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ON THE MINUTE MEASUREMENTS OF MODERN SCIENCE.

By Alfred M. Mayer.

Article XVIII.

On the Application of Rotating Mirrors to the Measurements of Minute Lengths, Angles, and Times.

THE EXPERIMENTS OF FEDDERSEN, HENRY, ROOD, AND MAYER ON THE NATURE AND DURATION OF THE ELECTRIC DISCHARGE.

If we except a remarkable discovery made by Joseph Henry in 1841, nearly a quarter of a century elapsed before anything of value was added to the information which Wheatstone had given us about the nature of the electric discharge.

In the year 1858, Professor Feddersen, of Leipsic, began a series of elaborate and refined experiments on the electric spark. The peculiarity of his method consisted in replacing the plane mirror, which Wheatstone had used, by a concave mirror (of one-half meter radius), which gave an image of the spark by reflecting its rays on to a piece of finely ground glass. In this image the observer could see the structure of the spark. This is an improvement of prime importance, and the want of it prevented Wheatstone from really seeing what his mirror otherwise would have revealed to him. In fact, as we shall soon see, the spark, as observed by Wheatstone, was so brilliant and minute that its more feebly luminous and colored parts could not be seen. As this brilliant part of the spark has a very minute duration—less than the millionth of a second—it followed that Wheatstone decided that the whole of the electric spark has a duration less than the above fraction of a second.

Feddersen studied the images of the electric spark given by the concave mirror when it was stationary, and then when it was revolving 100 times per second. He made both drawings and photographs of these appearances. Feddersen divides electric discharges into three kinds:

1st. *The continuous discharge.* The rotating concave mirror gives an image of this, composed of a brilliant narrow line joining the electrodes, and parallel to the axis of rotation of the mirror. At the ends of this line, and at right angles to it, appear two faintly luminous bands. The noise given by this kind of discharge is a sharp crack.

2d. *The intermittent discharge*, formed of a series of luminous lines (parallel to the line joining the electrodes), and separated by dark spaces which become wider as the lines are further from the electrodes. This discharge makes a crackling or rustling noise, and appears to the naked eye as "the electric brush."

3d. *The oscillating discharge*, composed of a series of luminous brushes or cones, which start from two lines drawn at right angles to the ends of the line which joins the electrodes. These brushes curve around till they are parallel to these lines, and are alternate in their positions. Fig. 61 shows the appearance of this character of discharge, which was predicted by Henry in 1841, and first actually seen by Feddersen in 1862.

With his mirror running with a velocity of 100 revolutions per second, Feddersen saw the image of the spark of a discharging Leyden jar drawn out to the length of 20 to 30 millimeters. Using a larger jar, he observed that the spark was elongated to 20 millimeters more by the addition of a reddish tail formed of the gradually cooling metal volatilized from the electrodes. He found that an increase of "the striking distance" between the electrodes, as well as an increase of surface of the Leyden jar, gave the spark a longer existence. Thus, with a jar of 2·2 square feet of surface, and the electrodes 1½ millimeter apart, the spark's duration was 1-25,000th of a second; but on separating the electrodes till the spark was 3¾ millimeters long the entire discharge lasted about 1-14,000th of a second. Feddersen also found that by increasing the resistance of the conductor leading from one coating to the other of the jar he greatly lengthened the time of the duration of the discharge. Thus, with a column of water of 9 millimeters in length, placed in the circuit, the duration of the discharge was 1-714th of a second; when a column of water 180 millimeters long, and of the same area of section, was interposed the duration lengthened to 1-54th of a second.

The most remarkable, however, of Feddersen's discoveries was that of the oscillatory character of the discharge of a Leyden jar, the discharge appearing to act like an elastic fluid, which alternately rebounded from the inside and outside coatings of the jar. Fig. 61 is a reproduction of an engraving contained in one of Feddersen's papers, and made from a photograph obtained from the image of the spark, thrown by the rotating concave mirror on to a sensitive plate. No one who examines this remarkable picture can fail to see the oscillatory character of this discharge. The spark was taken from a battery of 16 large Leyden jars with a conductor of high resistance connecting the inside and outside coatings. The electrodes were balls of iron, coated with varnish except at two points, between which flashed the spark. In this picture the positive electrode was at the right, the negative on the left. The spark is not only greatly elongated in a direction at right angles to the line joining the electrodes, but it is discontinuous and formed of curved brushes of light which appear alternately from the electrodes: first, a discharge takes place from the right hand electrode, then from the left, then from right, then from left, and so on. We also remark that the light which forms the brush coming from the negative electrode (and shown in the lowest part of the figure to the left) is streaked or ribbed, while that which next comes from the opposite or positive electrode is continuous and nebulous in its appearance. Then these appearances change places in the next act in the discharge, and the ribbed brush is now on the right and the nebulous one on the left, and so on.

I regard this photograph as one of the notable results of the modern art of experimenting. Here is a permanent record of the most transient of phenomena engraved by Nature herself, and giving the life history of intense physical actions whose whole existence is crowded into the duration of a hundred-thousandth of a second. Yet, in that short time, law has its reign; each circumstance of the transaction, from the generation of the spark till its final impress on the "sensitized" plate, follows in its allotted order and with its proper direction, duration, and intensity.

