·0600	0·1863	0·6096	0·902

assumption that the ultraviolet absorption wavelength λ 600 Å does not contribute to magnetic gyration, *i.e.*, $\gamma_1 = 0$ and γ_2 corresponds to that for λ_2.

4. DISCUSSION

It can be noticed from Table III that the value of $\bar{\gamma}$ calculated from the modified Becquerel relation using the experimental values of Verdet constant and the optical dispersion $dn/d\lambda$ found out from the dispersion formula for refraction, varies considerably with wavelength in the case of heavy glasses. As pointed cut in the earlier publications (Ramaseshan and Sivaramakrishnan, 1956; Sivarama krishnan, 1956), the variation in the value of mean anomaly factor $\bar{\gamma}$ may indicate that the value of the anomaly factor for the different absorption frequencies that are characteristic of the substance are different. In order to establish this, it is necessary to fit up a dispersion formula for refraction for these glasses using a number of dispersion frequencies that are either theoretically or experimentally justifiable. In the dispersion formulæ for refraction of crystalline and fused quartz, an ultraviolet absorption wavelength λ 600 Å is usually used along with two other experimentally observed absorption wavelenghts near about λ 1100 Å (Radhakrishnan, 1951; Chandrasekhar, 1951). Since all these glasses contain more than 50% SiO_2 as the main component, one should take into consideration all the above absorption wavelengths. There may also exist some more absorption frequencies due to the various other oxides in the glasses. In order to distinguish these various absorption wavelengths by the construction of a dispersion formula one

TABLE III

Magneto-Optic Data of the Glasses

Glass No.	Density	n_D	λ in Å →	5780	5461	4358	4047	3650	γ_z
1	2·49	1·5096	V	0·01798	0·02034	0·0333	0·0392	0·0499	0·843
			$\bar{\gamma}$	0·745	0·747	0·749	0·749	0·754	± ·003
2	2·53	1·5189	V	0·01995	0·0225	0·0372	0·0440	0·0561	0·862
			$\bar{\gamma}$	0·757	0·756	0·763	0·765	0·768	± ·003
3	2·87	1·5406	V	0·0216	0·0245	0·0403	0·0477	0·0609	0·883
			$\bar{\gamma}$	0·776	0·778	0·780	0·781	0·784	± ·003
4	3·23	1·5785	V	0·0344	0·0394	0·0693	0·0850	0·1143	0·924
			γ	0·795	0·798	0·805	0·816	0·822	± ·002
5	3·48	1·6047	V	0·0344	0·0393	0·0685	0·0832	0·1112	0·943
			$\bar{\gamma}$	0·809	0·810·	0·822	0·825	0·834	± ·003
6	3·56	1·6122	V	0·0231	0·0261	0·0435	0·0517	0·0662	0·846
			$\bar{\gamma}$	0·721	0·723	0·729	0·731	0·733	± ·002
7	3·63	1·6203	V	0·0423	0·0485	0·0872	0·1076	0·1473	0·917
			$\bar{\gamma}$	0·806	0·807	0·817	0·826	0·832	± ·003
8	3·9	1·6533	V	0·0483	0·0556	0·1007	0·1248	0·1725	0·902
			$\bar{\gamma}$	0·804	0·806	0·818	0·822	0·831	± ·002

would require the data on refractive dispersion extensively and to a very high degree of accuracy. Therefore, for lack of such data in this present investigation only two absorption wavelengths are used in the dispersion formula for refraction, one of them being the far ultraviolet absorption wavelength λ 600 Å and the other being the weighted mean of all the other absorption wavelengths that are characteristic of the glass. The refractive dispersion formulæ of two terms arrived at in the present studies, satisfy the available experimental data on refractive indices quite well. The calculated and the experimental values of refractive indices agree to 3 to 4 units in the fifth place of decimals from λ 6563Å to λ 4047Å. But in the dispersion formula for magnetic gyration only one absorption wavelength is made use of. This wavelength is found to be identical to the near ultraviolet absorption wavelength λ_2 used in the dispersion formula for optical refraction. This implies that the dispersion of magnetic gyration is controlled by only one of the two absorption wavelengths that are responsible for refractive dispersion. The other absorption wavelength λ 600 Å is ineffective towards the magnetic gyration. The values of the Verdet constant, calculated from the proposed dispersion formulæ of one term, agree well with the experimental ones within $\frac{1}{2}$%.

