A STUDY OF THE RESIDUAL IONIZATION IN A GAS WITH REFERENCE TO TEMPERATURE EFFECTS.

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Synopsis.

A Study of the Residual Ionization in a Gas with Reference to Temperature Effects.—A form of electrometer was constructed which used the principle of the Wulf electrometer in separating the conduction of charge across the insulation from the conduction in the gas due to ionization. *The new features of this apparatus* were that it was possible (1) to make a quick and accurate test of the insulation properties under the same conditions as those under which the ionization tests were made, and (2) to subject the instrument to a wide range of temperatures.

Ions generated per C.C. per Second.—The data experimentally determined show that the number of ions generated per c.c. per second within an air tight chamber is 8.22 in the basement of the Physical Laboratory and 4.15 over the Pacific Ocean.

Residual Ionization not due to Thermal Impact.—The results of tests between − 44.6° C. and 92.5° C. show no indications that the residual ionization is due in any part to a molecular impact of thermal agitation.

Effect of Temperature on Insulation System.—Observations made of changes in temperature on the insulation system, would seem to account for the apparent daily and seasonal variations of the residual ionization as previously reported.

Conclusions from Observations at Low Temperatures.—At temperatures from − 30.5° C. to − 44.6° C. an increase in conduction across the insulation system was noticed, which was comparable to the apparent increase in ionization as reported at high altitudes. It would therefore seem that it is not necessary to assume, as has been done by previous observers, that there is a highly radioactive cosmic layer in the upper atmosphere; or that the sun is a source of penetrating radiation sufficient to generate 90 ions per c.c. per second.

I. Introduction.

The experiments described in this paper were undertaken with the purpose of studying the ionization of a gas as observed in an air-tight vessel. This was done with a twofold purpose: (1) to find an accurate method of measuring this conductivity in the gas, and (2) to make a thorough investigation of the effect of temperature on this conductivity.

C. T. R. Wilson[1] and Geitel[2] were the first to notice that gases in closed vessels conducted electricity and were therefore ionized. The more recent experiments of Simpson and Wright,[3] King,[4] Murray,[5]

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[1] Wilson, Proc. Camb. Phil. Soc., II., 52, 1900.

[2] Geitel, Phys. Zeit., 2, 116, 1900.

[3] Simpson and Wright, Roy. Soc. Lon. Proc., 85, 175, 1911.

[4] King, Phil. Mag., 26, 610, 1913.

[5] McLennan and Murray, Phil. Mag., 30, 430, 1915.

McLeod,[1] McLennan,[2] Wright,[3] and the author[4] showed conclusively that ions are being generated in an airtight metal chamber, as free from radio-active substances as possible, at the rate of from 8 to 9 ions on land, and over the ocean and large lakes from 4 to 5 ions per c.c. per second. These results include observations made over practically every continent and ocean. Some observations indicate a pronounced variation. Lassalle[5] notices a diurnal variation in the Philippine Islands, while Gockel[6] finds the value for the winter months of December and January lower by 1 to $1\frac{1}{2}$ ions per c.c. per second than for the months of June and July.

In connection with the ionization within a closed chamber, we are confronted with two problems: (1) to find the source of the residual ionization of from 4 to 5 ions which is obtainable when the chamber is screened naturally over large bodies of water, or artificially on land; (2) to find an explanation for the very large increase in the ionization at high altitudes, as observed in a balloon by Hess[7] and Kolhörster.[9] The latter reports an increase of from 4.3 ions at 2,000 meters to 80.4 ions at 9,000 meters, over the values obtained at the earth's surface. Treleaven[9] concludes that the residual ionization of 4 ions is due to α, β, and possibly γ radiation emitted from the walls of the chamber. Murray[5] comes to the same conclusion from observations of this effect when the walls of the chamber were of ice. Kingdon[10] shows that a part of the residual ionization is due to thermal agitation and derives a formula which agrees with his experimental results.

The only other experimental works are those of Patterson[11] and Devik.[11] Patterson used a large iron chamber containing an electrode insulated by ebonite, and measured the current with an electrometer. He got a value of 61 ions, so it would be doubtful if he could observe a small temperature effect at ordinary temperatures. Devik attempted to measure the current at the instant of greatest compression in an adiabatic compression and found no effect at ordinary temperatures.

