ON TIME-LAGS IN FLUORESCENCE AND IN THE KERR AND FARADAY EFFECTS

By E. Gaviola

Abstract

A critical study of the experimental literature is made in regard to the existence of time-lags or "dark-times" in fluorescence and it is found that not a single experiment shows the existence of such things. Moreover experiments seem to show that in all the cases when the emitting state is the state reached directly as a result of the excitation process, the emission begins immediately upon excitation and decreases exponentially. Experiments interpreted as showing the existence of time-lags in the Kerr and Faraday effects are also considered and it is found that they do not prove the reality of such time-lags. An analysis is made of the way in which the "optical shutter" of Beams' works, with the result that it is found to behave quite differently from what it was supposed to do. Wave trains of light that were supposed to be cut off by it in parts of 3 cm length are certainly not reduced to less than 300 cm, or 100 times more than assumed.

Introduction

IT IS common to find in the literature references to time-lags or "dark-times" in fluorescence and the names of R. W. Wood, Gottling, Vavilov and Lewshin, Hoxton and Beams, W. Wien, and others are mentioned as having proved experimentally the existence of such "dark-times" between the moment of excitation and the beginning of emission for different fluorescent substances. The assumption made in most of the cases is that if one illuminates a fluorescing substance for a very short time, the substance will remain dark for a certain finite time after excitation, "bursting then into luminosity," luminosity which will decrease exponentially; and this assumption is supposed to be supported by many experimental results. The purpose of the present paper is to examine the experimental material in connection with time-lags in fluorescence and to see how far the mentioned assumption is justified. The investigation indicates there is not a single experiment which has shown the existence of "dark-times" in fluorescence, when the state reached due to the excitation is the state directly responsible for the emission of the light observed. Even when this last condition is not fulfilled, the emission always begins at the moment of excitation.

The Origin of the Idea of Time-Lags

In the classical theory there is no possibility of time-lags in fluorescence: If a classical oscillator is excited at a given moment, it will begin to emit radiation (if capable of doing so) at the very time of excitation and the intensity of the radiation will decrease exponentially with time, because of the damping of the oscillator.

The Bohr atom, with its stationary states in which the electrons could remain for some time without radiating, gave rise to the possibility of con-

ceiving the existence of "dark-times." In fact, the statement that the excited stationary states had a measurable mean life was often misinterpreted in the sense that *most* atoms, if not all, would remain in the excited state during the said mean life and then fall to the normal level emitting radiation. Curiously enough, this misinterpretation seemed to be supported by the extinction-curves of canal-beams as obtained by W. Wien and especially by an experiment of R. W. Wood.

The Extinction-curves of Canal-beams

As is well known, W. Wien[1] has repeatedly measured the intensity of light emitted by a canal-beam when it enters a vacuum as a function of the distance from the canal, or, what amounts to the same, as a function of the time after traversing the canal. The extinction-curves that he found originally were not exponential in the neighborhood of the canal: the intensity seemed to increase at first up to a certain maximum and then to decrease exponentially. This unexpected result gave rise to interesting theories of Mie[2] and Stark,[3] which with some assumptions about the emission-process of light, explained the increase found beyond the canal. This increase has later been shown to be due wholly to defective experimental conditions and a recent investigation[4] made in W. Wien's laboratory, in which the experimental difficulties were eliminated, has shown that the extinction-curve of canal-beams in vacuum is an exponentially falling line from the very beginning and that there is no increase in intensity after passing the canal. This result makes it unnecessary to consider the theories of Mie and of Stark.

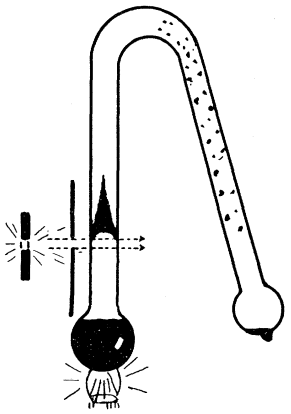

Fig. 1. Wood's experimental arrangement for showing "dark time" in mercury fluorescence.

