XVI. Dependence of the current through conducting gases on the direction of the electric field

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coinciding with the curve determined by the second set. The diagram is reproduced on Pl. IV. Only the volumes above 3.4 were taken into consideration, for reasons stated in our former paper (*loc. cit.* p. 364).

It will be seen that on the whole the two sets of dots agree very well. In places, however, there is a discrepancy between the two sets: *e.g.*, at small volumes on the isothermal of 240° C. the calculated values of p_v differ from the experimental values by slightly over 1 per cent. This error is partly to be accounted for by our not having chosen the most suitable value of λ ; by choosing a rather smaller value we could easily diminish the error spoken of. But we cannot diminish the error indefinitely in this way, since we are hampered by the condition that we must not introduce more serious error into fresh places by our changes in λ . Hence there will necessarily be some small outstanding differences between the two sets of dots whatever value of λ be chosen. We have not thought it worth while to draw a fresh diagram with a more suitable value of λ , as a slight correction in the diagram corresponding to a slight change in λ is easily allowed for by the eye.

As to whether the outstanding differences referred to above indicate the necessity for a correction in the law we have proposed, or whether they can be considered as due to errors of experiment, we are unable to decide with any confidence at present. But it seems certain that by far the greatest part of the difference in the behaviour of normal pentane and of isopentane can be attributed to the action of the law we have mentioned. We are therefore confirmed in the conclusion stated by us in a former paper "that the difference of pressure between two isomeric substances at the same temperature and volume involves the same power of the density as the first deviation from Boyle's law, *i.e.* the second power" (*Phil. Mag.* xlviii. p. 214).

XVI. *Dependence of the Current through Conducting Gases on the Direction of the Electric Field.* By E. RUTHERFORD, M.A., Macdonald Professor of Physics, McGill University, Montreal*.

IN the conduction of gases under the influence of Röntgen and Becquerel rays, it has generally been considered that the magnitude of the current between the electrodes is independent of the direction of the electric field, except in

* Communicated by Prof. J. J. Thomson.

the case of potential-differences of the order of one volt*, when the contact-differences of potential between the electrodes may cause inequalities in the currents. In the general case, however, of gas-conduction, I have found that there is, in most cases, a difference between the values of the current with the reversal of the electric field. This difference is due to the inequality of the velocities of the positive and negative ions.

It is only in certain special cases that the current is independent of the direction of the electric field.

These cases are :—

- (1) When the ionization of the gas is symmetrical with regard to the electrodes.
- (2) When the electric field is so great that the current is a maximum, *i.e.* when all the ions reach the electrodes before recombination occurs.
- (3) When the number of ions present is so small that their movement between the charged electrodes does not appreciably disturb the potential-gradient.
- (4) When the positive and negative ions have equal velocities. In all other cases the positive and negative currents are unequal in value, the difference depending upon the distribution and intensity of the ionization, the distance apart and shape of the electrodes, and the potential-difference applied.

In many of the experimental arrangements of previous observers, by means of which the equality of the current in the two directions was observed, one or more of the above conditions was fulfilled.

The essential conditions for obtaining unequal currents are :—

- (1) Ionization unsymmetrical with regard to the electrodes.
- (2) Disturbance of the potential-gradient due to the movement of the ions in the electric field.
- (3) Unequal velocity of the ions.

A few simple cases will now be considered, in which the difference between positive and negative currents is strongly marked.

The difference between the currents in air is most readily shown when the gas is dry, and when the ionization between the electrodes is powerful and confined mainly to the surface of one electrode. This condition can readily be fulfilled by allowing a thin stratum of strong Röntgen-rays to pass between two parallel plate-electrodes, but nearer one plate than the other, or by using a powerful radio-active substance,

* E. Rutherford, *Phil. Mag.* Jan. 1899.

like radium, where the ionizing-power due to the radiation is mainly confined to within a few centimetres of the active surface. Some experiments with Röntgen-rays will be given later, but, on account of the inconstancy of a Röntgen-tube, it was found more convenient and accurate to experiment with radio-active substances.

Fig. 1 shows the general arrangement of the experiment with radio-active substances.

Two parallel circular insulated plates of lead A and B,

Fig. 1.

