PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Electrification of Air, of Vapour of Water, and of Other Gases

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VI. *Electrification of Air, of Vapour of Water, and of Other Gases.*

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§ 1. In this paper we describe a long series of experiments on the electrification of air and other gases, with which we have been occupied from May, 1894, up to the present time (June, 1897). Some results of our earlier experiments, and of preliminary efforts to find convenient methods of investigation, have from time to time been communicated to the Royal Society, the British Association, and the Glasgow Philosophical Society.*

§ 2. The method for testing the electrification of air, which we used in our earliest experiments, was an application of the water-dropper† (long well-known in the ordinary observation of atmospheric electricity). Its use by Maclean and Goto,‡ in 1890, led to an interesting discovery that air in an enclosed vessel, previously non-electrified, becomes electrified by a jet of water falling through it. An investigation of properties of matter concerned in this effect, related as it is to the "development of electricity in the breaking up of a liquid into drops," which had been discovered by Holmgren § as early as 1873, and to the later investigations and discoveries

* "On the Electrification of Air," 'Proc. Roy. Soc.,' May 31, 1894, and 'Phil. Mag.,' August, 1894. "Preliminary Experiments to find if Subtraction of Water from Air Electrifies It," 'Brit. Assoc. Report,' 1894, p. 554. "Electrification of Air and other Gases by Bubbling through Water and other Liquids," 'Proc. Roy. Soc.,' February, 1895. "On the Diselectrification of Air," 'Proc. Roy. Soc.,' March, 1895. "On the Electrification of Air," 'Proc. Glasgow Phil. Soc.,' March, 1895. "On the Electrification and Diselectrification of Air and other Gases," 'Brit. Assoc. Report,' 1895, p. 630.

† Kelvin and Maclean, 'Proc. Roy. Soc.,' 1894, and Kelvin, Maclean, and Galt, 'Proc. Roy. Soc.,' February, 1895. "Electrostatics and Magnetism," § 262 (from 'Proc. Lit. and Phil. Soc. of Manchester,' October 18, 1859).

‡ "Electrification of Air by Water-jet." By Magnus Maclean and Makita Goto, 'Phil. Mag.,' August, 1890.

§ "Sur le développement de l'électricité à l'occasion de la dissolution en gouttes des liquides." 'Kongl. Svensk. Vet. Ak. Handl.,' 1 c., vol. 11, No. 8, pp. 14–43 (pour l'an 1873).

described by LENARD,* in his paper on the "Electricity of Waterfalls," forms the subject of §§ 25–37 of the present communication.

§ 3. The electrification of air by drops of water, breaking from a jet in it, or falling through it, or striking on the ground, or on water, or on metal below it, produces absolutely no practical disturbance of the electric potential measured by the water-dropper in its use for the observation of open-air atmospheric electricity, but constitutes a serious objection to its application for investigating atmospheric electricity within doors, unless in a very large room or hall, and renders it altogether unsuitable for the experimental investigations with which we are now concerned.

§ 4. We were, therefore, early led to abandon it; and, for testing the electrification of air, we have used three different methods, one or other of which we have found convenient in different cases.

Method (1). Observation of electrification of the substance receiving the electricity equal and opposite to that taken by air in any case of electrification of air.

Method (2). Observation of the electricity of a hollow metal vessel into which electrified air is introduced, or from which electrified air is removed.

Method (3). Observation of the electricity taken out of air by the electric filter (§ 9).

§ 5. Method (1) was used in the experiments described in our communication to the Royal Society of February, 1895, from which we concluded that air, and several other gases tried, became electrified by blowing them in bubbles through water, and through solutions of various salts, acids, and alkalies in water. We verified this conclusion, for the case of common air and pure water, by collecting into a large reservoir over water, air which had been bubbled through pure water in a U-tube. We tested the electrification of the air thus collected by a water-dropper taking the same potential as the air at the centre of the reservoir. We thus proved that the electrification of the air was negative, as was to be expected from the positive electrification which we had found on insulated vessels containing water through which air had been bubbled.

§ 6. Method (2) was used in the first experiments described in the present paper (§§ 16–24), which were undertaken for the purpose of determining approximately in absolute measure the total quantity of electricity in a given mass of electrified air, and particularly for finding the greatest electrification which we could communicate to a large quantity of air by needle points supplied with electricity from an electric machine. The result thus found in § 23 below, $3 \cdot 7 \times 10^{-4}$ C.G.S. electrostatic, is the greatest electric density (quantity of electricity per cubic centim.) which we have been able to communicate to air by electrified needle points. But, by an electrified hydrogen flame a density of 22×10^{-4} C.G.S. electrostatic unit was obtained (§ 65).

§ 7. In all the experiments described in our paper after § 24, method (3) was used; but, probably, we must return to method (2) if, in future, we undertake

* "Ueber die Electricitat der Wasserfälle." By P. LENARD, 'Annalen der Physik und Chemie,' 1892.

further experiments to find the greatest electric density which we can measure in air or other gases.

§ 8. LENARD's important discovery of very strong electric effects produced by drops of water falling on a hard surface, gave us a very convenient method for obtaining a steady and strong negative electrification of air, which we used in §§ 30–32 for preliminary efforts for finding a good and convenient form of electric filter to be used in further investigations on the electrification and diselectrification of air.

§ 9. In testing the efficiencies of the electric filters used in method (3), we at first used the filter described in our paper on "Diselectrification of Air," 'Proc. Roy. Soc.,' vol. 57, and which consisted of twelve discs of brass wire cloth, fixed in a short metal pipe, supported in a paraffin tunnel. This filter was joined to the insulated quadrants of a quadrant electrometer, and electrified air was sucked through it (§ 25) till a convenient deflection was obtained. Then the filter to be tested was connected to the sheath of the electrometer, and so placed that the electrified air passed through the tested filter before it passed through the filter attached to the electrometer (§ 68). In this way, by drawing equal quantities of electrified air, as nearly as may be equally electrified, through the different tested filters, a comparison of their relative diselectrifying powers was obtained. For example, d being the deflection obtained when no tested filter was used, and $d_1, d_2 \ldots d_n$ when the tested filters were successively used, then the relative diselectrifying powers of the filters would be $\frac{d - d_1}{d}, \frac{d - d_2}{d}, \ldots \frac{d - d_n}{d}$, if the primary electrifications were equal.

§ 10. In other sets of experiments (§§ 32, 69) we successively joined each separate tested filter to the insulated quadrants of the electrometer, and sucked approximately equal quantities of electrified air through them. The diselectrifying efficiencies of the filters were now approximately in simple proportion to the final readings on the electrometer.

§ 11. But none of these methods gave us a means of determining the absolute diselectrifying power of any filter without realizing an equality of primary electrification of the air in different experiments. We therefore, a long time later, used two insulated filters and two electrometers, as described in § 55 and fig. 7. Let the filters be called AB and A′B′ and their diselectrifying powers n and n'. In a first experiment the electrified air was sucked through AB and A′B′ in immediate succession, and in a second experiment the electrified air was sucked through A′B′ and AB.

§ 12. On the assumption that the two filters took out the same proportions (respectively n or n') of the electricity of the electrified air entering them in the two experiments, we get the following equations:

In the first experiment

Let Q = total quantity of electricity in air entering,

q_1 = total quantity of electricity taken out by filter AB,

q_2 = total quantity of electricity taken out by filter A′B′.

Then

$$q_1 = nQ \quad \ldots \quad (1),$$

$$q_2 = n'(Q - q_1) = n'Q(1 - n) \quad \ldots \quad (2).$$

In the second experiment

Let Q' = total quantity of electricity in air entering,
q_1' = total quantity of electricity taken out by A′B′,
q_2' = total quantity of electricity taken out by AB.

Then

$$q_1' = n'Q' \quad \ldots \quad (3),$$

$$q_2' = n(Q' - q_1') = nQ'(1 - n') \quad \ldots \quad (4).$$

From these four equations we find

$$n = \frac{q_1 q_1' - q_2 q_2'}{q_1'(q_1 + q_2)}; \qquad n' = \frac{q_1 q_1' - q_2 q_2'}{q_1(q_1' + q_2')}.$$

§ 13. By taking a movable plate of a small air-condenser charged to a known potential, and applying it to the insulated terminal of the quadrant electrometers used as described in § 18, we could calculate q_1, q_2, q_1', and q_2', and hence find Q and Q′, the absolute density of the electrified air or gases in C.G.S. electrostatic units. It was thus that we found 11×10^{-4} and 22×10^{-4} mentioned in §§ 64, 65.

§ 14. Up till the middle of December of 1895 the most efficient filter we tried had a diselectrifying power of about 0·8. During the Christmas holidays of 1895, we succeeded in obtaining a filter of fine brass filings, as described in § 62, which abstracted so much of the electricity from the electrified air passing through it, that what was left was not sufficient to show on a similar filter, A′B′, attached to an electrometer, E′ (see fig. 7). It was not necessary now to have two experiments, first with electrified air in one direction through two filters to be tested, and then with electrified air in the reverse direction through them. It was sufficient to take a filter, the diselectrifying power of which, determined as above (§ 12), is found to be very nearly unity, and attach it to electrometer E′. Then join the tested filter to another electrometer, E, and allow the electrified air to pass this filter first, and thence through the almost perfectly diselectrifying filter.

With the same notation as in § 12, we get

$$Q = \frac{n'q_1 + q_2}{n'},$$

and

$$n = \frac{n'q_1}{n'q_1 + q_2} = \frac{1}{1 + \frac{1}{n'}\frac{q_2}{q_1}}.$$

If n' = unity, as it is for a filter of fine brass filings (§ 62),

$$Q = q_1 + q_2, \quad \text{and} \quad n = q_1/(q_1 + q_2).$$

§ 15. With such a filter as this it is possible to determine the quality of the natural electricity of the atmosphere, and it may be desirable that it should be used for that purpose in meteorological observatories.

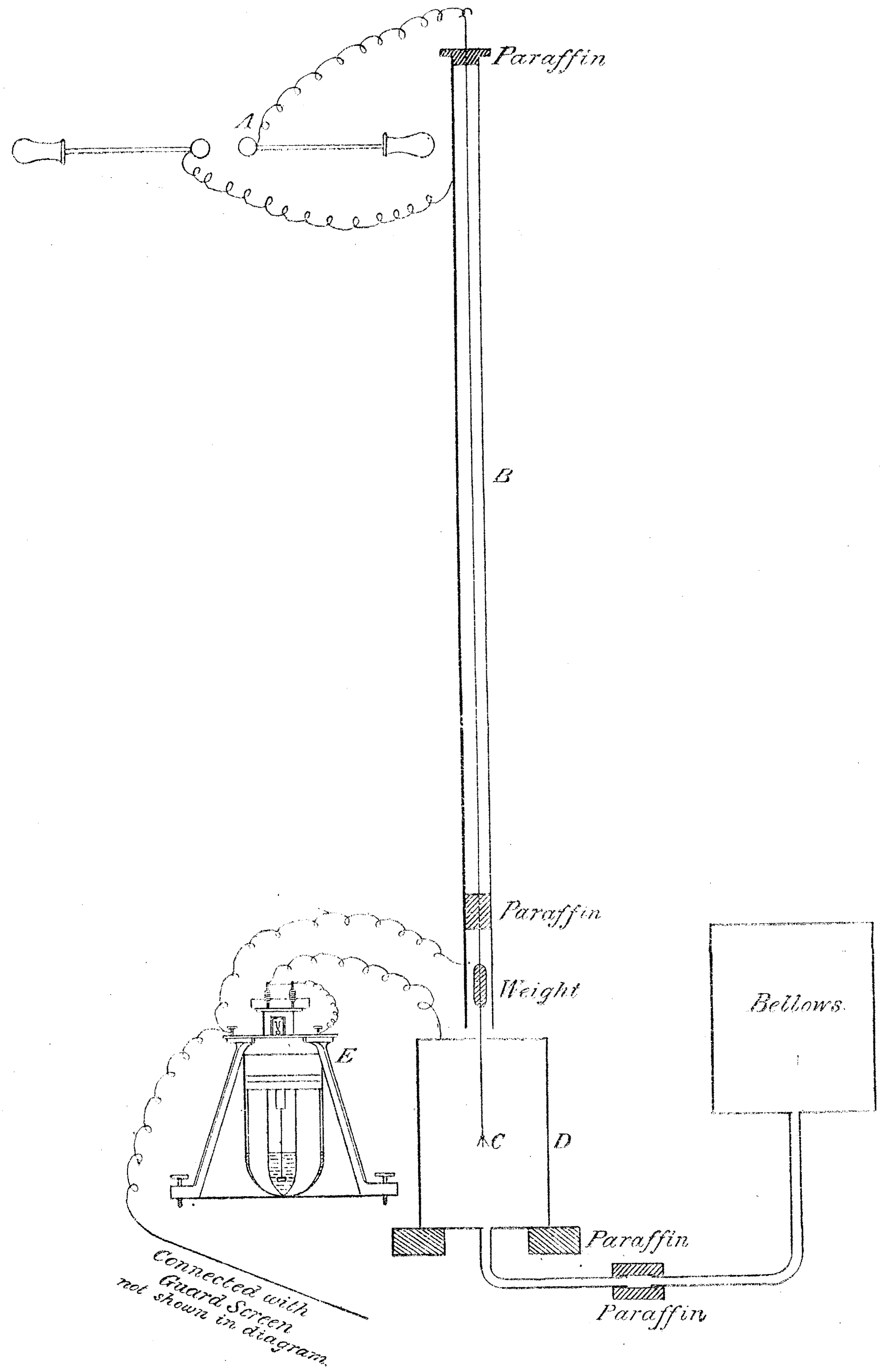
Greatest Electrification which we could communicate to a large quantity of Air by one or more Electrified Needle Points (§§ 16–24).

§ 16. The first apparatus used is shown in fig. 1. It consisted of a metal can, D, 48 centims. high and 21 centims. in diameter, supported by paraffin blocks, and connected to one pair of quadrants of a quadrant electrometer. It had a hole at the top to admit the electrifying wire, which was 531 centims. long, hanging vertically within a metallic guard-tube, B. This guard-tube was always metallically connected to the other pair of quadrants of the electrometer, and to its sheath and to a metallic screen surrounding it, which is not shown in the diagram. This prevented any external influences from sensibly affecting the electrometer, such as the working of the electric machine, A, which stood on a shelf five metres above it.

§ 17. The experiment is conducted as follows :—One terminal of the electric machine is connected with the guard-tube and the other with the electrifying wire, which is tipped with needle points or tinsel, and which is let down to place the point or points nearly in the centre of the can. The can is temporarily connected to the sheath of the electrometer. The electric machine is then worked for some minutes, so as to electrify the air in the can. As soon as the machine is stopped, the electrifying wire is lifted clear out of the can. The can and the quadrants in metallic connection with it are disconnected from the sheath of the electrometer, and the electrified air is very rapidly drawn away from the can by a blowpipe bellows, arranged to suck. This releases the opposite kind of electricity from the inside of the can, and allows it to place itself in equilibrium on the outside of the can and on the insulated quadrants of the electrometer in metallic connection with it.

§ 18. We tried different lengths of time of electrification and different numbers of needles and tinsel, but we found that one needle and four minutes' electrification gave as great electrification as we could get. The greatest deflection observed was 936 scale divisions on a half millim. scale put up in the usual way, with lamp at a distance of about a metre from the electrometer. To find from this reading the electric density of the air in the can, we took a metallic disc of 2 centims. radius, attached to a long varnished glass rod and placed at a distance of 1·45 centims. from another and larger metallic disc. This small air condenser was charged from the electric light conductors in the laboratory to a difference of potential amounting to 100 volts, or $\frac{1}{3}$ of an electrostatic unit. The insulated disc thus charged was removed and laid upon the roof of the large insulated can. This addition to the metal in connection with it does not sensibly influence its electrostatic capacity.

Fig. 1.