The Experiment of R. W. Wood

R. W. Wood[5] performed in 1921 a very interesting experiment, which was generally accepted as a proof of the existence of "dark-times" at least in some special cases. His experimental arrangement is reproduced here in Fig. 1. An inverted quartz U-tube contains liquid mercury in one side, which is heated by a bunsen burner. Mercury evaporates in this side, rises with considerable velocity (about 10 m per sec.) and condenses on the walls of the other side of the U-tube. A narrow region of the rising vapor is illuminated by an aluminum spark as shown in the figure. It is known that mercury vapor at sufficient density illuminated by an aluminum spark emits

[1] Wien und Harms, Handbuch d. Experimentalphysik **14**, 706.
[2] G. Mie, Ann. d. Physik **66**, 237 (1921).
[3] J. Stark, Ann. d. Physik **49**, 731 (1916).
[4] J. Port, Ann. d. Physik **87**, 581 (1928).
[5] R. W. Wood, Proc. Roy. Soc. **A99**, 362 (1921).

a blue-green fluorescence which can be easily seen with the naked eye. Now, Wood found that this green fluorescence was carried away from the illuminated zone by the rising vapor and that the maximum of it occurred a few millimeters above the primary light-cone. The green fluorescence appeared in the form of a flame, as indicated in Fig. 1. Let us consider now what one should expect in a case like this: It is known that mercury vapor has an absorption-band at about 1850A, which is certainly due to molecular mercury, and that light of the spark absorbed in this region is responsible for the emission of the green fluorescence. The absorption of the 1850A quant will bring the molecule to an excited state which will correspond to the level 2^1P_1 of the atom. On the other hand, it is known that the green fluorescence is emitted by molecules in an excited state corresponding to one of the 2^3P levels, probably 2^3P_1 of the atom. Before the green band can be emitted a process must occur which brings the excited molecule from the state corresponding to the 2^1P_1 level to the state corresponding to the 2^3P_1 level. This process may be a radiation jump, it may also be the result of collisions of the second kind. Fig. 2 illustrates the case. The levels indicated are not to be understood as levels of the atom, but as corresponding levels of the molecule where they are certainly multiple because of oscillation and rotation. The case we are considering is similar to a well-known one in radioactivity: If we start with a substance A which after a mean life τ_1 gives birth to a second substance B, which on its side decomposes after a mean life τ_2 emitting a certain radiation, and if we have at the beginning the substance A alone and observe the growing in the amount of B as a function of the time by measuring its radiation, we will find that B starts growing at the moment zero, reaches a maximum at a time

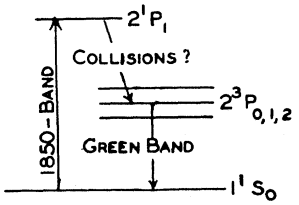

Fig. 2.

$$t_m = [\tau_1\tau_2/(\tau_1-\tau_2)]\cdot ln\tau_1/\tau_2 \qquad (1)$$

and decreases again more or less exponentially. The amount of B is given by the formula

$$N_B = N_A{}^0(e^{-t/\tau_1}-e^{-t/\tau_2})[\tau_2/(\tau_1-\tau_2)]. \qquad (2)$$

These formulas are to be found in any treatise on radioactivity and are illustrated in Fig. 3.

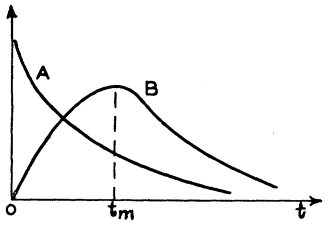

Fig. 3.

