III

FROM HERR W. VON BEZOLD'S PAPER: "RESEARCHES ON THE ELECTRIC DISCHARGE—PRELIMINARY COMMUNICATION"

(*Poggendorff's Annalen*, **140**, p. 541. *Berichte der Bayrischen Akad. d. Wissensch.*, 1870.)

As we must extract that part of v. Bezold's work which alone concerns us here, and remove it from its context, it may be advisable to preface it by some explanation.

Von Bezold's researches start with observations on Lichtenberg dust-figures. Herr von Bezold had noticed that under certain conditions the characters of the positive and negative figures appeared to undergo some modification and to resemble each other more nearly; so much so that the negative figure, for example, might be taken for positive. The first deviation from the normal character always presents itself in the form of a small positive figure appearing in the centre of the negative figure, or a small negative figure in the centre of the positive figure. It appeared that the more complicated figures always owed their origin to a spark associated with an alternating discharge, while the simple figures were produced by simple discharges. In every complicated figure an alternating discharge to a certain extent registered itself; and from the appearance of the figure the alternating character of the discharge and the direction of its first outburst could be directly recognised. We can, therefore, make use of the Lichtenberg figures in investigating the discharge.

Von Bezold produced the Lichtenberg figures in the following way:—A horizontal plate of well-insulating glass was covered underneath with tinfoil, and this was connected to earth. On the upper side of the plate was placed the point of a vertical knitting-needle, to which the discharge was led. The needle was then removed, the plate dusted, and the figure produced was examined. If this arrangement (which will be called the test-plate) is inserted directly in the discharge-circuit of a Leyden jar or of the conductor of an electrical machine, it naturally makes it impossible for an alternating discharge, and in general for any complete discharge, to occur. Hence the test-plate can only be inserted in a shunt to the actual discharge which is being investigated.

While Herr von Bezold was carrying out this method—using the discharge to earth of the conductor of his electrical machine as the principal discharge—he at once came upon certain very remarkable phenomena. Positive figures made their appearance where negative ones were to be expected; large figures appeared where one might have supposed there would be small ones, and *vice versa.* Ohm's law did not explain the facts; it appeared as if the electricity in motion had the power of carrying with it neighbouring electrifications, as if "phenomena occurred in electrical disturbances similar to those which are observed in the motion of fluids under the name of aspiration-phenomena." Of course many of the details were bound to remain unexplained at first. We now quote Herr von Bezold's own words:

"These peculiar observations led to further researches on the division of electrical discharge-currents.

"Here, again, alternating discharges gave more constant results than simple ones; care was therefore taken to provide always a suitable return-conductor. The above experiments show that a simple wire cannot be employed for this purpose; hence the induction-coil of the Ruhmkorff R was used as a return-conductor.

"If now the electrical machine Q was slowly turned until a spark passed at F, complex positive figures appeared with great regularity on the plate at A.

"If a portion of the current was diverted along a short wire D, and this branch-current led on to the plate in the same way by a conductor *B*, there appeared, as might be expected, two precisely similar figures. If, on the other hand, the branch-wire was of considerable length (somewhat more than 1 metre), there was a decided difference in size between the figures. As soon as the length of the wire exceeded this limit, the figure at *B* was always larger than at *A*, even when the branch had its origin quite near the end of the conductor (1 cm. above the plate). The difference in size between the two figures became more striking as the length of the branch-wire *D* was increased, until finally, when *D* was equal to 6·4 metres, and *F* (the length of the spark-gap) was equal to 4·0 mm., the figure at *A* was reduced to a small star, and often was altogether absent.

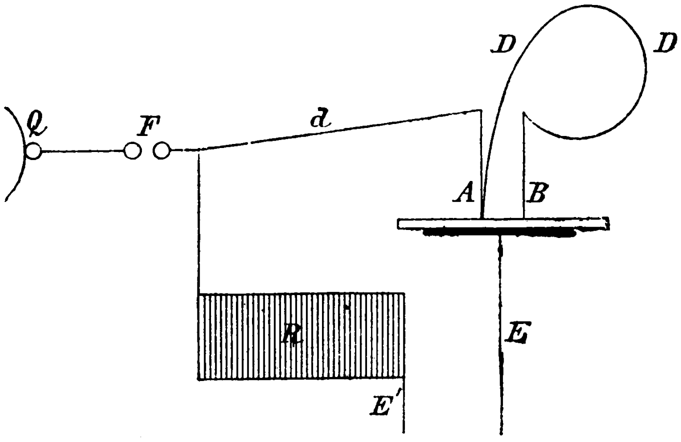

Fig. 12.

