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THE DIFFERENCES IN THE TIME LAGS OF THE FARADAY EFFECT BEHIND THE MAGNETIC FIELD IN VARIOUS LIQUIDS

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Abstract

Plane-polarized light from a zinc spark was passed through two liquid cells in succession. At the same time the current impulse through the spark passed, through leads of variable length, to oppositely wound solenoids surrounding the cells, where the magnetic fields rotated the plane of polarization of the light. By a proper adjustment of the positions of the cells and of the length of the lead wires it was possible to secure equal and opposite rotations of the plane of polarization in the two cells. Another liquid was then placed in one of the cells and its position changed until again the rotations were balanced. The distance the cell had to be moved, divided by the velocity of light, gave the difference in the time lag of the Faraday effect in the two liquids. The lag in carbon bisulphide behind that in hydrochloric acid was 0.3×10^{-9} sec. The lags in the following liquids behind that in carbon bisulphide were found to be (in 10^{-9} sec.): carbon tetrachloride 1.1; water 1.1; benzene 1.9; xylene 2.1; chloroform 2.4; toluene 2.5; amyl alcohol 4.0; bromoform 4.1. The precision of the results is about 0.3×10^{-9} sec., depending somewhat upon the liquid.

All transparent isotropic liquids when placed in a magnetic field acquire the property of rotating the plane of polarization, provided the light traverses the liquid in the direction of the lines of force. As long as the magnetic field is constant the rotation is constant, but if the field is reversed the rotation is reversed. This phenomenon is the well known Faraday effect.

Many attempts[1] have been made to detect a time interval between the removal of the magnetic field and the disappearance of the Faraday effect as well as the time interval between the application of the field and the appearance of the Faraday effect. Abraham and Lemoine[2] concluded from their experiments that the lag of the Faraday effect behind the magnetic field must be less than 10^{-8} sec. in the case of carbon bisulphide, while many others have shown that the magnetic rotatory polarization in an alternating field follows the variations of the field almost exactly and it has generally been concluded that if the above time lag exists, it is probably too small to measure. We have therefore thought it worth while to investigate this time lag by a very sensitive method by means of which a difference of 0.3×10^{-9} sec. in the lags of

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[1] See Wood, Physical Optics, p. 500, Macmillan Co., 1923.

[2] Abraham and Lemoine, Comptes rendus **30**, 499 (1900).

the Faraday effect behind the magnetic field in various liquids can be measured.

In Fig. 1, *C* is a parallel plate condenser with a capacity of 7×10^{-4} microfarads. *A* is a variable spark gap containing zinc electrodes, *L* a lens which renders the light from *A* parallel, *F* a light filter transmitting a narrow spectral region around the bright spark lines 4912, 4924A of zinc practically alone, while N_1 and N_2 are Nicol prisms. B_1 and B_2 are glass cells, made as nearly identical as possible, which contain the liquids under investigation. Each cell is provided with side tubes by means of which one liquid can be replaced by another. A helix of 18 turns of No. 18 copper wire is wound around each tube. T_1T_1 and T_2T_2 are cross wires by means of which the length of wire from *A* to B_1 and from *A* to B_2 can be lengthened or shortened symmetrically by the observer at *E*. The leads to B_2 were so arranged that B_2 could be moved in the direction of AN_1N_2 a distance of 4 or 5 meters without changing their lengths or distance apart. The source of high potential was an induction coil which charged the condenser *C* 500 times per second. It might be noted here that there were no oscillations in *C* large enough to affect B_1 and B_2, appreciably at least, after the initial discharge. This was verified experimentally.

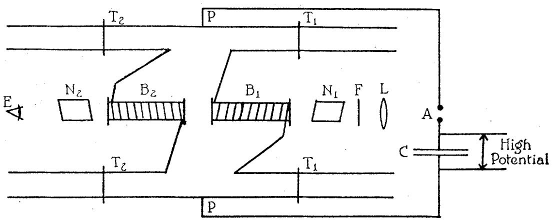

Fig. 1. Diagram of apparatus.

