DIFFERENTIAL ELECTRIC DOUBLE REFRACTION IN CARBON BISULPHIDE.[1]

By C. F. Hagenow.

THE phenomenon of double refraction in dielectrics when subjected to an electric strain was discovered by Kerr[2] and later studied by a number of other investigators.

The methods employed were, generally, to place the dielectric between parallel electrodes, maintained at a known difference of potential, and this system between crossed or parallel nicols (set at 45° to the field) in line with a source of light. The resulting double refraction was measured by a Babinet compensator. The potential was supplied by a static machine, induction coil or storage battery.

The law obtained from these investigations is expressed by the formula

$$\delta = \pm \frac{P^2 B l}{a^2} \tag{1}$$

where δ is the phase difference in wave-lengths between the two emerging components of light (vibrating, of course, at right angles to each other); P the potential in electrostatic units; l the length of the electrodes and a their distance apart in centimeters; B the electro-optical constant for the particular dielectric considered.

In determining B several difficulties are met with. An error of one per cent. in the value of a (and this must of necessity be taken small) causes an error of two per cent. in the result. For the same reason the error in potential, a factor necessarily large and hence difficult to measure, produces a double error in the result. The presence of small particles in the liquid often adds to the inaccuracy

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[1] Read at the Chicago meeting of Section B of the American Association for the Advancement of Science, January, 1908.

[2] J. G. Kerr, Phil. Mag., 50, pp. 337 and 446, 1875; 8, pp. 85 and 229, 1879; 9, p. 157, 1880; 13, pp. 153 and 248, 1882; 20, p. 363, 1885; 37, p. 380, 1894; 38, p. 144, 1894. Rep. British Association for the Advancement of Science, p. 157, 1892.

of the compensator settings by causing disturbances in the field of view.

The condition of the CS_2 also affects the value of this constant, though to just what extent is not definitely known. Quincke[1] found considerable variation in seemingly pure CS_2 and obtained values of B differing as much as 20 per cent. He shows a comparison of results obtained from two lots of the liquid; the one specially prepared for him by Kahlbaum and the other purified by himself by shaking with dried $CuSO_4$, distilling and filtering. On comparing the results obtained from these two, other parts of the apparatus being the same, the variation is not greater than 4 per cent. from the mean. He found further, on introducing a Leyden jar to steady the potential, a considerable increase in the observed effect. His results also indicate a decrease in the value of B with the length of the electrodes.

Quincke claimed an accuracy of 1/150 mm. in measuring a, and .000062 λ in the compensator, though he could hardly have obtained settings to that degree of accuracy in the presence of the fluctuations caused by the static machine. He ascribed the lower value of B, obtained without the use of the Leyden jar, to the rapid changes in potential. He used a long range Kelvin electrometer and also a Righi reflection electrometer to measure the potential and a Babinet compensator to measure the phase difference.

Later Schmidt,[2] using CS_2 as a standard of comparison, found that the presence of foreign substances did not appear to affect it to the extent of Quincke's results. He attributed the error chiefly to the measurement of the distance between the electrodes and the uncertainty of the setting of the compensator on account of the particles in the field of view. He gives no details as to purification.

Lemoine[3] made a determination of B, laying claim to greater accuracy than Kerr and Quincke, but he states nothing as to his method of purifying the liquid. He employed an absolute electrometer and a Babinet compensator. A correction was also made for the length of the electrodes, on account of the error due to the

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[1] G. Quincke, Wied. Ann., 19, p. 729, 1883.

[2] W. Schmidt, Ann. d. Physik, 7, p. 142, 1902.

[3] J. Lemoine, Compt. Rend., 122, p. 835, 1896.

edges of the latter, which is about one per cent. He gives $B = 3.70 \times 10^{-7}$ (using white light and a red glass as a filter) as the average of 21 series of observations, which did not depart from the law as stated above by more than one per cent.

The most elaborate attempt at the purification of CS_2 has very recently been made by Blackwell[1] in his investigation of its electric dispersion. However, he does not seem to think this treatment absolutely essential to the experiment. His work concerns itself chiefly with the relative values in the spectrum. Great care was taken in the preparation of the electrodes. A storage battery was employed, and the potential kept practically constant during the experiment. The dispersion was obtained by photographing the spectrum crossed by the dark band — using a spectroscope and Babinet compensator — and then measuring with a telescope the relative shift of the band on the negative.