19 centims. in diameter, were fixed horizontally inside a tin vessel C. The lower plate was covered with a layer of tinfoil on which a thin layer of radium was lightly sprinkled. The upper plate was also covered with tinfoil and rigidly attached to the lid of the vessel. The central portion D of the upper plate was separated from the outer by a narrow air-gap and insulated from it, so that the outer served as a guard-ring. The electrometer was connected to the central plate in the usual manner; the guard-ring and vessel were connected to earth; the lower plate to one terminal of a large battery of small accumulators, the other terminal of which was to earth. The crossed lines in the figure represent insulators. The current between the plates was measured by noting the deflexion of the electrometer-needle in a given time.

The quadrants were separated, and the connexion with the

plate D broken after a definite interval by two keys operated at a distance.

The following results were obtained on the difference between the positive and negative currents with variation of potential-difference between the plates.

Diameter of centre plate D 7 centims. Air dried over P_2O_5 for one day.

P.D. between Plates in volts.	Current.		Ratio between Currents.
	Lower Plate+.	Lower Plate-.	
6	1	1.10	1.10
12	2.1	2.5	1.20
26	4.9	6.2	1.26
53	12.5	15.8	1.27
104	31.7	41.7	1.32
157	54.7	70.4	1.29
211	84.7	109	1.29
310	130	157	1.21
460	171	190	1.11
610	190	206	1.08

Each division of arbitrary scale is $2.3 \cdot 10^{-12}$ amperes. The results are plotted graphically in fig. 1 a (p. 214), where the ordinates represent current and abscissæ volts.

It will be observed that the current when the lower plate is negative is always greater than when it is positive. The maximum ratio observed is 1.32 for 104 volts. Another peculiarity is that the current increases much faster than the potential-difference. For an increase of P.D. of 4 times from 26 to 104 volts, the currents increase 6.7 times and 6.5 times respectively. When the plates were brought closer together, the same general results were obtained for low voltages; but the currents approached to approximate equality sooner for the high voltages. For example, with the plates 3 centims. apart, the ratio of currents was 1.20 for 27 volts, but for 300 volts the currents were nearly equal.

In this case most of the ions are produced near the lower plate, and are then separated by the electric field. In consequence of this, when the current is passing, nearly all the ions near the upper plate are of one sign.

A special experiment, after the manner described in a previous paper*, showed that the intensity of the ionization rapidly diminished from the surface of the radio-active plate.

* E. Rutherford, Phil. Mag. Jan. 1899.

Using a thin layer of radium chloride, the intensity of the radiation was found to be about $1/10$ of its value at the surface after passing through a distance of air of 3 centim., and diminished approximately in G.P. with the distance.

Fig. 1 a.

Potential-Gradient between Plates.

J. J. Thomson* has worked out the mathematical theory of gas-conduction, due to distributed ions, under certain special conditions. He has shown that in the case of uniform ionization, the equation is not integrable in the practicable case when the ions move with different velocities. The present case is still more complicated than the one considered; for, in addition, the rate of production of ions is not uniform between the plates. Some light is, however,

* Phil. Mag. March 1899.

thrown on the question by examining the potential-gradient between the plates when a steady P.D. is applied.

In the present case, where the plate on which the radioactive substance was spread was horizontal, it was not convenient to use a water- or mercury-dropper to determine the potential at any point between the plates. Recourse was had to the method used by Zeleny, in which an insulated wire connected to the electrometer takes up the potential of the gas in which it is placed. The wire W, shown in fig. 1, was bent into a circle in a horizontal plane, and connected to a vertical rod inside an insulated glass tube, so that the potential to which the wire was raised was not in any way influenced by the vertical support. The wire and all the metal surfaces of the vessel were of tin, and in this way contact-differences of potential were to a large extent avoided. The wire takes up the potential rapidly at a point where positive and negative ions are plentiful, but more slowly at points near the upper plate where the ions are nearly all of one sign, and not nearly so numerous.

Unless special precautions are taken, there is a danger that near the upper plate the average potential may not be indicated. Suppose, for example, in the present case, that the lower plate is positively charged and the upper plate earthed. The ions near the upper plate are nearly all of positive sign, and the wire will continue to receive a positive charge and rise in potential until it has reached the potential corresponding to the gas in the neighbourhood of the wire where the potential is *highest*. Since there are no negative ions present, any accidental excess of charge on the wire cannot be got rid of, and the indicated potential may be too high. A mercury- or water-dropper has the advantage that it takes up the potential at a point rapidly whether the ions of one or both signs are present. The wire, however, gives accurate results if care is taken, and is often more convenient to use than the mercury- or water-dropper*.

