THE DIURNAL VARIATION OF THE SPONTANEOUS IONIZATION IN AIR IN CLOSED METALLIC VESSELS.

By T. Frederick McKeon.

Introduction.

Air and other gases within closed metallic vessels are found to possess a slight conductivity even when not acted upon by an artificial ionizing agent. For a time it was thought that the presence of these free ions in the gas was due to an intrinsic property of the gas by which it was capable of ionizing itself. Recent investigations, however, have shown that some at least of these free ions must be attributed to the action of external agents. McLennan and Burton[1] measured the natural conductivity of the air in a large closed metal cylinder by means of a sensitive electrometer, and found that when the cylinder was completely surrounded with water the saturation current, or leak, through the vessel was greatly reduced. Rutherford and Cooke[2] observed that the rate of discharge of a sealed glass electroscope was diminished by placing a lead screen around the electroscope. Cooke[3] continued the investigation of the decrease of the rate of discharge in the electroscope, when surrounded by metal screens, and found that a thickness of 5 cm. of lead around the electroscope decreased the rate of discharge about 30 per cent., while further increase in thickness of the screen had no effect. An iron screen also diminished the rate of discharge to about the same extent as the lead.

A. Wood[4] has found that the diminution of the ionization by a given screen depended upon the material of the vessel. The ionization in a lead vessel surrounded by a lead screen was reduced 10

[1] Phys. Rev., V. 16, p. 185, 1903, and Phil. Mag., V. 5, p. 419, 1903.

[2] Amer. Phys. Soc., Dec., 1902.

[3] Phil. Mag., Vol. 6, p. 403, 1903.

[4] Phil. Mag., Vol. 9, p. 550, 1905.

per cent., while in an iron vessel it was reduced 24 per cent. Wood concludes from his experiments that the ionization observed in a closed vessel has a threefold origin. A part of it is due to an external penetrating radiation, part to a secondary radiation set up by it, while the remainder is due to an intrinsic radiation from the walls, altogether independent of the external radiation.

Patterson[1] examined the variation of the ionization of air with pressure in a large iron vessel of diameter 30 cm. and length 20 cm. The current between a central electrode and the cylinder was measured by means of a sensitive electrometer. He found that the saturation current was practically independent of the pressure for pressures greater than 300 mm. of mercury. Below a pressure of 80 mm. the current varied directly as the pressure. For air at atmospheric pressure the current was independent of the temperature up to 450° centigrade. With further increase of the temperature the current began to increase. The current was more rapid when the central electrode was charged negatively than when it was charged positively. This difference was ascribed to the production of positive ions at the surface of the iron vessel.

Strutt,[2] by means of an electroscope, observed that the ionization produced in a closed vessel varied with the material of the vessel. He found considerable differences, however, between different samples of the same material, and was inclined to conclude that the intrinsic radiation from the walls of the vessel was due to traces of radioactive impurities. A. Wood, working in the Cavendish Laboratory, repeated the experiments of Strutt, but failed to observe any differences in the ionization produced by different samples of the same material. The order of activity which he observed for the different materials was the same as that given by Strutt, with one exception. Similar experiments by McLennan and Burton, and Campbell confirmed the order obtained by these two observers. These experiments of McLennan and Burton, Wood, Strutt, and the others show that part of the spontaneous ionization in a closed vessel containing gas is due to the influence of the walls. H. L. Cooke has observed also that the ionization of the air in a brass electroscope could be

[1] Phil. Mag., Vol. 5, p. 680, 1903.
[2] Phil. Mag., Vol. 5, p. 680, 1903.

reduced to about a third of its usual value if the interior surface of the brass was carefully cleaned. By removing the surface of the brass he was able to reduce the ionization of the inclosed air from from 30 to 10 ions per c.c. per second. This is an important observation, and, as Rutherford has indicated, shows that a large proportion of the radio-activity observed in ordinary matter is due to a deposit of radio-active matter on the surface. It is well known that bodies which have been exposed in the presence of an emanation retain a residual activity, which takes some time to die out. The experiments of Bumstead [1] prove beyond a doubt that radium and thorium emanations exist in the atmosphere, and we may reasonably suppose that the exposed surface of matter, in consequence, will become coated with an invisible film of radio-active matter deposited from the atmosphere.

The experiments described in this paper were primarily undertaken with a view to ascertaining the modifications that should be introduced in the results of experiments such as were carried out by McLennan and Burton, if material was made use of which had been exposed to the atmosphere for a long time. To this end material was selected from a supply purchased some ten years previous to the carrying out of the experiments. This supply had been stored in the machine shop connected with the Department of Physics at the time of purchase, and the portion used had remained practically undisturbed up to the time of carrying out these experiments. The method followed was practically the same as that employed by McLennan and Burton, except that the cylinders used were considerably smaller than theirs. The results of the first few experiments showed surprising variations in the leak. These variations, which could not be accounted for by any of the known properties of the emanations of the radio-active bodies, were attributed to defects in experimental arrangements, and the method was abandoned in favor of a method, which will be described shortly, and which is in the main due to McLennan. However, the same obstacle to the accurate study of the radio-activity of the material employed was encountered. The leak again showed daily, and even hourly variations. A systematic study of these variations was now begun, and consid-

[1] Amer. Jour. of Science, Vol. 8, p. 1, 1904.

erable evidence had been obtained, which tended to show that the variations follow some law, when the writer received the recent article by Wood and Campbell,[1] and became aware that they had made the study of the variations, and had given a preliminary account of their results in a letter to *Nature*, as early as April, 1905. Since, however, the method of experimenting was different from that of Wood and Campbell, and the results obtained point to a different conclusion than that given in their recent account of their complete study of the phenomena, and, moreover, since all the data so far available upon which to base the law of the daily variation of the ionization in closed vessels had been obtained in only two places (Cambridge and St. Petersburg), it appeared that the problem justified a complete investigation. The work described in the following pages resolves itself into three parts: (1) an investigation of the leak between two cylinders of the same metal, (2) an investigation of the leak between cylinders of different metals, (3) and principally, a study of the daily variation of the leak between the cylinders.

