

Dr. D. K. Morris, at Mason College, Birmingham, preliminary experiments having been performed in London at University College in the laboratories of Profs. Ramsay and Callendar. I have pleasure in expressing my thanks to these gentlemen, as well as to Mr. A. W. Porter, of University College, London, for friendly interest shown in my work.

IV. *On the Specific Velocities of Ions in the Discharge from Points.* By A. P. CHATTOCK, *Professor of Physics, University College, Bristol*; and WINIFRED E. WALKER, *B.Sc.*, and E. H. DIXON, *B.Sc.*, *Associates of University College, Bristol**.

IN a communication to the Philosophical Magazine for November 1899, it was shown by one of us that under suitable conditions the pressure of the electric wind furnishes a means of determining the specific velocities of the ions concerned in its production; and results obtained in the case of air were given in illustration of the method.

Subsequent experiments on other gases, while leading to values which were roughly in accord with the velocities of ions obtained by α -rays, have remained unpublished on account of the behaviour of hydrogen. The results for the negative ions in this gas were found to vary between the very wide limits 5.7 and 8.3, and in later work 4.7 and 10.0 centimetres per second in a field of one volt per centimetre.

It is true that, owing to the smallness of the wind-pressures for hydrogen, exceptionally large errors were to be expected in the readings of the pressure-gauge, and hence in the deduced velocities; but the magnitude of the observed variations was much too great to be accounted for in this way, and it seemed possible that these might be due to real changes in the specific velocities themselves.

Analysis of the results now obtained, without being absolutely conclusive, leaves little room for doubt that this view is correct.

Specific ionic velocities have been measured in the five substances, *Hydrogen*, *Carbon Dioxide*, *Air*, *Oxygen*, and *Turpentine* according to the formula

$$V = z/cp,$$

where c is the current from the point, and p the increase in the total wind-pressure corresponding with a shift of the discharging point through z along the axis of the discharge-tube (*l. c.*).

* Communicated by the Authors.

In the following tables these specific velocities ($V+$ and $V-$) are given for the positive and negative ions in centimetres per second in a field of one volt per centimetre; c being the current from the point in microamperes, n the number of values for which V is the mean, z_1, z_2 the distances in centimetres from point to ring used in the "double position" method (*l.c.* p. 413), and \bar{V} the mean of $V+$ and $V-$.

Hydrogen.

c .	n .	$V+$.	$V-$.	\bar{V} .	$V-/V+$.	z_1 .	z_2 .	
4.4	12	5.3	7.3	6.3	1.38	8.0	3.0	Tube A.
2.2	11	5.1	7.3	6.2	1.43	"	"	" "
3.2	3	5.6	8.5	7.0	1.67	Curves.		Tube B. I.
3.2	19	5.6	7.9	6.8	1.41	9.2	3.7	Tube B. II.
1.6	19	5.3	7.2	6.3	1.36	"	"	" "
0.8	19	5.2	6.8	6.0	1.31	"	"	" "
3.2	19	...	7.8	...	...	"	"	Tube B. III.
1.6	19	...	7.2	...	...	"	"	" "
3.2	7	5.4	...	...	...	Curves.		Tube B. IV.
3.2	7	...	7.6	...	...	Curves.		Tube B. V.
2.0	...	5.40	7.43	6.41	1.38...	Weighted means for Tube B only.		

Tube A in all the tables is the tube used in the original experiments on air. Its length was 34 centimetres, and its internal diameter 6.3 centimetres. Owing to the high values of the ionic velocities in hydrogen, it was necessary to use greater distances between point and ring than in other gases to obtain measurable pressures. This brought the discharge region so near the ends of the tube, that it became doubtful whether it was safe to assume that the ends were at an infinite distance from the wind. For this reason a second tube B of ebonite, 55 centimetres long and 5.6 centimetres internal diameter, was used in the later work; the decrease in diameter possessing the twofold advantage of decreasing the convection-currents in the gas and of increasing the pressures to be measured.

In the experiments with Tube A the readings were all taken under the same conditions, as the positive and negative discharges for the larger current were sandwiched both with each other and with those for the smaller current. All these values are therefore comparable. The same is true of each of the separate groups of experiments with Tube B, marked respectively I., II., III.; and the remark applies to the tables for the other gases as well as for hydrogen.

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Except in those experiments marked "curves," the "double-position" method was used.

The hydrogen in the case of Tube A was less pure than that used in Tube B. It was obtained from commercial hydrochloric acid and zinc, and was passed through strong sulphuric acid and over phosphorus pentoxide. In the other experiments the hydrochloric acid was pure, and the gas was passed through tubes of caustic potash, sulphuric acid, phosphorus pentoxide, and glass-wool, in that order. In all cases a very slow stream of gas passed through the discharge-tube during the experiments at a pressure greater than that of the atmosphere by a few centimetres of water.

The ring used in Tube A was the brass ring used before with air, cleaned and slightly vaselined on its surface. In Tube B. I. in every table a flat ring of brass, 1 millimetre thick, was embedded in the ebonite so that its inner edge was flush with the inner surface of the tube. By this device the whole pressure of the wind is measured on the pressure-gauge, but against this has to be set the disadvantage that conduction over the inner surface of the tube becomes appreciable for smaller distances between point and ring than in the other arrangement. The ring in experiments II. to V. was an exact copy in platinum of the ring used in Tube A, and was never vaselined. This also applies to all the tables.

The point was usually of fine platinum wire cut obliquely with scissors to a very sharp end, and sheathed, except a millimetre or two at the end, with glass. In a few of the experiments this was replaced by aluminium, filed sharp, but the change did not cause any certain difference in the results.

