

DETERMINATION OF THE MAGNETO-OPTIC ANOMALY OF SOME GLASSES

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1. INTRODUCTION

DARWIN AND WATSON (1927) have shown that in many substances the magnitude of the Faraday effect is expressible by a formula of the Becquerel type, *viz.*,

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

where V is Verdet's constant, e and m are the electronic charge and mass respectively, c is the velocity of light, λ is the wavelength of light and n the refractive index of the substance. γ is a factor, called the magneto-optic anomaly, which is constant throughout the visible and the ultraviolet regions of the spectrum provided the contribution to the dispersive power made by the infra-red absorption bands is eliminated from the formula. No reference to the data for glasses appears in the paper of Darwin and Watson. The present investigation was undertaken to fill this gap in the literature and to find whether the Becquerel formula is valid for glasses and if so to ascertain how the magneto-optic anomaly depends on the composition of the glass. Most of our knowledge of the magneto-optic behaviour of glasses is due to du Bois (1894) and to Ingersol (1917). The former measured Verdet's constant for the sodium line $\lambda 5893$ in nine glasses, while the latter studied the dependence of the constant on the wavelength in five glasses. The present paper records the values of Verdet's constant determined for $\lambda 5893$, $\lambda 5461$ and $\lambda 4358$ with 18 optical glasses made by the firm of Schott at Jena as well as of their dispersive powers for a test of the validity of the Becquerel formula. The results disclose the existence of interesting relationships between the composition and the magneto-optic anomaly.

2. MATERIALS AND METHODS

The specimens studied formed a set of eighteen optical glasses presented to Prof. Sir C. V. Raman by Messrs. Schott & Co., Jena, and had the form 426

of rectangular blocks $3 \times 3 \times 2$ cm. having all but two of the sides polished. The thickness of each glass did not deviate by more than 0.003 cm. from 2.000 cm. Table I gives the list of glasses studied, their melting numbers, approximate composition and density as supplied by the manufacturers.

TABLE I
List of Glasses Studied

Serial No.	Melting No.	Chemical composition		Density	n5893	100γ
		More than 10%	Less than 10%			
1	25188	SiO ₂ , B ₂ O ₃ , Al ₂ O ₃ , K ₂ O	Na ₂ O, F	2.3	1.46693	67
2	18415	SiO ₂ , B ₂ O ₃ , K ₂ O	Al ₂ O ₃	2.3	1.49340	67
3	16776	SiO ₂ , K ₂ O	Al ₂ O ₃ , Na ₂ O, CaO	2.4	1.50228	73
4	23975	SiO ₂ , B ₂ O ₃ , ZnO	Al ₂ O ₃ , Na ₂ O	2.5	1.50933	72
5	24906	SiO ₂ , B ₂ O ₃	Na ₂ O, K ₂ O, BaO	2.5	1.51714	71
6	22601	SiO ₂ , B ₂ C ₃ , Sb ₂ O ₃	Al ₂ O ₃ , Na ₂ O, K ₂ O	2.7	1.52998	68.5
7	23125	SiO ₂ , Na ₂ O, PbO	ZnO	2.7	1.52686	78.7
8	22638	SiO ₂ , PbO	Na ₂ O, K ₂ O	2.9	1.54495	77.4
9	24464	SiO ₂ , ZnO, BaO	B ₂ O ₃ , Na ₂ O, K ₂ O, PbO	3.1	1.57000	74
10	19510	SiO ₂ , PbO	Na ₂ O, K ₂ O	3.2	1.56991	77
11	23355	SiO ₂ , B ₂ O ₃ , BaO	Al ₂ O ₃ , Na ₂ O	3.3	1.58950	67.0
12	20672	SiO ₂ , PbO	B ₂ O ₃ , Na ₂ O, K ₂ O	3.4	1.59813	77.4
13	22986	SiO ₂ , BaO, PbO	Na ₂ O, K ₂ O, ZnO	3.5	1.80620	76.2
14	23441	SiO ₂ , PbO	Na ₂ O, K ₂ O	3.9	1.64712	77.6
15	23497	SiO ₂ , BaO, PbO	Na ₂ O, K ₂ O, ZnO	3.9	1.64917	77.4
16	23850	SiO ₂ , PbO	Na ₂ O, K ₂ O	4.4	1.7130	77
17	23590	SiO ₂ , PbO	Na ₂ O, K ₂ O	5.1	1.7850	78
18	S1075	SiO ₂ , PbO	B ₂ O ₃ , K ₂ O, Sb ₂ O ₃	6.7	1.8900	78

