LXXV. *Excited Radioactivity and Ionization of the Atmosphere.*

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THE experiments of Elster and Geitel† and C. T. R. Wilson‡ have shown that a well insulated charged conductor placed inside a closed vessel gradually loses its charge, and that this loss of charge is due to a small spontaneous ionization of the volume of air inside the closed vessel. Wilson calculated from his results that about 19 ions per c.c. are produced in the air per sec. In a later paper§ Wilson has shown that the ionization in different gases varies approximately as the density and pressure of the gas. These results point to the possibility that the ionization observed in gases may be due, in part at least, to the emission of an ionizing radiation from the walls of the containing vessel.

Recently Elster and Geitel‖ made the interesting discovery that a negatively charged conductor, placed in the open air, becomes temporarily radioactive. This radioactivity decays in the course of a few hours. The phenomena appear to be closely analogous to the "excited" radioactivity produced by the radioactive emanations of thorium and radium. The excited activity from the air can be concentrated on the negative electrode in exactly the same way as one of the authors¶ has shown for thorium-excited activity.

In addition Elster and Geitel have shown that the substance responsible for the radioactivity can be removed by solution in acid. On evaporating the solution to dryness an active residue, which decays with time, is left behind in the vessel. This also is in striking agreement with what one of us (*loc. cit.*) had previously shown for thorium-excited activity.

In the experiments of Elster and Geitel, and Wilson, the amount of ionization of air has been determined by observing the rate at which the leaves of a charged electroscope of special construction fall together. This method, while very simple and advantageous for some experiments, is, in general, slow, and in many cases does not allow of sufficient variation of experimental conditions.

In the present investigation the authors have utilized a

* Communicated by the Authors. [Communicated to the American Physical Society, Dec. 27, 1901; Abstract published in the *Phys. Zeit.* No. 11, 1902.

† *Phys. Zeit.* Nov. 24, 1900.

‡ Proc. Roy. Soc. March 1901. § Ibid. Dec. 1901.

‖ *Phys. Zeit.* iii. p. 76 (1901); xl. p. 590 (1901).

¶ Phil. Mag. Feb. 1900.

sensitive quadrant electrometer for examination both of the ionization and excited radioactivity produced in air.

The electrometer employed is a modification of the Dolezalek electrometer which is described in *Instrumente Kunde*, Dec. 1901. It is of the ordinary quadrant type, with a very light needle of silver paper suspended by a fine quartz fibre. The apparatus, as constructed by Herr Bartels, of Göttingen, was for determination of small P.Ds. for electrochemical work. For our purpose it was necessary to completely alter the insulation and method of connexion of the quadrants. In the present experiments the needle was charged at intervals of two days by lightly touching the needle by a fine wire connected to a battery of 200 volts. It was found that the needle did not lose more than 10 per cent. of its charge in 24 hours. The damping of the needle, on account of its lightness, was fairly rapid, and no extra damping vane was required. The deflexion was observed by a telescope and scale at a distance of 2 metres. The zero point was found to be very steady. For the first suspension employed the electrometer gave a deflexion of about 1800 mms. of scale corresponding to one volt P.D. between the quadrants, when the needle was charged to 200 volts. This suspension was accidentally broken in the course of the experiments and was replaced by a quartz fibre which gave only about $\frac{1}{4}$ of this deflexion for the same voltage. When dealing with the very small rate of discharge which is produced by the spontaneous ionization of air, it is very essential that every precaution should be taken to guard against external electrostatic disturbances. The electrometer and all the connecting wires were inclosed in gauze cylinders connected to earth. The floor and woodwork in the immediate neighbourhood of the testing apparatus were covered with metal connected to earth. The separation of the quadrants was done by means of a special mercury key operated from a distance by a cord.

The insulating substances necessary in experimental arrangements were completely diselectrified by means of flames.

Production of Excited Radioactivity.

The simplest method of obtaining a large amount of excited radioactivity from the air is to expose a long insulated wire charged to a high negative potential in the open air. After exposure for several hours the wire is removed and wound on a frame, or in the form of a flat helix. The ionization produced by the radioactive wire in the testing vessel is then observed, by means of the electrometer, in the usual way.

Elster and Geitel in their experiments have used an electroscope to measure the ionization produced.

In order to produce a considerable quantity of activity on the conductor it is necessary to charge the wire to a high negative potential. Potentials varying from −5000 to −100,000 volts have been used in the experiments.

A positively charged wire remains quite inactive however long it may be exposed.

Decay of Excited Radioactivity.

The excited radiation from the air decays with the time in a manner similar to the excited radiation from thorium and radium, but at a different rate. The excited radiation from thorium falls to half value in about 11 hours, while the excited activity from air falls to half value in about 45 minutes for the range of voltages examined. It has been shown* that the excited radiation from radium decays in an irregular manner, the rate of decay depending on the time of exposure. The rate of decay is rapid at first, then nearly stationary for some time, and then a regular decay to zero, falling to half value in about 30 minutes. It is thus seen that the rate of decay of excited activity, due to the atmosphere, is more nearly allied to that from radium than to that from thorium.

In the experiments detailed below the excited activity was produced on a long insulated copper wire, 15 metres long, suspended outside the laboratory window about 15 feet from the ground.

The wire was kept charged by means of a Wimshurst machine driven by a motor. The potential of the wire was measured by means of the sparking-distance between two brass knobs.

