VI. CONDUCTANCE PRODUCED IN GASES BY RÖNTGEN RAYS, BY ULTRA-VIOLET LIGHT, AND BY URANIUM, AND SOME CONSEQUENCES THEREOF [1]).

(Philosophical Magazine Vol. 43, 1897; pp. 418—439).

§ 1. We propose in the following paper to give the results of experiments carried out by us at Lord Kelvin's suggestion, and with his help, in the Glasgow University Physical Laboratory. We shall give first results which relate to the conductance produced in gases by Röntgen rays, by ultra-violet light, and by uranium. Secondly, results bearing on the quasi-conductance produced in solid dielectrics by Röntgen rays. Thirdly, we shall give an account of experiments which we made to measure the difference of potential between wires of the same metal connected metallically with two plates of any two metals between which Röntgen rays, ultra-violet light, or uranium rays pass.

§ 2. *On the Conductance produced in Air* at ordinary pressure and at different voltages, by Röntgen rays, by uranium, and by ultra-violet light.

To measure the conductance produced in air by Röntgen rays and by uranium, we used an arrangement consisting of two quasi leyden-jars, A and B, with their inside coatings connected together. The outside coating of A was connected to the case of a quadrant electrometer, the outside coating of B, which was insulated on a block of paraffin, to the insulated terminal of the electrometer (see fig. 1).

In all the experiments in which the two-leydens arrangement was used the leyden B remained the same. It consisted of a cyl-

[1]) [En collaboration avec Lord Kelvin et J. C. Beattie. Ed.].

indrical lead can, 25 cm. long, 4 cm. diameter. A metal bar about 1 cm. diameter, 25 cm. long, was supported centrally on paraffin filling the whole space between the metal bar and the containing lead. The metal bar was connected by a wire to the in-

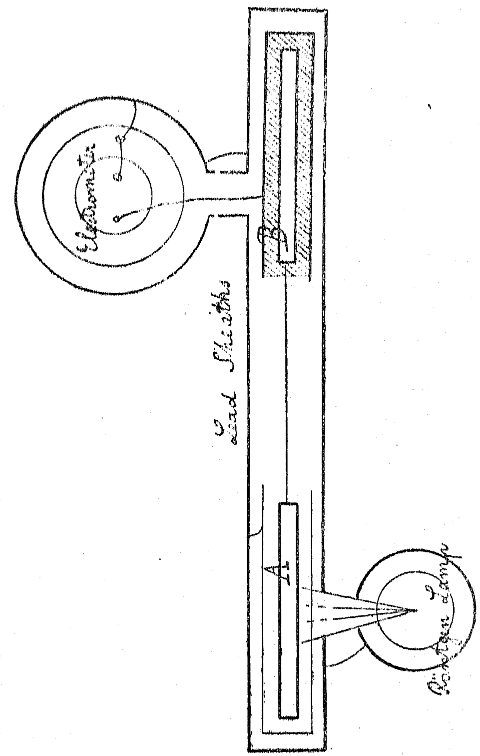

Fig. 1.

[From „Nature", Mar. 25, 1897].

ternal coating of A. To protect this wire from inductive effects it was surrounded by a tube of lead connected to the case of the electrometer.

In the experiment with Röntgen rays the leyden A consisted of an aluminium cylinder, 16 cm. long, 3 cm. in diameter. This cylinder was connected to the case of the electrometer. The insulated metal inside it, which was a flat strip of aluminium about 10 cm. long and $1^1/_2$ cm. wide, cut from the same sheet as the surrounding aluminium tube, was supported at one end by a small piece of paraffin so placed as to be out of reach of the action of the Röntgen lamp [1]). The rays from the lamp were allowed to pass from a lead cylinder surrounding it and connected to the case of the electrometer by a small hole about 0·3 square cm. in area. They fell on the aluminium sheath transparent to them and rendered the air between it and the insulated aluminium within conductive.

To get a definite difference of potential, the two pairs of quadrants of the electrometer were placed in metallic connexion. Then one terminal of a battery or of an electrostatic induction machine was connected to the internal coatings of the two quasi leyden-jars, and the other terminal to the case of the electrometer. The difference of potential produced was measured by a multicellular voltmeter in the case of voltages under 500 volts, and on a vertical single-vane voltmeter for higher differences.

When the desired difference of potential had been established, the metallic connexion of the battery, or of the electric machine, with the internal coatings of A and B was broken, and this charged body left to itself. To find the loss due to imperfect insulation the pair of quadrants in metallic connexion with the outside coating of B was insulated in the ordinary way, and the deviation of the electrometer reading from the reading obtained when the quadrants were metallically connected — which we shall call the metallic zero — per minute was observed. To find the loss when the rays were acting, the two pairs of quadrants were again placed in metallic connexion and the Röntgen lamp set going; then the pair of quadrants connected to the outside coating of B was insulated from the other pair, and the deviation from the metallic zero again observed per minute.

We tried various differences of potential, ranging from a few volts to 2200 volts. The results we obtained showed that the rate of leak did not appreciably increase from a voltage of about 6 volts to 2200 volts.