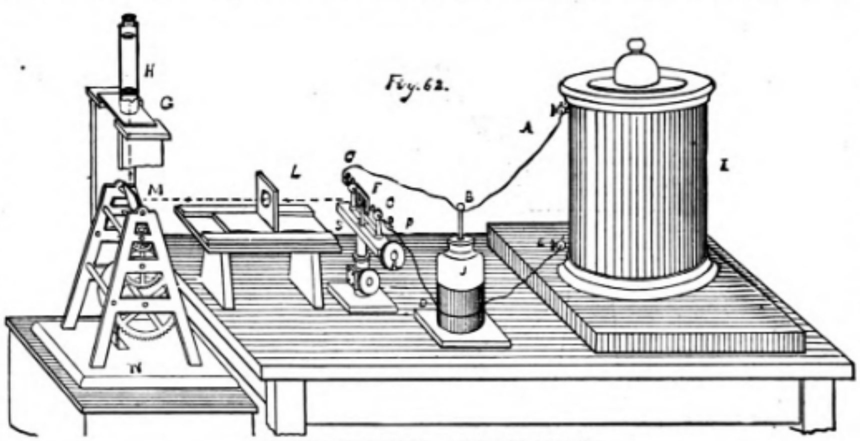
Speaking of the above experiments, those of Henry naturally recur for this remarkably talented experimenter saw with his mind's eye in 1841 what Feddersen, twenty years afterwards, succeeded in getting on his photographic plate. In a communication to the American Philosophical Society of Philadelphia, in 1841, Henry says: "The discharge, whatever may be its nature, is not correctly represented (employing the theory of Franklin), by the single transfer of an imponderable fluid from one side of a jar to the other; the phenomena require us to admit the existence of a principal discharge in one direction, and then several reflex actions backward and forward, each more feeble than the preceding, until the equilibrium is obtained. All the facts are shown to be in accordance with this hypothesis, and a ready explanation is afforded by it of a number of phenomena which are to be found in the older works on electricity, but which have, until this time, remained unexplained."

Henry was led to the above conception of the nature of the discharge of a Leyden jar by the observation of the magnetizing action of the discharge of the jar on needles, which were placed in a glass tube, around which a conducting wire was wound like a helix. Now when a needle, placed as above, has an electric discharge sent around it, it is magnetized, and the direction of its magnetism, that is, which of its ends will be N. or S. polarity, depends on the direction of the electric flash through the enveloping helix. But, to Henry's surprise, he found that the same end of the needle was sometimes of north and at others of south polarity, till, after many hundred experiments, he found that there was a connection existing between the direction of the polarity and the amount of charge the jar had, and on the distance over which its spark passed. Then it occurred to Henry that these phenomena could only be explained by the supposition that there were several flows, or oscillations, of the electric fluid, first from one coating to the other of the jar, then back again, and so on, and that the number of these alternate oscillations decreased with the striking distance, and increased with the surface of the jar. Thus the final magnetic condition of the needle depended on the direction and intensity of the last flash of electricity which encircled it. After Henry had premised all this he soon had such mastery over the phenomena that he could at will give to the end of a needle either polarity he wished.

Researches of Prof. O. N. Rood on the nature and duration of the discharge of a Leyden jar connected with an induction coil.—It must have been noticed that Feddersen gives for the duration of the discharge the length of time during which the whole electric explosion lasts; but this explosion is of a complex nature, and the separate acts which compose it now require our attention. The thorough study of the composite nature of the discharge (at least of one form of it) was the subject of a series of skillful researches made in 1869, 1871, 1872, and 1873, by Professor Rood, of Columbia College, New York, of which we will now give an account.

Feddersen's experiments were made on the spark of the Leyden jar kept charged with electricity from a frictional electrical machine. Rood's researches are on the nature and duration of the electric discharge of a Leyden jar which was charged and discharged while in the circuit of the secondary wire of an induction coil. The circumstances of the charging and discharging of a jar placed as in Rood's experiments, are quite different from those which had place in Feddersen's, for, while in Feddersen's the two coatings of the jar were always insulated, in Rood's these coatings were always in metallic connection through the secondary coil of the inductorium, both during the charging and discharging of the jar—"a circumstance," as Rood remarks, "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 with ordinary frictional electricity were applicable to those connected with an induction coil."

Professor Rood in his experiment worked, like Feddersen, on the image of the spark formed on a piece of glass having either a finely ground or a polished surface. He, however, replaced Feddersen's concave rotating mirror with a small plane mirror and an achromatic lens; the latter forming an image of the spark on the plate of glass placed directly over the rotating mirror.



PROF. ROOD'S APPARATUS.

Fig. 62 shows the arrangement of apparatus in Rood's experiments. The jar, J, has its inside and outside coatings in the circuit of the secondary coil of the inductorium through the wires leading from A to B, and from E to D. These wires then proceed from B to C, and from D to P. The discharge of the jar takes place between the metallic balls, or pointed wires, on the spark discharger, S. One of these balls is shown on the standard at O. The two standards, carrying the balls or points, can be placed at determinate distances apart by means of a micrometer screw which moves them. The head of this micrometer screw is shown at R.

The rays of light from the spark pass through the achromatic lens, L (of 9 inches focal length), which forms an image of the spark on the ground or plane glass at G, after their rays have been previously reflected from the stationary or revolving mirror at M. The mirror generally used was about one half inch square, and was formed of two silvered mirrors placed back to back. Thus two reflections were obtained from the mirror for one revolution. The image of the spark on G was examined by a microscope, H, which magnified about five times.