In determining the potential-gradient the method shown in fig. 2 was employed.

The insulated battery of small accumulators was connected to the terminals of a Thomson-Varley slide R of 100,000-ohms resistance. By means of the movable earth connexion E the potential-difference at the terminals of the resistance was divided in such a ratio that the potential of the air was zero close to the potential wire. When this is the case, the electrometer shows no deflexion on separating the quadrants. This

* This point has been discussed in a recent paper by C. D. Child, *Phys. Rev.* March 1901.

Fig. 2.

method was found in practice to be rapid and accurate. The following are results obtained for different voltages :—

Distance between plates 10·5 centims. Upper plate charged, lower plate earthed.

Distance in cms. from Lower Plate.	Upper Plate 107 volts +.	Upper Plate 107 volts —.	Upper Plate 214 +.	Upper Plate 214 —.
1	1·55	·91	4·50	2·44
2	3·32	2·14	9·03	5·84
3	6·01	4·20	16·1	12·0
4	9·79	7·11	26·2	22·3
5	16·8	15·3	44·4	38·6
6	27·0	25·1	67·8	63·1
7	41·2	40·1	99·5	97·3
8	59·4	58·3	131	127
9	76·5	76·0	167	164

The ratio of the two currents through the gas was 1·27 for 107 volts, and 1·20 for 214 volts.

Fig. 2 *a* shows the results graphically.

It will be observed that the potential-gradient, near the radio-active surface, is very small compared with that near the upper plate, and that, near the upper plate, the potential-gradients are very nearly the same whether the top plate is positive or negative. The potential-gradient near the lower

Conducting Gases on the Direction of the Electric Field. 217

plate is considerably greater when the upper plate is positive than when it is negative.

Fig. 2 a.

The results given in the table for 107 volts show that the rate of change of potential per centim. from about 6 centims. upwards from the lower plate is numerically very nearly the same for both directions of the electric field.

If this holds accurately, it can be readily shown that the currents through the gas in the two directions for the same P.D. are directly proportional to the ratio of the velocities of the positive and negative ions.

For let V be the P.D. between the plates. Let us suppose that the lower plate is positively charged, and that positive ions only are present near the upper plate.

218 Prof. Rutherford on *Dependence of the Current through*

Let n_1 be the number of + ions per c. c. at a distance x from lower plate.

Let K_1 K_2 be the velocities of the + and - ions for unit potential-gradient.

The current i_1 per sq. centim. through the gas is everywhere the same between the plates, and near the upper plate is given by

$$i_1 = K_1 n_1 e \frac{dV}{dx},$$

where e is the charge on an ion, and $\frac{dV}{dx}$ the potential-gradient.

By Poisson's equation,

$$\frac{d^2V}{dx^2} = 4\pi n_1 e.$$

We therefore have

$$i_1 = \frac{K_1}{4\pi} \cdot \frac{dV}{dx} \cdot \frac{d^2V}{dx^2}.$$

In exactly the same way it may be shown that i_2 , the current when the lower plate is negatively charged, is given by

$$i_2 = \frac{K_2}{4\pi} \cdot \frac{dV}{dx} \cdot \frac{d^2V}{dx^2}.$$

Since the potential-gradient near the upper plate is the same for both directions of the electric field,

$$\frac{dV}{dx} \quad \text{and} \quad \frac{d^2V}{dx^2}$$

are numerically the same for both currents at the same point. Therefore

$$\frac{i_1}{i_2} = \frac{K_1}{K_2},$$

or the currents are directly proportional to the velocities of the ions.

Since the current is greater when the lower plate is negatively charged, these results are in agreement with the fact, first observed by Zeleny, that the negative ion moves faster than the positive.

In the experimental case, there is always a small number of ions produced by the radio-active substance near the upper plate. For small voltages, the current near the upper plate is then not altogether carried by ions of one sign. The general effect of this is to bring the currents in the two directions more nearly to equality. When high voltages are

applied, the current must also tend to equality, since the maximum current through the gas for a P.D. sufficient to remove all the ions to the electrodes, before appreciable recombination takes place, depends only on the number of ions present and not on their velocity.

We should thus expect in the present case to obtain a maximum ratio of the currents for a certain P.D., and this ratio to diminish when the P.D. was raised or lowered.