Carbon Dioxide.

<i>c.</i>	<i>n.</i>	V +.	V -.	\bar{V} .	$V - / V +.$	z_1 .	z_2 .	
1.2	15	0.76	0.86	0.81	1.13	6.0	2.0	Tube A.
1.6	11	0.82	0.94	0.88	1.15	3.4	0.4	Tube B. I.
0.7	11	0.81	0.92	0.86	1.13	"	"	" "
1.1	18	0.85	0.92	0.88	1.08	6.2	3.2	Tube B. II.
1.13	...	0.83	0.925	0.88	1.11...	Weighted means for Tube B only.		

As regards the condition and arrangement of the apparatus and the production of the gas, the same remarks apply here as in the case of the hydrogen table, except that for zinc is to be read marble and for caustic potash water. In II. also the length of phosphorus pentoxide was nearly quadrupled,

and a second tube of glass-wool was inserted between the kipp and the drying-tubes.

Air.

<i>c.</i>	<i>n.</i>	V+.	V-.	\bar{V} .	$V-/V+$.	z_1 .	z_2 .	
3.0	26	1.38	1.80	1.59	1.31	5.2	3.6	Tube A.
2.0	3	1.46	1.84	1.65	1.26	3.4	0.4	Tube B. I.
3.2	15	1.33	1.84	1.58	1.38	6.2	3.2	Tube B. II.
1.6	15	1.31	1.81	1.56	1.38	"	"	" "
0.8	15	1.31	1.74	1.52	1.33	"	"	" "
1.9	21	1.41	1.85	1.63	1.30	"	"	Tube B. III.
1.9	15	1.41	1.72	1.56	1.21	"	"	Tube B. IV.
1.9	...	1.32	1.80	1.55	1.36.....	Means of Tube B. II.		

The experiments with Tube A are in this case the ones already published. In II. the air was drawn through glass-wool, caustic potash, sulphuric acid, phosphorus pentoxide, and glass-wool, in that order. In III. some of the air was afterwards found to have been drawn in past a badly-fitting cork, so that it did not all pass through the drying-tubes; the effect of which is probably to be seen in the lower value of $V-/V+$. In IV. the air was wet, its treatment being otherwise the same as in II.

The air was not passing through the discharge-tube during the readings, but fresh air was pumped through after every two determinations of V .

Oxygen.

<i>c.</i>	<i>n.</i>	V+.	V-.	\bar{V} .	$V-/V+$.	z_1 .	z_2 .	
1.9	15	1.42	1.84	1.63	1.30	6.2	3.2	Tube B. II.
3.2	14	1.33	1.90	1.61	1.43	"	"	Tube B. III.
1.6	14	1.33	1.86	1.59	1.40	"	"	" "
0.8	14	1.25	1.78	1.51	1.42	"	"	" "
1.9	...	1.30	1.85	1.57	1.42 ...	Means of Tube B. III.		

The gas came from an ordinary oxygen cylinder over phosphorus pentoxide and through glass-wool. The platinum ring was alone used. The gas passed frequently through the discharge-tube between the experiments, as in the case of air, but was not flowing while the readings were being taken.

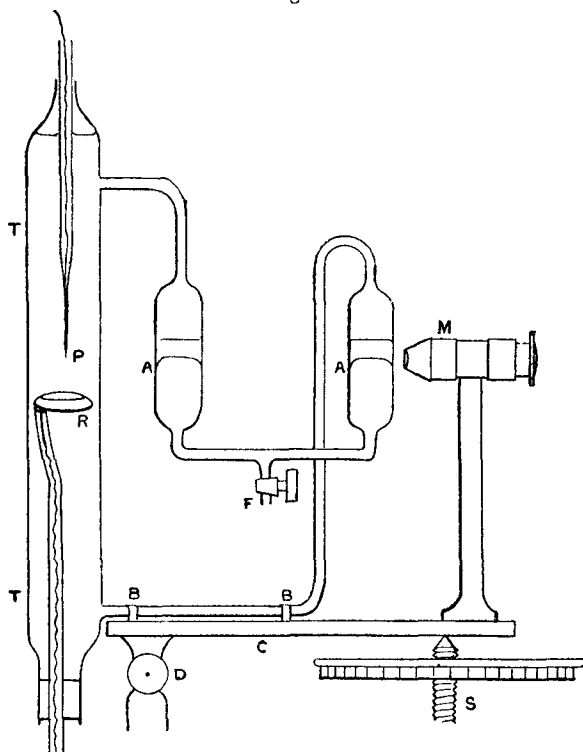
Experiments II. were made directly after a long series on hydrogen, and have been omitted from the mean on account

of the high value of $V+$. On emptying and filling the discharge-tube with oxygen, the readings changed to those of B III., and showed no further tendency to fall. It is worth noting the similarly high value of $V+$ for air in the case of B.I., as it was also obtained directly after discharging in hydrogen.

Turpentine.

It was of interest to see whether non-conducting liquids could be treated in the same way as gases, and several experiments were made with that object, mostly on turpentine. It was of course necessary to modify the apparatus to measure the discharge pressures, and after some failures the design shown in fig. 1 was adopted.

Fig. 1.



T is a glass discharge-tube of about 10 square centimetres cross-section, into the side of which are sealed the ends of the loop AAB; the lower portion of the loop being fastened to a metal slab C at BB. C is pivoted at D, and supported

at its other end by a micrometer-screw S with a large divided head. P is the discharging point and R the ring, both of them supported by glass-sheathed wires and capable of motion in a vertical direction.