Apparatus and Connections.

In the experiments of McLennan and Burton, already referred to, the apparatus consisted of two cylinders, one placed within the other, and insulated from it. The outer cylinder was hermetically sealed and connected to earth. The inner was connected with one pair of quadrants of an electrometer. Rather large cylinders were used. The outer ones were 120 cm. in length, and 24 cm. in diameter, the inner cylinders were 110 cm. in length, and 19 cm. in diameter. In the experiments described in this paper much smaller cylinders were used; the outer ones being 60 cm. in length and 15 cm. in diameter, and the inner 55 cm. in length and 4 cm. in diameter. The arrangement of the apparatus, which differs from that of the authors named above in minor details only, is outlined in Fig. 1. *A* represents the outer cylinder, and *B* the inner cylinder between which the leak is to be measured. The cylinders are insulated from each other by blocks of paraffin and ebonite. A short brass rod, in metallic connection with *B*, passes through an ebonite plug fitted into *A*, and is protected by an earth-connected guard

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

ring. The brass rod projects a short distance within a tube also of brass; a hole in the top of the tube permits connection to be made between the brass rod and a fine copper wire stretched along the

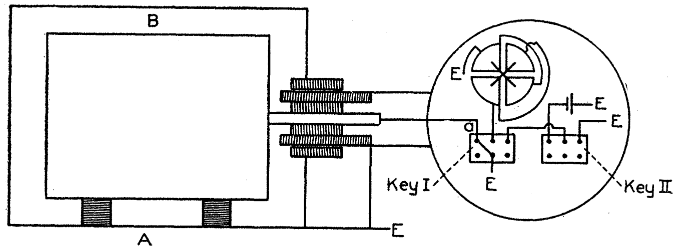

Fig. 1.

axis of the tube, and insulated from it by means of ebonite plugs. One end of this wire dipped into a mercury cup in a block of ebonite.

The electrometer used was of the Dolezalek type with amber insulation and adjustable quadrants. The needle was of silvered paper, and the suspension a quartz fiber dipped in a solution of calcium chloride to render it conducting. The needle was permanently connected with the negative pole of a Dolezalek-Nernst dry pile which kept its potential constant. The positive pole of the pile was connected to earth. The electrometer needle had a period of 60 seconds, and the damping was sufficient to make it dead beat. The zero position was fairly constant, the needle, except in one instance, not drifting through more than 2 cm. during the whole time of an experiment which was usually continued for more than four days. The sensibility did not vary appreciably during the same time.

The necessary connections were made with two simple trip keys which rested in mercury cups in a block of ebonite, and were worked mechanically, from a distance, by means of fine silk threads. A forward movement of key No. I., at the same time, broke the earth connection of the testing vessel, the earth connection of one pair of quadrants of the electrometer, and connected the vessel with the quadrants. When it was necessary to find the value of the scale readings in volts, a backward movement of key No. I. and a forward movement of key No. II. broke the earth connection of the free quadrants, and connected them with the negative pole of a Carhart-Clark standard cell. The positive pole of the cell was earthed. The connections are given in outline in Fig. 1.

As very small potential differences had to be measured it was necessary to guard carefully against external electrostatic disturbances. The electrometer, the pile, which gave the charge to the needle, the keys for making connections, and the standard cell rested upon a wall shelf covered with tin-foil which was connected to earth. The electrometer, keys, etc., were covered with an earthed metallic screen made of wire, having twenty-five meshes to the square centimeter, covered with tin-foil. This screen proved most satisfactory, and protected completely against all external disturbances. The connecting wire between the testing vessel and the electrometer was inclosed in an earth-connected metallic tube.

Method of Working.

After the outer cylinder had been adjusted upon two insulating blocks of ebonite, the inner cylinder and the insulating supports were placed in position within. A brass disk was inserted in the open end of the outer cylinder, and the joint thus made rendered air tight with paraffin wax. Connection was then made between the brass rod joined to the central cylinder and the wire, which dipped into the mercury cup *a*. The outer cylinder and the brass tube surrounding the connecting wire were next earthed. When the vessel was thoroughly sealed the free quadrants and the central cylinder were connected together, and their earth connections broken. The quadrants began at once to acquire a charge, which varied in intensity with the metals used. Because of the nature of the experiments, it was thought advisable to use a constant deflection method of measuring the current, and at the same time to avoid the complications which would arise from the use of resistance in parallel with the free quadrants. Under these circumstances the determination of the amount of charge to give the needle in order to obtain the maximum sensibility without causing the needle to deflect off the scale was a matter of several tests in almost every experiment. In case the current to be measured produced a deflection larger than could be measured on the scale, the sensibility of the electrometer was reduced by decreasing the charge on the needle. The manner of determining this necessary charge was as follows: The central cylinder and free quadrants were connected together and insulated. The quadrants were then permitted to charge up until it was certain that the deflection would go beyond the limits of the scale, when the connection between the cylinder and quadrants was broken, and both were put to earth. The charge on the needle was then decreased, and the zero and sensibility redetermined. A number of tests of the constancy of these quantities was made after each change. It was found that if the needle was given a deflection a few times by connecting the quadrants to the standard cell, it settled down to a certain zero to which it always returned on further deflection in the same manner. Furthermore, it was found that all changes in the sensibility between observations taken within a few minutes of each other could be traced to imperfect conductivity of the quartz fiber, and could be entirely eliminated by redipping the fiber. When perfect constancy of zero and sensibility were attained, the cylinder and quadrants were once more connected together, and insulated. If the needle was again deflected beyond the limits of the scale the process was repeated, and this as often as was necessary, until the whole amount of deflection could be read. As ordinarily used the needle was kept at a difference of potential sufficient to give a deflection of 14 cm. on a scale at 120 cm. distance from the electrometer for a potential difference of one volt between the quadrants.