The average measurements of the observed shifts of the band in different experiments under practically uniform conditions vary as much as five per cent. from the mean, which is greatly in excess of the refinements employed in the construction of the apparatus. However, his object was to obtain relative retardations, and these were found in the case of each experiment separately, using the retardation of sodium light as a standard of comparison. The results so found agree much more closely, the error not exceeding two per cent. He obtained an absolute value of the retardation for sodium light of 7.04×10^{-7} cm. at 24° C. and 56,000 volts per cm. This corresponds to $B = 3.57 \times 10^{-7}$, subject, of course, to the variation noted above.

The main object of the present investigation undertaken at the suggestion of the late Dr. Brace was to determine B for various colors, using a highly sensitive method of measuring the phase difference, viz., the Brace, half shade elliptic polarizing system.[2] The fact that it permits the use of very low potential has already been taken advantage of by Elmén.[3]

In the present case its high sensibility is used advantageously in

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[1] H. L. Blackwell, Proc. American Academy of Arts and Sciences, Vol. 41, p. 645, 1906.

[2] D. B. Brace, PHYS. REV., 18, p. 70; 19, p. 218, 1904.

[3] G. Elmén, PHYS. REV., 20, p. 54, 1905.

determining a change of a complete wave-length. The compensator is first set for a match, with no electric field, then the potential applied and increased until a match is again obtained. This method avoids the necessity of taking into account the variation in the double refraction of the mica strips, for different colors, and also of calibrating the compensator.

The potential was supplied by a static machine and measured by a Kaufmann[1] form of absolute electrometer constructed for the purpose. As this was probably the least accurate part of the apparatus, the care taken in its adjustment and use may well be given a more detailed description.

The movable disk was suspended by a bifilar of phosphor bronze wire, adjustable in length, spread and torsion. On the axis of the disk was mounted a small plane mirror and the deflections observed by the telescope and scale at about a meter distance.

The fixed plate and guard ring were first carefully leveled. Then three glass blocks of 3.115 mm. thickness (accurate to .005 mm.) were placed on the fixed plate, which was raised parallel to itself on its insulating screw until the blocks touched the movable disk. Any tipping of the latter due to this contact was detected by a microscope cathetometer for one direction, and by a telescope and scale for motion at right angles to it. The distance between the fixed and movable plates was also measured by the microscope cathetometer; this being simply the thickness of the glass blocks plus the distance through which the fixed plate was raised, beginning at any desired point, until the instant of contact of the blocks with the movable disk. Of course this distance was made to conform with that between the guard ring and the fixed plate.

The wires of the bifilar were then twisted until the disk was rotated through nearly 90 degrees, the position of greatest sensibility, and the system calibrated by the use of a series of nine weights (accurate to .0001 gram) suspended from a hook centered in the framework above the disk. After standing in adjustment about a week, the instrument gave a very constant calibration. However, calibrations were always made just before and after a set of observations. A number of readings were also compared with results

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[1] Cf. J. E. Almy, Ann. d. Phys. (4), Vol. 1, p. 508, 1900.

obtained from spark potentials and were found to check within an average of less than one per cent.

The static machine was driven at a constant speed and the potential changed by shunting with a variable point discharge.

The disposition of the optical apparatus is shown in Fig. 1. Light from the sun was focused on the slit m_1 by the lens L_1. The second slit m_2 is conjugate to m_1 through the lenses L_2 and L_3 and the dispersing prism A. The angular position of the latter was controlled by a screw T and its positions calibrated for definite wave-lengths passing through m_2 by use of the scale C. The lens L_4 focused the beam on the eye placed at O. The nicol N_1 polarized the light at 45 degrees to the lines of force and N_2 was set for extinction. The half shade S_1 was placed so that its principal axis was at 45 degrees to the plane of vibration of the polarized light (giving maximum illumination) with its edge perpendicular to the condenser plates; so that any variation of color might be the same on both sides of the dividing line. P is the tube with the electrodes and S_2 the compensator. A telescope was usually mounted at O to magnify the field of view.

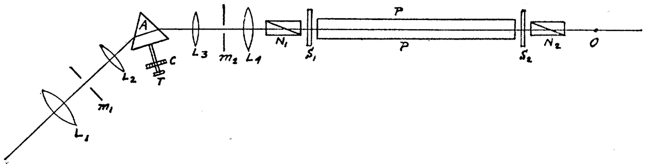

Fig. 1.

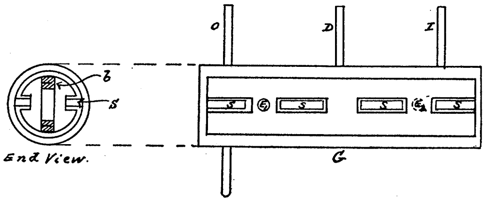

Fig 2

The electrodes were of nickeled brass 50 cm. long and about 9 mm. wide. Fig. 2 illustrates the arrangement, as designed by Mr. L. B. Morse who used them previously. The plates were kept at the proper distance apart by eight glass blocks *b* (see end view, Fig. 2) about 13 mm. long, a little more than 2 mm. wide and 1.97 mm. thick, the last dimension representing the distance between the electrodes.

