

THE EFFECT OF WAVE-LENGTH ON THE DIFFERENCES IN
THE LAGS OF THE FARADAY EFFECT BEHIND THE
MAGNETIC FIELD FOR VARIOUS LIQUIDS

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ABSTRACT

The lag of the Faraday effect behind the magnetic field was measured by the method of Beams and Allison in carbon bisulphide, toluene, carbon tetrachloride, benzene, xylene, chloroform, and bromoform for various wave-lengths of light from 4481 to 5896Å. It is found in every case that the difference in the lags of the Faraday effect behind the magnetic field increases as the wave-length of the light decreases. The extreme magnitudes observed in these time-lag differences range from 0.2×10^{-9} sec. for the longest wave-lengths to 12.2×10^{-9} sec. for the shortest, depending upon the two liquids compared. The precision is about 0.2×10^{-9} sec.

Effect of temperature on the lag of the Faraday effect.—Observations made on carbon bisulphide, toluene and chloroform failed to detect any effect of temperature on the lag of the Faraday effect for temperature differences of 40°C.

Ratio of the speed of electric impulses along wires to the speed of light in air.—The method of the experiment affords a means of measuring the ratio of the speed of electric impulses along copper wires to the speed of light. The value obtained for the ratio was about 96 percent.

IT HAS recently been found by Beams and Allison¹ that the Faraday effect lags behind the magnetic field a longer interval of time in one liquid than in another. The measurement of these time-lag differences could be repeated with a precision of 0.3×10^{-9} sec. The same source of light (the zinc spark lines 4912, 24Å) was employed in all the observations.

The investigation has been continued by the writer with the purpose of determining whether this lag in the Faraday effect depends upon the wave-length of light used. It is found² in all cases that the time-lag difference for any pair of the liquids increases with decreasing wave-length, or that the differences in the lags of the Faraday effect behind the magnetic field show roughly an inverse variation with the wave-length of light.

The experimental arrangement is the same as that described by Beams and Allison,¹ with some minor improvements whereby the precision of measurement has been somewhat increased. The setup is diagrammatically shown in Fig. 1. The condenser *C*, the capacity of which could be varied from 5×10^{-4} to 5×10^{-3} microfarads, was charged from an induction coil provided with a Wehnelt interrupter. The spark gap *A* was so constructed as to allow the ready interchange of the electrodes of the different elements whose spectra served as the sources of light. *B*₁ and *B*₂ are cylindrical glass cells which contain the two liquids under observation for time-lag differences. These cells are about 2.5 cm in diameter and 18 cm in length. Each is wound

¹ Beams and Allison, Phys. Rev. 29, 161 (1927).

² Allison, Phys. Rev. 29, 370 (1927), abstract.

with a helix of 54 turns of No. 18 copper wire. (Subsequently, the cells B_1 and B_2 were made of different dimensions, the length of each being 10 cm, the diameter 2 cm, and each helix consisting of 31 turns of No. 20 copper wire. The determinations made with these cells were in agreement with those made with the original cells.³ The dimensions of the cells, therefore, do not affect the results, a conclusion which is also supported by other variations of the apparatus mentioned in the sequel.) N_1 and N_2 are Nicol prisms, L is a converging lens and F is a Wratten color filter which transmits light practically monochromatic. T_1T_1 and T_2T_2 are conducting trolleys (strips of brass) which may be shifted back and forth along the lead wires indicated in the diagram, thus changing the lengths of the divided circuits $PT_1B_1T_1P$ and $PT_2B_2T_2P$. This movement of the trolleys is effected by means of a hand wheel mechanism operated by the observer at E .

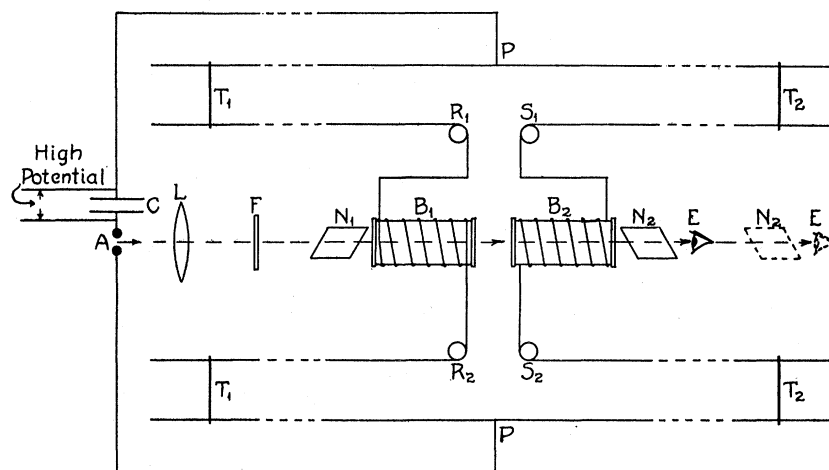


Fig. 1. Diagram of apparatus and connections.