Positive and negative charges leaked away at the same rate.

[1]) The Röntgen lamp was a focus tube of the Jackson pattern.

These results confirm and extend through a very wide range of voltage the result announced by Thomson and McClelland in a paper communicated to the Cambridge Philosophical Society, March 1896.

To test the conductivity induced in air by uranium, we first used the two-leyden method described at the beginning of this section. The leyden A was a cylinder of aluminium with one end covered with aluminium. This cylinder formed the external coating of the leyden-jar. The internal coating was a disk of aluminium insulated on paraffin. The uranium, which was a disk 5·5 cm. diameter, 0·5 cm. thick, was placed inside a cardboard cylinder with one end open and the other covered with aluminium, thin enough to be transparent to the uranium influence, so as to touch the aluminium end (see fig. 2).

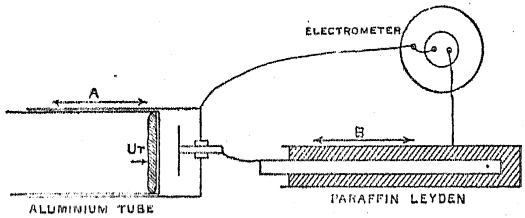

Fig. 2.

This cardboard cylinder could be moved backwards and forwards in the aluminium cylinder, so that the distance between the insulated disk in the latter and the aluminium end of the former could be varied. The uranium thus acted through the aluminium end of the cardboard box and made the air between the end and the insulated aluminium disk conductive. The leakage was in this way made slow enough to be easily observed in the electrometer. The rate of leak was not perceptibly increased when the piece of uranium was heated nor when the sunlight fell on it.

The aluminium end of the cardboard box and the outside coating of the aluminium cylinder were connected to the case of the electrometer. The insulated aluminium disk was connected to the inside coating of the leyden B. These inside coatings were charged to a known potential and then left to themselves. The air-space between the insulated aluminium disk and the aluminium end of the cardboard box was 2 cm. The voltages used were therefore voltages per two cm. of this air-space. With this arrangement the leakage per minute — the necessary correction due to the natural leakage with uranium removed having been made — at various voltages was:

(*a*)

Voltage.	Leakage per minute in sc. divs.
6	56·0
10	65·5
44	113·0
88	128·0
176	156·0
750	219·0
1250	229·0
2000	260·0
3000	276·0

[Sensibility of electrometer 24 sc. divs. per volt of subsidence of difference of potentials between coatings of A].

We also investigated the conductivity produced in air by a second piece of uranum 3 cm. long, 1 cm. broad, and about

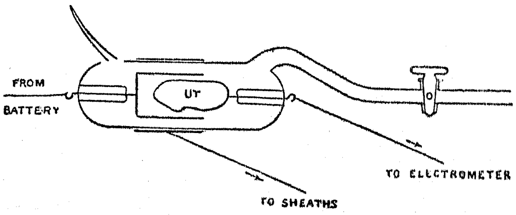

Fig. 3.

0·5 cm. thick. This was mounted firmly in a glass bulb 6 cm. long, 3 cm. diameter, on a platinum wire fused into one end of the bulb. The uranium in the bulb was surrounded throughout two-thirds of its length by a zinc cylinder 1·5 cm. in diameter. This zinc cylinder was kept in position by a stiff platinum wire fused into the other end of the glass (see fig. 3). Two glass tubes were fixed on to the bulb; by means of these any desired

gas could be introduced or any desired vacuum produced. Round the outside of the glass bulb a strip of tin-foil was placed and connected to the case of the electrometer. This prevented vitiation of our results by a leak between the two electrodes over the outside of the glass. The bulb was first evacuated and then filled with dry air. The uranium was then connected to the insulated terminal of the electrometer and the zinc to one terminal of a battery or of an electrostatic inductive machine, the other terminal being connected to the case of the electrometer. For voltages up to 100 volts the terminal was kept connected to the zinc while the leakage due to the presence of the uranium was being observed. For higher voltages the zinc was first brought to the voltage given in the table and then disconnected and left to itself.

(*b*)

Voltage	Leakage per minute in sc. divs.
2	92
4	100
22	120
92	129
132	138
200	130
300	137
415	136

[Sensibility of electrometer 140 sc. divs. per volt].

The appended curves (fig. 4) were drawn by taking the leakage per minute as ordinate, the voltage as abscissa. Curve (*a*) represents the results of the first series of experiments (*a*) reduced to voltages per 2 mm. between the outside coatings of A. Curve (*b*) gives the results of the second series of experiments (*b*). It will be seen that with uranium, as with Röntgen rays, the leakage through air is not proportional to the E.M.F. We found also that both positive and negative charges leaked away at the same rate.

With ultra-violet light we have as yet only observed the rate of leak from a charged body for voltages up to two or three volts. The method we employed is one originally used by Righi.

