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ON THE NATURE AND DURATION

OF THE

DISCHARGE OF A LEYDEN JAR CONNECTED WITH AN INDUCTION COIL.

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Part 1st.

When the terminal wires of an induction coil of sufficient size are connected with the exterior and inner coating of a Leyden jar, it is well known that the act of breaking the primary current charges the jar with electricity, and that a discharge will take place if the distance between the electrodes is not too great, otherwise the union of the two electricities is effected backward in the coil itself. The brightness of the light, and the ease with which it is generated, render it the most convenient means in our possession for the production of a nearly instantaneous illumination, while its richness in the violet and ultra-violet rays, make it suitable for experiments on fluorescence and phosphorecence. Before, however, it can become useful for these and other delicate investigations, involving the apprecation of minute intervals of time, it is of course necessary that the nature and duration of the discharge itself should be studied, a matter which, so far as I know, has thus far not received attention.

The case of a jar charged by an ordinary frictional machine is quite different from the above: here, during the act of charging and discharging, the two metallic coatings of the jar are entirely insulated, while when the induction coil is used in the manner above indicated, these coatings are during both acts in metallic connection, a circumstance which alone might be supposed to modify the duration of the discharge and its nature; besides this, it is known that the electricity from the coil continues to flow for a considerable fraction of a second along the terminal wires into the jar, which fact renders it questionable whether the duration of the discharge of the jar itself may not be proportionately lengthened. Hence it is evident that it would not be safe to conclude without experiment, that the results obtained by Feddersen with jars charged by ordinary frictional electricity, were applicable to those connected with an induction coil.

Historical.—In the year 1835, Wheatstone published in the Philosophical Transactions, part II, page 583, an account of his celebrated experiment on the duration of the discharge of a Leyden jar charged by a common frictional machine. The light from the spark was received directly on a plane mirror revolving at rates between 30 and 800 times in a second ; the mirror was driven by a set of multiplying wheels connected *by strings.* This apparatus was constructed by Mr. Saxton of Washington, who at that time was residing in London. The eye of the observer was placed near the mirror, and as the image of the spark was not sensibly drawn out by the rotation of the mirror, Wheatstone concluded that its duration was less than the one millionth of a second, a result which was accepted by the scientific world for about a quarter of a century, passing unquestioned till the publication in 1858 of the first of an admirable series of investigations of this subject by Feddersen ; (Pogg. Annalen, Bd. 103, seite 69.) This physicist employed a concave mirror with a radius of half a meter, driven by a train of *toothed wheels*, and obtained as high a rate of rotation as one hundred per second ; the spark was generated in one of the conjugate foci of the mirror, and its image, formed at the other conjugate focus on a plate of ground glass, was in a condition to be conveniently seen and measured by the naked eye or to be photographed. It was found that the image of the spark was drawn out by the revolving mirror into a whitish streak, from 20 to 30 millimeters long, which when a large amount of electricity was employed, was still farther lengthened by the addition of a red tail of about the same dimensions, this latter being due to the gradual cooling of the heated particles. With a jar of 2·2 feet inner coating, the distance of the copper balls which served as electrodes being 1·5 millimeters, and all the connections as short as possible, the duration of the discharge exclusive of the red tail was ·00004 of a second. It was also found by him, that an increase of the size of the coating of the jar of the "striking distance," prolonged the duration of the discharge ; so, for example with a spark 3·75 millimeters long, the duration of the whitish portion was ·00007 of a second.

A series of observations detailed at the end of this article, will point out a probable explanation of the great discrepancy existing between the results of Feddersen, which are undoubtedly correct, and those of Wheatstone. Finally, Feddersen in the course of his investigation found abundant proof of the oscillatory nature of the electric discharge, which had been predicted from the results of a set of experiments by Prof. Joseph Henry as far back as 1842.