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[1] McLennan and McLeod, Phil. Mag., Oct., 740, 1913.

[2] McLennan, PHYS. REV., 26, 526, 1908.

[3] Wright, Phil. Mag., 17, 295, 1909.

[4] Kunsman, PHYS. REV., 6, 493, 1915.

[5] Lassalle, PHYS. REV., 5, 135, 1915.

[6] Gockel, Phys. Zeit., 16, 350, 1915.

[7] Hess, Phys. Zeit., 14, 610, 1913.

[8] (*a*) Kolkörster, Phys. Zeit., 14, 1153, 1914; (*b*) Ber. Deut. Phys. Ges., 13, 721, 1914.

[9] Treleaven, Phil. Mag., 30, 427, 1915.

[10] Kingdon, Phil. Mag., 32, 397, 1916.

[11] Patterson, Phil. Mag., 6, 231, 1903.

[12] Devik, Sitz. d. Heid. Akad. Wiss., 24, 1914.

The question has been theoretically investigated by Langevin and Rey,[1] and by Wolfke.[2]

Results obtained by the author seem to throw light on each of the following questions: (1) Do molecules of gases under ordinary temperatures collide in such a way as to produce ionization? (2) Is it necessary to assume a source of ionization in the upper atmosphere sufficient to produce ions at the rate of about 90 per c.c. per second?

II. Apparatus.

Preliminary experiments on the measurements of the natural ionization at the State College of Pennsylvania, at the University of California,[9] and on the Pacific Ocean between San Francisco and Los Angeles, were made with a Spindler and Hoyer[10] aluminum leaf electroscope designed for radioactive tests when the gases tested could be drawn into the ionization chamber. Two chambers of different sizes were essential for the method used.

More extensive tests were made by means of an electrometer designed by the author which could be subjected to a wide range of temperature. The object of this was to make it possible to measure ionization down to the temperature of liquid air. The main feature of the instrument was that it provided an easy test for leak across the insulation system without altering the conditions under which the tests were made. Such a test of conduction over the insulation could not be made on the apparatus used by the observers previously mentioned.

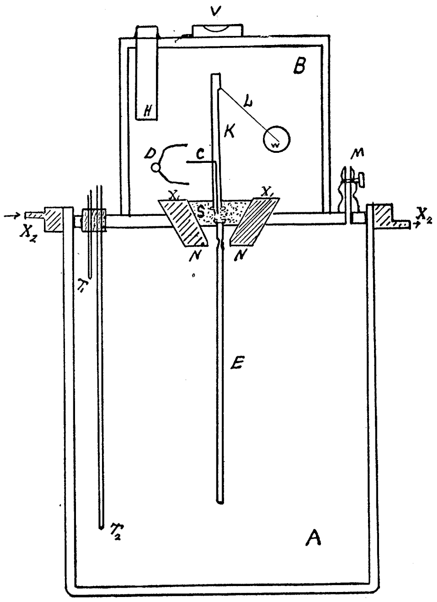

Fig. 1.

Practically the entire apparatus was built of as pure zinc as obtainable, since this metal seems more free from radioactive impurities than others. The ionization chamber *A* consisted of a zinc cylinder about 20 cm. long and 10 cm. in diameter, Fig. 1, the walls of the cylinder

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[1] Langevin and Rey, Le Radium, 10, 142, 1913.

[2] Wolfke, Le Radium, 10, 265, 1913.

being $2\frac{1}{2}$ mm. thick. Into this screwed the upper part which consisted of a zinc box B, forming the walls of the electrometer. The sulphur plug S holds in place the zinc electrode E, and another zinc rod K, upon which the aluminum leaf L was attached. A very small rod C moves up or down through the center of the zinc rod K. The rod C is raised or lowered by an insulated rod D which passes through a ground glass joint attached to the electroscope case. The volume of A or B can thus be electrically connected or separated as desired. The electric charge is communicated to the insulated system by means of the same rod D. After the system is charged, rod D is disengaged from rod C and grounded, as is also the case of the electrometer. An external dial on the case and an indicator on the charging rod assure the rod D being turned to the same position after each time the instrument is charged.

