



## XV. On the alternating electric arc between a ball and point

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of fluor and Iceland spar is far less absorbent than the direct-vision prisms ordinarily made with dense flint glass of a strong yellow tinge. For the purpose of achromatizing lenses the presence of a greenish or purplish tinge is of less importance, as a smaller thickness is used : and the purple fluorescence, which is objectionable in some ways, will not trouble the performance of the lens for any but photographic service.

It is of importance to note that the tint, whether purplish or greenish, of fluor-spar may be greatly reduced or nearly removed by simply heating the spar to a temperature a little above that at which it emits light in a darkened room. Care is necessary, however, that the crystals should not be heated either so suddenly or to so high a temperature as to cause decrepitation. Another point of even greater importance in the optical applications of fluor-spar is the selection of crystals which are not macled. Macled crystals of fluor seldom fail to show, when cut, some trace of double refraction which would unfit them for optical purposes.

The refractive index of the pale green variety seems to be a little higher than that of the colourless spar. I find 1.435 as the sodium-light index of refraction, as against 1.4338 found by Dr. Abbe.

City and Guilds Technical College,  
Finsbury, September 3, 1890.

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XV. *On the Alternating Electric Arc between a Ball and Point.* By EDWARD L. NICHOLS\*.

PART I.†

THE phenomenon which forms the subject of this paper was first brought to my notice by Mr. E. G. Acheson, the result of whose unpublished observation may be briefly stated as follows :—

Two wires, which formed the terminals of the secondary coil of an alternating-current transformer, were brought nearly into contact. One wire was armed with a ball, the other with a point. When the distance was such as to admit of a discharge between the two, it was found that a galvanometer in shunt around the ball and point indicated a considerable flow of continuous current.

This phenomenon has recently been subjected to investiga-

\* From Silliman's American Journal of Science, January 1891.

† From experiments made by Messrs. W. K. Archbold and G. L. Teeple.

tion by Messrs. Archbold and Teeple. Their experiments, from which in great measure the data used in the first part of this paper have been taken, are described at length in their Thesis in Electrical Engineering, which is now in the library of Cornell University\*.

The apparatus used in the verification of Mr. Acheson's observation consisted of a Ruhmkorff-coil of moderate size, the interrupter and condenser of which had been thrown out of circuit. The primary coil, as in all instruments of that type, consisted of a few turns of heavy wire surrounding a core of iron wires. When this coil was supplied with current from a small alternating-current dynamo, making 14,000 reversals a minute, and the terminals of the secondary coil were brought into position, a discharge of considerable brilliancy took place between them. To the unaided eye the discharge appeared to be perfectly continuous; but the fact that it was really of an intermittent and periodic character was indicated by the emission of a well-defined musical note, which corresponded in frequency with the period of alternation of the dynamo.

The terminals of the secondary coil were subsequently connected with a brass ball about one centimetre in diameter, and with a point consisting of a steel sewing-needle. These were mounted horizontally in well-insulated bearings, the centre of the ball in line with the axis of the needle. The distance between the ball and the point of the needle was capable of adjustment by means of a micrometer-screw. A mirror-galvanometer of two thousand ohms, having in its outer circuit about one hundred thousand ohms, was shunted around the ball and point (in parallel circuit with the air-space between them). When the induction-coil was put into operation, the ball and point being too far apart to admit of a visible discharge, the galvanometer-needle remained at zero, but when they were brought within striking distance a large and constant deflexion was produced. When the ball and point were interchanged the deflexion was reversed, its direction always being that which would have resulted from a current flowing from the ball to the point. Under the influence of the discharge, which was intensely luminous, the steel needle was fused at the point and rapidly wasted by oxidation, so that it became necessary to find some more

\* 'The Effect of placing a Ball and Point in a High Potential Alternating Current Circuit,' by W. K. Archbold and G. L. Teeple. Thesis in MS., Cornell University Library, 1889.

refractory material\*. It was finally supplanted by a pointed platinum wire, which, although rendered highly incandescent, withstood the temperature of the arc much better than steel had done.