A cage of brass wire gauze was made and connected to the case of the electrometer. Inside it the insulated metal was placed on a block of paraffin, and connected to the insulated terminal of the electrometer by a wire protected against inductive effects. The light from an arc lamp was then let shine through the gauze so as to fall on the insulated metal perpendicular to its surface (see fig. 5).

With this arrangement we found when the insulated metal was zinc, aluminium, or copper, and when a positive or negative charge was given to any one of these metals when insulated, that positive and negative charges leaked away at the same rate when the light

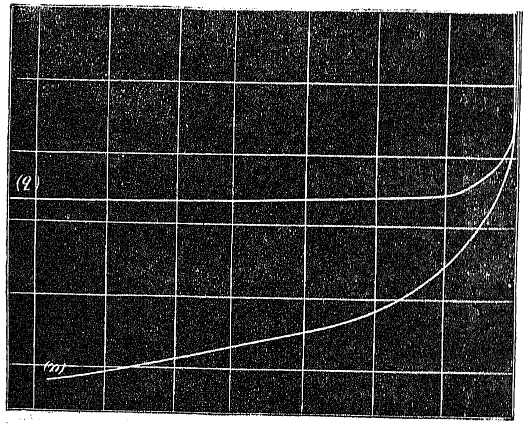

Fig. 4.

from the arc lamp fell on the charged metal, the positive or negative charges being reckoned from the steady electrometer reading which is obtained when the two quadrants of the electrometer are insulated and the ultra-violet light shining. Our results on leakage through air from a body illuminated by ultra-violet light agree with those obtained by Branly.

§ 3. *Effect of Röntgen Rays on the Conductance of Paraffin and of Glass.*

In our first experiments with paraffin we used a brass ball of about an inch in diameter, connected to the insulated terminal of the electrometer by a thin wire soldered to the ball. The ball and the wire were both coated to the depth of about an eighth of an

inch with paraffin. The ball was then laid on a block of paraffin in a lead box with an aluminium window, both of which were in metallic connexion with the case of the electrometer.

The paraffined ball was then charged positively, and the rays caused to play on it. After two minutes the electrometer reading was steady at 0·5 of the initial reading. The electrometer was then discharged by metallic connexion and again charged positively. Its reading remained steady after three minutes at 0·63 of the initial charge. In the third and fourth experiments the readings after three minutes were 0·81 and 0·90 of the initial charges respectively.

The ball was next charged negatively. When the rays were played on it a steady reading was obtained after four minutes at

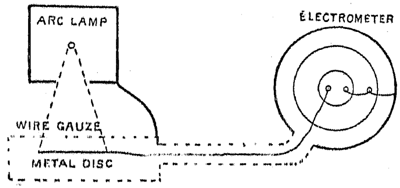

Fig. 5.

0·18 of the initial charge. In the second, third, and fourth experiments the steady readings after four minutes were 0·45, 0·70, and 0·78 of the initial charges respectively.

The paraffin was then removed and the brass ball polished with emery-paper; whether the charge was positive or negative it fell in about five seconds to one definitive position, 0·437 of a volt, on the positive side of the metallic zero, when the rays were played on the charged ball.

These experimental results demonstrate that, for the low potentials — usually 2 or 3 volts — we here used, the Röntgen rays did not produce conductance between the brass ball, when it was coated with paraffin, and the surrounding metal box. We have already seen in § 2 that air is rendered temporarily conductive by the rays, and Röntgen's comparison of the effect of the rays with that of a flame shows that our experimental results are explained by the augmentation of the electrostatic capacity (quasi-condenser) of the brass ball by the outside surface of its coat of paraffin being put into conductive communication with the surrounding lead box and the connected metals.

In our second series of experiments we endeavoured to eliminate the influence of the varying capacity of the quasi-condenser. For this purpose we placed a strip of metal connected to the insulated terminal of the electrometer inside an aluminium cylinder; the space between the metal and the cylinder was first filled with air, afterwards with paraffin. The aluminium cylinder was connected to the case of the electrometer, and inductive disturbances were avoided by surrounding the copper wire connected to the insulated terminal with a lead sheath in metallic connexion with the electrometer case.

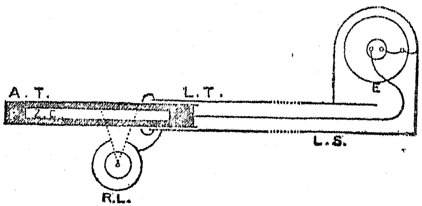

Fig. 6.

In our first experiments with this apparatus we had air, instead of the main mass of paraffin, separating the insulated metal from the surrounding aluminium cylinder, as shown in fig. 6, and we had only small disks of paraffin serving as insulating supports for the ends of the metal, and not played on by the Röntgen rays. When the metal thus supported was charged, whether positively or negatively, the Röntgen rays diselectrified it in about five seconds; not, however, to the metallic zero, but to a zero depending on the nature of the insulated metal and of the metal surrounding it. On the other hand, if the interior insulated metal had initially no charge given to it, yet when the Röntgen rays were played on it through the walls of the surrounding aluminium cylinder, the reading on the electrometer deviated to the same zero to which in the previous case it had fallen, and there remained steady.

