II.

EXPERIMENTAL INQUIRIES CONCERNING THE LAWS OF ELECTRICAL ACCUMULATIONS, BY MR. W. S. HARRIS, MEMBER OF THE PLYMOUTH INSTITUTION.

1. The peculiar arrangement of an insulated and uninsulated conductor exemplified in the construction of the Leyden Jar, appears calculated to develope, in a satisfactory way, many important properties of electrical action; it has consequently undergone, at various periods, so much investigation, that it would seem difficult to give any new interest to researches in this interesting department of science; but after a long series of observation and experiment, carefully compared with the present advanced state of our information, I am led to believe, that the following paper, will be found to contain some new and important facts, which appear hitherto to have escaped observation; and, I may therefore hope, that it will not be deemed unworthy of the Society's attention.

It may not be improper or uninteresting, before I proceed more immediately to the experimental inquiries, which are the subject of this paper, to give a sort of general account of the apparatus employed in the course of them, it being for the most part new, and so constructed as to insure as far as possible much precision, leaving more minute details to the accompanying drawings.

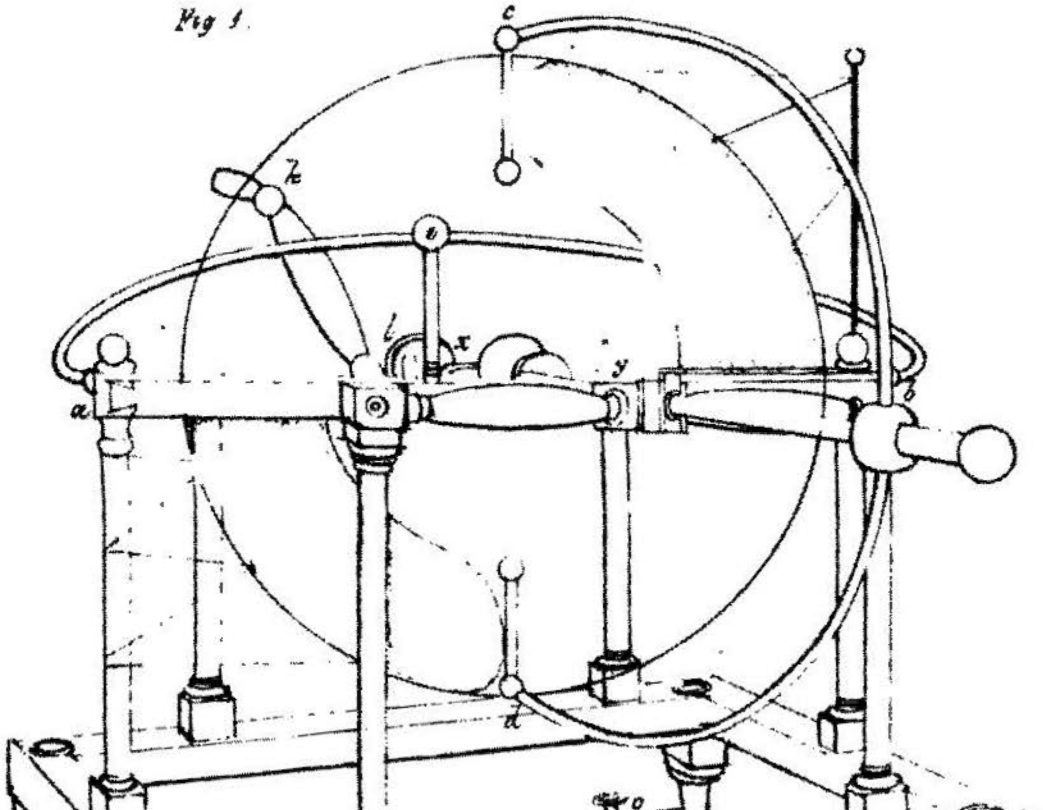
2. The electrical machine, fig. 1, consists of a circular plate of glass, three feet in diameter, mounted on an axis, between two horizontal supporters of mahogany; these are sustained by four vertical columns, of the same wood, fixed on a firm base. The rubbers are insulated on pillars of glass, (*a*) (*b*) and are placed at each extremity of a horizontal diameter of the plate. The positive conductor (*c b d*) projects in a vertical position, in front of the plate; whilst the negative conductor (*a e b*) passes in a curvilinear direction behind it and connects the rubbers of each side. The whole machine is sustained by four short legs, (*m n o p*) on a steady frame, (*n o*) furnished with rollers; and also with three levelling screws, (*h o p*) so that it may be easily moved into any required position; and may be eventually so adjusted and fixed, that the axis of the plate, which has free motion backwards and forwards in the holes, in which it turns, may not tend more to one side than the other, and produce an unequal action on the rubbers.