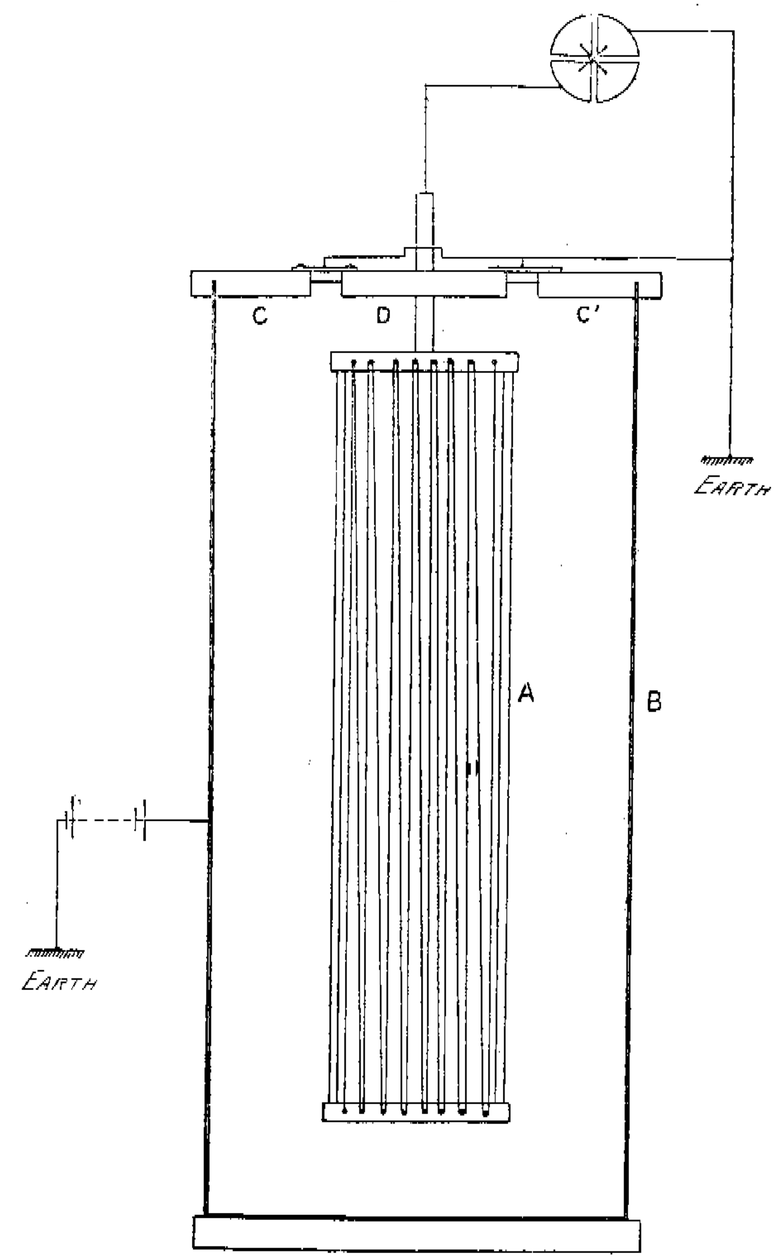
In order to regulate the potential of the exposed wire to any desired value a needle-point connected to earth was placed near a small plate connected to the charged wire. The distance between the point and the plate was adjusted until the spark just refused to pass between the knobs. This method was found to be more satisfactory than varying the speed of the machine.

After the wire had been exposed a definite time, it was rapidly removed and wound on a rectangular metal frame 120 cms. long and 10 cms. wide.

* Rutherford, *Phys. Zeit.* xii. p. 254 (1902); and Rutherford and Miss Brooks, Phil. Mag. July 1902.

The method of winding is shown in fig. 1, where the frame A is seen in position inside the testing cylinder B. The testing cylinder was of metal, about 150 cms. long and 30 cms. diameter. The outside cylinder was connected to a

Fig. 1.

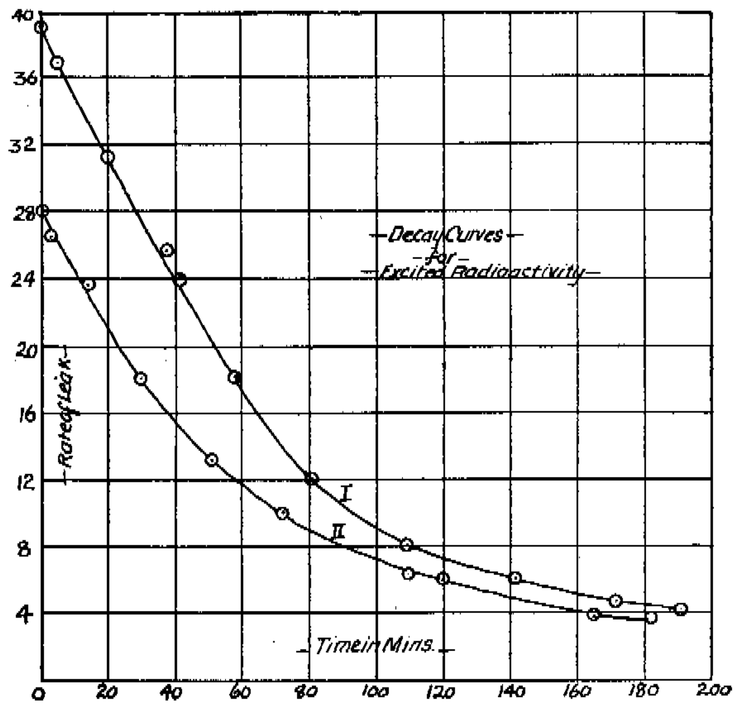


battery of 100 volts. In order to ensure that there was no conduction current between B and A over the supports the insulator CD was cut into two parts and separated by a metal ring connected to earth. The arrangement can be clearly seen from the figure.

The radiation from the wire ionized the gas inside the testing cylinder and the current between the electrodes was observed with the sensitive electrometer in the usual way. On account of the weak ionization of the air by the radiation a P.D. of 100 volts was sufficient to remove all the ions to the electrodes before appreciable recombination, and to give the maximum current through the gas.

Fig. 2, I shows the decay-curve for a copper wire exposed

Fig. 2.