We should expect then the green band in the case of Wood to behave like the substance B in the radioactive case: The green fluorescence should start at the moment of excitation, it should grow to a maximum at a time given by formula (1) if τ_1 and τ_2 mean now the mean life-times of the levels of 2^1P_1 and 2^3P_1 of the molecule respectively,* and should decrease afterwards more or less exponentially. Now in the flame drawn in Fig. 1, its lower limit is

* One of these two levels of the molecule, or both, seem to be metastable.

sharply separated from the illuminated region, but it is not so in the photographs reproduced in Prof. Wood's paper (see Figs. 4 and 5, Plate 5, reference 5), we can see there that the green flame really starts in the illuminated region and that its intensity distribution along the axis of the tube can be well accounted for by formula (2). Figs. 6 and 7 in Wood's paper, which have often been believed to be photographs, are in reality drawings made after subjective observation and the absolutely dark spaces between excitation and maximum of emission indicated in the drawings are certainly optical illusions due to the effect of contrast.

The delay in the appearance of the green fluorescence in the case of Wood is due then to the fact that the state which emits it is not the level reached as a result of the excitation, and the slow increase of the intensity at first indicates the growing number of molecules in the said state. The results of Wood can be readily interpreted without assuming the existence of any "dark-times" or time-lags in fluorescence.

The Experiment of Gottling

Using the arrangement of Abraham and Lemoine for the measurement of short times of fluorescence, as suggested by Wood, Gottling[6] attempted to determine the extinction-times of the fluorescence of rhodamine and barium-platino-cyanide. He obtained some values which he interpreted as time-lags in the fluorescence of the substances. Now, with the arrangement used by Gottling the only thing that can be measured is the displacement in time of the center of gravity, so to say, of the emission in regard to the absorption, but nothing can be said about the form of the emission-curve. The values obtained by Gottling could as well be interpreted as mean extinction-times of exponentially falling emission-curves. But these values were falsified by the fact that Gottling did not take into consideration the color-dispersion of the Kerr effect, and when he tried to measure time-lags he was really determining the different values of the Kerr effect for the blue light of the spark, the red light of rhodamine, and the green one of barium-platino-cyanide.[7]

The Experiments of Beams, Brown, Hoxton, Rhodes, Allison, Lawrence and Locher

We shall consider now a group of thirteen publications by the authors mentioned above, in which they claim to have found and measured "dark-times" and time-lags for the appearance of the lines in the spark, for fluorescence, and for the Kerr and Faraday effects in different liquids. These publications can be divided into three groups according to the experimental devices used in determining the time-lags. To the first group belong the ones

[6] S. I. Vavilov and W. L. Lewschin, Zeits. f. Physik **35,** 920 (1926).

[6] Gottling, Phys. Rev. **22,** 566 (1923).

[7] Compare E. Gaviola. Ann. d. Physik **81,** 681 (1926); Zeits. f. Physik **42,** 853, 862 (1927).

in which a single Kerr cell is used, placed between crossed nicol-prisms, which, charged by a transformer to high voltage, discharges through a spark gap; to the second one belong the experiments made with the "optical shutter" of Beams; and to the third one the determination of lags in the Faraday effect.