The potential-gradient, near the radio-active surface, is much greater with the lower plate negative than positive. The reason of this is easily seen. Since the current through the gas is greater when the lower plate is negative, more positive ions have to reach the lower plate than negative ions when the lower plate is positive. The positive ions also move more slowly than the negative in the dry gas, and both causes assist in requiring a steeper potential slope to force the number of positive ions, necessary to carry the current, towards the lower plate.

Effect of Moisture and Vapours on the Ratio of the Currents.

Zeleny * has directly measured the velocity of ions produced by Röntgen-rays, and found that the ratio of the velocity of the negative to that of the positive ion for dry air is 1.375, and for moist air 1.10. Townsend †, by comparing the rates of diffusion of ions, determines the ratio of the velocity for dry air to be 1.54 and 1.09 for moist air.

If the ratio of the currents in the experimental case considered depends on the ratio of the velocities of the ions, we should thus expect to obtain wide differences between the ratios of the current when the air is dry or moist. This is fully confirmed by the experiments.

The maximum ratio of the currents observed for air which had been left over P_2O_5 for a week was 1.45. The ratio observed for air standing over water at a temperature of $18^\circ C$. was 1.12. For intermediate stages of dryness the ratio of the currents took intermediate values.

The effect of alcohol-vapour on the ratio of the currents is more marked than in the case of water-vapour.

With fairly dry air in the apparatus, the ratio observed for the currents was 1.37. On introducing alcohol through a side tube into the closed apparatus, the ratio of the current with the lower plate negative rapidly diminished, while the current in the other direction was not appreciably affected. After a certain stage, however, the currents in both directions decreased.

* Trans. Roy. Soc. 1900.

† Ibid. 1900.

The ratio observed for air saturated with alcohol-vapour at 18° C. was 1·04.

We thus see that, since the currents are proportional to the velocity of the ions, the negative ion at first moves more slowly with the addition of alcohol-vapour, while the velocity of the positive ion is unaffected. This is probably due to the condensation of alcohol round the negative ion. The final slow decrease of the currents in both directions is probably due to the disturbance of the current of ionization at various points, and alteration of the velocity of the ions in consequence of moving through air mixed with alcohol-vapour, rather than to a condensation of alcohol on both positive and negative ions.

If the air was only partially dry, the effect of alcohol-vapour was not nearly so marked. The ratio of the currents for air with some moisture present was observed to be 1·19. On addition of alcohol-vapour the ratio fell to 1·12; while if the air had been completely dried, it would have fallen to 1·04, or even less. It thus appears that if the two vapours are present, the water condenses on the negative ion more readily than alcohol.

Since alcohol has a smaller value of surface-tension than water, it was thought that possibly surface-tension determined the amount of condensation in the negative ion. For this reason the vapour of ether was tried, which has a smaller surface-tension than alcohol. Ether-vapour, however, was found to occupy an intermediate position between alcohol- and water-vapour. The reduction observed was from 1·35 for fairly dry air, to 1·23 for air saturated with ether-vapour at 18° C.

The introduction of the vapour of methyl-iodide reduced the ratio of velocities from 1·37 to 1·11.

These results can only be considered as approximate; but they serve to show in a simple manner the effect of these substances in altering the velocity of the negative ion.

It is intended to continue the investigation of the effect of vapours and other agents in affecting the velocity of the ions by this method, which is very simple and convenient.

To account for the slow velocity of the ions through the gas, I have shown that, on the principle of the kinetic theory of gases*, the ion behaved as if a cluster of molecules travelled with it. This result has been confirmed by later investigations†. It has also been suggested that the slowness of motion through the gas might not be due to the size of the ions, but possibly

* Phil. Mag. [5] xliv. p. 422.

† Townsend, Trans. Roy. Soc. 1900; Lenard, Drude, *Ann.* iii. p. 298.

to the fact that a small charged body moving through a gas would experience a greater resistance than an uncharged body of the same size. It does not seem, however, that this explanation will suffice.

On introducing water- or alcohol-vapour into the dry gas, the velocity of the negative ion decreases by gradual and not sudden stages. If the ion were molecular in size, the addition of a molecule of water-vapour would greatly alter its velocity. The slow and gradual decrease of the velocity of the negative ion with the addition of water- or alcohol-vapour, seems to point to the conclusion that the ion on which it is condensing is already large, unless it is assumed that only a fraction of the number of ions is affected by the presence of the vapour. The addition of a molecule of water-vapour to an ion of the same dimensions as a molecule would greatly lower its velocity, while it would make only a slight difference to an ion already much larger in comparison.