The plate is turned by means of an insulated handle, immediately in front of which, there is a short index, fixed in the axis, which travels over a divided circle, (*l*) attached to the horizontal part of the frame, and through the centre of which the axis passes; thus, the number of revolutions of the plate may be accurately estimated.

The centre of the plate, is strengthened by two smaller plates of glass, cemented to each side by varnish; and there is a small stop inserted into the axis, to prevent the pressure from increasing beyond a certain point.

The conductors, when the machine is employed to accumu-

Fig 1.



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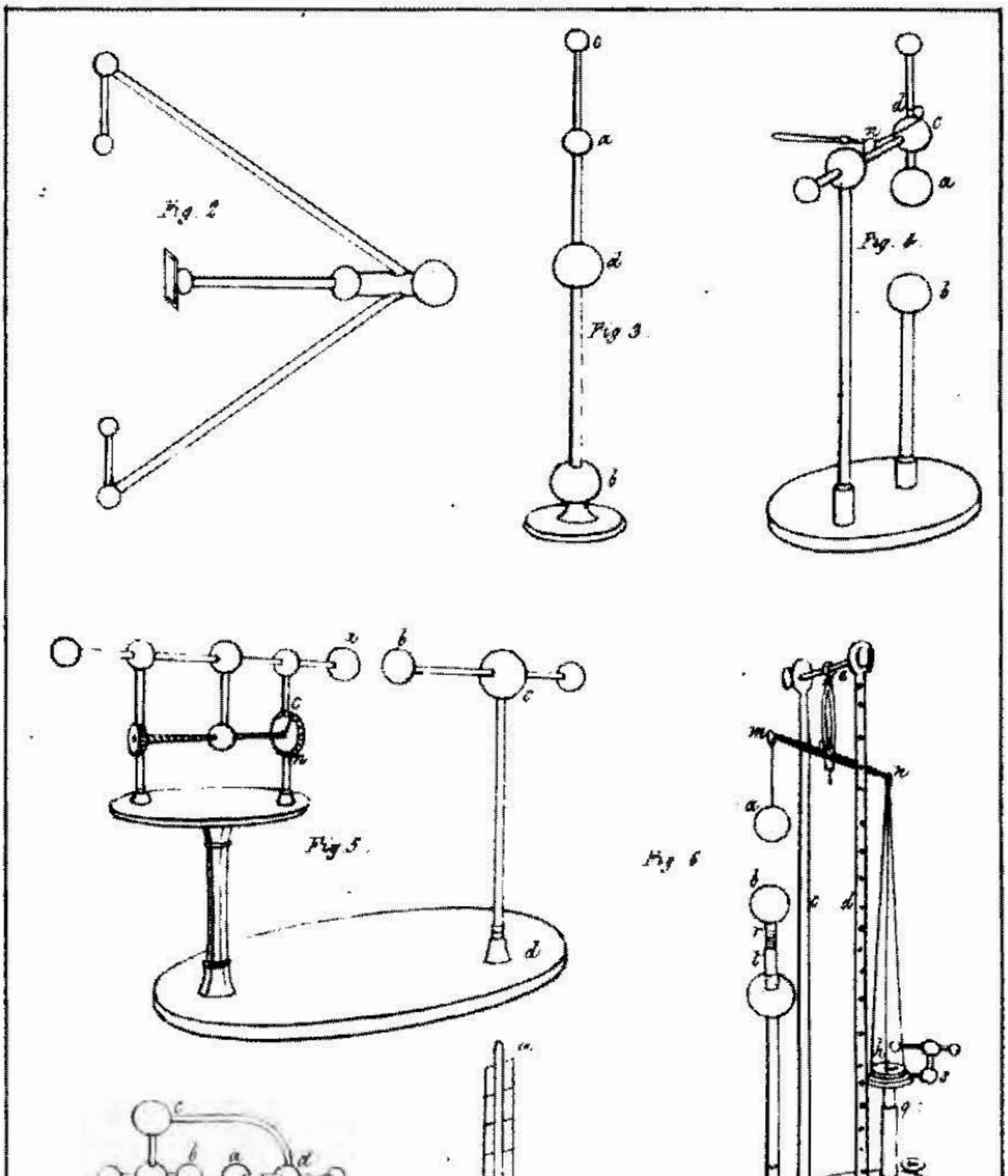