As a rule, an hour or more from the time the apparatus was sealed up and the quadrants first insulated, was spent in adjusting the charge on the needle so as to give the proper sensibility and finding the value of the scale readings in volts. Readings were begun immediately on insulating the quadrants, the spot of light from the mirror being read on a scale in the ordinary way. However, none of the readings taken before the final adjustment of the sensibility are given in this paper. For the first hour or two, from the beginning of the experiment, readings were taken every 3 or 7.5 minutes depending upon the rapidity with which the quadrants charged up. After that readings were taken at intervals of 12 or 15 minutes for 100 hours or more in each experiment.

It is evident that the method here outlined is open to some, though not serious, objections. First of all the method of rendering the needle conducting prevents the continuation of an experiment for any great length of time, and the necessity of regulating the sensibility of the electrometer makes it impossible to obtain the complete ionization curve from the time of sealing the apparatus.

Results of Experiments.

In the experiments cylinders of lead, tin, aluminum and brass were used. Observations of the effect produced by combinations of these metals are set forth in the accompanying figures, where curves are drawn with the time expressed in hours of the day for abscissas and the deflection of the needle in arbitrary scale divisions for ordinates. It will be noticed that the variation of the ionization for all combinations of metals tried show three distinct characteristics. On connecting the central cylinder with the quadrants and insulating, the quadrants gradually acquire a charge which attains a maximum in a few hours, and then falls off, but never dies out altogether, or changes sign. This initial rise was observed by McLennan and Burton, but in their experiments the ionization did not fall off with time. When the experiments have been continued for 20 hours or more, the character of the phenomenon changes. At the end of this time the ionization has fallen to its lowest value, and the influence of two weak, but very definite sources of ionization, manifest themselves. The effect of the one is a progressive increase or decrease of the ionization, which is very evident when the experiment is continued for some days. Riding upon this progressive change in the ionization there is a change of periodic character, which has two maxima and two minima each 24 hours. Some evidence of the existence of this diurnal variation had been obtained already by different observers, but Wood and Campbell alone have pointed out that the daily period is twofold. A more complete understanding of what takes place will be gained by a detailed study of each curve.

Aluminum in Brass.

An inspection of the curves for aluminum within brass, Figs. 2 and 3, gives unmistakable evidence of these respective changes in the ionization. The first curve, Fig. 2, shows the initial rise, which takes place on insulating the quadrants, and also the way the ionization falls off with time following this initial rise. A maximum is

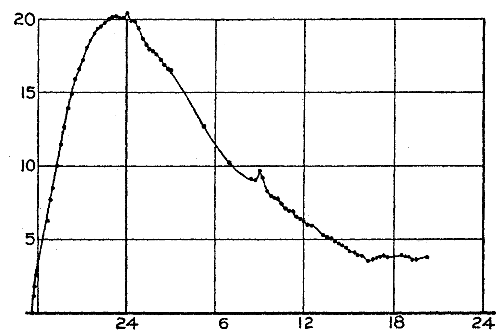

Fig. 2.

reached in about 6 hours, and in 22 hours the leak has fallen to a minimum. The subsequent periodic variations which take place in the leak, are already manifest in the latter part of this curve, but are made much more evident in the second curve, Fig. 3, which is plotted on a different scale. A period of 36 hours elapsed between

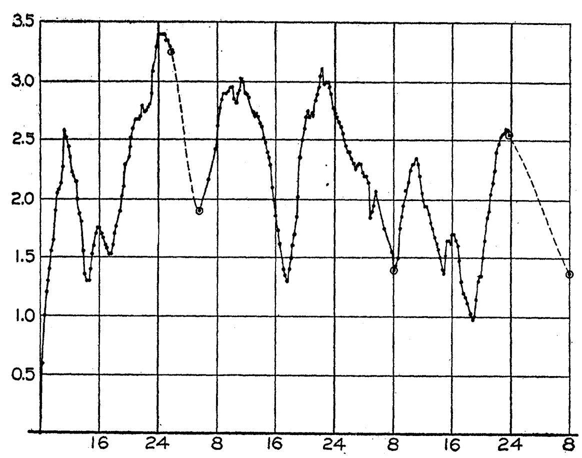

Fig. 3.

taking the observations plotted in the first curve and those plotted in the second, the quadrants in the meantime remaining insulated. This second curve shows a well-marked maximum for each day, at

Aluminum Cylinder within Brass Cylinder. Observations.

First Period. April 12, 1907. P. M.