The currents traverse the coils or helices about B_1 and B_2 in opposite directions and establish opposing magnetic fields in the two cells. If, now, the divided circuits $PT_1B_1T_1P$ and $PT_2B_2T_2P$ are such that they are traversed by equal and symmetrical electric impulses when the condenser discharges across A , we shall have the magnetic fields in B_1 and B_2 equal in magnitude and opposite in direction at every instant during their growth and decay. When this condition is realized, the magnetic rotation in one cell is, for any one liquid, completely neutralized by that in the other. This adjustment is attained by first crossing the Nicols N_1 and N_2 and then displacing the trolleys T_1T_1 and T_2T_2 until the light from the spark is completely extinguished by N_2 , when both B_1 and B_2 are filled with the same liquid.

Observations are carried out in the following manner. With B_1 and B_2 temporarily removed, N_2 is rotated until the light from the spark A , made

³ It should be noted that in very long cells the variation of the refractive index of the liquids with the wave-length of light might in some cases be appreciable, requiring a slight correction in the results.

plane-polarized by N_1 , is extinguished. B_1 and B_2 are then filled with, say, carbon bisulphide and replaced in the positions indicated in the diagram. As T_1T_1 or T_2T_2 are moved forward and backward, a point is passed at which the light is completely extinguished to an observer at E . This point of extinction is attributed to the fact that equal and opposite magnetic fields in B_1 and B_2 are applied and relaxed nearly simultaneously (or, more exactly, the field in B_2 is always behind the field in B_1 by a time equal to the distance between the centers of the cells divided by the velocity of light) and therefore that the magnetic rotation in B_1 is annulled by that in B_2 .

Carbon bisulphide in B_2 is then replaced by one of the other liquids, toluene, for example, the source of light (the zinc spark lines 4912, 24A), as well as all adjustments, remaining unchanged. Light now passes N_2 . But if B_2 is moved backward in the line AN_1N_2 (N_2 is now in the dotted position in order to permit the displacement of B_2 and is always kept crossed with N_1) a distance of 81 cm, a minimum of light passes the Nicol N_2 . In other words, as B_2 is moved back and forth, a distinct minimum appears when its displacement from its original position is 81 cm. (The light is not wholly extinguished because the Verdet constant is different for the two liquids.) This observation means that for this particular wave-length the Faraday effect lags behind the magnetic field longer in toluene than in carbon bisulphide by an interval of 2.7×10^{-9} sec. When the spark line Mg 4481A was used, the minimum appeared when B_2 was moved back a distance of 102 cm, giving a time-lag of 3.4×10^{-9} sec. Similarly, the minimum was found for the Cd 5338, 78A spark lines when B_2 was displaced toward E a distance of 33 cm, corresponding to a difference in lag of 1.1×10^{-9} sec. For the D -lines of sodium the displacement of B_2 was only 18 cm, or the time-lag difference was only 0.6×10^{-9} sec. Observations were made in the same manner with other wave-lengths and other pairs of liquids.

In the foregoing method the minima are located by keeping T_1T_1 and T_2T_2 fixed and moving the cell B_2 . Determinations of the time-lag difference may also be made with almost the same precision by keeping B_2 fixed in its original position and moving one of the trolleys T_1T_1 or T_2T_2 until the minimum appears. As a representative example of this method, we may refer again to the case of carbon bisulphide and toluene in B_1 and B_2 , respectively, with the Mg 4481A spark line as source. The light was found to pass through a minimum when T_2T_2 were displaced toward P a distance of 99 cm. This means that the path of the electric impulse along the straight copper wires is shortened in the branch containing B_2 by 99 cm and consequently that the magnetic field in B_2 is in advance of the field in B_1 by a time required for the electric impulse to travel 99 cm along the bare wires. The same result is obtained if T_1T_1 are moved a distance of 99 cm away from P , T_2T_2 remaining in the original position. It will be noted in the example just cited that the wire-path method gives a value of the time-lag difference 97% of that given by the air-path method. This percentage is itself of interest, in that it represents a direct measurement of the ratio of the speed of the electric impulse in the given wires to the speed of light in air. In as much as the time-

lag differences measured by the air-path and the wire-path methods were found to agree within three or four percent, the latter method has something to recommend it because of the ease and rapidity of locating minima by the displacement of the trolleys instead of the displacement of the cell.

The results of the measurements for the various wave-lengths and liquids are recorded in Table I. Each value is the mean of a number of observations which were taken at different times and with variations in the resistance, capacitance and inductance of the circuit. These changes showed

TABLE I
Lag of the Faraday effect in various liquids behind the lag in carbon bisulphide.