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late a charge, are of as small an extent as possible, and are covered, except at the receiving points, with sealing wax. The positive conductor being in this case constructed of small straight tubes, as represented in *fig.* 2; and its extremities terminate in balls of varnished wood, through the substance of which the necessary metallic communications pass.*

3. The requisite accumulation is obtained by means of coated jars, which are employed either detached or collectively; they are not furnished with covers, but the charge is conveyed directly to the bottom of each jar, by means of copper tubes, three-eighths of an inch in diameter; these terminate above in balls of baked wood, and are supported below by a convenient foot, firmly cemented to the bottom of the jar; which is previously covered with a circle of pasted paper, leaving a central portion of the coating free, for the perfect contact of the charging rod, which passes through the center of the foot, as indicated by the dotted lines in *fig.* 7.

These jars, when employed either separately or collectively, are placed on a conducting base, sustained by short columns of glass, or some other insulating substance, so that the whole

* This machine was constructed in the year 1824; I had previously seen one on a similar principle, by Mr. England, a Surgical Mechanician of considerable ability, residing in Poland-street, London. In Mr. England's machine, the same frame which sustains the plate also carries the rubbers in the usual away, but it is thrown into a horizontal position, the whole being insulated and supported by four long glass columns. The negative conductor passes in front under one of the arms of the positive conductor.

Mr. England's machine has very great power, and is an immense improvement on those of the ordinary kind. The great advantage obtained by the present arrangement, is stability; the requisite insulating pillars being relieved from the weight and straining of the framed plate, when in action: the conductors are advantageously placed, and the axis of the plate can be accurately adjusted, which is of great importance in obtaining a steady and equal excitation. The whole arrangement will be found very desirable and extremely convenient in practice.

can be insulated when required;* and for the purpose of allowing them to be charged and discharged with precision; they are connected with what may be considered as two centres of action;—the first of these consists of a brass ball, (*a*, *figs.* 3. 14. 16) which slides with friction on a metallic rod, (*c d*) so as to admit of its being adjusted to any required altitude; it it has a number of small holes, drilled in its circumference for receiving the points of the connecting rods of the jars.—The rod which sustains this ball, is either insulated on a separate foot, and connected with the conductor of the machine, as in *fig.* 16; or is otherwise inserted directly into it, as in *fig.* 14. The second centre, consists of a larger ball of metal, (*b*) attached to a firm foot, and placed on the same conducting base with the jars, so as to have a perfect connection with it. The wire (*n b fig.* 14) employed to transmit the explosion, terminates in this ball.

When it is required to give the first centre of action (*a*) *fig.* 3. a separate insulation, the insulating rod of glass, is screwed immediately into the lower ball; (*b*) and sustains the metallic rod above described, by the intervention of a ball of baked wood, (*d*) as seen in *figs.* 3 and 16; the opposite extremity of the rod terminates in a similar ball, (*e*) through the substance of which, the conducting communication with the machine passes when it is placed on a separate foot. All the metallic connections are covered with sealing wax, except at the points of junction; and the wood balls and different insulations are carefully varnished.

4. To transmit the explosion at any required period; two different methods were employed, according to the circumstances of the experiment—In the first, the discharge is effected by means of the instrument represented in *fig.* 4. There are two balls of brass (*a*) (*b*) placed one over the

* Rosin or brimstone answers very well for this purpose; the latter is easily moulded to any convenient form, by pouring it in a state of fusion into common drinking glasses.

other about three inches apart—The lower one, (*b*) is insulated and is connected with the positive side of the jar or battery; and the upper one, (*a*) with the negative side through the centres of action before described. (3) The ball (*a fig.* 4) connected with the negative centre, is attached to a rod of brass, (*d*) which falls freely through a smaller ball, (*c*) when allowed to do so. It is preserved at a given distance by a curved and finely pointed brass wire, (*n c d*) inserted into it; this wire being moveable about a centre (at *n*) can, by means of a glass handle, be readily disengaged; and thus the upper ball (*a*) is allowed to descend on the ball beneath it, by which the accumulation is always transmitted in a certain and invariable way, and without leaving any residuum in the battery.