Apparatus.—I arranged in the first place an apparatus like that of Feddersen, but it was soon found that to attain a rotation of one hundred per second, it was necessary in my case to employ a weight of 200 pounds, and in addition when using this form, I labored under the disadvantage of not being able to vary the size or curvature of the mirror readily ; in short it was found to lack *flexibility*, a quality more necessary in the present case than in the investigation which engaged the attention of the German physicist. On this account I decided to employ a plane revolving mirror with a stationary achromatic lens. The addition of an extra wheel, with a few other mechanical changes, converted the train of wheels furnished by Duboscq for Becquerel's phosphoroscope, into an admirable means for driving the revolving mirror, and with a weight of 30 pounds, 300 rotations per second were readily obtained, the motion being smooth and sufficiently uniform. In order to measure the rate of rotation, the cylinder on the lowest wheel was made to wind up a fillet of paper, upon which dots were made by an electro-magnetic apparatus regulated by a seconds pendulum, when a simple calculation furnished the rate of the wheel to which the mirror was attached. By this method it became possible to put to a sharp test the regularity of the rate of the train, which was found in all cases to be considerably greater than was at all necessary. These determinations were afterwards made with a watch having large seconds spaces, the dots being made by hand, as the refinement of a seconds pendulum and battery was found for my purpose to be superfluous.

The mirrors employed were always plane, being sometimes silvered at the back, while for the most delicate observations the rear surface was painted with black varnish, so as to destroy the second reflection. They varied in size from 1·5 inches square, down to ·2 by ·5 in., and were used sometimes double on the axis back to back, and at other times four mirrors were employed together. The arrangement is seen in figure 1. The light diverging from S, was received by an achromatic lens L, of nine inches focal length ; it then fell on the plane mirror at M, and was finally brought to a focus on the plain or ground glass at G, which was distant from the mirror about 16 inches. For the purpose of measuring the extent to which the image of the spark had been drawn out by the motion of the mirror, a scale consisting of bright lines on a dark ground, was projected on the ground glass, as seen in the figure at CC, the flame of a small lamp furnishing the illumination. The spark was generated between the balls or wires of a spark-micrometer, graduated in millimeters; this was placed of course in one of the conjugate foci of the achromatic lens. An automatic arrangement for breaking the circuit from three to six times

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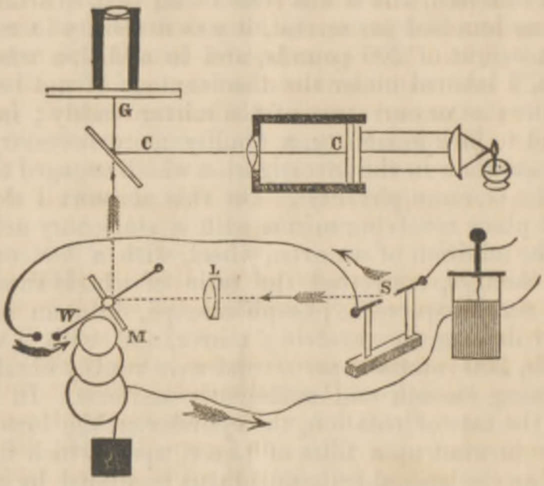

in a second, was employed, mercury and alcohol being used in it. The coil was a large one by Ritchie of Boston; it was excited during these experiments by two cups of the Bunsen form; the simple sparks furnished by it did not at the time exceed seven inches in length. The Leyden jar had a coating of 114·4 square inches, and all the connections were made as short as possible, so as to offer the least amount of resistance to the flow of the electricity. The experiments were usually made in a room not *entirely* darkened, as in a perfectly dark room it was found difficult to preserve the proper "accommodation" of the eyes.