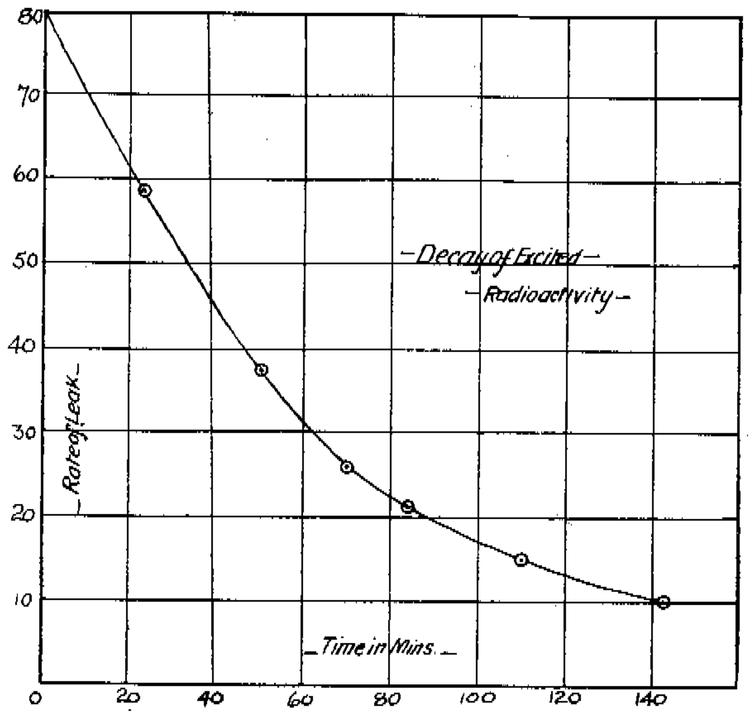
210 minutes inside the laboratory at a P.D. of −26000 volts; fig. 2, II the curve for the same wire exposed 270 minutes in the open air at −24000 volts. The ordinates represent divisions per sec. of the electrometer and the abscissæ time in minutes.

In most of the experiments (especially when the wire was exposed for several hours) it was found necessary to use a condenser in parallel with the electrometer to decrease the rate of movement of the needle.

There was always a current (about 2·5 divisions per sec.) in the testing vessel when the wire was inactive, due to the spontaneous ionization of the air in the cylinder. Allowing for this it will be seen that the current (which is proportional to the intensity of the radiation) falls off in a geometrical progression with the time, falling to half value for both cases in about 45 minutes.

Fig. 3 is a decay-curve for a lead wire exposed in an attic 190 minutes at −25000 volts. In this case the lead wire was wound in the form of a flat spiral and placed inside a testing vessel consisting of two parallel plates, one of which

Fig. 3.



was connected to the electrometer and the other to the battery. This again falls to half value in about 45 minutes.

A large number of curves of decay have been determined under very varying atmospheric conditions, but no certain differences in the rate of decay have been observed, although the *amount* of excited activity in a given time varies greatly with the weather and amount of wind. The rate of decay was the same for a copper as for a lead wire, and was independent of the diameter of the wire. The rate of decay for a brass rod charged at −100,000 volts was about the same as for a lead or copper wire exposed at −5000 volts. The rate of decay for low voltages has not been investigated.

We may thus conclude that over the range examined the rate of decay is regular and independent of conditions. In this respect also it resembles the excited radiations produced by thorium and radium.

It will be seen, from these results on the rate of decay, that if the intensity of the excited radiation is initially I_0, the intensity I after a time t is given by

$$I = I_0 e^{-\lambda t}.$$

Since $I=\frac{1}{2}I_0$ when $t=45$ mins.

$$\lambda=\cdot00026.$$

If the excited activity produced on the wire is due to a uniform rate of deposit of radioactive material the radiation from which decays with the time according to the above equation, it necessarily follows* that the intensity I after a time of exposure t is given by

$$I=I_0(1-e^{-\lambda t}),$$

where I_0 is the maximum value of the intensity reached after a very long exposure.

If this result is correct the amount of excited activity in a given wire for a fixed voltage should reach half its final value in 45 minutes.

Some experiments have been made on this point with wires exposed in the open air for different times. The amount of excited radioactivity in the air was found, however, to be too variable to test the truth of the equation. The results, however, showed that the amount of activity increased at first roughly in proportion to the time, but after three or four hours' exposure reached a practical maximum. More accurate experiments on this point are at present in progress, using a closed room instead of the open air, when the amount of excited activity is much more constant.

The amount of excited radioactivity from the air increased with the voltage of the exposed wire. On account of the variation of the amount of excited radioactivity in the air from hour to hour and day to day no definite results on the variation of the amount of excited radioactivity with the voltage were obtained.

Effect of Weather Conditions.

A large number of experiments were made on the effect of atmospheric conditions on the amount of excited radioactivity from the air. The wire was usually exposed for 30 minutes at a voltage of -25000 volts, outside a laboratory window, at a height of about 15 feet from the ground. The results showed that the amount of excited activity produced from the air varied very greatly with the atmospheric conditions.

Other conditions being the same, a bright clear day gave more excited activity than a dull cloudy day. The effect of temperature was not very marked. If anything slightly more activity was obtained on a bright day during the Canadian winter, with a temperature of about $-20°$ C., than

* E. Rutherford, Phil. Mag. Feb. 1900, p. 180.

on a bright warm day in the spring. The most powerful factor in determining the amount of activity given to the wire is the presence or absence of wind. A windy day always gave much greater effects than a quiet day, when other conditions were the same. This is true whether the air was cold or warm, or the day bright or dull.

Most of the experiments were made during the Canadian winter, when there was about two feet of snow over the ground. The prevailing wind was from the north, and had been carried over snow-covered lands. The fact that the amount of activity was uninfluenced by the presence of snow shows that the excited activity is not likely to be due to any effect arising from vegetation. The amount of water-vapour in the air appears to have little influence on the result, for at $-20°$ C. the air is extremely dry.

Penetrating Power of Excited Radiation.

It has been shown in a previous paper* that the penetrating power of the excited radiations of thorium and radium was the same. As the penetrating power is one of the methods of distinguishing between the various radiations a special experiment was made to compare the penetrating power of the excited radiation from the air with that of other known radiations from radioactive substances.

Lead wire was employed in these experiments as it could readily be retained in the form of a flat helix. The wire was excited by exposure of two to three hours at $-30{,}000$ volts. It was then wound to form a flat helix and placed between a parallel plate apparatus. The ionization current between the plates was observed for different numbers of sheets of thin aluminium foil placed over the helix. The average thickness of the aluminium foil was ·00034 cm.

