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A CRITIQUE AND STUDY ON THE NATURE OF THE VOLTA EFFECT.

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FOR over a century, physicists have diligently sought an explanation of the Volta effect. Although numerous and extensive investigations have been undertaken for that purpose, no general agreement has yet been reached. This is due in part to the difficulties and uncertainties inherent in the problem which extend even to the simplest experiments. It is a matter of importance, therefore, that simple and crucial experiments be devised and that they be performed in such a way as to yield results which are incontestable. Not before is it permissible to attempt "explanations." Hence the primary object of this paper is to establish more firmly some of the significant facts rather than to advocate vigorously any theory in regard to the fundamental nature of the Volta effect.

Examination of Sanford's Results.

A recent article[1] by Sanford makes such a study not untimely. He has described experiments the results of which, as he interprets them, furnish an effective argument against the so-called electrolytic theory of the Volta effect. He believes he has shown that the charge exhibited by an insulated conductor, such as a ball, after it has made contact with the *inner* surface of a hollow earthed conductor, such as a beaker, is dependent on the nature of the *outside* surface of the latter. This conclusion, upon which his argument is chiefly based, seemed untenable to the writer because the generally accepted facts of the phenomenon, together with incidental observations in an investigation now going on in this same field, left no doubt in his mind that the Volta effect depends *solely* upon the nature of the *opposed* surfaces. (By opposed surfaces is meant the two metal surfaces which, with the intervening dielectric,

[1] Phys. Rev., XXXV., p. 484, December, 1912.

constitute the condenser system, the charge upon which is measured in experiments upon the Volta effect.)

An attempt was therefore made to reproduce the essential elements of the experiment described by Sanford. The whole assemblage of apparatus was enclosed in a cage of wire netting however and a Dolazelek electrometer was used instead of an electroscope. While the results obtained were fairly consistent for observations taken consecutively there were large and apparently unaccountable variations from one time to another. After making several series of unsatisfactory observations, it was discovered that the silk cord which in Sanford's experiments served to insulate the ball and to raise or to lower it was invariably charged. Decided induction effects were therefore produced which could not be eliminated even when the ball was attached by a wire so that no part of the cord came within 20 or 25 cm. of any portion of the beaker. All the cases described by Sanford were investigated several times but none yielded results which could be interpreted as Sanford interpreted his. In spite of the disturbing influence of the charged cord, there seemed to be no doubt that the Volta effect depended on the opposing surfaces. It is certain that in Sanford's experiments, the true effect was masked to a large extent by disturbing causes. An insulating silk cord absolutely devoid of an electrical charge appears to be an impossibility. And when it is noted that the arrangement is then an ideal one for charging by induction it is obvious that the charge exhibited by the ball would depend to an indeterminable extent on the intensity and orientation of that on the cord.

A. Modification of the Experimental Arrangement: Qualitative Measurements.

In order to do away with the silk cord and the attendant disturbances, it was decided to insulate the metallic beaker instead of the ball and to operate the ball with an earthed wire. It was decided also to study a larger number of cases than had been investigated by Sanford.

It was found that pieces of sealing wax did not serve satisfactorily for insulating the discs and beakers which were to be used because leaks and noticeable charges very soon developed. An insulating stand was then constructed of small tubes and narrow strips of brass with a portion of the legs made up of slender ebonite rods. The apparatus was disposed as shown in Fig. 1, all being enclosed in a wire cage which was well grounded. All manipulations took place from the outside.

The sensitiveness of the electrometer needle was such that when charged to about 30 volts a potential difference of one volt between the pairs of quadrants caused the reflected image from the mirror attached to it to move 140 mm. at a distance of 125 cm. The conductor to be examined was placed upon the insulating stand and the ball lowered to contact. The grounding key, K_1, was raised by a lever whose fulcrum was at f_1. Then the ball was made to rise so far above the insulated body