If no means are employed to regulate the moment at which the discharge takes place, it is evident that images of the spark will be thrown on the ground glass only when the mirror happens to be in a favorable position, still as several of them occurred in a second, and as the mirror was always double it did not very often happen the weight ran entirely down before a single observation had been made. I selected a certain portion of the ground glass along the line of images, and exclusively fixed the attention on it, and disregarding the images formed in its neighborhood waited for their appearance in this locality. If the precaution be neglected, much time will be wasted in accumulating observations of comparatively little value. With velocities up to 223 per second, I succeeded in causing the discharge to take place when the mirror was in the proper position, by attaching to its axis a brass wire W, which was made to complete the connection between the exterior and inner coatings of the jar. The arrangement is seen in figure 1, and it was found quite valuable in facilitating *the use of the eye-pieces*, which were employed to magnify the lengthened images of the spark, or to examine the micrometer described at the end of this article. I had been apprehensive that this plan would not answer, as it evidently assumes that the jar remains charged a fraction of a second before it discharges itself backward through the coil.

Appearance presented by the spark, viewed with the stationary mirror.

(*a*) *With brass balls as electrodes.* Here the spark presented its ordinary well known appearance, being merely magnified by the eye-piece.

(*b*) *With pointed wires as electrodes.* When the "striking distance" was one millimeter, the form was that represented in figure 2 at A, viz: a central white portion surrounded by a yellowish envelop, which in the figure is shown by the coarse shading; the second envelop more densely shaded, being green and much inferior in brightness. With a "striking distance" of ten millimeters, the green envelop was produced only in the neighborhood of the electordes. (see B, fig. 2.) In both cases a number of brilliant minute jets of white light were seen to issue from the electrodes; these are only partially shown in the figures. The green color was due to the heated particles of metal, and the bright points of light to successive discharges, as will be shown farther on.

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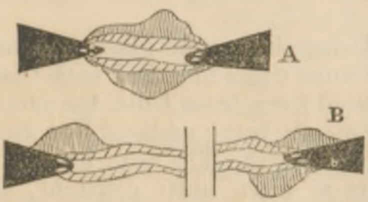
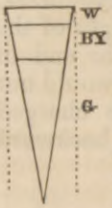


(*c*) *With fine platinum wires.* The appearance was the same as the last, except that the green tint was replaced by a gray or violet-gray hue. These observations were made with a mirror of plane glass, the rear side being blackened, which reduced the intensity of the light adequately for the purposes of distinct vision. The ground glass was replaced by a polished plate, which supported an eye-piece magnifying five diameters.

Appearance presented by the revolving mirror.

(*a*) *With brass balls as electrodes.* With a "striking distance" of one or two millimeters, the image being thrown on the ground glass and viewed by the naked eye, it was found that the spark was drawn out into a streak one and a half or two inches long, according to the rate of the mirror; the portion at W, (fig. 3) was white; this shaded into a brownish yellow tint, (B Y) the latter passing into a pretty distint green, (G.) It will be found by comparison that this result is exactly that obtained by Feddersen with frictional electricity, except that in my case the green color of the tail seem to have been much stronger, which is explained by the lower intensity of the illumination.

3.



With the unaided eye and ground glass, nothing additional of a remarkable character could be discerned, but on using the polised plate of glass and an eye-piece magnifying five diameters, a series of bright dots on each side of the streak became visible in the positions indicated by the dots in figure 3. These resemble the photographs obtained by Feddersen with frictional electricity. Here it is seen that the bright points before spoken of, correspond to a series of discharges following the first.

(*b*) *With platiuum points.* Using the ground glass, I found that the form of the streak was some times identical with that produced from brass balls, the green color merely being replaced by a violet-grayish tint. The form, however, was more often quite different, as shown in figure 4, the change in shape being due to the partial suppression of the tail, and to its irregular production; with low velocities the shape was often as in the smallest of the three sketches.

4.

With eye-piece, polished glass and high velocities, the series of bright points was seen beautifully developed.

(c) *With brass points,* this same figure was produced, yet not quite so distinctly. The tail was of course green.

Total duration of the discharge.