Time.[1]	Scale Reading.	Amount of Deflection.
5.41	26.4	0.
5.44	25.25	1.15
5.47	24.65	1.75
5.50	24.5	1.9
5.55	23.9	2.5
6.41	20.05	6.35
6.54	18.7	7.7
7.	17.9	8.5
7.12	16.75	9.65
7.24	15.55	10.85
7.36	14.45	11.95
7.48	13.5	12.9
8.	12.6	13.8
8.12	11.78	14.62
8.24	10.8	15.6
8.36	10.25	16.15
8.48	9.55	16.85
9.	9.05	17.35
9.12	8.4	18.
9.24	7.96	18.44
9.36	7.64	18.76
9.48	7.28	19.12
10.	7.	19.4
10.12	6.95	19.45
10.24	6.84	19.56
10.36	6.48	19.92
10.48	6.38	20.02
11.	6.28	20.12
11.12	6.25	20.15
11.24	6.38	20.02
11.36	6.35	20.05
11.48	6.3	20.1
12.	6.36	20.4
April 13. A. M.		
12.12	6.42	19.98
12.24	6.5	19.9
12.36	6.7	19.7
12.48	7.3	19.1
1.	7.7	18.7
1.12	8.	18.4
1.24	8.3	18.1
1.36	8.5	17.9
1.48	8.52	17.88
2.	8.75	17.65
2.12	9.04	17.36
2.24	9.15	17.25
2.36	9.55	16.85
2.48	9.7	16.7
3.	9.8	16.6
5.20	13.7	12.7
6.58	16.15	10.25
7.54	16.9	9.5
8.24	17.2	9.2
8.36	17.25	9.15
8.48	17.43	9.06
9.	17.65	9.75
9.12	17.8	9.6
9.24	18.	8.4
9.36	18.18	8.22
9.48	18.4	8.
10.	18.51	7.89
10.12	18.65	7.75
10.24	18.88	7.52
10.36	18.95	7.45
10.48	19.15	7.25
11.	19.45	6.95
11.12	19.52	6.88
11.24	19.8	6.6
11.36	20.	6.4
11.48	20.	6.4
12.	20.2	6.2
P. M.		
12.12	20.4	6.
12.24	20.6	5.8
1.18	21.15	5.25
1.36	21.3	5.1
1.48	21.4	5.
2.	21.55	4.85
2.12	21.7	4.7
2.24	21.8	4.6
2.36	21.89	4.51
2.48	22.	4.4
3.	22.17	4.23
3.12	22.35	4.05

[1] As given by ordinary watch.

Aluminum Cylinder within Brass Cylinder. Observations.—Continued.

Time.	Scale Reading.	Amount of Deflection.
3.24	22.43	3.97
3.36	22.55	3.85
3.48	22.63	3.77
4.10	22.4	4.
4.30	22.18	4.22
4 45	22.09	4.33
5.	22.05	4.35
5.15	22.	4.4
5.35	22.06	4.34
6.30	22.	4.4
6.50	22.05	4.35
7.	22.05	4.35
7.12	22.3	4.1
7.30	22.25	4.15
8.15	22.1	4.3
Second period. April 15. A. M.		
8.15	27.3	+ .6
8.30	26.9	1.
8.45	26.7	1.2
9.	26.6	1.3
9.15	26.5	1.4
9.30	26.35	1.55
9.45	26.26	1.64
10.	26.	1.9
10.15	25.85	2.05
10.30	25.82	2.08
10.45	25.73	2.13
11.	25.63	2.27
11.15	25.33	2.57
11.30	25.38	2.52
11.45	25.46	2.44
12.	25.55	2.35
P. M.		
12.15	25.67	2.23
12.30	25.7	2.2
12.45	25.75	2.15
1.	25.9	2.
1.15	26.02	1.88
1.30	26.1	1.8
1.45	26.35	1.55
2.	26.55	1.35
2.15	26.5	1.3
2.30	26.6	1.3
2.45	26.5	1.4
3.	26.38	1.52
3.15	26.3	1.6
3.30	26.2	1.7
3.45	26.15	1.75
4.	26.15	1.75
4.15	26.21	1.69
4.30	26.24	1.66
4.45	26.3	1.6
5.	26.33	1.57
5.15	26.38	1.52
5.30	26.38	1.52
5.45	26.3	1.6
6.	26.2	1.7
6.15	26.13	1.77
6.45	26.	1.9
7.	25.86	2.04
7.15	25.72	2.18
7.30	25.6	2.3
7.45	25.55	2.35
8.	25.46	2.44
8.15	25.38	2.52
8.30	25.3	2.6
8.45	25.22	2.68
9.	25.22	2.68
9.15	25.22	2.68
9.30	25.2	2.7
9.45	25.1	2.8
10.	25.16	2.74
10.15	25.15	2.75
10.30	25.12	2.78
10.45	25.1	2.8
11.	25.	2.9
11.15	24.8	3.1
11.30	24.7	3.2
11.45	24.6	3.3
12.	24.5	3.4
April 16. A. M.		
12.15	24.5	3.4
12.30	24.5	3.4
12.45	24.5	3.4

Aluminum Cylinder within Brass Cylinder. Observations.—Continued.

April 16. A. M.

Time.	Scale Reading.	Amount of Deflection.
1.	24.55	3.35
1.15	24.55	3.35
1.30	24.6	3.3
1.45	24.65	3.25
5.25	26.	1.9
6.48	25.72	2.18
7.45	25.47	2.43
8.	25.28	2.62
8.15	25.13	2.77
8.30	25.05	2.85
8.45	25.	2.9
9.	25.	2.9
9.15	25.	2.9
9.30	24.98	2.92
9.45	24.95	2.95
10.	24.95	2.95
10.15	25.05	2.85
10.30	25.08	2.82
10.45	25.	2.9
11.	24.98	2.92
11.15	24.87	3.03
11.30	24.9	3.
11.45	25.	2.9
12.	25.01	2.89
12.15	25.03	2.87
12.45	25.17	2.73
	P. M.	
1.	25.2	2.7
1.15	25.18	2.72
1.30	25.2	2.7
1.45	25.25	2.65
2.	25.28	2.62
2.15	25.33	2.57
2.30	25.41	2.49
2.45	25.5	2.4
3.	25.55	2.35
3.15	25.61	2.3
3.30	25.8	2.1
3.45	25.9	2.
4.	26.05	1.85
4.15	26.16	1.74
4.30	26.28	1.62
5.	26.5	1.4
5.15	26.55	1.35
5.30	26.6	1.3
5.45	26.5	1.4
6.	26.4	1.5
6.15	26.3	1.6
6.30	26.2	1.7
6.45	26.05	1.85
7.	25.88	2.02
7.15	25.54	2.36
7.30	25.4	2.5
7.45	25.3	2.6
8.	25.2	2.7
8.15	25.15	2.75
8.30	25.2	2.7
8.45	25.16	2.74
9.	25.18	2.72
9.15	25.05	2.85
9.30	25.	2.9
9.45	24.95	2.95
10.	24.84	3.06
10.15	24.86	3.14
10.30	24.91	2.99
10.45	24.9	3.
11.	24.9	3.
11.15	24.95	2.95
11.30	25.	2.9
11.45	25.12	2.78
12.	25.16	2.74
	April 17. A. M.	
12.15	25.2	2.7
12.30	25.24	2.66
12.45	25.28	2.62
1.	25.34	2.56
1.15	25.4	2.5
1.30	25.44	2.46
1.45	25.5	2.4
2.	25.5	2.4
2.15	25.55	2.35
2.30	25.6	2.3
2.45	25.64	2.26
3.	25.61	2.29