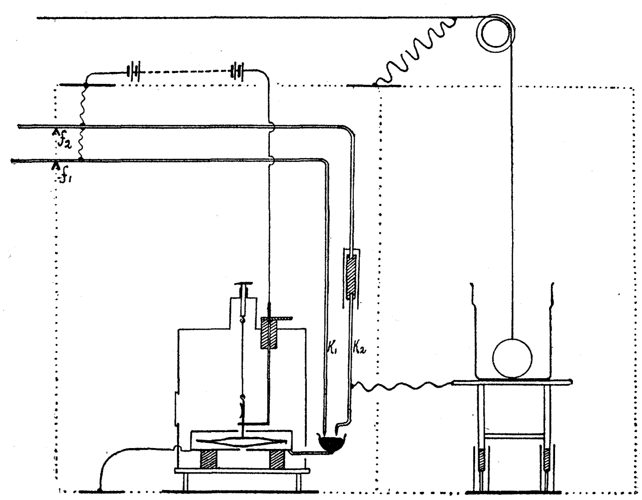

Fig. 1.

as to have no further influence upon it. This charge was divided with the insulated quadrants of the electrometer by bringing K_2 into the mercury cup. Then K_2 was raised, the ball lowered and raised, and K_2 again lowered in turn. These successive operations were repeated until the electrometer needle indicated practically no further increase in the charge on the insulated pair of quadrants. The latter were then at approximately the same potential as the insulated body. This method was used merely in order to conform as nearly as possible to Sanford's procedure. The keys, K_1 and K_2, as well as the wire attached to the ball were manipulated from the point at which observations were made. The potential indicated by the electrometer would of course not be the potential difference actually existing between the opposing surfaces at the time of contact. Nor indeed can the Volta P.D. be found with this sort of an experimental arrangement since the capacity of the system consisting of the ball and beaker or ball and disc cannot be evaluated. Comparisons may be made, however, between results obtained under the same conditions and definite conclusions drawn from them.

The ball was one of steel, 5 cm. diameter. Discs of brass and aluminum as well as beakers of these metals were used as the insulated conductor.

These were also covered in various degree with tinfoil. The discs were each 9 cm. in diameter. The brass beaker was 10 cm. in diameter and 12.5 cm. high and the aluminum beaker was 10 cm. in diameter and 14.5 cm. high.

With the above arrangement, series of results obtained at intervals extending over days were in such excellent agreement that disturbing influences must have been quite removed. Such differences as did appear were no larger than could be accounted for by the probable errors of observation in this simple and comparatively crude method of procedure. Changes with time are also to be expected because of the variable surface condition of the conductors. The numbers given in connection with each of the several cases to be described are the means of three values obtained in as many complete series of observations taken on different, not consecutive, days. They represent in volts the approximate maximum potential indicated by the electrometer in the manner outlined above when the steel ball had been in contact with the particular body under the conditions to be specified. The order of accuracy of the individual observations from which the means are taken lay within .02 volt.

With the ball making contact with the center of the brass disc, the observed values were

−.093 volt for one face,
+.027 volt for the other face.

This indicates merely a dissimilarity between the two faces. When one of the faces was completely covered with tinfoil the value was

+.403 volt for the tinfoil surface,

and when a circular hole 2.5 cm. in diameter was cut in the tinfoil thus allowing the ball to make contact with the brass without touching the tinfoil the value became

+.023 volt for the first of the two faces considered above in the presence of the tinfoil ring,
+.107 volt for the other face considered above in the presence of the tinfoil ring.

The tinfoil has thus a marked influence upon the result although the ball does not make contact with it. Similarly with one face of the aluminum disc the observations gave

+.690 volt for the naked disc,
+.400 volt for the tinfoil surface,
+.633 volt for the face covered with tinfoil except for circular space 2.5 cm. in diameter in the center.

Again the tinfoil makes its presence felt. In both cases the change which it brings about is such as to bring the combined effect toward that observed for it alone and indeed the amount of this change is the greater the larger the difference between the independent effects of the tinfoil and the metal upon which it is placed.

When the discs were replaced by the beakers in an upright position so that the ball made contact with the center of the bottom on the inside, the observed values were

−.103 volt for the brass beaker,
+.390 volt for the aluminum beaker.

Upon placing cylinders of tinfoil on the inside of the beakers leaving the bottoms exposed, the values became

+.047 volt for the brass beaker,
+.357 volt for the aluminum beaker.

The change brought about by the tinfoil is surprisingly great when it is noted that the portion of its surface nearest the ball was over 2 cm. away. The extent of the surfaces opposed to, and within range of each other, was very large however.

