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

# On the Least Potential Difference Required to Produce Discharge Through Various Gases

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*Phil. Trans. R. Soc. Lond. A* 1900 **193**, 377-394
doi: 10.1098/rsta.1900.0012

# XII. *On the Least Potential Difference Required to Produce Discharge through Various Gases.*

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*Communicated by Lord* RAYLEIGH, *F.R.S.*

Received October 17,—Read November 16, 1899.

## *Introduction.*

MANY experimenters have made observations on the potential difference necessary to produce electric sparks through gases. The field is a very wide one, since the number of circumstances which may be varied is large. The nature and the pressure of the gas, the shape of the electrodes, the distance between them, and the pressure of the gas, may each be altered. The investigation of which I wish to give an account in this paper deals with the potential difference required to produce sparks (or *striking potential* as I shall call it for brevity) in various gases, between large parallel planes, at a fixed distance apart, and at various pressures.

It was found by Mr. PEACE ('Roy. Soc. Proc.,' vol. 52, p. 99) that the striking potential between two parallel plates in air diminished as the pressure diminished till a certain point was reached, and then began to rise very rapidly. The pressure at which the striking potential was a minimum depended on the distance between the plates, and increased as the distance was lessened. The minimum potential itself, however, varied very little with the distance between the plates.

This minimum potential was of the same order as the cathode fall of potential in air, as has been pointed out by Professor J. J. THOMSON ('Recent Researches in Electricity and Magnetism,' p. 158). The following explanation may be offered of the fact that this is a minimum striking potential, and that it is approximately constant.

The negative glow in any gas [as has been shown by WARBURG ('Wied. Ann.,' 31, p. 579)] requires for its production a definite potential difference (about 340 volts in the case of air), independent of the pressure, and constant, so long as the glow is not crushed into a smaller space than that which it would naturally occupy. If the glow is crushed, the potential fall is more. Let us now suppose that the discharge takes place between two parallel plates; a part of the space between these plates is occupied by the negative glow, a part by the positive column. So long as any of the

positive column remains it is clear that the negative glow is not constricted, and consequently it only requires 340 volts to produce it. The greater the length of the positive column the greater the corresponding potential difference; so that the striking potential will be the least possible when the pressure is low enough to make the negative glow occupy the whole space between the plates, but not low enough to make it require more space.

Although Mr. PEACE found the minimum striking potential to vary very little with the distance between the plates, and consequently very little with the pressure, yet the variation with the pressure was much greater than that observed by WARBURG for the cathode fall. WARBURG gives a table showing that a tenfold diminution in the pressure does not alter the cathode fall by 1 volt, *i.e.*, by $\frac{1}{2}$ per cent.

Mr. PEACE gives data showing a rise of 67 volts (20 per cent.) in the minimum striking potential.

It will thus be seen that, though there are theoretical reasons for thinking that the minimum striking potential should be equal to the cathode fall, the experimental evidence hitherto produced is scarcely sufficient to establish this relation. My experiments have been made with a view to determining the relation. The results will be discussed after the experimental arrangements have been described.

## *Description of Experimental Arrangements.*

It was necessary to design the apparatus so as to require as little of the gas as possible, since it was intended to make some experiments on helium as well as on the common gases. The two brass plates of $1\frac{1}{2}$ inches diameter used as electrodes were embedded quite flush in ebonite plates 3 inches in diameter. The object of this was to prevent any tendency to sparking from the backs or edges of the brass discs. Three small ebonite distance pieces were placed between the brass plates, and the whole arrangement fastened together by means of three screws passing through the ebonite. Electrical connection to the brass plates was made by means of wires screwed into them, passing out axially through the ebonite.

The ebonite distance pieces were carefully measured before the apparatus was put together by means of a micrometer screw gauge. The lengths in millims. were :—

$$\text{No. 1} \begin{cases} 0{\cdot}755 \\ 0{\cdot}755 \end{cases} \qquad \text{No. 2} \begin{cases} 0{\cdot}755 \\ 0{\cdot}752 \end{cases} \qquad \text{No. 3} \begin{cases} 0{\cdot}757 \\ 0{\cdot}756 \end{cases}$$

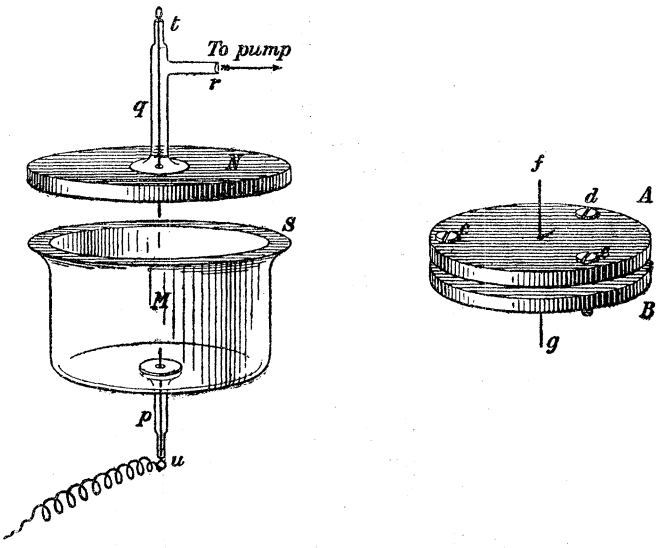
Mean 0·755 mm. = 0·0297 inch.

The brass plates being large compared with the distance between them, the electromotive intensity between them is sensibly uniform.