The mirror, M, was rotated by the wheel-work, W. Driven by a weight of 30 lb., the mirror could be brought up to a speed of 340 rotations in a second. To measure the rate of its rotation the cylinder on the lowest wheel of the train wound up a fillet of paper, on which dots were made by a Morse register, through which a current was sent by a pendulum at each second. The number of rotations made in a second by the mirror was readily computed from the record thus made on the fillet.

Two Leyden jars were used in Professor Rood's experiments. The larger of these had a coating of 114·4 square inches of foil, the smaller had only 11 square inches of surface. The discharge of the larger jar differed from the smaller both in its nature and in its duration.

Professor Rood first began a careful study of the structure which the spark presented when its image was formed by reflection from the stationary mirror.

Placing the larger jar in the circuit and sending its sparks between pointed brass wires one millimeter apart, the image of the spark on the glass surface at G appeared as in Fig. 63 *a*; "a central white portion surrounded by a yellowish envelope, which in the figure* is shown by the coarse shading; the second envelope, more densely shaded, being green and much inferior in brightness. With a striking distance of ten millimeters, the green envelope was produced only in the neighborhood of the electrodes, as shown at B of Fig. 63. In both cases a number of 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 further on."

With fine platinum wires for electrodes the appearance was the same as with the pointed wires, except that the green tint was replaced by a gray or violet-gray hue.

* This and the remaining figures describing Professor Rood's work I owe to the kindness of Professor Dana, editor of the *American Journal of Science*.

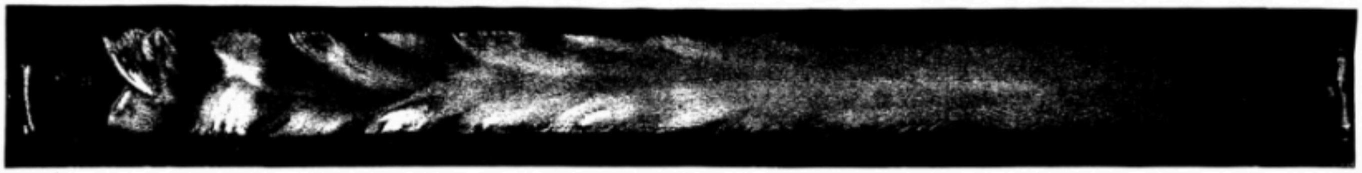


FIG. 61.

On examining in the same manner as above the spark given by the smaller jar, it appeared almost entirely composed of a bright white core.

Appearances of the images of the sparks when these are reflected from the rotating mirror.—Using the larger jar of 114·4 square inches area of coating, and brass balls as electrodes. "With a striking distance of one or two millimeters, the image being thrown on the ground glass and viewed with 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. 63*a*, was white; this shaded into a brownish yellow tint, B Y, the latter passing into a pretty distinct 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 seems to have been much stronger, which is explained by the low intensity of the illumination.

"With the unaided eye and ground glass, nothing additional of a remarkable character could be discerned, but on using the polished piece of glass and an eye-piece magnifying

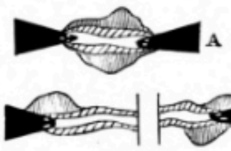


FIG. 63.

FIG. 63 *a*.

five diameters, a series of bright dots on each side of the streak became visible in the positions indicated by the dots in Fig. 64. 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.

"With platinum points, using the ground glass, I found that the form of the streak was sometimes 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 Fig. 64, 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.

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

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

On the duration of the whole discharge and on the times during which exist its separate parts.—Total duration of the discharge.—Rood found that sparks of three millimeters were drawn out in the revolving mirror to a total length which showed that the duration of the whole discharge was about ·00005, or 1-20,000th of a second.

The duration of the yellowish portion of the spark he found to be about ·000005, or the 1-200,000th of a second, which gives to this portion of the spark a duration of only one-tenth of the time occupied by the whole discharge.

The duration of the white portion, or core, of the spark.—Professor Rood now approached a portion of his work which was to tax severely his skill and patience. As yet no

FIG. 64.

experimenter had succeeded in seeing in a rotating mirror any difference in the width of the white core of the spark from what it had when viewed in the mirror when stationary. This clearly showed that the first, the most brilliant, and chief act of the discharge had a duration which was certainly less than the millionth of a second. How much less no one knew. Here we had better give Professor Rood's own words: "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

points were used as electrodes, its superior brightness 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 (of which the yellow portion of the spark was part) 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, Fig. 62, 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 viewed 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 yellowish 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 continued the following plan, which is moderately easy of application and safe."

We proceed with Professor Rood's account of his race with the spark, only substituting certain corrections which the Professor pointed out in a subsequent portion of his paper. "A small piece of card-board was ruled with two black lines; their distance apart was ·0067 inch, 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 (reflected from the mirror) was examined by an eye-piece magnifying five diameters. The breadth of the image of a single line on the ground glass was ·011 inch, that is, each

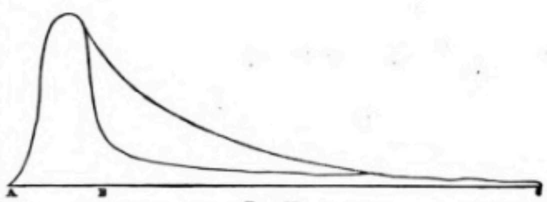


FIG. 65.

FIG. 66.

FIG. 67.