The deflection obtained was 122 scale divisions. The capacity of the condenser is approximately—

$$\frac{\pi \times 2^2}{4\pi \times 1{\cdot}45} = \frac{1}{1{\cdot}45} \text{ C.G.S. electrostatic unit.}$$

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The quantity of electricity with which it was charged was therefore

$$\frac{1}{1{\cdot}45} \times \tfrac{1}{3} = \frac{1}{4{\cdot}35} \text{ C.G.S. electrostatic unit.}$$

Hence, the quantity on the can and connected metal to give 936 scale divisions was

$$\frac{1}{4{\cdot}35} \times \frac{936}{122} = 1{\cdot}7637 \text{ C.G.S. electrostatic units.}$$

The capacity of the can was 16,632 cub. centims., which gives, for the quantity of electricity per cub. centim.

$$\frac{1{\cdot}7637}{16632} = 1{\cdot}06 \times 10^{-4} \text{ of the C.G.S. electrostatic unit.}$$

§ 19. This is about four times the electric density which we roughly estimated as about the greatest given to the air in the inside of a large vat, electrified by a needle point and then left to itself, and tested by the potential of a water-dropper with its nozzle in the centre of the vat, in experiments made more than three years ago and described in a communication to the Royal Society of date May, 1894.*

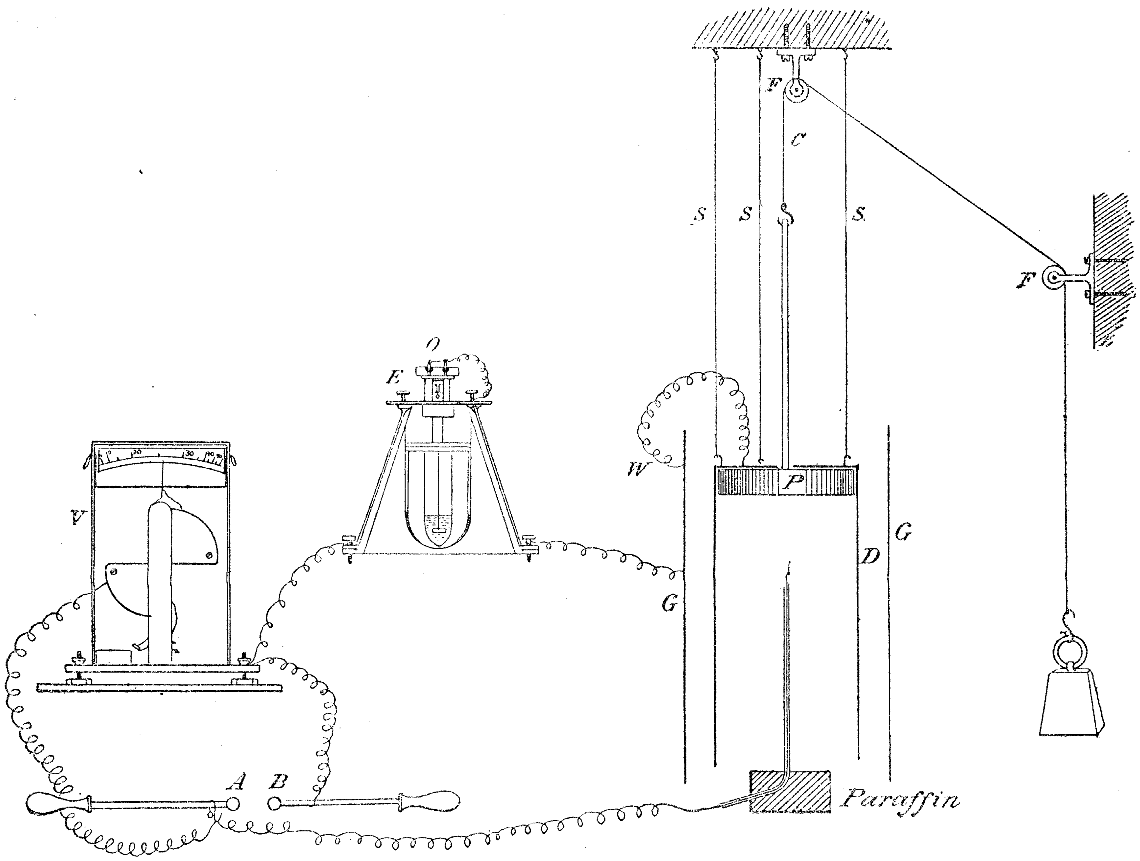
§ 20. To enable us to remove the electrified air quickly from the can, the following modification was adopted:—The can was suspended vertically by three stout silk threads (S, S, S, fig. 2) which had been previously soaked in melted paraffin; it was quite open at the bottom but closed at the top, with the exception of a central aperture for the piston-rod of a piston, P. The piston was of wood encased in lead, and was free to move up and down in the can by the movement of the paraffined silk cord, C, over the pulleys, F, F. The can and the piston and piston-rod were connected metallically by spiral springs of fine wire. The can was surrounded by a metallic guard-screen, G, kept in connection with the sheath of the quadrant electrometer, and with the sheath of a vertical electrostatic voltmeter, and with one terminal, B, of an electric machine. The other terminal of the machine was connected to an insulated needle-point inside the can and to the insulated terminal of the voltmeter.

§ 21. By working the machine the needle was kept charged positively or negatively at 12,000 volts for four minutes. The air inside the can became charged similarly by the brush discharge from the needle point. As soon as possible after stopping the machine, the needle was removed and A and B were joined. The wire, W, from the can was disconnected from the guard screen, G, and then attached to the electrometer terminal, O, after which this terminal was insulated and the downward

* "On the Electrification of Air," by Lord KELVIN and MAGNUS MACLEAN.

movement of the piston begun. Usually about thirteen seconds were required to make these changes.

Fig. 2.



§ 22. When the electrified air inside the can was expelled by dropping the piston to the bottom, the reading of the electrometer went off the scale, and a shorter drop had to be used to get a convenient deflection.

§ 23. A drop of 11·5 centims., by which 3979 cub. centims. of air were expelled, gave a deflection of 1060 scale divisions. The quantity of electricity on the can and connecting wire and insulated pair of quadrants of the electrometer which gives this deflection, was (by the method of § 18) found to be 1·47 C.G.S. electrostatic. This, therefore, was the quantity of electricity of the opposite kind in the 3979 cub. centims. of air expelled from the open bottom of the can; and the electric density of this air was therefore $3{\cdot}7 \times 10^{-4}$ C.G.S. electrostatic per cubic centimetre.

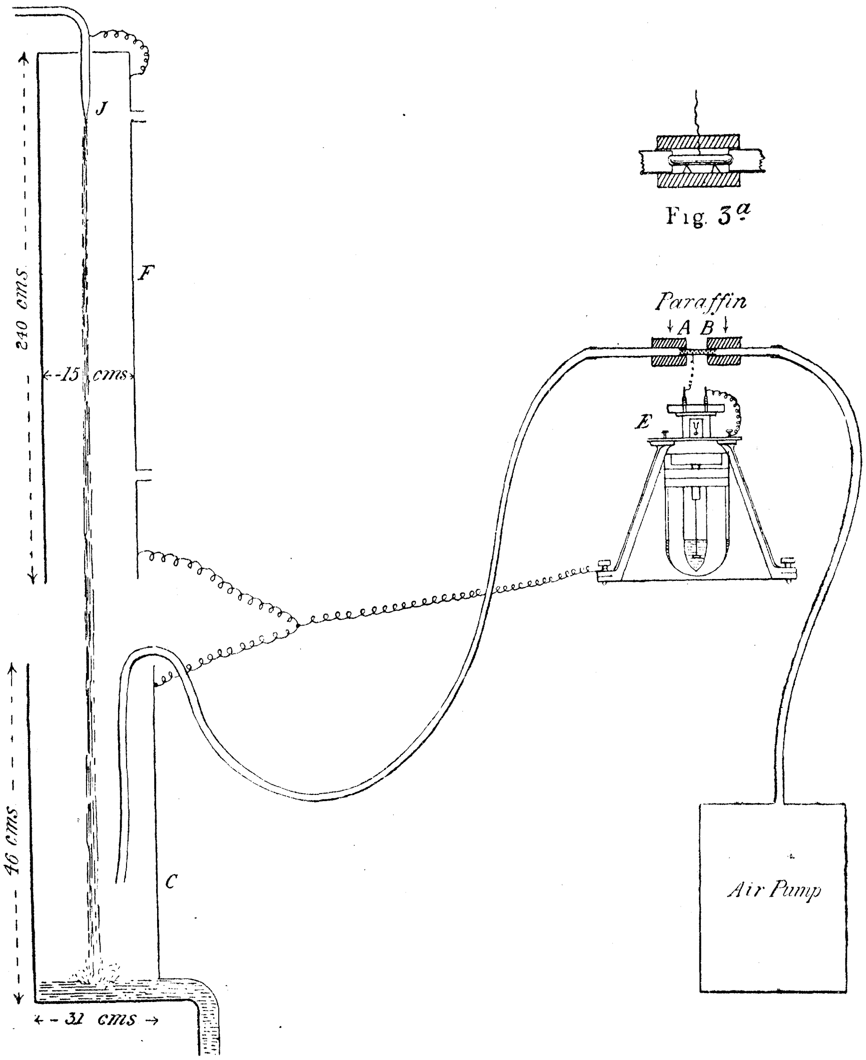
§ 24. In preliminary experiments before electrifying the air inside the can by needle point, it was found that the dropping of the piston produced no deflection on the electrometer.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Electrification of Air by Water Jet (§§ 25–37).

§ 25. In previous experiments* we found air to be negatively electrified by water falling in drops through it, and to pursue the investigation further the arrangement shown in fig. 3 was put up. Loch Katrine water, under full pressure, issues from a

Fig. 3.



jet, J, fixed in the lid of a funnel, F, and falls down the funnel centrally into a metal can, C, below. By means of an air-pump some of the air is withdrawn from the can or funnel through metallic tubing, as shown in the diagram, to a metallic filter, AB, containing 50 fine brass wire gauzes. In each experiment 200 strokes of the pump are taken.

* "Electrification of Air by Water Jet," by MacLean and Goto. 'Phil. Mag.,' August, 1890. "Electrification of Air," by Lord Kelvin and Magnus Maclean. 'Proc. Roy. Soc.,' May, 1894.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

§ 26. The greatest effect, 4·5 volts negative, was obtained, as was to be expected from LENARD's discovery, when the air was withdrawn from a point well down in the can, the can being close to the funnel, and the falling water rattling on the bottom of the can. Decreasing effects were observed (1) when the air was withdrawn from the can at increasing distances from the bottom; (2) when several inches of water were kept in the can;* (3) when air was drawn from the funnel, and the distance between the can and the funnel was gradually increased.

§ 27. A filter of 100 wire gauzes gave at the rate of 26 volts, and a filter of 2 gauzes, with a loose plug of cotton wool between them, gave 6·3 volts, in the same time and under the same conditions as the filter of 50 wire gauzes gave (§ 26) 4·5 volts.

§ 28. A *sloping metallic plate* was next fitted to the bottom of the funnel in such a way that the falling water on striking the plate passed out by the aperture between the funnel and the lower edge of the plate. In each experiment 120 strokes of the pump were taken at the rate of 40 strokes per minute. Drawing the air from the aperture near the bottom of the funnel gave, in 4 experiments, results averaging about 8 volts. These results were given by a filter containing 2 brass gauzes with cotton wool between them.

§ 29. Two simple brass tubes of different bores with no wire gauze or cotton wool were now tried as filters. Each was 10 centims. long and 1 centim. external diameter. The following results were obtained:—

Internal diameter of brass filter.	Air drawn from side aperture of funnel:—			
	Near the top.		Near the bottom.	
	Aperture near the bottom:—		Aperture near the top:—	
	Shut.	Open.	Shut.	Open.
centims.	volts neg.	volts neg.	volts neg.	volts neg.
0·3	1·5	1·0	3·2	3·0
0·18	3·0	2·8	4·5	4·3

Using the brass filter of 0·18 centim. bore, drawing from the aperture near the bottom, and varying the water pressure, we found mean results as follows:—

Full pressure	3·4	volts.
Diminished pressure	2·6	,,
Very low pressure (200 drops per minute)	0·17	,,

§ 30. In the long metallic tube between the funnel and the testing filter we placed, in successive experiments, an increasing number of brass gauzes and plugs of wool.

* See a Paper by LENARD on "Electricity of Waterfalls," 'Wied. Ann.,' 1892, vol. 46, pp. 584–636.

The air had to pass through these and the long length of tubing before reaching the testing filter at the electrometer. The testing filter consisted of a block-tin tube with two wire gauzes and one plug of cotton wool. Twenty experiments were made on air drawn from the aperture of the funnel near its lower end, and with jet from full pressure of water. The following are mean results, for 120 strokes of the pump :—

No gauze between the funnel and the testing filter.	2 gauzes and 1 wool plug.	3 gauzes and 2 wool plugs.	4 gauzes and 3 wool plugs.	5 gauzes and 4 wool plugs.	6 gauzes and 5 wool plugs.	7 gauzes and 6 wool plugs.
volts. 7	volts. 2·4	volts. 1·25	volt. 0·4	volt. 0·3	volt. 0·1	volt. 0·04

These results show that a large proportion of the electricity was taken, by the 7 gauzes and 6 plugs, from the air before it reached the testing filter.

§ 31. Extracting the air with no water falling gave no perceptible electrification.

§ 32. With the water again at full pressure, and falling on the sloping plate fixed into the bottom of the funnel, the negatively electrified air was drawn from the bottom aperture through different filters at different speeds. Two experiments at each speed were usually made, and whenever possible the deflection for 120 strokes of the pump was noted. In some cases, however, the reading exceeded 8 volts, and went off the scale with much fewer strokes; but to preserve uniformity the tabular results given below are all calculated for 120 strokes.

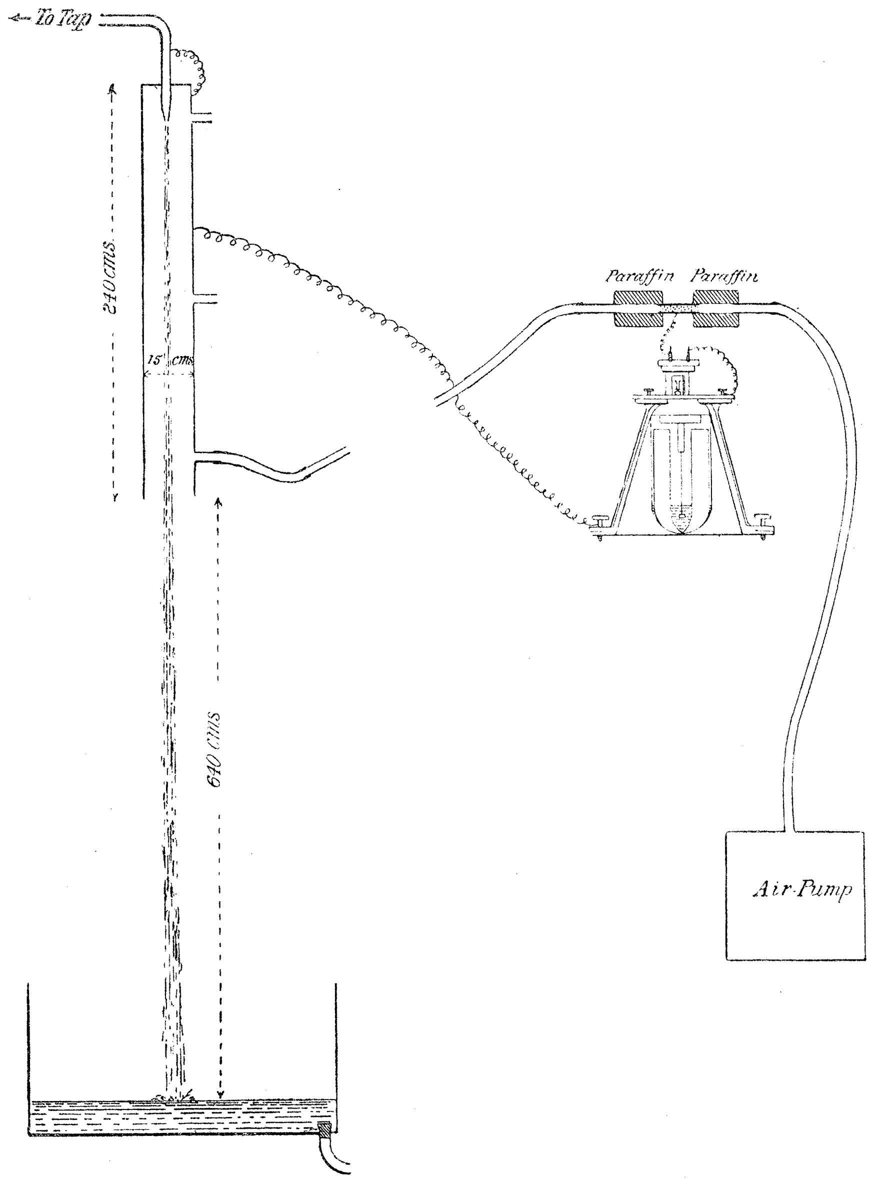
Results 2 and 4 are in accordance with Results 2 and 3 of § 68.