The results are shown in Curve I. fig. 4 (p. 712) where the penetrating power of other known types of radiation are added for comparison.

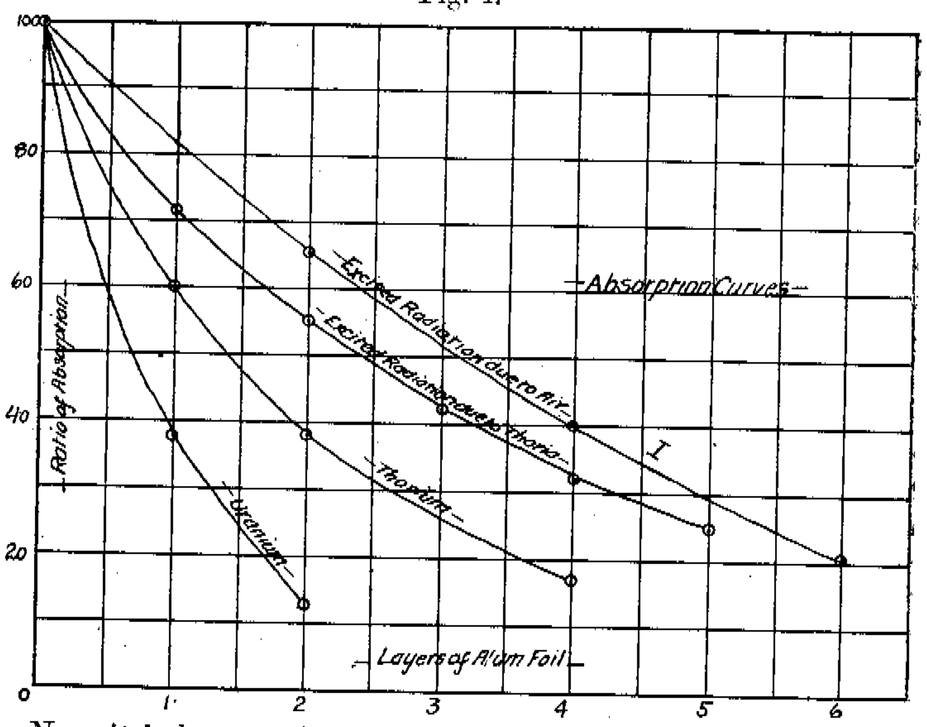
The excited radiation due to air has greater penetrating power than any of the types of radiations, not deviated by a magnetic field, from the radioactive substances uranium, thorium, and radium, and is also more penetrating than the excited radiation produced by radium and thorium.

No special experiment has been made to determine the absorption of the excited radiation in its passage through the air, but its approximate amount can be readily deduced from known data. In all the different types of radiations examined

* E. Rutherford and Miss H. T. Brooks, Phil. Mag. July 1902.

it has been generally found that if one radiation is more easily absorbed than another, in aluminium for example, it is also more easily absorbed in air. Since the excited radiation from the air is slightly less absorbed in aluminium than that due to thorium, we can thus conclude that it is slightly less absorbed in air.

Fig. 4.



Now it is known that the intensity of the excited radiation from thorium falls to half value after passing through 1·6 cms. of air. It thus follows that the intensity of the excited radiation from air falls to half value after passing through about 2 cms. of air, and is almost completely absorbed in a distance of 10 or 12 cms.

From the differences observed for the penetrating power and ratio of decay we can conclude that the excited radiation from air cannot be ascribed to the presence of any known radioactive substance in the atmosphere.

Transmission of Excited Activity.

We have seen that the excited radiation from the air is similar in all respects to the known types of excited activity by thorium and radium. In both cases the activity is confined to the cathode in an electric field, and can be partly removed by rubbing with a cloth or by solution in acid.

The differences observed in the rate of decay and penetrating power of the radiations show that the effects obtained

cannot be ascribed to the presence of a minute quantity of thorium or radium emanations in the atmosphere. The close resemblance in the phenomena, however, renders it probable that the excited activity from the air is due to a process similar in character to that which produces excited activity from the emanations of thorium and radium. One of the authors* has recently shown that in the case of radioactive substances the excited activity is due to a transmission of positively charged radioactive carriers to the cathode. These carriers travel in an electric field with about the velocity of the positive ions produced in air by Röntgen or Becquerel rays.

There seems to be little doubt that the excited activity is due to a deposit of a minute quantity of intensely active radioactive matter. Such an hypothesis is essential to explain the facts of solutions, and that the radioactivity can be transferred from the radioactive body to the cloth by rubbing. The production of excited activity from the air cannot be ascribed to any surface action on the conductor due to the electric field. A wire does not give any appreciable activity if it is confined in a cylinder where the volume of air is small, although the wire is subjected to the same voltage as in the open air. All the evidence obtained up to the present points strongly to the conclusion that the excited activity is derived from the volume of the air surrounding the charged wire. Since the activity is confined to the cathode, the carriers to which the activity is due must possess a positive charge. These carriers may obtain a positive charge either by the condensation of temporary radioactive matter of some kind round the positive ion already existing in the air, or by the expulsion of a negative electron from the carrier. The latter explanation seems the more probable, for we now know† that all the radioactive substances thorium, radium, and uranium, as well as the excited activity due to thorium and radium, possess the property of spontaneously expelling electrons.

There is as yet no definite evidence of the origin or mode of production of these radioactive carriers in the air, but assuming their presence, many of the experimental facts observed receive a simple explanation.

The higher the potential of the wire the greater the distance from which the carriers are conveyed to the cathode. The amount of excited activity on a wire exposed in free space, on this view, should increase rapidly with increase of voltage.

* *Phys. Zeit.* x. p. 210 (1902).

† Rutherford and Grier, *Phys. Zeit.* xvii. p. 385 (1902).