"This experiment obviously shows that Ohm's law only holds good for stationary currents, and not for electrical discharges, as indeed all theoretical investigations have shown. For whereas no electricity reaches the plate through the short branch *A*, it rushes, at any rate apparently, along the path through the wire *D* which is several hundred times longer.

"If the wire *D* is still further lengthened there is (within fairly wide limits) no change at first to be observed; only when the length has been about doubled does the figure at *A* again become larger, until with still greater lengths the difference in size between the two figures again completely disappears. It made no difference whether the wire used was thick or thin, whether it was a good or bad conductor, nor yet whether it was tightly stretched or curved. I have not yet experimented with wire spirals.

"On account of the complete novelty of the phenomena it appeared to me of interest to investigate the behaviour of the wire D at different places. For this purpose a modification shown in Fig. 13 was made. On the plate were placed the conductors A, B, C, which were connected together by two wires D and D'. If the length of these wires is chosen so as to produce as large as possible a figure at C, and, on the other hand, as small as possible a figure at A, then the figure at B is larger than that at A and smaller than that at C. If the wires are longer the sizes of the figures A and C are more nearly equal, whereas, when the ratio $D:D'$ is suitably chosen, B becomes quite small and even disappears altogether. When the sparking distance was 4·3 mm. and the length $A\ F$ was equal to 50 cm., $D = 6{\cdot}2$ m. and $D' = 8{\cdot}1$ m., the figures at A and C were large, whereas only a small star appeared at B.

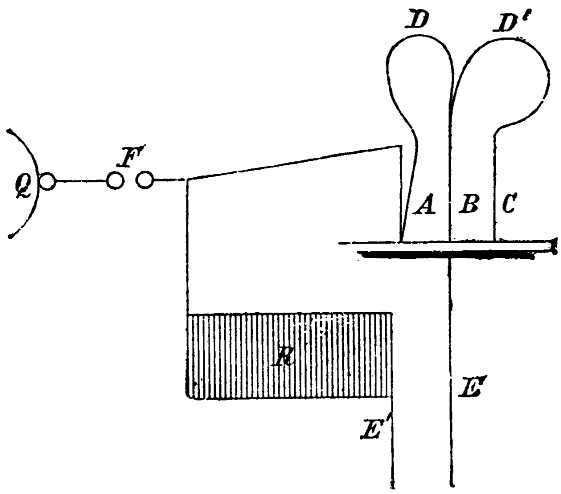

Fig. 13.

"If any one of the conductors is lifted away from the plate, the figures at the remaining conductors are not in the least altered thereby.

"This experiment teaches us a new fact, viz. that by simply connecting a conductor with a wire which has a blind end, we can produce important modifications in the figure which is formed by that conductor, and may even cause it to disappear. The most instructive way of performing the experiment is to bring near the conductor A a second spark-micrometer f (Fig. 14), one knob of which is connected with A while the other leads to the wire D. If now the distance between the knobs of the micrometer f is at first made large and then gradually diminished, it is seen that at the instant when the spark passes at f the figure at A becomes altered or disappears. But if we consider that in the case of an alternating discharge the wire forthwith becomes completely discharged, it follows that in such a case electricity is first driven to the outer end of the wire *D*, and then immediately back again; that, in fact, we have here disturbances which are entirely comparable with reflection.

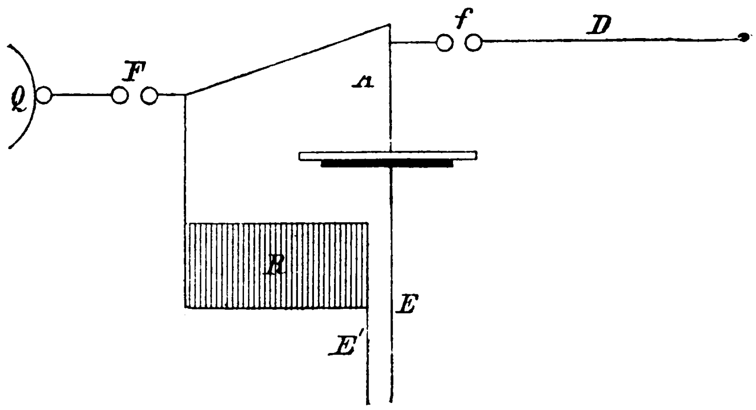

Fig. 14.

