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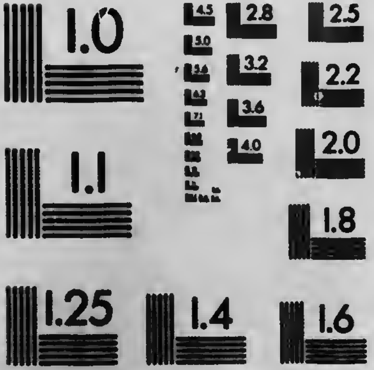

UNIVERSITY OF TORONTO
STUDIES

PAPERS FROM THE PHYSICAL
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No. 29: ON THE CHARGES GAINED BY INSULATED METALLIC CONDUCTORS, SURROUNDED BY OTHER CONDUCTORS, AND THE RELATION OF THESE CHARGES TO THE VOLTA EFFECT, BY J. K. ROBERTSON

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ON THE CHARGES GAINED BY INSULATED METALLIC CONDUCTORS, SURROUNDED BY OTHER CONDUCTORS, AND THE RELATION OF THESE CHARGES TO THE VOLTA EFFECT.

By J. K. ROBERTSON, M.A.

Communicated by Professor J. C. McLENNAN

OTTAWA
Published by the ROYAL SOCIETY OF CANADA
1908

VIII.—*On the Charges gained by Insulated Metallic Conductors, surrounded by other Conductors, and the Relation of these Charges to the Volta Effect.*

By J. K. ROBERTSON, M.A.,

University of Toronto.

(Communicated by Prof. J. C. McLennan, and read May 26, 1908).

I. INTRODUCTION.

In 1903 McLennan and Burton[1] found that a metal cylinder, either of lead, copper, zinc, tin, or aluminium, placed within, and insulated from an outer earthed one of the same material, gradually acquired a negative charge, the value of which steadily rose to a maximum which varied with the metal. In November, 1907, McKeon[2] published results of experiments made concerning the same effect, which are not altogether in agreement with those observed by McLennan and Burton. He found, in the case of lead and tin receivers, that the charge acquired was positive. Further, while the observations of McLennan and Burton extended only over a period of some hours, his were continued for several days. During such an interval, moreover, he observed very considerable variations in the value of the charge. From his observations he concluded that these changes took place at definite periods of the day, and, in explanation, suggested a connection between them and the diurnal variations in the ionization of atmospheric air, to which attention has been drawn by Campbell and Wood,[3] and others.

In view of the lack of agreement existing between the two sets of observations, the writer undertook to make a closer examination of the effect in order to ascertain, (1) its cause and (2) its relation to variations in the earth's penetrating radiation, and to the daily changes in the ionization of the atmosphere noted above.

On making a rather exhaustive set of observations with different metals, it was found that the sign acquired by the insulated cylinder varied largely with the treatment to which the surfaces of the outer and inner cylinders were subjected. For example, it was found possible, with two particular pairs of cylinders, to alter the sign of the charge merely by thoroughly cleaning the surfaces. A summary of the results obtained in a variety of cases is given in Table I, and it will

[1] Phil. Mag., Sept., 1903.
[2] Phys. Review, Nov., 1907.
[3] Phil. Mag., Feb., 1907.

be seen from it that a close connection exists between the surface condition and the nature of the charge acquired.

Variations with time in the magnitude of the charge were also observed in a number of cases, but these, in so far as the observations extended, were not such as to indicate any periodicity. In only one case, that of lead No. 1 in lead No. 2, were observations made for a very extended period of time, and the resulting curve (*vide* Fig 1), although showing marked variations, would hardly indicate the presence of definite periodic changes.

TABLE I.

No.	Combination.	Sign of charge of insulated cylinder.	Maximum and minimum values of potential of insulated cylinder in millivolts.	Remarks.
1	Lead No. 1 in No. 2.....	+	102 approx.	Needle positive.
2	Lead No. 1 in No. 2.....	+	113	Needle negative. Same day as No. 1.
3	Lead No. 1 in No. 2.....	+	79, 72, 78.	Needle positive. Radium used. Four days after No. 1.
4	Lead No. 1 in No. 2.....	–	46, 32	After cleaning. Radium used. Needle positive.
5	Lead No. 1 in No. 2.....	–	45, 41, approx.	Needle negative. Radium used.
6	Lead No. 1 in No. 2.....	–	31.8	One day after No. 4.
7	Lead No. 1 in No. 2	–	29 approx.	Radium inside inner cylinder. One day after No. 6.
8	Lead No. 1 in No. 2.....	–	27, 24, 25	Four days after No. 4. Radium used.
9	Lead No. 1 in No. 2.....	–	13	Twenty days after No. 4.
10	Lead No. 1 in No. 1.....	+	84.6, 83, 31	Fourteen days after No. 4. No. 1 had not been cleaned for some months.
11	Lead No. 1 in No. 3.....	+	59, 58, 55	Radium used but removed between the values 58 and 55.
12	Lead No. 1 in No. 3.....	+	22, 9	Radium used. Lead No. 1 had been cleaned about 7 days.

TABLE I. Contd.