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 twice 2′ 24″, or 4′ 48″, in the ·00000048 of a second. If, now, this first discharge (the white core of the spark) had actually lasted this minute portion of time, it is evident that the motion of the mirror would have just carried the image of one of the black lines forward, so that at the end of this infinitesimal period (·00000048th second), it would have occupied the space where just before the adjoining black line had been traced. Hence, owing to the retention of impressions on the retina, the white central line could have been obliterated, and in the place of three lines, a gray band would have been seen. On the other hand, if the duration had been only 1-10th or 1-5th 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 disk of card-board having a single slit cut in it, lines being drawn on its white side, and viewed by reflection from a mirror through the slit, the blackened side of the disk being turned toward the eye.

"To facilitate matters, three sets of these lines were drawn on the small card-board 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 rotations per second, a duration in the first act of the discharge of ·000001 second would just have obliterated them; they were, however, perfectly distinct, though faintly traced. The rate of rotation of the mirror 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 main act of the discharge is considerably less than ·00000048th of a second, probably less than half this period, or less than one five-millionths 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 plane 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 card-board half an inch broad with alternate white and black lines of this character; their real width was ·0075th inch, the image of

this I repeated the above mentioned sets 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 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 further demonstrated the fact, that four 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."

Failing to obtain any apparent sliding of the fine black lines on to the intervening white spaces, even when the mirror was making 223 rotations in a second, Professor Rood increased the velocity of the mirror till it made 340 rotations in a second, yet the ruled lines (though only separated by 67-10,000ths of an inch) remained separated, and appeared as they did when viewed reflected from the stationary mirror. With the velocity of rotation of 340 times a second the ruled surface of the paper would have melted into a uniform gray tint had the white portion of the spark lasted only for three millionths of a second. Nothing more could be done with paper, which was now replaced by a glass plate, slightly smoked with a lamp, and the lampblack fixed to the plate by flowing alcohol over it. This acted like a cement with the slight amount of resin in the lampblack, and gave a fine black surface, on which lines could be ruled by a finely pointed tool in a small dividing engine. After many trials and microscopic examinations a plate was obtained on which the lines were separated by black spaces of a width exactly equal to the breadth of one of the lines. These lines were so fine that the width of the image of one of them measured on the glass plate at G, Fig. 62, was only the 1-300ths of an inch. This ruled plate was placed at F, close to the fine platinum wires between which the spark passed. Thus placed the lines were brilliantly illuminated by the electric discharge, and a very distinct image of them, showing as bright lines on a dark ground, was formed on the glass, at G, by the action of the lens, L, Fig. 62.

With these fine lines Professor Rood at last succeeded in determining the duration of the white core of the discharge. As the velocity of the mirror approached 180 rotations in a second the lines became fainter and fainter, and, finally, when the mirror had reached 183 rotations in a second, the lines disappeared, showing that the duration of this portion of the discharge was ·000000175 of a second.

On the duration of the white portion, or core, of the spark given by the smaller jar with a coating of eleven square inches.—It had already been shown by Feddersen that the total duration of the discharge of a Leyden jar diminished with the surface of its coating, and Rood had observed that there was little or no difference in the appearance of the spark given by this smaller jar, whether observed in the stationary or rotating mirror.

The ruled smoked plate of glass remaining at F (Fig. 62), as in the previous experiment, and the larger jar, at J, having been replaced by the smaller one, Professor Rood found that the velocity of 183 turns per second on the mirror which had obliterated the lines when they were illuminated by the larger jar, failed to have any effect on the distinctness of these same lines when lighted by the flash of the smaller jar. He then urged the mirror till its velocity reached 340 in a second, yet the lines were unaffected, and appeared just as they did when looked at by the same light reflected from the stationary mirror, though the time required in the spark for their obliteration, with a velocity of 340 per second, was only the ninety-four billionths of a second! "Still," as Professor Rood remarks, "on experimenting, it was evident that the duration of the discharge was less than this quantity, as the lines were plainly to be seen."

actual duration of the discharge, another effort was made. A second lampblack plate was prepared, in which the breadth of the image of a line, black or white, on the observing plate, was 1-600th of an inch. These lines were viewed with the terrestrial eye-piece of a small telescope, it enlarged them ten diameters and care was taken with all the adjustments so that a good clean image should be produced. Platinum wires of 1-86th of an inch in diameter were used, with a striking distance of five millimeters. By gradually increasing the driving weight it was proved successively that the duration was less than eighty, sixty-eight, fifty-nine,

FIG. 68.

fifty-five billionths of a second; and finally, the lines, after growing fainter and fainter, entirely disappeared, giving as the result a duration of forty-eight billionths of a second. In a large number of observations I could detect no discharge lasting during a smaller interval, though the apparatus was now fully capable of making evident much smaller periods of time.

"When the striking distance was reduced to one millimeter, the duration was shorter; in the case of 5-6ths of the sparks, the duration was slightly greater than forty-one billionths of a second, the remaining 1-6th being slightly less than this figure.

"With a striking distance of three millimeters, the duration was between forty-one and forty-eight billionths; and when the striking distance was increased to ten millimeters, it was between forty-eight and fifty-five billionths of a second.

"It has thus been shown that the duration of the first act of the electric discharge (of this small jar) is in certain cases only forty billionths of a second, an interval of time just sufficient for a ray of light to travel over forty feet."