There seems to be considerable evidence that the ion, somewhere between the pressure of an atmosphere and about 1 millim. of mercury, alters greatly in size. I have shown that the velocity of the negative carrier produced by ultra-violet light is about the same as that of an ion produced by *x*-rays; but the results of J. J. Thomson, Lenard, and others show that it behaves at low pressures as if it were identical with the cathode-ray carrier, which is apparently much smaller than an atom.

Townsend * has also shown that the negative ion produced by Röntgen-rays at a pressure of about 1 millim. of mercury is very small compared with a molecule.

Experiments with Röntgen-Rays.

Fig. 3 (p. 222) shows the general arrangement. A thin stratum of Röntgen-rays was passed near the surface of the plate A but not touching it. The current between the vertical plates A and B was measured in the usual manner by an electrometer with suitable capacity in parallel with it. The plates C and D served as guard-plates for the plate B in order to produce a uniform electric field between A and B. In order to keep a check on the constancy of the rays, the current between two standard plates, between which the rays passed, was observed at the same time.

The following results were obtained when a strong stratum of rays passed through the fairly dry air of a Canadian winter.

* Phil. Mag. Feb. 1901.

Fig. 3.

Plates 10 centims. apart. Mean width of stratum 1 centim.

P.D. in volts.	Current.		Ratio of the Currents.
	Plate A +.	Plate A -.	
32.5	.63	.82	1.30
58	1.84	2.35	1.28
115	5.7	6.4	1.12

Further data of this experiment are given in a later calculation (pp. 226, 227).

The same general results are here observed as in the case of ionization produced by a radio-active substance. The current with the plate A negative is greater than with the plate A positive. It will also be observed that the current increases very much more rapidly than the P.D. For an increase of the voltage of 3.5 times the current with A positive increases nearly 9 times, and with the plate A negative nearly 8 times; *i. e.*, the current is more nearly proportional to the square of the P.D. than directly proportional to it. A general explanation of these results can readily be given when the movement of charged ions between the plates is considered. Imagine a thin stratum of rays producing very powerful

ionization-near the surface of the plate A. Suppose the plate A is positive and charged to a potential V , and the plate B to earth.

Let d =distance between the plates ; at all points between the parallel plates a short distance from the surface the ions are positive in sign.

Using the same notation as on p. 218, the current i_1 per sq. cm. through the gas is given by

$$i_1 = K_1 n_1 e \frac{dV}{dx},$$

where n_1 is the number of + ions per c. c. Also

$$\frac{d^2 V}{dx^2} = 4\pi n_1 e.$$

From these two equations we obtain

$$\frac{dV}{dx} \cdot \frac{d^2 V}{dx^2} = \frac{4\pi i_1}{K_1}.$$

If x is measured from the plate A,

$$\left(\frac{dV}{dx}\right)^2 = \frac{8\pi i_1 x}{K_1} + A^2,$$

where A is the value of $\left(\frac{dV}{dx}\right)$ at the surface of the plate A.

Now the value of A can be made as small as we please, by making the ionization very intense near the surface of the plate, since the potential-gradient, which will remove a sufficient number of positive ions from the ionized layer to carry the current, decreases with increase of the intensity of ionization.

Let
$$\frac{8\pi i_1}{K_1} = a.$$

Then
$$\frac{dV}{dx} = (ax + A^2)^{\frac{1}{2}}.$$

Integrating between the limits 0 and d ,

$$\begin{aligned} V &= \frac{2}{3a} [(ad + A^2)^{\frac{3}{2}} - A^3] \\ &= \frac{2}{3} a^{\frac{1}{2}} d^{\frac{3}{2}} \left[\left(1 + \frac{A^2}{ad}\right)^{\frac{3}{2}} - \left(\frac{A^2}{ad}\right)^{\frac{3}{2}} \right]. \end{aligned}$$

Since A^2 is very small compared with ad ,

$$V = \frac{2}{3} a^{\frac{1}{2}} d^{\frac{3}{2}},$$

or

$$V = \frac{2}{3} \sqrt{\frac{8\pi i_1}{K_1}} d^{\frac{3}{2}},$$

and

$$\frac{i_1}{K_1} = \frac{9V^2}{32\pi d^3}.$$

Similarly, if the plate is charged negatively and i_2 is the corresponding current,

$$\frac{i_2}{K_2} = \frac{9V^2}{32\pi d^3}.$$

Therefore

$$\frac{i_1}{i_2} = \frac{K_1}{K_2};$$

or the currents are directly proportional to the velocities of the ions.