Aluminum Cylinder within Brass Cylinder. Observations.—Continued.

Time.	Scale Reading.	Amount of Deflection.
3.15	25.6	2.3
3.30	25.61	2.29
3.45	25.67	2.23
4.	25.7	2.2
4.15	25.7	2.2
4.30	25.75	2.15
4.45	26.05	1.85
5.	26.	1.9
5.15	25.95	1.95
5.30	25.83	2.07
6.53	26.15	1.75
7.45	26.35	1.55
8.	26.5	1.4
8.15	26.48	1.42
8.30	26.4	1.5
8.45	26.15	1.75
9.	26.05	1.85
9.15	25.95	1.95
9.30	25.82	2.08
9.45	25.88	2.02
10.	25.75	2.15
10.15	25.65	2.25
10.30	25.6	2.3
10.45	25.6	2.3
11.	25.55	2.35
11.15	25.6	2.3
11.30	25.7	2.2
11.45	25.84	2.06
12.	25.9	2.
	P. M.	
12.15	25.96	1.94
12.30	25.96	1.94
12.45	26.03	1.87
1.	26.1	1.8
1.15	26.15	1.75
1.30	26.22	1.68
1.45	26.28	1.62
2.	26.33	1.57
2.15	26.4	1.5

Time.	Scale Reading.	Amount of Deflection.
2.30	26.5	1.4
2.45	26.53	1.37
3.	26.38	1.52
3.15	26.25	1.65
3.30	26.25	1.65
3.45	26.28	1.62
4.	26.2	1.7
4.15	26.2	1.7
4.30	26.25	1.65
4.45	26.3	1.6
5.	26.43	1.47
5.15	26.6	1.3
5.30	26.7	1.2
5.45	26.73	1.17
5.55	26.78	1.12
6.25	26.85	1.02
6.45	26.93	.97
7.	26.9	1.
7.15	26.75	1.15
7.30	26.6	1.3
7.45	26.55	1.35
8.	26.55	1.35
8.15	26.4	1.5
8.30	26.25	1.65
8.45	26.05	1.85
9.	26.	1.9
9.15	25.84	2.06
9.30	25.75	2.15
9.45	25.65	2.25
10.	25.5	2.4
10.15	25.43	2.47
10.30	25.37	2.53
10.45	25.35	2.55
11.	25.34	2.56
11.15	25.3	2.6
11.30	25.3	2.6
11.35	25.35	2.55
	April 18. A. M.	
8.	26.53	1.37

a time varying from 22.5 hours (10.30 P. M.) to 24 hours; second maximum about 11 hours; minimum between 17.25 hours (5.15

P. M.), and 18.5 hours (6.30 P. M.), and another between 5 hours and 5.5 hours. Hardly less interesting than these variations in the ionization is the difference in the amount of the charge on the quadrants on the first charging up, and that attained at any subsequent time during the continuation of an experiment. For the combination aluminum within brass the charge reached a maximum of 1.43 volts, and the highest value subsequently attained was only about .25 of a volt. The charge was negative. The observations from which the curves were drawn are given in the accompanying table of observations.

Lead in Brass.

The first part of the curve for lead in brass, Fig. 4, presents an interesting variation from the form of the curve for other combinations of metals. Instead of falling off almost altogether and then

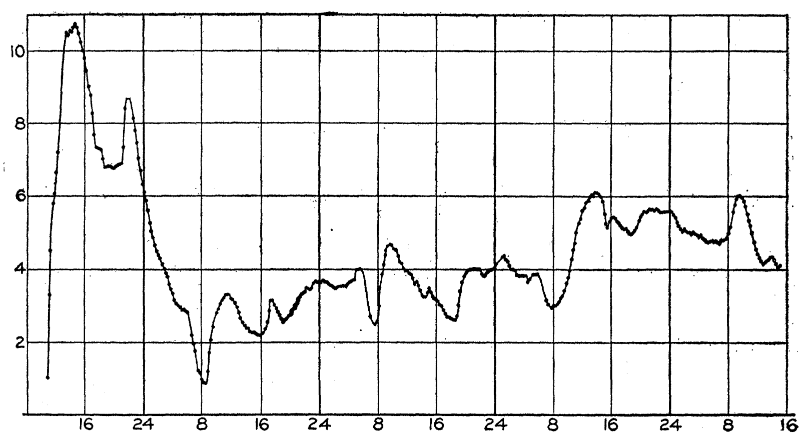

Fig. 4.