Professor Rood adds: "With another ruled plate I found it practicable to measure intervals as small as twenty-eight billionths of a second; and the mere act of increasing the focal length of the lens, L, would admit of the experi-


FIG. 69.

menter reaching a quantity as small as ten billionths—probably without much difficulty—though it would be necessary to pay more attention to the correction of the optical part of the apparatus, and the observations would naturally consume threefold as much time."

Professor Rood gives, in his paper, the accompanying curve, Fig. 65, by which he shows the duration of the whole discharge and the relative brightness of its various parts. The time during which the discharge lasts is represented by the length of the horizontal line, A C, and the relative degrees of brightness of the discharge at points of time, measured on the horizontal line, A C, are represented by the perpendicular distances of the curve (the unbroken line) from those points on the horizontal line. This curve shows that there is no break in the discharge; it is a continuous act. The steep peak, A B, stands for "the first and most brilliant act of the discharge;" though with the larger jar, of 114 square inches, it is neither so steep, as in the present case, nor so solitary, being followed by a series of minor elevations, while with the small jar the effective luminosity of the discharge is almost wholly concentrated in it; the far greater brilliancy of the light at the beginning of the discharge practically separates it from what follows, and makes it a first distinct act, whose duration, as we have just seen, Rood measured, and showed that its existence lasts for only forty billionths of a second.

After the success of his remarkable experiments, in which Rood showed that the flash of light from the small jar lasted for only forty billionths of a second, he made some very curious reflections on the very short time necessary for distinct vision. We will give his own words: "I obtained and measured sparks the duration of whose main constituent was only forty billionths of a second. With their light distinct vision is possible; thus, for example, the letters on a printed page are plainly to be seen; also, if a polariscope be used, the cross and rings around the axis of crystals can be observed with all their peculiarities, and errors in the azimuth of the analyzing prism noticed. There seems also to be evidence that this minute interval of time is sufficient for the production of various subjective optical phenomena: for example, for the recognition of Loewe's rings (using cobalt glass); also, the radiating structure of the crystalline lens can be detected when the light is suitably presented to the eye."

Hence, it is plain that forty billionths of a second is quite

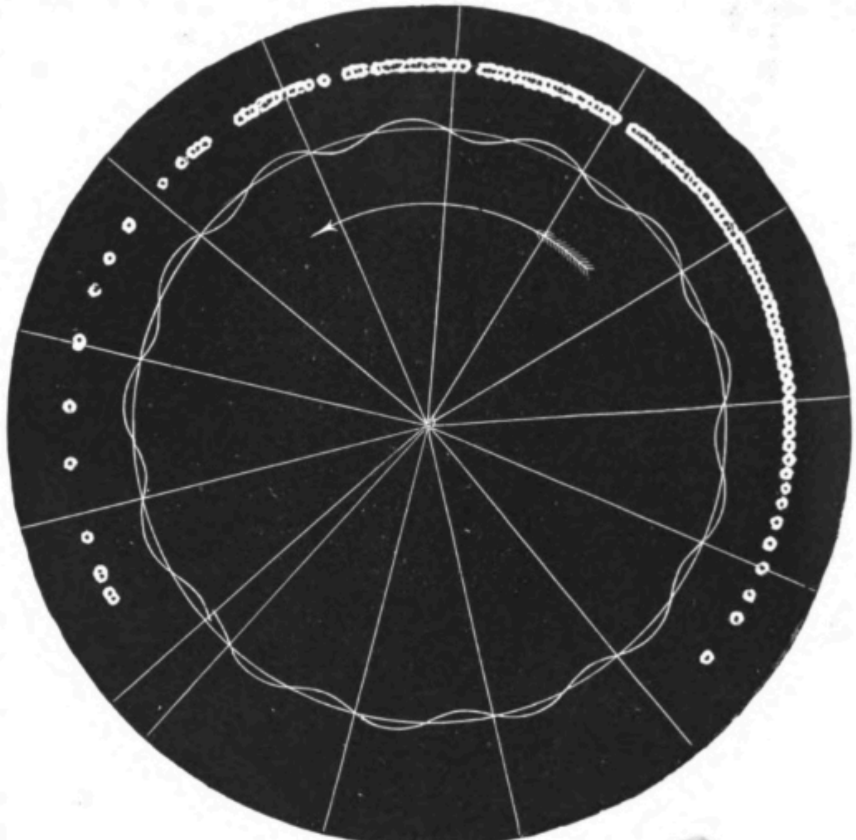


FIG. 71.

sufficient for the production on the retina of a strong and distinct impression; and as the obliteration of the micrometric lines in the experiment referred to could only take place from the circumstance that the retina retains and combines a whole series of impressions, whose joint duration is forty billionths of a second, it follows that a much smaller interval of time will suffice for vision. If we limit the number of views of the lines presented to the eye in a single case to ten, it would result that four billionths of a second is sufficient for human vision, though the probability is that a far shorter time would answer as well, or nearly as well. All of which is not so wonderful, if we accept the doctrines of the undulatory theory of light; for according to it, in four billionths of a second, nearly two and a half millions of the undulations of light reach and act on the eye.

On the multiple character of the discharge of the induction coil.—In the course of his experiments on the electric discharge Professor Rood observed that the explosive act of the induction coil was not concentrated into a single spark, but was formed of several distinct flashes, which, it is true, to the naked eye appear as a single flash; but on examination in the revolving mirror this apparent single spark appears as formed of several distinctly separated sparks. Professor Rood used two instruments in his study of these multiple discharges, viz., the revolving mirror already described, and a rotating disk with a slit cut out of it in the direction of one of its radii. If we look at a sheet of white paper through this slit while the disk is rotating, and the paper is illuminated by one instantaneous flash, we evidently will see the slit on the disk appear as a white radial band. If, however, the discharge, as usually is the case, is formed of several distinct and separated sparks, each spark will in order illuminate the slit, and we will see a white radial band on the disk for each separate spark; provided, however, that these sparks do not follow one another so rapidly that the disk has not time enough to carry the slit far enough to prevent the bright radial bands from blending into one broad band.