First Group.—The apparatus used is a modification of the one of Abraham and Lemoine[8] and is shown schematically by Fig. 4. The Kerr condenser, K, placed between crossed nicols N_1 and N_2 is charged to a certain potential by a transformer or by an electrostatic machine, and discharges through the spark gap S. The light of the spark is observed directly or after reflection in mirrors through the shutter N_1KN_2. Instead of the eye a spectrograph can be placed behind N_2. The lines of the spark will be seen or not, depending on the length of the light-path before they cross the shutter and on the capacity and self-induction of the circuit. It was found[9] that the different lines emitted by the spark appear in a certain succession, the air-lines first, the spark-lines later, and the arc-lines last. It was also found that there was a difference in the time of appearance of different spark-lines and of different arc-lines among themselves. The times measured ranged from 0.2 to 15×10^{-8} sec. Now, these results can be readily interpreted without assuming the existence of any time-lags in fluorescence. That the air-lines appear first is obviously due to the fact that the spark-discharge must begin by ionizing and exciting the air between the electrodes, after which metal from the electrodes will evaporate as a result of local heating and it will be ionized and excited by collisions. Since the spark-lines of the metal appear sooner than the arc-lines, it seems that at first most metal atoms are ionized and that it takes some time before they recombine and have a chance of emitting arc-lines. The fact that different spark-lines and arc-lines do not appear simultaneously among themselves can be easily understood by applying the same considerations that were used for explaining the experiment of Wood. An explanation in detail of the sequence of appearance of the lines can not yet be attempted because the quantitative measurements are not reliable. They are mostly calculated upon the assumptions that the Kerr condenser discharges suddenly (instantaneously) a certain time after the beginning of the spark, which is given by the length of wire between spark and condenser divided by the velocity of light; that a capacity-induction circuit does not oscillate even if there is no appreciable resistance in it, and that a Leyden jar connected in parallel with the spark-gap does not modify the time at which the condenser discharges. These three assumptions

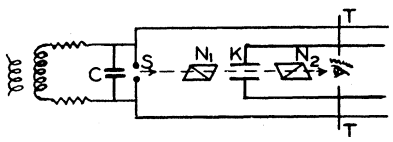

Fig. 4. Diagram of apparatus used to measure "dark time" and "time-lags."

[8] Abraham and Lemoine, C. R. **129,** 206 (1899).

[9] F. L. Brown and J. W. Beams, J. O. S. A. **11,** 11, (1925); J. W. Beams, Phys. Rev. **27,** 805 (1926), **28,** 475 (1926); J. W. Beams and P. N. Rhodes, ibid. **28,** 1147 (1926); G. L. Locher, J. O. S. A. **17,** 91 (1928).

are obviously incorrect and falsify the measurements. Furthermore, there is not sufficient consideration paid to the very large color dispersion of the Kerr effect. The fact that Beams finds that different terms of the same multiplet appear at different times may be due in part to this and in part to the method of measurement which was by changing the light-path, or the wire-length, until a line appeared or disappeared, the time of which will depend (since the Kerr condenser discharges in reality rather slowly) on the sensitivity of the eye or plate and on the intensity of the particular line. Moreover Locher found recently that multiplet-lines appear together.

Another experiment made with the same arrangement of Fig. 4 in a slightly modified form was performed by Hoxton and Beams[10] in order to measure the extinction-time of the fluorescence of solutions of fluorescein. They found a time $(3.2\pm0.3)\ 10^{-8}$ sec. for an aqueous solution and interpreted it as the "time elapsing between the beginning of incidence and the beginning of fluorescence emission." The considerations applied to the experiment of Gottling have here full validity and need not be repeated. This measurement is also not free from the objections outlined above. Furthermore, the extinction-time of fluorescein in water has been determined by Gaviola who found $(4.5\pm0.5)\ 10^{-9}$ sec. for it, a value confirmed by a quite independent calculation of Perrin[11] who found 4 to 6×10^{-9} sec. The value measured by Hoxton and Beams is then about six times too large and indicates by no means the existence of a time-lag in fluorescence.

Second group: The optical shutter of Beams.—We shall consider here a group of experiments made with the so-called "optical shutter" of Beams. The shutter was originally defined as "a method of obtaining light-flashes of uniform intensity and short duration" and it was assumed to "open abruptly, remain open any desired time from 10^{-9} to 10^{-7} seconds and then close abruptly."[12]

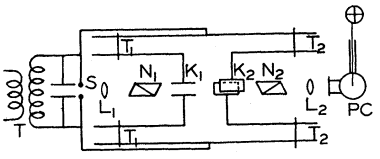

Fig. 5. The optical shutter of Beams.