To hold them in place, four of them were drilled with holes a little less than 1 mm. deep to fit corresponding pegs in the electrode. The pressure of eight springs *S* against the walls of the enclosing tube held them firmly together, and rendered them also fairly secure against displacement in the tube.

The tube *G* had five openings; the inlet tube *I*, outlet *O*, E_1 and E_2 for the insertion of wires connecting to the static machine, and the tube *D* to facilitate removing air bubbles which were caught between the glass blocks. Platinum wires sealed in short glass tubes which just fitted into E_1 and E_2 made electrical connection with the electrodes. These were cemented in place after contact with the electrodes was assured. The tube was sealed at the ends by thin cover glasses, cemented on by a paste, which, while resisting the action of the CS_2, had the further advantage of not drying to perfect hardness and thus causing strain and consequent double refraction. However, the cover glasses were tested for double refraction and many had to be rejected on account of showing evidence of strain.

The whole was mounted on a base together with two large bottles serving as reservoirs for the liquid; one connected to the tube *I*, the other to *O*. The first of these bottles was provided with a filter cup sealed into the neck by plaster of Paris; the other one, joined to the tube *O*, was closed with a rubber stopper. This gave a continuous flow from the filter cup through the main tube and into the second bottle, from which the liquid was drawn for fresh distillation.

Stopcocks provided for the different requirements of the system which was intended to keep the liquid, when once clean, from contact with the air, and at the same time to allow of introducing fresh liquid when desired. The liquid was filtered and forced through the system by means of compressed air.

No attempt was made towards complete purification, but care was taken to have the liquid free from water and dust particles, which in the reports of previous investigators, as well as from the writer's own experience, seem to be the only essential disturbing factors. Moisture especially caused the greatest trouble and delay.

The CS_2 was first distilled with fresh lard and fused $CaCl_2$, usually about three times; though considerable variation in their treatment seemed to cause no great change in the results. Attention will be called to this fact again later. A 32-candle-power incandescent lamp in an asbestos oven served admirably as a safe heating arrangement. After distillation the liquid was filtered through the porous cup into the receiving bottle above mentioned; and, after some of the liquid had been run through the system, the tube was filled and all the air bubbles removed by manipulating the flow of the liquid and by tipping the tube. In this way any particles present to begin with are gradually carried out into the second bottle to be filtered out.

Table I.

Temperature 25° *C.*

$\lambda\mu\mu$	Scale.	Average.	Potential.	$B \times 10^7$
	539			
	538			
430	538	538	40.75	4.67
	518			
450	514	516	42.30	4.34
	466			
500	465	465	46.00	3.67
	417			
550	418	417	49.35	3.19
	379			
590	380	379	52.05	2.87
	365			
600	367	366	53.00	2.76
	334			
650	333	333	55.30	2.54
700	310 (?)	310 (?)	56.90	2.40 (?)
430	290			
(2δ)	292	291	58.20	4.58
450	257			
(2δ)	258	257	60.45	4.25

Observations were taken as follows: The tube being filled and in place, the compensator was set for a match on any color.[1] The potential was then applied and gradually increased until a match was again obtained. A second observer read the corresponding deflection of the electrometer. Readings were taken at different points throughout the spectrum. *B* was then calculated according to formula (1). Table I. shows one set of readings in detail. The CS_2 used was distilled three times; twice with $CaCl_2$ and lard, the third time with $CaCl_2$ only. In case of the shorter wave-lengths it was possible to produce a change of two wave-lengths, as shown in the last two readings in the table.

Table II. gives another set of readings taken about a month later with CS_2 only once distilled with fused $CaCl_2$. The calibration of the electrometer was different but the values of *B* are only slightly lower.

TABLE II.

Temperature 25° *C.*

λ	Scale.	Av.	Potential.	$B \times 10^7$
	477			
	478			
	477			
430	476	477	41.55	4.50
	450			
450	452	451	43.40	4.12
	401			
500	400	400	46.80	3.54
	349			
	351			
550	349	350	50.20	3.08
	313			
	312			
	314			
	311			
590	312	312	52.75	2.79
	304			
	299			
	304			
	302			
	299			
600	299	301	53.50	2.71
	265			
	264			
	265			
	263			
	265			
	265			
650	267	265	55.90	2.48
				(?)
700	221	221	58.70	2.25
430	218			
(2δ)	217	217	58.90	4.48
	178			
	178			
450	177			
(2δ)	178	178	61.4	4.12
	88			
500	88			
(2δ)	87	88	66.85	3.47

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[1] It was then matched for all colors.