The apparatus having been completely filled with turpentine, mercury was introduced at F until it stood at AA, a layer of water separating it from the turpentine in each limb; the cross wire of the microscope M was then focussed on the mercury surface in the right-hand limb. Change of level due to discharge was measured by turning S until the mercury surface again appeared on the cross wire, after which it was of course a simple matter to calculate the pressure of the discharge.

The chief difficulty met with was the tendency for ions to pass from the ring to the point, and so reduce, and in some cases even reverse, the pressure. Brass rings were very troublesome in this respect, no doubt owing to chemical action of the turpentine on the brass; for which reason platinum was adopted. Dust particles in the liquid also reduced the pressures, presumably by playing the part of secondary discharge-points; and the pressures were found to rise as the purity of the turpentine was increased.

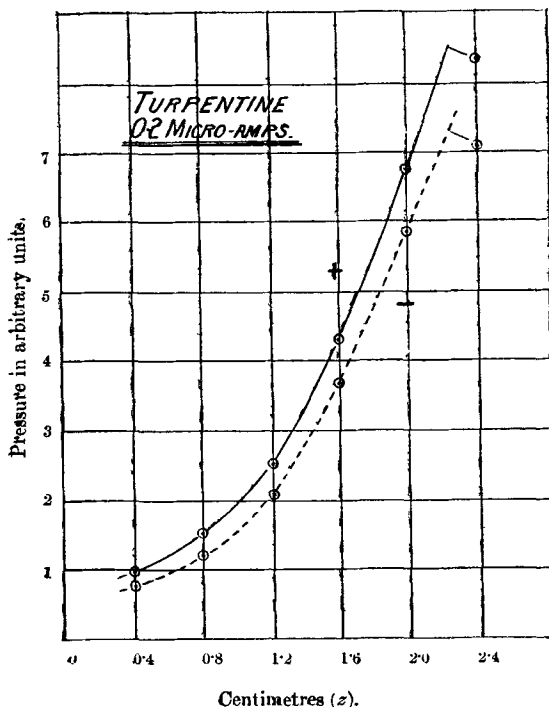
In Curves I. are plotted the pressures in arbitrary units as ordinates, observed in the purest turpentine we were able to obtain, between a platinum point and ring; the distances between these, in centimetres, being the abscissæ. The current was about 0.2 microampere, and each point is the mean of 24 observations.

The full curve is for positive discharge, the dotted for negative. Both curves show the existence of "back-discharge" from the ring, this being most marked for the negative. It will be seen that at a distance of 2 centimetres the curves have become practically straight, so that velocities should be calculated for distances above this value (see previous paper). Unfortunately, the effect of conduction along the sides of the tube then makes itself felt, the pressures at 2.4 centimetres falling below their proper values, and the curves at still greater distances tending downwards. It is thus unsafe to go beyond 2 centimetres, and we have therefore calculated \bar{V} from tangents drawn to the curves at this point. The results are thus possibly rather too high, and must be regarded as approximate only in the absence of experiments with a wider tube, which there is no immediate prospect of our being able to make. The following are the values obtained:—

$c.$	$V+.$	$V-.$	$V-/V+.$
0.2	< 0.0013	< 0.0015	1.15

Kohlrausch's value for hydrogen in the ordinary electrolysis of solutions is 0.003; our values thus lie between those for hydrogen and for many of the other metals respectively.

Curves I.



Variations in the Value of V.

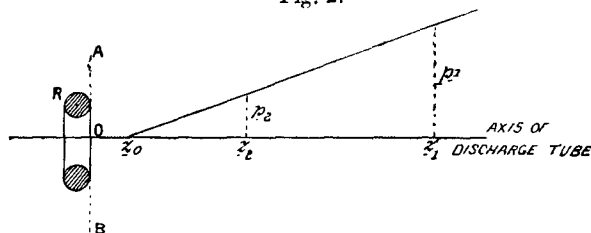
It is of course inevitable that the calculated values of V for given conditions should differ to some extent among themselves owing to errors of observation; but when, as in the case of negative discharge in hydrogen, the probable errors of observation are not sufficiently large to explain the differences observed, it becomes a question whether they may not be due to real changes in the motions of the ions.

In fig. 2, (p. 86) z_1 z_2 represent the two positions of the point in the "double-position" method, and p_1 p_2 the corresponding pressures. z is measured from O , the centre of the plane AB drawn to touch the front surface of the ring R . If z_0 is the distance of the point where the straight part of the pressure-

86 Prof. Chattock, Miss Walker, and Mr. Dixon on the curve prolonged cuts the axis of z , it is clear that

$$p_1/p_2 = (z_1 - z_0)/(z_2 - z_0).$$

Fig. 2.



Provided z_0 is constant, a real change in V will bring about an alteration in the pressures such that their ratio is still $(z_1 - z_0)/(z_2 - z_0)$; whereas if the change is apparent only the ratio will alter. It is thus possible to discriminate between the two kinds of variation of V , and for this purpose it is important to know the value of z_0 .

The table on page 87 contains the values of z_0 calculated for the various groups of experiments given above, and one or two others.

z_0 for the embedded ring is measured from the plane through its centre instead of from O.

As the brass and platinum rings are of the same size and shape, the values of z_0 obtained with them should be comparable with each other, though not with those for turpentine and the embedded ring. If we leave out of account the two latter sets, it will be seen that, apart from the negative discharge in hydrogen, the value of z_0 does not vary more than about 2 millimetres on either side of 0.06 centimetre, its mean value.