Fig. 5 shows the experimental arrangement used. Two identical Kerr cells, K_1 and K_2 are placed, one inclined 90° to the other, between crossed nicols N_1 and N_2. Light of the spark S, or of a steady light-source placed instead of it, will not pass the optical system $N_1K_1K_2N_2$ as long as the electrical fields in K_1 and K_2 are equal, owing to the fact that the difference of phase produced by K_1 on the light will be compensated by K_2. If the fields in K_1 and K_2 are different, light will pass the system and fall for instance upon the photocell PC. The shutter was originally supposed to work in the following way: The transformer T will charge the two cells K_1 and K_2 to equal potentials until the spark S strikes, before which moment no light will pass the shutter, since the two cells will compensate; at a time $t_1=l_1/c$ (where l_1 is the total length of wire from the

[10] L. G. Hoxton and J. W. Beams, Phys. Rev. **27,** 245 (1926).
[11] F. Perrin, C. R. **182,** 219 (1926).
[12] J. W. Beams, J. O. S. A. **13,** 597 (1926).

spark S to the cell K_1 and c the velocity of light) after the spark strikes the condenser K_1 will discharge abruptly; at a time $t_2=l_2/c$, where l_2 is the length of wire to the second cell, K_2 will discharge abruptly. If $l_1=l_2$, the two cells will discharge at the same time and no light will pass the shutter, but if l_2 is for instance longer than l_1, the second cell will discharge (abruptly) a certain time $\Delta t=t_2-t_1$ later than the first. During this time Δt the electric field will be present only in cell K_2 and light incident upon the system will be able to pass through it. This time Δt, during which the shutter is open, is then $\Delta t=(l_2-l_1)/c$ and can be varied at will by changing the positions of the trolleys T_1 and T_2.

As we see, the assumptions made in the above reasoning of Beams were: First, "that the fall of potential travels along the lead wires at about the velocity of light"; second, that a change Δl in the length of the wire will change the time at which the condenser discharges "abruptly" by $\Delta t=\Delta l/c$, and third that a spark circuit with capacity and self-induction will not oscillate even if there is not sufficient resistance in it to damp out the oscillation.

That these assumptions were incorrect has been recognized by Beams and Lawrence themselves who in a recent publication[13] make an approximate calculation of the way in which the shutter works under the assumption that the discharge of the Kerr cells occurs aperidocially with a time constant α ($1/\alpha$ is the time in which the field decreases to $1/e$). The same calculation in a more exact form has been repeated by v. Hámos,[14] who assumes also aperiodic discharge. Both authors come to the conclusion that the shutter neither opens nor closes abruptly and that the time during which it remains open does not depend in first approximation on the position of the trolleys. Only the total light intensity allowed to pass through depends on it. The curves published by v. Hámos in Fig. 3 of his paper show that the duration of the opening of the shutter is of the magnitude of $1/\alpha$ if we define arbitrarily this duration as the time between the beginning of the opening and the instant at which the light let through decreases to $1/e$ of its maximum value. Now Beams and Lawrence show that their previous results can be accounted for by assuming $1/\alpha=10^{-8}$ sec. in spite of which they state later (p. 177) that "the shortest flashes produced were more probably of the order of magnitude of 10^{-9} sec." The value of α found by Beams and Lawrence applied to the curves of v. Hámos would indicate a value ten times larger.

Beams and Lawrence and v. Hámos find also that the apparent time-lags of the Kerr effect measured before[15] were all probably due to the differences in the dielectric constants of the substances which produced differences in the capacities of the cells and with them also in the duration of their discharges.

[13] J. W. Beams and E. O. Lawrence, Jour. Franklin Inst. **206**, 169 (1928).

[14] L. v. Hámos, Zeits. f. Physik **52**, 549 (1928).

[15] J. W. Beams and F. Allison, Phil. Mag. **3**, 1199 (1927); J. W. Beams and E. O. Lawrence, Proc. Nat. Acad. Sci., **13**, 505 (1927).