There is strong evidence that a wire charged to a high potential attracts the carriers over a large volume of air. It was experimentally found that the amount of excited activity obtained from a wire charged to − 20,000 volts in a cylindrical vessel of volume 141,000 cub. cms., when outside air was drawn through it at a rate of 500 cms. per sec., was only a few per cent. of the amount obtained from the same wire in the open air.

The increase of excited activity observed on days on which a strong wind is blowing is, on this view, due to the continued supply of fresh carriers which are brought in the sphere of action of the electric field. Since the exposed wire merely acts as a collector of radioactive carriers under the influence of the electric field the amount and nature of the excited radiation should be independent of the nature of the conductor, and this is found to be the case.

It thus appears probable that radioactive carriers are continually produced from some constituent of the atmosphere, but at a rate depending on atmospheric conditions. Bright clear weather appears to be the most favourable condition.

Since the earth is nearly always charged negatively with regard to the upper atmosphere, it follows that these radioactive carriers are being continually deposited over the surface of the earth. We must thus regard the earth as covered with an invisible layer of intense radioactive material which ionizes the air strongly within a few centimetres of the surface. The presence of these carriers in the volume of the air will also cause the production of fresh ions throughout the atmosphere, for each carrier acts as a radiating centre. A hill or mountain peak, or any high mass of rock or land, concentrates the earth's electric field upon itself and consequently it will receive more excited radioactivity per unit area than the level plain. Elster and Geitel have pointed out that the greater ionization observed in the neighbourhood of projecting peaks, receives a satisfactory explanation on this view.

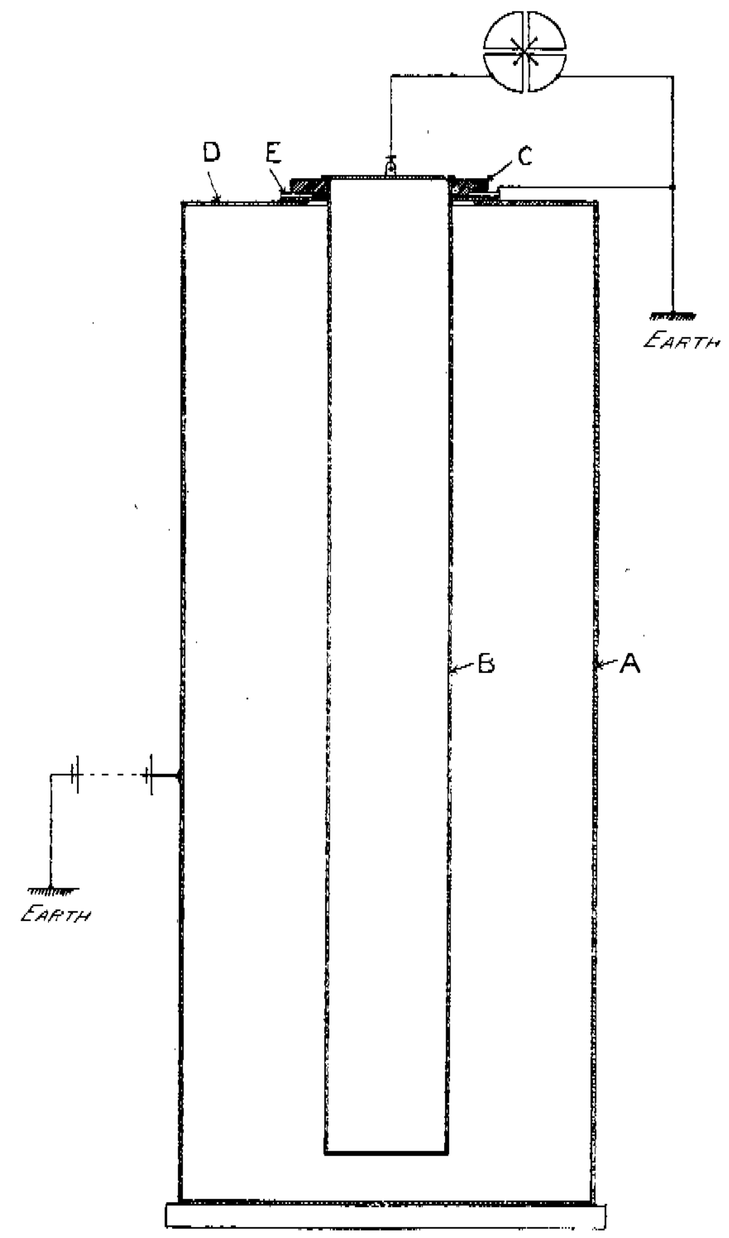
Spontaneous Ionization of the Air.

The experimental arrangement shown in fig. 5 was employed for determining the number of ions produced per c.c. per sec. in air and the variation of the ionization current with the strength of the electric field.

The current was observed by means of the electrometer between two concentric zinc cylinders A and B, 154 cms. in length, 25·5 and 7·5 cms. in internal diameter. The cylinders were placed vertical and the base of both cylinders closed.

The large cylinder was closed at the top by a zinc plate, in the centre of which was a circular opening slightly larger than the internal cylinder. A metal flange, fixed round the top of the inner cylinder, rested on an ebonite ring C.

Fig. 5.



Between the ebonite and the zinc plate D was placed a ring of thin metal E, connected to earth, which rested on a similar ring of a partial insulator like cardboard. The thin metal ring, connected to earth, served as a guard ring and ensured that even with a large P.D. between the cylinders, no current

could leak across the insulator to the inner cylinder, which was connected to the electrometer in the usual way. The outer cylinder was connected to one pole of a battery of small storage-cells, the other pole of which was earthed.

The electrometer needle showed quite a rapid movement due to the ionization current between the electrodes with a P.D. of a few volts between the cylinders.

The cylinder was made fairly air-tight and allowed to stand undisturbed. Observations of the current between the cylinders were made at intervals for over a month. In order to avoid correction for the slight variations in sensitiveness of the electrometer from day to day, the ionization current between two paralleled insulated plates due to a standard sample of uranium oxide was observed at the same time. Previous experiments have shown that the uranium oxide is a very constant source of radiation.