When the outside of the beakers was covered with tinfoil, leaving exposed the inside surfaces, the values observed, after the ball had been brought in contact with the bottom, were

−.100 volt for the brass beaker,
+.380 volt for the aluminum beaker.

These values are the same as those obtained with the naked beakers. The effect is, therefore, *completely independent* of the nature of the *outside* surface.

This last conclusion was confirmed by using what was in effect a hollow vessel with a brass bottom and tinfoil sides. The brass disc was placed in the bottom of the beaker, the sides of which were covered with the tinfoil cylinder used above. The ball then made contact with the center of the disc. This gave

+.093 volt with brass on the outside,
+.080 volt with aluminum on the outside.

Replacing the brass disc by the aluminum disc gave

+.477 volt with brass on the outside,
+.467 volt with aluminum on the outside.

Evidence that the effect is independent of the outside surface is not wanting. (That the values for the aluminum beaker should tend to be somewhat less than those for the brass beaker in these cases, is accounted for by the fact that, since the aluminum beaker is larger than the one of brass, the capacity of the insulated system is slightly greater with the former than with the latter, forming a part of it.)

When the brass disc was placed on the bottom of the inverted beakers with the ball making contact with the center of the disc, the observed values were

−.067 volt with brass disc on brass beaker,
−.060 volt with brass disc on aluminum beaker.

With the aluminum disc replacing the one of brass, the values were

+.403 volt with aluminum disc on brass beaker,
+.390 volt with aluminum disc on aluminum beaker.

It is here seen that the effect depends only on the opposing surfaces, as has been apparent in all the preceding cases.

These several cases were varied by using also a brass ball, and a number of other special cases were studied but the results are not here presented since they are in every respect similar to those given above. They all furnish unmistakable evidence that the Volta effect depends *only* on the nature of the *opposing* surfaces. By none of the results is there suggested any argument in favor of the possibility that the effect depends even in the slightest degree on the nature of the surface of the outside of a hollow conductor when a second conductor has made contact with the inside. It is only those portions of the surfaces which are exposed to, and within range of, each other that come into play. All such surfaces contribute to the general effect according to their extent and relative proximity.

It is to be noted, as stated before, that the numerical results which have been given do not represent the true values of the Volta P.D. Also, since the capacity and relative proximity and extent of the opposing parts are not the same in all cases, the deviations vary accordingly. Thus, the effect observed between the ball and the aluminum plate is apparently greater when the latter is examined alone than when it is placed upon the bottom of an inverted beaker. The real effect is the same for both but does not appear so because the capacity of the insulated system is greater in the one case than in the other. However, except for the aluminum beaker being somewhat larger than the one of brass, the conditions and circumstances surrounding those cases which furnished the arguments for any of the general conclusions were similar in all respects. Hence the conclusions which have thus far been drawn are the inevitable ones which would be reached through a knowledge of the exact values of the Volta P.D.'s.

It is obvious that the surfaces of different conductors in connection with the earth, either separately or in mutual contact, are at different yet definite potentials with reference to the earth and thus exhibit definite potential differences with reference to each other. It must be assumed that the entire surface of a conductor in air is a seat of electrification the nature and intensity of which is characteristic of the surface. If the conductor is composed of dissimilar metals or if its surface is non-homogeneous, then the intensity and character of the electrification displayed in various portions of the surface are variable and fluctuate in such a way as to reflect accurately the conditions in the region considered.

B. A Closer Study of the Phenomenon: "Approach" and "Separation" Charges.

A more detailed study of a few of the cases was found desirable and of service in extending and confirming the interpretations already given. The experiment was accordingly modified in this way: The conductor to be examined was permanently connected with the electrometer by means of the key, K_2 (Fig. 1). After bringing the ball in contact with the conductor on the stand and raising K_1, the grounding key, the ball was *very slowly* raised and the deflection of the electrometer needle noted as the ball moved upward.