increasing, this curve shows that the leak decreased for from 4 to 5 hours, and then increased rapidly for a time, finally falling to a minimum, as is usual in 18 to 20 hours. It is worthy of note that this variation took place about the twenty-fourth hour, or the hour of midnight, at which time all the curves show a maximum. Besides this irregularity the curve shows two other striking peculiarities. One is the constancy of the minimum for each day at about the eighth hour, and the other, the so-called notched maximum, about midnight. If we disregard the first part of the curve and consider only the portion given for complete days, we see that these midnight maxima are not the principal maxima as in the curves for aluminum in brass. The principal maximum in this curve comes at the time of the secondary in the former curve. The general outline of the two, however, are very like, and the variation is no doubt due to the increase in the amount of leak. As in the preceding curve, so here we find maxima for each day whose time of occurring varies from two to three hours. For lead in brass one variation of the maximum for successive days is from 22.5 h. to 24 h., and the other from 10 h. to 13.5 h. The minimum vary between 20 h. and 21 h. for one, and 7 h. and 9 h. for the other. If we consider the first part of the curve we have further evidence for the existence of the

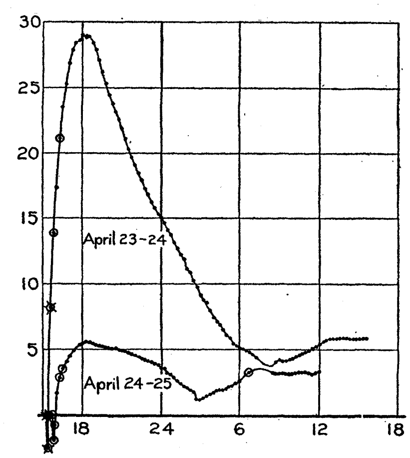

Fig. 5.

maximum between the twenty-second hour and the twenty-fourth. In this curve the progressive increase in the ionization is very evident, as it is in all the curves where one of the cylinders is of lead, and indicates that this steady increase is due to some property of the metal.

Lead in Lead.

The leak between a lead cylinder, and another of the same metal, was, in these experiments, so surprisingly great, that an effort was made to determine its source. Accordingly after the leak had fallen off, and had become comparatively constant, the inner cylinder and the quadrants were disconnected and earthed. After about half an hour they were again insulated, and a new set of readings begun. The curves drawn for the two periods show the same general form. The rise in the second case, however, falls short of that attained in the first, and indicates that the ionization is due to a radio-active deposit on the surface of the metal, whose activity dies out with time. For both sets of readings the curves show that the maximum was reached in the same time, but in the second case the fall is less rapid. Since the time of fall in this case is almost coincident with the time of the principal maximum daily variation, we

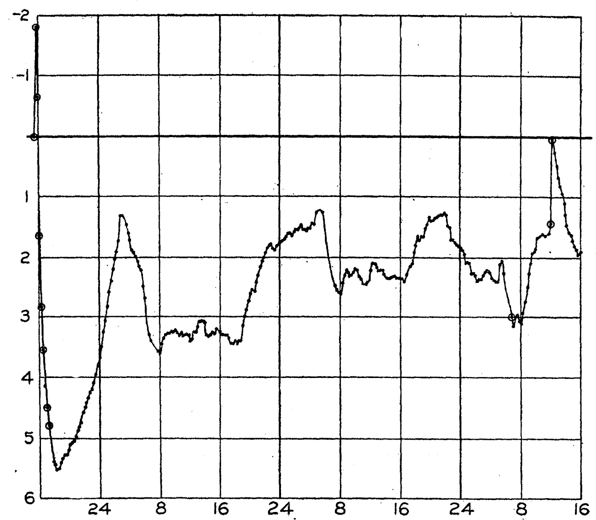

Fig. 6.

may attribute the retardation of the fall to whatever produces this variation. The observations from which this second curve was plotted, with subsequent observations are replotted in Fig. 6, in such a manner that the downward direction indicates a positive charge. The result of grounding the inner cylinder after the first twenty-four hours, and beginning a new set of observations is here clearly seen in a loss of definiteness in the periodic character of the curve. It is true, that we find maxima and minima at about the same hours at which they occurred in the curves previously given, but they are less clearly defined. If we consider full twenty-four hour periods from one hour we find a maximum for each day for which the curve is drawn, at 22.5 h. Most evident of all, however, is the morning minimum, occurring as it does at 8 h. on three successive days. The afternoon fall though less evident is clearly defined and occurs as usual about the sixteenth or seventeenth hour. It must be pointed out, however, that two of the maxima observed do not come at a time at which maxima are usually observed, and that the two very great fluctuations observed at a time somewhat later than the usual time of the night maxima seem to be connected with weather conditions, for a storm was on at the time, and it has been invariably observed that a violent rain storm produces a marked increase in the deflection of the needle always in the direction indicating a negative charge.

Aluminum in Lead.

The observations from which this curve for aluminum in lead, Fig. 7, was drawn were taken after the central cylinder had been

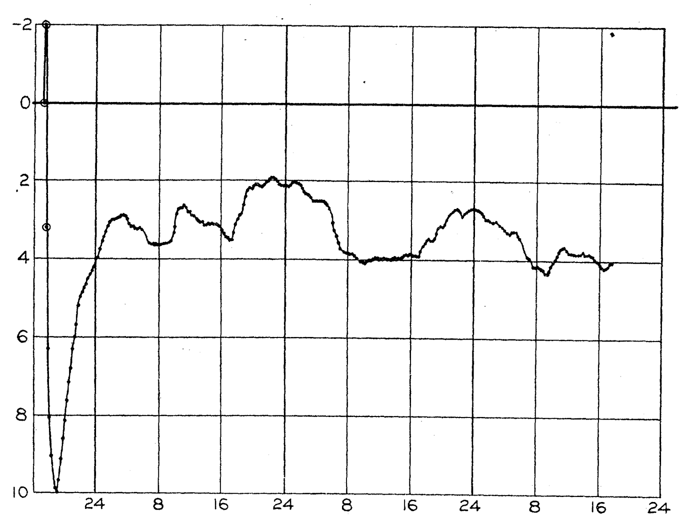

Fig. 7.