In order to be able to introduce various gases between the brass plates, and to vary the pressure, it was necessary to enclose them in an air-tight chamber,

The arrangement is represented in fig. 1. A, B, are the ebonite discs, into the fronts of which the brass sparking plates are let. These latter are not visible in the figure. The ebonite plates are held together by the three screws $c$, $d$, $e$. The small distance between them is equal to the thickness of the distance pieces. The leading wires pass to the plates at $f$ and $g$.

Fig. 1.



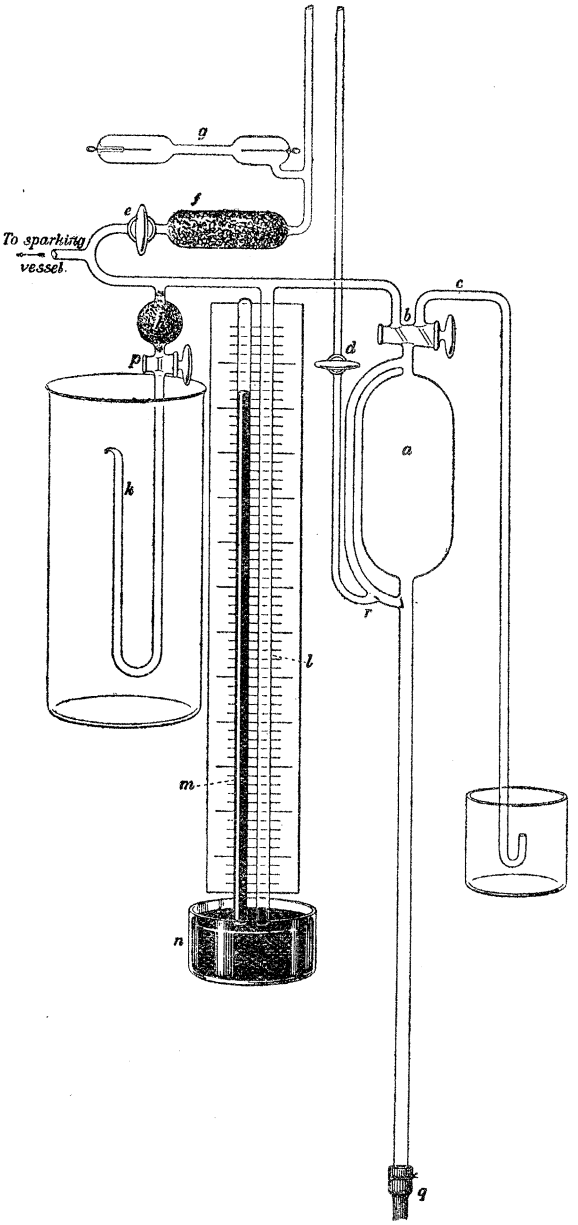

This whole arrangement is enclosed in the cylindrical glass pot M, shown separately for the sake of clearness. M has a broad ground flange S, which is covered by the glass lid N, the joint being made tight with sealing wax. The leads are introduced through holes drilled in the middle of the lid and the bottom of the pot. Over these holes are placed the glass tubes $p$, $q$, up which the wires pass. These tubes have flanges at the ends, ground flat so as to fit the flat surface to which they are cemented. A side tube $r$ provides the means of admitting and withdrawing gas. The wires are fused through the tube at $t$ and $u$.

In order conveniently to vary the pressure and adjust it to any desired value, it was necessary to provide a reservoir into which the gas could be drawn, or from which it could be expelled, by raising or lowering a mercury vessel. It was also necessary to provide a means of exhausting the apparatus. A special form of mercury pump was designed, by means of which both these objects could be attained. By thus dispensing with a separate reservoir, the apparatus was considerably simplified.

The pump is shown in fig. 2. The general arrangement of the various parts will, it is hoped, be sufficiently clear from the figure. $a$ is the pump, which also serves for the adjustment of the pressure in the manner to be presently described. $g$ is a vacuum tube, which serves for observing the spectrum of the gas as a test of its purity. $f$ and $h$ are phosphoric anhydride drying tubes. $d$ and $e$ and $p$ are ordinary

glass stopcocks. $b$ is a three-way glass stopcock. $l$ is the manometer tube. A barometer tube, $m$, is arranged by the side of it, and dips into the same mercury vessel $n$. The height of the mercury columns in these tubes can be read off to the $\frac{1}{10}$th of a millim. on the mirror glass scale behind them. The difference of these heights, of course, gives the pressure of gas in the apparatus.

Fig. 2.




$k$ is a U-shaped tube immersed in a glass beaker, and serves for the introduction of gas into the apparatus. Before filling with gas, it is necessary to remove the air from the sparking vessel.

For this purpose stopcocks $d$ and $e$ are opened, and $b$ is set so as to open communication between $a$ and $c$. The mercury reservoir (not shown) attached to the india-rubber hose $q$ is raised. Mercury rises in $a$, driving out the air through $c$, and on lowering the mercury, fresh air bubbles in at $r$, just as in the ordinary Toepler pump. When the apparatus has been exhausted, stopcocks $d$ and $e$ are shut. $b$ is turned so as to open communication between $a$ and $r$, and gas is admitted through $p$ to any desired pressure. The pressure can then be varied at pleasure by raising or lowering the mercury in $a$. The mercury reservoir attached to the hose $q$ can be fixed at any given height so as to make the mercury stand at a corresponding height in $a$. The object of shutting off the part between the stopcocks $d$ and $e$ is to make the volume in connection with $a$ as small as possible, thus making it possible to obtain a greater range of pressure without admitting or removing gas permanently. Another advantage of this contrivance was that, when helium was to be used, less of it would be required. The volume required to fill the apparatus to atmospheric pressure was only about 40 cc., when $a$ was entirely filled with mercury.