With a brass plate, there was a deflection of 6 mm. to the left just as the ball began to rise which became greater as the ball rose higher, reaching a maximum of 12 mm. when the lower extremity of the ball was 5 or 6 cm. from the disc. As would be anticipated from the above, there was a deflection to the right when the ball approached the plate if the latter had been first earthed and then insulated. Furthermore when the ball moved away from a point *near*, instead of in contact with, the surface of the plate which had been discharged to earth and then insulated, the deflection was of course to the *left*. The deflection to the right indicated a positive, that to the left, a negative, charge. These have been termed by Majorana[1] "*approach*" and "*separation*" charges respectively. These phenomena, if no others, make it necessary to assume that, whatever be the fundamental cause of the electrical manifestations at the surface of a conductor, they deport themselves just as would an insulated electrical layer of uniform (for a given conductor of homogeneous surface) distribution. It is under the limitations of this assumption that the surface of conductors will be spoken of as being *charged*. The surface of the ball being thus positively charged with reference to that of the brass plate induces a relatively negative charge in the latter upon approaching it, and a positive charge in the quadrants of the electrometer.

[1] Phil. Mag., XLVIII., p. 241, 1899.

When the ball moves away the charges that were induced are redistributed. With the aluminum disc the approach and separation charges due to the ball were larger and of opposite sign to those noted for the brass, the aluminum being positive with reference to the steel ball.

In the case of the brass disc covered with tinfoil except for a circular space in the center, it was found that while the deflection of the electrometer needle was 7 mm. to the right when the ball was far removed, it was to the left just as the ball began to rise, reaching a maximum in that direction when the ball was about 2 or 3 mm. away. Then as the ball continued upward it shifted to the right. This is to be explained as follows: While the brass is negative, the tinfoil is positive, with reference to the ball. Accordingly, a relatively negative charge is induced in the brass, and a relatively positive charge is induced in the tinfoil. When the ball is completely removed these charges become free, the resultant charge indicated being of the sign of the greater. A negative deflection is first indicated because for the first 2 or 3 mm. the charge induced by the ball in the brass is released at a greater rate than that induced in the tinfoil. Then the relative change in induction between the ball and the tinfoil becomes the greater. The final charge displayed is the net result of all the factors at work just as the ball leaves the point of contact. It is seen to some extent how the individual factors contribute.

A brass beaker was examined in the manner outlined above, first naked and then with a tinfoil band about 3 cm. wide covering the upper inside portion. Fig. 2 shows the various approximate positions of the ball at which the deflections of the electrometer were noted together with the corresponding magnitudes of these deflections in millimeters. The fact that the end results were the same for both indicates that when the

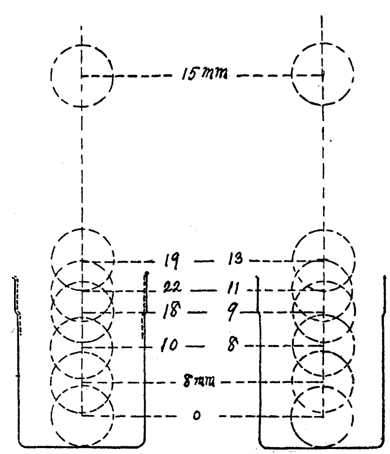

Fig. 2.

ball was in the bottom of the beaker the tinfoil was too far away to exert any influence. It was found that this continued to be the case when the beaker was covered half way down on the inside with tinfoil. When extended beyond this point, the tinfoil began to make its influence felt. It is seen that the deflection which was in the negative direction showed a temporary increase as the ball approached and passed by the tinfoil collar. Considering the brass beaker alone, the increasing deflection is due to the separation charge between the ball and the beaker. With the tinfoil present there are successively an approach, and a separation, charge due to the tinfoil and the ball. These are simply superimposed upon the separation charge due to the ball and the beaker. A "tinned" surface in place of the tinfoil produced an effect of approximately the same magnitude. A band of copper wire gauze on the inside of an aluminum beaker produced a similar effect, the deflections being in the positive direction since the aluminum was positive, and the gauze negative, with reference to the ball.

This minute study of the approach and separation charges thus furnishes an excellent means of analyzing the effects of composite surfaces. Each portion acts independently, its contribution to the general effect being just what it would be if it acted alone, so that taking into account the disposition and extent of the components, the estimated effect coincides with that observed.

C. Quantitative Measurements of the Volta Effect with Composite Surfaces.

While the above experiments serve admirably to establish general relationships, they are not adapted for exact quantitative measurements. To decide whether the components of a composite surface contribute to the general effect in *exact* proportion to their extent, their relative proximity, and the intensity and character of their electrification required another experimental arrangement.