Filter used.	Duration of each stroke of the pump in seconds.					
	0·5	1	2	3	4	5
	volts neg.	volts neg.	volts neg.	volts neg.	volts neg.	volts neg.
1. Platinum tube 2·4 centims. long, 0·1 centim. bore	..	4·9	9·9	14·5	18·7	
2. Brass tube 4·1 centims. long, 0·2 centim. bore	7·8	12·5	21·8	25·8	26	25
3. Brass tube 4·1 centims. long, 0·34 centim. bore	4	7·2	12	13·2	12·7	
4. Solid brass cylinder with rounded ends, 8 centims. long and 1·8 centim. diameter, insulated within a paraffin tunnel (fig. 3*a*)	20·1	34·1	52·7	59	62·1	

§ 33. A metallic water-dropper was now fixed into the lid of the funnel, and the metallic plate at the bottom removed. A strong solution of common salt was placed in the dropper, and allowed to fall down the centre of the funnel into a basin below.

On drawing the air from the funnel by the side aperture near its lower end, and testing it by the brass tubular filter, 0·18 centim. diameter (4 of § 32), a mean of four experiments showed 2·5 volts positive.

Fig. 4.



§ 34. Arrangements were now made to test the effect of falling water upon air only, uninfluenced by impact of drops on any hard solid. The metallic plate at the bottom of the funnel was removed, and the funnel, 240 centims. long, was placed vertically in a position giving a clear fall of 640 centims. from the lower end of the funnel to a water-trough below (see fig. 4). A new aperture was made in the funnel near the centre. The filter used had 12 wire gauzes and 11 plugs of cotton wool.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

The following results were obtained from 120 strokes of the pump :—

Water pressure.	Air drawn from aperture in funnel near the—			Remarks.
	Top.	Middle.	Bottom.	
	volts neg.	volts neg.	volts neg.	
Full	0·5	0·7	0·5	
Reduced . . .	0·16	0·23	0·33	
Full	21·0	37·0	21·0	Sloping plate inserted in the funnel at the bottom.
Full	6·7	7·4	4·8	Plate removed. Funnel tilted so that the water struck against the side.

§ 35. The lower half of the funnel was now removed and the upper half used. The water now fell clear through the whole length of the funnel, and the extracted air gave, by 120 strokes of the pump as usual, $\frac{1}{4}$ to $\frac{1}{2}$ volt negative. No electrification in the extracted air could be detected if no water was falling.

§ 36. Putting the water-dropper (§ 33) in the top of the shortened funnel and allowing a strong solution of salt water to fall down from the dropper, $\frac{1}{4}$ volt *positive* was got from the extracted air. Placing pure water in the dropper and testing again, $\frac{1}{4}$ volt *negative* was found.

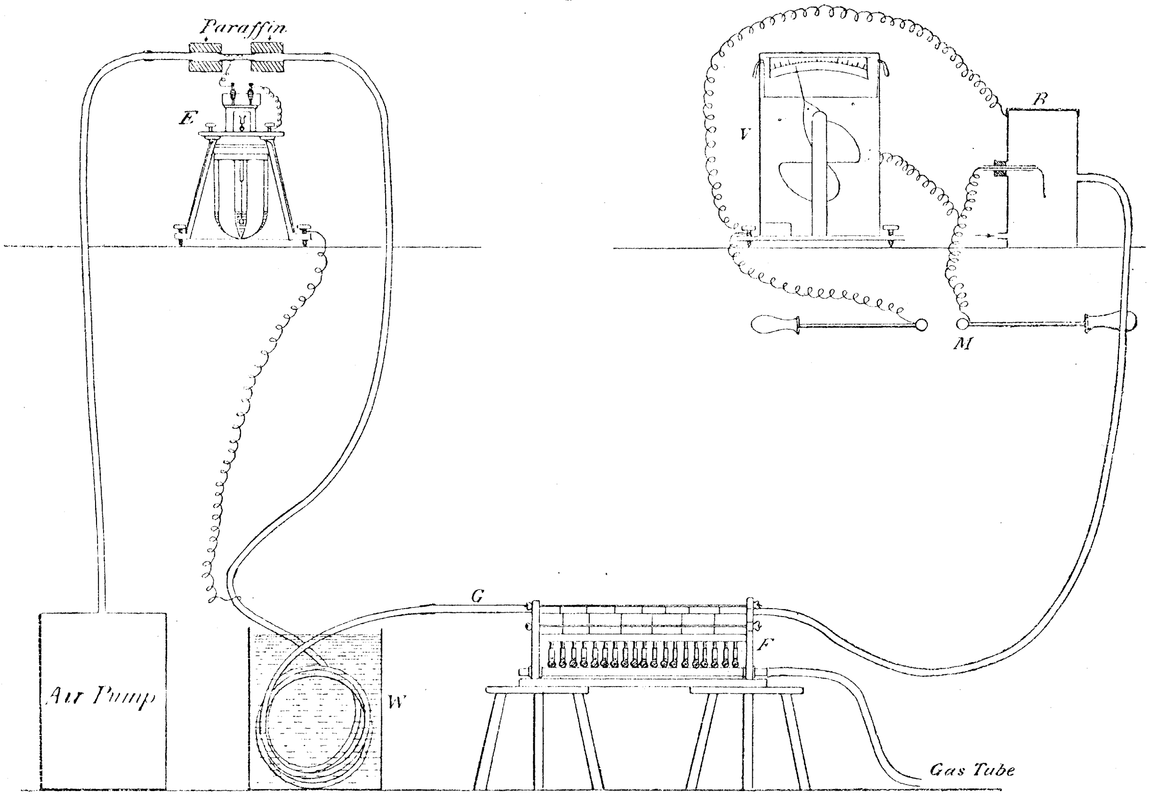
Electrification of Air by an Insulated Water-Dropper at Different Potentials (§ 37).

§ 37. The water-dropper was now insulated and connected with the positive terminal of 1 or more, up to 12, cells of a secondary battery, the negative terminal of which was connected with the funnel, and *vice versa*. On letting water fall from the dropper, and testing the electrification of the air in the funnel by drawing it through a testing filter, the results were not sensibly affected by substituting metallic connections for the connection of the battery terminals with the dropper and funnel. Hence, the large positive and negative electrifications thus given to the drops as they fell from the nozzle did not sensibly diminish or increase the negative electrification which they produced in the air through which they fell.

Effect of Heat on Electrified and Non-electrified Air (§§ 38, 39).

§ 38. The apparatus shown in fig. 5 was designed and used for the purpose of trying to diselectrify air by heat. Air is admitted into a tin plate biscuit canister, B, near the bottom. Two metallic tubes are fixed into it at the middle opposite each other. One of these two is plugged with paraffin through which passes a wire, ending in a needle point inside, and connected outside with the insulated terminal of an electric machine, M. By means of an air-pump air is drawn into the canister, where it is electrified by the needle. It passes thence through a few metres of indiarubber pipe, to a 2-metre length of glass combustion tubing, G, 2 centims. internal diameter, heated to a high temperature in a gas furnace, F. The hot air passes on through a length of $3\frac{3}{4}$ metres of block-tin piping coiled in a large vessel of cold water, W. The air thus cooled passes through two paraffin tunnels between which is the insulated filter consisting of block-tin pipe with two wire gauzes and a

Fig. 5.



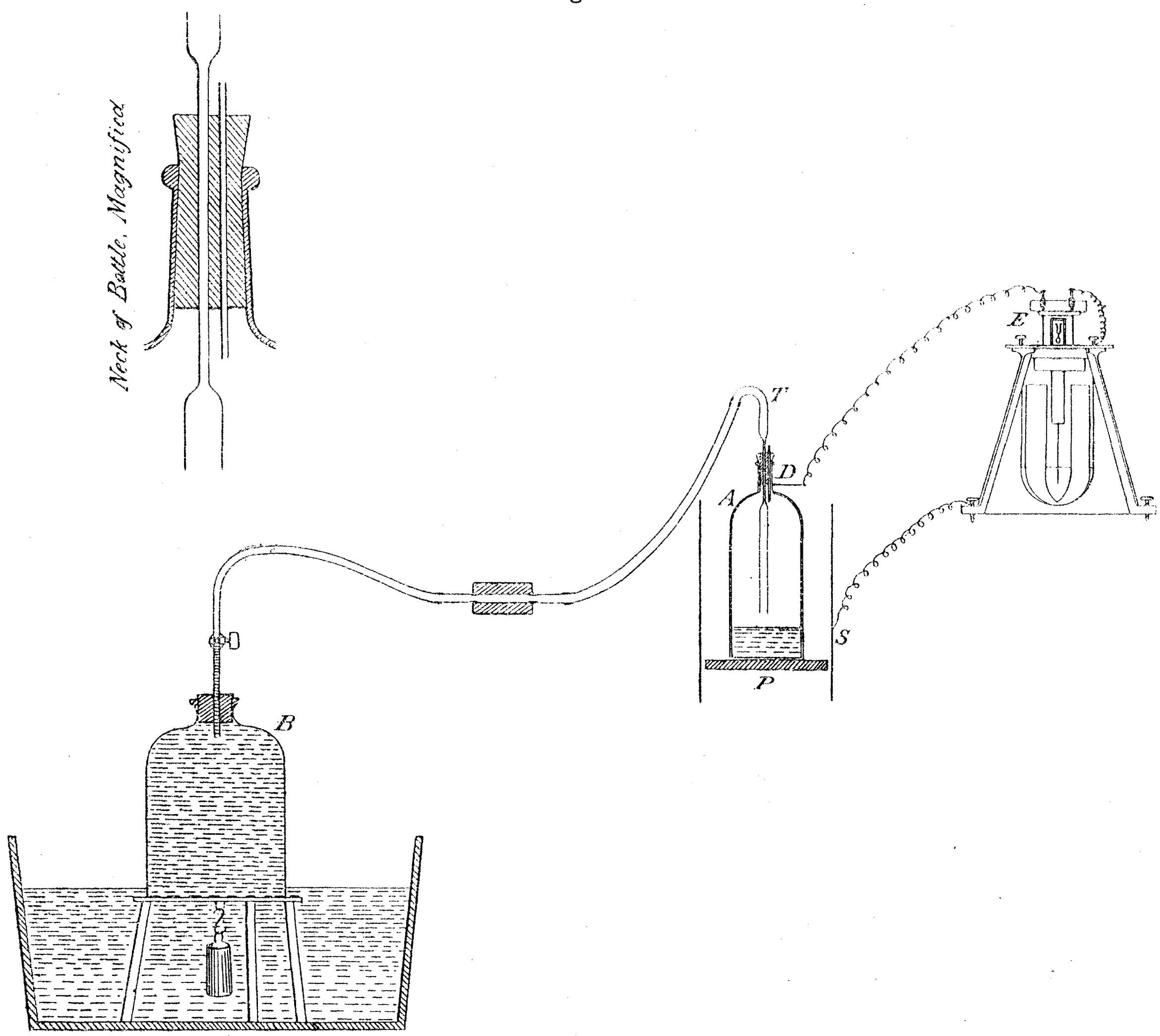
plug of cotton wool. There were altogether $10\frac{1}{2}$ metres of tubing between the canister and the filter. The air in the canister is kept electrified by an electrified needle point during an experiment.

§ 39. Beginning with the glass tube cold, the air gave an electrification at the rate of 14 volts positive for 200 strokes of the pump. On gradually increasing the temperature of the tube the electrification correspondingly diminished to less than 3 volts. In cooling, the electrification, now become negative by an accidental reversal in the inductive machine used, increased to 4·5 volts negative. On another occasion 5 volts negative were got with the tube cold, decreasing to 2 volts as the temperature was raised, increasing again to 5 volts as the tube cooled. Occasionally irregular results were noted, especially with positively charged air.

Non-Electrified Air Passed over Hot Copper and Hot Charcoal (§ 40).

§ 40. Passing air through the apparatus without first electrifying it, but keeping the glass tube at a high temperature, we found no deflection on the electrometer. But on repeating this experiment with copper foil in the tube an electrification of 9 volts *positive* for 200 strokes was observed. Replacing the copper foil by charcoal, with temperature high enough to keep the charcoal visibly burning, we found a *negative* electrification of 7 volts for 160 strokes.

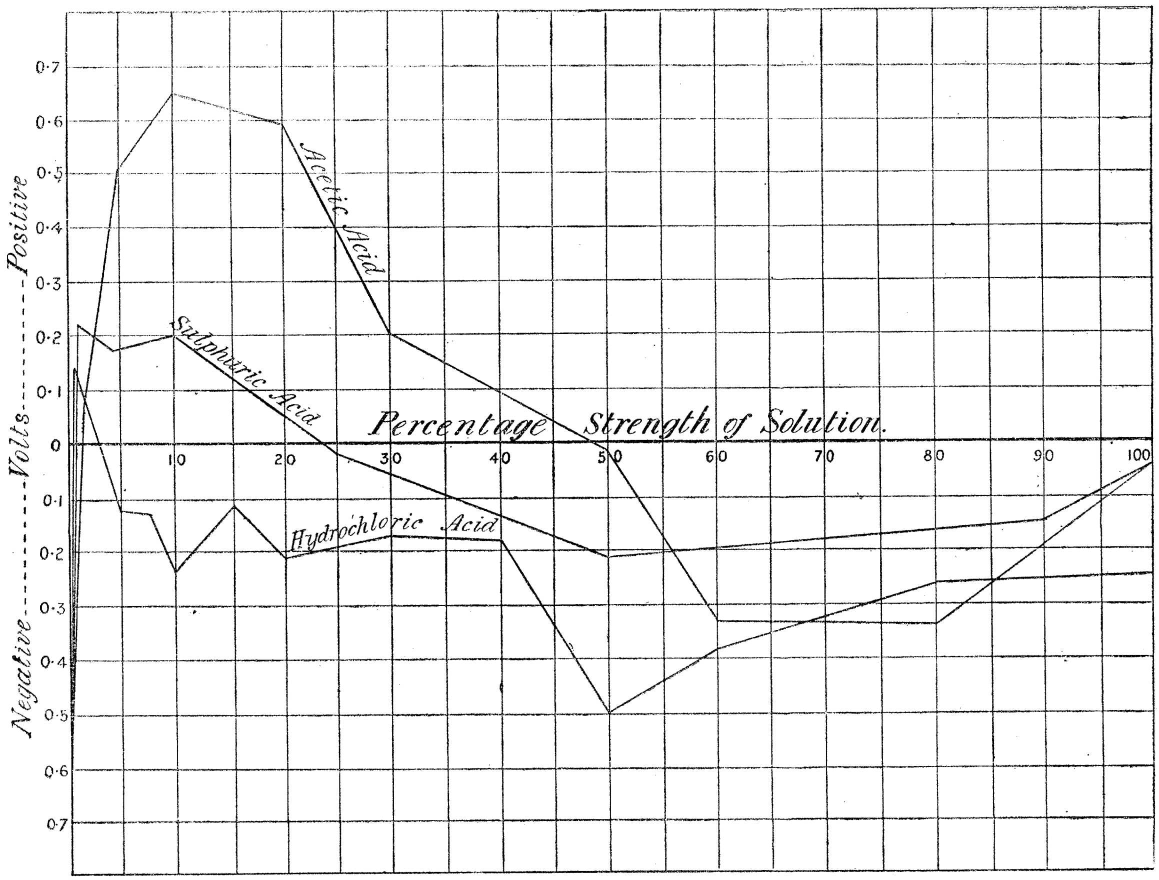
Fig. 6.