No.	Combination.	Sign of charge of insulated cylinder.	Maximum and minimum values of potential of insulated cylinder in millivolts.	Remarks.
13	Lead No. 1 in No. 3	+	42.5, 41	Fourteen days after No. 12.
14	Lead No. 2 in No. 3	–	50	Radium used, inner cylinder had been abraded with emery paper.
15	Double combination. Lead No. 1 in Lead No. 2. Lead No. 2 in Lead No. 3	–	27.2, 21	Radium used. Eleven days after No. 4, and four days after No. 14.
16	Double combination. Lead No. 1 in Lead No. 2. Lead No. 2 in Lead No. 3	–	13.5	Two days after No. 15.
17	Lead No. 2 in No. 4	+	174, 160	Cleaned one day before.
18	Lead No. 2 in No. 4	–	268.7	One day after No. 17.
19	Lead No. 2 in No. 4	+	105, 70	Three days after No. 17.
20	Lead No. 2 in No. 4	+	105, 70	Five days after No. 17.
21	Lead No. 2 in No. 4	+	105, 70	Six days after No. 17.
22	Lead coated with aluminium paint. No. 2 in No. 4	–	22.6	
23	Same combination, two coats of bronze paint.	+	75	
24	Same combination, two coats of bronze paint	+	125	One day after No. 23.
25	Tin No. 1 in Tin No. 1	–	83, 66, 85	
26	Tin No. 2 in Tin No. 2	–	91, 48, 89	Nos. 1 and 2 were made out of the same sheet of tin.
27	Double combination. Tin No. 1, No. 2 in Tin No. 2	–	94	Two days after No. 26.
28	Tin No. 2 in Tin No. 2	+	171, 38	After cleaning.
29	Tin No. 2 in Tin No. 2	+	82	One day after No. 28.

TABLE I. Contd.

No.	Combination.	Sign of charge of insulated cylinder.	Maximum and minimum values of potential of insulation cylinder in millivolts.	Remarks.
30	Tin No. 1 in Tin No. 1, both coated with aluminium paint........	–	162	Eleven days after No. 25.
31	Tin No. 1 in Tin No. 1, both coated with aluminium paint........	–	156, 155	One day after No. 30.
32	Same combination coated with tinfoil	–	36.4, 25.5	
33	Same combination coated with tinfoil	–	27.2	One day after No. 32.
34	Same combination with tinfoil scraped off.....	–	76, 60	
35	Combination No. 34 + a coat of bronze......	–	91, 66	Five days after No. 34. At first a small positive charge indicated.
36	Combination No. 34 + a coat of bronze......	–	103	Two days after No. 35. At first a small positive charge.
37	Zinc in Zinc	+	92, 51	Cleaned before using. The inner and outer cylinders were not out of same sheet.
38	Zinc in Zinc, both covered with one coat of aluminium paint......	+	189, 175	Two days after No. 37.
39	Zinc in Zinc, both coated with two coats of aluminium paint........	–	Off the scale, 475	Three days after No. 38.
40	Zinc in Zinc, both coated with two coats of aluminium paint........	–	Off the scale, 740	Four days after No. 39.

Throughout the investigation the Volta effect seemed to be of considerable importance, so much so that the writer was led to undertake a series of experiments to determine, if possible, by a somewhat similar method, the contact potential difference between two metals. A few measurements have been made, and these seem to indicate that, in this latter investigation at any rate, secondary radiation is a very important factor in modifying results arising from the Volta effect.

II. Experiments—Metal Effect.

In carrying out the investigation, an attempt was made to examine as many combinations of cylinders as possible, and use was made of the following materials, (1) four outer and two inner cylinders of lead. These were made of lead selected at random from different sheets taken from the stock in the laboratory workshop; (2) two outer and two inner ones of tin — all made out of the same sheet of the substance; (3) an outer and an inner of zinc, made from two entirely different sheets of the metal.

An effort was also made to ascertain, if possible, the connection between the surface condition of the metals, and the sign and nature of the charge gained by the inner cylinder. To accomplish this, cylinders were washed with the different solutions and abraded to a greater or less extent with emery paper. Sets of observations were also taken with cylinders coated with aluminium and with bronze paints.

The outer cylinders were about 60 cm. long, and 25 cm. in diameter, the inner ones two or three centimetres shorter, and about 15 cm. in diameter. Larger ones were made in one or two cases, by joining two outer ones and two inner ones together, so as to ascertain in this way the effect of thus varying the size of the cylinders.

Method of Experimenting.

The method of measuring the charge was essentially the same as that employed by the previous investigators. The inner cylinder was insulated from the outer by means of paraffin blocks, and the charge acquired measured by a sensitive quadrant electrometer. Connection was made as shown in Fig. 2. The lid at one end of the outer cylinder had a cylindrical projection of the same material, which was inserted into a box lined with tin foil. This box contained the special arrangement devised by Prof. McLennan,[1] for making and breaking the earth connection of one pair of quadrants without altering the capacity of the system. To one end of the inner cylinder was soldered a piece of metal of the same material, which also projected into the box, and was joined to the "make and break." The inner cylinder and all wires connecting it to the electrometer were screened from electrostatic disturbances by means of earthed conductors.

[1] Phys. Review, March, 1905.

The electrometer used was of the Dolezaleck type, the quadrants being insulated with ebonite supports, and it had a sensibility such that for a potential of one volt, it gave a deflection of about 600 mm., on a scale about one metre from the needle. A few readings were taken with another instrument of the same type, with amber supports. No difference was observed, however, between the results obtained with the two instruments.

The chief difference between this arrangement and that of the previous investigators lay in the fact that they used air-tight receivers, while those of the writer were not hermetically sealed. This is of some importance, as it has been shewn[1] that the conductivity of air enclosed in a metallic receiver gradually increases with the time it is confined. Meteorological conditions might also have a disturbing influence.