Suppose we have two plates, A and B, with their faces parallel and near, but not in contact with, each other. Let A be connected to one pair of quadrants of an electrometer which together with B are grounded. Then upon insulating the quadrants with which A is in communication and moving B away, a separation charge is noted by means of the electrometer because of a characteristic difference of potential between the surfaces of A and B. The plate B may be so charged with a potential divider that there will be no deflection set up in the electrometer upon moving B either away from, or toward, A. The potential thus applied to bring this about is simply superimposed upon the surface potential already existing so that it is numerically equal, and opposite in sign, to the original P.D. between the surfaces of A and B. Direct "contact" is not made between the surfaces; they are merely in temporary communication through the earth. This is one of the familiar methods of measuring the Volta P.D. between two given metals. The foregoing results suggest the hypothesis that if the surface of A be made up of two or more metals then the compensating potential will be the *average* P.D. between B and the constituent parts of A. It was to ascertain if this is a fact that the following experiments were made.

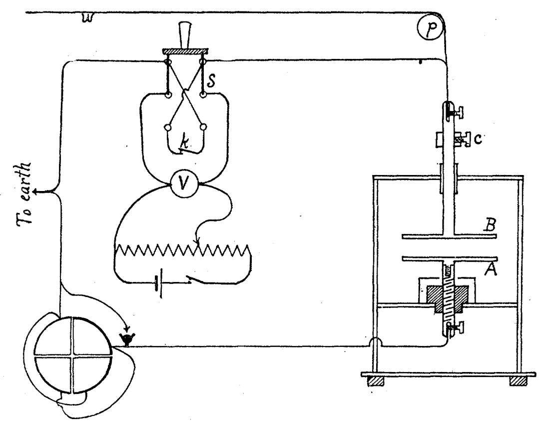

Fig. 3.

The arrangement is sketched in Fig. 3. A is the insulated plate which was removable, one of brass and one of aluminum being used. Each was tested against B, a brass plate, both naked and covered in various proportions with tinfoil. The insulating plug consisting of ebonite was covered with a metal cap to screen off disturbances likely to arise from possible charges on its surface. The initial distance between A and B was roughly adjusted by the set-collar c, and then more accurately by screwing A up or down in the insulating plug. When c rested upon the projecting sleeve of the upper portion of the brass frame, A and B were at a fixed minimum distance apart. The plate B was raised or lowered by means of the wire w operating over the pulley p. B and the frame were charged by means of a potential divider. The reversing switch S made it convenient to charge either positively or negatively and k served to ground the system. The functions of the other parts of the apparatus suggest themselves. The electrometer and the frame supporting the plates were enclosed in the wire cage of the preceding experiments.

In the actual experiment it was not wholly satisfactory to adjust the compensating potential until a balance was reached since the sensitiveness of the arrangement was greater than the accuracy with which the readings on the voltmeter could be made. Therefore the P.D. across the terminals of the voltmeter was fixed at some convenient value. The method was then to apply this P.D. positively and negatively in turn to B, noting in each case the deflection in the electrometer upon raising B. Proceeding in this way we have:

$$E = PD\frac{d_1 + d_2}{d_1 - d_2},$$

where

E = natural P.D. (*i. e.*, the Volta P.D.) between the surfaces.
PD = applied P.D.
d_1 = deflection of electrometer when $+PD$ is applied to B.
d_2 = deflection when $-PD$ is applied.

d_1 and d_2 are to be taken with their sign, the balancing point of the needle being zero.

The plates were 8 cm. in diameter and the initial distance between their surfaces was 1.75 mm. The tinfoil covering the surface of A in whole or in part was of course nearer. It was smoothed out by pressing it with a similar piece of foil covering the fingers. Its upper surface was estimated to be on the average approximately .25 mm. above that of the plate beneath. The fact of its being nearer to the opposing surface than that of those exposed portions of the surface upon which it is placed will involve a correction which will be taken up later.

In the table which follows are given a sample series of results. The plate was first examined entirely covered with tinfoil. Then a sector of 120° of the tinfoil was removed, followed by 60°, 60°, 120° more successively so that the final test was with the naked plate. The latter part of the table gives the results with the surfaces divided concentrically, *i. e.*, a circle of one half the area of the plate was cut out of the foil exactly covering it. Measurements were made with the ring of foil as well as with the small circle which had been cut out, each being centrally placed upon A.

