PHILOSOPHICAL TRANSACTIONS.

I. The Bakerian Lecture.—*On the Stratifications and Dark Band in Electrical Discharges as observed in Torricellian Vacua.* *By* John P. Gassiot, *V.P.R.S.*

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1. The striated condition of the electrical discharge *in vacuo* that takes place when the terminal wires of Ruhmkorff's inductive coil are inserted into a well-exhausted receiver, in which a small piece of phosphorus has been previously placed, was first announced by Mr. Grove in his communication to the Royal Society, 7th January, 1852; his paper is printed in the first part of the Transactions for that year, and was subsequently published in the Philosophical Magazine of December 1852, with a supplementary note dated 9th June, wherein Mr. Grove states "that he had found the transverse dark bands could be produced in other gases when much attenuated, probably in all, and that he thought the reason why they are more easily seen in phosphorus vapour is that all the oxygen having been consumed, a better vacuum is formed."

2. I had, at the time, the pleasure of witnessing many of these experiments, which are now so well known to electricians; shortly afterwards I examined the discharge in a Torricellian vacuum: my apparatus consisted of a glass cylinder 6 inches long, in which two platinum wires are hermetically sealed about 4 inches apart; the cylinder forms the upper portion of a barometer, the lower part being made of the usual sized tubing; the mercury, when at the height of 30 inches, reaches to within about 6 inches of the cylinder; the mercury was carefully boiled in the usual manner by M. Negretti, and the apparatus fixed in my laboratory, where it at present remains as originally placed.

3. When the discharge is made with a Ruhmkorff's coil, by connecting the above platinum wires with the terminals of that apparatus, the cylinder is brilliantly illuminated with a dense white phosphorescent light, filling the entire vacuum, the intensity of the light depending on the energy of the battery. The mercury sinks at each discharge, but not the slightest trace of any transverse bands can be detected.

4. The phenomenon of stratifications in the discharge *in vacuo* were subsequently observed in Paris by M. Ruhmkorff, who obtained the effect by using the vapour of alcohol; they were again noticed by Masson, Du Moncel, Quet, and other continental

electricians, who all describe the *intense white light without stratification* produced in the barometrical vacuum*.

5. The Rev. Dr. ROBINSON, who has made a series of beautiful experiments with the inductive coil†, says, "Nothing satisfactory has yet been ascertained as to the cause of the stratification of light. Mr. GROVE appears to think that it arises from some vibration in the metal of the contact breaker, which produces a fluctuation in the inducing current; he finds that it is not always visible in the light caused by a single discharge, and that it is influenced by the nature of the metals between which the interruption spark occurs." Dr. ROBINSON, in a previous communication to the Royal Irish Academy‡, considered that the fact of their being produced by a single discharge, shows that they do not depend on the discontinuity of the current; and in a note to his paper of December 1856, he adds, "as the rarefaction proceeds, the intensity of the spark at the contact breaker decreases, and also we should suppose the vibration there, yet the stratification becomes more decided; this seems against Mr. GROVE's hypothesis." When the discharge from the terminals of RUHMKORFF's coil is taken in the air or *in vacuo* from thin platinum wires, the negative terminal becomes heated, and if the discharges are continued it is fused; in the voltaic battery it is the positive terminal that is heated by the discharge. *In vacuo* Dr. ROBINSON describes "the negative terminal as wrapt in a coat of bright blue light, through which, by an optical delusion, the platinum *seems* red-hot." Under some conditions the intense blue round the negative wire will appear without the red (43.), in other conditions it will appear red as if intensely heated, and in other instances white.

6. In Mons. DU MONCEL's work on the Inductive Coil, the stratifications are figured as concave towards the positive end, the concavity *decreasing* as the bands extend towards the negative; at the centre they become straight, and then gradually concave towards the negative terminal *until* they arrive at the dark space which separates the bands from the negative discharge. Dr. ROBINSON, in the paper of January 1856, already alluded to, has given a drawing of the beautiful stratifications obtained by him in the vacuum of an air-pump prepared with great care over sulphuric acid (34.).

7. In Dr. ROBINSON's figure the bands are all concave towards the positive terminal, this being a globe, while the negative is a point. I can bear witness to the correctness of both representations; for although I have not had the pleasure of seeing Dr. ROBINSON's experiments, I have seen and obtained a somewhat similar figure to that which he has represented by using Mr. GROVE's method with phosphorus vapour, while in the vapour of naphtha I have on other occasions observed the discharge as figured by DU MONCEL; these different effects do not however in any way arise, as might be assumed, from the difference of vapour, but from other causes, which will be explained in this paper.

* In the Torricellian vacuum the inductive spark is white, filling the whole tube.—NOAD's 'Electricity,' 4th edition, p. 742.

† Proceedings of the Royal Irish Academy, 8th December, 1856.

‡ Proceedings of the Royal Irish Academy, January 14, 1856.

8. The conditions necessary to enable the experimentalist to produce the phenomena of the striæ or band discharge, have been stated by different authors to be as follows:—1st, that the vacuum in the receiver should be as perfect as can be obtained by the air-pump; 2nd, that care should be taken to absorb all trace of moisture; and lastly, that means should be used to introduce the vapour of naphtha or phosphorus, or other similar bodies.

9. The induction apparatus used in the following experiments was constructed for me by Mr. LADD; in form it is similar to that of M. RUHMKORFF; the primary coil consists of three layers of No. 12 copper wire, total length 50 yards; the secondary, about three miles of No. 35 covered with silk, each layer of the secondary coil being carefully insulated by folds of thin gutta percha; with four or five cells of the usual size nitric acid battery, this apparatus gives a discharge in air of $4\frac{1}{2}$ inches; but my experiments, except when otherwise described, were made with only one cell, and generally without any condenser; this is separate from the apparatus, it consists of two sections, one of 50 and the other of 40 square feet of coated surface, which can be used either separately or connected.