(*a*) *Using brass balls.*

Rate of rotation per second.	Number of observations.	Distance of electrodes in millimeters.	Duration in seconds.
109·	6	3	·000050
291·	5	2	·000028
294·	9	1	·000017
120·	6	1	·000030
30·	8	1	·000023
110·	15	1	·000022

No red tail was ever observed in my experiments, the amount of electricity employed not being sufficient for its production. The difference in these observations arises partly from the faintness of the terminal portion of the tail, and also from the fact that its length is a little variable even in discharges following each other in quick succession. Still on the whole, these results correspond pretty well with those obtained by Feddersen, when it is remembered that the coating of the jar employed by me, was less than one half the size of that used by him, which, as well as shortening the "striking distance," tends to lessen the duration of the discharge as proved by his observations.

(*b*) *Using brass points.*

Rate of rotation per second.	No. of observations.	Distance of electrodes in millimeters.	Duration in seconds.
100	10	1	·000025
48	10	1	·000028

(*c*) *When platinum points* were used as electrodes, with a striking distance of three millimeters, the duration, as obtained, varied between ·00004 and ·00014 of a second: the variation seems to be owing to the faintness and narrowness of the tail, which rendered observation difficult and rather uncertain.

Duration of the white and yellow portion.

As it had all along been evident that the main illuminating power of the spark was concentrated in the first explosive act, I made still further efforts to determine the duration of the white and yellow portion of the discharge. The image of the spark, using platinum wires as electrodes with a striking distance of five millimeters, was thrown on the ground glass, a set of observations being made with the naked eye, and also with the aid of the magnifying lens. The color was found to be rather brownish-yellow, shading off and becoming fainter in illumination toward its farther boundary. This yellow flame-like portion was not nearly so bright as the white band, the latter being to all appearance unaffected by the motion of the mirror. The appearance was that indicated in figure 4, the farther boundary *resembling the irregular outline and color of a burning splinter of wood.*

The duration was found to vary from

·000003
·000007

of a second. The rate of rotation was 206 per second. Determinations of this same point had previously been made at an early stage of the work; their result was

·000008
·000006

of a second. There can be no doubt but that the duration of the yellow portion in individual sparks varies within limits like the above as can be seen by a comparison of successive discharges.

Duration of the white band.—Up to this time I had been able to obtain no evidence that the duration of the white band was other than instantaneous, indeed with this mode of experimenting the contrary cannot be proved. The preceding analysis had shown that a large portion of the light of the spark resided in this white band, i. e., in the first discharge, and when points were used as electrodes its superior brightness to some extent isolated it from the rest of the streak To ascertain whether it was to be regarded as a separate act by itself, or as only the beginning of a continuous action lasting ·000005 of a second or longer, I made the following simple experiment: instead of receiving the light of the spark directly on the achromatic lens L, it was used to illuminate a strip of white paper ·14 of an inch in breadth; this was placed horizontally, the direct light from the spark being prevented from reaching the lens by a screen. The "striking distance" was 1·3 millimeters. With low rates of rotation, the appearance of the image of the band *viewd by an eye-piece* magnifying five diameters, was quite unaltered; as the rates of rotation were increased the illumination of the image of the band grew fainter, but with the highest velocity, 223 per second, it was *distinctly visible and of the same breadth*, as far as could be ascertained by the use of the micrometer. This proves of course that the first discharge is a simple act, and isolated from those that follow. Next, as an appropriate termination to this experiment, I blackened all the surface of the strip of white paper except so much as served to form a square. On examining the image of this with the same rate of rotation, the square was tolerably visible: it was followed by a faint flame-shaped tail, corresponding to the yellowesh portion of the discharge.

Having thus proved the existence of an isolated discharge, at once the first and most brilliant act in the explosion, a method was contrived for measuring its duration, or at all events for setting a limit to it on at least one side. Ordinary micrometric methods, conducted on the naked spark or on a strip of paper illuminated by it, were out of the question, and would have served no purpose except to lead the observer into error, so I contrived the following plan, which is moderately easy of application and safe.