The sulphur insulation was kept cool or warm as was necessary by means of a system X_1 through which water or alcohol was run. A similar cooling system X_2 kept the wax joints cool.

Chamber B was kept as dry as possible by means of metallic sodium, contained in a receiver H. Thermo-couples T_1 and T_2 made it possible to measure the temperature of the gas quickly and accurately. A stopcock M permitted the ionization chamber to be exhausted and filled with dry gas. A spirit level V made it possible to keep the instrument always in the same position. A very fine quartz fiber was attached to the end of the leaf and the position of the fiber observed through windows by means of a telescope. The quartz fiber greatly increased the accuracy of the observations.

The zinc electrode E could be easily removed and a small cup containing sodium could be sealed to the bottom of the water jacket N, so that the loss of charge due to the volume B together with the total leakage across the insulation support could be determined. The volume of chamber A was 1,277 c.c. The electrostatic capacity of the electrometer as determined with two spheres of different radii,[1] was 4.48 cm. with the cup at N in place, and 6.50 cm. with the cup removed and the central electrode replaced. The drop in potential for a given number of scale divisions was obtained from the calibration curve, Fig. 2.

III. THEORY.

If C is the electrostatic capacity of a body, which is charged to a potential E, and after a certain time some of the charge has disappeared, it is evident that we can express this loss, or change of quantity, of electricity as $\Delta Q = C\Delta E$; where ΔE is the drop in potential for a unit of

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[1] Lichtenecker, Phys. Zeit., 13, 516, 1913.

time Δt. This loss of charge may be thought of as a neutralization of N ions, each carrying the unit charge, e. If n is the number of ions formed per c.c. per second in the volume V in the time Δt, we may write $N = nV\Delta t$. It follows that $\Delta Q = C\Delta E = NE = n\Delta teV$, or $n = C\Delta E/Ve\Delta t$.

Now ΔE is made up of two parts (A) a conduction of charge across the insulation support and (B) a loss of charge due to ions being formed in the gas, which neutralizes some of the charge on the insulated system. If two different volumes of gas are taken in such a way as not to alter the conduction of charge over the support, two equations can be set up of the form, $Q_1 = A + BV_1$ and $Q_2 = A + BV_2$; where Q_1 and Q_2 are the loss of charge per second with volumes V_1 and V_2 respectively and where $B = ne$. From this we get

$$n = \frac{C_1\Delta E - C_2\Delta E}{(V_1 - V_2)e},$$

which is the formula used for all calculations of n.

IV. First Investigation.

In the first set of experiments dry, dust-free air was introduced in the ionization chamber of the Spindler and Hoyer electroscope, in which the amber insulation was replaced by sulphur. Observations were taken of the rate of fall of the leaf, or loss of charge, after the rate of loss became constant. An apparent soaking in of the electric charge was shown by the relatively rapid fall just after the instrument was charged. This effect lasted about two hours. Quite a pronounced increase in ionization was always noticed immediately after the instrument was filled with air. This effect largely disappeared in about 4 days, which leads one to conclude that it was due to radium emanation, its half period being 3.8 days. The rate of fall was observed for about 4 weeks for each ionization chamber, and a mean value of n calculated. The mean value of n as obtained in the basement of the physical laboratory was 8.68 ions. Variations in this number were observed. In the light of recent experiments, these variations can be attributed to a change in the temperature of the instrument and were not due to a change in ionization.

In a test made the same year (1915) with the same apparatus, the value of n on the Pacific Ocean, between San Francisco, and Los Angeles was found to be 4.15 ions. In the calculation of the results of the observations over the ocean, the leak over the support was calculated from data obtained on land. The differences between the observed loss of charge on the ocean, and the calculated leakage across the support, as observed on land, was attributed to the formation of ions.