10. While pursuing my experiments, it occurred to me that an apparatus similar in some respects to that used by DAVY, could without much difficulty be constructed, which would enable me not only to make experiments in a Torricellian vacuum, but also with great facility in any gas which does not act on mercury: Plate I. fig. 1 represents this apparatus. In the glass tube, two platinum wires, *a* and *b*, are carefully sealed about 6 inches apart; the tube is filled with pure mercury. A stopcock, fixed at C, can, by means of a flexible tube, be connected with an air-pump. When the air is extracted from the ball of the apparatus, the mercury sinks in the tube, and in this manner the Torricellian vacuum is formed, the mercury in the tube descending to "*d*."

11. In my first experiments the discharge did not exhibit the uniform white light of the Torricellian vacuum, but striæ in confused or irregular forms; and although there was not the slightest appearance of even a trace of air in the tube when first filled with mercury, a minute bubble constantly appeared after the discharge had been continued for three or four minutes, and the mercury was allowed to rise in the tube. On incautiously letting in the mercury after the lower wire had been heated by the negative discharge, the tube broke.

12. This experiment having convinced me that under some conditions the stratification could be produced in a Torricellian vacuum, I ordered other similar apparatus to be made, one of which I directed should not only be very carefully filled, but that the mercury should be boiled in the tube. The effect I obtained fully compensated me for the trouble I had taken. In this apparatus the discharge from the coil, when excited by a *single* cell of GROVE'S battery, the upper wire being negative, consisted of eight or ten distinct stratifications, extending from the positive wire to the dark space, while the usual blue flame surrounding the intense red, which has the appearance of red heat, is visible on the negative wire. On reversing the direction of the primary current by the

commutator, the stratifications appear from the upper wire, while the lower, which is now negative, has the blue and red glow; but in this case there is a phosphorescent light from the surface of the mercury at *d* to the lower wire.

13. When the connexion with the battery is broken, the negative wire (if the discharge has been continuous for a *short* time) is found to be black, and the sides of the glass tube covered for a certain distance with minute greyish dust, which comes off as the mercury ascends in the tube; this is probably the condensed vapour of mercury, from the vicinity of the heated negative wire, as the mercury removes the particles as it ascends the tube, without leaving any trace on its surface.

14. In some experiments which I made as far back as October 1854, I noticed a deposit when the discharge was made from platinum wires sealed in a glass globe, exhausted by means of the air-pump. I showed the globe to Dr. FARADAY, who kindly tested and examined the deposit, and found it to be finely divided platinum in the metallic state. At the time I did not follow up the experiment; it now occurred to me to test this action in the apparatus, similar to fig. 1, Plate I. (of which I had several constructed): I made the discharge constantly in the same direction, the upper wire being negative; the result was that the upper portion of the tube, as far down as a line drawn even with the end of the wire, was covered with platinum in a minute state of division; when this deposit is examined by transmitted light it is translucent, presenting to the eye an extremely thin bluish-black film; but by reflected light, either on the outside or inside, it has the appearance of highly polished silver, reflecting the light as from the finest mirror*.

15. When the upper wire is negative and the lower positive, if the mercury in the globe is allowed slowly to ascend the tube the stratifications collapse, but the dark band between them and the negative glow remains; as the mercury rises, the stratification merges into a series of rings on the surface of the mercury, which, when the circuit of the primary is broken, is not found to be tarnished, but as bright as when the experiment commenced.

16. If the upper wire is positive and the lower negative, as soon as the mercury ascends above the negative wire, a beautiful lambent bluish white vapour appears to arise, while a deep red stratum becomes visible on the surface of the mercury; as the mercury ascends in the tube, the stratified discharge from the positive wire collapses, giving the appearance of a compressed spiral; on exhausting the globe the mercury descends in the tube and the stratification expands, as if the pressure on a spiral spring had been removed.

If, during the exhaustion, the descending mercury is permitted to remain stationary

* Since I wrote the above my attention has been drawn to Mr. GROVE's paper in the Philosophical Magazine, March 1853, of which the following is an abstract.

On the interior of the tube was a dark pulverulent deposit, far too minute in quantity for analysis, but which had evidently proceeded from the platinum; the only possible mode in which I can account for this experiment is, that this deposit consisted of an oxide or peroxide of platinum.

for a few seconds, the discharge being continued, the tube will (at each place where the mercury has rested) be found coated with minute particles of condensed mercurial vapour, which clear off when the mercury ascends.

17. I have stated (10.) that I had several of the apparatus (fig. 1) constructed, but in no two could I obtain precisely the same result: in some the stratification was more or less distinct, in others scarcely visible, but in all a residuum of air, more or less, could be detected when the mercury was allowed to ascend the tube; but it appeared surprising that there should be so marked a difference in the discharge when, as in some instances, so very minute a quantity of air (less than $\frac{1}{6000}$th of the contents of the tube) was present.

Mr. CASELLA, who had made all the glass apparatus already described (with the exception of the barometer), placed one of his most intelligent workmen at my disposal; this enabled me to proceed with my experiments, and I had five separate tubes prepared in the following manner:—three were of the same length and dimensions as the tube of the original apparatus, Plate I. fig. 1; two were made of the usual barometer tubing, the wires of the one *set* being 10 inches, and of the other 16 inches apart.

Each of these tubes was filled with pure mercury, carefully boiled; a tube about 34 inches in length being attached to each, also filled with mercury; the apparatus was inverted into a basin of mercury, thereby forming the usual barometrical vacuum, and the tubes were then sealed about 4 inches below the lower platinum wire.