With paraffin between the aluminium cylinder and the insulated metal within (see fig. 6) we found no perceptible increase of conductance produced by the Röntgen rays above the natural conductance of the paraffin when undisturbed by them. If the insulated metal was not charged and the Röntgen rays played on it through the aluminium and the paraffin, no deviation from the metallic zero took place when the two pairs of quadrants of the electrometer were insulated from one another.

To make a similar series of experiments with glass we used a piece of glass tubing 9·5 mm. internal diameter, 70 cm. long, and 10 mm. external diameter. The inside of this tube was coated with a deposit of silver, which was placed in metallic connexion with the insulated terminal of the electrometer. The outside of the glass was covered with wet blotting-paper connected to the case of the electrometer. No increase of conductance was produced in the glass when the Röntgen rays were played on it.

We next removed a part of the wet blotting-paper from the outside of the glass, and, after charging the insulated interior metal deposited on the inside of the glass, we heated the exposed part with a spirit flame, in this way making the glass a conductor. The charge was completely removed in $2^1/_2$ minutes. We thus see that our method is amply sensitive to the conductance produced in glass by heating.

The differences of potential concerned in the experiments described in the last paragraphs were not more than two or three volts per centimetre of paraffin or per half-millimetre of glass.

To extend our experiments to higher voltages we used the two-leyden method described in § 2. In the experiments on paraffin the leyden A was the aluminium cylinder filled with paraffin in which an insulated metal — now connected to the inside coating of B — was embedded, already referred to. With this arrangement we found that, with a difference of potential up to 2500 volts per centimetre of paraffin, no increase of conductance was produced by the Röntgen rays.

In the experiments with glass the leyden A consisted of the glass tube already used. Its inside coating of silver was now connected to the inside coating of B. With glass also we could not find any increase of conductance produced by the Röntgen rays with differences of potential reaching up to 2000 volts per half-millimetre of glass.

§ 4. *Analogous Effects produced by Flame and by Röntgen Rays.* Two similar sticks of paraffin, which we shall call C and D respectively, each of about 4 sq. cm. cross section, were coated throughout half their lengths with tinfoil. These tinfoils ought to be each metallically connected to the case of the electrometer.

To obtain a sufficiently delicate test for their electric state, a metal disk of 3 cm. diameter was fixed horizontally to the insulated terminal of the electrometer.

The two pieces of paraffin were first diselectrified by being held separately in the flame of a spirit-lamp. Their nontinfoiled ends were then pressed together, and their electric state tested after separation. It was found that they were still free from electric charge. After this, D was charged by being held over the pointed electrode of an inductive electric machine. The quantity of electricity given to it in this way was roughly measured by noting the electrometer reading when the paraffin was held at a distance of 4 cm. above the metal disk connected to the insulated terminal of the electrometer.

The free ends of C and D were again held together, and, after separation, both pieces were tested separately. The charged one, D, had suffered no appreciable loss, and the other, C, induced an electrometer reading of a few sc. divs. in the same direction, when held as near as possible to the metallic disk without touching it. This showed that an exceedingly minute quantity of electricity had passed from D to C when they were in contact.

C was then diselectrified by being held in the flame. The ends of C and D were again put together — D still having the charge previously given to it — and in this position were passed through the flame. They were tested with their ends still pressed together, and it was found that, when held as near as possible to the metal disk without touching it, no reading was produced on the electrometer. After this they were separated and tested separately; and it was found that D, when held over the disk, gave a large reading in the same direction as before the two with their free ends together had been passed through the flame, and C (which was previously non-electrified) gave a large reading in the opposite direction.

Exactly similar results were obtained with the two paraffin sticks when Röntgen rays were substituted for flame, and when glass or ebonite was used instead of paraffin.

The explanation clearly is this: — The flame or the Röntgen rays put the outer paraffin surfaces of C and D temporarily in conductive communication with the tinfoils, but left the end of D, pressed as it was against the end of C, with its charge undisturbed. This charge induced an equal quantity of the opposite electricity on the outer surfaces of the paraffin of C and D between the tinfoils; half on C, half on D.

When the application of flame or of Röntgen rays was stopped, this electrification of the outer paraffin surfaces became fixed. D, presented to the electrometer, shewed the effect of the charge initially given to its end, and an induced opposite charge of half its amount on the sides between the end and the tinfoil. C showed on the electrometer only the effect of its half of the whole opposite charge induced on the sides by the charge on D's end.

We have here another proof that paraffin is not rendered largely conductive by the Röntgen rays. Had it been made so, then the charge given to the end would have leaked through the body of the paraffin to the outside, and have been carried away either by the tinfoil or by the conductive air surrounding the non-tinfoiled parts.

To show that the induced charges were fixed on the sides, the two sticks, C and D, were next coated with tinfoil throughout their whole length, only one end of each being uncovered. The uncoated end of D was then charged and pressed against that of C, and the two were held either in the flame of a spirit-lamp or in the Röntgen rays. When taken out of the flame or the Röntgen rays, and then separated and tested separately, it was found that D had retained its charge practically undiminished, and that C had acquired a very slight charge of the opposite kind.