We now come to the arrangements for producing and measuring the striking potential. A large Wimshurst machine was used. It was driven at a constant speed by means of an electric motor. The potential difference between its terminals was measured by means of one of Lord Kelvin's multicellular electrostatic voltmeters. This instrument has been checked by Mr. Capstick. He compared it with a quadrant electrometer standardised by Clark cells, and found it practically correct. I have also verified it to some extent myself, by observing the *additional* deflection produced by 50 volts, this latter voltage being determined by a Weston voltmeter, believed to be trustworthy. No measurable discrepancy was detected.

Some previous experimenters have used a Wimshurst machine in direct connection with the spark terminal, and have turned it till the spark passed. This method succeeds fairly well when large spark lengths and, consequently, large spark potentials are to be measured. But when the spark potential is small it is scarcely possible to raise the potential slowly enough to prevent the needle of the instrument swinging violently; and if this occurs, it is of course impossible to make any accurate observations. Peace (*loc. cit.*) failed to get consistent measurements with the Wimshurst machine. He was driven to the use of a battery of storage cells. The use of these, however, very much adds to the trouble of the investigation, and I was able to avoid it in the following manner. The machine was shunted by means of a fluid high resistance column of variable length. When running at a constant speed the difference of potential at the terminals of the resistance column was constant, and depended of course on the length of the resistance column in use. By gradually increasing the amount of this resistance the potential difference could be raised to any desired value and adjusted with the utmost nicety.

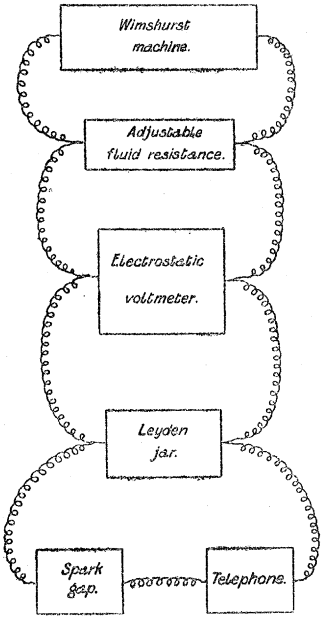
In order further to improve the electrical steadiness of the arrangement a large

Leyden jar was also connected across the terminals of the machine. The capacity thus added diminished the effect of any slight irregularities in its action.

It is not easy to observe the faint sparks which pass between the sparking plates unless the observer gives his undivided attention to watching for them, and if this be done it is impossible to read the potential difference at the exact moment when the spark takes place. A telephone was therefore inserted in series with the spark gap, and arranged in a clip so as to be against the observer's ear when his eye was in the proper position for reading the voltmeter. Whenever a spark passed, the telephone gave an easily audible click. By means of these arrangements the measurements could be taken with considerable rapidity and precision.

A diagram (fig. 3) of the electrical connections is given below.

Fig. 3.




It must be remembered that the first spark taken through a gas passes with far greater difficulty than those which succeed it. I have found a gas able to sustain for a short time a potential difference three times as great as that required to produce discharge through it when this initial resistance had been broken down. If the measurements of the spark potential are to be compared with the cathode fall measurements made while a continuous current was flowing through the gas, it is clear that they should be made with the gas in its electrically weakest condition, that is, immediately after it has been vigorously sparked through. This condition was complied with in my experiments.

In taking a measurement of the spark potential, the pressure of the gas was adjusted to the desired value and read off. The machine was started, and the resistance column lengthened until the potential rose sufficiently to cause the first spark to

pass. This first spark was followed by a torrent of others, the telephone emitting a chattering noise. The resistance column was gradually shortened until these sparks ceased, and then cautiously lengthened until they just began again.

At the moment when this happened the voltmeter was read. The voltage was allowed to rise slowly enough to prevent any appreciable swing of the needle.

When an observation had been taken, the voltage was again reduced below the sparking value, and then again cautiously increased by lengthening the resistance column. When the telephone began to click the reading was again noted. Ten observations were usually taken at each pressure. They could be obtained in fairly rapid succession.

### *Experiments on Atmospheric Air.*

The first set of measurements was made on atmospheric air, not specially well dried.

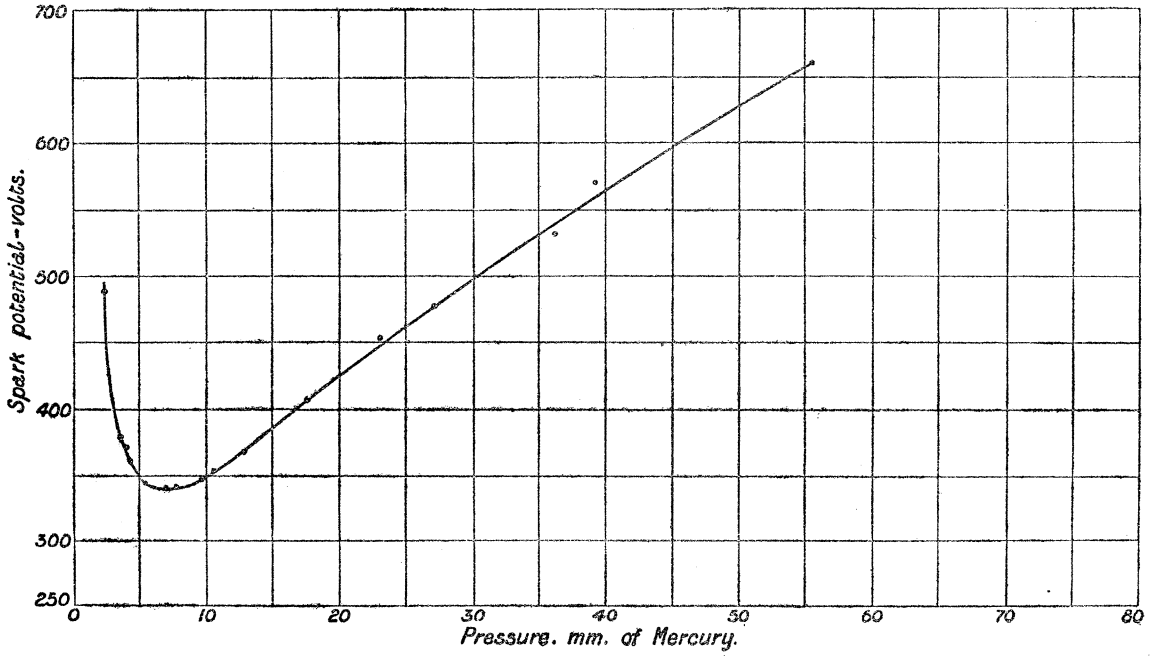
The readings will be given in full, as an example, to show the degree of concordance obtained.

| Pressure (mm.) of mercury. | Spark potential (volts). | Mean value of spark potential. |
|---|---|---|
| 72·4 | 800, 780, 760, 740, 740, 760, 780, 770, 770, 770 | 767 |
| 55·6 | 640, 650, 665, 650, 660, 667, 662, 680, 670, 660 | 660 |
| 39·1 | 570, 580, 555, 578, 580, 572, 563, 575, 560, 565 | 570 |
| 36·1 | 540, 530, 520, 550, 510, 520, 520, 540, 525, 550 | 531 |
| 27·2 | 470, 470, 466, 470, 490, 475, 485, 480, 484, 485, 468 | 477 |
| 23·1 | 461, 460, 458, 440, 462, 459, 451, 432, 457, 455 | 454 |
| 17·5 | 410, 413, 421, 402, 405, 400, 412, 409, 407, 405 | 408 |
| 13·1 | 370, 376, 360, 370, 359, 358, 380, 375, 365, 375 | 369 |
| 10·7 | 350, 351, 358, 360, 353, 360, 350, 352, 353 | 354 |
| 9·6 | 355, 345, 348, 340, 349, 350, 351, 345, 350, 347 | 348 |
| 7·9 | 341, 339, 341, 342, 342, 340, 341, 341, 346 | 341 |
| 7·0 | 342, 348, 330, 350, 340, 339, 339, 340, 343, 336 | 341 |
| 5·4 | 345, 347, 343, 340, 348, 346, 347, 347, 345, 341 | 345 |
| 4·4 | 360, 362, 362, 361, 365, 365, 360, 365, 355, 360 | 362 |
| 4·0 | 370, 372, 380, 372, 372, 375, 365, 364, 375, 375 | 372 |
| 3·8 | 372, 380, 380, 380, 381, 385, 380, 380, 380, 378 | 380 |
| 2·4 | 500, 490, 483, 483, 502, 480, 470, 487, 500, 483 | 488 |
| 1·8 | 755, 800, 780, 790, 790, 770, 790, 800, 780, 760 | 782 |

The minimum spark potential is thus 341 volts. It will be noticed that the larger potential differences, *i.e.*, those furthest on either side from the minimum, could not be measured with the precision that was possible with those in the neighbourhood of the minimum. As, however, the value of the minimum is the point of chief interest, this is of small importance.

The results are plotted on Diagram No. 1. The smoothness of the curve is some guarantee of the accuracy of the observations.

Diagram No. 1.—Air.




*Hydrogen.*

We now come to the experiments on hydrogen. The hydrogen was prepared first by the electrolysis of caustic potash solution, and dried by means of phosphoric anhydride. The sample of gas thus prepared gave a minimum spark potential of 300 volts. The readings were as follows :—

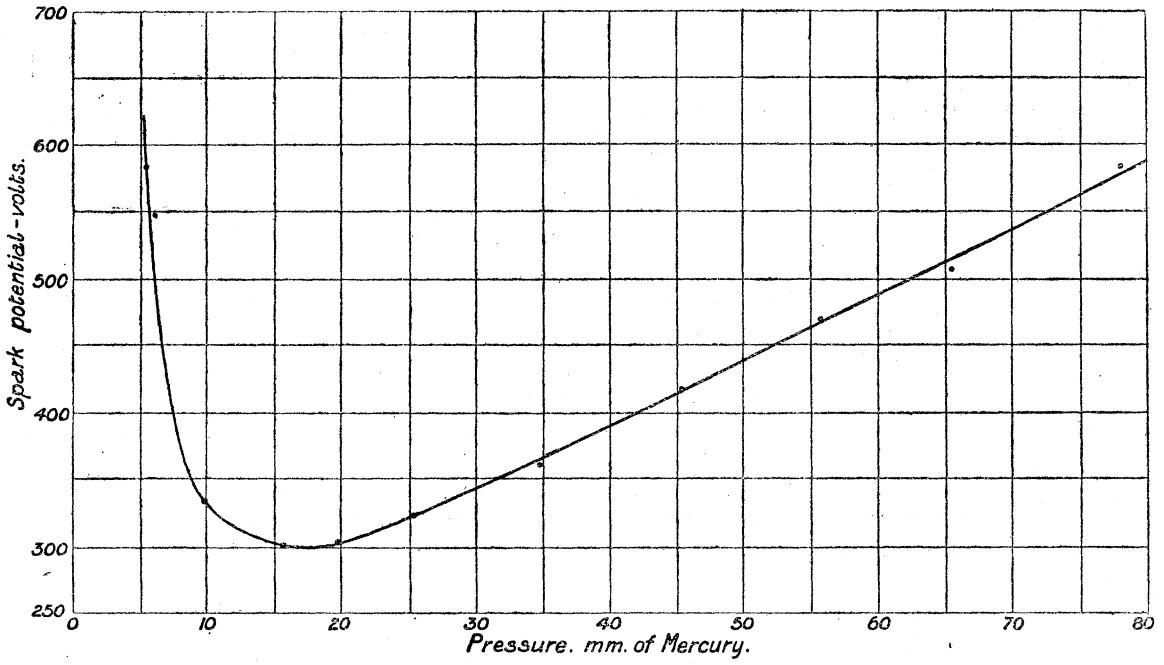
| Pressure (mm.). | Spark potential (volts.) |
|---|---|
| 90·9 | 589 |
| 78·0 | 584 |
| 65·5 | 507 |
| 55·8 | 470 |
| 45·4 | 416 |
| 34·8 | 360 |
| 25·1 | 323 |
| 19·9 | 303 |
| 15·5 | 302 |
| 9·9 | 333 |
| 6·0 | 548 |
| 5·4 | 583 |

These results are plotted on Diagram No. 2.

It will be seen that the minimum is very nearly 300 volts.

In order to check this result a sample of hydrogen was used which had been occluded by palladium foil. This gave results in close agreement with the above, the minimum spark potential being 308 volts.

Diagram No. 2.—Hydrogen.




*Nitrogen.*

This gas is extremely troublesome to deal with. Although each sample tried gave smooth curves for the relation between the spark potential and the pressure, yet no agreement could be obtained between different samples of the gas, even though they were prepared in the same way and with the greatest care I was able to bestow.

Thus, for example, a specimen of nitrogen prepared from air by absorption of the oxygen with alkaline pyrogallol gave for the minimum 347 volts.

A sample from ammonium nitrite purified by passage through caustic potash and sulphuric acid and over phosphoric anhydride gave 351 volts.

Another sample prepared in the same way and dried with especial care, by being allowed to stand in contact with phosphoric anhydride all night, gave 369 volts.

A sample prepared by the removal of oxygen from air by means of metallic copper gave 388 volts.

Although these values for the minimum spark potential vary so widely, yet the rate of change of the spark potential with the pressure, at pressures well above that corresponding to the minimum, was approximately the same in all the samples.

My experience with the nitrogen is entirely in accord with that of Warburg. He

found that the cathode fall in ordinary nitrogen was extremely inconstant. Thus in one case the value of this quantity, at first 315 volts, gradually rose to 410 volts during the passage of the current for many hours. He found that this variation in the value of the cathode fall was connected with the presence of traces of oxygen in the nitrogen—traces too small to be removed by the ordinary chemical absorbents, such as alkaline pyrogallol. I was anxious to try whether the same cause was operative in my case.

The method employed by WARBURG for getting rid of the last traces of oxygen from his nitrogen was to transport metallic sodium electrolytically through the heated glass of his discharge tube, so as to form a clean surface of that metal on the inside. At the high temperature used the sodium rapidly absorbed all traces of residual oxygen.

Such a method was obviously inapplicable to my apparatus, put together as it was with sealing wax joints. I used, therefore, a somewhat different method, which, though troublesome to carry out, gave good results.

This method was to bubble the sample of gas employed repeatedly through the liquid alloy of sodium and potassium.

The alloy must be manipulated in the absence of air to prevent its surface becoming fouled. The vessel in which it was contained is represented in the next figure.

*a* and *b* are glass bulbs blown on the side limbs of a Y-shaped tube *f*. On the bottom limb of this Y there is a stopcock *g*. The lower part of the limb is of capillary bore.

The bulbs *a* and *b* can be placed in communication by means of the stopcock *c*. *d* and *e* are bulbs containing phosphoric anhydride to constitute an additional safeguard against the access of moisture to the alloy. The exit tubes from these bulbs lead respectively to the pump-reservoir and to the sparking vessel.

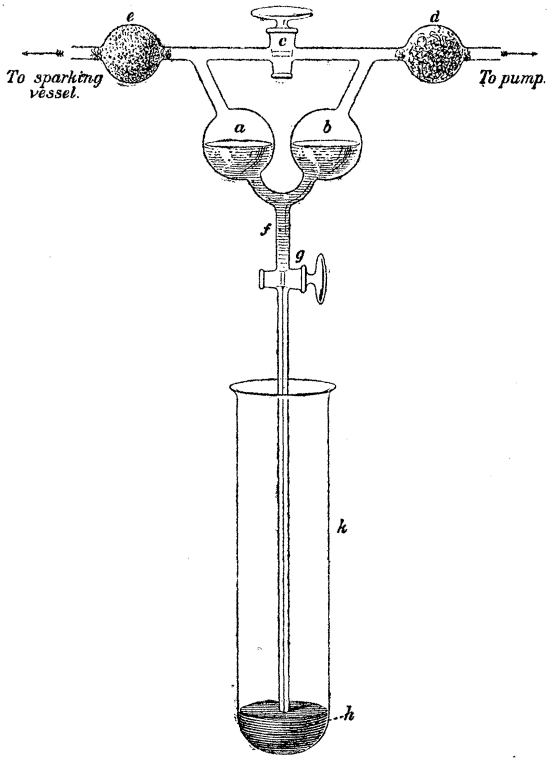
The alloy was prepared in a test-tube *k*, by melting some sodium and adding potassium until the product remained liquid on cooling. A few drops of rock oil were from time to time placed on the surface of the alloy. The vapour from this sufficiently guarded against the access of air.

To introduce the alloy into the apparatus, *c* was opened and *g* closed. The air was then pumped out from the system of tubes.

The test-tube containing the alloy was then brought up as shown in the figure, the end *h* of the Y being *under the surface* of the alloy. *g* was then cautiously opened so that the alloy was sucked up into the bulbs *a* and *b*. When it had risen about half-way up them, as shown in the figure, *g* was closed, thus preventing the entry of any more of the alloy. In this way the alloy could be introduced without any contamination. It had all the appearance of clean mercury. This apparatus was used to absorb traces of oxygen from nitrogen in the following way :—*c* being open and in communication with the pump reservoir, the gas was admitted. *c* was then

closed. On allowing the mercury to rise in the pump reservoir, the gas in the bulb $b$ was compressed, and forced the surface of the alloy down to $f$. The gas then bubbled up through the bulb $a$, and was compressed into the sparking vessel. When the mercury reservoir was lowered again, the gas bubbled back again through the alloy, now in the bulb $b$.

Fig. 4.



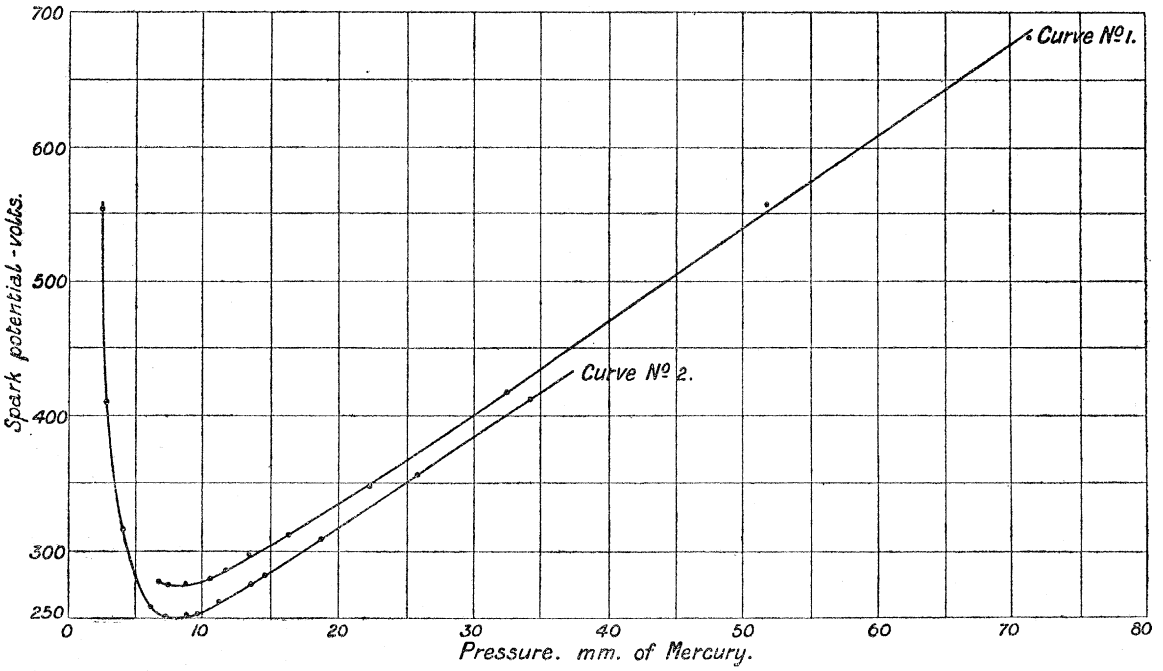

This process was repeated as often as required.

It was not possible to pass *all* the gas through the alloy at each operation; yet by giving time for the diffusion of the gas compressed into the sparking vessel, so as to allow it to become of uniform composition throughout, before being again passed through the absorbent, a very efficient purification could be effected by a few passages of the gas through the alloy. When as much had been drawn into the pump reservoir as circumstances allowed, the amount remaining behind in the sparking vessel was not more than one-fifth of the whole. Thus, supposing all the oxygen to be taken out of that part of the gas which had actually bubbled through the alloy, only $\frac{1}{5}$ would remain after the first operation, $\frac{1}{25}$ after the second, $\frac{1}{125}$ after the third, and so on.

When it was desired to measure the spark potential in the purified gas, the tap $c$ was opened, so as to make the pressure the same in the manometer as in the sparking vessel. If this had not been done, the pressure due to the column of alloy would

have destroyed the equality of these pressures. The nitrogen employed was prepared by the action of heat on ammonium nitrite. Ammonium chloride solution was contained in a flask, fitted with an india-rubber cork, through which passed a dropping funnel and an exit tube for the gas. Potassium nitrite solution was contained in the funnel, and could be dropped into the warmed ammonium chloride. The gas passed through strong sulphuric acid and caustic potash solutions, each contained in ordinary potash bulbs. From these it passed into a chamber containing phosphoric anhydride, closed at either end by taps. An approximate vacuum was first made in the entire arrangement by means of a water pump. This reduced the pressure to something less than a centimetre of mercury. Gas was then liberated so as to slowly fill the apparatus up to atmospheric pressure. A current was allowed to flow for some time through the phosphoric anhydride chamber, so as to wash out all traces of air. When this had been done the chamber was shut off, and the gas left in it all night, so that it might become thoroughly dry. It could then be admitted through a tap into the sparking vessel.

Diagram No. 3.—Nitrogen.




After the gas had been passed several times through the alloy, the following measurements were taken (Diagram No. 3, curve 1) :—

| Pressure (mm.). | Voltage. |
|---|---|
| 71·1 | 683 |
| 51·7 | 559 |
| 32·4 | 418 |
| 22·2 | 348 |
| 16·2 | 311 |
| 13·5 | 298 |
| 11·7 | 287 |
| 10·6 | 280 |
| 8·9 | 276 |
| 7·6 | 276 |
| 6·8 | 279 |

It will be seen that the minimum was about 276 volts—much lower than the values obtained with nitrogen not specially treated.

The treatment with the alloy was now continued for some hours.

The following set of readings was obtained after this :—

| Pressure (mm.). | Voltage. |
|---|---|
| 34·2 | 411 |
| 25·8 | 356 |
| 18·9 | 308 |
| 14·6 | 281 |
| 13·8 | 275 |
| 11·1 | 262 |
| 9·8 | 251 |
| 8·9 | 251 |
| 7·3 | 251 |
| 6·0 | 259 |
| 4·0 | 315 |
| 2·9 | 410 |
| 2·3 | 553 |

Further treatment with the alloy did not appreciably reduce the minimum voltage.

A repetition of this experiment with a fresh sample of nitrogen gave a result in close agreement with the above. The minimum may be therefore taken as 251 volts.

It will be seen that the perfect removal of oxygen does not much affect the slope of the curve in its straight part, where the pressure is above the critical value. The interpretation of this (on the view given above) is that the cathode fall of potential, not that near the anode, is affected by the presence of traces of oxygen.

### *Helium.*

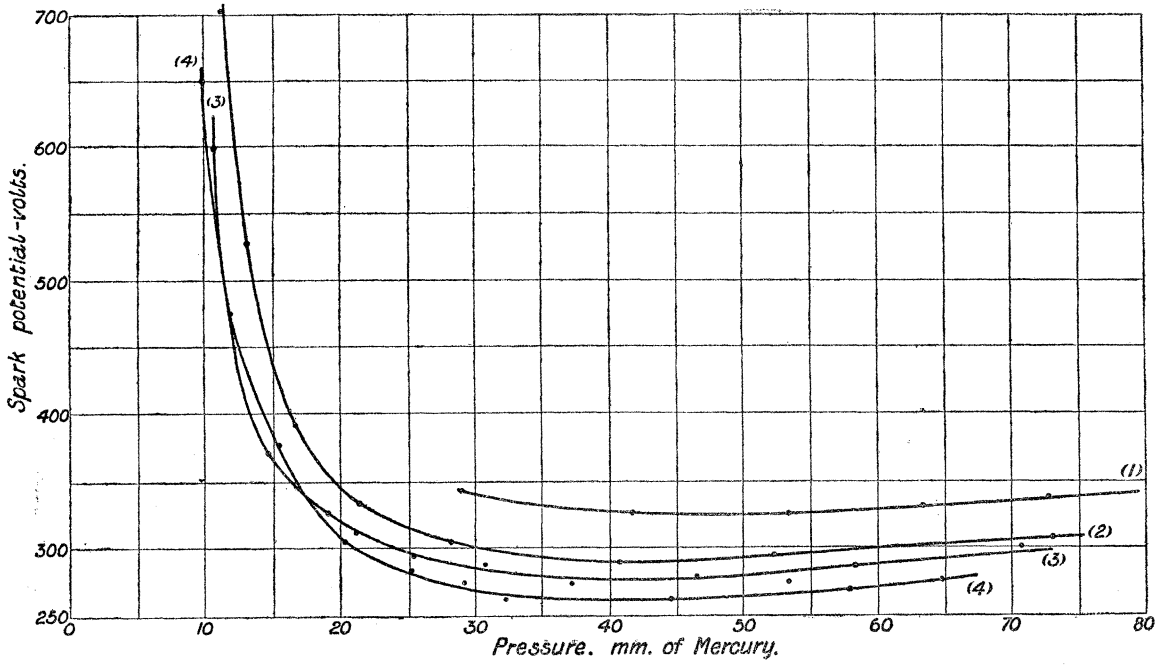
It has been shown by Professor Ramsay and Dr. Collie (‘Roy. Soc. Proc.,’ vol. 59, p. 259) that helium at atmospheric pressure allows sparks to pass through it much

more easily than does air. With a given E.M.F. ten times as long a spark was obtained in helium as in air. This is a very striking result. It seemed, therefore, well worth while to investigate the behaviour of helium as regards its spark potential in the same way as the other gases.

For the method of preparing this gas I must refer to a paper "On the Discharge of Electricity through Argon and Helium," which I hope shortly to publish, where it is described in detail. I merely state here that it was extracted from monazite by means of strong sulphuric acid, and that nitrogen and other impurities were removed from it by mixing with oxygen and exposing it to the action of electric sparks in presence of caustic alkali. The oxygen was then removed by suitable absorbents.

Although all the care I was able to give was spent on the purification of the gas, some cause, the nature of which remains a mystery, made the spark potential variable. It was found that if a specimen of helium remained in the apparatus, and measurements of its spark potential were taken at intervals, the value of this quantity went down. As an example of this, I will give a series of measurements made on a sample of helium from which the surplus oxygen had been removed by the copper-ammonia method of HEMPEL.*

Diagram No. 4.—Helium.




Any gaseous ammonia which might remain in the helium was removed by means of dilute sulphuric acid. The helium was dried by phosphoric anhydride, and examined

* This method consists in bringing the gas into contact with metallic copper at the ordinary temperature, the copper having just been washed free from oxide by a solution of ammonia to which some ammonium carbonate has been added. See HEMPEL, 'Methods of Gas Analysis,' p. 126.

spectroscopically. No trace of nitrogen bands could be seen. The red hydrogen line was visible, as it always is in a vacuum tube. This sample of gas gave the following readings when first put into the apparatus :—

1.

| Pressure (mm.). | Voltage. |
|---|---|
| 94·0 | 348 |
| 83·1 | 340 |
| 72·8 | 339 |
| 63·5 | 332 |
| 53·5 | 326 |
| 41·9 | 326 |
| 29·0 | 343 |

Minimum 326.

The gas was left in the apparatus untouched. Next day the readings obtained were :—

2.

| Pressure (mm.). | Voltage. |
|---|---|
| 91·7 | 341 |
| 73·0 | 309 |
| 52·3 | 295 |
| 40·9 | 288 |
| 28·1 | 303 |
| 21·5 | 332 |
| 16·5 | 391 |
| 13·2 | 528 |
| 11·3 | 703 |

Minimum 288.

The gas was again left untouched till next morning:—

3.

| Pressure (mm.). | Voltage. |
|---|---|
| 81·9 | 316 |
| 70·7 | 301 |
| 58·1 | 285 |
| 46·5 | 280 |
| 37·2 | 274 |
| 30·8 | 288 |
| 25·4 | 294 |
| 21·2 | 311 |
| 19·2 | 326 |
| 1·48 | 370 |
| 1·09 | 599 |

Minimum 274.

It will thus be seen that, after the gas has been sparked through, its sparking potential is lowered. In this case the minimum was lowered from 326 to 288, and then to 274.

To see what the effect of further sparking would be, a torrent of sparks was passed through the gas by means of the machine for an hour. The readings then taken were :—

4.

| Pressure (mm.). | Voltage. |
|---|---|
| 64·9 | 276 |
| 57·9 | 269 |
| 44·8 | 261 |
| 32·3 | 261 |
| 29·2 | 274 |
| 25·2 | 284 |
| 20·3 | 303 |
| 15·6 | 377 |
| 12·0 | 475 |
| 10·0 | 650 |

Minimum 261.

It will be seen that the minimum has gone down still further. Another three hours' sparking did not make any further difference. The minimum spark potential after this treatment was 262 volts, practically the same as before. Other specimens of helium from which the surplus oxygen had been removed by means of phosphorus (at the ordinary temperature) behaved very similarly.

It may be remarked that this behaviour of helium is very like that observed by WARBURG in the case of nitrogen which had not been put through any exceptional treatment for the removal of its surplus oxygen : with this difference, however, that he found the cathode fall go up (from 315 to 410 volts) with the sparking, whereas, in my measurements on helium, the spark potential went down.

It seems not unlikely that if the last traces of oxygen were removed from the helium by means of the sodium-potassium alloy, normal and constant results might be obtained. I hope to examine this point on some future occasion.

## *General Conclusions.*

It remains to discuss the results obtained, and to inquire how far they bear out the conclusion that the minimum spark potential is equal to the cathode fall measured over the whole extent of the negative glow in a vacuum tube.

For this purpose it will be convenient to tabulate the values of these quantities for the various gases side by side.

| Nature of gas. | Cathode fall given by Warburg. | Minimum spark potential found above |
|---|---|---|
| | | volts. |
| Atmospheric air . . . . | 340–350 volts (' Wied. Ann.,' vol. 31, p. 559) . | 341 |
| Hydrogen . . . . . | About 300 volts (' Wied. Ann.,' vol. 31, p. 581) . | 302, 308 |
| Ordinary nitrogen, carefully dried | Varies 315–410 ( „ „ „ p. 557) . | 347, 351 369, 388 |
| Nitrogen specially freed from all traces of oxygen | 230 volts (' Wied. Ann.,' vol. 40, p. 1) . . . . | 251 |
| Helium . . . . . | . . . . . [Values found by myself (see paper on "Discharge of Electricity through Argon and Helium"). 226 volts.] | Varies 326–261 |

In the case of air, the agreement is as good as could be expected, and, indeed, much better. It is also satisfactory in the case of hydrogen.

In ordinary nitrogen the results are in neither case constant. But my numbers all lie between the extremes found by WARBURG.

In the specially purified nitrogen a difference of about 10 per cent. is to be observed. For measurements of this kind the discrepancy is not enough to establish an essential want of equality. It is possible that my method of removing oxygen, which depended on the use of alkali metals at ordinary temperatures, was not quite so efficient as that of WARBURG, who used a high temperature.

In the case of helium alone is the value of the cathode fall seriously different from that of the minimum spark potential.

Although this discrepancy is large, I do not think that, in view of the satisfactory agreement in the other cases, it can be considered to weigh seriously against the equality. It must be remembered that the values found for helium differ much more among themselves than the lowest of them differs from the measured cathode fall. Measurements of the same quantity which do not agree with one another cannot be expected to agree with other independent measurements.

I think it may be considered to be established by these experiments that the minimum spark potential *is* equal to the cathode fall.

One point is very strikingly brought out by the curves. I mean the extremely small rate of increase of the spark potential with the pressure in the case of helium, and the relatively high pressure at which the minimum occurs. All the features shown by the curves for the common gases are seen in the curve for helium, but the difference in degree is very striking. The enormous length of spark at atmospheric pressure in helium as compared with air might almost suggest that the conduction is

effected in some radically different way. But these curves show that the behaviour of helium when conveying the discharge, though very peculiar, is not radically different from that of the common gases.

In conclusion, I must record my best thanks to Professor J. J. Thomson. I cannot adequately express how much I owe to his kind encouragement and advice.



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