18. Designating these tubes (Plate. I. fig. 2) as A, B, C, D and E, the stratification in A is nearly equal to what I obtain in my best mercurial apparatus (12.). In B the discharge is of conical form, and the stratification visible, but confused and indistinct. In C the discharge is in a wavy line, without any stratification. In D the discharge is clear, bright and white, but no appearance of stratification. In E the stratification is very distinct and well-defined.

19. On examining the apparatus B, a minute bubble of mercury can be perceived in the stem, and in C there is evidently moisture in the lower part, below the platinum wire. Taking advantage of this accident, I inserted the stem of C in a freezing mixture of pounded ice and muriatic acid. The change in the character of the discharge was very striking; instead of the straight luminous line, the discharge assumed the conical form, exhibiting the striæ in a very much more clear and distinct manner than in B, though not quite so good as in A.

20. I could not but feel assured that there must have been something wrong in the mode of obtaining vacua which exhibited such irregularity of action, and I determined on trying an experiment for which I had long since made preparation, viz. to examine whether any different effect would take place in a barometrical vacuum obtained by the non-boiling process first suggested by Mr. WELSH, and which he so successfully carried out in filling the large barometer of the Observatory at Kew; an apparatus so exhausted might also effectually test Mr. WELSH'S process of filling a large barometer, the value of which those who are practically acquainted with the difficulty of boiling such

a mass of mercury as is contained in a tube of upwards of an inch internal diameter and 34 or 35 inches in length, can fully appreciate.

Mr. WELSH kindly superintended at Mr. CASELLA'S the filling of a tube on his principle (Plate I. fig. 3): the process used by this gentleman, which avoids all the difficulty of boiling, has been fully described in the Philosophical Transactions for 1856*. The only difference in the present instance is the previously inserting the platinum wires at *a* and *b*, the tubes being hermetically sealed at *d*, about 4 inches from the wire *b*.

The result realized to the fullest extent our expectations: in this tube the bands were clear, well-defined and distinct; and, provided care be taken in manipulating with the coil, so as always to send the discharge in the same direction, the platinum coating is deposited on the portion of the tube surrounding the negative wire, but none at or near the positive.

21. With this tube I obtained the stratification by the discharge of the electrical machine. This experiment was first made by me on the 28th of December last, in the Theatre of the London Institution, in the presence of Professor TYNDALL and Mr. MALONE, connexion being made from one platinum wire to the conductor of a 4-feet electrical machine, while the other wire was attached to the rubber. On turning the plate the discharge took place through the tube, filling it with the usual phosphorescent light, but exhibiting the striæ very distinctly.

22. The cause of the dissimilarity in the discharge of A, B and C, and of D and E, although respectively of similar dimensions, did not arise from any dissimilarity in the mode of obtaining the vacuum, but from the glass tubes not having been, previous to the insertion of the mercury, equally well cleaned or equally well deprived of moisture, a circumstance which Mr. WELSH has shown is indispensable in the construction of a good barometer, and this cleansing can only be obtained by mechanical means; in C the moisture is, as I have observed, perceptible, and in this the discharge is most imperfect.

With a tube prepared on Mr. WELSH'S principle, and a moderate-sized RUHMKORFF'S coil excited by a single cell of GROVE'S nitric acid battery, the phenomena of the stratified discharge can be seen and examined with ease, without the trouble and uncertain manipulation of the air-pump, or using phosphoric and other vapours.

23. My next experiments were made with apparatus the form and size of which were different to those I had already used, but which had been made previous to experimenting with the last-named tube, fig. 3. Fig. 4, Plate I., represents an apparatus with moderate-sized thermometer tubing, having wires, *a* and *b*, inserted as before, with stopcock C for exhausting by air-pump: in this apparatus the discharge is divided into alternate white and dark bands, having the appearance of ruled lines.

24. Fig. 5 represents a similar apparatus, but of a pear shape, 3 inches internal diameter; the wires are 5 inches apart from point to point. Although great care had been taken in boiling this large vessel of mercury, containing about 10 lbs. of the metal, the vacuum was not found to be perfect, and moreover the mercury remained deposited

* vol. cxlvi. p. 507.

in a film on some portions of the vessel when it was exhausted. In this condition of the apparatus the discharge was similar to what I had often obtained (with Mr. GROVE's experiment) in the vapour of phosphorus, the stratifications being very distinct near the upper or positive wire, and spreading towards the negative in a confused manner. If the mercury was permitted to rise above the negative wire, as in the former experiment (16.), the surface of the mercury would become covered with the bright red glow, surmounted by a thin film of white flame, the entire surface being thus covered until it had risen to within 4 inches of the positive wire: from this point, as the mercury rose, the diameter of the red spot gradually reduced in size, until the mercury was within ·1 or ·2 of an inch of the wire, when the glow contracted into a minute spot. In this manner the diameter of the base of the conical discharge could be measured, showing its increase in proportion to the length of the discharge when it is not compressed by a narrow tube.

25. Although great care had been taken in boiling the mercury in this apparatus, the results obtained were so unsatisfactory, in respect to the stratification, that I had the mercury withdrawn and the glass thoroughly cleaned: for this purpose it became necessary to remove the upper wire; this afforded me an opportunity of examining it. This wire had been generally used as the negative terminal; it was black and rough, as if much corroded, evidently from the abstraction of the minute particles deposited on the surface of the glass tube (14.); the wire being resealed in the tube, which was subsequently filled with entirely new mercury, a minute bubble of air remained, but the result obtained was so satisfactory, that I have not attempted to remove it. In Plate I. fig. 5, I have endeavoured to give a faint representation of the beautiful appearance of the stratification, as exhibited when the upper wire is positive and the lower negative. If the mercury is permitted to ascend, immediately it covers the negative wire the stratifications disappear, and the interior of the globe is filled with bluish light; a bright spot of light is visible on the end of the positive wire, but the negative mercury no longer exhibits the red glow of the former experiment, its entire surface, until it ascends to within an inch of the positive wire, being covered with a brilliant white phosphorescent film about $\frac{1}{8}$th of an inch in thickness.