The refractive indices of the glasses were determined with the aid of a Pulfrich refractometer. The differences in refractive indices for different wavelengths could be determined with an accuracy of 2 or 3 units in the fifth place of decimals. Even so, the dispersion values were accurate only to one or two per cent. The refractive indices were determined for λ 5893, λ 5461 and λ 4358 and the constants in the dispersion formula

$$n^2 = A + B\lambda^2/(\lambda^2 - \lambda_0^2)$$

were evaluated. The values of $\lambda \frac{dn}{d\lambda}$ for different wavelengths were calculated. As the glasses 16, 17 and 18 had refractive indices much higher than the prisms supplied with the refractometer, their dispersions are not so accurate as those of the other glasses. Table II gives the refractive indices and the values of $\lambda \frac{dn}{d\lambda}$ of the glasses for different wavelengths.

An electromagnet of the Rutherford type with the distance between the polepieces 22 mm. was used in the work. When 7 amperes were passed

TABLE II
Dispersion Data for Glasses

No.	n_{5893}	n_{5461}	n_{4358}	$\lambda \frac{dn}{d\lambda}_{5893}$	$\lambda \frac{dn}{d\lambda}_{5461}$	$\lambda \frac{dn}{d\lambda}_{4358}$
1	1.46693	1.46868	1.47575	0.02316	0.02482	0.03897
2	1.49340	1.49522	1.50266	0.02217	0.02509	0.04130
3	1.50228	1.50430	1.51262	0.02457	0.02879	0.04649
4	1.50933	1.51138	1.51968	0.02501	0.02912	0.04578
5	1.51714	1.51910	1.52715	0.02393	0.02782	0.04356
6	1.52998	1.53249	1.54295	0.03045	0.03584	0.05892
7	1.52686	1.52939	1.53992	0.03087	0.03592	0.05614
8	1.54495	1.54782	1.55999	0.03478	0.04103	0.06814
9	1.57000	1.57243	1.58273	0.02938	0.03481	0.05891
10	1.56991	1.57320	1.58712	0.03979	0.04712	0.07945
11	1.58950	1.59183	1.60171	0.02823	0.03331	0.05637
12	1.59813	1.60190	1.61801	0.04551	0.05408	0.09317
13	1.60620	1.60962	1.62408	0.04124	0.04883	0.08279
14	1.64712	1.65182	1.67209	0.05666	0.06754	0.1174
15	1.64917	1.65335	1.67116	0.05052	0.05986	0.1023
16	1.7130	1.7191	1.7434	0.074	0.089	0.159
17	1.7850	1.7932	1.8281	0.097	0.116	0.210
18	1.8900	1.8999	1.9430	0.123	0.149	0.282

through the coils of the magnet, a field of 17200 gauss was developed. A pair of wide-angle nicols were used as polariser and analyser and the angles measured were to 0.05 of a degree and this gave an accuracy of about $\frac{1}{2}\%$. It was considered that a greater accuracy was not necessary as the dispersions were accurate to 1% only. Conductivity water whose Verdet's constant is accurately known ($V_{5461} = 0.01547$ at $25^\circ C.$) was used as the standard for the determination of the field. 1.24 cm. of water gave a rotation of 3.30° when 7 amperes were passed through the coils of the magnet. The field developed was, therefore, 17200 gauss.

A sodium lamp and a mercury point-o-lite lamp with suitable filters were used as the different sources of light for the measurement of the Verdet's constant of the glasses. If the glasses were kept exactly normal to the incident light, it was difficult to determine the true crossing position 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 surfaces of the glass was not rotated through the same angle as that which came without any reflection. To avoid this the glasses were turned through a small angle (about $\frac{1}{2}^\circ$) away from the normal position. Usually a mean of about 20 readings was taken to determine each crossing position. Table III gives the actual rotation ρ due to a field of 17200 gauss, the Verdet's constant V , and the anomaly γ for the three wavelengths $\lambda 5893$, $\lambda 5461$ and $\lambda 4358$ for the 18 glasses.