TABLE III.

Summary.

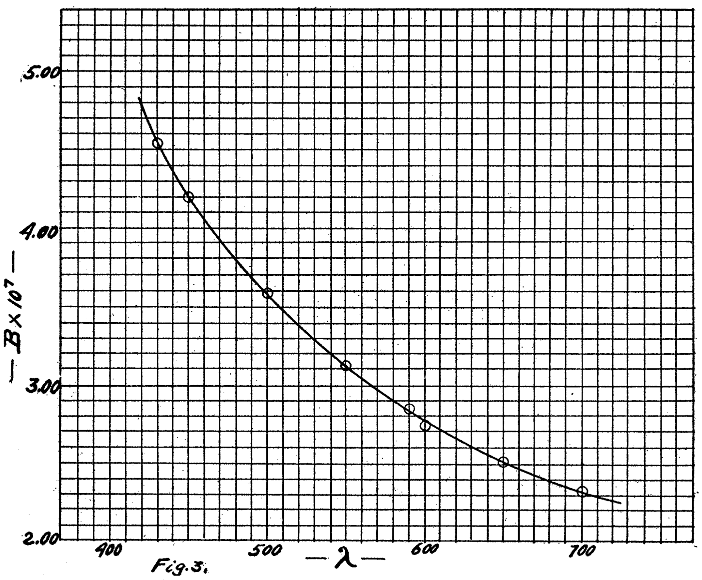
No. of Ex.	1	2	3	4	5	B Av.	$B \times \lambda$	Per Cent.
λ 430	—	4.67	4.50	4.47	4.51	4.54	1952	116.2
λ 450	4.32	4.34	4.12	4.10	4.11	4.20	1890	112.5
λ 500	3.67	3.67	3.54	3.55	3.54	3.59	1795	106.8
λ 550	3.19	3.19	3.08	3.07	3.07	3.12	1716	102.1
λ 590	2.94	2.87	2.79	2.84	2.79	2.85	1681	100.0
λ 600	2.80	2.76	2.71	2.69	2.70	2.73	1638	97.5
λ 650	2.57	2.54	2.48	2.50	2.45	2.51	1632	97.1
λ 700	—	2.40	2.25	—	2.31	2.32	1624	(?) 96.7

Table III. is a summary of five different sets. The values of B are slightly lower in the last three than in the first two. This difference is hardly to be accounted for by the change in the condition of the liquid used in beginning the last set. For in experiment 4 some of the liquid first used was again employed after being redistilled and filtered. In fact, owing to the impossibility of entirely emptying the system of one lot of the liquid before refilling it, the portion experimented upon at any given time was always more or less of a mixture. The average values of B are plotted in Fig. 3.

The actual retardation is given by $\delta \times \lambda$, that is, by

$$\lambda \times \frac{P^2 Bl}{a^2}$$

from formula (1). For purposes of comparison it is sufficient to find the product $B \times \lambda$ at the different points of the spectrum. These values are shown in Table III. and are plotted in Fig. 4. For com-


5.00
4.00
3.00
2.00
— B × 10⁷ —
400
500
600
700
— λ —
Fig. 3.

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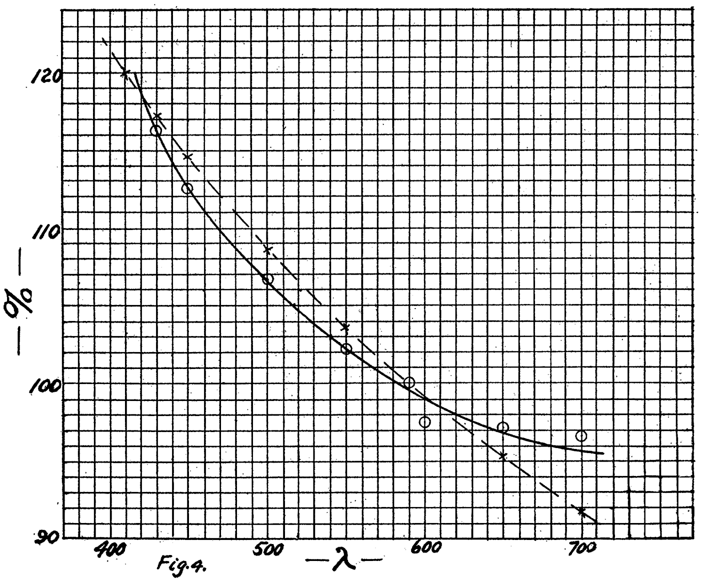
120
110
100
90
— % —
400
500
600
700
— λ —
Fig. 4.