The following quotation will serve to indicate the conclusions reached by the observers in the course of their preliminary experiments with the platinum point :—

“The behaviour of the arc as its length is increased is very curious. As the point is withdrawn the arc forms and sings with an even tone, the pitch corresponding to the number of alternations. The point becomes of a dull red colour, while the galvanometer gives a small but quite steady deflexion. As the arc is drawn out it sings louder and more harshly, the point becomes redder, while the galvanometer deflexion increases and becomes very unsteady. At a certain critical length the following phenomena suddenly occur:—the tone becomes smooth and even, the point brightens almost to a white heat, the intensity depending upon the strength of the current, while the galvanometer deflexion becomes much greater and very steady. The explanation suggested, and which subsequent experiments seem to confirm, is as follows:—At first the arc forms both ways, the rapid succession giving the tone. As the arc lengthens the arc still forms from ball to point, but is only intermittent (occasional) from point to ball, giving the unsteady tone and deflexion. Finally, the distance becomes too great for the arc to form from the point to the ball, while it still passes freely the other way, and the tone and deflexion become steady” †.

It was to the conditions existing in the circuit when the critical length of the arc, above mentioned, had been reached, that Messrs. Archbold and Teeple chiefly devoted themselves. The limits between which it was necessary to maintain the arc were exceedingly narrow, a very slight extension of the striking distance beyond the critical point resulting in total extinction of the discharge. Small changes in the speed of the machine

\* The attempt to use carbon terminals led to the following observation :—“A carbon pencil substituted for the point gave the same effect, but upon putting the carbon in place of the ball it still acted as a ‘point.’ If two carbons were used the more pointed one acted as a ‘point.’ (It was observed that the end of the needle was fused into a ball by the heat of the arc, and would then act as a ‘ball’ to the smaller particles of carbon projecting from the end of the pencil.) Two brass balls brought together caused a drifting of the galvanometer-needle from one side to the other, according, it is to be presumed, as the discharge changed the nature of the two surfaces, so that minute points formed on one or the other.” (Archbold and Teeple, Thesis, p. 3.)

† Archbold and Teeple, Thesis, p. 5.

were sufficient to throw the apparatus out of adjustment, and the arc, once ruptured, would not reappear spontaneously. It could be re-established, however, by the momentary introduction of a bit of metal between the ball and point, or even by the interposition of a candle-flame. The complete stability of the discharge was finally secured by driving the dynamo by means of a motor, the latter being supplied from a storage battery.

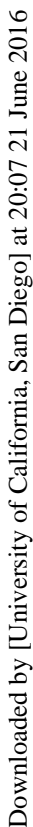
The main portion of the investigation consisted in the determination of the periodic changes of electromotive force and current during a complete cycle, when no arc existed, and of the modifications introduced into the curves of potential and current by the discharge between ball and point. Throughout the entire series of measurements, the striking-distance was greater than the critical values already defined, a condition the maintenance of which was secured by watching the indications of the galvanometer.

The instrument used in the measurement of electromotive force was a Thomson mirror-galvanometer of ten thousand ohms resistance. The galvanometer line was carried to the dynamo, where, by means of an instantaneous contact device, the circuit was closed during an interval of exceedingly short duration, once in every revolution. The device consisted of a wooden disk, mounted upon the shaft of the machine. A single bar of brass, on the periphery of the disk, passed under a brush at every turn. This bar was connected metallically with a brass collar on the shaft, and a second brush bearing upon the collar completed the circuit. By thus closing the line through the galvanometer, for an instant, once in a revolution, the electromotive force of the second circuit, at that particular point of the cycle for which the contacts were made, could be measured; and since the brush was adjustable through considerable range, the entire cycle could be explored.