TABLE III
Magneto-optic Data for Glasses

Serial No.	λ 5893			λ 5461			λ 4358		
	ρ in degrees	V min./cm. gauss	γ %	ρ in degrees	V min./cm. gauss	γ %	ρ in degrees	V min./cm. gauss	γ %
1	5.15	0.0149	64.2	5.80	0.0169	67.4	8.95	0.0260	66.3
2	5.10	0.0148	66.4	5.85	0.0170	67.8	9.5	0.0276	66.4
3	6.35	0.0185	74.6	7.35	0.0214	73.7	11.40	0.0332	71.0
4	6.25	0.0182	72.1	7.40	0.0215	73.3	11.25	0.0327	71.0
5	5.90	0.0172	71.2	7.00	0.0204	72.6	10.50	0.0305	69.6
6	7.25	0.0211	68.7	8.50	0.0247	68.5	13.85	0.0403	67.8
7	8.20	0.0239	76.7	9.80	0.0285	78.8	15.45	0.0449	79.4
8	9.35	0.0272	77.6	11.00	0.0320	77.4	18.25	0.0531	77.3
9	7.80	0.0227	76.6	8.95	0.0260	74.2	14.75	0.0429	72.3
10	10.65	0.0310	77.3	12.70	0.0369	77.8	21.10	0.0614	76.7
11	6.75	0.0196	69.0	7.70	0.0224	66.7	12.95	0.0377	66.3
12	12.25	0.0356	77.7	14.50	0.0422	77.4	24.80	0.0721	76.9
13	10.85	0.0316	76.0	12.95	0.0377	76.6	21.75	0.0633	75.9
14	15.10	0.0439	76.9	18.20	0.0529	77.8	31.75	0.0953	78.0
15	13.35	0.0388	76.3	16.05	0.0467	77.4	27.45	0.0799	77.5
16	19.80	0.0576	77	23.85	0.0694	77	42.25	0.123	77.0
17	26.15	0.0761	78	31.30	0.0910	78	56.45	0.164	78.0
18	33.25	0.0969	78	40.55	0.1180	78	76.75	0.223	78.0

3. DATA FOR FUSED SILICA AND QUARTZ

Cotton (1931) has determined the Verdet's constant of vitreous silica for three wavelengths, λ 5780, λ 5461 and λ 4358. The constants were re-determined for the above wavelengths as well as for λ 5893 using a plate of 8.40 mm. thickness. The values obtained were within $\frac{1}{2}\%$ of those obtained by Cotton. $\lambda dn/d\lambda$ for this substance was calculated from the dispersion formula

$$n^2 = 1.36112 + \frac{0.74655 \lambda^2}{[\lambda^2 - (0.107044)^2]} - 0.01350 \lambda^2,$$

where λ is expressed in microns. The last term which is due to the infra-red absorption is omitted in the calculation. Table IV gives the optical and

TABLE IV
Magneto-optic Data for Fused Quartz

Wavelength in A. U.	Refractive Index	Verdet's constant		γ %
		Cotton	Author	
5893	1.4585	..	0.01421	78.1
5780	1.4590	0.01479	0.01491	78.1
5461	1.4601	0.01671	0.01664	78.1
4358	1.4667	0.02602	0.02640	75.8

magneto-optical constants of vitreous silica for the four wavelengths mentioned above.

A large number of workers (1903, 1912, 1917) have devoted themselves to the study of the Verdet constant of quartz for different wavelengths in the spectrum. Actual measurements extend from 20000 Å to 2000 Å. $\lambda dn/d\lambda$ is calculated from the dispersion formula

$$n_w^2 = 3.53445 + \frac{0.008067}{[\lambda^2 - 0.00127493]} + \frac{0.002682}{[\lambda^2 - 0.000974]} + \frac{127.2}{[\lambda^2 - 108]},$$

where n_w is the ordinary refractive index and λ is the wavelength expressed in microns. Here also the last term is omitted in the calculation. Table V gives the Verdet's constant, and for the value of γ different wavelengths.