Electrification Produced by Shaking Air and Other Gases with Water and with Solutions of Different Substances (§§ 41–46).

§ 41. An ordinary Winchester glass bottle, A, fig. 6, of capacity 2500 cub. centims., has two broad strips of tin foil cemented on its outer surface on opposite sides, from top to bottom. To the foil at the shoulder is attached a metallic disc, D, of 5 centims. diameter, and having a small hole to allow a connecting wire from the quadrant electrometer to be quickly hooked or removed. 500 cub. centims. of Loch Katrine water having been put into the bottle, its mouth is stopped by hand, and the bottle vigorously shaken for 5 seconds, thoroughly and violently mixing the enclosed 2000 cub. centims. of air and 500 of water. It is now immediately placed on a block of paraffin, P, and the disc, D, is connected to the electrometer. A bent metallic tube, T, supported by an insulating paraffin stopper, is placed in the bottle, and a foot

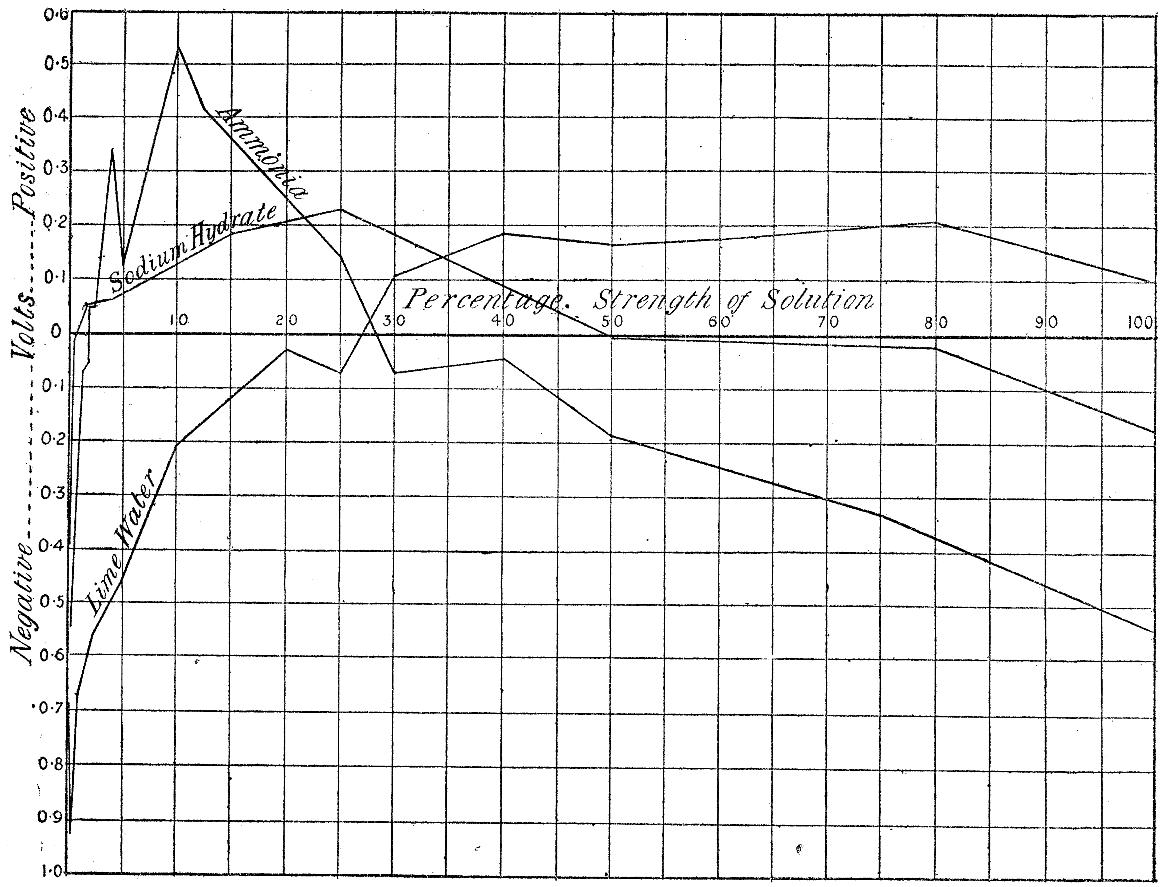
Curves 1, 2, 3.



length of rubber tube connects it to one end of a paraffin tunnel, from the other end of which a rubber tube, 2 metres long, passes to an aspirator consisting of a large bell jar, B, of capacity 8500 cub. centims., filled with water, and resting on supports near the water surface. The metallic guard-screen, S, which surrounds the bottle, is always connected to the sheath of the electrometer. The outer surface of the bottle is always wet. Less than half a minute is required after shaking the bottle to make the necessary arrangements and connections. The electrometer terminal connected with the bottle is now insulated, and then, by opening the stop-cock of the aspirator, air is drawn rapidly out of the insulated bottle, its place being taken by air flowing in through a small vertical slit in the paraffin stopper. The electrometer shows positive electricity, which proves the withdrawn air to have been negatively electrified.

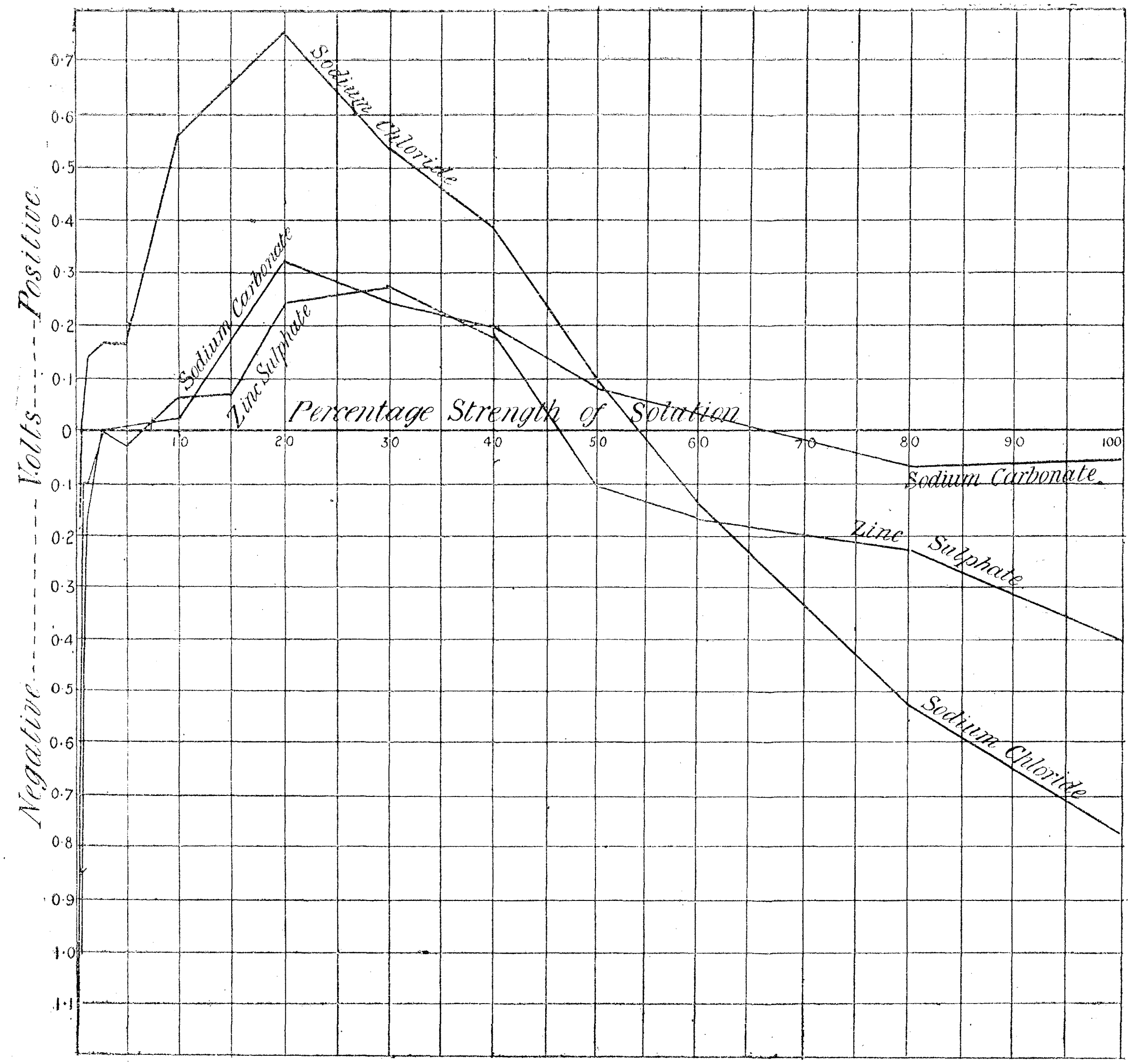
§ 42. Very many experiments were made to test the effect of shaking up the air in the bottle with solutions of different substances, the solutions being varied from saturated (100 per cent.) down to practically pure water. For this purpose three acids (sulphuric, hydrochloric, and acetic), three alkalies (sodium hydrate, lime, and ammonia), and three salts (sodium chloride, sodium carbonate, and zinc sulphate), were used.

Curves 4, 5, 6.



§ 43. Curves 1 to 9 show the results obtained. Generally, each test was repeated a large number of times, and the curves are drawn for mean values. It will be noticed that, with the exception of lime water, all the acids, alkalies, and salts, when added to the water in the bottle in very minute quantities, showed a rapid diminution in the negative electrification of the air produced by shaking it up with the liquid. In some cases a single drop of a saturated solution of the substance added to the water and shaken up with the air was almost enough to entirely neutralize the negative electrification of the air which is obtained by shaking up with pure water. On gradually increasing the strength of any of the solutions named, the zero line is crossed and the electrification of the air now becomes positive, increasing to a maximum and then diminishing till the zero line is again reached, the air becoming negative again. The air continues to receive negative electrification, on shaking it with the solution, for all further increase of strength of the solution up to saturation. All the acids, all the alkalies except lime water, and all the salts tested, show two zero points.

Curves 7, 8, 9.



§ 44. Experiments were now tried in which different liquids (500 cub. centims.) and gases (2000 cub. centims.) were shaken up in the bottle, and the electrification of the gas in each case was tested. The following is a tabular summary of the results. In all the experiments, except No. 1, the gas was got into the bottle by displacement of water. The bottle was first filled with water and inverted in a large trough of water and 2000 cub. centims. of the gas admitted.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

	Substances shaken up together in the bottle.		Deflection on electrometer. 1 volt = 69 divisions.	Quantity of electricity found in the gas per cub. centim., C.G.S. electrostatic unit.
	Liquid.	Gas.		
1	Water	Coal gas from gas mains	37 pos.	$0{\cdot}17 \times 10^{-4}$ neg.
2	,,	Coal gas from pressure cylinder	89 ,,	$0{\cdot}42 \times 10^{-4}$,,
3	,,	Oxygen from cylinder	52 ,,	$0{\cdot}24 \times 10^{-4}$,,
4	,,	Carbonic acid gas from cylinder	50 ,,	$0{\cdot}23 \times 10^{-4}$,,
5	,,	Carbonic acid gas from marble and hydrochloric acid, the gas being passed direct from generator to bottle	34 ,,	$0{\cdot}16 \times 10^{-4}$,,
6	,,	Carbonic acid gas, as in 5, but allowed to pass into a gasholder first	30 ,,	$0{\cdot}14 \times 10^{-4}$,,
7	,,	Hydrogen from zinc and dilute sulphuric acid, direct from generator	33 ,,	$0{\cdot}15 \times 10^{-4}$,,
8	,,	Hydrogen, as in 7, but allowed to pass into gasholder first	20 ,,	$0{\cdot}09 \times 10^{-4}$,,
9	,,	Nitrogen from air, the oxygen being removed by burning phosphorus	71 ,,	$0{\cdot}33 \times 10^{-4}$,,
10	Water impregnated with carbonic acid from a gazogen or siphon	Carbonic acid gas, as in 4	40 ,,	$0{\cdot}19 \times 10^{-4}$,,
11	Strong solution of common salt	Carbonic acid gas, as in 4	68 neg.	$0{\cdot}32 \times 10^{-4}$ pos.
12	,,	Coal gas from mains	71 ,,	$0{\cdot}33 \times 10^{-4}$,,
13	,,	Oxygen, as in 3	43 ,,	$0{\cdot}20 \times 10^{-4}$,,

§ 45. Some experiments were made to ascertain how long the air, on being shaken up with Loch Katrine water, retains its negative electrification.

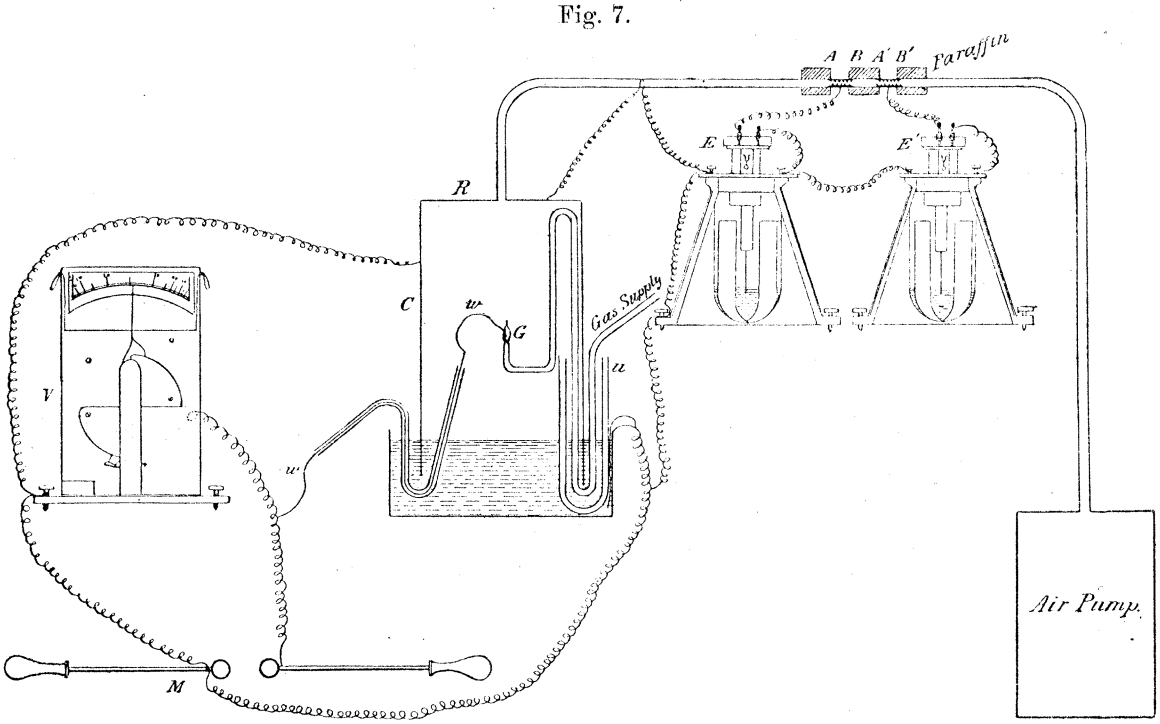
Time between stopping the shaking of the bottle and beginning to draw out the air.	Deflection of the electrometer. 1 volt = 69 divisions.
	Divisions.
25 secs.	52 pos.
27 ,,	50 ,,
1 min.	26 ,,
2 mins.	28 ,,
5 ,,	17 ,,
15 ,,	7 ,,
15 ,,	10 ,,
30 ,,	1 ,,

§ 46. A strong solution of ammonia (500 cub. centims.) was placed in the bottle. Without shaking the bottle, the mixed air and ammonia evaporating from the surface of the liquid were aspirated. They were found to be negatively electrified to a fraction of a volt.

Electrification of Different Gases by Electrified Needle Points and Flames. Absolute Efficiencies of Filters (§§ 47–66).

§ 47. The arrangement shown in fig. 7 was put up to test the electrification of different gases by needle points and by flames. At first we only used one electrometer, E, and one filter, AB. The filter used was a block-tin pipe 4 centims. long, 1 centim. bore, with two brass gauzes and one plug of cotton wool between them. A large glass cylinder, C, with a removable metal roof, R, has strips of tinfoil pasted on its inside and outside. These strips are kept in metallic connection with R, with one terminal, M, of an electric machine, and, with the sheath of the vertical electrostatic voltmeter, V, and with the sheath of the quadrant electrometer, E.

