Dr. P. ZEEMAN. *Measurements concerning the influence of a magnetization, perpendicular to the plane of incidence on the light reflected from an iron mirror.*

1. Dr. C. H. WIND in his paper on KERR's phenomenon has derived from theory the very interesting and unexpected result, that also a magnetization perpendicular to the plane of incidence must influence the light reflected from a magnetized mirror. This influence however is only exercised, if the incident light is polarized perpendicular to the plane of incidence. The phenomenon may be described in this manner: in the case mentioned and with a magnetization, perpendicular to the plane of incidence, a magnetical component is originated also perpendicular to the plane of incidence. Mr. WIND calculated magnitude and sign of the action to be expected and hence numerically has described also the new phenomenon.

In the academical report concerning Mr. WIND's paper it is mentioned that a non-occurrence of the phenomenon would make necessary a thorough revision of the theory of magneto-optic phenomena. Therefore it was of a particular interest to test Dr. WIND's prediction. I have done this by means of BABINET'S compensator. It appears from the calculations kindly furnished me by Mr. WIND (his paper not yet being published) that the phenomenon is so exceedingly small, that it may easily remain unobserved.

The amount of the variations of the re-established azimuth and difference of phase is of the same order of magnitude as the errors of measurement. It is only with the utmost care and from long series of measurements that one may hope to detect the effect.

I have made 2 complete series (series I and II) of measurements by means of BABINET'S compensator. In both series are measured the variation of the difference of phase and that of the re-established azimuth with reversal of magnetization.

In taking these measurements, I was not subjected to the well-known unconscious temptation to see the thing we desire to see (extremely dangerous when such small quantities were to be measured). After having determined sign and amount of the variations in both series in phase and azimuth I perceived from the results then sent to me by Mr. WIND, that the sign and amount of the variations were in good agreement with theory. Also as to the expectations, both series are wholly independent of each other. The disposition of series II sufficiently differs from that of series I to make it difficult, without further considerations, to foresee the result to be expected. This consideration concerning the relation of the results of series I and II was made only after their termination.

2. *Method.* It has already been said that the measurements were made by means of BABINET'S compensator. In making the observations, the precautions were taken and the auxiliary apparatus used, which have been described on various occasions [1]). The light used was of the mean refrangibility of the sodium lines. Using this light about 14.3 revolutions of the head of the screw correspond to a phase-difference of half a wavelength. The head has been divided into 50 parts. The mirror (see 3) was adjusted for an angle of incidence $i=75^0$. The polarizer was placed in an azimuth of 45^0 and in the 4 possible positions. The observations were made with each of the 4×2 possible positions of the analyser. The determination of the variation of the phase-difference was made in the following manner. The black band in the compensator was made as dark as possible by turning the analyser. With positive and negative magnetizations the band was brought as accurately as possible between the wires, the analyser remaining in the same position. The determination of the variation of the azimuth was also observed in the 8 positions of the analyser, the position of the compensator now being unchanged. With the successive alternately directed magnetizations, the central part of the black band in the compensator was made as dark as possible, by turning the analyser. The position of the analyser commonly is read on a graduated circle, fixed

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1) SISSINGH, Dissertation 1885.
„ Archiv. Néerland. T. 20.
ZEEMAN. Archiv. Néerland. T. 27, p. 259, 1893.

to the analyser. I have however considerably increased the accuracy of this reading, by determining with a mirror and a vertical scale the angles over which the analyser is turned.

3. *Mirror.* Dr. SISSINGH used in his investigation of aequatorial reflexion, mirrors ground on iron rings. I have now used one of these rings, preserved since that time under a clock with chloride of calcium. The length of the mirror is 28 m.M. and the breadth of the middle part 2.8 mM. The ring was easily placed in a vertical plane, being fastened on a wooden board, which itself was clamped to the plate of copper [1]), used in my investigation of polar reflexion to support the magnet. The copperplate being fastened to an adjustable platform, it was also possible to put the mirror accurately into the correct position.

4. *Arrangement of the observations.* In order to give a clear survey of the measurements, I will give a complete set of observations in one position of the analyser. At the same time it will be possible to consider the degree of accuracy obtained. In one position of the analyser 12 observations were always taken. In the table below, the readings on the head of the compensator screw are entered. The magnetization is called positive for lines of force going vertically upwards.