connected to the quadrants, and insulated for twenty-four hours. At the end of this time the quadrants were earthed and, after a brief interval, insulated again, and a new set of readings begun. The curve for the first period is not given, as the first part of this curve corresponds with it in outline. The activity of this combination of metals was very great, the maximum deflection indicating a potential difference of over 2 volts. The curve is noticeable for the likeness it bears to the other curves where lead was the metal of the outer cylinder. To point out this likeness is of some importance since it indicates that the metal of the outer cylinder modifies, to some extent, the results obtained. As plotted the downward direction indicates the deflection corresponding to a positive charge and shows that there is a gradual increase of the charge from day to day. It will be noticed in these curves that the maximum and minimum are not preceded and followed by a rapid rising and falling of the curve, but that the maximum continues fairly level throughout the night, and the minimum throughout the day. Even so it is possible to recognize the usual maximum occurring from the twenty-second to the first hour, and a second maximum between 10 h. and 12 h. Minima occur between 16 h. and 18 h. and between 6 h and 9 h.

Brass in Lead.

Observations with this combination of metals, Fig. 8, were continued for a somewhat longer time than in the preceding experiments with the hope that most convincing evidence of the regularity of the

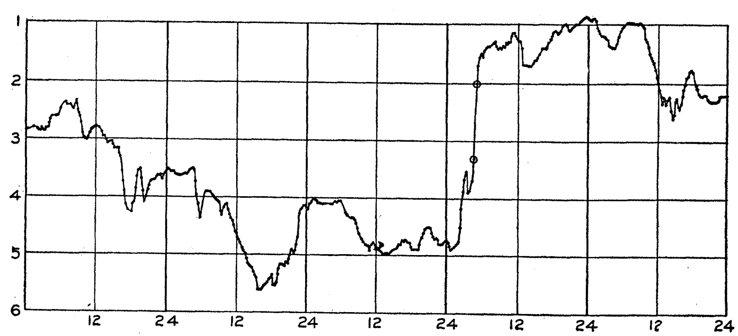

Fig. 8.

maxima and the minima would be obtained. However, the progressive change in the amount of ionization and in meteorological conditions, which undoubtedly have an influence, has broken up the regularity somewhat, and on one day at least evidence of maxima and minima is not clearly defined. The curves, moreover, never indicate clear-cut maxima and minima quite satisfactorily when the deflection indicates a positive charge on the free quadrants. Except on one day when there was an unusually large variation which was coincident with a heavy rain storm accompanied by thunder and lightning, the time of occurrence of maxima and minima is in fair agreement with the results obtained by Wood and Campbell. Maxima occur at a time varying between 22 h. and 2 h. for the different days, and morning maxima varying between 7 h. and 9 h. The principal minima occur with great regularity between 14 h. and 18 h., and secondary minima may be recognized between 2 h. and 5 h. In general the results obtained with this combination of metals is in agreement with the results previously obtained, yet there are differences which suggest that the influences which bring about the variations are modified in their action by the nature of the metals used, and especially by the metal of the outer vessel. This supposition is strengthened by its general likeness with the other curves where the outer cylinder is of the same metal.

Tin in Tin.

This experiment was made merely for purposes of comparison with the results from other experiments, and to verify the order of activity of the metals, lead and tin, given by Strutt and others. This order is confirmed by the results obtained, lead having been found much more active than tin. A quantitative comparison was not attempted as it was next to impossible on account of the differences in experimental conditions.

Discussion of Results.

Some of the results obtained in these experiments are not in agreement with those obtained by McLennan and Burton. For example, they found, for all the metals tried, that if the cylinders

[1] At the end of this experiment it was found that the zero had changed considerably An effort was made to trace the cause. For this reason the apparatus was left intact for several hours. In about 12 hours a drift toward the original zero of 5 mm. was noted. Later the needle and quadrants were earthed then insulated, and a drift of 5 mm. noted in two hours. This would seem to indicate that the quartz fiber had suffered fatigue under the continued strain.

were of the same metal, the inner cylinder acquired a negative charge, whereas for the two metals, lead and tin, which I have tried, the inner cylinder acquired a positive charge. McLennan and Burton thought that the negative charge acquired by the cylinder resulted from a process in which an excess of positively charged corpuscles was expelled from its surface. At first sight it seems impossible to reconcile my results with those they have obtained, but if we consider that the discharge is due to some agent on the surfaces of the cylinders, or to a radiation from the surface of the metal itself, then the inconsistency may be explained away. In either case the amount of radiation should be proportional to the area of the surface of the cylinders. Hence if the cylinders are nearly of a size the amount of radiation from each will be about the same. On the other hand, if the cylinders are of quite different sizes then a much greater number of corpuscles will be shot off from one than from the other, and the cylinder from which the greater number is shot off will become negative with respect to the other. In McLennan's experiments the area of radiation does not greatly differ for the two cylinders, while in the experiments described in this paper the effective area was quite different. If now we suppose that the negative charge of the earth has a restraining influence on the escape of the positive corpuscles, the leak from the inner cylinder, which is insulated, will start first, and the two cylinders will act like a galvanic battery, with the inner cylinder as the negative pole and the air as a dielectric. The direction of the field thus created will have a retarding influence on the corpuscles from the outer cylinder, and more of them will be absorbed in their passage through the gas than if this field did not exist. If this absorption is sufficient to overcome the excess of corpuscles from the outer cylinder in McLennan's experiments, but not sufficient in the experiments herein described, then the two results are reconciled. Moreover, this interpretation not only reconciles the two results, it also enables us to explain why all the curves which ultimately indicate a positive charge show that at the start there was a deflection in the negative direction. The length of time of this negative deflection gives us a means of determining the strength of the retarding influence exercised by the earth's field, and by the leak between the cylinders. Furthermore, the smallness of the negative charge measured by McLennan shows that the absorption was barely sufficient to overcome the excess of corpuscles from the outer cylinder. Further experiments will be made to test the soundness of this view.