III. Discussion of Results.

(*a*) Change of sign of charge acquired by the insulated cylinder. A glance at Table I will show the great variation observed in the sign of the charge acquired, by the respective insulated cylinders. Even with a selected combination of cylinders, the sign acquired was not always found to be the same, for, in some cases, it was possible to reverse the sign by simply cleaning the metals. Lead No. 1 in lead No. 2 (*vide* Table I, Nos. 3 and 4) changed from positive to negative after the cylinders had been thoroughly cleaned by being abraded with emery paper, and then washed with distilled water, dilute hydrochloric acid, water, ammonia, water and alcohol. On the other hand, tin No. 2 in tin No. 2 was reversed from negative to positive, after being washed in the same manner (*vide* Table I, Nos. 26, 28 and 29).

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[1] McLennan and Burton, Phys. Rev., Vol. XVI, No. 3, 1903.

TABLE II.

Lead No. 1 in lead No. 2.
Without radium.

Time.	Deflection (millivolts).
50″	6 positive
1′ 20″	11
2′ 15″	17
2′ 55″	21
4′ 8″	27
4′ 52″	32
6′ 5″	38
7′ 5″	42
9′ 7″	51
11′ 5″	57
14′ 10″	65
19′ 45″	76
26′ 50″	84
36′ 45″	91
58′ 15″	96
79′ 10″	96
1 hr. 30′	97
1 hr. 43′	97
3 hr. 16′	100
5 hr. 37′	102
6 hr. 18′	108
18 hr. 22′	113

In all cases where the inner and outer cylinder were known to be of the same composition, namely, tin No. 1, tin No. 2, and tin No. 1, with its various coats of paint, with the single exception of the cleaned tin, the sign was negative. Whenever the outer and inner cylinders were not of exactly the same material, there would be a contact potential difference, and in all such cases this would be an important factor in determining the nature of the charge acquired. Assuming that there was a negative effect due to another cause, this Volta effect would explain the variations in the sign for many other combinations, and also for the change from positive to negative of the lead combination after cleaning. It would not, however, explain the change from negative to positive of the tin combination after cleaning, unless, indeed, we are to suppose that it was possible to select two pieces of tin from the same sheet which differed in constitution and structure sufficient to exhibit a contact difference of potential. It would also not explain the different sign of lead No. 2 in lead No. 4 (*vide* Table I, Nos. 17 and 18) on two successive days, nor the change from negative to positive, when, to the same combination of cylinders coated with aluminium paint, was added two coats of bronze (*vide* Table I, Nos. 22 and 23).

In the case of the tin combination coated with aluminium and with bronze paints, at first a small positive charge was observed, which slowly changed into a comparatively large negative one. This was observed on two different days, and would seem to indicate the presence of two opposing influences, one of which became insignificant as time went on.

TABLE III.

Lead No 1 in lead No. 2.
With radium.

Time.	Deflection (millivolts).
8″	41 positive
12″	61
15″	67
20″	69
30″	77
3 1/2 mins.	79
"	79
35 "	78
46 "	77
66 "	76
1 hr. 33 "	75
1 hr. 50 "	75
2 hr. 13 "	74
3 hr. 15 "	74
3 hr. 58 "	72
4 hr. 10 "	75
4 hr. 22 "	76
4 hr. 33 "	78
4 hr. 43 "	78

(*b*) Extent of the charge and variation in its magnitude with time.

The charges in all the experiments were found to rise with varying rates to their maximum values. These rates, however, were found to be very greatly increased by the presence of radium bromide. Typical sets of readings showing the rates at which the charge was acquired with and without radium are given in Tables II and III. Other sets of readings, illustrating various phases of the work are given in Tables II, IV, V, VI, VII and VIII, from which the curves shewn in Figs. 3, 4, 5, 6, 7 and 8 are plotted.

TABLE IV.

Tin No. 2 in tin No. 2. Without Radium.

Time	Deflection (millivolts).
1 1/2 mins.	8 positive
2 2/3 "	15
4 "	22
5 1/2	28
6 3/4	33
9 1/4	42
11 2/3	47
19	58
33	65
44	70
78	76
1 hr. 40 mins.	80
2 hr. 5 "	80
2 hr. 39 "	82
2 hr. 51 "	82
4 hr. 1 "	82

In agreement with McLennan and Burton, the writer found that the extent of the charge varied little with the size of the cylinders, and with the sign of the charge on the needle of the electrometer. A double combination was made by joining the two inner tin cylinders together by means of a piece of tin soldered to each, and also by joining in a similar way the two outer ones. With such an arrangement, the magnitude of the charge acquired (—94 millivolts) was about the same as the maximum values for each combination separately, namely,— —85 and —91 millivolts (*vide* Table I, Nos. 25, 26, 27. See also Nos. 4, 14, 15, and compare Figs. 3 and 8).

The maximum value, it will be seen (*vide* Table I) varied greatly with different combinations, and also was different at different times

TABLE V.

Cylinder – Tin No. 1 + Aluminium paint.
Without radium.