"This consideration leads to an hypothesis respecting the peculiar changes of size which the dust-figures undergo when the discharge branches as above described.

"If electric waves are impelled along a wire and forced to return along the same path after reflection at the end, the advancing and reflected waves would interfere and so give rise to phenomena analogous to those observed in organ-pipes. The observations already described point distinctly to such an analogy, and we may venture to compare the positions of the wire in which maximum and minimum figures appear with the antinodes and nodes.

"The hypothesis that the phenomena under discussion are due to interference gains additional support from the fact that it is only with alternating currents that the experiment is a decided success; differences in size between the various figures are indeed observed with simple discharges too, but not nearly to the same extent.

"In connection with the above experiments, a small modification was tried, which in turn became the starting-point for fresh researches:—

"If the end of the wire *D* (Fig 12) is brought back to and connected with the first conductor *A*, as shown in the accompanying diagram, the figure can again be made to disappear by suitably choosing the length of the wire. Strictly speaking, this experiment was the starting-point of all the others already described; but I have deferred the description of it until now because it does not help us much to understand the above experiments. For my own part, I at first believed that I had

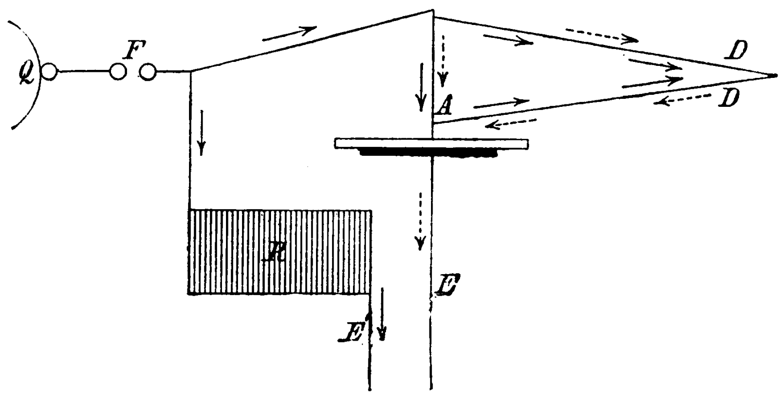

Fig. 15.

found in it an analogue to Savart's interference-experiment for sound-waves, and pictured the currents to myself as moving in the direction of the dotted arrows. This view was upset by the experiments in which the wire with a blind end was used, as well as by the fact that the distance between the two points of divergence on *A* exercised no decided effect on the result. In order to remove all doubt on this score I introduced a spark-gap into the branch *D* at various places in turn. The knobs of this second micrometer were only 0·01 to 0·03 mm. apart. I reasoned thus: If the current enters the wire from both ends there must be some point on the wire at which the two trains of waves meet. When the spark-gap is exactly at this point, the potential on the two balls must reach the same value simultaneously, and there can be no cause for the production of sparks at this point; whereas, at all other points, sparking was to be expected.

"And, as a matter of fact, the sparking ceased when the micrometer was introduced in the middle of a branch, and began again as soon as it was removed from this point a few decimetres on either side. It is thus proved that the direction of the current is as indicated by the continuous arrows; and, on the other hand, the small retardation which the electric discharge-current suffers while traversing a few decimetres of wire is here made evident.

"I now endeavoured chiefly to find out under what experimental conditions this retardation was most effectively shown. I found it best to use the direct discharge of a Ruhmkorff coil, as shown in the diagram (Fig. 16). The inducing current was provided by a Grove cell, and the sparking distance F in the

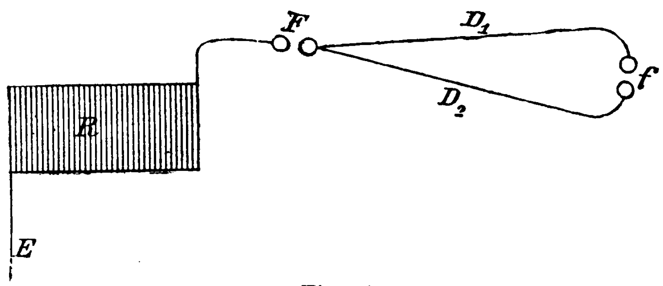

Fig. 16.

spark-micrometer was made about 2 mm., inasmuch as neither larger nor smaller spark-gaps gave such good results.