Fig. 7.



A pump was used for drawing the electrified gas from the cylinder, C, through the electric filter, AB. By this means, calculating the effective volumes of the two cylinders of the pump, we knew the volume of electrified gas that was drawn through the electric filter in each experiment. Placing the cylinder, C, over water, as shown in the diagram, we found that 10 strokes of the pump raised the water inside to a height of 8·1 centims. The cylinder was 38 centims. high and 81 centims. in circumference. Hence the volume of gas drawn through the filter was 422·8 cub. centims. per stroke of the pump. This agrees with the measured effective volume of the two cylinders of the pump.

§ 48. An electrifying wire, *ww*, was put inside a glass tube full of paraffin and bent as shown. A gas burner, G, was fixed in a brass tube which was connected by sealing wax to a bent glass tube varnished with shellac leading in from the gas supply.

§ 49. The method of experimenting was as follows:—The gas was lit at the burner, G, and the machine started. The machine was worked for 4 minutes at potentials from 3000 to 10,000 volts in different experiments. At the instant of stopping the machine the gas supply was stopped, and an indiarubber cork put into the tube, U, which was used to keep the gas in the cylinder at atmospheric pressure during the electrification. Ten strokes of the pump were taken in every experiment, immediately or after the lapse of certain intervals of time from stopping the machine.

The results of a large number of experiments performed in May, 1895, are briefly summarised in the following table:—

Electrification of Air by Electrified Coal-Gas Flame.

Interval between stopping electric machine and starting pump.	Number of experiments.	Average deflection by 10 strokes of the pump. (47 divs. per volt.)	Remarks.
minutes.		divs.	
0	3	+210	Potential of electrification ± 3000 volts.
0	3	−234	
1	2	+108	
1	2	−110	
2	2	+ 76	
2	2	− 94	
3	3	+100	
3	3	− 82	
5	2	+110	
5	2	−107	
30	1	+ 40	
30	1	− 36	
60	1	+ 53	
0	3	+360	Potential of electrification ± 4000 volts.
0	2	−395	
1	1	− 90	
5	1	− 52	
10	1	− 45	
15	1	− 36	

§ 50. We now electrified the air in the glass cylinder by six needle points without flame. The method of experimenting was in other respects exactly the same as before. A very wonderful result was noticed, namely, that short times of electrification at 5000 volts gave greater results as indicated by electrometer and filter than longer times of electrification.

Time of electrification.	Number of experiments.	Average deflection for 10 strokes of pump.
30 secs.	6	30·6
1 min.	6	22·1
5 „	6	0

§ 51. A conjecture occurred to us that this very surprising result might possibly be due to the formation of lines of conductance from the electrifying needle to the inside of the containing cylinder, so that all the electricity from the needle might be passing to the glass and tinfoil strips without electrifying the intervening air, and that if means were provided for continually breaking these conjectural lines of conductance the results would be different. Accordingly a hexagonal ring of sheet tin an inch broad was constructed to serve as stirrer. Its outer diameter was slightly less than the diameter of the cylinder. Two rods which passed through two air-tight holes in the metallic top of the glass cylinder were fixed at the ends of a diameter of this stirrer. Several experiments were tried (1) with the stirrer not moved but resting near the surface of the water at the bottom of the cylinder, (2) with the stirrer kept moving up and down during the electrification, which was by needle points at 5000 volts. in each experiment. The results obtained disprove our conjecture. They are summarised as follows :—

Time of electrification.	Number of experiments.	Average deflection per 10 strokes of the pump.	Remarks.
30 secs.	5	16·0 neg.	No stirring.
30 „	6	16·3 „	Stirring.
1 min.	6	11·6 „	No stirring.
1 „	6	13·3 pos.	„
1 „	5	9·3 neg.	Stirring.
1 „	6	10·4 pos.	„
5 „	No deflection, stirring or no stirring!		

Electrification of Carbonic Acid Gas from Pressure Cylinder.

§ 52. One of the carbonic acid cylinders of the Scottish and Irish Oxygen Company was taken and laid on its side near the glass cylinder, C (fig. 7). Carbonic acid gas from it was let in by a tube into the glass cylinder, and electrified by six needle points. To start with, the stop-cock of the carbonic acid gas cylinder was kept shut, and ten strokes of the pump caused the water in the cylinder to rise. The stop-cock was then opened and carbonic acid was allowed into the cylinder, the average time of letting it in being one minute. This was performed five or six times, and then the experiments were done exactly as already described in § 49, except that carbonic acid gas was let in instead of air. The machine, in the two sets of experiments summarised below kept the needle points at a potential of 8000 volts positive.

ELECTRIFICATION OF CARBONIC ACID GAS BY ELECTRIFIED NEEDLE POINTS.

Time of electrification.	Interval between stopping machine and starting pump.	Deflection for 10 strokes.
min.	min.	
1	0	463 pos.
1	2	303 ,,
1	5	158 ,,
1	10	97 ,,
1	30	43 ,,
0	..	4 pos.*
1	0	414 ,,
5	0	106 ,,
2	0	309 ,,
10	0	2 ,,
1	0	554 ,, in 9 strokes.
0	..	128 neg.†
1	0	554 pos. in 7 strokes.
1	1	338 pos.
1	2	254 ,,
1	5	160 ,,
1	10	89 ,,
1	30	37 ,,
1	60	6 ,,

§ 53. The nearly perfect annulment of the electrification by 10 minutes of the electrified needle point in carbonic acid, and by 5 minutes (§§ 50, 51) in common air, is very wonderful. So far as we can see at present, its explanation seems to be a conductive quality, such as that first discovered, we believe, by SCHUSTER, produced throughout the carbonic acid, and throughout the air, by continued electric disruptive action.

§ 54. It was noticed in some of the experiments with the carbonic acid cylinder that, when it was lying on its side on the table beside the glass vessel, C, and when the gas issued in a jerky manner, the electrification found was invariably negative, even when the needle points were positive. This was, of course, due to the boiling

* This first experiment was made with the carbonic acid gas which had been in the glass cylinder overnight.

† For explanation of this negative electricity in the gas with no electrification of the needle points, see § 54.

and freezing, and ultimate evaporation from the liquid carbonic acid in the cylinder. Various experiments were tried, with the cylinder (1) lying on its side, (2) standing, straight up: in both cases without any electrification of the needle points. Very *slight positive electrification* was found with the cylinder straight up; and *very large negative electrification* when the cylinder was lying on its side. In the latter case, the more rapid the rush of the carbonic acid gas from its cylinder, and the shorter the time it was left in the glass vessel before observations were taken, the greater was the electrification observed.

Testing Efficiency of different Filters by using two at a time in Series and two Electrometers (§§ 55–60, with reference to §§ 11, 12 above).

§ 55. For the purpose of testing the efficiencies of various filters, two electrometers were fitted up side by side, as shown in fig. 7, each with a filter of block-tin pipe, 4 centims. long and 1 centim. bore, containing six wire gauzes and five plugs of cotton wool. These filters were put in series, with a paraffin tunnel between them to insulate the one from the other. Thus the electrified air passed the second receiver immediately after it passed the first. Call the one filter AB and the other filter A′B′; then, in the first experiment, the electrified gas passed in the direction AB A′B′, and in the second experiment it passed in the direction B′A′ BA. Each filter is kept metallically connected always to the same electrometer. The sensitiveness of electrometer, E, with the filter, AB, was 52·3 divisions per volt, and 100 divisions per 0·154 electrostatic unit of electricity. The sensitiveness of electrometer, E′, with the filter, A′B′, was 158·3 divisions per volt, and 100 divisions per 0·071 electrostatic unit of electricity.

§ 56. Air was electrified negatively by six needle points in the glass cylinder and the pump worked at the same time with the U-tube open, so that the water did not rise inside. 100 strokes of the pump gave a deflection of 160 divisions on electrometer, E, and 32 divisions on electrometer, E′. This gives

$$q_1 = 0·246 \text{ electrostatic unit,}$$
$$q_2 = 0·023 \quad ,, \quad ,,$$

Reversing the direction of the current of air through the filters, 100 strokes of the pump gave a deflection of 156 divisions on electrometer, E′, and 123 divisions on electrometer, E. This gives

$$q_1' = 0·111 \text{ electrostatic unit,}$$
$$q_2' = 0·189 \quad ,, \quad ,,$$

Hence (§ 12)

$$n = 0·77 \text{ (filter AB),}$$

and

$$n' = 0·31 \text{ (filter A′B′).}$$

Similar numbers were got when the air was electrified positively.

For carbonic acid gas, electrified positively and negatively, the same filters gave

$$n = 0{\cdot}82 \text{ (filter AB)},$$
$$n' = 0{\cdot}42 \text{ (filter A'B')}.$$

§ 57. We now used the filter ($n = 0{\cdot}77$) for determining electric density of electrified air or gas. A known volume of the electrified gas (§ 47) was sucked through the filter in connection with an electrometer whose constant was determined as in § 18 (0·154 C.G.S. electrostatic quantity per 100 divisions deflection). We thus found—

(1.) For air electrified, positively or negatively, by six needles at a potential of 5000 volts, an electric density of $0{\cdot}92 \times 10^{-4}$ C.G.S. per cub. centim.

(2.) For air electrified, positively or negatively, by electrified gas flame at a potential of 5000 volts, an electric density of $1{\cdot}98 \times 10^{-4}$ C.G.S.

(3.) For carbonic acid gas, electrified negatively by gas out of a cylinder lying on its side (§ 54), or positively by six needle points at a potential of 5000 volts, an electric density of $2{\cdot}4 \times 10^{-4}$ C.G.S.

§ 58. We now set about to definitely determine the relative efficiencies of various forms of filters. A standard filter of block-tin pipe, 4 centims. long and 1 centim. bore, with 6 brass gauzes and 5 plugs of cotton wool was used, and it was permanently kept in metallic connection with electrometer, E′. The filter to be tested was joined to electrometer, E. Air electrified positively or negatively was sucked through in one direction, passing through the tested filter first, and then through the standard filter, the diselectrifying power of which was 0·77 for electrified air. Hence it is possible to determine the diselectrifying power of the tested filter by § 14. Thus, from the numbers in the following section, we get for the diselectrifying power, for positive electricity, of the 7 millim. brass tube—the least effective of those mentioned—$n = 1 \div (1 + 4/0{\cdot}77) = 0{\cdot}16$; and for the block-tin pipe, 90 centims. long, and coiled into a spiral $n = 1 \div (1 + 0{\cdot}63/0{\cdot}77) = 0{\cdot}55$.

§ 59. Let q_2 = quantity of electricity taken out by the standard filter of block-tin pipe with six brass gauzes and five plugs of cotton wool; and

q_1 = the quantity of electricity taken out by the tested filter from the air before passing the standard filter. A long series of experiments with no wire gauze or cotton wool in the tested filters is summarised in the following tables. The potential of the machine was in each experiment 10,000 volts.

Bore of brass tube in millims. (length = 4 centims.).	$\frac{q_2}{q_1}$ for positive.	$\frac{q_2'}{q_1'}$ for negative.
2·0	3·0	2·75
3·4	2·1	3·3
4·2	3·5	3·1
6·0	3·9	3·1
7·0	4·0	5·5

Thus the 3·4 millims. filter is the most effective and the 7·0 millims. filter is the least effective of these five filters of equal length. The following table shows results for different lengths and different bores :—

Length of tube.	Bore of tube in millims.	$\frac{q_2}{q_1}$ positive.	$\frac{q_2'}{q_1'}$ negative.
1. Brass, 9·9 centims.	2·0	2·96	3·05
2. " 10·0 "	4·5	2·85	4·99
3. " 9·9 "	8·0	4·0	6·45
4. Block tin, 2·0 "	6·0	3·1	1·6
5. " 10·0 "	6·0	3·26	7·5
6. " 90·0 " (coiled in spiral)	6·0	0·63	1·15
7.* " 4·0 "	10·0	1·37	1·31
8. " 4·0 "	10·0	2·96	2·8

§ 60. A glass tube filter, 4 centims. long and 3·3 millims. in bore, covered outside with strips of tinfoil along its length, was similarly compared with the standard filter. When newly put up, and as long as the glass was dry, it took out very little electricity from the air; but as the experiment proceeded, and the glass became less dry by taking up moisture on its inner surface, the quantity of electricity taken out by the glass tube became greater and greater. Thus in a first experiment $q_2/q_1 = 28·5$; but after working the pump for one hour $q_2/q_1 = 3·8$.

§ 61. Up to this time (December, 1895), we had not been able to find a filter which could take all the electricity from the air, and we now proceeded to search for a filter which would be able to practically do so. The first filters tried with this object were tubes filled with very small pieces of fine copper wire, and closed at each end by a plug of cotton wool and a disc of brass gauze. The diameter of the wire was 0·00296 centim. The containing tube was in one case block-tin pipe 10 centims. long and 1 centim. diameter: and in another it was a glass tube of the same length and diameter, coated both inside and outside with longitudinal strips of tin-foil. The diselectrifying power of each was calculated from the observations by the

* Tube No. 7 had twelve wire gauzes inside it, and, as the table shows, its filtering efficiency was more than that of the equal and similar tube No. 8, which was clear inside.

formulæ in § 12. That of the block tin was thus found to be 0·93 for negative electricity and 0·9 for positive, and that of the glass nearly the same, 0·9 for negative and 0·84 for positive. The block-tin filter contained 18·927 grms. of wire.

§ 62. The next filter tried was a block-tin pipe, 10 centims. in length and 1 centim. in diameter, containing 8·33 grms. of clean, very fine brass filings, enclosed at each end by a plug of cotton-wool and a piece of brass gauze. These brass filings, which were got from a brass-finishing workshop, were poured into a glass tube about 4 feet long and about three-quarters full of water. The filings and water were well shaken up, and the tube was then allowed to stand for several hours, so as to give the filings time to settle. After washing the filings three times in this manner, the top portion was taken off and dried before a fire, and used for filling the filter. It was found that when the electrified air passed through this filter of brass filings, before it passed through the copper-wire filter attached to electrometer, E, no deflection was obtained on the latter. This showed that the brass-filings filter deprived the air of practically all its electricity. We tried also a filter with sawdust instead of brass filings, but its efficiency was comparatively low.

Filter of Brass Filings used to find Effects of Spirit Flame, Coal Gas Flame, and Hydrogen Flame in Electrifying Air (§ 63–66).

§ 63. Having found the brass-filings filter thoroughly satisfactory, we used it to investigate the effect of various kinds of flames in electrifying air. First of all, we electrified the air of the laboratory by means of an insulated spirit flame, joined to the insulated positive terminal of a Voss electric machine. The machine was worked for 40 minutes, and then, 2 minutes after it was stopped, the electrification of the air in the vicinity was tested by drawing some of it through a tube leading to the brass-filings filter, joined to electrometer, E. The pump was worked at the rate of 1 stroke per 4 seconds, and after 200 strokes the electrometer read 174 divisions, or about 3·3 volts positive. After the lapse of half-an-hour, the air of the laboratory was found to be still strongly charged with positive electricity.

§ 64. Removing the water vessel from below the glass cylinder, C, in fig. 7, and substituting for it a metal plate kept in metallic connection with the sheath of the electrometer and the disinsulated terminal of the machine, we kept a coal-gas flame burning within the glass cylinder, while the machine and pump were worked and observations taken by electrometer, E, and filter, AB. With the machine at 10,000 volts, we found that, after two or three strokes of the pump, the deflection was about 500 scale divisions, positive or negative, according as the machine was positive or negative. This gives (§ 13) for the electric density, per cub. centim., 11×10^{-4} C.G.S. electrostatic, which is much greater than any of our previous results (§§ 23, 57).

§ 65. To burn hydrogen, the burner, G of fig. 7, was made of rolled platinum foil with a fine nozzle, which was kept in metallic connection with the insulated terminal of the electric machine. The hydrogen gas was generated from zinc and dilute sulphuric acid in a WOULFF bottle. The electrification which we obtained in this way, with the machine at 10,000 volts, was very large, the greatest deflection being 500 divisions in one stroke of the pump. This indicates an electric density in the air of the glass cylinder, of 22×10^{-4} C.G.S. electrostatic, which is about six times as great as that obtained by electrified needle points (§ 23). This electric density was got for both positive and negative electrification.