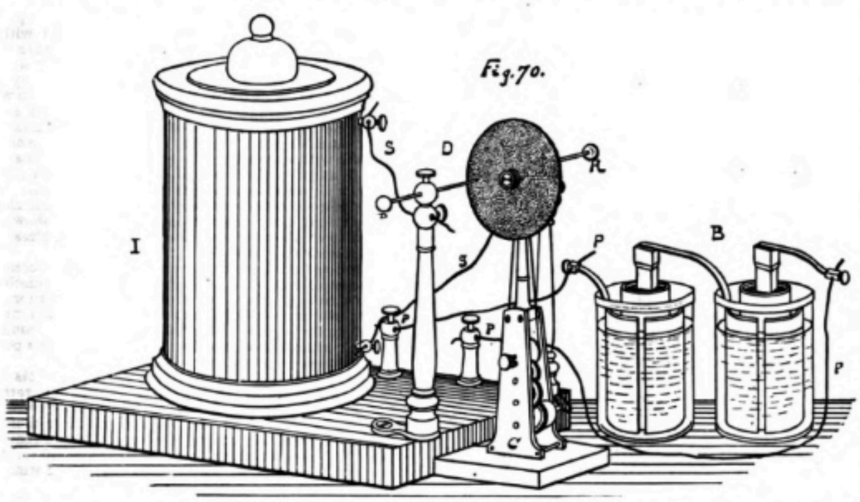
To facilitate the observations on these complex phenomena Professor Rood devised what he called a micrometer-disk, formed of two disks superposed. Each disk had a radial slit cut in it, and one of these disks revolved on the other so that the slits could be placed at various angular distances apart. Fig. 66 shows the disks of blackened cardboard with the two slits. On viewing through the revolving disk the white paper surface, illuminated by the electric flash, the slits in the disk appeared as in Fig. 67. By revolving the inner disk on the larger one the two fan-like images of the multiple slits could be brought together so that the end of one just touched the beginning of the other, and thus the angular breadth of the set of multiple slits was readily measured. This measure, with the knowledge of the velocity of rotation of the disk, gives us the data for computing the total duration of these discharges.

Flashing the discharge of his coil between brass balls one millimeter apart, and viewing the discharge in the rotating mirror, the appearance of the flash was as in Fig. 68, showing that sometimes the discharge was formed of three separate sparks, and sometimes of four. The duration of the whole discharge was about 1-165th of a second, the interval separating the sparks being about 1-500th of a second. With a striking distance of two millimeters he observed only one spark.

With platinum points as electrodes, and separated 1, 2, 3, 4, and 5 millimeters, the number of sparks observed at these respective distances of the electrodes was 4, 3, 2, 1 and 1, showing that an increase in the striking distance of the discharge diminishes the number of its component sparks. Placing in the circuit of the induction coil the small Leyden jar of eleven square inches of surface, and sending the discharge between brass balls separated by one millimeter, the character of the discharge, as shown by the revolving mirror and of the rotating disk, was more complex. Fig 68 shows the appearance it presented on the revolving mirror. Here we see that the act of discharge was formed of a bright spark followed by a violet discharge, extending from C to A, and the latter followed by four sparks, extending from A to B. The total duration of these discharges was 1-50th of a second. The violet portion, C A, lasted for 17-1000th of a second, and the four sparks, between A and B, lasted the 9-1000th of a second. Other forms were sometimes present, like that in Fig. 69, consisting of a faint violet streak terminated at each end by a spark, the whole duration being about 1-35th of a second.

On increasing the striking distance between the balls to 2, 3, 4, 5, 6, 7, 9, and 10 millimeters, the total number of sparks forming the discharge for these striking distances was respectively 5, 8, 4, 3, 3, 3, 2, and 1 spark.

Professor Mayer's Experiments on the Electric Discharge of the Induction Coil.—Professor Rood's mode of experimenting is not competent to unravel the tangle of sparks composing a flash from an induction coil, for the number of separate electric actions forming the discharge are far too many ever



MAYER'S APPARATUS FOR ANALYZING THE ELECTRIC DISCHARGE.

to be viewed in a revolving mirror or to be detected and counted in the multiple images of a slit cut in a rotating disk.

The writer of these articles, in 1874, invented "A new method of investigating the composite nature of the electric discharge," in which the whole life history of a flash from the coil is permanently recorded by the discharge itself on a rapidly revolving disk of smoked paper. The apparatus used is very simple, and will be readily understood after an examination of Fig. 70.

The electric current from the battery, B, passes by the wires, P, P, P, P, into the primary coil of the inductorium, I. The secondary current of the coil, obtained on breaking the primary circuit, passes over the wires, S, S, to the points at the ends of the rods, R, R, between which flashes the discharge of the coil. A disk, D, of thin printing paper, about 15 centimeters in diameter, rotates between the above-mentioned points with a velocity of from 20 to 30 turns per second, given to it by the train of wheelwork, C. If, while the plane of the disk is thus moving between the points, you flash the discharge from the inductorium with a Leyden jar in circuit, the discharge perforates the disk and leaves on it a permanent record of its character, which is shown by the dissipation of the lampblack from off the paper in a series of little circles, giving to the disk the beaded appearance shown in Fig. 71. Each of the white circles has been made by one of the flashes, or separated acts, which this simple experiment shows the discharge of the coil to be composed of.