That variations in z_0 should occur with a ring which catches any of the wind-pressure is of course intelligible; for the amount caught will depend on the paths taken by the ions in approaching the ring, and these must depend to some extent on the relation between the current-density and the potential slope in that region, which will vary with the gas as well as with the sign and strength of the current. This is borne out by the way in which the discrepancies between the values of z_0 for air and for carbon dioxide almost vanish when the embedded ring is used; for there is then no reduction in the force of the wind by the ring.

In the case of hydrogen, the same argument leads to the conclusion that the large value of z_0 for negative discharge is *not* due to the stoppage of an abnormally large amount of

wind-pressure by the ring; since practically the same value is obtained with the embedded as with the other rings.

Substance.	Micro-amperes.	z_0 in centimetres.		
		+	—	
Hydrogen	3.3	0.2	0.8	A. Brass ring*.
	3.2	0.1	0.9	B. I. Embedded ring.
	3.2	0.1	1.3	B. II. Platinum ring.
	1.6	0.1	1.1	" " "
	0.8	0.0	1.1	" " "
	3.2	...	0.8	B. III. " "
	1.6	...	0.8	" " "
	3.2	0.1	...	B. IV. Curves II.
	3.2	...	1.0	B. V. " "
Carbon Dioxide ..	1.2	-0.2	0.0	A. Brass ring*.
	1.1	-0.06	-0.03	B. I. Embedded ring.
	1.1	-0.2	0.0	B. II. Platinum ring.
Air	3.0	0.3	0.1	A. Brass ring.
	2.0	0.00	0.05	B. I. Embedded ring.
	3.2	0.2	0.1	B. II. Platinum ring.
	1.6	0.1	0.0	" " "
	0.8	0.0	0.1	" " "
	1.9	0.0	0.1	B. III. Impure air.
	1.9	0.0	0.0	B. IV. Wet air.
Oxygen	1.9	0.1	0.1	B. II. Platinum ring.
	3.2	0.1	0.0	B. III. " "
	1.6	0.0	0.0	" " "
	0.8	0.2	0.0	" " "
Turpentine.....	0.2	>0.9	>0.9	Platinum ring.

The only other way of accounting for the high values of z_0 in this case is by assuming the presence in the tube of ions travelling against the wind, and therefore of similar sign to the ring.

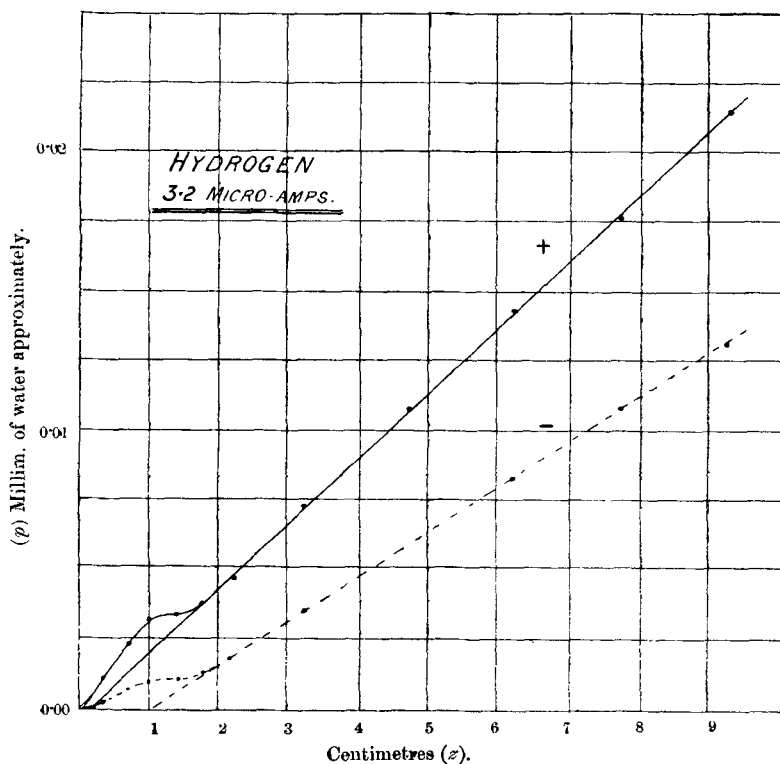
These might conceivably be liberated at the surface of the ring, or else in the gas itself by the passage through it of the ions from the point†.

* In the Hydrogen and Carbon Dioxide experiments with tube A the values of z_0 are unfortunately not known to within a constant. The constant is, however, the same for both gases; and the closeness of the agreement between the values for the brass and platinum rings in the case of CO_2 makes it probable that the constant we have assumed is about correct.

† Townsend, 'Nature,' August 9, 1900.

Now, if they are formed in the gas, the process may be expected to occur chiefly in the strong field near the point, in which case it is practically equivalent to lengthening the discharging point; that is to adding a more or less constant quantity to the values of z of from 8 to 13 millimetres. That this has not occurred seems to follow from Curves II., the

Curves II.



pressure-distance curves for hydrogen. In these each negative point is the mean of ten, and each positive of four observations. The positives (full curve) were not sandwiched with the negatives (dotted curve) as usual, in order to obtain greater constancy in the negatives. There is a bend in each curve near $z = 1.2$ centimetre, due no doubt to the shifting of the region where the current enters the ring from the front to the inner surface of the latter as the point approaches. It will be seen that these bends are vertically over one another; also that the pressure vanishes at about the same value of z

for both curves. There is thus no evidence that the negative curve has been shifted bodily along z to anything like the extent required; and this renders it very improbable that the gas is ionized in the region of the point to an appreciable distance from it.