§ 66. We next tried the effect of the insulated hydrogen flame alone, without working the electric machine, and we found that when the height of the liquid rising in the long, open glass tube of the WOULFF bottle was not more than about 10 centims. above the level of the liquid in the bottle, there was a small negative electrification. When the liquid rose to a greater height than 10 centims. in the tube (indicating that the gas was issuing at a greater pressure to feed the flame), the electrification was positive. On one occasion, the positive electrification produced by the flame was $0{\cdot}84 \times 10^{-4}$ C.G.S. electrostatic unit per cub. centim. of the air which carried the electricity to the filter. This was the greatest effect obtained from the flame without electrification by the machine, and the height of the liquid in the tube of the WOULFF bottle was 14·5 centims.

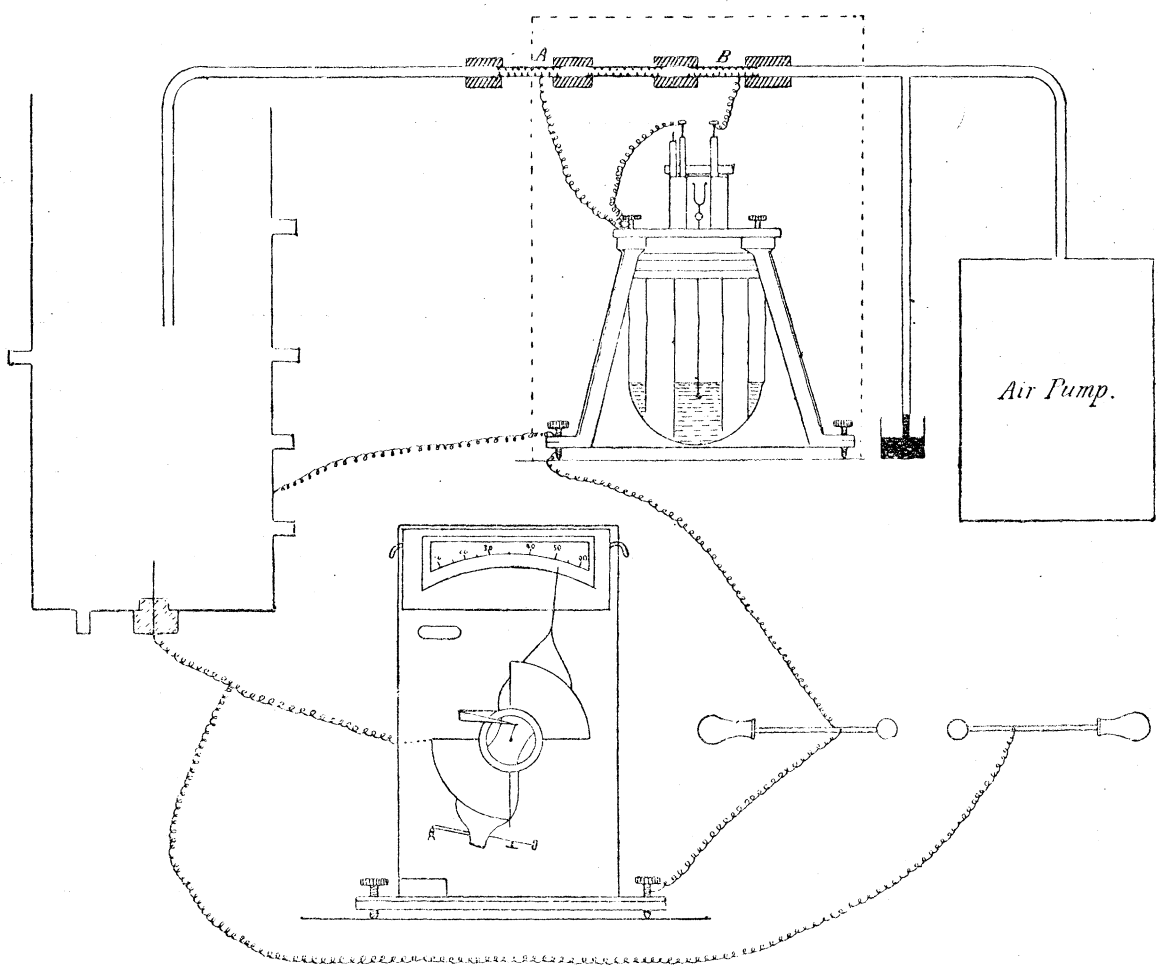
The hydrogen gas, when not burning, gave no electrification at any pressure up to 26 centims. of water.

PLATINUM TUBE HEATED EITHER BY A GAS FLAME OR BY AN ELECTRIC CURRENT (§ 67).

§ 67. Through the kindness of Mr. E. MATTHEY, we have been able to experiment with a platinum tube 96 centims. long and 1 millim. bore. It was put in between the glass cylinder, C, and the filter, AB, in the apparatus of fig. 7. The other filter, A′B′, was not used in these experiments. The platinum tube was heated either by a gas flame or an electric current. When the tube was cold, and non-electrified air drawn through it, we found no sign of electrification by our filter and electrometer. But when the tube was made red or white hot, either by gas burner applied externally or by an electric current through the metal of the tube, the previously non-electrified air drawn through it was found to be electrified strongly positive. To get complete command of the temperature, we passed a measured electric current through 20 centims. of the platinum tube. On increasing the current till the tube began to be at a scarcely visible dull red heat we found butl ittle electrification of the air. When the tube was a little warmer, so as to be quite visibly red hot, large electrification became manifest. Thus 60 strokes of the air-pump gave 45 scale divisions on the electrometer (0·86 of a volt) when the tube was dull red, and 395 scale divisions (7·5 volts) when it was a bright red (produced by a current of 36 amperes). With stronger currents raising the tube to white-hot temperature the electrification seemed to be considerably less. The following summary may be taken as a specimen of several experiments. It is a copy of our notes of an experiment made on 20th July, 1895:—

Time of starting.			Deflection after 60 strokes. 52·3 divs. per volt.	Time of 60 strokes.		Current in amperes.	Remarks.
hrs.	mins.	secs.	Divisions.	mins.	secs.		
11	6	0	1·0 pos.	5	15	0	Air left overnight in glass cylinder drawn through platinum tube
11	17	0	3·5 neg.	4	50	19·7	Tube hot, but not visibly red
11	27	0	1·0 ,,	5	30	26·4	Tube beginning to be dull red
11	34	15	395 pos.	5	18	33·5	Tube very bright red
11	42	30	45 ,,	5	40	28·6	One end dull red. End next ingress of air always duller
11	50	15	0	5	10	26·4	
11	57	30	9 pos.	5	30	27·5	Tube red before using pump
12	5	30	37·5 ,,	5	30	28·6	One end perceptibly red.
12	14	10	190 ,,	5	47	30·5	One-third next ingress moderately red; other two-thirds (14 centims.) dull red
12	22	0	174 ,,	5	58	34·5	Nearly whole tube (20 centims.) bright red
12	29	30	86 ,,	5	51	39·0	White hot
12	46	15	58 ,,	5	1	46·6	White hot
12	58	30	0	3	57	0	

Fig. 8.



§ 68. *The Diselectrifying Power of Various Filters* was farther tested as follows :—Air, electrified in a metal vessel by a needle point kept electrified by a Voss electric machine, was drawn through 340 centims. of block-tin pipe (0·91 centim. bore), to one or other of the experimental filters which was connected to sheath (fig. 8). After passing through A, the air was drawn through an insulated testing filter, B, connected to the insulated terminal of the electrometer. B was a standard filter of block-tin pipe, 5 centims. long, 0·66 centim. bore, and filled with fine brass filings. Tests were occasionally made with A removed, to ascertain the diselectrifying power of the standard filter (B) alone ; then A being inserted, the effect on B was again noticed.

Filter A.	Deflection for 6 strokes of pump.		Percentage extracted by A.
	A. removed.	A. in position.	
	divisions.	divisions.	
(1.) Standard filter, similar to B.	220	35	84
(2.) Brass tube, 5 centims. long, and 0·18 centim. bore	192	158	18
(3.) Solid brass cylinder, rounded ends, 8·1 centims. long, and 1·8 centim. bore	222	132	40
(4.) Block-tin tube, 5 centims. long, and 0·91 centim. bore	160	158	1·25

§ 69. The standard filter, B, was now removed, and the various tubes used in the last experiments as tested filters (A's), were now tried separately as testing filters (that is, insulated filters, B), connected to the insulated terminal of the electrometer. The following are the particulars and deflections noted for 6 strokes of the pump in 1 minute :—

Filter used.	Divisions of deflection.	
	Positive.	Negative.
Block tin { 5 centims. long and 0·91 centim. bore	none	none
Block tin { 10 ,, ,, 0·91 ,, ...	,,	,,
Block tin { 10 ,, ,, 0·66 ,, ...	4	4
Brass . . { 4·1 ,, ,, 0·18 ,, ...	5	none
Brass . . { 10 ,, ,, 0·18 ,, ...	5	5
Brass . . { 10 ,, ,, 0·50 ,, ...	5	11
Brass . . { 17·5 ,, ,, 0·90 ,, ...	6	8
Solid brass (rounded ends) 8·1 centims. long and 1·8 centims. diameter	45	
Standard filter, block tin, 5 centims. long and 0·66 centim. bore, filled with brass filings	90	100

§ 70. We then tried as filters tubes of different materials, but all of the same length (10 centims.), and bore (0·91 centim.). Glass, brass, block tin, copper, and zinc were used: the glass tube was covered externally with tin-foil, and also a little way inside at each end. As usual, the air in the can was charged from the insulated needle point at 4000 volts positive, and 3200 volts negative (§74), and drawn off through 340 centims. of block-tin pipe of 0·91 centim. bore, extending from the centre of the can to the insulated filter, which was either glass, brass, or block tin. Before testing the copper and zinc tubes, the can was brought nearer to the electrometer, so that the length of the block-tin pipe conveying the electrified air to the filter was reduced from 340 centims. to 100 centims. The mean of a large number of tests gave the following deflections for 6 strokes of the pump in 1 minute, the mean result in every case being very similar to the individual results.

Filter used.	Deflection per 6 strokes of pump.	
	Positive.	Negative.
Glass (covered outside with tin-foil)	1·1 mean of 3 experiments	7·0 mean of 3 experiments
Brass	1·4 ,, 2 ,,	3·8 ,, 2 ,,
Block tin	3·3 ,, 2 ,,	3·1 ,, 2 ,,
Copper	6·3 ,, 4 ,,	8·0 ,, 3 ,,
Zinc	8·4 ,, 6 ,,	2·3 ,, 6 ,,

§ 71. The zinc filter was the only one which showed a distinctly greater deflection for positive than for negative electricity, a result which is opposite to one obtained by RUTHERFORD,* experimenting with air which had been electrified from an electrified body under the influence of RÖNTGEN rays. The previous experiments having shown that, on drawing electrified air over the insulated and non-electrified solid brass cylinder with rounded ends, the cylinder extracted from the air a large proportion of its charge, we now arranged to charge the cylinder and draw non-electrified air over it to the standard insulated filter connected with the electrometer, to see if the air would take up from the cylinder a part of its charge. The arrangements were as shown in fig. 9. The cylinder was charged positively and negatively at potentials varying from 1000 volts to 15,000 volts, *but no trace of electrification of the air after passing over the brass cylinder could be detected.*

The Effects of the Uranium "rays," discovered by BECQUEREL, *and of a Candle Flame, on Electrified Air.*

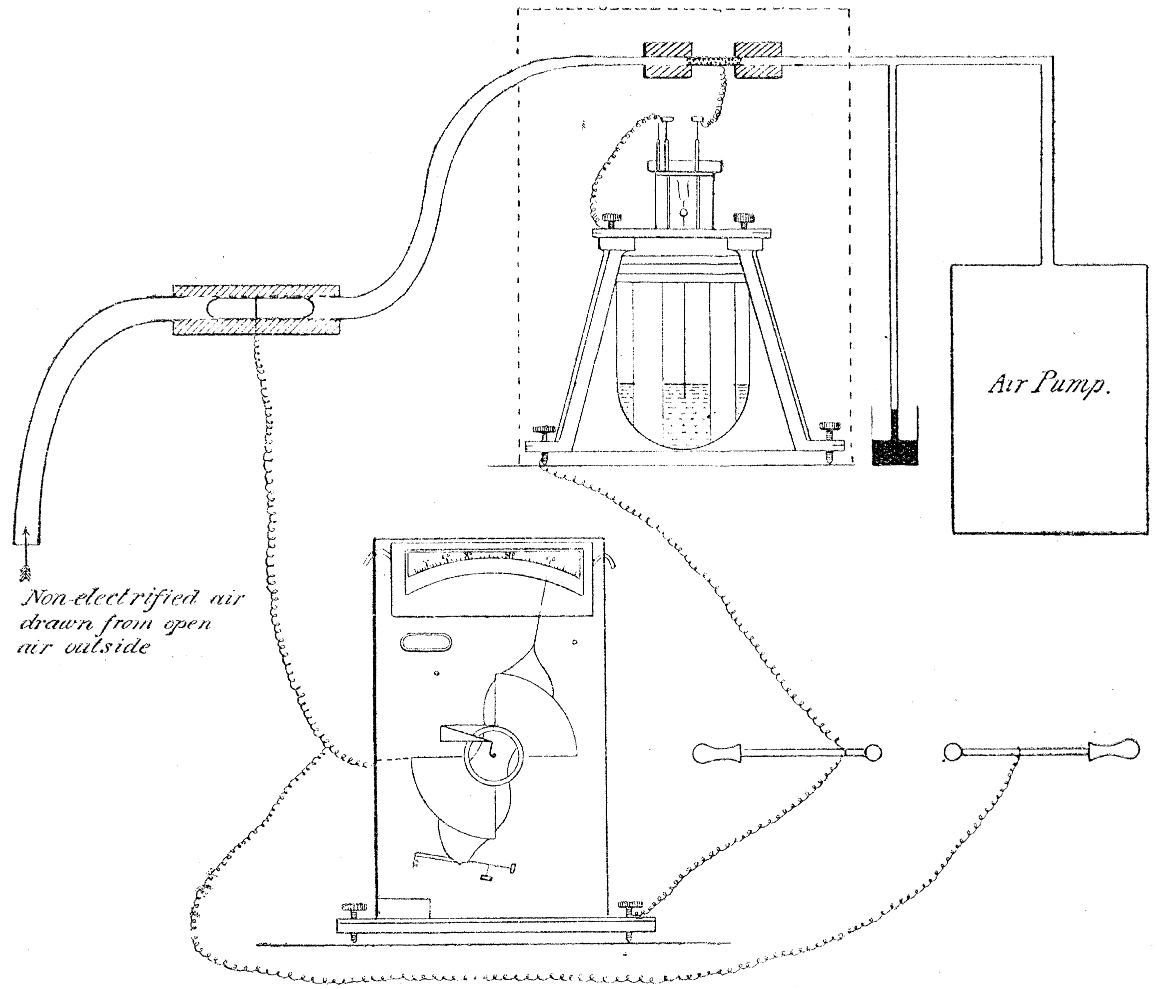
§ 72. The air in the can (fig. 8) was charged in the usual way by a needlepoint at 3200 volts negative for 1 minute, and the electric machine was then stopped; the

* See 'Phil. Mag.,' April, 1897, p. 246.

electrified air was drawn from a point half-way down the can to the insulated standard filter connected to the electrometer, and the deflection noted. The experiment was repeated with a uranium plate suspended three-quarters of the way down in the can by wires metallically connected with the can. The following results were noted :—

Without uranium, 50 strokes of the pump were required before the electrometer ceased to give a deflection, the total deflection being 271 divisions.

Fig. 9.



The uranium was now placed in position in the can, and the air was then charged for one minute. It was kept in position till all the electrified air was drawn off to the filter, the total deflection being 61 divisions. When the uranium was inserted after the electric machine was stopped, and before the air in the can was drawn to the filter, little more than 10 strokes were required before the electrometer ceased to give a deflection, and the deflection was now 121 divisions.