V. Second Investigation.

The zinc electrometer was used in all experiments where the temperature of the gas was varied. The instrument was made airtight by covering all possible sources of leak with sealing wax and finally applying a number of coats of shellac. The ionization chamber was filled with air or carbon dioxide which was made as free from moisture as possible by drawing the gas through calcium chloride and phosphorus pentoxide tubes, and finally bubbled through two bottles of concentrated sulphuric acid. The thermocouples, previously annealed and calibrated from the temperature of liquid air to the melting point of lead, were sealed into a hard rubber plug with sealing wax. This plug was then screwed into the top wall of the ionization chamber, and covered with more sealing wax. The other junctions of the thermo-couples were kept in a bath of melting ice. The E.M.F. was measured on a potentiometer in microvolts. In practically all tests the instrument was charged in the even-

Table I.

Length of Test.	Chamber A Connected, Disconnected or Cup in Place.	Average Temp. of Gas °C.	Rate Scale Div. per Min.	Rate Volts per Min.	n (Calculated).	Remarks.
			Air.			
14 dys.	Conn.	21 to 24°	.0915	.02955	8.22	Instrument surrounded with felt.
10 hrs.	Conn.	" "	.0931	.03007	8.55 (max.)	Instrument surrounded with felt.
8 hrs.	Conn.	" "	.0896	.02914	7.88 (min.)	Instrument surrounded with felt.
5 dys.	Cup in place	" "	.0703	.02271		Instrument surrounded with felt.
10 dys.	Disconn.	" "	.0336	.01085		Instrument surrounded with felt.
20 hrs.	Conn.	−12.5	.0721	.02603	6.20	Chamber immersed in ice and salt.
10 hrs.	Disconn.	−12.5	.0298	.01076		Chamber immersed in ice and salt.
48 hrs.	Conn.	22.0	.0815	.02632	6.37	Chamber immersed in brine.
5 hrs.	Disconn.	22.0	.0327	.01056		Chamber immersed in brine.
5 hrs.	Conn.	34.0	.0905	.02920	8.04	Chamber in heater.
			Carbon Dioxide.			
7 dys.	Conn.	21 to 24°	.1104	.03566	11.95	Chamber in heater.
6 hrs.	Conn.	38.8°	.0985	.03171	9.58	Chamber in heater.

ing beyond the field of view of the telescope so that by morning it was within view. This did away with irregularities previously mentioned.

The residual ionization was determined at room temperature for air and carbon dioxide. The results for carbon dioxide are somewhat higher than those obtained by Treleaven. Since commercial carbon dioxide was used the increase may be attributed to radioactive impurities in the gas. By means of the formula for n, the given constants of the apparatus and the data given in Table I., the resulting values of n were calculated.

Tests were undertaken at low temperatures for two reasons: (1) if ionization is produced by molecular impact due to thermal agitation, such an effect could best be investigated by decreasing this molecular motion as much as possible, (2) there is no record of such tests being made at low temperatures.

The electrometer was clamped rigidly in a frame and a Dewar flask containing solid carbon dioxide and alcohol raised until the ionization chamber was completely surrounded with the cooling solution. During this change of temperature of the gas within the chamber, very pronounced variations of the rate of leak were observed. When the warm instrument first came in contact with the cold solution, the divergence of the leaf increased a few scale divisions. However, in a few minutes the leaf came back to its original position, and quite a rapid rate of fall of the leaf was observed. For some time, depending upon how rapidly the temperature was lowered, the rate of leak appeared to be normal. With a further decrease in temperature the rate of loss of charge became quite rapid, and with a further lowering of temperature the charge on the insulated system had disappeared entirely. Table II. shows how this leak depends upon the temperature.

The central electrode was then disconnected from the charged system and a similar set of results obtained, also given in Table II. This at once shows us that the increased conductivity takes place across the insulation. Repeated tests with additional precautions against air leaks were taken, and in every case the same effects were noticed. Separate insulation tests were made on sulphur, amber and hard rubber, in order to determine whether the increased conductivity at low temperatures was due to a property of the insulator or was due to the presence of water vapor. The insulators were attached to wires and were sealed into glass tubes. In some cases the tubes were exhausted and filled with air which had been passed through calcium chloride, phosphorous pentoxide, and concentrated sulphuric acid. No noticeable increase in the conduction was observed at the temperatures of − 72° and − 187° C., when the air was carefully dried. But in cases where water vapor

TABLE II.