The thin printing paper is smoked by wrapping it around a cylinder, which is then revolved over burning camphor. The paper is removed from the cylinder, and disks of 15 centimeters in diameter are cut out of it. One of them is carefully centered on the axle of the rotating apparatus, C, and the spring driving the train of wheel-work is fully wound up. The thin paper disk soon reaches a velocity of rotation that causes the centrifugal action to flatten it out, and then it can be slid between the discharging points, even when these are only 3-4 of a millimeter apart.

After the disk has run for a certain number of minutes by the watch, the discharge is passed between the points and through the disk. At the same moment or immediately afterward a delicate tip of foil attached to the end of a prong of a vibrating tuning-fork is brought to touch momentarily the disk. Thus is made the wavy line which is seen in the figure just within the white circles made by the dissipation of the lampblack by the electric discharge.

The fork made 256 vibrations in one second (as determined by the method described in Article XVI. of this series), and hence a complete wave of the fork, that is, a flexure toward the edge of the disk together with a flexure toward the center, is traced in 1-256th of a second time. Thus the circumference of the disk is divided off into 1 256ths of a second. To read subdivisions of these small units of time we cut these tuning fork waves by the circumference of a circle, whose center is the center of the disk. This circumference, as an axis, divides the waves symmetrically, so that a flexure without or within the circle equals 1-2 of 1-256th, or 1-512th part of a second. The length of these separate flexures can readily be subdivided on the circumference which cuts them, so that I have been able readily to read off from the disk fractions of time as small as the 1-20,000th of a second.

The disk, of which we give a very careful copy in Fig. 71, revolved between the points in the direction of the arrow, so that the very regular beading on the disk was made toward the end of the discharge.

These records of the history of these remarkable actions which have such short existences have been permanently preserved by floating the disk, after the experiment, on the surface of alcohol to which has been added a few drops of spirit varnish.

Many new results have been obtained with this apparatus. I have space only to describe three experiments made with the large inductorium of the Stevens Institute of Technology, which gives an electric flash of 21 inches in length.

1. *Discharge of large inductorium between platinum points one millimeter apart. No Leyden jar in the circuit.*—The platinum electrodes were neatly rounded and formed on wire 6-10 millimeter in diameter. After the discharge through the rotating disk nothing was visible on it, except a short curve formed of minute thickly set dots; but, on holding the disk between the eye and the light, it was found to be perforated with 33 clean round holes, with the carbon undisturbed around their edges. The portion of the discharge which makes these holes lasts 1-23d of a second, and the holes are separated by intervals which gradually decrease in size toward the end of the discharge, so that the last spark-holes are separated about one-half of the distance which separates the holes made at the beginning of the discharge. The average interval between the spark-holes is 1-750th of a second. After this portion of this discharge has passed there is a period of quiescence lasting about 1-1000th of a second; then follows a shower of minute sparks, which forms the short dotted line above spoken of. This spark-shower lasts 1-330th of a second, and is formed of 30 sparks; hence the average interval of time separating these sparks is 1-9900th of a second. The intervals separating these minute sparks, however, are not uniform, but are smaller in the middle of the spark-shower than at the beginning and at the end of this phenomenon. The spark-shower, indeed, is a miniature of the phenomenon obtained when a Leyden jar is placed in the circuit of the coil, and which is described below. The above numbers were determined as the average measures on six disks. It is here to be remarked that all of the discharges studied in this paper were made by suddenly depressing the platinum faced "break" of the primary circuit, and the break was held in this position until the disk had been removed from between the points or balls.

2. *Discharge of large inductorium between platinum points one millimeter apart, with a Leyden jar of 242 square centimeters of surface of foil, connected with the terminals of the secondary coil.*—After this discharge through the disk a very remarkable appearance is presented. The discharge in its path around the disk dissipates little circles of carbon. (See Fig. 71.) There are 91 of these little circles, each perforated with either 4, 3, 2, or 1 hole. I shall here have to adopt a new nomenclature for the description of this complex phenomenon. I call the whole act of discharge of the coil, the discharge. Those separate actions which form the little circles by the dissipation of the carbon I denominate flashes, and the perforations in these circles I shall call sparks. The discharge in the above experiment lasted 1-24th of a second. The flashes at the beginning of the discharge are separated by intervals averaging 1-555th of a second up to about the 10th flash; after this the intervals of the flashes rapidly close up, so that during four-fifths of the discharge they follow each other at each 1-5883 of a second. During the last fifth of the discharge the intervals between flashes gradually increase, and the last flash is separated from its predecessor by 1-1000th of a second.

3. *Discharge of large inductorium between brass balls, one centimeter in diameter, separate one millimeter, with a Leyden jar of 242 square centimeters of inner coating in the circuit of the secondary coil.*—This discharge also lasts 1-24th of a second, and is similar in character to the preceding, except that larger circles are made in the disk by the dissipation of the carbon, and that there are fewer flashes, viz., 71. The total number of spark-holes in these flashes is 123. Thus, there are fewer flashes than in the experiments where the platinum points replaced the brass balls, but the total number of spark-holes is the same in each case. Hence there is, on an average, 1-34 spark-hole to each flash with the points, and 1-73 spark-hole to each flash with the balls.