§ 5. *Leakage of Electricity from an Electrified Body* in gases other than air at ordinary pressure, due to the presence of uranium.

We were able to investigate the rate of leak in different gases by means of the smaller piece of uranium mounted in a glass bulb as described in § 2 (fig. 3). The gas used was first stored in a reservoir over water. It was then bubbled through strong sulphuric acid and passed over caustic potash, calcium chloride, and phosphoric anhydride into the glass bulb. The bulb was first exhausted to an atmospheric pressure of about 6 mm., then the gas to be used was passed into it. It was again evacuated and refilled. This was repeated about twenty times. Finally, it was strongly heated so as to draw off any adhering layers of the gas which had previously been in the bulb, and then allowed to cool in an atmosphere of the gas at 760 mm. pressure. One of the tubes was then sealed up; the other was closed by a wellfitting and well-greased glass stop-cock.

The following tables give the results obtained with the gases we have experimented on:

Hydrogen.

Voltage.	Leakage per minute in sc. divs.
2 volts.	32
4 „	37
22 „	39
34 „	38
100 „	39
135 „	38

Oxygen.

4 „	125
96 „	157

Carbonic Acid.

4 „	94
95 „	167
238 „	183
255 „	180
2900 „	Spark discharge.

[Sensibility of electrometer 140 sc. divs. per volt].

The results given for these three gases are comparable to the second series of results given in § 2 for conductance produced in air by uranium. We see that the rate of leak is greater in oxygen than in air. No comparative figures need be given as these would vary according to the voltage chosen. The leakage in hydrogen is less than in air; in carbonic acid it is less for 4 volts but greater for 90 volts than it is in air. For the latter voltage the leakage in carbonic acid is greater even than the corresponding leakage

for oxygen. The appended curves show the peculiarities of the leakage in the different gases (fig. 7).

§ 6. *Leakage in different Gases at different Pressures due to Uranium.*

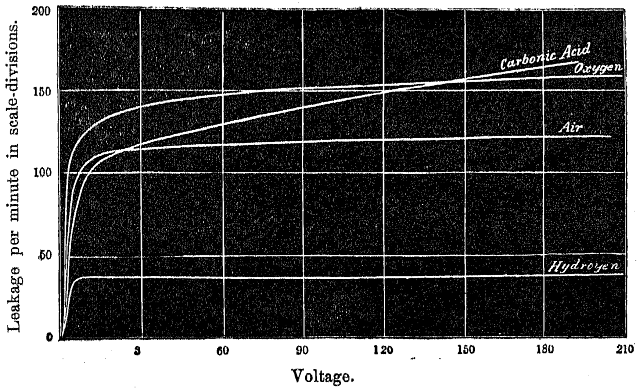

Fig. 7.

The method of filling the glass bulb with any given gas has already been described in § 5. The vacuums up to 2 mm. were produced by a double-barrelled air-pump; higher vacuums were produced by a Töpler pump.

The following tables give the results obtained with the gases we have used:

Air.

α. Atmospheric pressure in mms.	β. Leakage per minute for 4 volts.	γ. Leakage per minute for 96 volts.	β/α	γ/α
760	100	131	·132	·172
240	44	46	·183	·192
190	40	39	·210	·205
121	24	26	·197	·214
64	12	13·5	·187	·212
58	11·0	10·0	·189	·172
23	4·4	3·75	·191	·163
3·6	1·2	1·2	·339	·339

It will be seen from the last two columns of the table that th rate of leak at 4 volts and at 96 volts is nearly proportional to the atmospheric pressure. The results obtained at 3·6 mm. are not very trustworthy. With lower pressures no appreciable leakage at these two voltages was observed.

Hydrogen.

α. Atmospheric pressure in mms.	β. Leakage per minute at 4 volts.	$\frac{\beta}{\alpha}$	$\frac{\beta}{\sqrt{\alpha}}$
760	37	·041	1·43
197	11	·056	·77
66	4	·061	·50
8	1·5	·187	·55

With lower pressures no leakage was observed. The rate of leak is at higher pressures somewhat approximately proportional to the pressure, at lower ones to the square root of the pressure.

Oxygen.

α. Atmospheric pressure in mms.	β. Leakage per minute for 4 volts.	$\frac{\beta}{\alpha}$	$\frac{\beta}{\sqrt{\alpha}}$
760	125	·16	4·5
205	48·5	·25	3·3
64	15·0	·24	2·9
2	2·0	1·00	·71

Carbonic Acid.

Atmospheric pressure in mms.	Leakage per minute for 4 volts.	Leakage per minute for 100 volts.
760	94	167
62	18	21
2	not observable.	

The curves for air, oxygen, and hydrogen, given in fig. 8, were obtained by taking the atmospheric pressure in mm. as abscissa and the leakage per minute for four volts as ordinate.