Suppose B_1 and B_2 are first filled with carbon bisulphide and the condenser *C* is charged until the spark jumps across *A*. The electric impulse travels from *A* along the lead wires to *P* where it divides, equal and symmetrical parts passing over PT_1B_1 and PT_2B_2. When the electric impulse reaches B_1 a magnetic field is established in the carbon bisulphide and hence because of the Faraday effect, light from the spark *A* made plane polarized by the Nicol N_1 has its plane of polarization rotated and will therefore pass the Nicol N_2. On the other hand, if the other part of the electric impulse reaches B_2 over the path PT_2B_2 at a time equal to the distance between the centers of the cells divided by the velocity of light, after the arrival of the electric impulse at B_1, the plane of polarization of the light is rotated back into its original direction provided the helix around B_2 is so wound that the direction of the lines of force in B_2 is opposite to that of those in B_1 and that the magnitudes of the magnetic fields are identical. The length of the lead wires APT_1B_1 was first adjusted so that the electric impulse arrived at B_1 during the time that the spark lines 4912, 4924A of zinc were of maximum intensity.[3] The length of APT_2B_2 was then adjusted by moving T_2T_2 until no light from A passed N_2. This adjustment insures that the rotation of the plane of polarization produced in B_1 is exactly neutralized by the rotation in B_2. If now B_2 is moved backward in the direction AN_1N_2 without changing the length or relative position of the lead wires APT_2B_2, it was found that light passed N_2. If, however, each of the lead wires APT_2B_2 was lengthened an amount equal to the distance through which B_2 was moved, the light was again extinguished, i.e., the velocity of the impulse along the lead wires was approximately equal to the velocity of light, which is in accord with many well known observations.

B_2 was placed immediately behind B_1 and the lead wires were adjusted so that no light passed N_2. The carbon bisulphide in B_2 was then removed and carbon tetrachloride substituted in its place. Light from A then passed N_2. B_2 was then moved back in the direction of N_2 and at a distance of 32 cm the light coming through N_2 passed through a distinct minimum.

When the same liquid, carbon bisulphide in this case, was in both B_1 and B_2 and the lead wires adjusted so that no light passed N_2, then the magnetic fields in B_1 and B_2 were established and removed almost simultaneously, differing only by the time required for light to pass from B_1 to B_2. When the carbon bisulphide was replaced by the carbon tetrachloride, the magnetic fields were still applied and relaxed together as before, but it was necessary to move B_2 back a distance of 32 cm in order to obtain a minimum amount of light through N_2. The Faraday effect must therefore lag behind the magnetic field in carbon tetrachloride 1.1×10^{-9} sec. longer than in carbon bisulphide. Various other liquids when substituted for carbon tetrachloride showed distinct differences in time lags. The results are shown in the table together with the Verdet constant, and the magnetic susceptibility.

In practically all the above cases, because of differences in the magnitudes of the Verdet constants it was not possible completely to extinguish the light passing N_2, but in every case a very sharp minimum occurred. By checking each liquid against the various other liquids having almost equal Verdet constants, the possible errors of reading a

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[3] Beams, J.O.S.A. & R.S.I. **13**, 597 (1926).

minimum were somewhat reduced and the precision of the results given in the table is about 0.3×10^{-9} sec., although differing slightly for different liquids.

TABLE I

Liquid	*Verdet constant in minutes $\lambda = 5890$A	**Magnetic susceptibility $K \times 10^6$ at 20°C	Time lag behind Carbon bisulphide Seconds
Hydrochloric acid HCl	0.0224 (15°C)	−0.83	-0.3×10^{-9}
Carbon tetrachloride CCl_4	0.0321 (15°C)	−0.72	1.1
Water H_2O	0.0130 (15°C)	−0.75	1.1
Benzene C_6H_6	0.0297 (20°C)	−0.69	1.9
Xylene C_8H_{10}	0.0221 (15°C)	−0.69	2.1
Chloroform $CHCl_3$	0.0164 (20°C)	−0.76	2.4
Toluene C_7H_8	0.0269 (28°C)	———	2.5
Amyl Alcohol $C_5H_{11}OH$	0.0131 (15°C)	−0.68	4.0
Bromoform $CHBr_3$	0.0317 (15°C)	−0.98	4.1
Carbon bisulphide CS_2	0.0441 (20°C)	−0.74	0

*From the Smithsonian Tables.
**Landolt-Börnstein Tabellen, 5. Auflage.

The fact that it was possible to obtain a sharp distinct minimum of the light transmitted by N_2 indicates that the time between the application of the magnetic field and the appearance of the Faraday effect is practically equal to the time between the removal of the magnetic field and the disappearance of the Faraday effect; or that the differences in the two above times are the same for the liquids investigated. It will be noted from the table that the differences in the time lags are not simple functions of the differences in the Verdet constants or the magnetic susceptibilities.

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