Time	Deflection.
4/5 mins.	7 negative
1 1/3	12
1 3/4	17
3	28
4	38
5 1/2	50
6 3/4	60
7 3/4	67
10	80
11 1/2	88
14 1/2	103
17 3/4	116
24 1/6	133
36	149
50 3/4	158
1 hr. 3 mins.	161
2 hr. 1 "	162

of observation for the same combination. A good example of this latter effect is to be found on the case of lead No. 1 in lead No. 2 (*vide* Table 1, Nos. 4, 5, 6, 7, 8 and 9). Shortly after the cylinders had been cleaned the maximum negative charge acquired was 46 millivolts, one day later the value was 32, four days later 27, and twenty days later only 13. Another good illustration of this is the case of lead No. 1 in lead No. 3 (*vide* Table I, Nos. 12 and 13), where the maximum value of the positive charge increased in fourteen days from 22 to 42 millivolts.

These results would seem to indicate the growth of a deposit or deposits removable by cleaning, which resulted in the insulated cylinders gaining a positive charge, and here we may have an explanation of the high positive charge which McKeon found for his lead combination.

TABLE VI.

Zinc in zinc. Without radium.

Time.	Deflection (millivolts).
3 4/5 mins.	8 positive
6 1/2 "	16
8 1/2	23
11 5/6	33
16 1/3	42
19	49
25 1/2	62
36 1/2	72
50 5/6	83
60 1/2	88
1 hr. 17 1/2 mins.	92
1 hr. 35 "	96
2 hr.	71
2 hr. 47 "	51

It is known that on old lead, such as McKeon used, radioactive deposits are gradually formed, and on this account, there would be an emission of charged particles from both the inner and the outer cylinders. It is evident that this might result in a difference in the number of charged particles coming to the insulated cylinder and in the number leaving it. It could then happen that the insulated cylinder would acquire a positive charge, the magnitude of which would be largely determined by the na[illegible]e of the active deposit.

TABLE VII.

Tin No. 2 in tin No. 2. Without radium.

Time.	Deflection (millivolts).
3 1/2 mins.	9 negative
10	18
13 2/3	25
18 3/4	33
23 3/4	42
27 3/4	49
35 1/5	59
41 1/4	65
50 1/2	75
61 2/3	82
74 1/4	89
80 1/3	91
86 1/2	89
1 hr. 33 1/4 mins.	85
1 " 38 1/4	79
1 " 43	72
2 " 3	48
3 " 11	52
4 " 13	75
5 "	81
5 " 57	85
6 " 27	86
6 " 47	88
7 " 12	89

It was found, too, that the charge did not always remain at a maximum value. With some cylinders it gradually decreased in amount, and in a few of these cases a second rise was observed (*vide* Figs. 6 and 7). As noted above, with the combination lead No. 1 in lead No. 2,

TABLE VIII.

Tin No. 1 + tin No. 2 in tin No. 1 + tin No. 2. Without radium.

Time.	Deflection (millivolts).
57 secs.	8 negative
2 mins. 50 secs.	15.5
5 " 5 "	23
7 1/2 mins.	31
10 5/6 "	39
15	46.5
20 1/2	54
29 4/5	62
52 2/3	71
74 1/2	77
2 hr. 5 mins.	87
2 " 34 "	90
3 " 5 "	91
4 " 1 "	94
4 " 2 1/2 "	93

observations, for which the values are given in Table IX, and the curve representing them is shewn in Fig. 1, were continued for an extended period of time. As in this case, considerable variations were observed,

TABLE IX.

Lead No. 1 in lead No. 2.

Time.	Deflection (reduced to millivolts).	Time.	Deflection (reduced to millivolts).
Wed. 4.01 p.m.	0	Thur. 9.05 p.m.	52.6
4.02	2	10.00	54
4.03	5	11.05	54.6
4.05	8	12.00	56
4.08	11	Friday 1.05 a.m.	57
4.11	13	2.00	59
4.17	16	3.05	60.5
4.22	18	4.00	62
4.31	21	5.05	63
4.44	25	6.00	63
4.48	27	7.00	63.5
4.55	29	7.30	63.3
5.05	32	8.37	34
5.17	33	10.10	64
5.25	34	10.24	61
6.24	40	10.34	60
7.06	42	11.19	63
7.25	43	11.54	56
Thur. 12.30 a.m.	36	12.39 p.m.	55
1.00	34	12.54	55.6
1.40	33	1.55	57.5
1.52	33	2.25	58
2.55	34	2.52	59.5
3.55	34	3.30	60
4.55	33	4.26	57.5
6.00	33.5	4.43	58
7.00	33	6.18	58
8.00	33	7.05	58
8.48	29	8.00	56
9.37	33	9.05	53
10.08	34.5	10.00	51
10.40	33	11.00	48.7
10.52	32	11.30	47.7
11.20	33.5	12.00 a.m.	47
12.10 p.m.	36	Sat. 1.05 a.m.	47
12.50	39	2.00	41.7
2.06	42	3.10	37.9
2.45	46	4.00	37.8
2.55	47.5	5.05	35
3.49	50.5	6.00	34
4.10	55	7.00	32.8
4.37	53	8.48	31.2
5.46	50	9.51	31.4
7.06	50	10.53	30.1
8.04	52		

it is possible that all the others would have exhibited similar changes, had the observations been continued long enough. With these lead cylinders, which were freshly cleaned the day before readings were commenced, the highest maximum value of the negative charge acquired was about 64 millivolts (a scale deflection of about 33 millimetres). At the end of the period of sixty-seven hours, it was found that the zero had drifted 6.5 mms. to the negative side. The readings given in Table IX, however, were all corrected for this change in zero, and also for a gradual change in the sensibility of the electrometer due to a dropping in the potential of the storage cell used to charge the needle, from 170 volts to 144 volts.