"Under these circumstances it sufficed for the production of the spark if one of the wires D was only one decimetre longer than the other. On the contrary, no spark ever appeared if they were of the same length. It can, however, be made to appear at once if the symmetry of the two branches is upset by placing the knob of a Leyden jar in contact with one of the wires.

"In this experiment, again, the material and thickness of the wires had not the slightest effect. Whether I used a silvered copper wire of 0·06 mm. diameter, or an iron wire of 0·23 mm., or a copper wire of 0·80 mm. diameter, there was never any spark as long as the two wires were of equal length.

"Thus the velocity of electricity for all (stretched)[1] wires is the same.

"The experiment is still not easily visible in the form above described, for one can only work with a small spark-gap in the auxiliary micrometer f. I therefore endeavoured to modify it in such a way as would admit of its being exhibited in a lecture-room.

"Trials with small Geissler tubes gave no definite result. On the other hand, the retardation can be very well shown in the following way, provided the difference of path amounts to a few meters (Fig. 17):—

"Let a (negative) discharge, preferably from a Ruhmkorff coil, be divided as above directly beyond the spark-micrometer into two branches. Let one of them be connected with the coating of a completely insulated test-plate, while the other is

[1] Wires wound spirally would probably have given a different result.

led by the conductor A on to the upper uncovered surface. Under these conditions a positive figure, or a negative one, or no figure at all, may appear on the upper surface according as the upper branch is larger, smaller, or of the same length as the lower. Indeed, we can predict what results the experiments must give if the supposition is correct that they are caused by time-differences. For if we recollect that the effect of leading

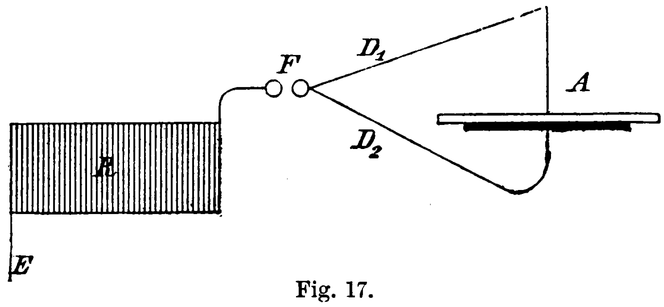

Fig. 17.

positive electricity on to the plate is the same as the effect of removing negative electricity, we can understand how a positive discharge gives rise to a positive figure if the electricity reaches the point of the conductor before it reaches the coating, *i.e.* if D_1 is shorter than D_2. If, on the other hand, the discharge arrives first at the coating, the induced electricity traverses the conductor in the opposite sense, and hence a negative figure must make its appearance upon the pane as soon as D_2 is shorter than D_1. In the course of the disturbance the induced charge in the wire D_1 must meet the electricity arriving directly from F, and hence a complex character will be impressed upon the figure.

"Between these two dispositions, which give opposite results, there obviously must be another in which no figure can be produced, because there is no reason why the one kind or the other should appear. This must be the case when the electricity arrives simultaneously from both sides, *i.e.* when D_1 and D_2 are of the same length.[1]

"The experiments entirely coincided with these theoretical predictions. With either kind of electricity figures of both kinds can be obtained if the lengths of the wires are rightly chosen.

[1] A small difference of length in favour of the upper wire may occur here, inasmuch as the electricity arriving from below has to spread itself out over the whole coating.

"It is true that this assertion may appear incorrect to many who may try the experiment under conditions which are not quite favourable; excepting the one case in which, on account of the exact equality of the two paths, no figure appears. For it may happen that at first sight all the figures appear to be positive under whatever conditions one works and with either kind of electricity.

"The reason is simply that the complex negative figures in this case belong to the class which already bear a strong positive character, and can scarcely be recognised as negative even after thorough experience of them.

"But the considerable difference in size which results from a change of pole amply suffices to remove at once any doubt respecting the real nature of the figures, and to show the accordance between the experiments and the theoretical predictions.

"To sum up, the following results were obtained:—

"1. If, after springing across a spark-gap, an electric discharge has before it two paths to earth, one short and the other long, and separated by a test-plate, the discharge-current splits up, so long as the sparking distance is small. But when it is larger the electricity rushes solely along the shorter path, carrying with it out of the other branch electricity of the same sign.

"2. If a series of electric waves is sent along a wire which is insulated at the end, the waves are reflected at the end, and the phenomena which accompany this process in the case of alternating discharges appear to be caused by interference between the advancing and reflected waves.

"3. An electric discharge traverses wires of equal lengths in equal times, whatever may be the material of which these wires consist."