The following tables show the variation of the current, due to the spontaneous ionization of the air, with the P.D. between the cylinders. Table I. is for air which has stood undisturbed for a month inside the vessel; Table II. for the ordinary air of the room several hours after it had been introduced into the apparatus.

TABLE I.

P.D. in volts.	Current in divisions per sec. of electrometer.
·4	·34
·8	·50
2·1	·59
4·2	·65
6·5	·67
13	·71
26	·72
52	·73

TABLE II.

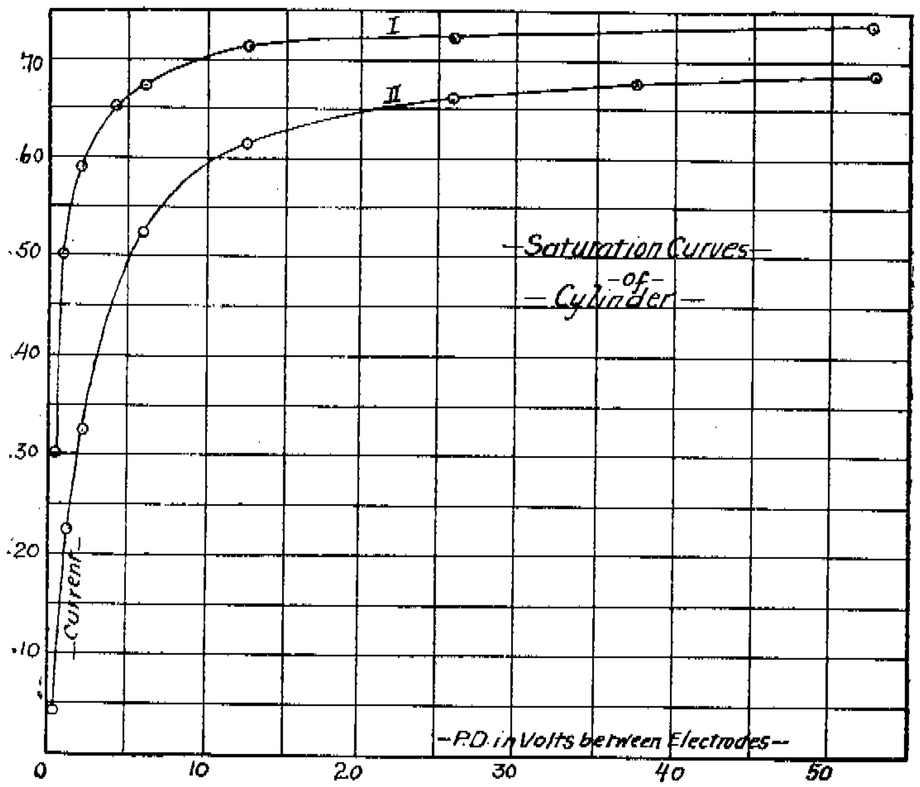
P.D. in volts.	Current in divisions per sec. of electrometer.
·2	·04
1·05	·22
2·1	·32
6·5	·52
13	·61
26	·65
39	·67
52	·68

The results are expressed graphically in fig. 6, curves I. and II. respectively.

The curves are very similar to those observed when the air is ionized by Becquerel or Röntgen rays. The current first increases approximately directly as the voltage, but soon reaches a stage in which large variations of the voltage only cause a slight increase in the current. On account of the very small amount of ionization of the air and consequent slow rate of recombination of the ions, the maximum current is reached for a very small voltage. The current for 50 volts

is not very different for the two samples of air, but in Curve I. the current reaches an approximate maximum much earlier than in Curve II. This difference is probably due to the presence of dust particles in the air in the latter case. Some

Fig. 6.



of the ions in their slow passage between the cylinders give up their charges to the dust nuclei. This action causes an increase in the rate of combination of the ions and consequently a larger electric field is required to produce the maximum current.

The capacity of the electrometer, cylinder, and connexions, was 150 E.S. units when 1 mm. division of electrometer corresponded to ·00182 volt. The average value of the movement of the electrometer needle was 100 divisions in 132 seconds for 50 volts between the cylinders.

The current between the cylinders was thus

$$6{\cdot}9\ 10^{-4}\ \text{E.S. units}$$

or $2{\cdot}3\ 10^{-13}$ amperes.

The volume of air between the cylinders was 71200 c.c. Taking the value of $6{\cdot}5\ 10^{-10}$ E.S. units, found by J. J. Thomson * as the charge on an ion, the number of ions produced per c.c. per second is 15.

* Phil. Mag., 1898.

This is not very different from the value of 19 found by Wilson for air inside a silvered glass vessel, using the electroscope method.

No certain difference was observed in the current for a period of time extending over one month. The production of excited radioactivity from the air suggested the possibility that a radioactive emanation was present in the air and that this might cause the ionization observed. If this is so, the radiating power decays at an extremely slow rate, or the emanation is being continuously reproduced in the inclosed space.

Application of the Ionization Theory.

In the spontaneous ionization of air we are dealing with an extremely slow rate of production of ions, and it is of interest to see how far the experimental results are in agreement with the ionization theory of gases, which has been previously tested in cases where the ionization is many thousands of times more intense than the present one. We have already noted that the variation of current with the voltage is in general agreement with the theory.

If q is the constant rate of production of ions per sec. and no electric field is acting, the number n of ions per c.c. increases until the rate of production is equal to the rate of recombination of the ions, or $q=\alpha n^2$, where α is the constant of recombination.

Now we have shown that $q=15$, and McClung * has found from the recombination of ions of Röntgenised air that

$$\alpha=3400\,e \text{ about,}$$

where e is the charge on an ion.

Substituting these values, we find

$$n=2600,$$

i. e., when a steady state is reached, the number of ions per c.c. is 173 times the number produced per second. The time T taken for this number of ions to diminish to half, supposing the rate of production stopped, is given by

$$t=\frac{1}{\alpha \bar{N}}$$
$$=174 \text{ seconds.}$$

We can obtain a rough approximation of the agreement with theory of the current voltage curve shown in Curve I. (fig. 6) from the following considerations.