The arrangement of the entire apparatus is shown in fig. 1. PC and SC are the primary and secondary coils of the inductorium,  $p$  and  $b$  are respectively the point and ball. R is a non-inductive resistance,  $g$  the indicating galvanometer, in parallel with the ball and point,  $r$  a non-inductive resistance,  $s$  a switch by means of which the Thomson galvanometer could be shunted at will around R or  $g$ . K is the instantaneous contact-device, and G is the Thomson galvanometer. When the Thomson galvanometer was shunted around R, which was placed in the main circuit leading from the induction-coil, it served to indicate the current flowing in that circuit during that portion of the cycle for which contact was being made; when connected in shunt with the gal-

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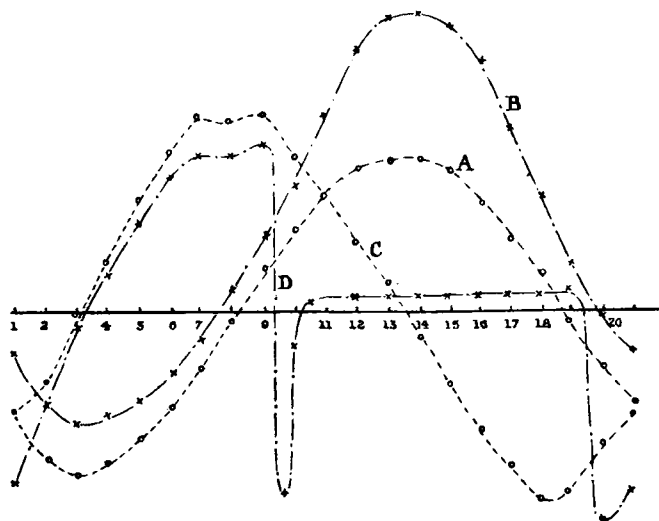


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between copper poles (approximately 112,000 ohms), on the one hand, and the parallel circuit between the ball and point on the other. The resistance of the latter path was infinite

Fig. 2.

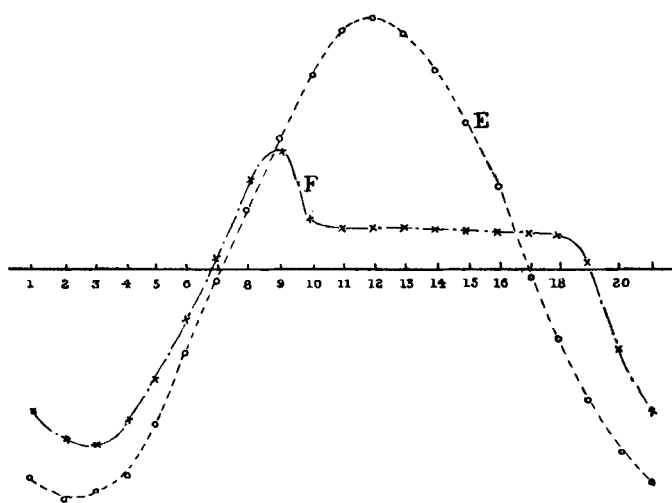


whenever the arc was interrupted, falling to finite values during each discharge. Increase of current through R indicates, therefore, the formation of the arc. Such increase is found to exist during the second half of each cycle, that is to say, during that interval in which the ball is positive; and it might be inferred from these curves alone that the discharge was an intermittent one taking place always from ball to point. Other curves, taken simultaneously with A and B, the Thomson galvanometer being shunted around the indicator galvanometer, lead to the same conclusion. The curves marked C and D (fig. 2) show the results obtained. It was thought that they would give the fluctuations in electromotive force between ball and point, corresponding in time to the current fluctuations in the resistance R. The indicating galvanometer, however, owing to the very rapid alternations to which the circuit was subjected, was found to possess such high self-induction as to materially influence the result. Strictly speaking, the curves C and D, therefore, give the periodic changes of electromotive force at the terminals of the indicator and not those occurring at the ball and point.

These curves are nevertheless of considerable interest. The

curve C shows the character of the cycle when no arc was formed, and D, when the arc was in operation; C, like A, is approximately a curve of sines. The irregularity at its positive crest, which also appears in D, is probably due to the imperfect performance of the contact brush, and, having no bearing upon the phenomena which the curves are intended to elucidate, may be disregarded. Since no current was passing between the ball and point when A and C were taken, they represent the fluctuations in successive portions of the same circuit. The lag, due to self-induction, however, is very marked, amounting to almost  $90^\circ$  of phase. Curve D, which shows the influence of the arc, is especially instructive. The potential rises during the first part of the cycle (ball positive); then follows a very sharp oscillation, occupying about one twentieth of the entire period or  $1/4600$  of a second of time. The potential then reaches a small positive value, which it maintains without fluctuation for at least four tenths of a complete cycle, when it suddenly becomes strongly negative.

Fig. 3.



To obtain curves of electromotive force between ball and point directly, a non-inductive resistance was substituted for the indicating galvanometer, and the measurements from which curves C and D had been drawn were repeated. Of the two curves thus determined, the one taken when the arc was not playing (E, fig. 3) is a sine curve closely coinciding in phase



with the simultaneous curve of current (A, fig. 2). The corresponding curve F, which was taken while the discharge was passing between the ball and point, is in its essential features of the same character as curve D (fig. 2). The interval of uniform positive potential is of the same length, and it is coincident with the interval of excess of current which shows itself in the positive branch of curve B. It is noteworthy that this interval of uniform potential which marks the duration of the arc, occupies in both cases the same portion of the cycle (between scale-divisions 10 and 19, approximately), although there is otherwise a difference of phase, due to self-induction, amounting to at least four scale-divisions. Curve C, for instance, reaches its maximum in the neighbourhood of scale-division 8, curve E at scale-division 12. The exclusion of the coils of the indicating galvanometer from the circuit reduced this difference of phase to a small quantity, and it suppressed altogether the remarkable oscillation of electromotive force (see curve D) which in all preceding experiments had introduced the formation of the arc.

The results exhibited graphically in these six curves afford abundant verification of the theory of the ball and point phenomenon, given in a previous paragraph; and they establish the fact that in the secondary circuit of a transformer, such as that made use of in these experiments, the striking-distance from ball to point exceeds that from point to ball. It follows that whenever the space between the ball and point is less than the former and greater than the latter distance, discharge will occur only during that portion of each alternation for which the ball is positive, and that under such circumstances a galvanometer placed in the circuit will show a constant deflexion.

Complete corroboration of the foregoing conclusion was obtained by studying the image of the arc in a revolving mirror. With an arc of less than the critical length the discharge was seen to consist of two distinct sets of sparks, all of the same duration but differing in colour. Each alternate discharge was purple, the intermediate ones being of a greenish cast. The spark-images were everywhere equidistant, and their duration was about four times as great as the intervening intervals of darkness. The extension of the sparking-distance beyond the critical point resulted in the complete suppression of the series of purple images, the intermediate ones remaining undisturbed in position, duration, and appearance. The intervals of darkness were then estimated to occupy six tenths of each cycle, the discharges four tenths; a ratio which corresponds with that of the duration of positive poten-

tial of the ball (as shown in the curve) to the total length of a complete cycle.

The ball-and-point phenomenon is unquestionably very closely related to a class of effects with which students of static electricity have long been acquainted. One recalls, to begin with, Faraday's experiments with the Leyden jar; in which, of two paths, the spark invariably followed that involving passage from a positive ball to a negative point, in preference to another, through equal air-space between a negative ball and a positive point\*. Wiedemann and Rühlmann have since shown that, between spherical electrodes which differ in diameter, the quantity of electricity necessary to produce a discharge is less when the larger ball is positive than when it is negative†; and Macfarlane has measured the electromotive force which will produce a spark between a point and plate, and has found it to be greater when the point is positive than when it is negative‡.

In view of the experiments described in the present paper, it appears that what is true, in this particular, of the spark from the Leyden jar and the discharge of the Holtz machine, is true also of the alternating-current arc.

## PART II. §

After the completion of the experiments of Messrs. Archbold and Teeple, the study of the Ball-and-Point Phenomenon was taken up under the writer's direction by Mr. F. C. Caldwell; the chief purpose of the investigation being to test the applicability of the effect to alternate current measurement ||.

Irregularities of action due to rapid changes in the surfaces of the point and ball, by corrosion and disintegration under the arc, finally caused the attempt to be abandoned for the time being, but Mr. Caldwell in the course of his work made a large number of observations of the discharge under various conditions. Many of these are of interest in this connexion on account of the light which they throw upon the original experiments, and because of the lines of further research which they suggest.

\* Faraday, *Experimental Researches*, § 1493.

† Wiedemann and Rühlmann, *Annalen der Physik und Chemie*, cxlv. See also Wiedemann, *Elektricität*, iv. p. 462.

‡ Alexander Macfarlane, *Proceedings of the Royal Society of Edinburgh*, vol. x. p. 555 (1879-80).

§ From experiments made by Mr. F. C. Caldwell.

|| Frank Cary Caldwell, "A study of the Alternating Arc between a Ball and Point." Thesis in MS. Library of Cornell University (1890).

Mr. Caldwell's first step, after having repeated the preliminary experiments of Archbold and Teeple, and verified their statements, was to substitute a ball with a surface of platinum for the brass ball used by them. The new ball withstood the action of the arc no better than the old one had done. It soon became covered with a black deposit, the growth of which modified and vitiated the action of the apparatus. In experimenting with such a ball, the surface of which was still bright and new, and with a point of the same metal, it was noticed that within the critical distance, while the spark was passing in both directions, there appeared to be two distinct paths along which the discharge was taking place. One of these was nearly in the line from the point to the ball, normal to the surface of the latter, the other from the point in a direction approximately at  $45^\circ$  with the common axis of the pointed rod and ball. Upon increasing the distance until the discharge entered the "one way" stage, the longer and oblique path of flow vanished. In the revolving mirror the two classes of sparks were easily identified. They were found to occur in alternation with each other, the spark which followed the normal path being that which passed from ball to point, the other that from point to ball. The images of the discharge from the point disappeared as soon as the critical distance was reached. In order to place the matter beyond all doubt, the times of the discharge which followed the normal path were determined by an ingenious method, quite independent of that used by the first observers, and it was found that the spark occurred always in that part of the cycle during which the ball was positive.

Mr. Caldwell's method of fixing the time of the discharge, briefly stated, was as follows. An adjustable contact device, similar to that used by Archbold and Teeple, was attached to the shaft of the dynamo. A wire from one pole of a large Holtz machine, driven by power, was carried to the neighbourhood of the ball and point, where two platinum terminals, 1 millim. apart, were set up. The wire was connected with one of these, and a line was carried from the other to the contact device. A wire from the latter to the remaining terminal of the Holtz machine completed the circuit. Whenever the brush made contact, a spark leaped between the platinum terminals just described. By adjustment of the brush, the spark could be made to appear at any desired instant in the cycle of alternations of the dynamo. The platinum terminals were placed so that the image of the spark in the revolving mirror was seen side by side with that of the discharge

between the ball and point, and the precise position in the cycle occupied by the latter was thus readily determined.

Closer study of the two paths of discharge showed that the oblique arc left the very apex of the point, swinging out laterally into its path; also that the normal arc, on approaching the point, avoided the apex and entered the wire from the side, never passing in at the point itself.

From these observations it appears:—

1. That the discharge from the ball (positive) leaves the latter in a direction normal to the surface, but that it enters the other terminal at some distance from the apex.

2. That the discharge from the point (positive) leaves the very apex of the latter, but is deflected into a course nearly  $45^\circ$  from the axis and reaches the ball obliquely at some point on its side.

Taking these observations into consideration, the explanation of the cessation of the discharge from the point at the critical distance and of the establishment of the "one way" arc, follows at once. The two paths of discharge differ in length, and for a given electromotive force the maximum striking distance is sooner reached in the case of the oblique than of the normal arc, so that the latter continues to pass at greater distances (of ball and point) than the former.

Further inspection of the images of the two arcs in the revolving mirror revealed another curious fact. The mirror was set up with its axis of revolution parallel to the common axis of the ball and point. The image of an instantaneous spark following the line of the normal arc would therefore be a line parallel to the axis of the mirror. Since the duration of the discharge was nearly  $\cdot 001$  second, this linear image was expanded into a broad rectangular band. The image of any oblique discharge would in general be an oblique parallelogram. The image of the discharge from point to ball, however, was not of that form. It appeared rather as a warped surface the form of which could be explained only by supposing that the discharge at first followed the normal path to the ball, and was gradually displaced as the cycle progressed, until it reached its extreme position at  $45^\circ$  to the axis, just before the rupture of the arc.

Definite results were obtained only while the platinum surface was new and bright. The region where the normal arc left the ball soon became tarnished and corroded and there was an increasing tendency on the part of the oblique arc to leave its own path and join the other.

When the ball was supplanted by a platinum wire, 1 millim.

in diameter, with rounded tip, the object being to force the two discharges into a common path, it was found that the arc from the point (positive) avoided the end of the wire altogether, and struck in upon the cylindrical surface beyond. When the end of this wire was surrounded by an insulated platinum ring which was connected with the terminal of the induction-coil by a separate wire—the intention being if possible to separate the two phases of current and conduct them over different wires—it was found that the arc from the point (positive) always entered the centre wire, never being diverted to the ring, although the intervening air-space was less than a millimetre. The returning arc, however, would sometimes leave the ring and sometimes the wire, and a galvanometer placed in the circuit between the ring and the induction-coil showed a large deflexion, such as would be caused by a flow of current towards the ring. This result seems to be in accordance with the conclusion reached from the inspection of the images in the revolving mirror; namely that the arc from the point always formed first along the shortest path. Deflexion from that path in the case of the wire and ring would probably be hindered by the insulating medium which intervened. When, finally, a cluster of points were opposed to the single point, it was found that the discharge from the latter was always along a single path, whereas the return arc from the cluster (positive) often followed several paths.

It had been noted by Messrs. Archbold and Teeple, that the platinum point used in their experiments, which was red-hot while the arc was passing in both directions, became white-hot during the "one way" stage. The heating-effects at the surface of the brass ball were not discernible, but when Mr. Caldwell substituted a thin sheet of platinum for the ball, this became incandescent under the action of the arcs. The spot where the oblique arc (point positive) impinged upon the foil became white-hot, while that at which the normal arc (ball positive) left the foil was barely red-hot. In this respect, then, the discharges act like the ordinary sparks of the influence-machine or induction-coil, which, as has been shown by Despretz, Poggendorf, Naccari, and other observers, heat the negative electrode to a higher degree than the positive one. This action is in marked contradistinction to that of the continuous current arc, the positive terminal of which takes the higher temperature.

In this brief account of Mr. Caldwell's experiments, I have omitted to mention many of the observations recorded by him. He had occasion in the course of his investigation to study

the discharge under a variety of conditions, and found that when liquid surfaces (mercury or water) were used in place of the ball, also that when hydrogen, carbon-dioxide or illuminating-gas were substituted for air, as a dielectric, the ball-and-point effect, more or less modified, could still be obtained. The investigation of these points, although it has already led to some results of significance, is as yet very incomplete.

Physical Laboratory of Cornell University,  
September 1890.

## XVI. *Conductivity of Hot Gases.*

*To the Editors of the Philosophical Magazine and Journal.*

GENTLEMEN,

Cambridge, January 19, 1891.

IN the January number of Wiedemann's *Annalen* Dr. Arrhenius publishes an account of some experiments on the conductivity of hot vapours. His results differ from those obtained by me (*Phil. Mag.* April and May 1890) in the cases of the vapours of hydrochloric acid, hydriodic acid, and ammonium chloride. According to his experiments these vapours do not conduct appreciably better than air at the same temperature, while I found that their conductivities were very greatly in excess of that of air. The difference between these results is, I think, easily explained on the view given in my paper, that the conduction of electricity through hot gases is due to dissociation. The method employed by Dr. Arrhenius was to inject these substances into a flame; thus the hydrochloric-acid gas, for example, would be surrounded by a multitude of other gases, and especially by hydrogen. The presence of a large excess of hydrogen would retard the dissociation of a gas such as hydrochloric acid, of which hydrogen is one of the products of dissociation; for it is a well-recognized principle in the theory of dissociation, that it is retarded by the presence in excess of one of the products of dissociation. This has been verified by Wurtz, who found that an excess of  $\text{PCl}_3$  stopped the dissociation of  $\text{PCl}_5$ . In Dr. Arrhenius's experiments the dissociation of the hydrochloric acid would thus be very much less than it was in mine, when the gas was heated by itself, and when the dissociation was large enough to be detected by chemical means. This, on the view that the conductivity is due to dissociation, would be sufficient to explain the difference in the results. I have found myself that the conductivity of  $\text{HCl}$  is very much reduced by dilution with hydrogen, more