[1]) ZEEMAN, l. c. p. 258.

Reading polarizer 173.7, Reading analyser 246.
Readings compensator (position 45,..)

—	+ magnetization	difference
36	34	— 2 parts of screwhead
33	33	+ 0
33	30	— 3
34	32	— 2
39	34	— 5
36	34	— 2
35	35	— 0
35	37	+ 2
39	37	— 2
37	36	— 1
42	38	— 4
34	35	+ 1
	mean	— 1.5 (0.5)

The mean error of the mean is entered in brackets.

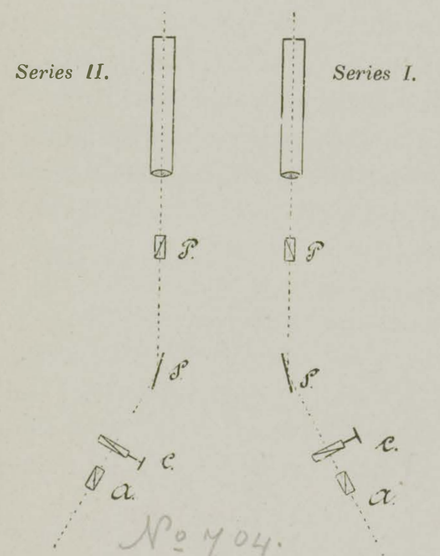
The following table may serve as an instance of the observation relating to the variation of the re-established azimuth The figures are the readings on the vertical scale; 1′ corresponds to 1.4 divisions of the scale.

Reading polarizer 353.7, Reading analyser 246.
Readings analyser.

—	+ magnetization	difference.
262	238	—24 divisions of scale.
265	259	— 6
243	226	—17
201	193	— 8
241	185	—56
249	218	—31
250	195	—55
228	214	—14
218	204	—14
268	294	+26
269	204	—65
166	235	+69
	mean.	—16 div. = 12′ (8′).

Also here the mean error is entered in brackets. It follows from the now given figures that the mean error of one determination of the analyser amounts to about 28′, of one determination of the compensator to about 1.8 [1]) divisions of the screwhead. The expected theoretical variations (with reversal of magnetization) are about 14′, viz. 2.6 divisions of the head, hence of the order of magnitude of the errors of measurement.

The position of the compensator was in both series that for which the difference of phase is rendered half a wave length.



5. *The two series of observations.* The two series taken in order to secure mutual control (see 1) differ from each other by the direction of the normal to the mirror. In Series I it was directed to the S. W., in Series II to the S. E. The joined figure represents, as seen from above, schematically the disposition of the apparatus, a further

1) Perchance this value is very small, the mean is 3.1 divisions of the screwhead.

elucidation of which seems unnecessary. However it should be observed that P is the polarizer, S the mirror, C the compensator and A the analyser.

6. *Results of Series I.* Polarizer and analyser have graduated circles divided in degrees. Rotations are negative if in the same direction as the motion of the hands of a watch for an observer placed in the mirror. Negative rotations gave lower readings on the divided circles. The magnetization is positive if the lines of force run vertically upwards. The readings 128.7 and 308.7 on the circle of the polarizer correspond to incident light polarized parallel to the plane of incidence, the readings 38.7 and 218.7 to light polarized perpendicular to that plane. The light emergent from the polarizer, is quenched at the positions 128.7 and 308.7, the position of the analyser being given by 93 and 273, to the other two positions of the polarizer correspond the analyser positions 3 and 183. During the experiments the polarizer was placed in the azimuth 45°, corresponding to the readings 83.7, 173.7, 263.7, 353.7.

The difference of phase produced by the compensator is 0 for the reading 38.78 of the index which is fixed to the movable plate of the compensator. The difference in phase was $+\frac{\lambda}{2}$ and $-\frac{\lambda}{2}$ for the readings 53.08 and 24.48 During the measurements the reading of the index was about 45,..... Rotations of the head (divided in 50 parts) in the direction of the higher readings, gave also higher readings on the index-scale.

The results of the measurements concerning the re-established azimuth are entered in the following table;

the rotations are given in minutes. Each separate number is the result of a set of twelve observations. The angle of incidence was 75°. The analyser was approximately in the position given by the cipher behind A.

Position I. Variation of the re-established azimuth with + magnetization.