26. Fig. 6 represents an apparatus having for terminals platinum balls $\frac{1}{8}$th of an inch in diameter instead of the wires, the distance between each being about 5 inches; with this apparatus the stratifications *at first* were nearly the same as in the previous experiment with points (12.); but when the mercury had been permitted to rise and fall in the tube several times, a very marked difference in the character of the stratification was observed; instead of exhibiting eight or ten divisions, they were reduced to two or three, of the shape as in fig. 6.

These stratifications did not take place directly from the end of the positive ball, but from that portion of the wire that was immediately in connexion with the glass; by carefully manipulating with the contact breaker, the discharge could be observed to travel down the wire, overlap the ball and descend into the tube, followed by another,

and sometimes a third and fourth, each separated by the dark striæ; they were beautifully drawn out by approaching to them a magnet.

27. When the upper ball is positive and the mercury is permitted to rise so as to cover the lower or negative ball, the stratifications instantly disappear, as in the previous experiment (26.); the tube is then filled with beautiful phosphorescent light.

The difference in the stratification from wires and balls in this experiment probably arose from the latter having received a coating of liquid mercury, and the greater mobility of that metal which thus formed the terminals. In this apparatus there was not any fixed deposit on the glass; near the negative ball, during the discharge, mercurial vapour condensed on the tube in a considerable quantity, but this came off when the mercury ascended the tube and came into contact with it; there was not any sign of deposit near the positive ball, or on any other portion of the tube.

28. Plate I. fig. 7 represents a tube 28 inches long and of about $\frac{5}{8}$ths of an inch internal diameter; it is cemented into a brass plate, *a*, and when carefully filled with mercury, was placed on the open mouth of a receiver on the air-pump, the lower part of the tube being at the same time immersed into a tumbler of mercury; platinum wires were sealed in as before, only in this instance they were 18 inches apart; by this arrangement I could with facility regulate the length of the discharge from the $\frac{1}{16}$th of an inch to 18 inches, either suddenly or very gradually, by allowing the air to enter into the receiver, or by exhausting it with the pump; the vacuum was not so good as I could have desired, *a very minute* bubble of air always remaining; but the stratifications were very distinct when the discharge traversed the full length of 18 inches.

If the mercury is permitted to ascend the tube, immediately it covers the lower wire, the upper being positive, a dark discharge, 3 inches in length, appears; immediately contiguous to this dark discharge there are about four stratifications to the inch; towards the upper part of the tube they appear as compressed; about 9 inches from the positive terminal they are six or seven to the inch, but above this they are very close; when the mercury ascends to within from 7 to 5 inches of the positive terminal, all appearance of stratifications ceases, and in lieu thereof we have the white phosphorescent light of the barometrical discharge (4.). If, instead of one or two cells, the coil is excited by four or five, and care is taken to manipulate with the contact breaker so as to give sudden discharges, the lower portions of the striæ assume a form as Plate I. fig. 8, which represents the diameter of the tube and the striæ as they appear in the apparatus.

29. If the hammer of RUHMKORFF'S contact breaker is removed, or the contact breaker of BENTLEY'S or of HEARDER'S is separated, the primary circuit can be completed by wires attached to the screws usually used for the condenser, which in the following experiments is used.

Having fixed two flexible wires (those I use are made of wire-rope covered with the India-rubber tubing) in the screws as above, turn the commutator so as to allow the current to pass through it: the primary circuit can now be completed and the secondary charged, by means of the flexible wires attached to the screws.

30. Let the terminal of one wire be firmly fixed to a bright copper plate, $\frac{1}{8}$th of an inch thick, having a sharp edge in order to ensure a sudden disruption of the primary current; complete the circuit by steadily pressing the end of the other wire on the plate, using one or two of GROVE'S cells to excite the primary: no trace of any discharge will be perceived in the tube.

Pressing the wire on the plate so as to ensure perfect continuity, bring it across the sharp edge of the copper plate, and a quick, sudden break of the battery circuit can be effected; the stratifications will appear in the tube in a very distinct and beautiful manner; in a discharge of 18 inches the entire tube is filled with them to the extent of the dark band (36.); the more sudden the break, the more distinct will be the effects.

If the experiment is repeated by making contact with the wires without the plate, or by dipping them in the mercury, the same results are obtained. I have made the experiment of a single disruption of the primary circuit under every variety of form, and in no instance did it fail, although unless care is taken, it might be fairly doubted whether the discharge was single or continuous.

31. When the intensity of the primary circuit is increased by using eight or ten of GROVE'S battery, the stratification is plainly visible and *on making contact*, but in an opposite direction and very inferior in intensity or brilliancy to the discharge on breaking; the effects are much heightened by the condenser.

32. Although no signs of any discharge can be observed in the *vacuum* on making contact when the primary current is excited by a single cell, still evidence of action in the secondary coil can be detected by the galvanometer, as also in the following manner:—let the ends of two platinum wires attached to the terminals of the secondary coil rest on a piece of bibulous paper, moistened with a solution of iodide of potassium; complete the circuit of the commutator, and then remove the paper: iodine will be evolved from one terminal:—make contact with the moistened paper, keeping the primary circuit complete; remove the paper; no trace of iodine is perceivable, proving that in this state there is no evidence of a current in the secondary wire: again make contact with the moistened paper and the platinum wire, break the circuit with the commutator, and iodine is immediately evolved at the opposite terminal in a much larger quantity than the former.

33. In the phenomena of the induction spark, time appears to be an important element, at least it is so in the secondary coil as at present constructed; experiment teaches us that the effect from breaking is far more powerful than that from making contact. In RUHMKORFF'S coils we have, however, not only the induced effect from the primary current, but we have the induced effect from the powerful electro-magnet; to attain the maximum effect of the latter time is essential*, *particularly* if the primary coil is formed of several convolutions of the wire ("three convolutions are used by RUHMKORFF").

* Time, as is well known, is necessary for the development of electro-magnetism, and M. MATTEUCCI, in his recent valuable book on induced electricity, has shown some remarkable results flowing from this fact. —GROVE, Philosophical Magazine, January 1855, p. 2.

If the wires or iron core are made of well-softened iron, although they require some time to obtain their maximum power, they lose it instantly; consequently the more sudden the contact is broken, the clearer and more intense will the discharge appear *in vacuo*.

34. I have already alluded to the form of the stratifications as figured in M. Du Moncel's pamphlet and other papers, as also to that of Dr. Robinson (4.); in the former they are concave towards the positive terminal, gradually becoming parallel towards the centre and then concave to the negative; in Dr. Robinson's drawing they are all concave towards the positive; the former is the appearance the stratifications exhibit when eight or ten or more cells are used to excite the primary, and when by the rapidity of the action of contact breaker the discharges alternate from each wire and intermingle with each other; Dr. Robinson states he used three and subsequently only one of Grove's; hence the difference in the representations.

35. While experimenting with a battery of thirty or forty cells, I observed that the positive terminal, when the discharge was taken in air, became heated as soon as the negative; the cause of this, as well as the difference in the stratifications, as figured by M. Du Moncel and Dr. Robinson, is explained by the preceding experiments: in Dr. Robinson's experiments the primary current was excited by only three cells of Grove's battery, which will not produce any sign of a luminous discharge *in vacuo* on *making* contact; the figure as depicted by that gentleman is the discharge on breaking contact; and when the vacuum was improved by allowing it to remain for several days, exhausting the receiver four times, each time filling it with dry hydrogen, the same figure was produced by a single cell of Grove's battery. The discharge, as figured in M. Du Moncel's work, has precisely the appearance which is produced when a sufficient series of Grove's batteries is used, which will produce a luminous discharge on making as well as breaking contact.

36. Whether the discharge is taken in a tube of 5 inches or one of 18 inches, or even of 5 feet 3 inches (41.) in length, the full intensity of the discharge is visible at a single contact, exhibiting from 80 to 100 stratifications, their separation from each other evidently depending on the density of medium through which the discharge takes place, or the increased energy of the primary current.

The luminous arc of the voltaic battery carries with it minute particles from the terminals, and experiment has shown that an emanation of particles takes place from both wires, although more powerfully from the positive to the negative*; with the inductive coil the emanation of particles only proceeds from the negative, not in a direct line to the positive, but laterally; if the *negative* wire is inserted from the top of the tube, these emanations are deposited on the sides of the glass, more dense at the part nearest the wire, but not below the level of the extreme end of the negative wire; at the positive there is not any sign of deposit, and the wire remains bright and clear.

37. If care is taken so as to make the discharge in one direction, the negative wire

* De la Rive's 'Electricity,' vol. ii. p. 288.

will be found to have become black and rough (25.), so as to have the appearance of being corroded; the glass tube to a line with the end of the wire will be covered with a deposit of platinum, which reflects light either from the inside or outside, but when examined by transmitted light will be found (unless the action has been continued for a considerable time) to be translucent, presenting a layer of a bluish-black colour.

38. Under certain conditions, when the discharge is heightened by increasing the intensity of the battery to the maximum, but short of the double discharge, in order to prevent the confusion arising therefrom, the effect on the stratifications is much altered, as in fig. 8, Plate I.: this experiment, which requires a little care in the manipulation of the contact breaker, exhibits a direction of force from the positive to the negative, and in no way connected with the passage of particles from pole to pole, as in the voltaic discharge.

39. The spheroidal form of the voltaic arc has been assumed to arise from the mutual repulsion of the parts detached from each polar extremity*: De la Rive has shown that the same effects are produced by frictional electricity; the distribution of currents in the liquid electrolyte is also of this character, as are the forces of the north and south poles of two magnets when placed in a line with each other. In a moderately good vacuum the discharge from the secondary coil is in the form of a cone, having its apex at the positive and its base towards the negative, Plate I. fig. 2 B; and in this medium it is immaterial whether this positive discharge is taken from a point or a base: the discharge in such a medium is always in this form.

40. That the glow discharge from the secondary coil is not due to the particles emanating from the negative wire is probable, from such particles being always deposited in a lateral direction from the wire, and not beyond the line on the glass tube even with the end of the negative wire, from whence, to the top of the tube, the platinum is copiously deposited; and although the discharge would seem to show by its form that its direction is from the positive terminal, and that whatever may be the separation between the positive and the negative terminal, the positive discharge or stratifications generally proceed to within a short distance of the negative, still the negative plays an important part in this form of the electrical discharge,—witness the brilliant luminosity by which it is surrounded, and the remarkable heating of the wire whether *in vacuo* or in air (5.); that there is also an apparent repelling force is shown by the stratifications receding as the mercury ascends, leaving, in some instances, 3 or 4 inches of the dark discharge, the stratifications gradually collapsing until in a long tube they disappear.

41. In order to test whether any signs of interference could be observed by making the discharges of two separate coils intermingle with each other, two instruments were constructed, Plate I. figs. 9 and 10, in each of which four platinum wires were carefully sealed: a reference to these figures will explain the manner in which the experiment was made; the terminals of one coil were attached to $a\,a'$, and of another to $b\,b'$; in

* De la Rive's 'Electricity,' vol. ii. p. 296.

fig. 9 the discharges were parallel to each other; in fig. 10 one discharge was made in the centre of the other.

Whether the discharges were made in the same direction or opposed to each other, there were not any signs of interference, the separate stratifications from the discharge of each coil remaining visible, although producing a degree of confusion from their interposition.

These two experiments will probably be considered strong evidence to show that the stratifications in the positive discharge do not arise from interference, but from a succession of impulses or pulsations from the force meeting a resisting medium. The positive division of the discharge is of a greater intensity, and consequently much greater length than the negative; indeed, as yet, we do not know the limit: I have obtained the stratifications in a tube of 5 feet 3 inches length, in which as in that of 18 inches they are beautifully shown.

42. The dark discharge between the positive and the negative I venture to assume arises from interference. When the discharge is taken, in the apparatus, Plate I. fig. 7, it is curious to observe the stratifications retreating from the negative as the mercury ascends the tube, or following them as they descend when the vessel is being exhausted, the dark line of discharge being compressed or expanded in proportion as the length of the stratifications is increased or decreased.

Mr. GROVE, in his note to his paper, to which I have already referred, says, "having in my mind the analogy of interference, it seemed to me that this dark space might be due to the crossing of the lines of discharge from successive points of the needle, the knob, or plate from which the negative discharge issues*.

43. I made several experiments in order to ascertain the cause of the red strata on the negative mercury (12. 16. 23. 25.), which was evidently identical with the red glow of the platinum, described by Dr. ROBINSON (5.) as giving the wire, by an optical delusion, the appearance of being red-hot; in one of the apparatus (Plate I. fig. 1) the negative terminal, lower wire *b*, in a short time became, for about half its length inside the tube, coated with mercury, while the remaining half presented the corroded black appearance already referred to (25.); in this state, when the discharge was made, the red glow was very brilliant on the black portion of the wire; but the other, which was the furthest from the glass, was enveloped with white phosphorescence.

The pear-shaped apparatus (23.), Plate I. fig. 5, is filled with new mercury; in this there is now not any sign of red glow, while in the long tube (fig. 7) it is most brilliant, giving the lower portion of the negative discharge a beautiful rose-coloured tint, gradually shading off through pale blue into the dark space; the glow was also seen in apparatus, Plate I. fig. 1. I have not any note whether the mercury inserted in this apparatus was new, but that in the long tube (fig. 7) had been previously used and cleaned in the usual manner, first with dilute nitric acid, then with water, the mercury being subsequently dried. The red glow on the surface may be due to some impurity in the mercury; it is always

* Philosophical Magazine, December 1852, p. 514.

far more brilliant on platinum wire after the discharge has been made for a short time, probably from the incandescence of the minute points of the metal in the act of emanation as they are deposited on the glass; if a very thin platinum wire is used for the negative terminals, it will be fused. I have already mentioned, that in the ball apparatus (fig. 6) there was not any discharge or emanation of particles of mercury from the positive ball, but much from the negative, another evidence that the force from the positive is not accompanied by the transfer of particles of the metallic terminal.

Action of a Magnet on the Inductive Discharge.

44. The stratifications are very powerfully affected by a magnet. When the discharge is made from wire to wire, Plate I. figs. 1, 2, 3 or 7, if a horseshoe magnet is passed along the tube so as alternately to present the poles to different contiguous positions of the discharge, it will assume the form of ~ in consequence of its tendency to rotate round the poles in opposite directions, as the magnet in this position is moved up and down the side of the tube.

The effect is still more striking if the straight bar of a powerful electro-magnet is placed close to the ends of the stratifications; they then tend to rotate in one direction round the north, and in another round the south pole of the magnet.

45. If the mercury in apparatus (28.), fig. 7, is allowed to ascend so as to cover the negative wire, and thus produce a mercurial negative terminal, the action of the magnet on the stratifications will be found to be much heightened; as soon as the electro-magnet is excited, whether the polarity is north or south, the stratifications from the positive are violently drawn down the tube as an elongated spiral; under certain conditions they will assume the appearance of rotation, and if the magnet is such as to present north polarity to the discharge, the rotation is from right to left; if south, from left to right. I am aware that there is a difference of opinion as to the actual rotation of these bands, and that in many cases there is no evidence or even appearance of rotation; but under the influence of the magnet, as thus arranged, there cannot be any doubt as to the appearance being such as I have described. On the negative glow in this apparatus the magnet appears to have, in comparison with that on the positive discharge, a very slight effect, but it attracts or repels it according to the polarity of the magnet; it does not influence or produce any signs of stratification in the negative discharge.

46. When the discharge was first made in the pear-shaped apparatus, fig. 5 (24.), the mercury being negative and about 2 inches from the end of the positive wire, the discharge formed nearly a straight line; in this position, when the pole of a powerful electro-magnet was placed close to the glass vessel of the apparatus, the discharge was deflected across the pole at right angles, the discharge being from the positive wire to the negative mercury; if the magnet presented a northern polarity, the discharge deflected to the right, when looking from the magnet to the discharge, carrying with it the red spot in a direct line across the mercury.

47. When the discharge was made in the apparatus (fig. 6), the upper ball being

positive and the mercury negative, the tube was filled with brilliantly illuminated phosphorescent light. If, under this condition, a powerful magnet was presented to the light, the stratifications were drawn over and from the upper ball, while a minute spot of liquid mercury suspended from it was attracted and repelled according to the polarity of the magnet.

48. In this experiment I noticed another effect which I have not seen in any of my other apparatus. The magnet so divided the electrical discharge, that the rays producing the fluorescence in the glass tube were all accumulated in the neighbourhood of the negative terminal, the glass in that part being highly fluorescent, while the positive portion exhibited little or no signs of this phenomenon.

49. I refrain for the present from offering any observations as to the action of the magnet on the discharge. The intimate relation of magnetic and electric action has long since been shown; but the curious effect of the power of a magnet to draw out the stratification from the positive terminal (47.), and in some instances its powerful action on that portion of the discharge which exhibited the phosphorescent light in its greatest intensity (48.), are worthy of further examination. *In the preceding experiments my object was entirely directed to the examination of the stratified and the dark band discharge; at present I am inclined to the opinion that the stratifications in the positive, and the dark broad band between it and the negative glow, although apparently similar, are effects arising from distinct causes—the former from pulsations or impulses of a force acting on highly attenuated but a resisting medium, the latter from interference.* I am at this time engaged in making further experiments for the elucidation of this novel and remarkable phenomenon.

JOHN P. GASSIOT.

Clapham Common,
5 *January*, 1858.

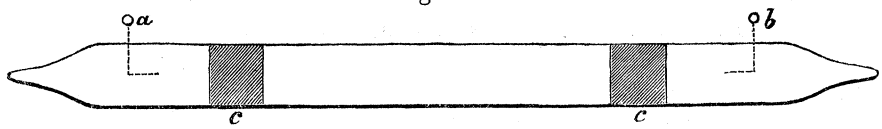
NOTE.—Received March 3,—Read March 4, 1858.

50. Shortly after presenting the preceding account of my experiments to the Royal Society, I had the pleasure of being introduced to Dr. ESSELBACH of Bonn, who informed me that M. GEISSLER of that city had recently constructed some vacuum tubes of great delicacy, and that an account of his experiments with RUHMKORFF'S inductive apparatus had been published in Germany. Through the kindness of Dr. BENCE JONES I have since procured several of the tubes from M. GEISSLER; their forms are varied, and show great skill in the construction, the stratifications from the inductive discharge being thus exhibited in a most beautiful and striking manner; but the complexity in the form of the apparatus renders these tubes to a great extent unsuitable for the careful examination of the phenomena. I have not as yet seen any publication of M. GEISSLER'S experiments, but I presume the tubes must have been constructed for a different object from what I have been pursuing, and for which I purposely had mine made in the most simple form I could devise.

51. Since the date of my paper I have made numerous experiments, some of which require further verification before they are published. I however avail myself of the opportunity afforded by the Council having appointed me to deliver the Bakerian Lecture, to submit the following for the consideration of the Royal Society.

52. Fig. 11 represents the vacuum tube that I now generally use; the vacuum is obtained by Mr. WELSH's process (20.); the tube is about 38 inches in length, the wires *a b* 32 inches apart; *cc'* are moveable coatings of tinfoil 2 inches long wrapped round the tube.

Fig. 11.



53. I have already stated that I obtained stratifications by the electrical machine (21.), and I have since ascertained that if a charged Leyden jar is discharged through a vacuum tube by means of a wet string, the stratifications are as large and as distinct as when taken from the induction coil.

54. When the discharges from an induction coil are made from wire to wire, the stratifications appear as already described (22.); and if the tube is placed in a horizontal position *over the pole of a magnet*, the stratifications evince a tendency to rotate as a whole in the direction of the well-known law of magnetic rotation; but when the discharge is made from coating to coating, or from one wire to one coating, an entirely new phenomenon arises: the stratifications have no longer a tendency to rotate as a whole, but are *divided*. If the tube is now placed *between* the poles of a powerful electro-magnet, one set of stratifications are repelled from, and the other attracted towards, or within the bent portion of the magnet; when the tube is placed on the north pole, the divided stratifications arrange themselves on each side of the tube, changing their respective positions when placed on the south pole, but in all cases each set of stratifications are concave in opposite directions.

55. If a vacuum tube, with or without wires or coatings, is placed on the induction coil in action, or on the prime conductor of an electrical machine, stratifications are discernible, and these can be divided by the magnet; the tube, after receiving discharges from the electrical machine, retains the charge for a short time; and if it is in this state laid on a table, flashes of light can be observed for several seconds, but gradually getting fainter and fainter.

56. Having thus ascertained that there are two distinct forms of the stratified electrical discharge, I propose, for the sake of clearness of expression, to designate them as the *direct* and the *induced* discharge. The direct discharge is that which is visible when taken from two wires hermetically sealed in a vacuum tube; this discharge has a tendency to rotate as a whole round the poles of a magnet; the induced discharge is that which is visible in the same vacuum when taken from two metallic coatings attached to the outside of the tube, or from one coating and one wire, or from one wire: one of my tubes has only one wire placed in its centre. The induced discharge is divisible by

the magnet into two sets of stratifications, each set having a tendency to rotate round the pole of the magnet in opposite directions: the character of the electrical discharge with relation to these two forms can always be determined by a magnet.

57. I have in all instances found that the discharge from the positive terminal exhibits a dominant action, as if the force issued from this direction. I have already alluded to the remarkable length (36.) of the column of stratifications, and I have given a drawing, Plate I. fig. 8, which I consider exhibits a direction of force from the positive to the negative, centring to the axis of stratification; in the following arrangement this dominant character of the positive discharge is further developed.

58. Plate I. fig. 12 represents a bent glass tube, about *one* inch internal diameter, in which both wires can be covered with liquid mercury; the wires a to b are 31 inches apart, from a to c the distance is 24 inches, from b to d 4 inches, from d to c 3 inches; by inclining the apparatus, the mercury from a can be elongated towards c to the length of 8 or 10 inches; in this condition, if a is negative, the entire surface of the mercury is covered with a brilliant white glow; if it is positive, the mercury is entirely luminous at the extreme end nearest c, but the remainder is unaffected by the discharge.

59. I cannot conclude this Note without expressing the deep sense of the obligation which I owe to Dr. FARADAY, who has, during the course of these investigations, not only afforded me the advantage of many important suggestions, but has also spared me much of his valuable time. I am at present continuing these most interesting experiments on the stratification, and should the results obtained be such as I anticipate, they will form the subject of a further communication.

J. P. G.

March 2, 1858.

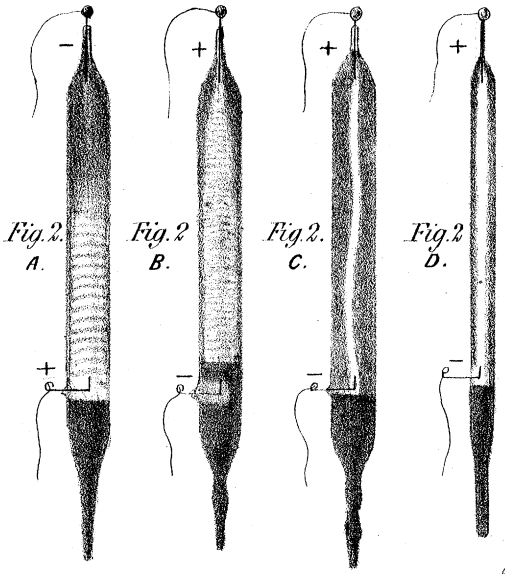


Fig. 2.
A.
Fig. 2
B.
Fig. 2.
C.
Fig. 2
D.

Fig. 1.

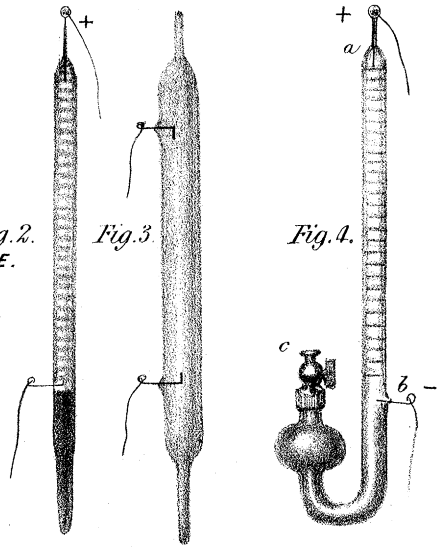


Fig. 2.
E.
Fig. 3.
Fig. 4.
a
c
b

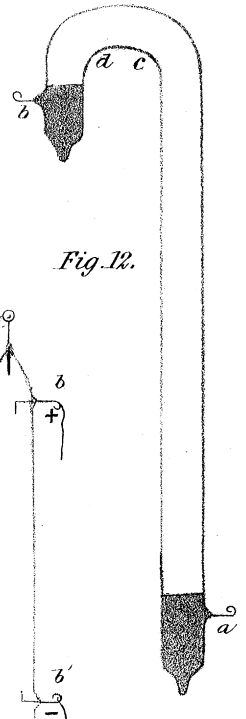

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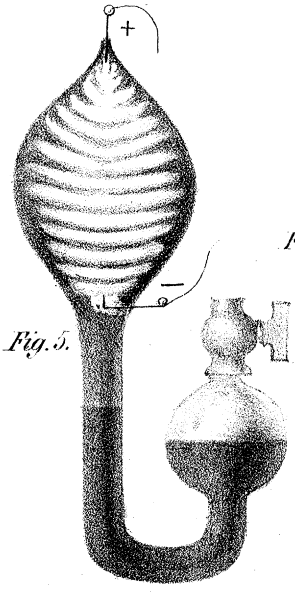
Fig. 12.
a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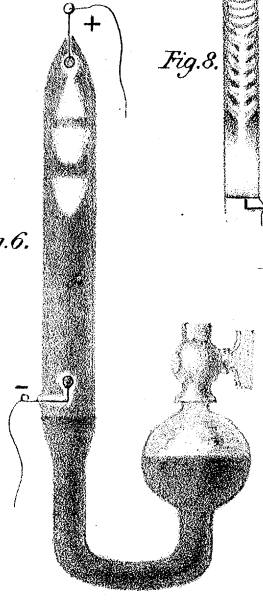
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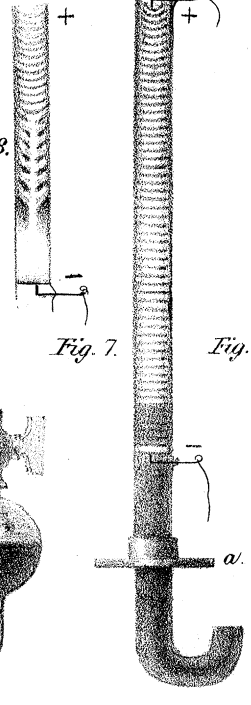
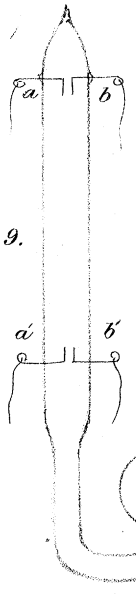
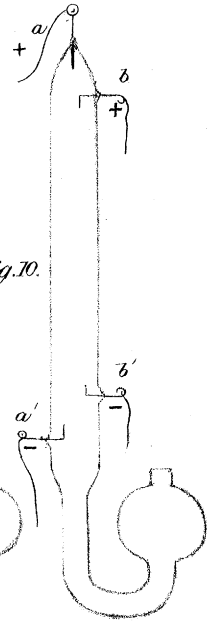


Fig. 8.
Fig. 7.
a


a
b
Fig. 9.
a'
b'


a
b
Fig. 10.
b'
a'