To assign a cause for the periodicity of the ionization in a closed vessel, in the present state of our knowledge of the subject, is to present what must be considered more or less probable, and what must remain so until experiments have been made in widely different parts of the world. At best the explanations put forth, as in all cases where new ground is broken, must be looked upon as working hypotheses. So it is with the explanation offered by Wood and Campbell, and the one favored in this paper. Wood and Campbell trace a connection between the periodicity and the potential of the atmosphere, and give comparative ionization and potential curves for several consecutive months. These curves do, indeed, show a decided similarity, yet that Wood and Campbell themselves are not altogether satisfied that this seeming interdependence fully explains the phenomena is implied in their cursory reference to another possible cause.

One explanation of the phenomena that readily suggests itself is that the periodicity is due to the ionization which is known to be present in the atmosphere and indirectly to whatever produces this ionization.

Several observers have shown that radium and thorium emanations exist in the atmosphere, and Elster and Geitel have made a detailed examination of the effect of meteorological conditions on the amount of excited radio-activity to be derived from this source. A large number of observations were taken extending over a period of twelve months. They found that the amount of excited activity obtained was subject to great variations. Yet no evidence is given to show that these were periodic in character. No direct connection could be traced between the amount of ionization in the atmosphere and the amount of excited activity produced. More recently Dike[1] has obtained some evidence, which tends to show that there is a daily variation in the amount of radium emanation in the lower regions of the atmosphere. He found that the induced radio-activity depos-

[1] Terrestrial Magnetism, Vol. II., No. 3, p. 128.

ited on a negatively electrified surface in the Cavendish Laboratory has diurnal periods with a well-marked maximum at 1 A. M. Dike's observations, however, were continued only through six days. Similar diurnal variations in the amount of induced radioactivity have also been observed by Simpson[2] in Lapland.

In view of the fact that the theories already put forth to account for the periodic character of the ionization are not wholly convincing, it will not be out of place to consider another source of the ionization. O. W. Richardson[3] has pointed out that the connection between the periodicity in the ionization in closed vessels, and the variation in the intensity of the electric field near the earth's surface may be explained on the theory of conduction through gases if it is assumed that the ionization is caused by radiation from extra-terrestrial sources. The source of this radiation which Dr. Richardson suggests is the sun. Certain of the rays from the sun possess ionizing properties. These rays will be absorbed in passing through the atmosphere, and only the more penetrating will reach the earth. But in proportion as the rays are absorbed, ions are produced, hence the ions from this source will be more numerous in the upper regions of the atmosphere than nearer the earth. If, as Dr. Richardson does, we regard the earth and the upper atmosphere as two plane electrodes maintained at a constant difference of potential, we see that the ionization in the air near the upper atmosphere will be much more intense than near the earth, and hence the potential gradient will be least, for it has been found that where the ionization is to a large extent confined to the volume of air near one electrode, the potential gradient is least in its neighborhood and increases as the other electrode is approached. Thus any cause which brings about an increase in the intensity of the ionization in the upper air will increase the electric intensity near the surface of the earth.

The results of the experiments described in this paper are an indirect confirmation of this view in so far as they give evidence in favor of the source of the earth's electric field, upon which Richardson's conclusions are based. His theory of the origin of the earth's field is that it arises in rainy regions on account of the neg-

[1] Phil. Trans., 205, p. 61, 1906.
[2] Nature, April 26, 1906, p. 607.

atively charged rain conveying its charge to the earth, which thus becomes negatively charged. This leaves a high positive potential in the atmosphere immediately above the rainy region, which very rapidly distributes itself over the earth's surface by means of discharges in the upper regions of the atmosphere, where the pressure is low enough for ionization by collisions to occur. Owing to the high conductivity of the upper regions of the atmosphere, therefore, the potential will differ only to a relatively slight extent over different regions of the earth's surface; most of the fall of potential between the positive charge over the rainy region and any point on the earth's surface will occur in the badly conducting layer of air at a high pressure, which is comparatively close to the earth's surface. The main point in support of the above view of the origin of the earth's field, derived from the experiments herein described, is the observation, made repeatedly during the course of the experiments, that a rain storm was invariably accompanied by a rapid fluctuation of the charge on the free quadrants. On several occasions the fall of rain was preceded by lightning and thunder, but it was not until the rain began to fall that the rapid fluctuations of the charge took place. The connection between weather conditions and the unusual fluctuation of the charge on the quadrants has been pointed out in the discussion of each particular combination of metals, except for the first part of the experiment with the combination lead in lead, which was carried out while a heavy rain was falling. The observations taken during this period have not been plotted, as the fluctuation of the charge was accompanied by a change in the position of the zero, which rendered the value of the readings very uncertain.

Whatever be the source of the ionization, one thing is evident, the ionization in a closed vessel has a double daily period. Moreover, the uniformity in the time of occurrence of the respective maxima and minima in experiments made in so widely different parts of the world as Cambridge, St. Petersburg[1] and Washington makes the view that the variations are caused by radiation from the sun ionizing the air and thus bringing about a fluctuation in the earth's electric field, appear the most probable explanation of the phenomena.

[1] See Science Abstracts, 1904, No. 1580.