The only alternative seems to be a back-discharge from the ring into the gas; and as this is also consistent with the shape of the curve, we shall assume that it occurs in the case of negative discharge through hydrogen.

Coming now to the fluctuations in V , it looks at first sight suspicious that it is precisely in the case in which back-discharge is high that these fluctuations are so marked; for if the ions of the back-discharge travel as far as the part of the tube in which the pressure measurements are made, changes in the amount of this discharge must give rise to apparent changes in V .

This, however, would mean that dp/dz must increase as z increases; whereas inspection of the negative curve for hydrogen shows that for points beyond $z=1.8$ centimetre the curve is straight. We may therefore conclude that in the region beyond that distance from the surface of the ring back-discharge ions are not present in any appreciable number.

Errors of observation being also insufficient to account for the apparent changes in V , the possible explanations of these thus reduce themselves to

- a. Fluctuations in the back-discharge outside the region of pressure measurements.
- b. Real changes in the value of V .

Now fluctuations in the back-discharge must affect p_1 and p_2 about equally on the average, and they will therefore produce the same sort of effect on V as the accidental errors of observation. It is true that the amount of the back-discharge may depend, for a given current, on the field at the surface of the ring; and it might be objected that, as this field is greater for p_1 than for p_2 , owing to free electricity in the tube, p_1 should be more reduced than p_2 . But if fluctuations in the amount of this free electricity are to account for changes of 50 per cent. and more in V , the free electricity itself must produce a far greater effect in increasing the apparent value of V ; from which we should have to conclude that our value of $V-$ is too high, the true value falling considerably below that of $V+$. This would be contrary to the results obtained by other observers however, and the objection thus falls to the ground.

At the same time it is quite possible that our value for $V-$

in hydrogen may be somewhat too high from this cause, and we have therefore marked it doubtful in the summary of results.

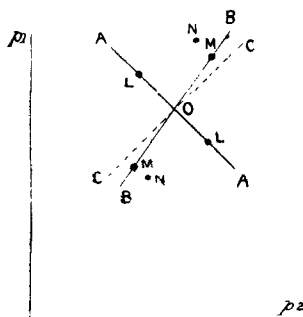
The effect of real changes in V being to alter the difference $p_1 - p_2$ without altering the ratio p_1/p_2 , while fluctuations in the back-discharge alter the two pressures independently, and on the average equally, we may apply the test of proportionality between p_1 and p_2 to distinguish between the two alternatives a and b .

Take z_1, z_2 as before for the two distances from point to ring used in the "double-position" method, and let p_1, p_2, p_1', p_2' be two pairs of pressures observed at these distances which give different calculated values of V . In case a there will be no particular connexion between these pairs of pressures; but in case b we shall have

$$p_1/p_2 = p_1'/p_2' = (z_1 - z_0)/(z_2 - z_0) = \text{constant}.$$

This may be shown graphically as in fig. 3, by plotting p_1 with p_2 and p_1' with p_2' ; the higher pressures being ordinates, the lower abscissæ. If the above equation holds, the two points thus obtained will lie on the line BB , of which the tangent of the angle with the horizontal is $(z_1 - z_0)/(z_2 - z_0)$.

Fig. 3.



In fig. 3 besides BB two other lines AA and CC are shown at right angles to each other and at 45° to the vertical. CC is obviously a line for which $p_1 - p_2$ and therefore V is constant; points falling above CC giving values of V below that for CC , and *vice versa*.

Suppose that in the case of an actual determination of V the point O represents the mean value of, say, n individual observations. If these were plotted separately in the figure they would lie symmetrically within a circle centred at O for case a ; but for case b they would all lie on BB .

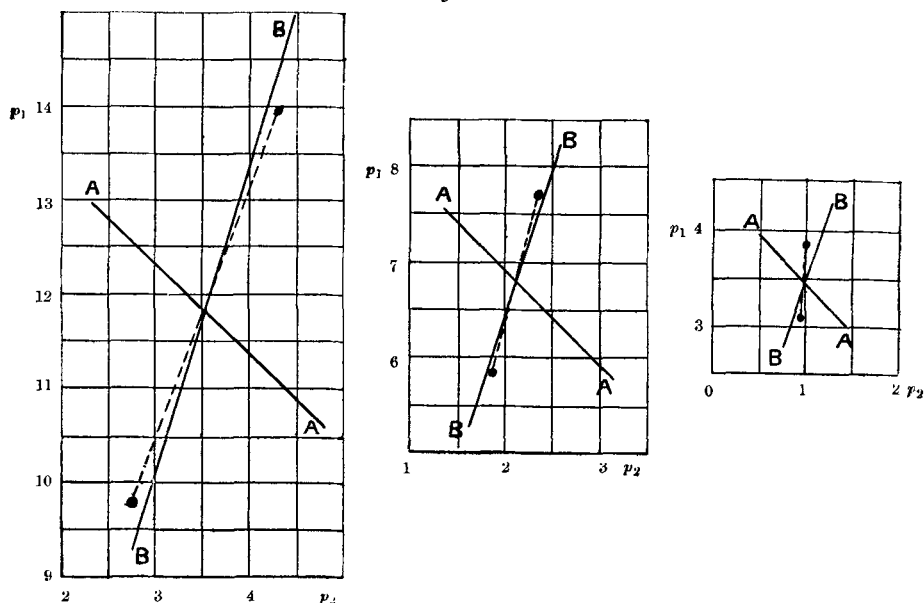
Arrange the n values of V with their corresponding pres-

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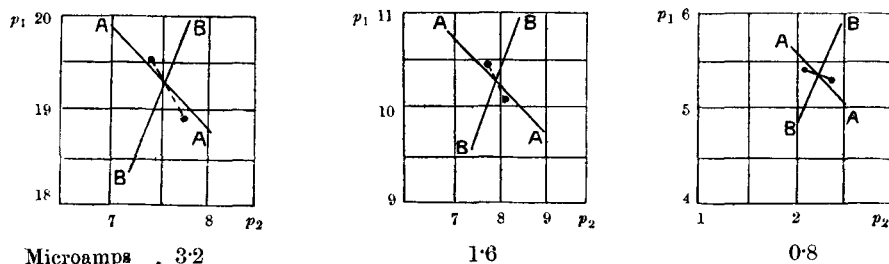
asures in columns according to the descending order of V ; divide each column into two at its centre; take the means of the pressures in the upper and lower halves of each column respectively; and plot the two pairs of corresponding pressures thus obtained. In case *a* these points will fall on AA, say at LL; in case *b* they will fall on BB at MM; and in the latter case,

Fig. 4.—HYDROGEN. $n=19$. B. II.

Negative.



Positive.



Microamps . 3.2

1.6

0.8

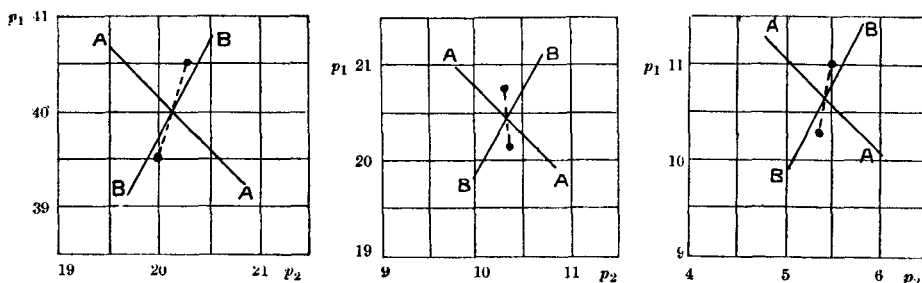
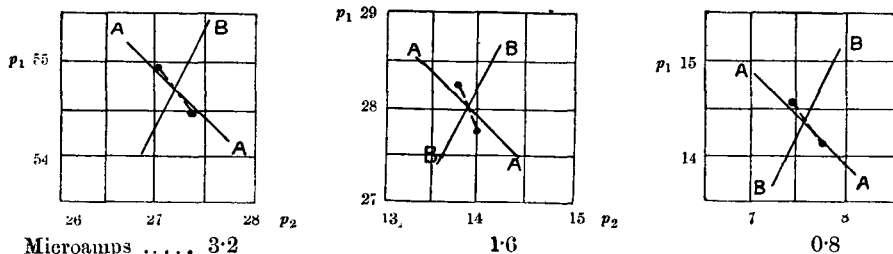
as there cannot fail to be errors of purely accidental character also present, we should expect the points to show a trace of the "*a*" effect by falling somewhat off BB as at NN.

In fig. 4 are given the results of the application of this test

to the hydrogen pressures for tube B. II., the pressures being expressed approximately in thousandths of a millimetre of water. As explained above, observations belonging to separately labelled groups were sandwiched together when made, and the results for the different strengths and signs of discharge are therefore comparable. AA and BB have the same meanings as in fig. 3. The dotted line joins the two points N, N.

The fundamental difference between the positive and negative discharges is very apparent. In the former the dotted line is short and roughly coincides with AA; in the latter it is longer, and the coincidence is with BB.

We conclude, therefore, that while the small variations in $V+$ are due to errors of observation and chance alterations in the condition of the hydrogen, the much larger ones in the case of the negative discharge correspond with real changes in $V-$.

Fig. 5.—AIR. $n=15$. B. II.*Negative.**Positive.*

In figs. 5, 6, 7, and 8 are given the results of similar tests applied, where possible, to the pressures for air, oxygen, and carbon dioxide; as well as a second set, taken by itself, for the negative discharge in hydrogen. The latter is closely in accord with the set in fig. 4, though the variations are not so

Fig. 6.—OXYGEN. $n=14$. B. III.

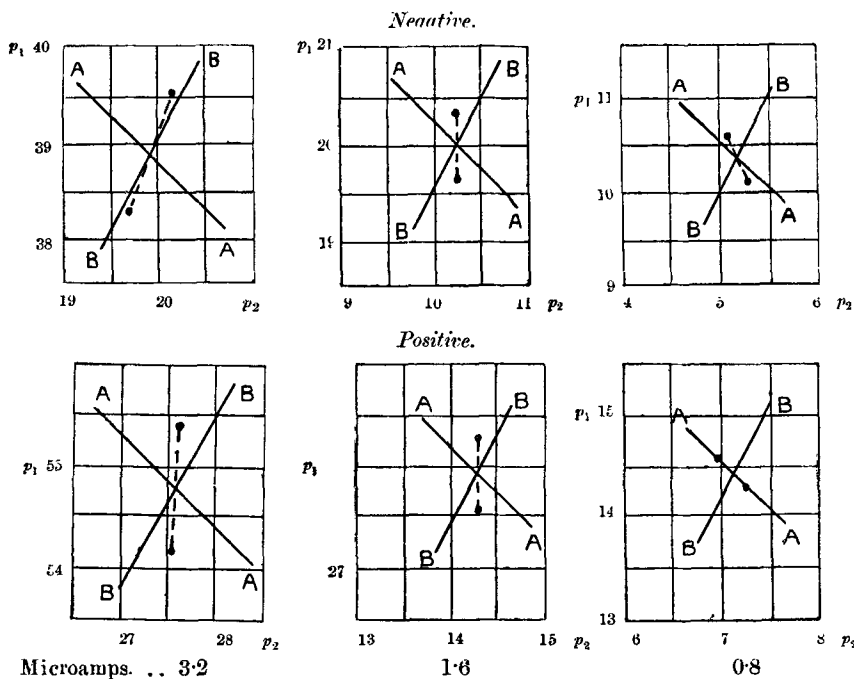
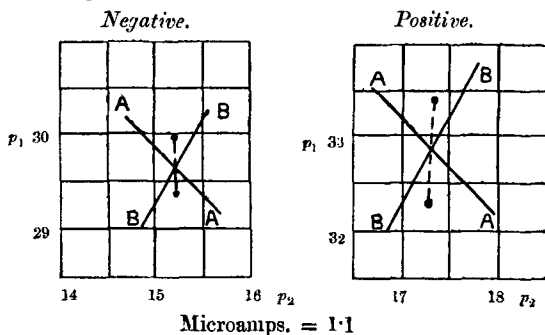
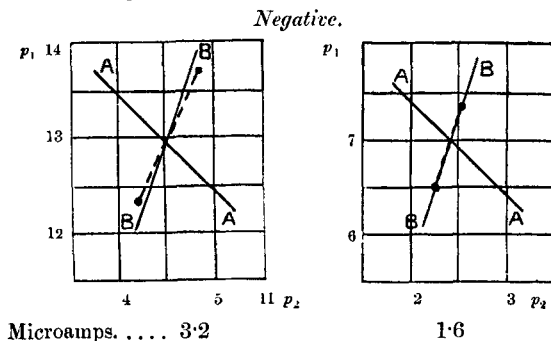


Fig. 7.—CARBON DIOXIDE. $n=18$. B. II.



large; perhaps because no positive discharges were taken with the negatives. $V-$ in air and oxygen shows the same tendency to vary more than $V+$, though it is not nearly so marked. $V+$, on the other hand, varies more than in hydrogen; but this may be due to the formation of ozone. In carbon dioxide the effect seems to be absent.

As the current is reduced the effect of accidental errors should become increasingly important, the dotted line tending towards AA. This is well shown in the figures. In the case of the highest negative discharges in hydrogen the dotted line

Fig. 8.—HYDROGEN. $n=19$. B. III.

has actually crossed BB, which is not in accordance with theory. If this is due to more than an accident, it may be explained by supposing that the more rapidly moving ions give rise to greater back-discharge than the slower ones, which seems reasonable enough.

If the conclusions arrived at above are to be accepted, we have, in considering the case of hydrogen, to reconcile variations of something like 100 per cent. between the extreme values of $V-$ with practical constancy in the value of $V+$. The only obvious changes in the conditions of discharge were those of temperature, pressure, and purity of the gas, which must have been extremely small in our experiments; and it seems hardly possible that they should be responsible for such large effects.

A solution of the difficulty is perhaps to be found in the fact that the negative discharge from a point is apparently much more closely dependent upon the condition of the point surface than the positive.

It is an instance of this that a needle-point which when discharging positive electricity is covered with a smooth velvety glow, often discharges negative from a single spot on its surface, the position of which will move irregularly and suddenly in a manner suggestive of local surface changes.

The frequent and large fluctuations in the strength of the field close to a point discharging negative electricity—changes

which do not occur with positive discharge—furnish another instance*.

So also does the gradual and permanent increase in the strength of this field when the point is discharged from for long periods; an increase which is not shared by the field for positive discharge from the same point*.

If, then, we may assume that the starting-place of the positive discharge is in the gas surrounding the point, while that of the negative is at or just below the surface of the metal, it may quite well happen that while the positive ions are all formed of hydrogen, some of the negative ions consist of gases other than hydrogen occluded in or condensed on the point, which, by occurring in greater or less numbers, give rise to the fluctuations observed in V . Our value of $V-$ for hydrogen may thus be too low.

Summary of Results.

In the following table are collected the most reliable of our values for V ; the results of Rutherford† and of Townsend‡ being added for comparison. Numbers in square brackets are for wet gases. The velocities are in centimetres per second in a field of 1 volt per centimetre. The value of $V-$ for hydrogen may be too high or too low for one or other of the reasons already given.

Substance.	\bar{V} .			$V-/V+$.	
	Rutherford.	Townsend.	Point-Discharge.	Townsend.	Point-Discharge.
Hydrogen	5.20	6.60 [5.40]	6.41	1.54 [1.11]	1.38
Carbon Dioxide...	1.07	0.98 [1.00]	0.88	1.13 [1.04]	1.11
Air	1.60	1.39 [1.34]	1.55 [1.56]	1.54 [1.09]	1.36 [1.21]
Oxygen	1.40	1.29 [1.29]	1.57	1.58 [1.24]	1.42
Turpentine .....	.....	.....	<0.0014	.....	1.15

Apropos of the fact that our values of $V-/V+$ lie between those for dry and wet gases, we may mention that in the cases of air and carbon dioxide we quadrupled the length of P_2O_5 -tubes, with the only result that the ratio fell a trifle lower.

* Chattock, *Phil. Mag.* Sept. 1891, p. 295.

† Rutherford, *Phil. Mag.* Nov. 1897.

‡ Townsend, *Phil. Trans.* vol. 193, 1899.