§ 7. *Measurement of the Difference of Potential* between wires of one metal connected with two mutually insulated metals when the air between them is rendered conductive by Röntgen rays, by ultra-violet light, and by uranium.

The fact that gases are made conductive by Röntgen rays, by ultra-violet light, and by uranium supplies us with a means of measuring the difference of potential between wires of one metal connected with two mutually insulated conductors. This method has already been used by Righi. He determined the difference of potential of wires of one metal connected to two mutually insulated conductors by rendering the air between them conductive under the influence of ultra-violet light. Minchin, Righi, and Murray have made experiments of a similar kind with Röntgen rays.

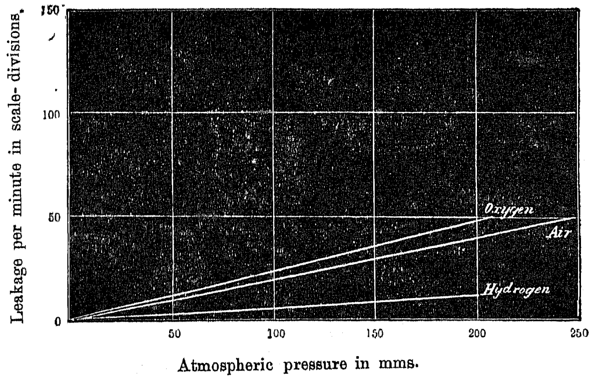

Fig. 8.

In our experiments to measure this difference of potential between wires of one metal connected to two mutually insulated conductors by rendering the air between two mutually insulated conductors conductive by means of Röntgen rays, we used a cylinder of unpolished aluminium connected to the case of the electrometer. Along the axis of this a conductor was placed, supported by its ends on small blocks of paraffin. This insulated conductor was connected by a copper wire to the insulated terminal of the electrometer. Suitable means were taken to protect this connecting wire from inductive effects (see fig. 9).

The Röntgen lamp was placed in a lead cylinder connected to the case of the electrometer. The rays passed into the cylinder of aluminium through a window in the lead cylinder 2 cm. broad and 4 cm. long. This window could be screened or unscreened at will.

The course of the experiment was the same with each insulated conductor. The conductor was charged first positively, then negatively; the Röntgen rays were then caused to shine on it through the aluminium cylinder surrounding it and the electrometer-readings taken at fixed intervals, until a steady reading on the electrometer was obtained. The point at which the electrometer-reading remained steady with the rays acting we shall call the rays-zero.

Finally, the insulated conductor was discharged by metallic connexion in the electrometer and re-insulated; the rays were again

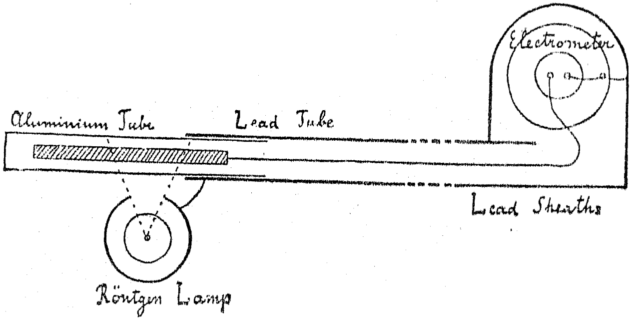

Fig. 9.

caused to shine on it till the deviation from the metallic zero reached the rays-zero and there remained steady.

This deviation from the metallic zero was not stopped by placing an aluminium screen over the window of the lead cylinder surrounding the Röntgen lamp; on the other hand, it was stopped if a lead screen was used.

In the following table, column II. gives the potential-differences of the rays-zero from the metallic zero for twelve different metals insulated within the unpolished aluminium cylinder as described above. Column III. gives the differences for two of the same metals in the interior but with the surrounding aluminium cylinder altered by its inner surface being polished by emery-paper.

I. Insulated metal.	II.	II.
Magnesium tape	— ·671 of a volt.	
Amalgamated zinc	— ·66 „	
Polished aluminium . . .	— ·465 „	
Polished zinc	— ·343 „	
Unpolished aluminium . .	— ·349 „	+ ·35 of a volt.
Polished lead	— ·257 „	
Polished copper	+ ·129 „	
Polished iron nail	+ ·182 „	
Palladium wire	+ ·255 „	
Gold wire	+ ·264 „	+ ·930 „
Carbon	+ ·429 „	

It will be noticed that the difference of potential depends very much on the state of polish of the two mutually insulated conductors.

To make similar experiments with ultra-violet light we used the brass wire gauze cage arrangement described in § 2. That is, we have now air between the wire gauze and the insulated conductor rendered conductive by ultra-violet light. The insulated conductor was 2 cm. distant from the gauze. The steady electrometer-reading after the two pairs of quadrants were insulated and the ultra-violet light shining (which we shall hereafter refer to as the ultra-violet-light-zero) was observed. The difference of potential indicated on the electrometer between the rays-zero and the metallic zero does *not* give, however, the contact-force between the gauze and the insulated conductor within. The reason for this we shall see in the next section.

The following table shows the steady potential-differences in the electrometer due to the conductive effect produced by ultra-violet light in the air between the brass wire gauze and the insulated conductor.

Insulated metal.	Potential-difference.
Polished zinc	— ·75 of a volt.
Polished aluminium	— ·66 „
German silver	— ·19 „
Gilded brass	+ ·04 „
Polished copper	+ ·12 „
Oxidized copper	+ 1·02 „

When the insulated metal was charged either positively or negatively and the ultra-violet light let fall on it, the electrometer-reading deviated until the ultra-violet-light-zero was reached. The rate of deviation was the same for a positive or a negative charge if we reckon the charge from the ultra-violet-light-zero.

We have used two different methods to measure the potential-difference between wires of the same metal connected to two mutually insulated metals when the air between them is rendered conductive by the presence of uranium. The more convenient method is to take uranium as one of the mutually insulated metals. To do this we fixed a metallic disk, 3 cm. diameter, to the insulated terminal of the quadrant-electrometer. Opposite this disk, and separated from it by air, we placed the disk of uranium, 5·5 cm. diameter, connected to the case of the electrometer. With this arrangement we found, after contact between the quadrants was broken at the electrometer, a deviation from the metallic zero. This deviation took place gradually till a steady reading was reached. This steady reading we shall call the uranium-conductance-zero, or shortly the uranium-zero. If the insulated conductor had a charge given to it of such an amount as to cause the electrometer-reading to deviate from the metallic zero beyond the uranium-zero, the reading quickly fell to this conductance zero and there remained steady. When no charge was given to the insulated metal the steady uranium-zero was reached in about half a minute.

The following table gives the potential-differences found in this way:

Metal.	Potential-difference, in volts.
Polished aluminium (1) immediately after being polished	— 1·13
Polished aluminium (1) next day	— ·90
Polished aluminium (2)	— 1·00
Amalgamated zinc	— ·80
Polished zinc	— ·71
Unpolished zinc	— ·55
Polished lead	— ·54
Tinfoil	— ·49
Unpolished aluminium (1)	— ·41
Polished copper	— ·17

Metal.	Potential-difference, in volts.
Silver coin	+ ·05
Unpolished copper	+ ·07
Carbon	+ ·20
Oxidized copper (*a*)	+ ·42
Oxidized copper (*b*)	+ ·90

The great effect of the surfaces as to polish is very evident in the above table.

With a third specimen of oxidized copper a potential-difference of + ·35 of a volt was obtained. This specimen was afterwards connected to the case of the electrometer; a piece of polished aluminium was placed opposite it and connected to the insulated terminal of the electrometer. The uranium disk, insulated on paraffin, was then placed between them, and the deviation observed was equivalent to a potential-difference of — 1·53 volts; that is, we obtained an effect equal to the sum of the effects we obtained when the metals were separately insulated in air opposite uranium.

Instead of placing the uranium directly opposite the insulated metal in air, we also observed the uranium-zero by mutually insulating two metals in air, one of which was transparent to the uranium influence.

For this purpose we made a tinfoil box with tinfoil sufficiently thin to be transparent to the uranium influence. The tinfoil forming the box was connected to the electrometer case. Inside it another metal was insulated on a glass stem and placed so as to be parallel to one end of the tinfoil box. This metal was connected to the insulated terminal of the electrometer. The uranium was placed outside the box about half a centimetre distant from the end to which the insulated metal was parallel. The same uranium-zero was obtained whether the uranium was insulated or connected to the case of the electrometer. The time required to reach the uranium-zero with this arrangement was usually four or five minutes. A charge given to the insulated metal large enough to produce a deviation beyond the uranium-conductance-zero was discharged till this zero was reached. A charge causing the electrometer-reading to deviate in the opposite direction was discharged to the metallic zero and thence on to the uranium-conductance-zero, where it remained steady.

§ 8. *Dependence of the Difference of Potential* as measured in § 7 on distance between the two mutually insulated conductors.

A cardboard box, 46 cm. long, 19 cm. square (see fig. 10), lined with tinfoil, connected to the case of the electrometer was used. Inside this box an insulated disk of oxidized copper 10 cm. diameter was supported in such a way as to allow of its being fixed at different distances from the tinfoil-coated end-wall of the box, facing it. Two windows were cut in the side of the box as shown in the diagram. The Röntgen lamp was placed outside the box at the line joining the windows. These windows were covered with tinfoil gauze to prevent inductive effects from the lamp.

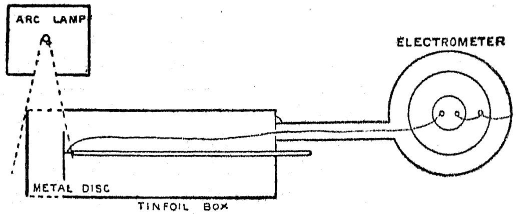

Fig. 10.