Source	Toluene C ₇ H ₈	Carbon Tetrachlorid CCl ₄	Benzene C ₆ H ₆	Xylene C ₈ H ₁₀	Chloroform CHCl ₃	Bromoform CHBr ₃
	seconds	seconds	seconds	seconds	seconds	seconds
Mg 4481A	3.4×10^{-9}	4.6×10^{-9}	5.5×10^{-9}	7.3×10^{-9}	8.3×10^{-9}	12.2×10^{-9}
Zn 4722, 4811A	3.2×10^{-9}	4.4×10^{-9}	4.9×10^{-9}	6.4×10^{-9}	7.2×10^{-9}	9.8×10^{-9}
Zn 4912, 24A	2.7×10^{-9}	3.3×10^{-9}	3.5×10^{-9}	4.4×10^{-9}	4.6×10^{-9}	6.6×10^{-9}
Mg 5173, 83A	2.1×10^{-9}	2.6×10^{-9}	2.5×10^{-9}	3.1×10^{-9}	3.3×10^{-9}	4.2×10^{-9}
Cd 5338, 78A	1.1×10^{-9}	1.1×10^{-9}	1.1×10^{-9}	1.3×10^{-9}	1.7×10^{-9}	2.2×10^{-9}
Na 5890, 96A	0.6×10^{-9}	0.6×10^{-9}	0.6×10^{-9}	0.8×10^{-9}	1.2×10^{-9}	1.2×10^{-9}
*Verdet Constant in minutes $\lambda = 5890\text{A}$	0.0269 (28°C)	0.0321 (15°C)	0.0297 (20°C)	0.0221 (15°C)	0.0164 (20°C)	0.0317 (15°C)

* From the Smithsonian Tables.

no effects on the minima, the time-lag differences obtained under different conditions being in very close agreement. The time interval in each case is the Faraday lag in the specified liquid behind the lag in carbon bisulphide. Observations were also carried out with different pairs of the liquids, as checks on the results, all of which gave consistent values of the time-lag differences.

Each determination recorded in the table was done by both the air-path and the wire-path methods. The results were in consistently closed agreement throughout, showing on the average a lag by air-path about three or four percent greater than by wire-path, or that the speed of the electric impulse in the wire is about 96% or 97% of the speed of light in air. The measurements can be repeated with a precision of about 0.2×10^{-9} sec., depending upon the liquids and upon how nearly the source is monochromatic. The greatest uncertainty attended the location of minima with the Zn 4722, 4811A lines. In many cases, however, the setting on a minimum may be repeated a number of times within 1 cm or 0.3×10^{-10} sec.

It was thought that the presence of the liquids in B_1 and B_2 might possibly exert retardations upon the flow of the electric impulses through the divided circuit, of a different amount for each liquid, which would account, in part at least, for what appeared to be a lag of the Faraday effect. In order to detect the existence of such a retardation four dummy cells, wound with

helices and similar in all essentials to B_1 and B_2 , were constructed. Two of these were connected in series in each branched circuit, designated in the diagram by R_1 , R_2 and S_1 , S_2 . If the liquids should exert different retardations upon the electric impulses, the effect would be shown by a change in the setting of B_2 (or T_1T_1 or T_2T_2) on the minimum observed before and after the dummy cells are filled with the different liquids, all other adjustments remaining unchanged. Various tests were made with different combinations of liquids, without any observed effects, the minimum persisting in each case. It was therefore concluded that the liquids do not contribute any influence to the rate of flow of the electric current in the branched circuit.

There are two facts disclosed in these experiments which may account, to some extent, for the failure of other observers to detect a measurable lag in the Faraday effect. One is that the liquid showing the smallest lag is carbon bisulphide, which has usually been the liquid employed in the observations. The other is the fact that the lag is very small for the longer wave-lengths, with which the observations have usually been made.

It will be noted that the time-lag differences herein reported for the zinc spark lines 4912, 24A are larger than those found by Beams and Allison. The discrepancy is to be accounted for by certain refinements in the present method whereby the location of minima are made with greater certainty, along with the use of more nearly monochromatic light.

A temperature effect in the Faraday lag was looked for in carbon bisulphide, toluene and chloroform. A setting on the minimum was made in the usual manner with B_1 and B_2 filled with the liquid, both cells being at the same temperature. The cells were then emptied and refilled with the same liquid, but from vessels kept at different temperatures, one about 40°C above the other. The minimum had not changed, showing therefore no measurable temperature effect.

Oscillations in the circuit were found experimentally not to exist, or at any rate to be too feeble to show any effects.

My acknowledgement is made with pleasure of much indebtedness to Dr. J. W. Beams, National Research Fellow, who suggested this investigation and who has made valuable suggestions during the progress of the work. I wish to thank Professor L. G. Hoxton for his interest in the work and for the loan of equipment.

ALABAMA POLYTECHNIC INSTITUTE,
April 13, 1927.