Our conclusions may be summed up as follows:—

1. The values of V for point-discharge in gases are in approximate agreement with those obtained for the same gases when ionized by x -rays.
2. In non-conducting liquids V appears to be of the same order of magnitude as in ordinary electrolytes.
3. In hydrogen for negative discharge only, and probably in turpentine for both kinds of discharge, a considerable "back-discharge" of ions seems to occur from a brass or platinum ring towards the point.
4. The amount by which this back-discharge lowers the wind-pressures in the case of hydrogen is closely proportional to the strength of the current from the point. This is proved by the constancy of z_0 in each group of observations.
5. Negative ions in constant fields travel at very varying rates in hydrogen; the same being true of oxygen and air, but to a much less extent. These variations are real, and not attributable to errors of observation or other accidents. Positive ions are not similarly affected to anything like the same extent, if at all.
6. To account for this it is suggested that a certain number of the negative ions may owe their origin to occluded gases in the point; that this number may be variable owing to changes in the accessibility of the occluded gases and other causes; and that the specific velocity of the positive ions may be constant owing to their being formed exclusively of the gas outside the point.

In conclusion we wish to express our thanks to Mr. H. Strachan for much assistance in the work of taking the readings.

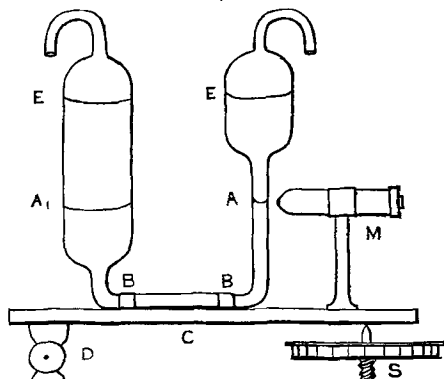
Note on a Sensitive Pressure-Gauge.

As will be seen from the magnitudes of the wind-pressures we have measured and the smoothness of the curves obtained, our gauge was sensitive enough to indicate pressures of a few ten-thousandths of a millimetre of water. As it presents features which we believe to be new, it may be of interest to describe it.

It was necessary to use a well-known combination of oil and water to obtain the requisite sensitiveness. In fig. 9 E B B E is a glass U-tube, about 4 centim. in diameter at the wide parts and 1 centim. diameter at A. From centre to centre of the limbs is about 13 centim., and from D to S about 25 centim. The lower part of the tube is filled with

water to A A₁, and then to E E with oil of specific gravity 0·88. The other letters in the figure have the same meanings as in fig. 1.

Fig. 9.



As far as sensitiveness is concerned, the level of A responds to differences of pressure applied to the upper ends of the U as readily as though the gauge were filled with a single liquid of density equal to the difference between the densities of the water and the oil; but if the pressure is measured by the displacement of A in the tube temperature troubles are introduced which are serious in proportion to the sensitiveness, owing to the unequal expansions of water and oil. In addition to this there is the danger that, when the pressure measured is small, an appreciable part of this pressure may be used in distorting the oil-water surface, and thus fail to be observed.

Both these sources of error may be avoided by the device, already alluded to, of keeping the level of A always in the same position in the tube by screwing S up or down, and so tilting the whole gauge.

If A is not allowed to move far from its zero position, which will be the case if the pressures are small, the shape of the oil-water surface will be constant when brought back to the cross-wire, and the surface-tension error will therefore vanish. On the other hand, constancy in the position of A implies constancy in the heights of the oil columns A E, with the consequence that pressure-differences, p , between the limbs of the U are measured by a column of water only, of height equal to the change in the difference of level between A₁ and A introduced by the tilt, according to the formula

$$p = nax/y,$$

where n is the amount by which S is moved, reckoned in

screw-turns, x the pitch of the screw, z the distance from A_1 to A between the centres of the tubes (the latter being supposed circular), y the distance from D to S , and p is expressed as a column of water. The effect of temperature on the calculated values of the measured pressures is thus no more than it would be for a gauge containing water only.

As is probably inevitable, a slow drift occurs in the level of A due to temperature-changes in the room. It is regular, and therefore easily eliminated by timing the observations and alternating zero- with pressure-readings. It has the advantage, moreover, that it prevents all the measurements being made near one position of the screw.

When the surface of A is clean and illuminated with convergent light, it is just possible to estimate a change of pressure of two ten-thousandths of a millimetre of water with our gauge; but the surface must be very clean for this and the light faint.

V. *On Balfour Stewart's Theory of the Connexion between Radiation and Absorption.* By LORD RAYLEIGH, F.R.S.*

ON a recent occasion† I remarked that Stewart's work appeared to me to be insufficiently recognized upon the Continent. One reason for this is probably the comparative inaccessibility of the Edinburgh Transactions in which his first paper appeared‡. Another may be found in the fact that the paper itself is not well arranged, and that the principal conclusion is put forward in the first instance as if it were the result of Stewart's special experiments. The experiments were indeed of great value; but this course gave an opening to Kirchhoff's objection that "this proof [of the law that *the absorption of a plate equals its radiation and that for every description of heat* §] cannot be a *strict* one, because experiments which have only taught us concerning *more* and *less*, cannot strictly teach us concerning *equality*" ||. I am inclined to think that Stewart would have received more recognition if he had never experimented at all!

While yielding to no one in admiration for Kirchhoff, I can hardly regard him as in this matter an impartial critic.

* Communicated by the Author.

† Phil. Mag. S. 5, vol. 1. p. 539 (1900).

‡ Edin. Trans. vol. xxii. p. 1, March 1858.

§ The italics are Stewart's.

|| Kirchhoff, On the History of Spectrum Analysis, &c., Phil. Mag. vol. xxv. p. 258 (1863).