The calculation of the average P.D. which exists between a homogeneous surface B, and a composite surface A, is made as follows:

Suppose the dissimilar surface to consist of two metals, each of which is homogeneous, and in the same plane, then

$$E = \frac{a_1e_1 + a_2e_2}{a_1 + a_2},$$

where

E is the average P.D. between A and B.
e_1 is the P.D. between B and one of the parts of A.

a_1 is the area of this part of A.
e_2 is the P.D. between B and other portion of A.
a_2 is the area of this portion of A.

Ratio of Exposed Surfaces.		P.D. Observed.	P.D. Calc. Supposing Surfaces in Same Plane.	P.D. Corrected by Reducing Surfaces to Same Plane.
Surfaces divided radially				
Tinfoil	Aluminum			
1	0	+.352	.352	.352
2	1	.472	.483	.469
1	1	.530	.548	.533
1	2	.597	.614	.600
0	1	.744	.744	.744
Tinfoil	Brass			
1	0	+.336	.336	.336
2	1	.237	.225	.236
1	1	.184	.169	.182
1	2	.118	.113	.125
0	1	.002	.002	.002
Surfaces divided concentrically				
Tinfoil	Aluminum			
1	0	+.366	.366	.366
1	1			
Aluminum outside.		.549	.560	.544
Aluminum inside		.539	.560	.544
0	1	.754	.754	.754
Tinfoil	Brass			
1	0	+.380	.380	.380
1	1			
Brass outside.		.207	.192	.206
Brass inside.		.214	.192	.206
0	1	.004	.004	.004

If the parts of the dissimilar surface are not in the same plane, the portion which is the closer contributes relatively as much more to the general effect as it would if its surface were larger in the ratio by which it is the nearer to the opposing surface. The above expression must then be rewritten in the form,

$$E = \frac{a_1 e_1 + a_2\left(1 + \dfrac{d_1 - d_2}{d_2}\right) e_2}{a_1 + a_2\left(1 + \dfrac{d_1 - d_2}{d_2}\right)},$$

where
d_1 is the distance between B and portion a_1 of A.
d_2 is the distance between B and portion a_2 of A.
Upon applying this correction it is seen that the agreement between the

observed and calculated values as shown by the first and third columns of the table is as close as the limits of the accuracy of the measurements permit. In the case of the surfaces being divided concentrically it appears that the portion exposed in the form of a ring contributes more than an equal portion in the form of a circle in the center. This is accounted for by the fact that the effect due to the edges of the opposing surfaces is not negligible so that the effective surfaces are slightly greater in extent than the dimensions indicate. This increment accrues to the advantage of the outer ring.

A composite surface of brass and lead was formed by pressing brass gauze into a sheet of lead by means of a roller press. The lead coming through the openings was pressed flat but left exposed one face of the brass gauze. The strands of the latter were also flattened at their crossing points so that the whole surface was approximately plane. The lead alone when passed through the press showed a P.D. of +.37 volt against the brass plate, and the gauze similarly passed through gave −.13 volt. The gauze and lead together gave +.14 volt. Since the gauze was made up of wire .55 mm. in diameter, 12 strands to the inch, the ratio between the exposed surfaces of lead and brass was approximately 52 to 48. The computed average P.D. between the brass plate and this composite surface was thus +.13 volt which compares favorably with +.14 volt, the observed value.

A piece of very fine copper gauze of 45 strands to the inch was almost completely imbedded in a sheet of lead by pressing it well in and then burnishing with a convex-faced steel tool, leaving the copper exposed only at the crests formed by the crossing strands. The ratio between the exposed copper and lead surfaces as estimated by examining under the microscope was 7 to 93. While the measured P.D.'s against the brass plate were −.20 volt and +.37 volt for the gauze and lead respectively, that for the combined surface was +.34 volt, as compared with +.33 volt, the theoretical value.

It is unnecessary to produce further evidence that the Volta effect observed for a composite surface may be determined by considering the independent effects of the constituent parts of this surface.