If the condition of very intense ionization at the surface is fulfilled, so that the potential-gradient is very small near the surface, the following results must hold:—

(1) Currents in the two directions vary directly as the velocities of the ions.

(2) Current varies as the square of the P.D.

(3) Current varies inversely as the cube of the distance between the plates.

(4) There is a limiting current for a given P.D. which depends only on the distance apart of the plates and the velocity of the ions, and is independent of the ionization at the surface, provided it exceeds a certain value.

These results must hold, whether the ionization is produced by the agency of flames, glowing bodies, Röntgen-rays, ultra-violet light, or any other means of producing intense ionization near the surface of an electrode.

When this investigation had been completed and was ready for publication, a paper by C. D. Child appeared in the 'Physical Review' for March. In the paper Child fully develops this same equation in order to utilize it for the purpose of measuring the velocity of ions drawn from flame-gases.

I had also independently concluded an experimental investigation in order to verify the theory, where strong surface-ionization was produced at the surface of a plate heated by the electric current. These results, which amply confirm the theory, will be published shortly.

Child's results show clearly that, using a flame as a source

of ions near one electrode, the ratio of the velocities is equal to the ratio of the currents in the two directions, and that the current is proportional to the square of the voltage.

Explanation of the Results.

The theory given above suffices to offer a general explanation of the results given when the ionization is produced by radium or Röntgen-rays. For the thin stratum of Röntgen-rays, the current varies roughly as the square of the P.D. between the plates, and the currents vary directly as the velocities of the ions. It is probable that with 115 volts between the plates the ionization was not sufficiently intense to fulfil the condition that the potential-gradient was very small near the plate A.

In the experiments where radium-rays are used to produce ions, the ionization is not confined to a definite layer, but falls off gradually between the plates. In consequence of this the relations between current and P.D. occupy an intermediate position between the results obtained in the case of uniform symmetrical ionization and those obtained with strong surface ionization; *i. e.*, the current increases faster than the P.D., but not so fast as the square of the P.D.

With a thin layer of intense ionization confined to the surface of one plate, the value of the velocity K_1 of the positive ion is given by

$$K_1 = \frac{32\pi}{9} \cdot \frac{d^3 i_1}{V^2},$$

Since i_1 is independent of the intensity of the rays when this intensity exceeds a certain limit, it can be accurately measured, and the other quantities on the right-hand side of the equation easily determined. All that is necessary for determination of the velocity of the ion is to send a very strong beam of Röntgen-rays close to one plate, and then determine the current between parallel plates for a definite P.D. With a bulb giving out strong rays, there is no practical difficulty in producing sufficiently intense ionization near the surface of one electrode, such that with 30 volts between the plates the potential-gradient close to the electrode may be small enough to satisfy the theoretical conditions.

Practical Drawbacks of the Method, using Röntgen-Rays.

The method given above seemed at first sight a very satisfactory one for determination of the velocities of the positive and negative ions produced by Röntgen-rays in different

Phil. Mag. S. 6. Vol. 2. No. 8. Aug. 1901.

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gases and under different pressures. On studying the matter experimentally, however, an unexpected source of error disclosed itself, which renders the method inapplicable in the case of ionization by Röntgen-rays. With a very intense beam of rays, the ions produced were not confined only to the cross-section of the beam, but were produced far outside the geometrical limit of the rays. By means of suitable lead screens, with slits cut in them, care was taken that the rays did not impinge on the surface of the plate close to which they passed, so that the effect was not due to the secondary rays emitted by the metal plate.

The effect appears to be entirely due to the fact that the air through which the rays pass becomes a source of secondary radiation, which has the power of ionizing the gas in its neighbourhood. The experiments of Röntgen and others show that such an effect exists; for a fluorescent screen is lighted up outside the path of rays. The effect of these secondary rays in producing ions between the plates was readily examined by allowing the rays to pass near one plate, and then measuring the current between a metallic gauze placed outside the path of the rays, and a parallel plate placed some distance away. The experiment showed that with an intense beam of rays, the amount of ionization produced between the gauze and the plate was large enough to give an error of several hundred per cent. in the determination of the velocities, if the ionization was assumed to be confined to the surface of one plate.