Length of Observation.	Average Temp. of Gas ° C.	Rate Scale Div. per Min.	n.*	Remarks. Carbon Dioxide in Chamber-connected.
30 min.	22.0	.1010	10.0	In alcohol bath at room temperature.
18 min.	−30.5	.1385	20.0	No warming bath used.
50 min.	−34.5	.1310	18.6	No warming bath used.
30 min.	−29.0	.1265	17.6	No warming bath used.
40 min.	−36.5	.1250	17.4	No warming bath used.
30 min.	−41.0	.1785	28.8	No warming bath used.
10 min.	−41.2	.2778	50.3	No warming bath used.
6 min.	−43.2	1.0820	222.5	No warming bath used.
1½ min.	−44.6	5.4800	1,162.0	No warming bath used.
½ min.	−44.6	7.0500	1,498.0	No warming bath used.
4 min.				Small stream of alcohol used for warming bath.
7 min.	−38.9	1.0000	204.0	No warming bath used.
2 min.	−42.3	4.1000	867.0	No warming bath used.
6 min.				Small stream of alcohol used for warming bath.
7 min.	−38.8	.8560	181.5	No warming bath used.
10 min.	−39.2	.8550	181.0	No warming bath used.
20 min.	−40.1	.6250	124.5	No warming bath used.
25 min.	−36.2	.2320	40.5	No warming bath used.
				Air in Chamber-connected.
1 hr.	24.5	.0938	8.68	No warming bath used.
45 min. later	−41.7	charge lost		No warming bath used.
30 min.	+20.0	.1140		Instrument recharged (25 min. later).
8 min.	−31.1	.1250	17.4	Warming bath used.
14 min.	−31.1	.1570	25.1	Warming bath used.
11 min.	−35.2	.1820	29.7	Warming bath used.
10 min.	−33.4	.2000	33.4	Warming bath used.
11 min.	−25.8	.1630	25.5	Warming bath used.
37 min.	−28.1	.162		No warming bath.
15 min. later	−40.2	charge lost		No warming bath.
				Air in Chamber-disconnected.
2 hrs.	22.5	.0337		Room temperature.
45 min.	−21.4	.0248		Warming bath used.
36 min.	−30.1	.0694		No warming bath used.
20 min.	−29.6	.0588		No warming bath used.
8 min.	−34.5	.1250		No warming bath used.
5 min.	−36.4	.6450		No warming bath used.
1 min.	−41.0	3.2500		No warming bath used.
	−41.0	charge lost		No warming bath used.

* n calculated upon the supposition that the increased rate of loss of charge is due to ionization within the gas.

was present an increased conduction took place. The rate of increase depended upon the insulator and form of the electrode. Insulation tests were also made above room temperature. Sulphur proved to be the best insulator under all conditions. Amber seemed to be especially sensitive to traces of moisture.

It was found that more even temperature conditions could be obtained at these low temperatures by allowing a small stream of alcohol at room temperature to flow through the system designed to keep the insulation cool when the gas was heated to higher temperatures.

As seen from Table II., there is a very marked increase in conduction across the insulation support when the average temperature of the gas is from − 15° C. to − 30° C. and at a temperature of about − 41° C. the charge is lost entirely. The temperature of the sulphur, although below zero, as shown by the amount of ice crystals which form on the external surface of the instrument, is not as low as the temperature of the gas, since the insulation part of the instrument is not immersed in the cooling solution.

Kolhörter[18] does not give the definite temperature of the electrometer for various altitudes, but states that when the temperature of the instrument had fallen to − 10° C. (5 to 6 km. above sea level) and below − 10° C. (6 to 9 km.) one would disturb the readings, if the electrometer was touched with the bare hands. In Table III., we have listed Kolhörster's results and probable atmospheric temperature for such elevations.

TABLE III.

Elevation Km.[18b] Above Sea Level.	* Value in 1913.	* Valve in 1914.	† Temp. °C.[21]
0	——	——	24.9
1	− 1.5	——	21.6
2	+ 1.2	——	16.6
3	+ 4.0	+ 4.3	10.3
4	+ 8.3	+ 9.3	3.9
5	+16.5	+17.2	− 2.5
6	+28.7	+28.7	− 8.5
7	——	+44.2	−14.3
8	——	+61.3	−20.9
9	——	+80.4	−27.2
10	——	——	−33.9

* Increase in ionization over value obtained on the earth's surface.