Now the calculations mentioned above are based on the assumption of an aperiodic discharge of the Kerr cells. This assumption requires the existence of suitable resistances in the circuits, resistances which, according to the statements of Beams and Lawrence were not present (pp. 166 and 177). Moreover they point out that "the discharge, instead of falling off exponentially, ... was less rapid initially and more rapid in its later stage." All of this makes certain that the discharge in the shutter was actually a periodic oscillation with a certain damping coefficient. Furthermore, Locher detected actual oscillations in his circuit with a wave meter, but he disregarded them because their period seemed to him too long to affect the working of the apparatus. The period was on the contrary of the order of magnitude that one may expect for the oscillatoric discharge of the Kerr cell. It is necessary, therefore, to analyze how the shutter works in the case of a periodic damped oscillation under the conditions that actually existed in the original experiments.

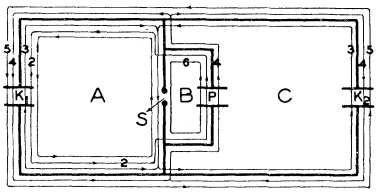

Fig. 6. Diagram of electrical circuit in the optical shutter of Beams.

Figure 6 shows a diagram of the electrical circuit. K_1 and K_2 are the Kerr condensers, S the spark-gap, and P the Leyden jar connected parallel to it. As we see, we have three circuits A, B, and C, coupled together and they will be capable of oscillating in many different ways. The thin lines drawn in Fig. 6 indicate the possible oscillation affecting directly the Kerr condenser K_1. As is well known, in a spark-discharge circuit every possible oscillation does actually take place with its own amplitude and frequency, which can be calculated knowing the capacities, inductances, and resistances of the circuit. Since the ohmic resistances of the circuit were probably low, all the indicated oscillations were certainly periodic with a certain damping coefficient. Let us consider some of the oscillations: Oscillation 1 is the discharge of the Kerr condenser K_1 through the spark S; oscillation 2 is the discharge of the same through the large capacity P; oscillation 6 is the discharge of the Leyden jar P through the spark S, which will probably be of large amplitude and induce a forced oscillation of the same frequency upon the circuit A, and so on. The discharge of the Kerr condenser K_1 will then be determined by the superposition of six periodic damped oscillations, each of them with its own frequency and amplitude. Not knowing the inductances and resistances of the circuit (they have not been published), we can not calculate the amplitude of each of the oscillations and so we can not know which of them will be strongest and which can be neglected, but we can try to eliminate some of them by general considerations. Oscillation 5 will be surely weak, 6 will be strong as said before and have a long period, but we may arbitrarily assume that the induced forced oscillation upon K_1 be of small amplitude and thus eliminate these two. But oscillations 1, 2, 3, and 4 will probably be of comparable amplitude, and none of them should be neglected. Of these four 1 has the shortest period and is the only

one that has been considered by the authors working with the shutter. The fact that Locher found that a change in the inductance connecting the jar P with the spark S increased the values he was measuring up to five times, indicates that the main oscillation in his case was 2, or 4, or 6, all of which have a longer period than 1. But let us assume the most favorable case for the quick closing of the shutter, let us assume that only oscillation 1 affected the Kerr cell K_1 and let us make a similar assumption for the Kerr cell K_2. The period of oscillation 1 can not be exactly calculated because the inductance of the circuit has not been published but one can estimate, according to the dimensions of the apparatus, that the inductance, L, was of the order of 10 microhenries. The capacity of the condenser K_1 was of about 5 cm and the capacity of the wires of about 20 cm so that the period will be approximately $T=2\pi(LC)^{1/2}=10^{-7}$ sec. Let us consider now how the cells will discharge: If we limit ourselves to the consideration of the first quarter period of the oscillation, that is, to the first breakdown of the field in K_1 we can assume that the electric field E_1 in the cell will diminish following a sine curve