In one or two cases where a drop from the initial maximum charge occurred, it was observed that, for the same combination, on different days the drop was not always in evidence. (See Table I, compare Nos. 28, 29, and Nos. 32, 33). After the cylinders had been cleaned, tin No. 2 rose in about four hours to a maximum of 171 millivolts, and then dropped to 38. The next day, in the same time, it rose steadily to 82 millivolts. It is, of course, possible, that had the observations been continued long enough a drop might have been observed here too, and it should be mentioned that the former set of observations was taken between 3 p.m. and 7.30 p.m., while the latter were taken between 9.30 a.m. and 2 p.m. McKeon's explanation of these results as being due to daily variations in an external cause is possible, but it would seem that a more probable one is found in a change taking place in the surface of the metals, perhaps arising from modifications in the state of the atmospheric air.

(*c*) Variation in the magnitude of the charge with the intensity of penetrating rays.

McKeon attributed the variations which he observed to changes in the amount of ionization of the enclosed air. That this can not be the cause is shewn by the fact that, while the presence of the radium affects very greatly the rate at which the charge is acquired, it modifies but little the maximum value. This was observed by McLennan and Burton, as well as by the writer.

McLennan and Burton also found that, when the cylinders were placed in a tank filled with water, the layer of water being 13 cms. thick, the maximum value of the charge was unchanged. By this means the natural radiation was lessened,[1] and yet the charge remained the same.

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[1] Univ. of Toronto Studies, Phys. Science Series, No. 2; also, Phys. Rev., Vol. XVI, No. 3, p. 184, 1903.

To further investigate the effect of varying the amount of ionization, some measurements were made on the charge acquired by the inner of two lead cylinders when some radium in a small glass tube was placed within the inner cylinder and successively surrounded with a series of different thicknesses of sheet lead. In each case the charge acquired by the insulated cylinder rose in half a minute or less to a maximum value. From Table X a comparison can be made of the values of the charge acquired in each case, and of the relative intensities of the radiation used to hasten the action. The intensities were compared by placing the radium with its different coverings at a fixed point near the electrometer, and measuring the current from the needle to the free quadrants.

TABLE X.

Remarks on manner of screening radium.	Limiting charge (Negative). Arbitrary Scale.	Intensity of radiation Arbitrary Scale.
In glass tube	7.0	304
First covering of lead	7.0	210
Second covering	6.8	188
Third covering		
1st reading	6.8	167
2nd reading	6.5	167
Fourth covering		
1st reading	6.2	135
2nd reading	6.7	135

It will be seen that while there were slight changes in the value of the charge acquired, these were by no means proportional to the changes in the intensity of the radiation.

One must conclude, therefore, that, although variations do occur in the charge acquired by the inner cylinder in combinations such as those investigated, these can not be due to changes in the amount of ionization produced by the earth's penetrating rays. They may possibly be due, however, to some changes in the surface of the metals themselves, or to changes in the radiations given off by these metals.

It is possible that further light may be thrown on these experiments by measurements similar to a series which the writer has recently made in seeking to determine the contact potential differerence between two metals, by using a modification of the apparatus used in the early part of this investigation.

IV. Volta Effect.

In these experiments the following apparatus was used:

A circular copper plate AB, about 9 cm. in diameter, was joined to the electrometer by means of a conductor of the same material, insulated from a surrounding earthed tube by means of amber. A box CC′ DD′, also of copper, served as a guard ring to the plate AB, and as a screen from electrostatic disturbances. Above the plate AB and insulated from it by small amber supports, a second plate HK of a selected metal was placed, and this was kept joined to earth while experiments with it were being made. Over all a wooden box MM′ NN′, lined with tin foil, was placed to complete the electric screening.

With both the plates AB and HK joined to earth, on account of the contact potential difference between them, there would be a current set up between them, if any free ions existed in the intervening space. If, with this arrangement, the earth connection to the lower plate were broken, this plate would, as a result of the current, acquire a charge which would tend to annul the original contact difference. It was therefore thought that, by placing a strong ionizing agent, such as radium, above the plates, the needle would, on breaking the earth connection to the lower plate, at once take up a maximum deflection, and so give a measure of the contact difference.

It was found that, by using strong radium near the plates, the lower one did acquire in a very few minutes a maximum charge. It was found, too, that as the radium was removed farther and farther from the apparatus, the rate at which this maximum was reached became slower and slower.

It has been found, however, as a result of the experiments so far performed, that the value of this maximum charge varied, (1) with the material and the thickness of the upper plate, (2) with the distance between the plates, (3) with the distance of the radium from the plates.

TABLE XI.

Plates.	Sign and magnitude of charge acquired by free copper plate.	
	2 mm. apart millivolts.	10 mm. apart millivolts.
Aluminium	−9	+289
Zinc (thin)	+4	+277
Zinc (thick)	−15	+261
Lead	+38	+212
Copper (thin)	−68	−79
Copper (thick)	−85	−48

Table XI gives the results of some measurements made by using different upper plates. The metals are arranged in the order in which they occur in the Volta series, and it will be seen from the values of the maximum potentials recorded that other influences besides the Volta effect must have contributed to the result. The values obtained are very much lower than the contact potential differences usually recorded. Further, although aluminium and zinc come higher in the contact series than lead, yet, when the plates were 2 mm. apart, lead gave a higher positive potential to the copper plate than either of them. Indeed, aluminium and the thicker zinc plate, as will be seen, gave a slightly negative value to it. With both the zinc and copper plates, an increase in the thickness resulted in an increased negative charge on the free plate.