The electric field X, at any point distant r from the centre

* Phil. Mag. March 1902.

of two concentric cylinders of radii b and a, is given by

$$X=\frac{V}{r\log_e\frac{b}{a}}=\frac{\cdot 82\,V}{r},$$

substituting values of b and a of cylinders in fig. 5.

Now if N is the maximum number of ions per c.c., the current i per unit length of cylinder over any cross-section, when a small P.D. V is applied, is given by

$$i=2\pi r\,.\,N\,.\,e\,.\,u\,.\,X,$$

where u = sum of velocities of positive and negative ions in unit field.

Substituting the value of X

$$i=1\cdot 64\,\pi N e u V.$$

If I is the maximum current when all the ions produced reach the electrodes

$$I=qe\pi(b^2-a^2),$$

and

$$\frac{i}{I}=\frac{1\cdot 64\,N\,.\,u\,.\,V}{q(b^2-a^2)}.$$

Now for a P.D. of ·36 volt the current i is ·4 of its maximum value (see Table I. p. 716).

Now it will be shown later in the paper that the velocity of the ions produced in air is about the same as that of the ions produced by Röntgen rays. The value of u (the sum of the velocities of the positive and negative ions) for a gradient of 1 volt per cm. is thus about 3·2 cms. per sec.

Substituting these values, we obtain

$$\frac{N}{q}=32.$$

Taking into consideration that 4 of the ions are removed by the current before recombination, it follows that when no voltage is acting

$$\frac{N}{q}=\frac{32}{\cdot 6}=53 \text{ roughly.}$$

Now we have shown that if α has the same value as that obtained for intense ionizations

$$\frac{N}{q} \text{ should equal } 174,$$

a value over three times as great.

There are, however, several causes at work which tend to make the observed value less than the theoretical. In the

first place, no correction has been made for the disappearance of ions by diffusion to the sides of the vessel. This can be shown to be quite an important factor in causing a low value of $\frac{N}{q}$.

Curve II. (fig. 6) shows what an important influence the presence of dust has on the shape of the current voltage curves. In addition, it has been assumed, for simplicity of calculation, that the potential gradient is not disturbed by the movement of the ions. Experiment and theory have, however, shown that there is a sudden drop of potential near both electrodes and that the electric field some distance from them is less than if no ions were present. All of these three causes act in the same direction and tend to give too low a value of $\frac{N}{q}$. The agreement between theory and experiment is thus as close as could be expected under the experimental conditions.

The results show clearly that, when air is kept in a closed vessel and no electric field is applied, the number of ions per unit volume, when equilibrium occurs between the rate of production and dissipation, is more than 50 times the number produced per sec. per unit volume.

Velocity of the Ions.

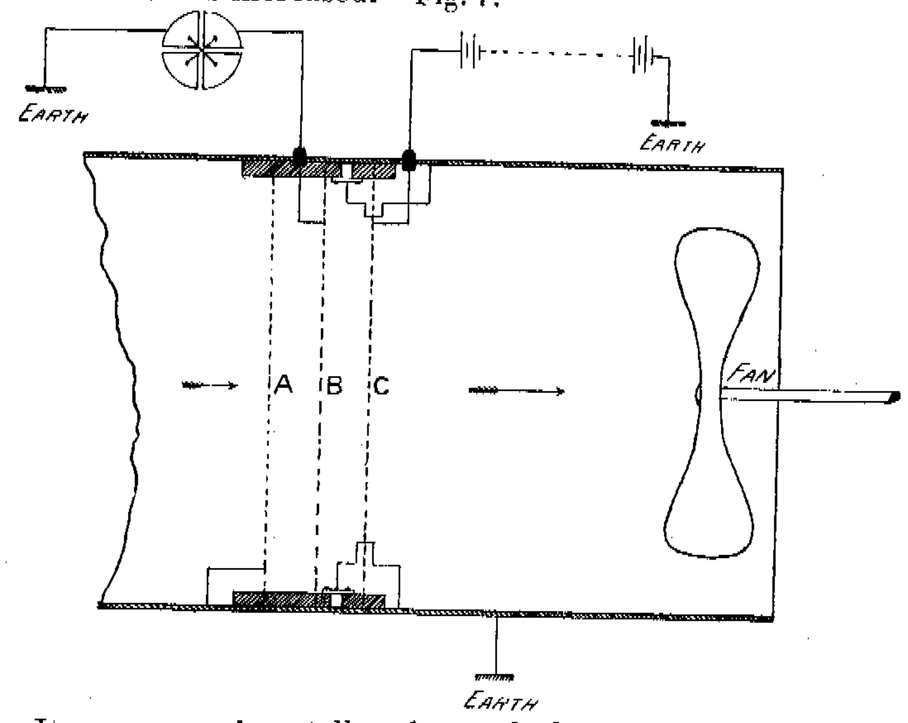
Some experiments were made to obtain an approximate estimate of the velocity of the ions which are spontaneously produced in air and at the same time to determine the number of ions per unit volume present in the outside air.

For this purpose, the apparatus shown in fig. 7 was employed. Air from the outside of the building was drawn through a zinc cylinder, length 200 cms., diameter 30 cms., by means of a fan driven by a motor.

The air in its passage through the tube passed through three circular parallel wire gauzes, A, B, C, 2 cms. apart and insulated from each other. The first gauze A was connected to earth, the second B to the electrometer, and the third C to one terminal of a battery of storage-cells, the other terminal of which was to earth. A guard-ring, connected to earth, was arranged between B and C to ensure there was no conduction leakage across the insulators between B and C.

Suppose gauze C is charged positive. The positive ions, carried with the current of air between the gauzes, start to travel up against the current of air, while the negative ions travel to the positive electrode with the current. If the velocity of the positive ions in the electric field is greater

than the current of air, they will all reach the gauze B and for a given current of air the current observed with the electrometer will be unaltered when the strength of the electric field is increased. Fig. 7.