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NOTES ON THE MICROSTRUCTURE OF SPIEGELEISEN.

CONDENSED FROM A REPORT BY A. MARTENS TO THE SOCIETY OF GERMAN ENGINEERS.

FRACTURES.

In spiegeleisen, cavities are frequently found, partially filled with tabular crystals protruding to about half of their length into the hollow space. From the ends embedded into the solid mass lines issue, running in vertical direction to the cooling surfaces of the piece from which the sample was taken. Along these lines the iron splits easily, with smooth surfaces. The crystalline plates within the cavities are arranged like the leaves of a fan or a book, and the groups thus formed intersect each other frequently. Fig. 1, next page, represents schematically the mode of intersection. Some of those books contain as many as fifty leaves, the thickness of which varies from 0·029 to 0·039 of an inch. Their edges are lined with a row of fine teeth, formed by bundles of minute crystals, a certain number of which always issues from one central point. The surface of the large crystals is covered with parallel lines or bands forming angles of 60° and 120° with each other respectively. Surfaces of this character are represented by Figs. 2*a*, 2*b*, and 3. Fig. 2*a* shows plainly that these lines are formed by rows of rectangular crystals protruding over the surface and penetrating the film of oxide covering the latter. Hereby parallel grooves are formed between the rows of crystals, into which the oxide has been crowded so as to form numerous folds and elevations. This shows that the oxide was formed before solidification. Fig. 2*b* illustrates the character of this structure, and Fig. 3 is a more theoretical representation of the same. The crystals form angles of 60° with the general direction of the rows. The large tabular crystals are, near the point of intersection, frequently bent out of shape, as shown in Fig. 4. It will also be noticed that the vertex of the obtuse angle, *a*, Fig. 1, is sharply defined, while the lines forming the angle β seem to run together a short distance from the point of intersection.

When the surface of a tabular crystal is treated with dilute muriatic acid (1 : 3) in order to remove the oxide and adhering foreign substances, these figures become more clear and comprehensive. The crystals protruding from the surface are more distinctly visible.

The surface of these crystals is covered with peculiar figures and lines (Fig. 2*b* and 3), forming right angles with the long axis of the crystals. The examination of these "etched figures" is very interesting and promises to furnish much information, especially as similar figures have already been observed on the polished surfaces of several samples of other iron. A magnification of 100:1 is best adapted for their observation.

When heated, these figures acquire and pass through successive shades of yellow, red, green, and blue, and those portions that resist longest the action of the acids are also slowest in changing colors. On such portions they are less intense and more glossy.

Supposing our sample of spiegeleisen to be a mixture of pure iron, iron containing a small quantity of carbon as a mechanical admixture, and spiegeleisen proper, Fe_4C, manganese, silicium, etc., and that, corresponding to a regular, systematical arrangement of these different substances throughout the entire mass, they be arranged in this manner also in the small crystal forming our object, we may, from the general appearance of the etched surface, conclude that spiegeleisen, Fe_4C, is less affected by acids than the surrounding portions of pure and slightly carburetted iron. And we may infer that, the other constituents being brought into similar relations with the iron, they will exercise similar influences, determined by their special character.

It must, however, not be overlooked, that the deepest portions of these etched figures, where consequently the body of our object is thinnest, shows the colors sooner than the elevations or thicker portions.

In considering the surfaces obtained by splitting a piece of spiegeleisen, we find them generally to be of a silver white color and very smooth, but frequently interrupted by cracks and crevices, on the walls of which will be found formations similar to those observed in the larger cavities. Magnified about fifty times, the surface shows a scaly texture, as represented in Fig. 7 and 7*b*. The latter is a detailed theoretical representation. Numerous thin, indistinctly defined, minute scales are superposed upon each other and their edges seem to have a tendency to develop in two directions chiefly, forming right angles with each other. Hereby the entire structure receives a peculiar character, which is yet strengthened by a number of lines running in the same direction. These are formed by the shadows of undulations, which probably correspond to the rows of crystals observed in the crystalline plates of the cavities. On the surface of a transverse fracture the scales will be noticed protruding to some extent (Fig. 7*a* and *b*). I estimate their thickness at from 0·0008 to 0·0011 of an inch. Pictures, extremely difficult to be reproduced by drawing, are formed by peculiar deposits, resembling in form mossy growths, branches of trees and fern leaves, and affording magnificent views indeed under the microscope. I have attempted to reproduce some of them in Figs. 8, 9, and 10. They are not unlike the pictures formed by the ice on window-panes.

EXPLANATION OF FIGURES.

Fig. 1. Schematic representation of intersection of crystals in cavities.

Fig. 2. Figures on the surfaces of crystals, 30:1.

Fig. 3. Theoretical representation of figures.

Fig. 4. Two crystals, bent out of shape at point of intersection, 20:1.

Fig. 5. Figures on the surface of crystals, 40:1.

Fig. 6. Surface of a crystal with etched figures, 180:1.

Fig. 7, *a*, *b*, *c*. Surface of split spiegeleisen, 70:1.

Fig. 8. Moss, tree and fern shaped figures, 80:1.

Fig. 9*a*. " " " " 250:1.

Fig. 9*b*. " " " " 100:1.

Fig. 10. Transverse fracture of spiegeleisen.

(*To be continued.*)