TABLE XII.

Upper plate zinc.

Distance between plates.	Deflection for thin plate.	Deflection for thick plate. (1 volt = 550 mm.)
2 mm.	+30 mm.	+2 mm.
3	69	37
5	151	106
7	209.5	165.5
10	223	193
12	214.5	192.5
15	194	176
17	183.5	168
20	163.5	148
25	132.5	123.5
30	114	105.5
35	97	91
40	83	77

TABLE XIII

Upper plate copper,

Distance between plates.	Deflection. (1 volt = 550 mm.)
2 mm.	—31
3	—19.5
5	—10
7	—10.4
10	—15
13	—19
15	—20.5
20	—25.2
25	—28
30	—30
35	—31.5
40	—32.5

It will be observed, also, that when the plates were 10 mm. apart, there was a marked positive increase in the values. This was more carefully investigated by taking a series of measurements with different distances between the plates. The results obtained are given in Tables XII and XIII, and are illustrated by the curves in Figs. 10 and 11. It will be seen that, as the distance between the plates was increased, the values of the charge acquired became more and more positive, until a maximum point was reached, after which the values became more negative.

In these latter experiments it must be remembered that not only was the distance between the plates varied, but, since the radium was kept in a fixed position, the distance from the upper plate to the radium, as a consequence, was varied also. That this is an important factor is shewn by the results of some measurements made with the radium at various distances from the plates, which were kept at fixed distances apart.

The results obtained are given in Tables XIV, XV and XVI, and are represented graphically by the curves in Figs. 12, 13, and 14. From these it will be observed that as the distance of the radium was increased

TABLE XIV.

Upper plate zinc. Distance between plates, 2mm.

Distance of radium.	Deflection. (1 volt=575 mm.)
7.3 cm.	+32. mm.
14.1	—26
19.8	—42.8
24.6	—48.8
32.1	—50.8
42.9	—49.5
52.8	—44.8
62.8	—40.4
71.2	—35
80.2	—33

there was a gradual decrease in positive values or an increase in negative ones until a minimum point was reached. After this there followed a slight increase in the positive or a decrease in the negative readings. The appearance of a final maximum is suggested but not well marked by the form of each of the curves.

TABLE XV.

Upper plate zinc. Distance between plates, 10mm.

Distance of radium.	Deflection. (1 volt=522 mm.)
7.3 cms.	+215.5
14.4	+114.5
21.9	+ 51.5
17.6	+ 81
27.5	+ 26.5
32.6	+ 11.5
37.4	+ 4.5
42.2	— 1
48.6	— 4
56.8	— 6
68.1	— 4.5
79.6	— 0.5

In order to ascertain exactly whether the potential acquired by the free plate continued to approximate to a final steady value, a set of observations was taken with the two copper plates at 2 mms. apart, when the radium was moved through a more extensive range of distance. These results, which are recorded in Table XVII, and are represented by the curve given in Fig. 15, shew that the charge on the free plate did not continue to approach a steady value, but that as the radium was removed, very considerable variations occurred in the magnitude of the charge. Some readings were also taken of the potential acquired by the free copper plate without the use of radium, when both zinc and copper plates were placed at different distances above it. These results are recorded in the first column of Table XVIII. For the purpose

TABLE XVI.

Upper plate copper. Distance between plates, 2mm.

Distance of radium.	Deflection. (1 [illegible] =540 mm.)
7.3 cms.	— 39.5
13.8	— 53
19.2	— 59.5
24.2	— 63.5
31.9	— 65.5
41.8	— 60.8
52.0	— 58.5
61.8	— 54.5
70.4	— 49.8
80.4	— 46.5

of comparison, the final maximum values obtained in the cases illustrated by the curves 12, 13, and 14, are also recorded in the second column of this table. From these results it will be seen that in every case the values obtained without the radium were more positive than those obtained with it.

TABLE XVII.

Upper plate copper. Distance between plates, 2mm.

Distance of radium.	Deflection. (1 volt=570 mm.)
7.3 cms.	— 47.8
10.5	— 47.5
16.0	— 50.5
24.7	— 55
31.2	— 57.5
41.7	— 56.5
59.0	— 54
80.1	— 55
108.0	— 56.2
156.3	— 51.5
204	— 54.4

TABLE XVIII.

Plates.	Column I. Without radium	Column II. With radium at greatest distance. (In Figs. 12, 13, 14, 15)
Zinc, 2 mm. from copper........	+37 millivolts.	−57 millivolts.
Zinc, 10 mm. from copper.........	+27 millivolts.	+ 1 millivolt.
Copper, 2 mm. from copper........	−33 millivolts.	−90 millivolts.

One should have expected that as the radium was removed the values given in column II of Table XVIII would have approximated to those obtained without the radium and recorded in column I, but their failure to do so can probably be traced to the difficulty experienced in obtaining satisfactory readings when the radium was placed at the longer distances or entirely removed. Under these circumstances the rate of deflection was exceedingly slow and, consequently, the readings, owing to the comparatively small capacity of the plate system, were subject to large errors arising from disturbances to the measuring system which with the radium nearer were negligible.

In analyzing the observations made on the Volta effect in the plate experiments it is difficult to account for all the results. It is evident that at least two influences were present, namely, (1) the conductivity of the air between the plates, and (2) secondary radiation, and it is clear that each [illegible]buted, with the different combinations, to the magnitude and sig[illegible]he charge acquired.