$$E_1=E_1^0 \sin\left[(2\pi t/T)+\pi/2\right] \tag{3}$$

Now, the amount of light passing the shutter at a given moment will be

$$J=A \sin^2 \alpha/2 \tag{4}$$

if α is the resultant phase-difference produced by both Kerr cells (see Fig. 6), which is given by

$$\alpha=2p(E_2^2-E_1^2) \tag{5}$$

where p is a constant and E_2 the field in the cell K_2, therefore

$$J=A \sin^2\left[p(E_2^2-E_1^2)\right]. \tag{6}$$

In Fig. 7 curve 1 represents E_1^2 as a function of the time and it gives the decrease of the square of the field in the cell K_1. If the trolleys T_1 and T_2 (Fig. 6) are placed symmetrically the cell K_2 will discharge also following curve 1 and the difference of phase α will be constantly equal to 0 and so will the light-intensity J. If we displace now the trolley T_2 a certain amount, say 83 cm, the cell K_2 will *begin* to discharge $83/c$ sec. later than K_1, that is, the phase of the discharge in K_2 will have a delay of $83/c$ sec. At the same time the self-induction of the circuit of K_2 will increase and with it the period of the discharge, but since a small change in the position of the trolley will produce a still smaller change in the self-induction and since the period changes only with the square root of the self-induction, a small change in the position of the trolley will in first approximation not modify the period of the discharge. The square of the field in K_2 will be given then by curve 3 (Fig. 7), which is the same curve 1 displaced 83 cm to the right. The curve "diff.(3–1)" of Fig. 8 gives the difference $E_2^2-E_1^2$ as a function of the time in a five-times larger scale, difference to which α is proportional

[formula (5)]. The curve "$J(3-1)$" indicates the light-intensity which will pass the shutter according to formula (6). We see that light will pass practically during the whole time that the condensers take to discharge. Let us consider now what happens if we reduce the difference in the positions of the trolleys to 25 cm: Curve 2 will represent now E_2^2, curve "diff.(2–1)" the difference $E_2^2-E_1^2$ and curve "$J(2-1)$" the light-intensity which will pass the shutter. As we see the total intensity allowed through has diminished but not the time during which the shutter remains open. The bringing of 2 still nearer to 1 will flatten down curve J. All this means is that the displacement of the trolleys will in first approximation not change the time during which the shutter remains open but only the total light-intensity

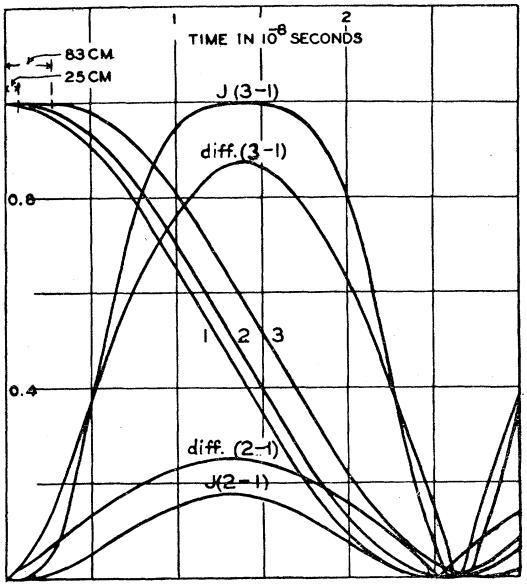

Fig. 7.

allowed through, and that in no case will the shutter remain open for less than about 10^{-8} sec.

The optical shutter behaves then in quite a different way from what it was originally supposed to do and since the fundamental assumptions upon which all measurements made with it are based are incorrect, every result obtained with it has to be considered as doubtful. So, for instance, in a paper "On the nature of light"[16] it is claimed that trains of light-waves have been cut in pieces of 3 cm of length, while we have seen that the shutter can by no means reduce the length of a wave-train to less than 300 cm, or one hundred times more than what the authors claim.