TABLE V
Magneto-optic Data for Crystalline Quartz

Wavelength	Refractive Index	Verdet's Constant	γ %
20000	1.5199	0.001266	71
16000	1.5270	0.002106	75.4
12000	1.5323	0.003727	75.1
8000	1.5383	0.008802	79.0
5893	1.5443	0.01664	78.9
5460	1.5462	0.01952	78.5
5085	1.5482	0.02257	77.1
4799.9	1.5501	0.02574	78.6
4358	1.5538	0.03081	78.5
4046	1.5572	0.03555	74.4
3612	1.5635	0.04617	74.5
2573	1.5962	0.1079	75.4
2194.6	1.6250	0.1586	69.9

4. DISCUSSION OF RESULTS

It will be seen from Table V that the Becquerel formula is obeyed by quartz for the visible spectrum. There appears to be a small drop in the value of γ in the infra-red and the ultra-violet regions, but more accurate measurements are needed before the data could be accepted as indicating a real variation of γ with wavelength in quartz. Although the data for fused quartz (Table IV) are not so extensive as those for crystal quartz, it is seen that γ is sensibly constant in the visible region. It is worthy of remark that the values of γ for fused quartz and crystal quartz are practically identical, and this is particularly remarkable in view of the large difference in density and refractive indices of the two substances.

An examination of Table III shows that the value of γ is independent of wavelength in many of the glasses. Nevertheless, there are a few glasses in the list (Nos. 1, 3, 9 and 11) in which γ is apparently not constant. Since these variations in γ mostly occur in glasses of low dispersive power, they may be ascribed to inaccuracies in the measurement of the refractive indices. But a more probable reason is that the dispersion due to the infra-red term has not been eliminated (as has been done in quartz and fused silica) in calculating the value of $\lambda \frac{dn}{d\lambda}$ for the glasses. The variation in the value of γ in glass No. 9 is probably too large to be explained on these lines. In general, however, one could say that most of the glasses studied obey the Becquerel formula, the γ value of each glass being approximately constant for the visible spectrum. The mean value of γ of each glass has been incorporated in Table I.

A study of Table I reveals many interesting facts. All the glasses which do not contain B_2O_3 or Al_2O_3 have values of γ lying between 76% and 78%, thus differing very little from the values for fused and crystalline quartz. This is all the more remarkable when one considers the large variations in composition, density and dispersive power of the glasses. For instance, in spite of the dispersion of glass No. 18 being four times that of glass No. 7 the γ factor is not appreciably different. The variations in content of PbO and ZnO —which are principally responsible for the large dispersion and high density in some of the glasses—do not appear to involve any noticeable variations in the magneto-optic anomaly.

The presence of B_2O_3 seems to have a large influence on the γ value of a glass. All borate glasses have low γ values, γ being lower in glasses having a higher percentage of B_2O_3 . Glass No. 1 and No. 2 which contain more than 10% of B_2O_3 have lower γ values than glass No. 9 which has less than 10% of B_2O_3 . The results with glass 3 seem to suggest that Al_2O_3 also depresses the γ value of a glass. The simultaneous presence of B_2O_3 and Al_2O_3 is obviously the cause of the very low value of γ in glasses No. 2, 6 and 11. It would seem that the presence of trivalent elements not only diminishes the dispersive power of a glass but also has the effect of diminishing the magneto-optic rotation in a still greater proportion, and that on the other hand, γ is practically the same for all silicate glasses which do not contain the trivalent elements.

In conclusion, the author wishes to thank Prof. Sir C. V. Raman for his kind advice and encouragement during this investigation.

5. SUMMARY

The paper records the values of Verdet's constant determined for $\lambda 5893$, $\lambda 5461$ and $\lambda 4358$ with 18 silicate glasses made by Schott & Co., Jena. The dispersive powers of the glasses have also been measured. It is found that most of the glasses obey a modified Becquerel formula, in which the multiplying factor γ is practically constant over the visible spectrum. The γ factor for fused quartz and crystalline quartz for different wavelengths have also been calculated. It is found that the value of γ for both the substances is about 78%. All the glasses which do not contain B_2O_3 or Al_2O_3 have γ values lying between 76% and 78% in spite of large variations in composition, density and dispersive power, the presence of the heavy elements like Pb, Ba and Zn in varying proportions having no influence on the γ value. On the other hand, trivalent elements like Boron and Aluminum when present in glasses diminish γ to values between 67% and 74% depending on the amount of B_2O_3 or Al_2O_3 present.

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