That conductivity is a[illegible]mportant factor in determining the limiting charge given to the free plate was shewn by simply blowing filtered air between the plates. It was found that in all cases, where the upper plate was positive to the lower, positive values were decreased by blowing. On the other hand, by using a carbon plate above, so as to make the copper plate below acquire a negative charge through the Volta effect, the negative deflection was also lessened by the same means.

It has been shewn by Prof. MacKenzie[1] that the secondary radiation from the back of metallic plates, upon which the rays from radium are allowed to fall, is of considerable importance. Negative particles will, under these circumstances, come to the lower plate from the upper, while there will also be an emission of negative particles from the lower one itself. The nature of the charge acquired by the lower plate

[1] Phil. Mag., July, 1907.

will be determined, therefore, partly by the ratio of the number of particles leaving it to the number coming to it. An alteration in this ratio would take place when both the thickness and the material of the plates were varied, when the distance between the plates was altered, and when the distance of the radium was increased, and it was quite conceivable, therefore, that this ratio could vary in such a manner as to give rise to the results obtained.

From the experiments which have been cited in this paper, it is evident that the manner in w'ı .ı insulated metallic cylinders surrounded by others joined to earth, or insulated plates of metal placed close to others of the same or of different metals become electrically charged is both complex and obscure. It is clear, too, that bc'h the Volta effect and secondary radiation are influences affecting the process of charging, and, although the experiments of the present investigation throw considerable light on the relative influence of these two factors, it will be necessary to take m..e extensive observations before a complete explanation can be offered.

In conclusion, the writer wishes to express his sincere thanks to Prof. McLennan for his kindly interest and helpful suggestions during the progress of the investigation.

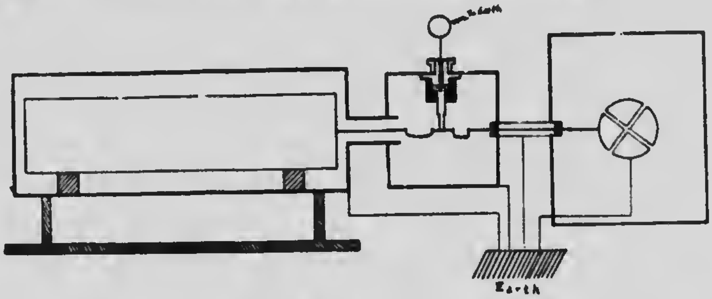


Figure. 2.