Using a very small lighted candle instead of the uranium plate, we found the following results :—

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

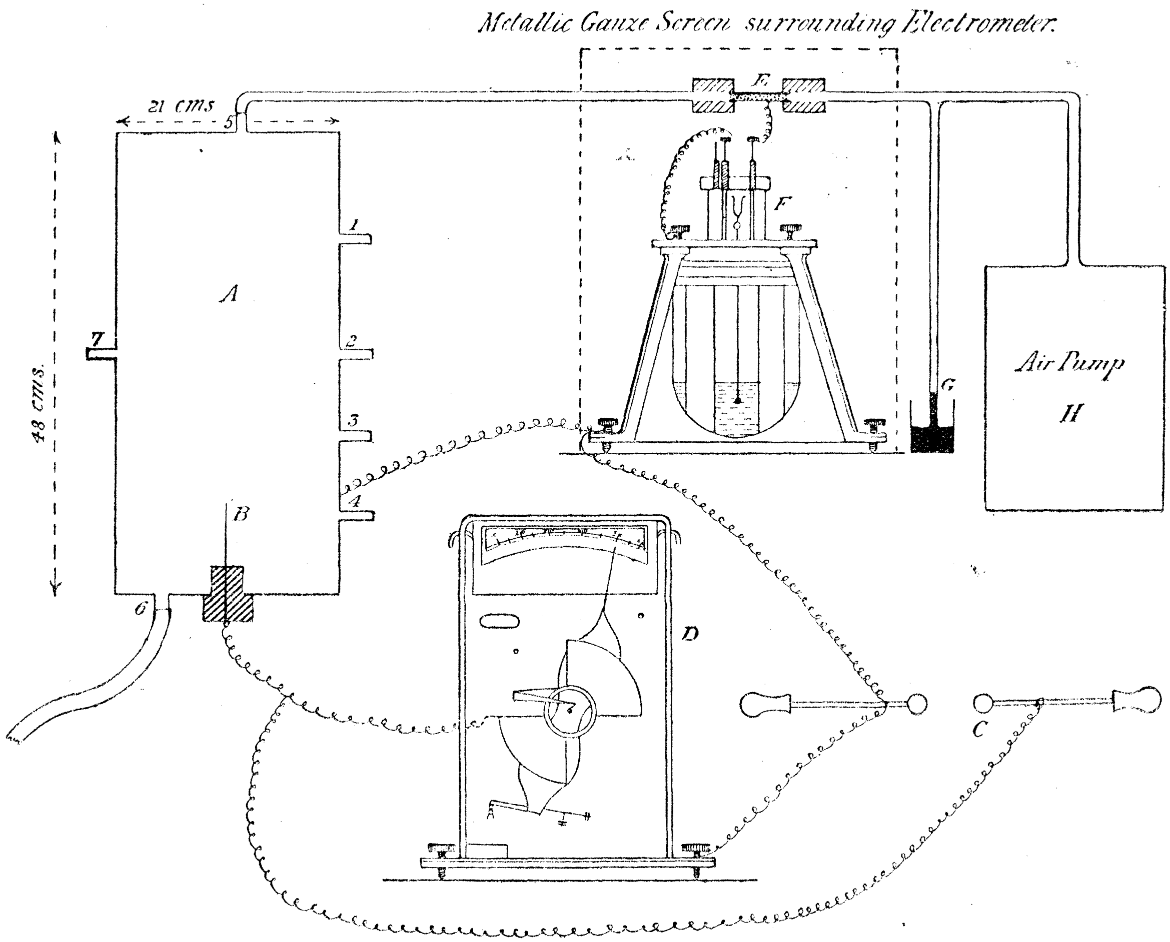
Without the candle, 195 divisions negative for 60 strokes were noted.

With the candle inserted when about to withdraw the electrified air to the filter, the deflection was, for 40 strokes, 81 divisions.

Best Charging Potential for Air and for Carbonic Acid Gas, in a Cylinder of Metal, 48 *centims. long and* 21 *centims. diameter. Greatest Electric Density Obtained, and Loss of the Electrification.*

§ 73. Numerous experiments were made to find the charging potential which would give the greatest electric density to air drawn off from a metallic can, A, fig. 10. An insulated needle-point, B, was fixed by a paraffin stopper in the bottom

Fig. 10.



of the can, and was connected with the insulated terminal of a Voss electric machine, C, and of a vertical electrostatic voltmeter, D. A pipe passed from aperture No. 5 in the top of the can to a standard electric filter, E, insulated on

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

two paraffin blocks. The filter was of block-tin tube, 5 centims. long and 0·6 centim. bore, and was filled with fine brass filings. It was connected by a short platinum wire to the insulated terminal of a quadrant electrometer, F, and beyond the filter were tubes passing to a mercury gauge, G, and air-pump, H. The can was connected to the uninsulated terminal of the electric machine and to the sheaths of the voltmeter and electrometer.

§ 74. The experiment was conducted as follows :—Apertures Nos. 1, 2, 3, 4, and 7 in the can were closed, and the electric machine started, the air in the can being charged by a brush discharge from the needle point. The electrometer terminal joined to the filter was insulated, and the pump worked for some time, fresh air filtered through cotton-wool entering the can by a pipe attached to aperture No. 6. The tests were made at potentials ranging from 2500 up to 12,000 volts, and it was found that 3200 volts negative and 4000 volts positive gave about the best results. The speed of the pump was kept constant, and the cubic contents of the cylinders of the pump and the electric capacity of the insulated filter and quadrants of the electrometer being known, the quantity of electricity in absolute measure taken from each cub. centim. of air by the filter could be determined. In experimenting with carbonic acid gas, the procedure adopted was almost exactly the same as that for air, the only difference being that instead of admitting air by the pipe attached to aperture No. 6 the same pipe was attached to the nozzle of an upright pressure cylinder containing carbonic acid gas. The gas was admitted to the can under very slight pressure. For carbonic acid gas, the charging potentials which gave the best results were found to be about 4000 volts negative and 5000 volts positive.

In order to find out the electric density of the electrified air or carbonic acid gas when left in the can for some time after charging had ceased, the electrification was stopped after the machine and pump had been worked for several minutes. The charging wire was removed from the needle and the apertures in the can blocked. The enclosed electrified air or carbonic acid gas was left to itself for different times in different experiments, generally just $1\frac{1}{4}$ hours. The gas in the can was then drawn from No. 5 aperture through the insulated filter to the pump (aperture No. 6 being opened to admit fresh air), and the pump was stopped when all signs of electrification ceased.

The following results were obtained :—

ELECTRIC Densities in C.G.S. Electrostatic Units.

Gas.	Greatest electric density, while working electric machine and pump.	Percentage loss in stated time.
Air	$0·877 \times 10^{-4}$ negative	73 per cent. in 90 minutes
,,	$0·370 \times 10^{-4}$ positive	92·7 ,, ,, 120 ,,
Carbonic acid	$1·17 \times 10^{-4}$,,	93·1 ,, ,, $1\frac{1}{4}$ hours
,,	$0·833 \times 10^{-4}$,,	96·1 ,, ,, $1\frac{1}{4}$,,
,,	$0·63 \times 10^{-4}$ negative	98·8 ,, ,, $1\frac{1}{4}$,,

Diffusion of Electricity from Carbonic Acid Gas into Air.

§ 75. We next tried a series of experiments to find if an electric charge given to carbonic acid gas diffused from the gas into air. The method of experimenting finally adopted was as follows :—

Carbonic acid gas was slowly passed from an upright pressure cylinder into the metallic can, A, by aperture No. 6; atmospheric air was freely admitted through aperture No. 7; while 12,000 cub. centims. of mixed carbonic acid and air were drawn out per minute from aperture No. 2, and 6100 cub. centims. of air from the top aperture (No. 5); the other openings in the can being kept closed.

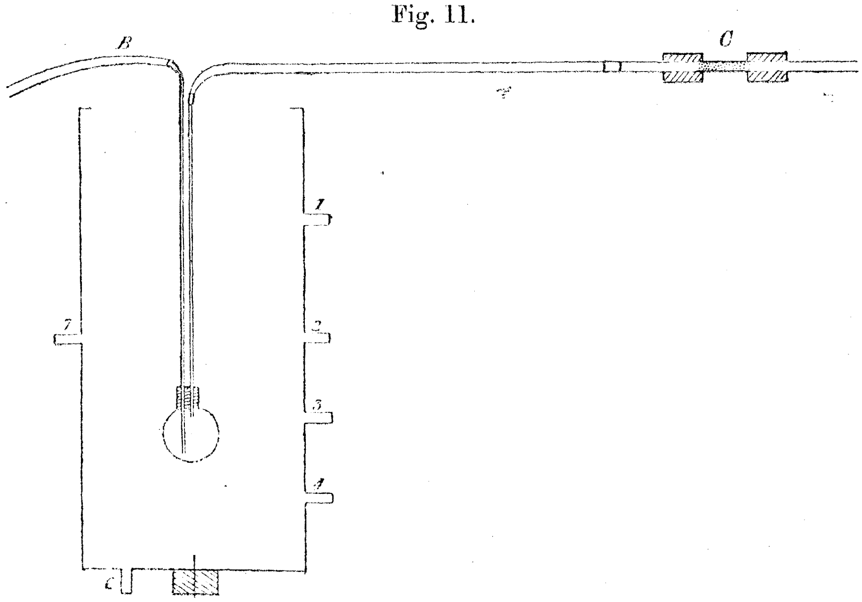
In these conditions, it was found that air entered abundantly through No. 7, showing that the volume drawn off from (2) and (5) was much greater than that of the carbonic acid gas entering by (6). Hence there must have been nearly pure carbonic acid gas below the level of aperture No. 7, separated by a very thin transitional stratum from nearly pure air, above the level of No. 7. Nos. 7 and 2 were on the same level. The air drawn off from No. 5 passed through the insulated standard filter, E (already described), which was connected to the insulated terminal of the quadrant electrometer, F. The Voss electric machine, C, was worked to give a brush discharge from the needle point, B, the charging potential being indicated by the vertical electrostatic voltmeter, D. Within 15 seconds after starting the machine, a decided electrical effect was observed, the reading of the quadrant electrometer almost immediately rising to a maximum rate of deflection of 55 divisions per minute when the needle was charged positively, and 50 divisions per minute when it was charged negatively. The electrification observed was not sensibly affected by stopping the supply of carbonic acid gas. But when the working of the electric machine was stopped and the charging wire to the needle removed, and whether the supply of carbonic acid gas was continued or stopped, the electrical effects noticed on the electrometer rapidly fell, and 3 minutes after the electric machine was stopped, no further electrification was detected. The sensibility of the electrometer was 117 divisions per volt.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

In order to test if the carbonic acid gas in the lower half of the can still retained any electrical charge, the connection to the filter and pump was removed from aperture No. 5, at the top of the can, to No. 6 at the bottom, and the gas drawn through the filter, but no electrification could be detected. We were surprised with the results, and we do not see how to explain it: we expected that the stagnant carbonic acid gas in the bottom of the vessel would have retained electricity as in experiments of § 52 and § 74.

§ 76. Further experiments on diffusion of electricity were tried with a porous ball (fig. 11). The mouth of the ball was tightly closed, and through the cork passed two glass tubes, one (B) projecting nearly to the bottom, the other being just through the

Fig. 11.



cork. The ball was suspended in the metallic can, which was filled with carbonic acid gas or air. The gas in the can was electrified from the insulated needle point at the bottom. Meantime, a strong blast of non-electrified air from a large bellows passed into the ball by the tube, B, and out again by the other tube to the insulated standard filter of block-tin tubing, 5 centims. long and 0·66 centim. bore, filled with fine brass filings, the filter being connected to the insulated terminal of the quadrant electrometer.

There was thus an air pressure from the inside of the ball towards its outside surface, and under these conditions there was no evidence on the electrometer that any part of the electric charge in the carbonic acid gas or air surrounding the ball had made its way against the outward pressure of air, from outside the ball into the interior, and thence to the filter. This experiment was varied by removing the bellows, blocking the tube, B, partially or completely, and attaching an air-pump to the insulated filter at C. On working the air-pump, some of the electrified carbonic acid gas or air surrounding the ball must have been drawn inside, and thence to the insulated standard filter connected with the electrometer; but, again, no evidence of electrification on the filter could be detected on the electrometer. It thus appears as if the porous ball itself had withdrawn the electric charge from the gas which passed through the ball.

Communication of Electricity from Electrified Steam to Air (§§ 77–81).

§ 77. Steam was generated in a kettle, A, and electrified by brush discharge from a needle point, B, attached to the lower end of a long copper rod, CB. The rod was kept central and insulated in the brass tube, D, by two rubber corks. The upper end of the rod was connected to the insulated terminal of a voltmeter, E, and of a Voss electric machine, F (fig. 12).

§ 78. To preserve the insulating properties of the corks during the experiments it was found necessary to keep a current of air passing in the tube between the corks, and to surround the lower part of the tube with a jacket of oil kept at a temperature of 235° F.

§ 79. The electrified steam from the kettle passed up into a vertical tube, G, where it mixed with air drawn, by an air-pump shown on the right-hand side of the drawing, from a bottle into which the lower end of the tube was fitted. Air to take the place of that drawn from the bottle entered by a long pipe from outside a window of the laboratory. The mixed steam and air passed from G into a Liebig's condenser, H, where the steam was condensed. The water thus formed dropped into a Woulff's bottle, and the air was drawn from another neck of the bottle through a drying tube, K, containing sulphuric pumice. From this it passed direct through an electric filter, L, insulated by two paraffin tunnels, and thence to the air-pump. The filter was connected to the insulated terminal of a quadrant electrometer, whose constant was 117 divisions per volt.

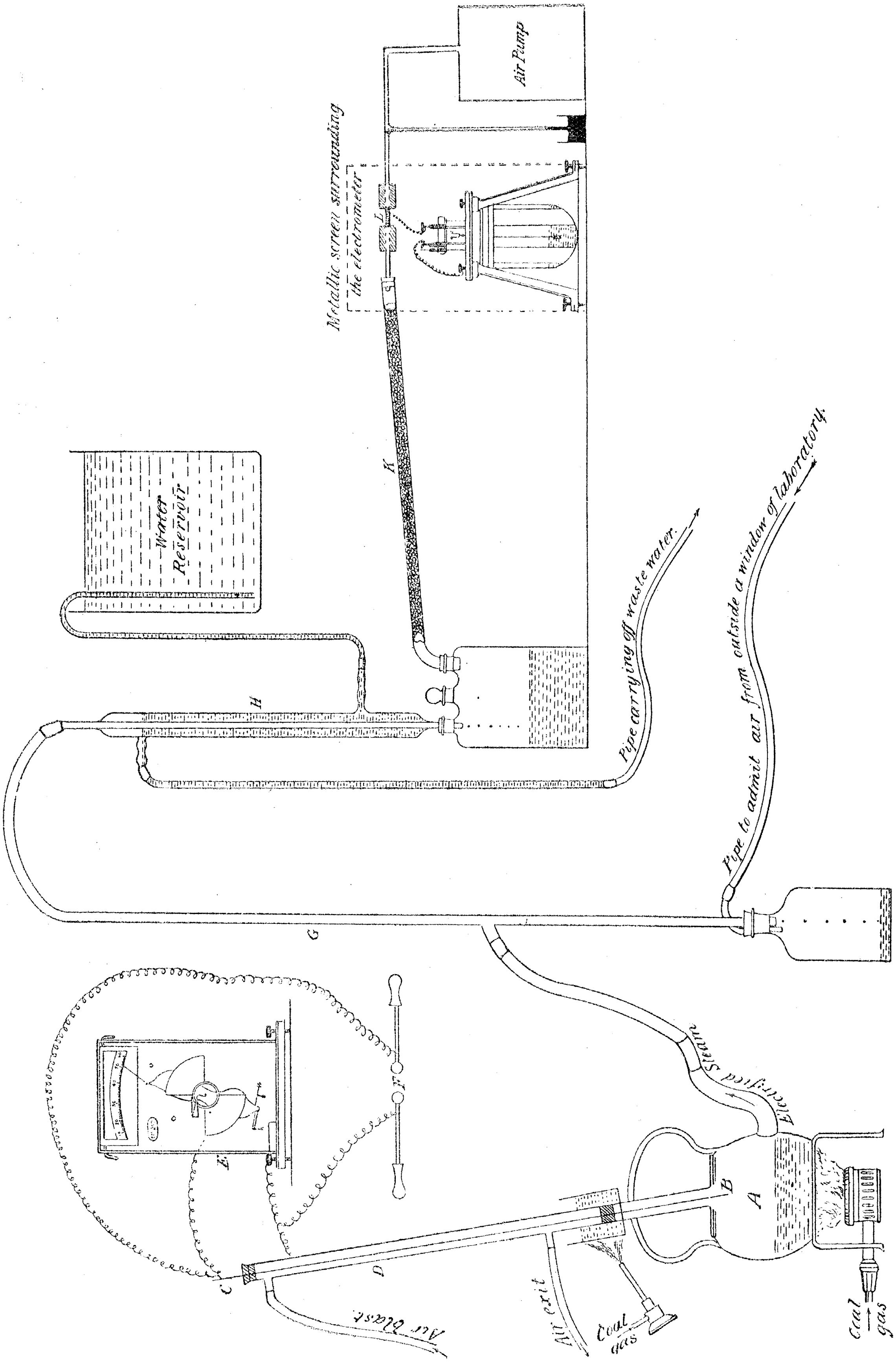
§ 80. When the air-pump and the electric machine were worked, with the kettle cold, the electrometer showed no electrification. It also showed no electrification when the kettle was boiling and the air-pump worked, but the electric machine stopped.