Fig. 4.

parison, the curve, according to Kerr[1] is added, shown in dotted lines. This is plotted according to his statement that the retardation varies inversely as the square root of the wave-length. The departure of the results of the present investigation from this law is apparent from the figure. The writer's curve agrees closely with a similar curve of Blackwell[2] in this respect.

The abrupt change in the values of $B \times \lambda$ about 600 $\mu\mu$ seems difficult to account for. Anything that might have caused a constant error in this region of the spectrum was carefully examined, but no inaccuracy was discovered.

As to the accuracy of the various measurements and constants involved in the experiment, it is believed that they are well within the limits set by the conditions of the problem itself. The positions of the dispersing prism were calibrated by means of the Fraunhofer lines, and the calibration was checked up after the experiment. The micrometer screw controlling the prism could be set to a half of one $\mu\mu$.

The glass blocks separating the electrodes might be uncertain as to thickness as much as .01 mm. which would affect the result not more than one per cent. The setting of the compensator for the match, before the potential was applied, was easily accurate to less than 0.2 per cent. and the settings for the various potentials used may be seen from Tables I. and II. which are typical. Thus the total range of the scale was 900 mm., and it was possible to determine a match to one division of the scale in the best instances, and within three divisions of the mean in the worst cases. This means an accuracy of 0.2 per cent. in the shorter wave-lengths and not more than 0.5 per cent. in the larger ones. The settings for wave-lengths greater than 650 $\mu\mu$ were found to be too uncertain to be of any value.

At every match the color of the field would change to the complimentary tint, which proved to be as delicate a test of uniformity as the match of intensity itself and in the blue end of the spectrum was the only means of determining the match.

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[1] J. G. Kerr, Rep. British Association for the Advancement of Science, p. 157, 1892.

[2] H. L. Blackwell, Proc. American Academy of Arts and Sciences, Vol. 41, p. 650, 1906.

The two wave-length retardations as shown in Table II. are interesting as showing the uniformity of the formula for greater retardations. These values have not been used in the averages.

Experience showed that a much greater dispersion might have been used with sunlight to advantage. A more nearly monochromatic light would undoubtedly make closer settings possible in the red end of the spectrum.

These experiments were all performed at a nearly constant temperature of 25° C. It was noticed that the presence of particles caused a considerable increase of the potential necessary to get the same double refraction, which can be explained by the greater conductivity of the liquid. On allowing a fresh supply to flow into the tube from the receiving bottle the liquid would at once regain its former state. According to Quincke,[1] particles have the same effect as decreasing the distance between the electrodes, *i. e.*, increasing the double refraction. But this effect is evidently more than offset by the charge carrying capacity of the particles.

When sparks passed through the liquid the effect was the same as that caused by particles (particles of carbon probably being produced), and a new supply had to be admitted.

The writer performed a series of similar experiments a year before the present set. The same apparatus was employed with the exception of the electrometer, instead of which a spark gap was used. The results were not deemed sufficiently reliable for the purpose of the investigation, though the greatest variation in the value of B was 5 per cent.; and, comparing averages with the present set, the differences are not greater than 3 per cent. The method of purification was the same, though various combinations of liquids were used on account of the circulating system used in connection with the tube.

In conclusion it would seem that a fairly stable condition of CS_2 for optical purposes can be obtained by a simple process of distillation and thorough filtering, and that this treatment allows of considerable variation without corresponding changes in the results.

It is not possible at this stage to make a systematic comparison of the values of B with those obtained by others; since, owing to the difference in method or object in view in previous investigations,

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[1] G. Quincke, Wied. Ann., 19, p. 758, 1883.

the data do not correspond. Quincke, in the reference given above, gives values ranging from 2.877 to 3.544 for sodium light. In the particular case where he used electrodes 47 cm. long his values vary from 2.877 to 2.981. Lemoine does not state the exact wave-length of light used, and Blackwell gives only one instance of the absolute value of the constant for sodium light; but, as noted above, this varies considerably in the different experiments.

As to the dispersion, the results do not bear out the law stated by Kerr, but give a curve steeper at the blue end of the spectrum and flatter at the red end, agreeing with the results obtained by Blackwell.

Finally the writer wishes to thank Dr. Skinner and Dr. Almy for their kind assistance and many helpful suggestions.

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