Pol. 83.7	A. 120	+	9′(5′)
	300	+	2(5)
Pol. 173.7	A. 66	—	11(7)
	246	—	28(11)
Pol. 263.7	A. 300	+	5(8)
	120	+	15(6)
Pol. 353.7	A. 246	—	5(9)
	66	—	12(3)
		mean	10.9′

With + magnetization the compensator was to be displaced to higher readings. In this case I give the positive sign to the variations of the phase (double variations) given in divisions of the head. The results are entered in the following table. Also the mean error of each series of 12 observations is given.

Position I. Variation of the phase with + magnetization.

P. 83.7	A. 300	+ 4.4(1.0)
	120	+ 0.9(1.5)
P. 173.7	A. 66	+ 0.4(1.1)
	246	+ 1.7(1.3)
P. 263.7	A. 300	+ 2.6(0.5)
	120	+ 1.1(0.7)
P. 353.7	A. 246	+ 1.1(0.5)
	66	— 0.2(1.0)
	mean	+ 1.5

Hence from the 2 tables it follows: with + magnetization the re-established azimuth increases, the difference of phase diminishes.

7. *Results of Series II.* The results of the measurements in Position II I have entered in the following table.

Position II. — Variation of the re-established azimuth with + magnetization.

P. 83.7	A. 120	—	14′(9′)
	300	—	7(7)
P. 173.7	A. 66	+	20(10)
	246	+	1(6)
P. 263.7	A. 300	—	12(6)
	120	—	10(10)
P. 353.7	A. 246	+	12(8)
	66	+	16(8)
		mean	11.2′

Position II. Variation of the phase with + magnetization.

P. 83.7	A. 120	— 0.3(1.0)
	300	+ 0.5(0.5)
P. 173.7	A. 246	— 1.5(0.5)
	66	+ 0.8(0.6)
P. 263.7	A. 300	+ 0.6(0.5)
	120	— 1.8(0.7)
P. 353.7	A. 66	— 3.4(0.8)
	246	— 1.8(0.8)
	mean	— 0.8

Hence it follows: In Series II with + magnetization the re-established azimuth diminishes, the difference of phase increases.

8. *Agreement of Series I and II.* If there exists a phenomenon causing in Series I the then observed phenomena, it must manifest itself in series II in the manner given in (7). If in the first mentioned case with a positive magnetization the re-established azimuth increases, it must be diminished in the second case. Prof. LORENTZ was so kind as to point out to me how this is most easily seen in applying the theorem of reciprocity.

9. *Accuracy of the observations.* Now it is still the question what is the value to be attributed to the results of the two series, viz. what is the mean error of the final result? Dr. E. F. VAN DE SANDE BAKHUIJZEN kindly informed me of the best manner of calculation in this case. The manner in which the 2 series are to be combined follows from (8). Taking this into account I have found the result, the disposition being as in series II, that the diminution (double) of the phase is + 1.14 divisions of the head, the mean error being 0.38 divisions. For the final result of the increment (double) of the re-established azimuth I find 11.2′, the mean error being 1.9′ [1]). (The mean error being calculated from the degree of agreement of the 16 separate results.)

10. *Result.* Mr. WIND's theoretical result is:

[1]) The accuracy of the phase determinations is given by SISSINGH to be $0.005 \frac{\lambda}{4} = 1.8$ divisions of the head and that of the determination of the re-established azimuth to 0.1°. Hence since his investigation one has succeeded in increasing not unconsiderably the precision of the observations.

Angle of incidence.	*Magnetization.*	*Difference of phase*	*Re-established azimuth.*
75°	+ 1400 C. G. S.	$0.004 \times \frac{\lambda}{4} = 1.4$	
71°	+ 1400 C. G. S.		8.5′

Taking into account that in my experiments the magnetization was somewhat above 1100 C. G. S. and paying attention to the well known result, that a real error equal to 3 or 4 times the mean error is not at all so improbable as is stated in the calculus of probabilities, one finds this result: The general conclusion to be drawn from the observations, is that a variation of the re-established azimuth and of the phase occurs, agreeing with the magnetic component polarized perpendicular to the plane of incidence predicted by Mr. WIND.

Herewith the phenomenon is, at least qualitatively, sufficiently confirmed. Hence there is no reason in this case for constructing a theory of the KERR-phenomenon on an entirely new basis.