† Mean value of atmospheric temperature based upon sounding balloon observations at Fort Omaha, Nebraska; Indianapolis, Indiana; Huron, South Dakota; and Avalon, California, for the summer season.

[21] Gregg, Month. Weather Rev., 46, 17, 1918.

On comparing Tables II. and III. we see very marked evidence that we are dealing with similar results due most probably to the same cause, and that there are no abnormal ionization effects at great elevations; nor any additional source of penetrating radiation in that region. There is no need of introducing the theory of a very radioactive cosmic atmosphere at that elevation to explain these results. It also seems very improbable that the sun could be the source of a penetrating radiation sufficient to form 90 ions per c.c. per second within a closed vessel. And if the value of 90 ions represents the number generated at 9 km., might we not expect a much greater increase in ionization at 17 km. elevation where the temperature[1] is about − 84° C.? It does not seem at all unreasonable for us to believe that results would be obtained which would be in agreement with those in Table II.

In order to get such large results by experiments with a radioactive substance, it was necessary to place a considerable quantity of a very active material quite close to the chamber. This would lead us to believe that it is very improbable that there would be such quantities of radioactive material in the upper atmosphere as it would require to produce ionization at this rate. Then again experiments on the earth's surface,[2] show that the radioactive content of the atmosphere only contributes from 0.1 to 0.2 ions per c.c. per second, to the residual ionization. It would thus be necessary for the upper atmosphere to be from 450 to 900 times as radioactive as the atmosphere close to the earth's surface.

There seems to be no record of insulation tests being made at these altitudes. The author has found in measurements made with a similar Wulf electrometer obtained from Germany, that there is a very probable air leak when the change from one volume to the other is made, and in order to keep the gas as dry as possible, it is necessary to replace the metallic sodium from time to time. It would seem that the moisture in the closed gas has no noticeable effect on the insulation at ordinary temperatures, but when sufficiently low temperatures are reached minute ice crystals form on the insulation and conduct the charge to the walls of the instrument; again when the enclosed air is sufficiently warm, these crystals vaporize and normal conditions are established. One notices (see Table II.) that at one instance the rate had increased to 7 divisions per minute, and on allowing a small stream of alcohol at room temperature to flow through the water jacket for 4 minutes, the rate was decreased to one division per minute. A similar effect was noticed a little later in the test when a small stream of alcohol running 6 minutes caused the rate to change from 4.1 to 0.856 divisions per minute. No matter how rapidly the loss of charge takes place at low temperatures on bringing the temperature of the instrument back to room temperature the rate of loss of charge again becomes normal.

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[1] Nature, 98, 21, 1916.

[2] Chauveay, Le Radium, 10, 18 and 70. 1913.

Other observations were made with the instrument surrounded by a mixture of ice and salt (Table I.) in this case the temperature of the gas was subject to only small variations during the test. Since a pronounced decrease in the loss of charge was noticed, tests were made when the chamber was surrounded with the same brine at room temperature. Differences were observed both when the chamber was connected and disconnected. A search for the difference led the author to calibrate the instrument at the corresponding temperatures. The result was two distinctly different calibration curves as given in Fig. 2. At room-temperature one scale division is equal to 0.232 volts; while at a temperature below zero, one scale division is equal to 0.361 volts. So that on reducing the respective scale divisions to volts per minute (Table I.) the rate of loss of charge is the same, when the gas is at – 12.5° C. in the ice and salt solution, or when the gas is at room temperature and the ionization chamber is immersed in salt water. The difference between 8.22 ions at room-temperature (Table I.) and 6.37 ions with the chamber immersed in salt water is due to the screening effect of the salt water.

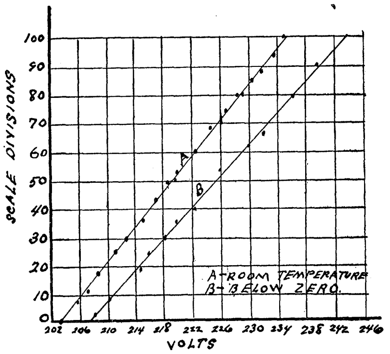

Fig. 2.

For investigations above room-temperature, the ionization chamber was placed in an electric heater formed by winding climax wire about a thin cylindrical sheet of asbestos, and packing this heating coil in magnesia. The heater was made just large enough to contain the ionization chamber. Both the sulphur insulation and the wax joints were kept cool by water jackets. From three fourths to two and one half amperes of current were passed through the heating coil. The results, as given in Table IV., show no increase with temperature below 92.5° C., but from 95 to 100° C. a pronounced increase is noticed, which is again evident when the volume is disconnected, at from 101° C. to 110° C. This shows an increased conduction across the insulation support, and is sufficient to account for the apparent increase in ionization in the gas noted by Kingdon from 80° to 100° C. His only method of testing the insulation was to exhaust the chamber. Thus different conditions were introduced whenever the insulation tests were made.

One notices from Table IV. that from 22° to 92.5° C. and from 22° to 101° C., with volumes connected and disconnected respectively, there

TABLE IV.

Air above Room Temperature.

Chamber Connected.		Chamber Disconnected.	
Temp. ° C.	Scale Div. per Min.	Chamber Temp. ° C.	Scale Div. per Min.
22.5	.091	22.0	.0333
38.0	.089	54.0	.0310
43.0	.088	76.0	.0308
52.0	.090	90.5	.0306
56.0	.087	95.0	.0300
68.0	.087	101.0	.0412
82.0	.079	109.5	.0450
90.0	.085		
92.5	.091		
95.0	.132		
100.0	.130		

is a decided decrease in the rate of loss in scale divisions per minute, instead of an increase as would be the case if there were an increase in the ionization. This change is no doubt largely due to a change in the dielectric constant of the sulphur.

The effect of temperature upon the insulated system can be easily shown by allowing solutions of different temperatures to flow through the water-jacket surrounding the sulphur insulation. When water at room temperature is allowed to flow through there is no change in the position of the leaf. When a solution above room temperature passes through, the leaf at once took a higher position on the scale. When a cold solution was allowed to flow through the water-jacket the leaf immediately took a lower place on the scale than that which it occupied at room temperature. When the temperature of the instrument was again at room temperature the leaf returned to its original position, except for the natural loss of charge which took place in the mean time. The greater part of this change is due to the change in the dielectric constant of the sulphur for various temperatures, as is shown by Schmidt.[1] A small variation may also be due to the change in the flexibility of the aluminum leaf with the change in temperature.

Bearing in mind that it requires a change of about 0.005 scale divisions per minute for an increase or decrease in the generation of one ion per c.c. per second, we find, on referring to Table I. and IV. that we cannot attribute the residual ionization to a thermal agitation of the molecules. Since the apparent variations in ionization can be attributed to temperature effects on the insulation system, it does not seem reasonable to

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[1] Schmidt, Ann. der Physik; 44, 335, 1914.

attribute any part of the residual ionization to a temperature effect upon the gas.

VI. Summary.

1. The mean value of the electrical conductivity of air in the basement of the physical laboratory at the University of California was 8.22 ions per c.c. per second when measured in a zinc chamber and 8.68 ions per c.c. per second when measured in a chamber where part of the walls were brass and the other part aluminum.

2. The mean value of the electrical conductivity as measured on the Pacific Ocean was 4.15 ions per c.c. per second.

3. This electrical conductivity, or residual ionization, is not due to molecular impact of thermal agitation.

4. The apparent increase in ionization as observed at high altitudes is solely a temperature effect, and is due to an increase in conduction over the insulation.

5. The effect of changes in temperature on the insulation system of an apparatus of this kind is sufficient to account for the apparent daily and seasonal variations of the residual ionization as reported by some observers, and is not due to a variation of the ionization of the gas within the chamber.

In conclusion I wish to express my thanks for the valuable guidance of Professor E. P. Lewis, under whose direction this work was done; and to Professor E. E. Hall for the laboratory facilities placed at my disposal, and also for helpful suggestions. Finally, acknowledgement is due Mr. W. R. Stamper for help in construction of apparatus.

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March 31, 1920.