In a recent paper on "The element of time in the photoelectric effect,"[17] assumptions are made which can not be regarded as free from the con-

[16] E. O. Lawrence and J. W. Beams, Proc. Nat. Acad. Sci. **13**, 207 (1927).
[17] E. O. Lawrence and J. W. Beams, Phys. Rev. **32**, 478 (1928).

siderations outlined above in connection with the optical shutter. None of the experiments of this group proves then the existence of any time-lags.

Third group. Using an arrangement similar to the optical shutter, in which the two Kerr cells are substituted by Faraday cells, Beams and Allison find time-lags for the Faraday effect in various liquids. In a first publication[18] values for the time-lags are found which are reproduced in the second column of Table I.

TABLE I

Substance	Time-lag in seconds according to Beams and Allison	Allison
$C Cl_4$	$(1.1 \pm 0.3)10^{-9}$	$(3.3 \pm 0.2)10^{-9}$
Benzene	$(1.9 \pm 0.3)10^{-9}$	$(3.5 \pm 0.2)10^{-9}$
Xylene	$(2.1 \pm 0.3)10^{-9}$	$(4.4 \pm 0.2)10^{-9}$
Chloroform	$(2.4 \pm 0.3)10^{-9}$	$(4.6 \pm 0.2)10^{-9}$
Toluene	$(2.5 \pm 0.3)10^{-9}$	$(2.7 \pm 0.2)10^{-9}$
Bromoform	$(4.1 \pm 0.3)10^{-9}$	$(6.6 \pm 0.2)10^{-9}$

In a second publication by one of the same authors[19] which appeared a few months later, the lags reproduced in the third column are found for the same substances under the same conditions. As we see the differences between both measurements are about ten times larger than the limits of error indicated and are of the order of magnitude of the quantities measured themselves. Since no explanation is offered for the divergence, these results can not be considered as proving the existance of time-lags in the Faraday effect.

SUMMARY

(*a*) The idea of the existence of time-lags in fluorescence was probably conceived because of a misunderstanding of the concept introduced by Bohr, that excited atoms can live for finite time without radiating.

(*b*) The extinction-curve of the light emitted by canal-beams has now been established by J. Port to be an exponentially falling curve from the very beginning.

(*c*) The experiment of Wood with streaming mercury vapor, which was accepted as a proof of the existence of "dark-times," is explained as due to the fact that the light observed is emitted by a state which is not directly reached as a result of the excitation. It is shown that there is no real "dark-time" even in this case.

(*d*) The time-lags measured by Gottling were in reality mainly due to the color dispersion of the Kerr effect.

(*e*) The successive appearance of different lines in the spark can be readily understood without the assumption of time-lags. A detailed explanation could be attempted if the quantitative material were more reliable.

[18] J. W. Beams and F. Allison, Phys. Rev. **29,** 161 (1927).

[19] F. Allison, Phys. Rev. **30,** 66 (1927).

(*f*) The time-lags measured by Hoxton and Beams for the fluorescence of liquid solutions were probably due to color dispersion of the Kerr effect, as in the case of Gottling, and to an inaccurate method of measuring and calculating.

(*g*) The optical shutter of Beams which was supposed to "open abruptly, remain open any desired time from 10^{-9} to 10^{-7} seconds and then close abruptly" is analyzed and found to open and close during a time of the order of 10^{-8} sec. and to remain open for at least 10^{-8} sec. in the best case. The time during which it remains open does not depend in first approximation on the position of the "trolley" as was assumed.

(*h*) The former result indicates that in the experiment of Lawrence and Beams where it was claimed that light wave-trains were cut in pieces of 3 cm length by the optical shutter the wave-trains were really not shortened to less than 300 cm in the best case.

(*i*) The time-lags found for the Kerr effect in liquids with high dielectric constants were probably due to the fact that increase in dielectric constant means increase in the capacity of the Kerr condenser and with it of the time that it takes to discharge.

(*j*) The time-lags measured by Beams and Allison for the Faraday effect can not be considered as proving the existence of the said lags.

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