With the Röntgen rays shining in between the insulated disk and the opposing tinfoil wall so as to illuminate both, the following results were obtained:

Difference of potential between rays-zero and metallic zero.	Distance between the surfaces.
+·168 of a volt.	1·2 cm.
+·179 "	2·2 "
+·165 "	3·8 "
+·165 "	6·0 "

With a polished zinc disk in place of the oxidized copper disk we found:

—·580 of a volt.	at 1 cm. distance.
—·565 "	" 1·5 " "
—·580 "	" 3·0 " "
—·640 "	" 7·0 " "
—·640 "	" 7·5 " "

The effect of changing the distance between the opposed surfaces is to vary the capacity of our arrangement. Had the Röntgen rays given a charge to the insulated conductors other than that necessary for the equalization of the volta difference of the two mutually insulated conducting surfaces, this would have been shown by a variation of the potential-difference observed in the electrometer when the distances were changed. We should not, however, be justified in concluding that the difference between the rays-zero and the metallic zero is *the contact-difference* between the electrically effective surfaces of the mutually insulated conductors.

We used the same arrangement with ultra-violet light. A glance at fig. 10 will show how the light was placed so as to fall on both surfaces. The insulated conductor employed was the same oxidized copper disk as used in the Röntgen rays experiments. The difference between the metallic zero and the ultra-violet-light-zero was found to depend on the distance between the two surfaces. This will be seen from the following table:

Difference of potential between ultra-violet-light-zero and metallic zero.	Distance between the surfaces.
+ ·615 of a volt.	·6 cm.
+ ·730 "	1 "
+ ·805 "	2 "
+ ·955 "	3 "
+1·205 "	4 "
+1·07 "	4·3 "
+1·15 "	5·0 "
+1·42 "	7·0 "

The fact that the ultra-violet-light-zero depends on the distance between the two mutually insulated conductors was first observed by Righi. We have here something in reality much greater than a mere equalization of the volta difference between the two surfaces, and we cannot say that the difference of potential between the ultra-violet-light-zero and the metallic zero at any arbitrary distance is *the volta difference* between the electrically effective surfaces of the two metals.

To observe the uranium-conductance-zero at different distances an aluminium box connected to the case of the electrometer was substituted for the tinfoil one. The insulated metal was again oxidized copper — not, however, the same specimen as was used with ultra-violet light and with Röntgen rays. The uranium was placed outside the aluminium box about 5 mm. from the end, to which the oxidized copper was kept parallel.

Potential-difference between uranium-conductance-zero and metallic zero.	Distance between the mutually insulated surfaces.
+ ·96 of a volt.	·5 cm.
+ ·97 "	1·5 "
+ ·95 "	2·0 "
+ ·98 "	4·0 "
+ 1·03 "	8·0 "

We see that the potential-difference does not depend on the distance. We cannot, however, infer that therefore the difference between the conductance-zero and the metallic zero is *the contact-difference* between the electrically effective surfaces of the mutually insulated conductors.

§ 9. *Difference of Potential due to Uranium in different Gases at different pressures.*

To observe the effect of different gases at different pressures on the uranium-conductance-zero we used the small piece of uranium mounted in a glass bulb as described in § 2. The precautions taken in filling the bulb with gas are also described in the same section.

The uranium was connected to the insulated terminal of the electrometer and the zinc cylinder to the case of the electrometer. In the following table the results obtained with air, hydrogen, and oxygen are given.

Pressure, in mm.	Difference of potential between the uranium-conductance-zero and the metallic zero.		
	Hydrogen.	Oxygen.	Air.
760	+·17 of a volt. (in about a minute; afterwards steady).	+·105 of a volt. (in about a minute; afterwards steady).	+·11 of a volt. (in about a minute; afterwards steady).
193	+·12 of a volt. (in about a minute; afterwards steady).		
66	+·05 of a volt. (6 minutes).	+·11 of a volt. (3 minutes).	

Pressure, in mm.	Difference of potential between the uranium conductance-zero and the metallic zero.		
	Hydrogen.	Oxygen.	Air.
8	+·04 of a volt. (8 minutes).		
2	. . . .	+·10 of a volt in 27 minutes.	
$<\frac{1}{1000}$	·05 of a volt in 28 minutes.		

The uranium-conductance-zero between mutually insulated uranium and zinc differs much less from the metallic zero than it did with the arrangement described in § 7. This is probably due to the oxidation of the zinc of the zinc cylinder. The conductance zero, however, it will be noticed is approximately the same in all three gases.

§ 10. *Voltage necessary to produce a Spark between Uranium and Zinc* at different atmospheric pressures when the distance apart was constant.

The small piece of uranium before referred to was used. The distance between it and the surrounding zinc cylinder was about 2 or 3 mm. We found that at ordinary atmospheric pressure sparking took place in air at 4800 volts. At 232 mm. pressure the potential necessary to produce a spark fell to between 1500 and 2000 volts. At 127 mm. it had fallen to between 1100 and 1300 volts. At 54 mm. it was 700 volts; at 7 mm. 420 volts. At about $\frac{1}{1000}$ mm. the voltage had risen again to 2000 volts.