§ 81. When the kettle was kept boiling, and the electric machine and air-pump both worked, strong electrification, positive or negative, according as the machine was positive or negative, was observed, 52 divisions per minute being our largest value. This, with the known capacity of the electrometer, corresponds to 0·11 C.G.S. electrostatic unit taken per minute from the air by the filter.

Electrification of Air at Different Air-Pressures and at Different Electric Potentials. Measurement of Current (§§ 82–88).

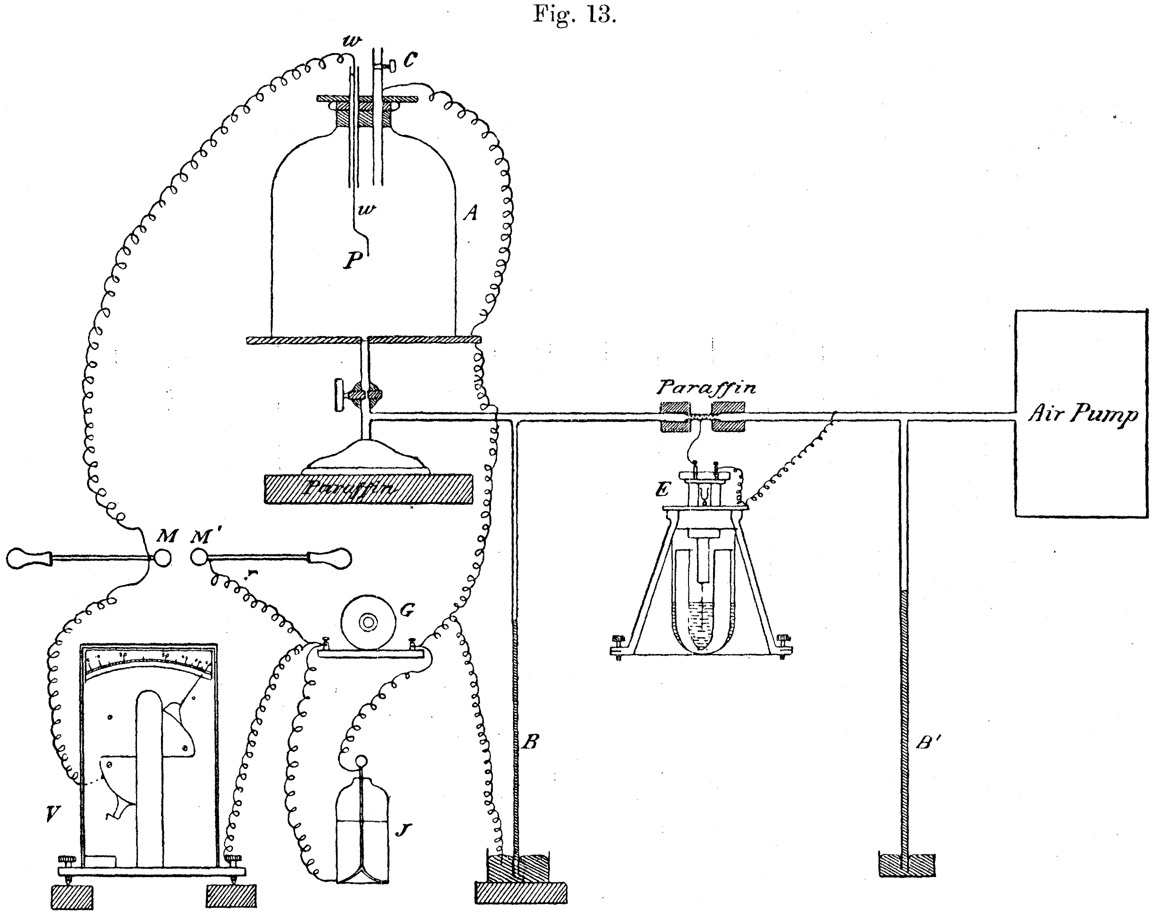
§ 82. In February, March, and April, 1896, we made experiments on the electrification of air at different air-pressures, using for this purpose the apparatus repre-

Fig. 12


Air Pump
Metallic screen surrounding the electrometer
Water Reservoir
Pipe carrying off waste water.
Pipe to admit air from outside a window of laboratory.
Steam
Electrified
Air blast
Air exit
Coal gas
Coal gas

sented in fig. 13, and electrifying by one needle point joined to the insulated terminal of the Voss electric machine. The air was contained in a glass bell-jar, A, which was coated inside with strips of tin-foil kept in metallic connection with one terminal, G, of a high-resistance mirror galvanometer, the other terminal of the galvanometer being joined to the sheath of the voltmeter, V, and to the disinsulated terminal, M′, of the electric machine. The stand of the bell-jar rested on a piece of paraffin. The pressure of the air in the bell-jar was measured by noting the height to which mercury rose in the tube, B. The vessel containing the mercury was insulated by a paraffin block.

Fig. 13.



The pressure of the air after it had passed the electric filter (block-tin pipe with fine brass filings) was also measured by means of the rise of mercury in tube, B′. A barometer tube not shown in the diagram gave us the atmospheric pressure. The differences of the heights of the mercury in tubes B, B′, and the height of the mercury in the barometer, gave the pressures of the air in the bell-jar and on the exit side of the filter respectively.

All the tubing through which the air passed was block tin.

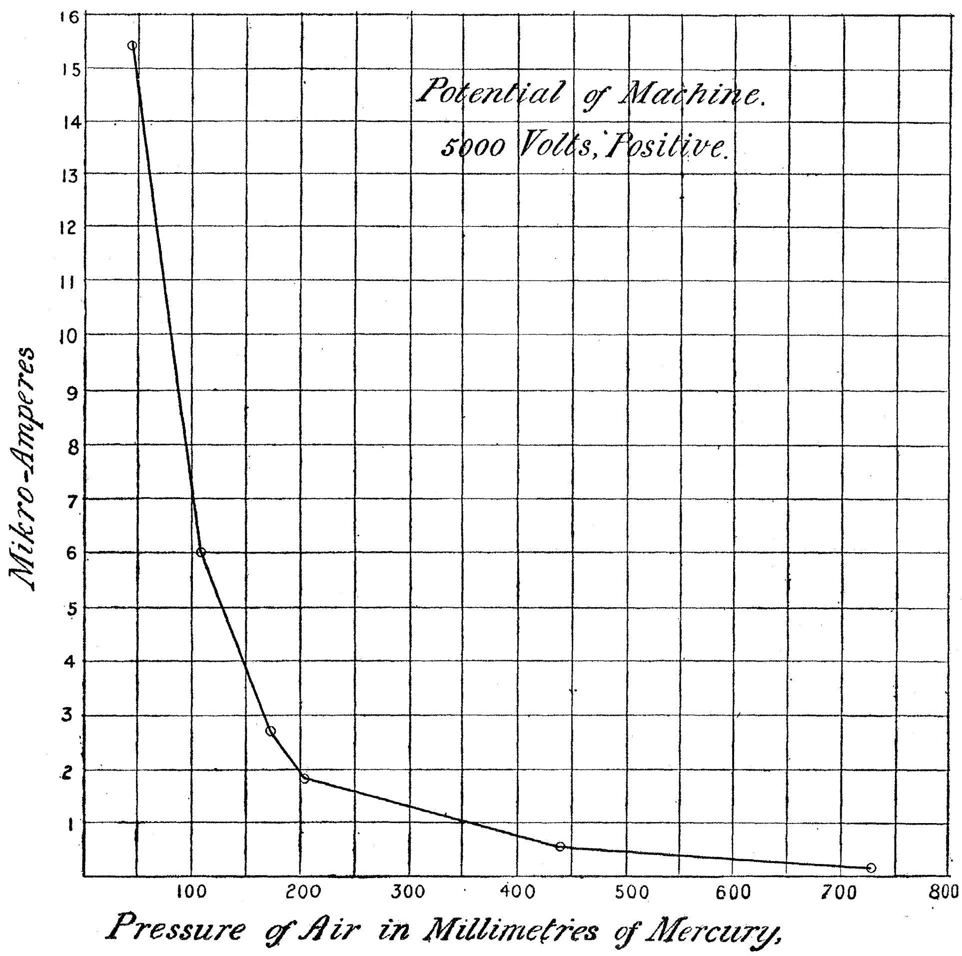
Throughout each experiment the pressure of the air in the bell-jar was kept constant by regulating the stop-cock, C, so that the abstraction of air by the pump was exactly compensated by the gain through C.

The galvanometer measures only that part of the electricity entering the bell-jar by the wire, *ww*, which leaves it by its metal base. This part is *very nearly* the whole. The observed results show that it is enormously great in comparison with the very small part which is carried away in the current of air to the electric filter.

The galvanometer was shunted by a battery of LEYDEN jars, J, to give steady deflections. Its sensitiveness was 1/22·1 of a mikro-ampere per scale division.

§ 83. First, we kept the potential of the needle constant throughout a set of experiments made at different air-pressures, and in this way we found that the current through the air to the metal of the jar became greater as the pressure of the air in the bell-jar became less, down to the lowest pressure to which we went, which was 40 millims. Curve 10 shows the relation between the current and the air-pressure at a potential of 5000 volts. Similar curves were got for other electric potentials.

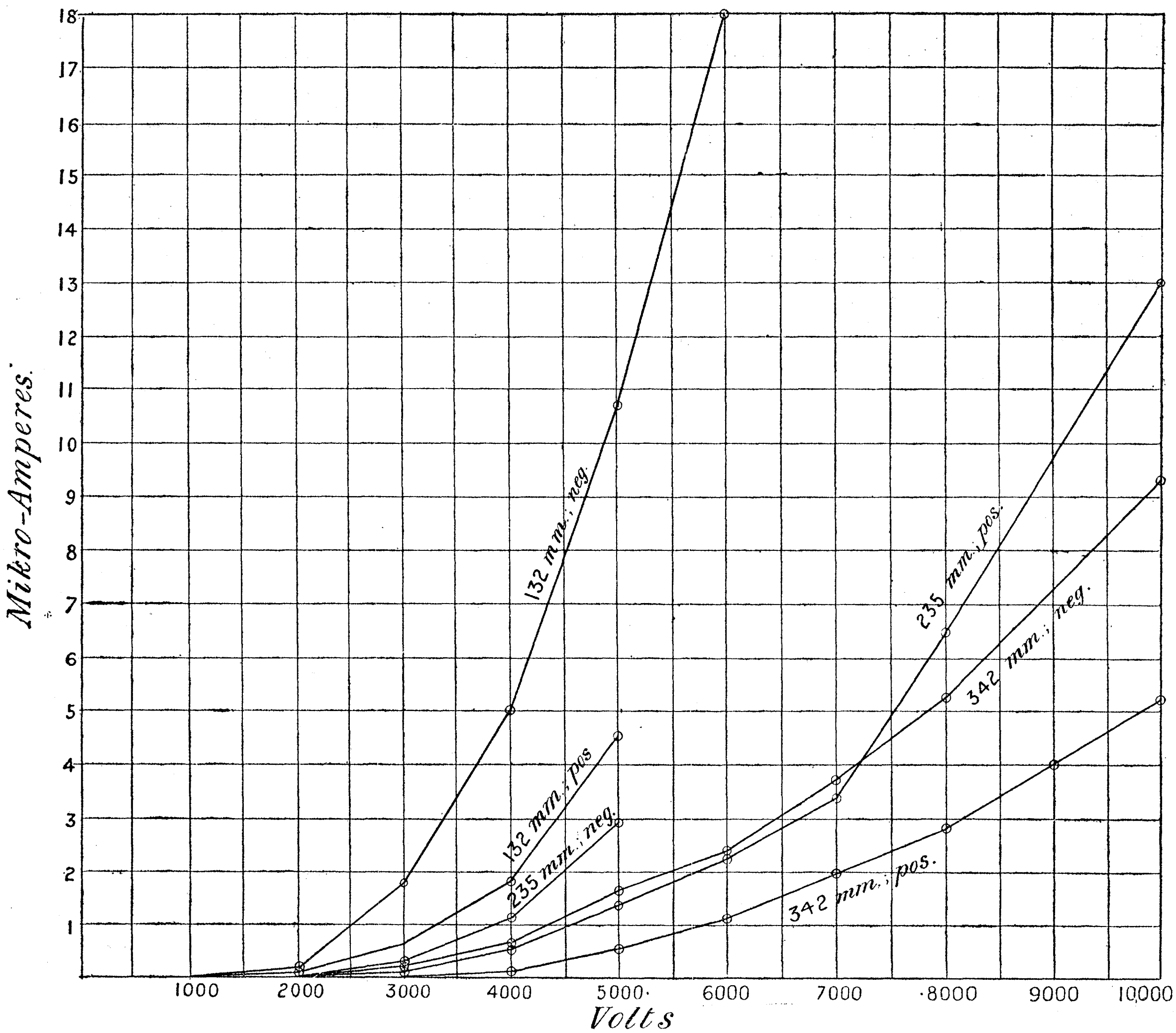
Curve 10.



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

§ 84. We found also that as the air became rarer it was not so much electrified. This was shown by the electric filter and electrometer. Thus the electrometer deflection for a pressure of 360 millims. was only about one-sixth of that for 760 millims. with the same number of strokes of the pump, and the same potential of the electric machine.

Curves 11 to 16.



§ 85. We next kept the pressure of the air in the bell-jar constant and varied the electric potential of the electrifying needle. In this manner we found how much the current through the air in the jar was increased by increasing the potential. The curves 11 to 16 represent the relation between the potential of the needle and the current from the needle-point through the air to the metal of the bell-jar, for certain definite air-pressures, and for positive and negative electrification. It will be noticed that for the same air-pressure the current is greater for negative tnan for positive electrification.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

§ 86. At each air-pressure the electrifying needle must be raised to a certain potential before the galvanometer shows any current. Thus for a pressure of 342 millims. no current was shown by the galvanometer at a potential of 2000 volts negative; and for a pressure of 235 millims. no current was shown at a potential of 1000 volts negative or 2000 volts positive.

§ 87. We found also that air at a given pressure was electrified to a greater extent by a certain potential of the needle than by other potentials higher or lower. Thus air at a pressure of 470 millims. was electrified by the needle at 10,000 volts 1·6 times more than at any other potential we tried; while air at a pressure of 340 millims. received maximum electrification, whether positive or negative, when the potential of the needle was 3000 volts.

§ 88. We are indebted for valuable help and co-operation in the carrying out of these experiments to WALTER STEWART, M.A., B.Sc., to VINCENT J. BLYTH, to JOHN F. HENDERSON, to WM. CRAIG HENDERSON, M.A., B.Sc., and to W. S. TEMPLETON, M.A., B.Sc.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES