VII. *On the Stratifications in Electrical Discharges, as observed in Torricellian and other Vacua.—Second Communication.* *By* JOHN P. GASSIOT, *V.P.R.S.*

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60. IN my former communication I stated that I had obtained several vacua tubes from M. GEISSLER of Bonn; shortly afterwards I had the pleasure of a visit from M. PLÜCKER, the distinguished Professor of Physics in that University, when I ascertained that the experiments to which I referred as having been made in Germany, had been made by that gentleman in vacua-tubes constructed by M. GEISSLER.

During Professor PLÜCKER'S visit to this country, I witnessed, in the laboratory of the Royal Institution, his experiments on the action of a powerful electro-magnet on the negative luminous discharges from an inductive coil, which discharges *in vacuo*, under the influence of the magnet, "coincide in their direction with magnetic curves *;" this phenomenon is very clearly shown in GEISSLER'S tubes, in which the wires are hermetically sealed at the extreme ends, projecting in a straight direction along the tube. Through the kindness of Mr. J. J. GRIFFIN, I had the opportunity of experimenting with upwards of sixty of GEISSLER'S vacua-tubes, in which many beautiful and novel results are produced; in some, for several seconds after the discharges had ceased, the tubes remained throughout their entire length highly phosphorescent. I have not been able to ascertain with accuracy what is the gas, which, however attenuated, must remain in each tube; but from most of them being constructed of a varied form, the discharge presents in the several portions of the same tube an entirely different appearance, not only in colour, but also in the form of the stratifications.

61. As I was desirous, during the progress of the experimental research I had entered on, to know the exact conditions under which each vacuum was obtained, and found, by comparison, that there was some uncertainty in the description of those I had received from M. GEISSLER, I reluctantly laid them aside, and for all the experiments I have to describe in this communication, each tube was charged and exhausted by myself or in my presence. The tubes were constructed by M. CASELLA, and marked with consecutive numbers, a note being taken of each as it was finally sealed; considerably above 100 were prepared, the major part similar in their form to those described in my former paper†; some of these, during experiment, were broken or otherwise destroyed, but

* A translation of Professor PLÜCKER'S paper "On the Action of the Magnet upon the Electrical Discharge in Rarefied Gases," has since been published in the Philosophical Magazine for August 1858.

† Philosophical Transactions, 1858, Pl. I. fig. 3.

those that remain are as they were originally hermetically sealed. To describe all would in several instances be nearly a repetition, although I use some of the original numbers in this communication for the sake of future reference.

62. The terms Air, Hydrogen, Oxygen or Nitrogen Mercurial Vacua, denote, unless otherwise described, that previous to the insertion of the mercury each tube was filled either with air, hydrogen, oxygen, or nitrogen. The tubes were then exhausted by a good air-pump; another supply of air or of gas was admitted, and the tube again exhausted; this was generally repeated two or three times before the introduction of the mercury; any residue remaining after the tubes had been finally exhausted as a Torricellian vacuum would necessarily be mercurial vapour plus the remains of air or of the gas with which the tube had been originally filled.

The greater intensity of the discharge from the outer terminal of an induction coil, compared with that from the inner, whether the discharge is positive or negative, renders it advisable if not indispensable in many experiments that this point should be noted: I had intended to apply the terms inductric and inducteous (first used by FARADAY in 1838), the former to the outer and the latter to the inner; but finding this might lead to some misconception, in the present communication I use the terms *outer or inner positive, outer or inner negative*, to denote the condition of the discharge.

Continuous and reciprocating discharges.—These terms denote the peculiar conditions of the discharge from an induction coil, when taken in vacua-tubes. In a continuous discharge, the needle of a galvanometer placed in the circuit will be deflected; and the stratifications in the vacuum-tube will be also deflected by, and have a tendency to rotate as a whole round, the pole of a magnet.

In a reciprocating discharge, the needle of the galvanometer placed in the circuit is not deflected; such discharge in the vacuum-tube, whether stratified or otherwise, will be divided by a magnet, similar to the discharge when taken from a single terminal (54), which is always reciprocating, as is also the discharge under certain conditions to be described, where both wires of a vacuum-tube are attached to the terminals of the induction apparatus.

In the following experiments, unless when otherwise expressed, one wire in the vacuum-tube was connected with the outer and the other with the inner terminal of the coil.

Character of the Stratified Discharge under different conditions of rarefied Media.

63. If the tube is filled with dry hydrogen, and the discharge from the induction coil be made in the usual manner, no trace of the discharge (the wires being separated in the tube beyond the striking distance in air) will be observed until the gas is rarefied by the air-pump. The discharge first appears as a wavy line of bluish-grey colour; on continuing the exhaustion by the air-pump, assisting the rarefaction by gently heating,

the tube becomes filled with a luminous discharge to within about one inch of the negative wire; the stratifications appear gradually increasing in width, as the vacuum becomes more perfect; and if care is taken to continue the pumping, so as to prevent air being introduced, the tube can be sealed without the stratifications showing the slightest appearance of any redness. Dr. FRANKLAND subsequently suggested to me a mode of exhausting these tubes, which effectually prevents a possibility of the introduction of any air.

64. In a vacuum-tube exhausted by the air-pump alone I have not been able to observe any approach to the cloud-like stratifications which are always to be obtained in good Torricellian vacua. That they evidently do not depend either on the mercury or the tube being free from dirt, but are dependent on the perfection of the vacuum and the total absence of all trace of moisture, is evident; as in one instance the cloud-like stratifications were very distinct at the first discharge, although in the tube the mercury was very dirty, attaching itself in black patches on the sides; the dark band was nearly 10 inches in length while the mercury covered the negative wire. In another instance, during the process of the withdrawal of the mercury from a long tube, the discharges from the induction coil were continued, the wire in the upper portion being positive and the mercury negative; as the mercury descended the stratifications assumed the cloud-like appearance, each nearly one inch in length; on examining the tube traces of moisture were observable adhering to the sides near the negative wire; as soon as the mercury descended sufficiently down the tube, so as to expose the moisture to the vacuum, the cloud-like stratifications instantly changed to narrow bands. This tube was 38 inches in length, and the wires 32 inches apart, the internal diameter being about one inch; the proportion of moisture to the total capacity of the tube must consequently have been very minute.

65. Whenever a perceptible although minute residue of the gas or air remains in a Torricellian vacuum-tube, the stratifications are narrow and close; and if further portions of air or of gas are subsequently introduced, the stratifications gradually close until the discharge assumes the usual appearance of the aurora, as when taken in an air-pump vacuum from the electric machine. In the best Torricellian vacua which I have been enabled to obtain, the stratifications invariably assume the character of a distinct and clearly defined cloud-like discharge; these stratifications are generally more clearly defined towards the negative terminal, close to the dark band, than nearer to the positive.

66. If care be taken in the preparation of Torricellian vacuum-tubes by Mr. WELSH's process*, it is immaterial whether the original air-pump vacuum be from air or from either of the gases I have enumerated (62); the last trace of air or gas being by this process sealed off in the bulb, the discharge in the mercurial vacua will invariably present the cloud-like stratifications. If any appreciable trace of air or gas was permitted to remain, I always found, if air, the stratifications had a red tinge, which by degrees

* Philosophical Transactions, 1856, p. 507.

gave a bluish grey. In some instances oxygen gave the reddish tinge, in others grey, similar to hydrogen. This apparent anomaly I subsequently ascertained arose from the impurity of the oxygen.

67. If the extremity of a vacuum-tube is presented to the prime conductor of an electric machine, or to one of the terminals of an induction coil, a spark can be taken and the glass will be perforated. The perforation is extremely minute, but sufficient under the pressure on the vacuum to admit air or gas; but so slowly does the gas or air enter, that the experimentalist is enabled to note the gradual change which takes place during the progress of the discharges of the induction coil; the change (depending on the size of the perforation) sometimes occupied two or three hours. The extremity of a vacuum-tube after perforation was connected by means of tight-fitting gutta percha tubing to a glass cylinder containing fused chloride of calcium, through which air, hydrogen, oxygen, or nitrogen was permitted to pass into the vacuum; the result of many repeated experiments showed that with hydrogen or oxygen no change in the *colour* takes place; with air or nitrogen the colour of the stratifications changes from bluish grey to a fawn, and ultimately to a deep red tinge; and during this addition of gas or air, the cloud-like stratifications gradually close, becoming narrower and narrower until they are entirely destroyed, passing to a mere luminosity filling the entire tube, and finally into the wave discharge.

Condition of Discharge at Negative Terminal.

68. In some instances several seconds elapsed, during which the induction coil was in action before any luminous effect could be produced in the tube, the first luminous discharge filling the entire tube without any stratifications, the negative wire being surrounded with a brilliant *blue* phosphorescence; if the discharges are now continued for a few seconds, the cloud-like stratifications appear gradually becoming clear, and distinctly separated, leaving the dark band near the negative terminal 3 to 6 inches in length. At this time, and before any black deposit from the negative platinum wire (which now becomes intensely red) is deposited on the glass, a brilliant white luminous discharge (which for the sake of reference I name the White-tongue Discharge) is visible close to the negative wire; this tongue has a tendency to rotate round the pole of a magnet, and consequently assumes the appearance of being repelled or attracted as each pole is alternately presented; while a long brilliant phosphorescent discharge, proceeding from the upper part of the negative terminal towards the positive, is also similarly attracted or repelled by the magnet. This phosphorescent discharge can by manipulation be contracted or expanded by a magnet in a remarkable degree (for distinction I name this the Blue-tongue Discharge).

If the north pole of a magnet is placed close to the negative wire, and over the blue tongue discharge, the discharge will be elongated and repelled, the end thereof being forced on the opposite side of the tube, illuminating the portion on which it impinges with a brilliant phosphorescent blue light.

If the south pole be presented the discharge will be contracted, impinging on and brilliantly illuminating the portion of the tube round the negative wire.

69. In the apparatus* (Plate IX. fig. 7 of my last paper), when one wire is positive and the mercury negative, if the vibrating hammer of the induction coil be pressed by the finger so as to ensure a sudden disruption, the redness on the surface of the mercury instantly disappears, an intense white glow being substituted, while the dark band is nearly filled with stratifications. On carefully examining the discharge when in this state, it will be observed that on pressing the contact-breaker so as to ensure a more sudden disruption, the stratifications which now fill the space previously occupied by the dark band appear also to emanate from the surface of the mercury. If a portion of air $\frac{1}{2000}$ of the capacity of the tube be introduced, the stratifications assume a reddish tinge, and this redness increases as air is added, the redness on the surface of the mercury disappearing; if the discharges are taken from wire to wire on the introduction of a minute quantity of air, the negative wire loses its red glow and becomes intensely blue.

70. I have alluded to a remarkable phosphorescent *blue* tongue discharge from the negative wire (68), and stated that this discharge is strongly affected by the magnet.

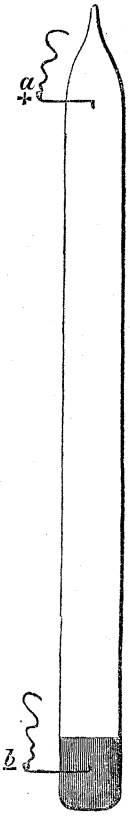
While experimenting with many of the vacuum-tubes, I observed that this peculiar form of the discharge was always more distinct when the stratifications assumed the cloud-like appearance already described. When the stratifications are narrow and close this blue discharge is scarcely visible, although traces of it can sometimes be brought out by a magnet. In vacua which show narrow stratifications, fluorescence pervades the tube equally in all parts; but when the stratifications assume the cloud in a distinct form, *the fluorescence is almost entirely confined to the portion of the tube near the negative wire.* In my first experiments it appeared doubtful whether this blue tongue discharge might not be due to the reflexion on the sides of the glass, from the white-tongue discharge already described; but the result of many experiments made under a variety of conditions, lead me to the conclusion that it is a *distinct phenomenon*, having the appearance of being due to a force or action emanating from the negative terminal.

71. In one tube (Hyd. Merc. Vacuum, No. 47) the white tongue was peculiarly distinct, and the blue very brilliant and clear: in this tube the stratifications were much separated, exhibiting the large and long clouds from the positive terminal, to within four inches of the negative. The phosphorescence in the glass did not appear in any part except close to the negative wire, where it was very brilliant, illuminating that end of the tube with a deep blue colour. If during the discharges a horseshoe magnet is placed *under* the negative wire, the stratifications are brought down towards the magnet, and the white tongue is strongly deflected; on moving the magnet across the tube, the tongue is attracted or repelled according to the pole which is presented; while the blue discharge around the negative, although attracted and repelled, is so, comparatively with the white, in a far less degree.

* Philosophical Transactions, 1858, Part I. Pl. I. fig. 7.

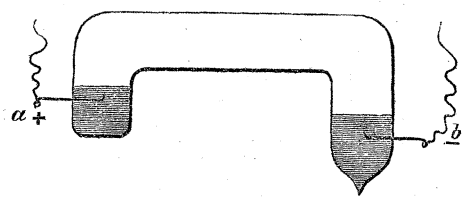
72. Fig. 1 represents a tube 22 inches long, $1\frac{3}{4}$ inch internal diameter: the wires *a*, *b* are 19 inches apart; sufficient mercury remains in the tube to cover the lower wire, and in this manner one terminal is a wire of platinum and the other a surface of mercury. The tube when used is suspended by a string. In this apparatus, with a single cell of the nitric acid battery, particularly clear and distinct large cloud discharges are obtained, leaving a dark band of 14 to 15 inches in length. When a magnet is presented a little above the surface of the mercury, which in this apparatus I always made the negative terminal, the blue-tongue discharge is produced in a most brilliant and beautiful manner, while at the same time the cloud-like stratifications from the positive wire are brought down the tube. By manipulating with a magnet, the blue tongue can be made to extend up the tube, illuminating the side of the glass wherever it impinges with the phosphorescent blue rays. In this tube the vapour of mercury rises very rapidly; condensing on the sides of the glass, the condensation can be easily removed by the liquid mercury. In this tube, moreover, the redness does not appear on the surface of the negative mercury, which is covered with a bright lambent white glow.

Fig. 1.



73. Fig. 2 is another form of a vacuum-tube, 10 inches long, 1 inch internal diameter, in which each of the platinum wires *a* and *b* can be covered with mercury, so as to permit the surface of the metal to be used for both terminals at the same time. With one terminal of mercury and the other of wire, the white-tongue discharge is very distinct, and either with this arrangement or with both terminals of mercury, the blue phosphorescent discharge from the negative is shown in a very marked manner. When a horseshoe magnet is presented towards the cloud-like stratifications in this tube, the stratifications are attracted towards the magnet when the latter is approached in one direction, and repelled when presented in another. I shall, in the course of this communication, have occasion to refer to the form which this peculiar discharge assumes when the shape of the negative terminal is altered.

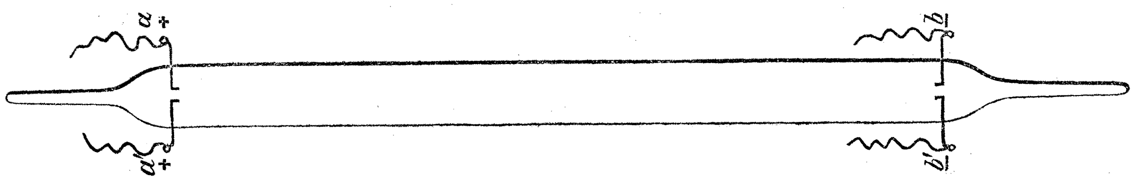
Fig. 2.



74. I have already stated (68) that in some instances several seconds elapsed during which discharges were made without producing any luminous effect, the stratifications ultimately appearing when the discharges had been further continued. The following experiment shows, that with the wire terminals the stratifications are much modified by the particular state of the negative terminal, while that of the positive does not influence them. Fig. 3. In this tube four wires, *a*, *a'*, *b*, *b'*, are hermetically sealed; *a* and *a'* were alternately attached to the positive terminal of the coil, and *b*, *b'* to the negative.

The discharges, whether from *a* or *a'* to *b* or *b'*, were at first luminous, filling the whole tube *without* stratifications. On the discharges being continued from *a* to *b* for a few

Fig. 3.



seconds, the stratifications *appeared* of the cloud-like form, increasing in brilliancy, and leaving a dark negative band 3½ inches in length. The positive terminal of the coil was then attached to *a'*, and the discharge taken from *a'* to *b*; there was no alteration in the character of the stratifications; they remained as in the last experiment, clear and distinct. The negative terminal wire of the coil was then removed from *b* to *b'*, the discharge (luminosity without stratifications filling the entire tube) returned; the positive terminal wire of the coil was then removed from *a* to *a'*, with the same result.

The apparatus was allowed to remain in this state for one hour, when the experiment was repeated with the same result. On continuing the discharge from *a'* to *b'*, the stratifications appeared, and the tube now remains in this state. If *b* and *b'* are connected together by a wire so as to form one negative terminal, the stratifications are clearer and better defined than when the discharge is made to either separately, but there is not any increase or alteration if the *a a'* are connected. From these experiments it would appear that with platinum terminals the character of the stratifications is much modified by the altered condition of the negative wire, which it undergoes shortly after the discharges take place.

Stratified Discharge from both Terminals.

75. On one occasion I obtained a result, which, although as yet I have not been able to repeat with other tubes, yet with our present imperfect knowledge of the causes of the stratifications, may be worth recording. The following is an extract of a note taken at the time:—

In a short tube, 10 inches long, No. 13, the discharge presented the cloud-like stratifications. From the long time this tube had been used, and the direction of the discharges having been often altered, much metallic deposit had taken place at both terminals. In this state one end of the tube was perforated by an electrical spark while connected with the coil; as the discharges were continued, the stratifications gradually assumed greater distinctness, at first with a light fawn, and then of a slightly red colour, but they did not alter in their shape: after one hour the discharges were discontinued, and again renewed in about thirty minutes, when I observed that the red colour had increased, but the size of the stratifications remained unaltered. The discharges were further continued for about thirty minutes: during the whole of this experiment only one cell of the battery had been used. On trying the effect of ten cells, I observed two distinct series of stratifications, one from each terminal, separated in the centre of the tube by a dark band of about $1\frac{1}{2}$ inch. In this state the tube was sealed, and remained for several days, during which time I repeatedly obtained the same double set of stratifications. Unfortunately, on one occasion I continued the discharges too long: one of the wires became heated and the tube fractured.

Influence of Temperature.

76. If the heat from the flame of a spirit-lamp is applied along *one side* of a Torricellian vacuum-tube in which the stratifications are narrow and close, that side of the tube aids the transmission of the discharge which now leaves the cooler for the heated side, the stratifications becoming clearer and wider apart. If a *section* of the tube is equally heated, that section will exhibit the stratifications much wider apart than the portion which has not been heated, where they appear to collapse; as the tube returns to its normal state of temperature, the stratifications throughout resume their original figure. If heat is applied to a section of a tube which exhibits the cloud-like stratifications, they lose their clear distinctness, becoming confused and intermingled; in this state the black from the negative wire appears to be more freely deposited; and when the flame of a spirit-lamp surrounds the negative wire, distinct discharges can be heard inside the tube near the negative, but none from the positive.

77. Through the kindness of Dr. FARADAY, to whom I am much indebted for suggestions, advice, and personal assistance in the progress of these researches, I had the opportunity of making the following experiments in the laboratory of the Royal Institution:—

Fig. 4.

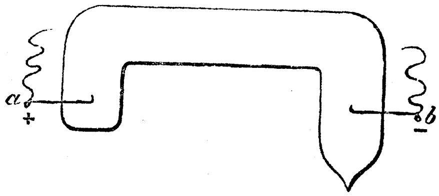
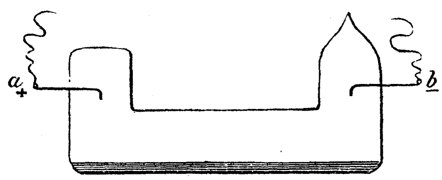


Fig. 4 represents an air Torricellian vacuum, the tube being bent in the form of the figure, 10 inches in length, and about 1 inch internal diameter. This tube was placed in a mixture of ice and salt, without altering the form of the stratifications, which were of the cloud-like character. It was then placed in a bath of ether, which, by solid carbonic acid, was gradually cooled to about $-100°$; all trace of the stratifications disappeared, the tube being filled with a luminous discharge, the negative wire no longer exhibiting the red glow.

Fig. 5.

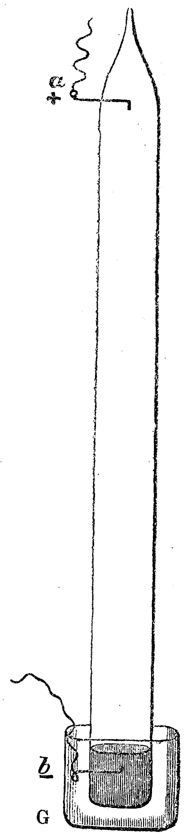


78. Fig. 5 represents a tube of the same dimensions, with sufficient mercury to cover both wires. In this tube the stratifications are narrow, but very clear and distinct; the centre of the tube was placed in the ether bath, leaving the ends and both wires exposed, the mercury remaining in the bend of the tube. The mercury soon froze, and the stratifications underwent considerable alterations, particularly near the positive terminal, where they were much wider apart; over the surface

of the mercury they appeared very brilliant from reflexion. The mercury was then allowed slowly to liquefy, and the position of the tube reversed, so as to permit the mercury to cover both wires, the larger end of the tube was heated by the spirit-lamp until the mercury boiled, passing over to and condensing at the other end. The stratifications entirely disappeared, the discharge passing in a direct line along the tube, and illuminating in its passage the lower side.

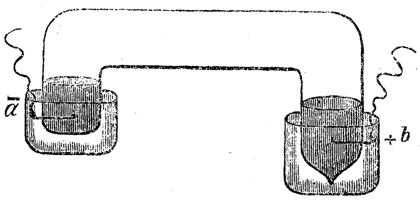
79. In the case of the tube represented in fig. 1, I have stated that with one cell of the nitric acid battery the discharges show two or three broad and distinct clouds (72); and if a magnet is brought near the negative mercury, eight or ten additional cloud-like stratifications are brought out equally clear and defined. In experimenting with this tube, I suspended it, as before, with a strong loop; in this manner it hangs freely in the air, the platinum wires being connected to the induction coil in the usual manner by helices of thin copper wire. The lower end of this tube was inserted in a glass vessel (fig. 6) containing ether to which a quantity of solid carbonic acid was from time to time added; owing to the large mass of mercury, some time elapsed before the metal froze; when the temperature of the ether was reduced to −85° FAHR., discharges from the induction coil being made, the stratifications were no longer visible, but a small luminous spot remained at the end of the positive terminal. On presenting the north pole of a magnet on one side of this luminous spot, or the south pole on the other, another luminous spot was visible, and on drawing the magnet down the tube the stratifications came out, but not so clearly separated as before. The blue negative discharge was perceptible, but not so defined as when the tube is in its normal state of temperature. The interior of the tube was progressively luminous from the negative mercurial terminal, the luminosity decreasing in intensity towards the positive wire. On removing the ether-bath, the mercury gradually liquefied; the temperature rose, and at +20° FAHR. the stratifications reappeared.

Fig. 6.



80. Fig. 7 represents a tube similar in form to fig. 4, but having, as in fig. 2, sufficient mercury to cover both wires. In this tube the cloud-like stratifications are very clearly defined. The white tongue, when the negative wire is exposed, is also very distinct, as is also the blue from the negative wire. Two glass vessels, containing ether, were placed so as to receive the two ends of the tube, the wires being covered with the mercury; solid carbonic acid was applied as before, the mercury in both ends quickly froze; on trying the temperature, one end indicated −98° and the other −102° FAHR.; the surfaces of the mercury, in the act of cooling, assumed a concave form, that at *a* being more depressed than that

Fig. 7.



at *b*; the negative terminal *a*, from its form concentrating the blue-tongue discharge on the upper surface of the tube, where it impinged, forming an oval-shaped spot remarkably rich in the fluorescent blue rays. This illuminated spot could be repelled or attracted, concentrated or diffused, according to the direction in which the magnet was presented. On removing the ether from *a*, and allowing the mercury to liquefy, a tremulous motion was purposely imparted to the mercury, while at *b* it remained rigid when kept frozen. By these means a vibrating or oscillating motion was imparted to the blue-tongue discharge, as it impinged on the glass; this discharge appearing as a focus of light, its form being regulated by that which the negative terminal assumed.

81. From these experiments in temperatures through a range of upwards of 700° FAHR., I obtained the following results:—

In a Torricellian vacuum which gave good cloud-like stratifications, no change could be observed when the temperature was lowered to +32°; but at a temperature of −102° all traces of stratifications were destroyed, and in this state the red or heated appearance of the negative wire disappeared, the discharge filling the entire vacuum with a white luminous glow; on the temperature being raised by the application of heat to the mercury, the stratifications reappeared. When the mercury was boiled, indicating heat of upwards +600°, the stratifications were all destroyed, but in this case the discharge passed along the mercury as it condensed in the cooler portion of the tube. When the mercury was frozen the stratifications disappeared, and the discharge did not illuminate the entire length of the tube, but merely the terminals; in this state, when a horseshoe magnet was brought near the tube, the cloud-like stratifications immediately appeared from the positive wire very distinct and large, but not so clearly separated as when the tube was at its normal temperature.

On Vacua free from Vapour of Mercury.

82. I was desirous to obtain a vacuum, if possible, more perfect, and particularly one free from any trace of mercury. In those with which I had to this time experimented, I believe the only medium remaining in the tube was mercurial vapour, for I had ascertained that the slightest trace of air altered the colour of the stratifications, and I found by using the process suggested by Mr. WELSH, I had obtained precisely the same result, whether the tubes were previously filled with air, hydrogen, or oxygen. In the experiments hitherto described in this, as well as in my former communication, I had obtained the best results by filling carefully prepared glass tubes with pure mercury, and thus forming good Torricellian vacua. Such vacua necessarily contain mercury in a state of vapour, and I assumed that the stratifications observable when electrical discharges are taken in such vacua, were "probably due to the pulsations or impulses of a force acting on this highly attenuated but resisting medium*." In a perfect vacuum all the effect due to such assumed resistance ought to be removed, and I anticipated that the discharge would either not pass from wire to wire, or it might pass in some other form than that

* Philosophical Transactions, Part I. p. 14, 1858.

which has been hitherto observed. To test this opinion, I endeavoured to obtain a vacuum with fusible metal instead of mercury, but I could not succeed in getting it free from the presence of air, which was denoted by the colour of the discharge (66). I also prepared apparatus for a tin vacuum; but as similar difficulty would have occurred in this as with fusible metal, I laid the apparatus aside, and endeavoured to obtain a vacuum by inserting sodium in a closed glass vessel, previously charging it with pure oxygen; the stratified discharge was very clear, but the sodium as it melted adhering to the sides of the glass in irregular masses, conducted the discharge from the different surfaces, and the form of the stratifications was rendered so irregular that the results in this respect were unsatisfactory; I however succeeded in obtaining sufficient evidence to convince me that with better arrangements, sodium, and probably potassium with oxygen, will produce vacua which cannot fail to exhibit the stratified discharge with great brilliancy, and possibly by this process even a still more perfect vacuum may be obtained.

Carbonic-acid Vacua.*

83. The experiments I now proceed to describe were made in glass tubes, many of which were of similar form and dimensions to those I had used with mercury, but the vacua were obtained by an entirely different process. In the preparation of these I am indebted to Dr. FRANKLAND, who not only suggested and explained to me the process to be adopted, but kindly devoted much of his valuable time to the superintending many of the experiments, which were made in his laboratory at St. Bartholomew's Hospital. Fig. 8, Plate IX. represents a tube in which the platinum wires *a* and *b* are hermetically sealed; in the narrow portion A, one or two sticks of caustic potash are inserted, one end of the tube being connected by means of gutta-percha tubing to a vessel in which pure carbonic acid gas is generated; the other end passes through a tight-fitting collar into a vessel containing a little mercury under a receiver attached to the plate of a good air-pump. A portion of the air is first expelled by the rush of the carbonic acid; after this the passage of the gas is stopped at B, and the tube is exhausted by means of the air-pump. The mercury (M) acting as a valve, prevents any risk of air entering into the tube; the process is repeated two or three times, when, if the discharge from the induction apparatus is found to be entirely free from any trace of redness, it may be assumed that all the air has been expelled, and the tube can be then prepared for sealing. When it is full of the gas, the glass is sealed at B. The tube is again exhausted to the utmost limit of the capability of the pump, and finally sealed at C. The apparatus is now ready for experiment.

84. In carbonic-acid vacua obtained by this process, the discharge from an induction coil is at first in a wave line, strongly affected by the magnet or by the hand when placed on the tube; in this state the discharge does not generally present the stratified appearance, or if present the stratifications are only near the positive terminal; sometimes in the course of a few minutes, but often not until several days have elapsed, the

* Dr. ANDREWS of Belfast was, I believe, the first to describe a method of obtaining carbonic acid vacua in the receiver of an air-pump (Philosophical Magazine, February 1852, p. 104).

stratified discharge becomes visible, and as the carbonic acid is absorbed by the potash, the stratifications gradually appear more clearly defined. I have obtained clearly defined stratifications when a little moisture was perceptible in the tube, this moisture probably assisting the absorption of the carbonic acid by the caustic potassa; as the stratifications gradually become more distinct and divided, they assume a conical form, and lastly the cloud-like appearance (64) of the best mercurial vacua; after this, under some conditions, the stratified appearance of the discharge will entirely cease, the whole length of the tube being filled with faint luminosity; when in this state, if the outside of the tube is touched by the finger, pungent electrical discharges arise, and sparks one-eighth of an inch in length can be elicited. On testing this discharge by a magnet, it will divide in a similar manner to the discharge when taken from a single wire; on continuing the discharges, the peculiar blue phosphorescence previously noticed at the negative (68) is often perceivable at *both* terminals (87); and when in this state, if a galvanometer is introduced in the circuit, the needle is not deflected, proving that the discharge is not continuous but reciprocating; but if during the discharges the potash in the tube is heated, the stratifications become perceptible, and the needle of the galvanometer will be deflected, showing that a continuous discharge is now present: this experiment is fully described in another part of this paper (88).

85. I have often found it difficult, and at times impracticable, to obtain precisely the same results in carbonic-acid vacua; they are probably modified, not only by the relative purity of the gas and of the potash, but also by the quantity of moisture. When the gas was passed through chloride of calcium or through strong sulphuric acid, the stratifications appeared more quickly. When moisture had been purposely added, as by placing a piece of asbestos moistened with boiled distilled water within the tube, the cloud-like stratifications were not obtained, although the stratifications of the conical form were remarkably clear: in a vacuum-tube thus prepared, No. 61, the caustic potash remains in the centre, the asbestos being placed in the narrow end; the potash has absorbed the moisture, leaving the asbestos to all appearance perfectly dry. The potash in this tube has been repeatedly heated; when heat is applied the stratifications at first become clearer; they gradually lose the conical form and become narrow. As the heat continues, all trace of stratifications or discharges over the potash is destroyed, that portion nearest the negative is blackened (possibly by carbon being evolved). If the tube is permitted to cool, the stratifications gradually reappear, until they resume their normal state; on carefully examining the potash, a minute hole is observable in the end of it nearest the positive wire, apparently showing a direction of force in the discharge.

On Non-conducting Vacua.

86. I have stated that under certain conditions the stratifications entirely disappeared, and as this result is, I believe, new, and has been confirmed by three separate experiments, I will briefly describe two as they are entered in my note-book. On the 12th of June, two tubes were prepared in the laboratory of St. Bartholomew's Hospital; in each, exclusive of the caustic potash, some fused chloride of calcium was introduced; in addi-

tion to these, in one tube, No. 66, small crystals of SULPHUR were placed, and in the other, No. 67, pieces of SELENIUM. The tubes were then charged with carbonic acid, and exhausted as before. No. 66, on the 21st of June, showed clear narrow stratifications, the potash was then heated; on the 26th the stratifications had increased, assuming the conical form, clear and defined; some of the sulphur was melted, condensing at each end of the tube; as it cooled the stratifications which had been destroyed reassumed their conical form. The stratifications improved very slowly, and on the 14th of July they assumed the large cloud-like appearance, similar to those of the mercury vacuum (63). The caustic potash was then again heated, and the stratifications became very narrow; from this time they gradually improved, and on the 28th, on trying the discharge, I found that it no longer passed. The potash was then heated and the discharges continued, the tube shortly became illuminated; this was followed by large cloud-like stratifications, then by the conical and narrow; on allowing the potash to cool, the tube resumed its insulating state.

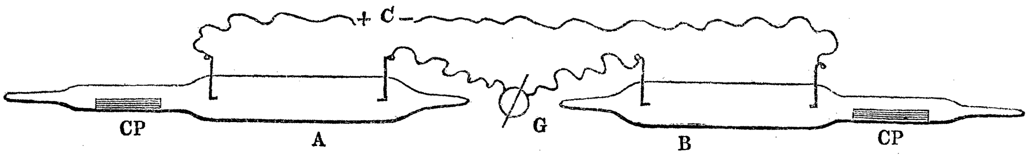
87. SELENIUM, No. 67.—From the 12th to the 19th of June the discharge was a wave line; on the 20th the potash was heated; on the 22nd stratifications appeared of a greenish tinge, inclined to the conical form; from the 23rd to the 28th they assumed the cloud-like character; on the 28th the selenium was melted; the stratifications were then of a reddish tinge, but they remained nearly of the same form, the vapour of the selenium condensing very quickly in the cooler portions of the tube. On the 6th of July the end of the tube was placed in a freezing mixture, and the tube was heated in order to free the sides thereof from a quantity of selenium which had deposited and thus obscured the view of the discharge. On the following day (7th July) the discharge illuminated the tube *without* stratification, and on grasping the tube with the hand both wires were surrounded with the intense blue discharge (84), which, under ordinary conditions, only appears at the negative. On the 11th of July, on heating the caustic potash, the blue phosphorescence at the positive wire was destroyed, and the cloud-like stratifications reappeared. This tube was subsequently placed aside, after having been heated two or three times, for a month, when, on trying the discharge on the 4th of October, I ascertained that the discharge no longer passed, the vapour which had evolved by heating the caustic potash having been again absorbed.

88. When a vacuum-tube is in a state to show the stratified discharge, it is so good a conductor that sparks from the outer terminal of the induction coil will pass to one of its wires (the other being attached to the inner terminal) one inch in length through air; but when no signs of a luminous discharge can be observed through the tube, or merely faint luminosity without stratifications, the spark is scarcely visible, although it will pass from the outer terminal of the coil through air to a wire attached to a glass rod, or to one insulated by shell-lac, showing that a vacuum-tube in this state is a more perfect insulator of the electrical discharge than air. The following experiment will perhaps be considered as conclusive as to vacua under this condition insulating the discharge.

Fig. 9 represents two tubes and a galvanometer attached to the induction coil C.

A, carbonic acid vacuum-tube, similar to the sulphur or selenium one (86, 87); B, vacuum-tube (which shows stratification when discharges are passed); G, a delicate

Fig. 9.



galvanometer placed at a sufficient distance to preclude any action on the needle from the iron core in the induction coil. If discharges from the induction coil C are now made, there will not be a trace of any luminous discharge in A; in B, the stratified discharges are reciprocating, and, when tested by a magnet, will be found to divide; they are merely discharges from the terminal of the coil to which one of the wires is attached, the needle of the galvanometer remains stationary.

If in this state heat is applied to (CP) the caustic potash in A, in a few seconds the stratified discharges will be visible; the needle of the galvanometer will be deflected, and the stratifications in B will at the same time assume the usual appearance of the conductive discharge.

Vacua-tubes prepared with Arsenious Acid, Bromine, Iodine, Pentachloride of Antimony, Bichloride and Bisulphide of Carbon.

89. Arsenious acid, No. 68.—A few crystals being first introduced with some caustic potash and chloride of calcium, the arsenious acid being kept separate, the tube was charged with carbonic acid gas and exhausted as before (83); the discharge at first appeared in the form of a wave line of a greenish tinge; the potash being heated, in a few days the discharge assumed a tendency to the cloud-like stratifications; the arsenious acid was then heated, the stratifications immediately narrowed, a brilliant luminous wave discharge passing through them from wire to wire; for about three months a gradual change took place, until the discharge again assumed the cloud-like, stratified appearance; on heating the potash, the stratifications suddenly became clear and defined with a greenish tinge, showing remarkably brilliant bands.

90. Bromine, No. 69.—The bromine was inserted in a small glass bulb, and placed within the vacuum-tube previous to its being charged with carbonic acid and exhausted. In about ten days the cloud-like stratifications were visible, when the glass bulb was broken; the tube instantly filled with bromine vapour so dense that the discharge would not pass. On the following day the potash had absorbed a portion of the vapour, and the discharge was visible with very narrow stratifications; these gradually improved, and in twenty-seven days assumed the cloud-like appearance. On the twenty-ninth day, finding the stratifications becoming indistinct, while the blue tongue at the negative remained peculiarly fine and extremely sensitive to the magnet, I sealed off that portion of the glass tube in which the caustic potash had been placed; the discharge up to the

present time retains the same appearance, showing the blue tongue expanded or contracted by the magnet in a very beautiful and clear manner.

91. Iodine, No. 70.—Crystals of iodine were placed in a sealed glass bulb within the tube with caustic potassa; it was then charged with carbonic acid gas and exhausted as before; the cloud-like stratifications appeared in about eleven days; the bulb was broken and the heat applied to a few of the crystals of iodine; at first a wave discharge was visible, passing through the vapour without stratifications; in a few days stratifications were visible, and the tube has remained ever since in the same state. If the contact breaker is pressed so as to cause a more sudden disruption in the discharge, a wave line brilliantly illuminated can be obtained, passing conjointly with and through the narrow stratifications, as in the arsenious-acid tube (89). When the discharge is taken from one terminal in vapour of iodine, the difference of the action between the outer and inner terminal is very remarkable; when the former is positive, if the tube is grasped by the hand, the discharge shows stratifications between the hand to the discharging wire; from the inner terminal no stratifications can be seen, but only a faint luminosity divisible by a magnet.

92. Pentachloride of Antimony, No. 71.—The small glass bulb containing the pentachloride having been inserted in the tube as in the previous experiment, was broken after the cloud-like stratifications had appeared, when all trace of stratification ceased, the discharge passing in the form of an intensely brilliant wave line; the gradual progress first to the narrow and ultimately to the cloud-like stratifications was subsequently very slow, for it was upwards of two months before the latter appeared.

93. Bichloride and Bisulphide of Carbon, Nos. 73 & 74.—These were introduced into the separate tubes in glass bulbs, as in the previous experiments; the bulbs were broken as before after the discharges had assumed the cloud-like appearance; but although every means was adopted, first by melting the potash, and then applying freezing mixtures to condense the vapour, it remained under every condition so dense, that, after the glass bulbs were broken, the discharge could not pass even in the form of the wave line.

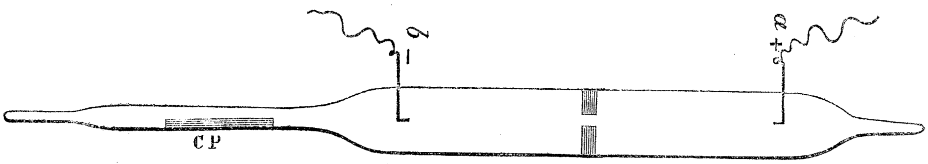
All the experiments hitherto described were made in glass tubes of about 1 inch internal diameter, similar to those of my previous experiments with Torricellian vacuums, in which I had been necessarily limited as to the size of the tubes by the difficulty of manipulating with large masses of mercury; with carbonic-acid vacua this difficulty no longer arose, and I was induced to try the effect that could be obtained in larger vessels.

94. Fig. 10, Plate IX. represents a large glass vessel, egg-shaped, the globular portion being 18 inches in length and 7 inches in diameter; the wires are 22 inches apart, the caustic potash being placed in the narrow end; total length 25 inches. It was charged with carbonic acid and exhausted in the usual manner; a portion of the potash being heated by a spirit-lamp, in about two months the discharge assumed in a very marked manner the character of large and distinct clouds, most clearly and separately defined;

these are strongly affected by induction as the hand approaches the globe, presenting a very striking appearance; there is a slight tinge of red, showing that a very minute quantity of air remains: the cloud-like stratifications *extend to the entire diameter of the vessel.*

95. Fig. 11 represents another form of apparatus. This glass tube, No. 81, is 12 inches long, and about 1 inch internal diameter; it has a glass division in the centre, perforated with a hole about $\frac{1}{8}$th of an inch in diameter, my object being to ascertain in what manner the stratified discharge would be affected during its passage through the aperture; the wires are 10 inches apart. I had already ascertained that if an electrical discharge passes through a vacuum-tube a portion of which is of very small dimensions, the glass is

Fig. 11.



very much heated, while that portion of the glass which is wider remains cool. In the apparatus fig. 11, if *a* is positive and *b* negative when the discharge shows narrow striæ, those near the diaphragm in the *a* positive side are indistinct, while on the *b* negative side the striæ are very clearly defined, although the luminous portion is much contracted; when the discharge has assumed the cloud-like appearance, the aperture only affects them by contracting the cloud, which passes immediately through it. In this tube I had at one time succeeded in entirely insulating the discharge, the same as in both those in which sulphur and selenium were placed (86), (87), and I subsequently repeated this experiment with the same tube in the presence of Dr. FRANKLAND and his assistants, in his laboratory; but a few days afterwards, on heating the potash, the discharge returned to, and has ever since retained the cloud-like appearance.

96. I had always found there was apparently much less deposit on the sides of the glass from brass than from platinum wires; this was so decided, as to make me doubtful whether this deposit was not in all cases due to the platinum to which the brass wire is attached. In a tube, No. 82, with brass terminal wires, on the interior of which, from long continuance of the discharge, I observed much deposit had taken place, on examination Dr. FRANKLAND found this deposit was entirely brass in a minute state of division, the metal being deposited precisely the same as the platinum (37), translucent when examined by direct light, but presenting by reflected light a dark metallic lustre.

Condition of Discharge at Negative Terminal (continued).

97. That the stratified discharge is considerably influenced and modified by the particular condition of the negative terminal in a vacuum-tube, is evident by the experiment, where it did not appear when new platinum wires were used, until such wires were corroded by continuous discharges (74). I have also invariably found that if brass wire

terminals were used, the stratifications were visible at the first discharge; the only explanation I can offer is, that the stratifications may be influenced by the presence of the very minute points in the brass wire used in my tubes, while the new smooth platinum did not produce them until corroded by the discharges.

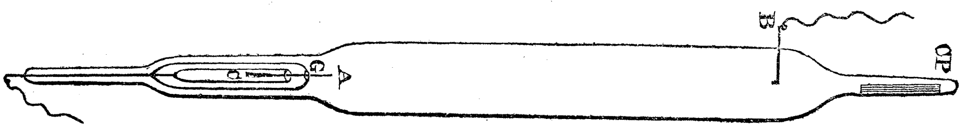
98. When the negative terminal is of liquid mercury, whatever be the length to which the mercury is elongated, its entire surface is covered with a luminous white glow; if it is made positive, it is only the extreme point from which the illumination proceeds (58). If a tube with mercury is placed in a perpendicular position, the blue tongue is very large, and the surface of the mercury (which in this experiment must be made negative) is covered with a lambent white glow (72). This phenomenon appearing to me to be intimately connected with the blue-tongue discharge (68), which is always present under certain conditions of the stratified discharge, I determined on examining a phenomenon that presented the appearance of a distinct form of discharge from that at the positive terminal; for this object I had several vacua-tubes constructed, in which the platinum, as well as brass wires hermetically sealed, were more or less protected by being covered with glass tubing.

99. After many trials, I ascertained that if the negative wire is protected by glass tubing open at the end about one-eighth of an inch beyond the point of the wire in the tube, no stratifications can be observed in the discharge, which in such cases merely exhibits a luminous glow; for this experiment it is necessary that the orifice in the tube should be contracted in order to prevent the wire being exposed, and the discharge from the coil should also be of moderate intensity; as if the intensity is much reduced, either by the battery or by manipulation with the contact breaker, faint stratifications in the discharges may at times be observed. In a tube thus constructed, No. 90, a discharge appears to emanate from the negative wire, issuing with great intensity through the orifice; and if the wire and the tubing are a little inclined, the discharge will impinge against the side of the vacuum-tube (fig. 12), brilliantly illuminating the spot on which it impinges, in a similar manner to the blue-tongue discharge (68, 70); if this discharge is continued for a few seconds, that portion of the tube on which the discharge impinges will be sensibly heated; and if a magnet is presented, the spot will be contracted with one pole, and with the other the discharge will be bent in a manner so that its extreme portion will itself impinge on the other side of the tube, illuminating and heating it as above. If the experiment is made by reducing the intensity of the discharge, so that stratifications from the positive terminal are observable, these stratifications vanish, as the discharge, which apparently proceeds from the negative terminal, is forced by the magnet along the tube (fig. 13). In this experiment there is the appearance of a direction of a force emanating from the negative terminal as well as one from the positive, while from the latter we have, under certain conditions, as I have already described, a direction of force from the positive to the negative, centring to the axis of stratification * (57).

* In a recent communication from Professor W. Thomson to Mr. Joule, read before the Literary and

100. I have already alluded to the difficulty of obtaining separate carbonic acid vacua in which the stratified discharge presents in all respects precisely the same appearance; and in order that I might examine the discharge with protected as well as non-protected negative terminals in vacua made under precisely the same conditions, I had two glass tubes constructed. No. 101, fig. 14, represents one, a carbonic acid vacuum-tube, with

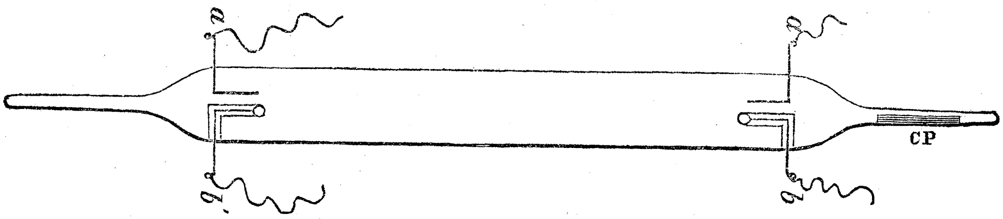
Fig. 14.



caustic potash inserted in the narrow portion CP; the wire A can, by inclining the tube, be dropped into the inner case of brass tubing C, which is itself protected by a glass tubing G; the brass tubing is soldered to a platinum wire P, and thus hermetically sealed; B, the other wire, which is fixed, is also of brass. When both wires are exposed, the stratified discharges show the clear cloud-like appearance so often described, whether A is positive or negative; but if A is made negative and the tube is inclined so as to let the wire drop into the brass tubing, almost all trace of stratifications immediately disappear, that which remains being evidently due to the portion of wire and the brass tube which is exposed through the orifice; in this state each discharge is accompanied by a ringing noise from within the brass tube: reversing the direction of the discharge, A becomes positive and B negative; the stratifications are immediately perceivable, and the ringing noise in the brass tube ceases.

101. In the other tube, No. 104 (fig. 15), four wires are hermetically sealed; *a*, *a'* are

Fig. 15.



exposed; *b*, *b'* are protected by being placed in glass tubing, extending about one-eighth of an inch beyond the points of the metal. When discharges are taken from *a* to *a'*, or when *b* or *b'* is positive and *a* or *a'* negative, the stratifications are clear and distinct; and by heating the potassa they can be altered from the cloud to the conical shape; but under whatever condition the tubes may be, the stratifications entirely cease if *b* or *b'* is made negative; in this condition no trace of stratifications can be observed, *the negative discharge issuing through the orifice as from a jet.*

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102. In vacuum-tubes, particularly in some obtained by the carbonic acid process, I

Philosophical Society of Manchester, the former gentleman alluded to the remarkable difference in the effects of positive and negative electrifications.

have often observed beyond the clear cloud-like stratifications towards the negative, several faint but clearly-defined striæ or bands; when repeating Mr. Grove's experiment, of allowing the discharge to be intercepted between two metallic points attached to the coil*, I observed that however short might be the interval by which the discharge was thus separated, these faintly illuminated striæ or bands always vanished, leaving the clear clouds without change of form; for this experiment I use my micrometer-electrometer, described by me in the Philosophical Transactions, Part I., 1840, and in which, by means of the micrometer screw, I can obtain a separation of $\frac{1}{5000}$th of an inch.

103. Most striking and beautiful effects of the stratified discharge were obtained in a large glass cylinder, of about $4\frac{1}{2}$ inches internal diameter, in which brass wires were hermetically sealed about 20 inches apart. The caustic potash being inserted in the narrow portion, the cylinder was charged with carbonic acid gas, and exhausted in the usual manner. With one wire attached to the outer positive terminal of the coil, the stratifications (large cloud-like form) are very clearly defined and most remarkably sensitive to inductive action, by the approach of the hand; on the four fingers being successively placed on the stratifications, the stratifications disappear in succession; but while in this state, if a powerful electro-magnet is put in action close to the negative, the stratifications reappear and pass by the fingers of the hand, which during the experiment rest on the glass; the power of the magnet overcoming the inductive resistance. The stratifications in this apparatus can be separated for a considerable space by placing both hands on two separate portions of the cylinder; and if one hand is placed within about 2 inches of the positive wire, where two or three clouds are then visible, and the other hand is placed on the cylinder about 4 to 6 inches nearer the negative, a large single cloud will be brought out in a very striking manner, showing that even where stratifications are no longer visible, they can be elicited by the mere effect of induction. If the wire previously attached to the outer is connected with the inner terminal of the coil, the effects of induction, by the approach or even on touching the cylinder, cannot be obtained, but the power of the magnet to draw out a further number of the stratifications is equally strong as before.

General Conclusions.

104. From the absorption of carbonic acid by caustic potash, we not only obtain a far more perfect vacuum than the Torricellian, but the process of absorption is so gradual, that we are enabled to examine with much accuracy the different phases which the electrical discharge assumes. With the air-pump vacuum, a discharge that will not pass one inch in air will, in the form of a wave-discharge, pass from wire to wire through 30 or 40 inches, or even more; and as the vacuum improves by the absorption of the carbonic acid, the discharge gradually fills the tube with a luminous glow, showing narrow stratifications commencing at the positive wire, the negative wire being surrounded with a blue glow; as the vacuum continues to improve, the narrow stratifications extend throughout the discharge to about one inch of the negative wire, where

* See note at end of this paper.

they terminate abruptly in a dark space, the negative wire becoming intensely red; in this state, if the contact-breaker is pressed so as to make the discharge more sudden, stratifications extend to the negative wire, which loses its red and assumes a luminous white appearance. As the absorption of the carbonic acid continues, the stratifications become more distinct and separated, and the dark space often extends, in a tube of 20 inches in length, to 6 or 8 inches; they then assume a conical form, showing, when the contact-breaker is pressed, an apparent direction of force from the positive wire, centring on the axis of the stratified discharge *; the stratifications are then of the cloud-like appearance, precisely the same form as in the best Torricellian vacua. Under some conditions the stratifications gradually disappear, the glass tube is filled with faint luminosity, which, when tested by placing a galvanometer in the circuit, is found to be no longer a conductive but a reciprocating discharge. When the process was carried still further, vacua-tubes were obtained, in which even this luminosity could not be perceived except with a stronger charge, as by attaching the condenser. In addition to a galvanometer, another vacuum-tube (which under the ordinary action of the coil showed stratifications) was introduced into the circuit and no light perceived in it; thus *the non-transferring condition of a vacuum has been experimentally ascertained* †.

105. Whatever may be the length of the stratified discharge, it will always be found to be in the same electrical condition; from its great length the positive would appear to be the dominant, as it is equally long whether taken from the outer or inner terminal. In my previous paper I stated that I was inclined to the opinion "that the stratifications arose from pulsations or impulses of a force acting on highly attenuated matter;" and I am the more confirmed in this opinion, as, *if the pulsations or vibrations are greatest in bright bands and least in the obscure, this system of interference or of pulsations would also account for the entire absence of stratifications when the air or gas is not sufficiently rarefied, as well as when the vacuum becomes nearly perfect*, while the graduations of narrow to the broad cloud-like stratifications can be thus satisfactorily explained.

106. The absence of a dark band and of stratifications when the sides of the negative wire are completely protected by glass tubing, is strong evidence that both must in some way be governed by the portion of the negative metallic surface which is exposed; by carefully protecting the negative wire, we not only destroy all trace of stratifications, but *we obtain evidences of apparently a direct force from the negative terminal.* If the negative wire is uncovered and placed in a direct line with the positive, the negative discharge is entirely in a lateral direction, as is denoted by the metallic deposit on the

* This direction of force in the positive discharge is also noted by the perforation in the stick of potassa (85).

† While preparing this communication for the Royal Society, I observed that Professor PLÜCKER states that, after passing the discharge in a tube containing oxygen for about 1½ hour, "the discharge through the tube began to be discontinuous, till at last only single separate discharges occurred; finally, the current entirely ceased to traverse the tube." I have since repeated the experiment in tubes carefully prepared by Dr. FRANKLAND, continuing the discharges for several hours, but without obtaining this result.

sides of the vacuum-tubes; and PLÜCKER has shown that it arranges itself between the poles of a powerful electro-magnet in the line of magnetic force. In this communication I have shown not only the appearance of the direction of a force as evinced when passing through a narrow orifice, but that wherever this discharge impinges heat is evolved. At present I do not alter the opinion that I ventured to offer, that the dark band may be due to interference; but the new facts which have been elicited in relation to the negative discharge require a further, and probably an extended experimental investigation, and I am at present engaged in endeavouring to test the accuracy of the opinion I have offered, by means of apparatus now in the progress of construction.

107. I am aware that in this paper I have entered somewhat more fully into detail, when describing my experiments, than is usual in communications to the Royal Society, but I have been induced to be thus minute, as the subject is novel; and by explaining some of my experiments in detail, it may afford to others the means of examining directly, and possibly more correctly, into the nature of that mysterious force which we denominate Electricity, and which is in many respects so nearly related to heat, magnetism, and other forces, each being, as Mr. GROVE has long since shown, convertible into each other; while the fact that a vacuum so perfect can be obtained in a closed vessel containing such a substance as hydrate of potassa, would excite a hope that the limit to vaporation, the existence of which FARADAY* and others have, if not proved, at least rendered so probable, may be determined, and even its consequences exhibited by direct experiment.

JOHN P. GASSIOT.

Clapham Common,
December 8, 1858.

Note.—Received January 11, 1859.

Since I sent my communication to the Royal Society, I have again obtained a non-conducting vacuum without the introduction of sulphur or selenium (95). In the extremity of a tube, No. 140, 40 inches long, $1\frac{7}{8}$ inch internal diameter, four pieces of caustic potash were inserted; the tube was then charged with carbonic acid, exhausted and hermetically sealed, as already described; in this state the potash was carefully heated by a spirit-lamp until it melted; the tube being slowly turned, the potash on gradually cooling covered the surface of that portion of the tube in which it had been placed; in this manner it presented a large surface; in a short time the remainder of the carbonic acid was absorbed, and the vacuum thus formed no longer conducted the discharge.

If two vacuum-tubes which conduct are attached, one to the inner and the other to the outer terminal of an induction coil, without being otherwise connected with each other, a reciprocating discharge will take place in each, that from the outer being far more vivid: if the circuit is now completed, either by a wire or by a tube

* Philosophical Transactions, 1826, Part III. p. 484.

which conducts, the stratifications in each tube become clear and distinct, the dark discharges becoming as visible as if the circuit with the coil had been completed by a single tube.

If the tube which conducts is replaced by one such as I have described in this Note, it will be found that the discharges in the two tubes attached to the coil are reciprocating, while in that with which they are connected no luminous discharge will be perceptible, until heat is applied to the caustic potassa, when in a short time flashes of light will be observed, and then the cloud-like stratifications, the discharge in the two tubes at the same time being no longer *reciprocating*, but *continuous*.

If a vacuum-tube is connected by flexible wires to the terminals of an induction coil, the tube can, when held by the hand, be moved to and fro with a rapid motion; if while in this state the discharges are made they will appear separated, forming in darkness a very brilliant fan-like figure. In my former communication* I have shown that, whatever might be the length of a luminous stratified discharge in a vacuum-tube, "the full intensity of the discharge is visible at a single contact, exhibiting 80 to 100 stratifications (36)." When a single disruption of the primary circuit is made in the manner I have described (30), while the vacuum tube is moved to and fro with rapidity, or if by an apparatus which I have had constructed, the tube is rotated in a plane, only a single discharge showing stratifications will be visible; the discharge takes place in that part of the circle in which the tube happens to be situated, at the instant of the disruption of the primary circuit; but when the vibrating contact breaker of the coil is substituted for the single disruption (30), the motion of the tube gives it the appearance of illuminated spokes in a rotating wheel, the discharges being separated according to the velocity of the rotation.

I venture to offer this experiment as an evidence that the stratified discharge *in vacuo* is entirely due to a single disruption of the primary circuit.

Jan. 10, 1859.

Note.—Received February 17, *read March* 3, 1859.

Since my communication to the Royal Society (read January 13) I have repeated the experiment of Mr. GROVE, wherein by an interruption of the secondary circuit through air the stratifications of the electrical discharge in a vacuum-tube are destroyed; the results I have obtained, and which I now proceed to describe, tend to confirm me in the opinion I originally ventured to offer, that the stratifications arise from the effect due to pulsation, or impulses of a force acting on highly attenuated matter, and are not due to a conflict of two currents *in the manner* explained by Mr. GROVE, which his experiment of simply making an interruption of the secondary circuit† has led him to suggest; these results also show that the varied form observable in the stratifications *mainly* depend on the greater or less density of the matter remaining in the tube.

* Philosophical Transactions, 1858, Part I.

† Philosophical Magazine, 1858, p. 18.

I have already stated that the striæ can be obtained by the electrical machine* if a Leyden jar is discharged through a vacuum-tube; they may at times be observed, but the discharge generally passes in the form of a wave of light of dazzling brightness; this has also been observed by Messrs. QUET and SEGUIN†; but if the intensity of the discharge is reduced by means of a wet string, the striæ can be developed in a vacuum-tube as clearly and as distinctly as from the induction coil; this led me to suppose that when the circuit is interrupted, as in the experiment of Mr. GROVE, the absence of striæ is due to the heightened intensity of the discharge.

Having at this time a considerable number of vacuum-tubes at my command, I have been enabled to repeat Mr. GROVE'S experiment, and to test the above supposition in a variety of ways, and I invariably found that with the best vacuum-tubes which show large cloud-like stratifications, I could obtain the result described by Mr. GROVE with greater certainty; for instance, in my large cylinder (103) which I exhibited at the meeting of the Royal Society on January 13, and with which Mr. GROVE subsequently repeated his experiment at the Royal Institution on January 28, the stratifications are destroyed by an interruption of about one-eighth of an inch, although with other tubes the distance must not only be considerably increased, but the stratified and non-stratified discharges, "notwithstanding all the care used, pass in irregular succession." Now if the disappearance of the stratifications be due, as suggested by Mr. GROVE, to the cutting off of the feeble current by the interruption introduced into the circuit, it remains to be explained why a space of one-eighth of an inch abolishes the stratifications in one tube, while three times that space will fail to do so in another.

With a vacuum-tube in which the stratifications were entirely destroyed when the secondary circuit was interrupted, I found they were always restored when the space thus interrupted was completed by *means of a wet string*; but as this experiment is not strictly analogous to the reduced discharge of a Leyden jar, it was varied by making a second interruption in the circuit and closing this by a wet string; in this manner the discharge passed through the space in air, but being retarded by the string the stratifications were again visible.

This experiment appears to be fatal to the theory of Mr. GROVE; for the introduction of a wet string *in a distant portion of the circuit* cannot possibly help a feebler current to cross the interval opposed to it; it is quite evident that in this case, as well as in that of the Leyden jar, the appearance of the striæ depends not upon the conflict of "secondary and tertiary" currents, but simply as to the manner in which the discharge passes.

I also ascertained that when, by means of an interrupted discharge, the stratifications are destroyed, they are reproduced in a carbonic acid vacuum-tube, when heat is applied to the caustic potash; in this experiment the increased resistance arises from the greater density of the matter formed in the tube; if this be correct, the discharge, when passed simultaneously through two tubes, in each of which the attenuated matter possesses different densities, would produce different effects; if one tube exhibits with the ordi-

* Philosophical Transactions, 1858, Part I. p. 10.

† Comptes Rendus, December 13, 1858.

nary discharge the cloud-like character, and the other narrow striæ, in the former the current, when interrupted through space in air, would pass without stratification, and in the latter they would be retained.

Two tubes were so arranged, one showing the cloud discharge, in the other (filled with the vapour of iodine) in which the stratifications are clearly defined but very narrow; by means of my micrometer-electrometer the secondary circuit could be interrupted or completed with great precision. When the secondary circuit is interrupted by separation with the electrometer to about one-eighth of an inch, the large cloud stratifications in the tube disappeared, the discharges passing "with uniform luminous flow," as described by Mr. GROVE; but no alteration is perceptible in the iodine tube, in which the stratifications continue as before, even when the separation extends to half an inch; it is manifest that this result is also irreconcileable with the explanation offered by Mr. GROVE, as, if the alleged feeble current were cut off in one tube, it would be cut off in both.

J. P. G.

Clapham Common,
February 14, 1859.

FIG. 10.

FIG. 12.

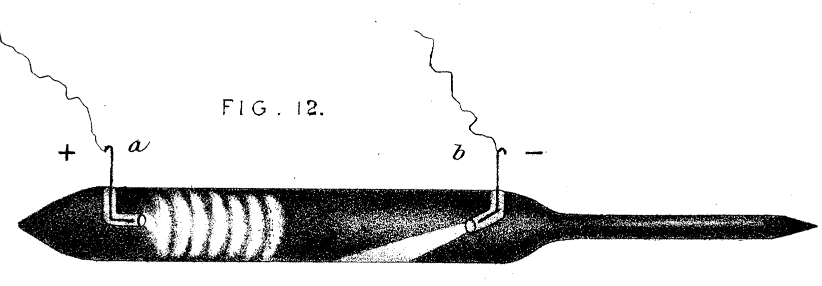

FIG. 13.

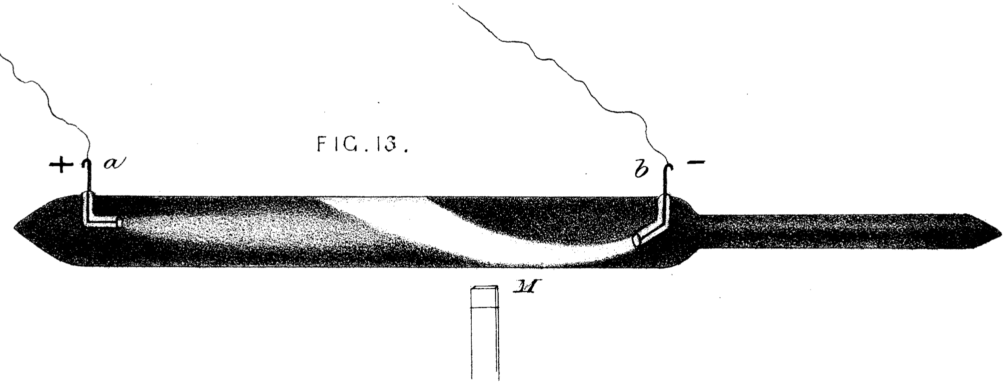

FIG. 8.