D. The "Screening" of the Volta Effect with Wire Gauzes.

The question as to what extent a metal plate will contribute to the effect through a perforated sheet placed upon it was suggested by the foregoing experiments. A qualitative study of this point was made by placing gauzes of different meshes upon the brass and aluminum plates. The latter having shown P.D.'s of +.004 volt and +.754 volt respectively against the movable brass plate, would, to the extent that they were effective through the gauze, produce a difference in the observed P.D. when a given sheet of gauze was placed upon each in turn. The pieces of gauze were cut slightly larger than the plates upon which they were placed to preclude the possibility of the edge effects of the latter, and were smoothed out so as to conform as nearly as possible to a plane. The distance between the plates was kept at 2.5 mm. so long as this distance was two times, or more, that between the upper surface of the gauze and that of the plate beneath, being increased however when the coarser gauzes were used so as to make this ratio about 2 to 1. Proceeding in this manner the following results were obtained, as the means of three observations in each case.

Kind of Gauze.	No. of Strands to Inch.	Diameter of Strands in Mm.	P.D. Observed on Aluminum.	P.D. Observed on Brass.
Copper	45	.15	−.202	−.203
Brass	30	.25	−.259	−.260
Brass	16	.45	−.208	−.210
Brass	12	.55	−.249	−.256
Brass	6	.75	−.168	−.111
Brass	16/3	.45	+.033	−.106

Not until there are 12 strands to the inch is there an effect through the gauze which is decisive. The differences up to that point are no greater than the probable errors of observation. Indeed the observed effect is practically that which we would have with the gauzes alone until the size of the holes is equal to or greater than their depth. For the finer gauzes the average depth of the holes was about 2½ times, perhaps more for the finest one, the diameter of the strands, because the gauze could not be made to lie perfectly smoothly upon the plates. As the ratio between the size and depth of the holes grows, the plate beneath becomes increasingly effective through them.

Perhaps the only way to study this point in a really quantitative fashion would be to have two metals made up in the form of square rods and arranged on the order of a thermopile, each set rigidly connected together and movable along their axes. A plane surface consisting of the two metals could be formed of the ends of the rods by proper adjustment. Then by moving one set of rods one way or the other, holes of varying depth could be obtained with either metal in the foreground. In order to have holes of different sizes, would of course require rods of corresponding dimensions. An experiment of this kind will be necessary to determine whether, upon taking proper account of the relative extent and distances of the surfaces of the two metals (including the sides of the holes) with reference to an opposed surface, the simple considerations outlined above for composite surfaces will lead to results which are related in some exact way to those observed.

Summary.

The Volta effect depends, under *all* circumstances, on the nature of the *opposing* surfaces of conductors which have been brought near, or in contact with, each other. Indeed it depends *only* on the surfaces exposed to, and within range of, each other. All, and only, such surfaces, or portions of surfaces, of conductors contribute to the general effect. The results of experiments purporting to prove otherwise are spurious. Hence Sanford's chief argument against an electrolytic theory of the Volta effect fails because of a misapprehension in the premises.

The surfaces of conductors which have been discharged to earth act just as though they were definitely and characteristically charged. In the case of a homogeneous surface, this postulated electrification is uniformly distributed, while for a surface of dissimilar parts, its nature and intensity vary from part to part. The surfaces being the seat of such electrical manifestations exhibit, as a consequence, a definite P.D., the so-called E.M.F. of contact, between each other. It is only in terms of these potential differences that the phenomenon lends itself to quantitative treatment.

The effect observed with composite surfaces has been shown to be the *average* effect of the constituent parts, each of which contributes in *exact* proportion to its extent, its relative proximity, and its own P.D. with reference to the opposing surface.

The effect is practically completely "screened" when the lateral dimensions of the openings in the screen are not greater than their depth. An increase in the ratio from unity upward between the width and depth of the holes results in an increasing effect through the openings.

Taken as a whole, the results show that the phenomenon has its seat in the surface. The fundamental question, then, reduces to one in regard to the actual conditions on the surface of a conductor. Is there an insulated electric layer brought into existence by chemical or other means, or are the manifestations due to intrinsic properties of the conductor which make themselves felt at its boundaries? This question is still an open one so far as the present investigation goes.

The facilities for this study were afforded at the Ryerson Physical Laboratory. The writer takes this opportunity to thank Professor Millikan, whose unfailing interest in the work has been a source of inspiration.

The University of Chicago,
March, 1913.