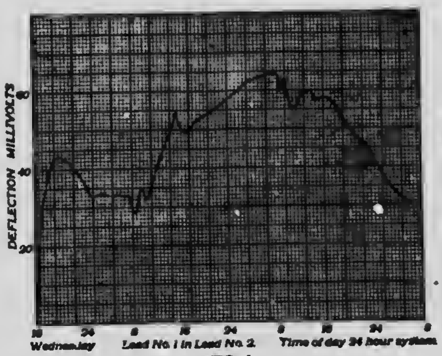


FIG. 1

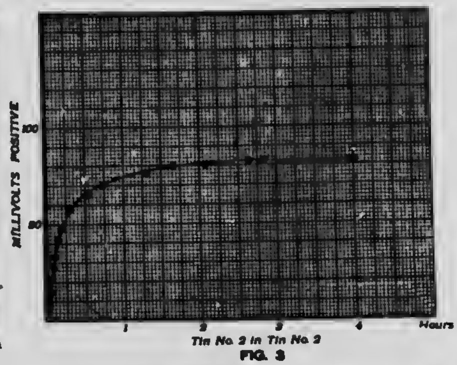


FIG. 3

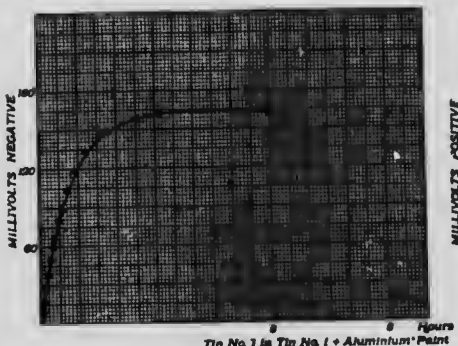


FIG. 4

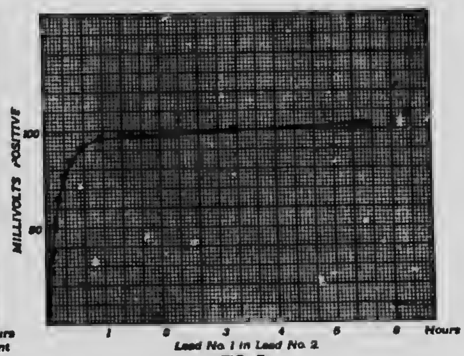


FIG. 5

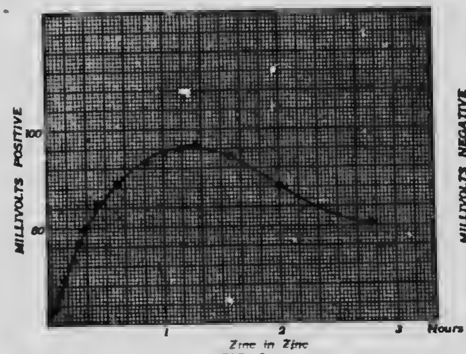


FIG. 6

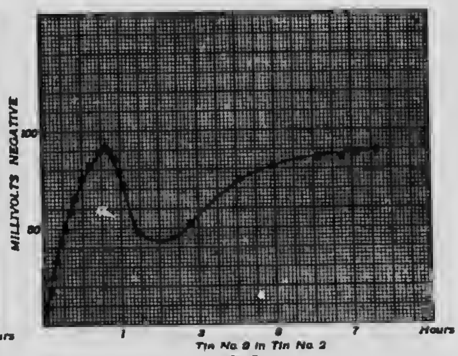
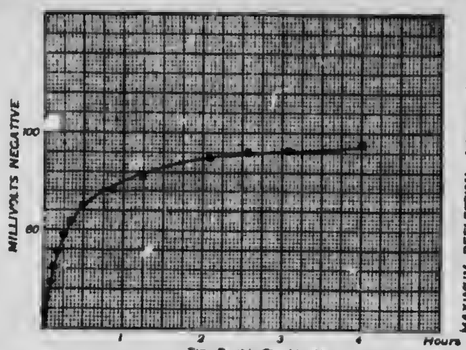
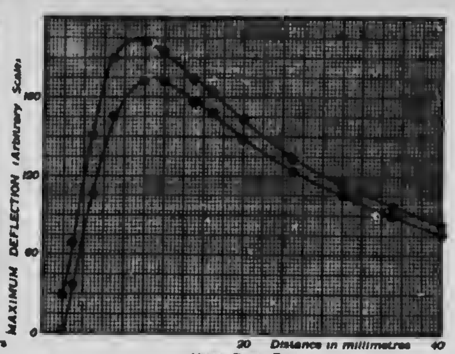


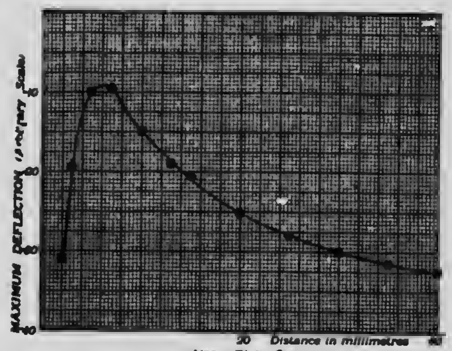
FIG. 7



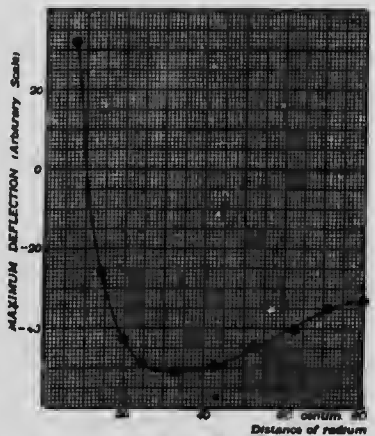
Tin Double Combination
FIG. 8



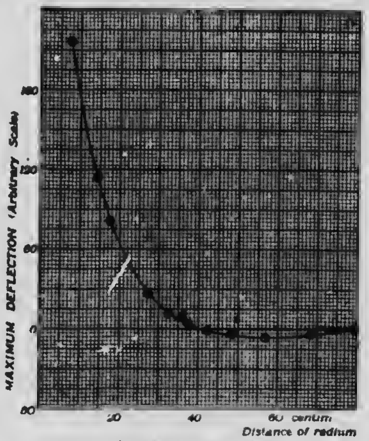
Upper Plate-Zinc
FIG. 10



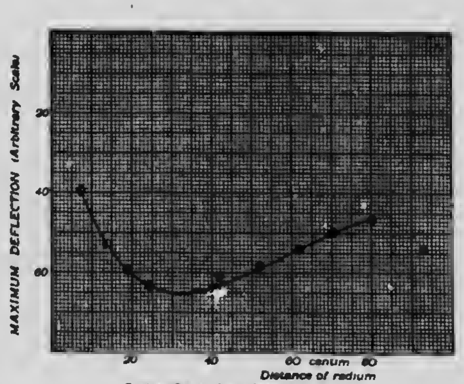
Upper Plate-Copper
FIG. 11



Zinc-2 m.m. from Copper
FIG. 12



Zinc-10 m.m. from Copper
FIG. 13



Copper-2 mm. from Copper
FIG. 14.

Copper- 2 mm from Copper
FIG. 15

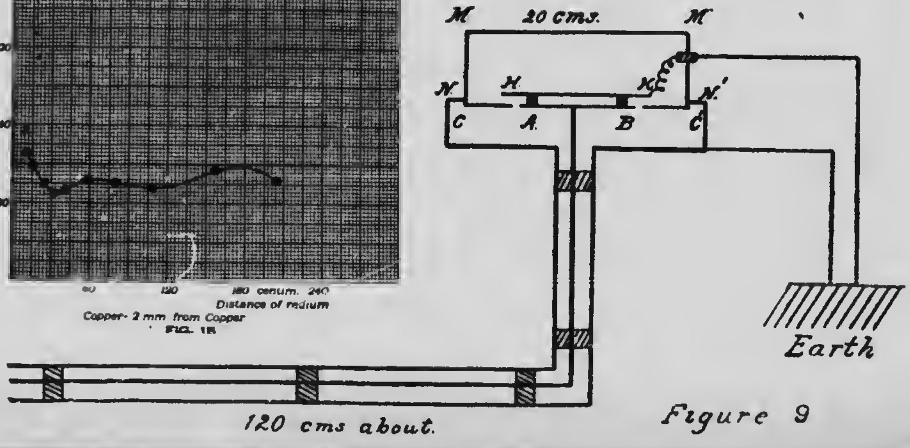


Figure 9