A small piece of cardboard was ruled with two black lines; their distance apart was ·0067 inches, and they were separated by a space exactly equal to the width of a single line. A small dividing engine was used for their production; they were tested with a microscope. These lines were illuminated by the spark, and their image examined by an eye-piece magnifying five diameters. The breadth of the image of a single line on the ground glass was ·011 inches, that is, each line subtended an angle of 2′ 24″, reckoning from the mirror. With a velocity of 223 per second the mirror is able to move the reflected image through 2′ 24″ in the ·00000024 of a second. If now this first discharge had actually lasted this minute portion of time, it is evident that the motion of the mirror would just have carried the image of one of the black lines forward, so that at the end of this infinitesimal period, it would have occupied the space where just before the white line had been traced: hence owing to the retention of impressions by the retina the white central line would have been obliterated, and in place of three lines, a gray band would have been seen. On the other hand if the duration had been only $\frac{1}{10}$ or $\frac{1}{5}$ of the above mentioned interval, the white line not having been much encroached on, would still have remained visible. The correctness of the above reasoning can be experimentally proved, by means of a revolving disc of card board with a single slit cut in it, lines being drawn on its white side, and viewed by reflection with a mirror through the slit, the blackened side of the disc being turned towards the eye.

To facilitate matters, *three sets* of these lines were drawn on the small cardboard at considerable distances apart to prevent confusion, and while illuminated by the electric spark were examined with increasing velocities. With low rates they were quite unchanged in appearance, with a velocity as high as 102 per second, a duration of the first discharge of ·00000052 seconds would just have obliterated them; they were however perfectly distinct, though more faintly traced: the rate of rotation was then by degrees carried up to 223 per second, when the lines were still distinctly visible, though of course with less contrast between the white and black, than was the case with low velocities or a stationary mirror.

This experiment proves then, that the duration of the light accompanying the first discharge is considerably less than ·00000024 of a second, probably less than half this period, or less than one ten millionth of a second of time. To make the observations required some patience, as it was necessary to use an eye-piece, the ground glass being replaced by a plain polished plate, and it was seldom that the image of the lines fell exactly in that portion of the field to which the attention was directed. To obviate this difficulty, I afterward *covered* a piece of cardboard half an inch broad with alternate white and black lines of this character, their real diameter was ·0075 in., that on the plate of glass being 0125 in. With these I repeated the above mentioned set of experiments with rapidity, obtaining with ease the same result, as some of the lines were almost certain to be in the right part of the field of view. It is thus shown, that the first act of the electric explosion lasted through an interval of time so short as to be immeasurable with the means then at my disposal ; it is not impossible that it may still be reached by the use of finer lines, and a lens of greater focal length.

From the foregoing then it appears that if a jar having a metallic coating of about 100 square inches, be connected as above described with an induction coil, its discharge will be effected by a considerable number of acts, of which the first is by far the most intense. Farther, the metallic particles heated up by the first discharge to a white heat, almost instantly assume a lower temperature, marked by a corresponding change from white to brownish yellow, and as their temperature continues to fall the tint changes in the case of brass electrodes to green, in that of platinum to a gray or violet-gray. A spectroscopic examination of these isolated tints would be interesting but not without difficulty. These observations farther demonstrated the fact, that two ten millionths of a second is an interval of time quite sufficient for the production of distinct vision.

When the light from the spark is received directly on a plane revolving mirror, and viewed by the eye as in Wheatstone's original experiment, only the white unanalyzed portion of the spark is ordinarily visible ; at least in repeating the experiment a few times, it is all that I saw. Its form is of course that of the spark itself. In all probability this is also the case in a jar charged by frictional electricity, and may serve to explain the great discordance between the results obtained by Wheatstone and Feddersen, the method used by the former furnishing only a view of the first act, the eye being too much dazzled to perceive those that are subsequent and of far less intensity.