This volume ionization, which is produced outside the path of the rays, causes the current for a given P.D. to be much larger than if the theoretical condition of surface ionization only was fulfilled.

It is possible that by using a bulb giving out soft rays, the effect of this secondary ionization may be greatly diminished; but in any case it will always be a very serious source of error in the method.

As an instance of the value of the velocity deduced by the application of this method, we will consider a numerical example:—

Distance between plates 10 cms.

Mean width of stratum of rays 1 cm.

The distance d lies somewhere between 9 and 10 cms.

As an approximate value we will take $d=9$ cms.

The current per square centim. was experimentally found to be $\cdot 0021$ E.S. unit per square centim. when the plate A was positive, and 32·5 volts between the plates.

Substituting in the equation

$$K_1 = \frac{32\pi}{9} \frac{d^3 i_1}{V^2};$$

and expressing V in E.S. units, we find the value of K_1 1450 cms. per sec., *i. e.* $K_1 = 4.8$ cms. per sec. for 1 volt per cm.

The value found recently by Zeleny was 1.36 for dry air.

The value obtained from the equation is thus much too high, for the reasons explained above.

Application of Results to Flames.

In the course of this paper, numerical results have been given only for the differences between currents due to reversal of electric field, for ions produced by Röntgen-rays and radioactive substances. The general explanation, however, applies equally well to production of ions by all known agencies. Whenever there is strong unsymmetrical ionization and difference between the velocity of the ions, the currents in the two directions will always be unequal.

Child's results show clearly that in the case of ions drawn from the flame into a region outside, the currents are unequal, on account of a difference in the velocity of the ions.

It seems probable that the so-called "unipolar conductivity" of flames can in many cases be explained purely on the assumption of unequal velocities of the ions. In flame-conduction, where the electrodes are unequal, we have all the conditions necessary to cause unequal currents; for the ionization produced both in the flame itself and at the surface of the electrodes is very intense, and the negative ion also moves much faster than the positive. The subject is, however, a very complicated one, and it is unlikely that the same explanation will apply for all cases.

Wilson, Marx, and others have shown that the ionization in a flame depends largely on the temperature of the electrodes, and is confined mainly to the glowing electrodes. There is always, however, a certain amount of volume ionization throughout the gas. In the case of unequal electrodes at a white heat, the inequality of the currents is probably due almost entirely to the greater velocity of the negative ion; for in this case the glowing electrodes produce a numerous supply of positive and negative ions. With electrodes at a lower temperature, however, the matter is complicated by the fact that the electrodes discharge positive and negative electricity unequally. For example, Elster and Geitel have

shown that for air at atmospheric pressure, a platinum wire at a red heat discharges positive electricity, but not negative. At a higher temperature both positive and negative electricity escape.

Within certain ranges of temperature, therefore, other causes besides unequal velocities of the ions may lead to unequal values of the current with reversal of the electric field.

Macdonald Physics Building,
McGill University, Montreal,
March 20, 1901.

XVII. *On a Model which Imitates the Behaviour of Dielectrics.*
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[Plate V.]

1. **I**T has been shown by Profs. Ayrton and Perry, and by the late Dr. J. Hopkinson and others, that the behaviour of dielectrics with regard to what are termed their "residual charge" effects is analogous to that of wires subjected to mechanical stress. If an iron wire be suspended by one end and a weight applied at the other, it is found that if the application of the weight has only lasted for a fraction of a second, the wire assumes its original length immediately the weight is taken off, provided the stress has not exceeded a certain limit. If the application of the weight is continued for a considerable time, it is found that the wire does not assume its original length immediately the load is removed; a small elongation still remains which slowly disappears, the wire very gradually decreasing in length to its original dimensions. In the case of the condenser, if the time of charge is very short, the whole of the charge disappears almost immediately on the condenser-plates being short-circuited. If, however, the charging pressure is kept on for a considerable time, we have first a discharge taking place immediately on short-circuiting the condenser; and this is followed by a slow giving-up of residual charge causing a continually decreasing current through the short-circuiting wire. The stress on the wire in the mechanical experiment is analogous to the electromotive force in the electrical experiment; the charge of the condenser corresponds to the elongation of the wire. The rate of variation of the charge, *i. e.* the charging or discharging current, is therefore analogous to the rate of change of displacement of the movable end of the wire, that is the velocity of that end of the wire.

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