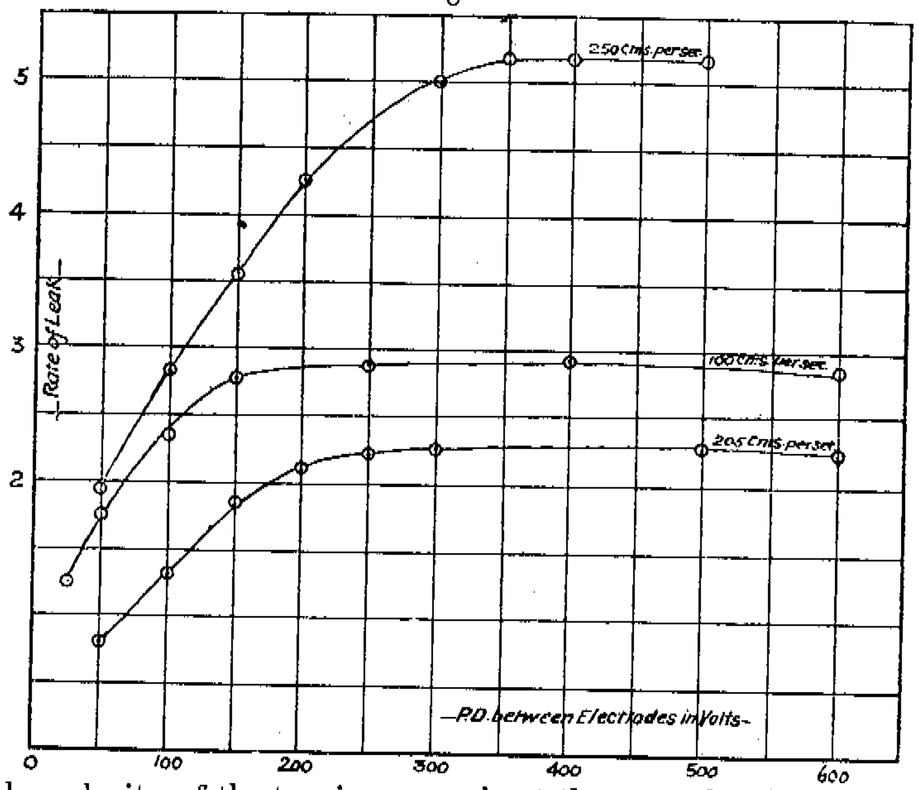
It was experimentally observed that even with a small electric field, there was some current to the gauze B. This amount increased with the voltage to a practical maximum. The experimental results are shown graphically in fig. 8 (p. 722) for velocities of the current of air of 100, 205, and 250 cms. per sec. respectively, when the gauze C was charged positively. It will be seen from the curves that, for a velocity of 250 cms. per sec., the maximum current is reached with a P.D. of about 350 volts. Since the gauzes were 2 cms. apart, the velocity K of the positive ions for a potential gradient of 1 volt per cm. is given by

$$K = \frac{2u}{V} = \frac{2 \times 250}{350} = 1{\cdot}4 \text{ cms. per sec.},$$

where u is velocity of current of air and V the smallest P.D. for which the maximum current is reached. The other two curves also give a value of the positive ion of about 1·4 cms. per sec. It was not found possible to obtain more than an approximate result for the velocity of the ions, on account of the variation in the conductivity of the air drawn through in the course of a series of observations. The curves shown in fig. 8 were obtained on special days when the variation of the conductivity was small.

Observations made in a similar way, to determine the velocity of the negative ion, were not very definite on account of variations during an experiment. The results showed that

Fig. 8.



the velocity of the two ions was about the same, but it was not possible to decide whether the negative ions move slightly faster than the positive, as is the case for ions produced by Röntgen and Becquerel rays in air.

The results obtained for the velocity of the ions are only approximate in character, but they point to the conclusion that the ions produced spontaneously in the atmosphere travel at about the same rate in the electric field as the ions produced in air by Röntgen and Becquerel rays. In a recent determination Zeleny * has shown that the sum of the velocities of the positive and negative ions, produced by Röntgen rays in dry air, is about 3·2 cms. per sec.

Variation of the Number of Ions in the Air.

By noting the *maximum* current between the gauzes, an estimate can be made of the number of ions per unit volume present in the air drawn through.

If A is the area of the cross-section of the cylinder, u the mean velocity of the current of air, N the number of ions per unit volume, the maximum current i observed by the electrometer is given by $i = \mathrm{A} \,.\, u \,.\, \mathrm{N} \,.\, e$,

where e is the charge on an ion.

* Phil. Trans. Roy. Soc. 1900.

Substituting the observed values of i, A, and u in this equation, the value of N can be deduced. The value of N was found to be variable both from hour to hour and day to day. The following numbers illustrate a few of the results obtained.

Date.	Number of ions per unit volume.
Nov. 20, 1901	40
„ 21 „	30
„ 23 „	14
„ 27 „	16
„ 30 „	13

The temperature of the air in most of these cases was about $-12°$ C.

A bright clear day was found to give a greater value of N than a dull day.

A very similar apparatus has been employed by H. Ebert * to determine the number of ions present in the air, only in his experiments the air was drawn between concentric cylinders, and an electroscope employed instead of an electrometer.

We see from the above results, that the number of ions per unit volume in the air varies considerably, but on three days was almost the same as the number produced *per sec.* in a closed vessel.

This is a surprisingly small number if we consider the outside air to be ionized at the same rate as the air inside the closed vessel; for we have shown earlier in the paper, that in a closed space the number of ions per c.c. increases to 50 times the number produced per sec. before the rate of recombination is equal to the rate of production.

After making due allowance for the causes tending to remove the ions, viz., the presence of dust and other particles in the outside air, and the electric field between the upper atmosphere and the earth, the number per unit volume is far lower than would be expected. It is possible that the spontaneous ionization of the air observed in closed vessels may be due (in part at least) to a *radiation* continuously emitted from the walls of the vessel. The spontaneous ionization of the outside air may, on this view, be much smaller than that observed in closed vessels, and the number of ions present per unit volume correspondingly less.

McGill University, Montreal,
June 9th, 1902.

* *Phys. Zeit.* No. 46, 1901.