It may be noticed here that one of the absorption wavelengths, *i.e.*, 600 Å, has its γ value as zero. No great significance need be attached to the fact that the γ value for this wavelergth is *actually* zero, since due to lack of experimental data we have taken only two approximate mean absorption wavelengths for the construction of the dispersion formulæ instead of the many actual ones that would exist in the various glasses. However, these results definitely establish that the value of the anomaly factor for the different absorption frequencies are different.

MAGNETO-OPTIC ANOMALY FACTOR AND THE CHEMICAL COMPOSITION

It has been pointed out by earlier workers both from theoretical and experimental studies (Rosenfeld, 1929; Serber, 1932; and Ramaseshan, 1947), that the decrease in the value of the magneto-optic anomaly factor from the value of unity can be taken as a measure of the distortion of the electron atmosphere or the degree of covalency that exists in the bonds connecting the ions and atoms. Using this simple concept an attempt has been made here to correlate the magneto-optic anomaly factor with the chemical composition. Since the glasses studied here are multi-component systems it is not possible to establish precise relations between the anomaly factor and the composition. Since the values of $\bar{\gamma}$ changes with wavelength in heavy glasses, only the values of γ_2 given in the last column of Table III are taken in the discussion below. The values of γ given by Ramaseshan (1946) and Cole (1950) correspond to $\bar{\gamma}$ here.

All the glasses which do not contain B_2O_3, Al_2O_3 or BaO, have their γ values lying between 0·90 and 0·94 ($\bar{\gamma} = 0{\cdot}79$ to 0·82). This is remarkable when the large variations in composition, magnetic rotation, density and optical dispersion are considered. It can be concluded that B_2O_3, Al_2O_3 and BaO reduce the value of γ considerably. For these glasses the γ_2 values lie between 0·84 and 0·88

($\bar{\gamma} = 0{\cdot}72$ to $0{\cdot}77$). This is also quite in accord with Ramaseshan's (1946) observations. From Zachariasen's theory it is known that the oxides of Al_2O_3, B_2O_3, etc., should definitely form glasses and the bonds between the glass forming cation and its oxygen neighbours are of a substantially covalent nature. Perhaps this covalency may be the reason for the low value of γ in these glasses. Even in glasses containing BaO as one of the main components, it has been pointed out by Stanworth (1948) that the barium atom can have appreciable covalent bond character and take part in the glass structure as the network forming atoms. This has been amply supported by studies on infrared reflection spectra and Raman effect carried out by Schott-Anderson (1950) and Norris (1941) respectively.

In the case of lead glasses the values of γ_2 appear to be high compared to others and lie between $0{\cdot}90$ and $0{\cdot}94$ (Glasses 4, 5, 7 and 8). It can be noticed that the variation in PbO content, which is mainly responsible for large dispersion anc high density in these glasses, does not affect the value of the anomaly factor much. The value of γ_2 in glasses containing very high percentage of PbO seems to be slightly less than that containing lesser amount of PbO (Glass No. 8 compared to No. 5). Perhaps this may be due to the easy deformability of the cation thereby enabling covalent PbO bonds to be formed in melts of high lead content. But Cole has reported that the value of the anomaly factor (corresponding to $\bar{\gamma}$ here) increases with the increase in lead content from $0{\cdot}70$ to $0{\cdot}80$ when the PbO content is varied from 30% to 80%. But repeated measurements with these eight glasses and also eighteen others, do not show any such variation in the value of $\bar{\gamma}$ up to 55% of PbO content. This variation noticed by Cole may, most probably, be due to an error in the determination of optical dispersion for the evaluation of γ. Cole has obtained his dispersion values by measuring the refractive indices for two wavelengths (λ 5896 and λ 5876) varying by only 20 Å and so one feels his dispersion values are subject to experimental error.

All the above conclusions drawn here are supported by further studies on another set of eighteen optical glasses of approximately known compositions studied earlier by Ramaseshan (1946). But since all the glasses studied till now are multicomponent systems, no definite conclusion regarding the percentage of the particular oxide in the glass and the anomaly factor could be drawn. It is necessary to study glasses of two component systems before drawing precise relations between the anomaly factor, the composition and the structural binding present in the system.

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