5. In the second method, the charge is allowed to proceed until it can break through a known interval; to measure which, a discharging electrometer is employed, *fig.* 5 on the principle first proposed by Mr. Lane, and described in vol. 61 of the Transactions of the Royal Society—the interval between the balls (*a* and *b*) being adjusted by a screw and index, the motion of which last is shewn by a graduated circle; (*c n*) thus the interval may be regulated with very great precision: the connexion with the opposite sides of the jar are made through the two centres of action, as in the preceding case.

This discharging electrometer is also occasionally used in its more ordinary and simple form, as represented in *fig.* 7; the only difference being that the insulating portion (*c d*) terminates in balls of varnished wood, one of which (*c*) sustains it, whilst the other (*d*) contains the tube, through which the graduated metallic slide passes: there is likewise an additional ball, (*b*) placed in the charging rod, from which the jar discharges itself.

6. For the purpose of investigating the operation of the attractive force of the accumulation, and the law of its action under different conditions, I availed myself of a delicate and accurate balance, in the following manner:—

The beam (*m n fig.* 6) is sustained in the required position, between two vertical rods of glass; (*c*) (*d*) a covered wire indicated by the dotted line, (*e f*) passes through one of these and connects it with the negative coating. From one of the arms, (*m*) a hollow gilded ball of wood, (*a*) is suspended by a metallic thread; this ball is about two inches in diameter, and weighs about 160 grains. From the opposite arm, is suspended a light brass pan, (*p*) by means of silk lines in the usual way—in this pan, is placed as much additional weight as is requisite to balance the ball just mentioned; and to put the whole mass in a state of equilibrium. The attractive force of the accumulation, is caused to act directly on the suspended ball (*a*) by means of an insulated ball of brass, (*b*) of the same dimensions, which is fixed directly under it, and is connected with the positive coating: it is so placed, that it can be depressed from contact with the suspended ball, through given distances, by means of a cylindrical slide, (*r*) to which it is attached, and a socket (*t*); the slide (*r*) has a scale engraved on it, divided into twentieths of an inch, and is supported on a glass pillar, by means of a varnished ball of baked wood, in which the socket is fixed, and through which the connection with the positive coating passes.

It will be immediately perceived, that in this arrangement the attractive force acts directly between the balls, (*a*) (*b*) and it can therefore be measured under any given condition, by weights, placed in the pan, (*p*) suspended from the opposite arm of the beam. The pan is allowed to rest on a small circular support, (*q*) the elevation of which can be changed so as to accommodate it to the horizontal position of the beam, and check any oscillation: there is also a small stop, (*s*) inserted into this stand, which projects over the pan, and prevents the further descent of the beam, after the equilibrium is destroyed; without which, the explosion would pass, and destroy the gilding of the ball.

7. Lastly, to measure the effect of a given accumulation, an electrometer was employed, represented by *fig*. 8: it is very simple in its construction, being little more than an air thermometer, having a metallic wire passed air tight through its bulb; it consists of a glass tube, (*a b c*) whose interior diameter is somewhat less than the tenth of an inch; one of its extremities is bent upwards and outwards for about two inches, and is united by welding to a glass cup, at (*c*) which is of a large diameter and contains some coloured spirit: the bulb (*m n*) is about three inches in diameter, and with its transverse wire above mentioned is screwed air tight upon this cup. The opposite leg of the tube is sustained by a graduated scale, (*a b*) fixed on a convenient base, (*b*) and the point at which the fluid rests is marked zero. When an electrical explosion is passed through the wire, the fluid will be observed to ascend along the scale. The method of fixing the wire is easy; two flanches of brass, (*m n*, *fig*. 9) with projecting screws and shoulders, are cemented in and over the holes drilled through the glass, the wire is passed directly through the bulb by means of corresponding holes in these flanches, and being gently put on the stretch, is secured by short metallic or wood pegs, by which it is slightly compressed and retained in its situation. When metallic pegs are used it is necessary to have a small longitudinal notch cut in them. Both the pegs and extremities of the wire project a little for the convenience of removal; and thus wires of various kinds, and of different diameters, may be easily substituted.* The whole is finally rendered air tight by means of small balls of brass, which are made flat at one extremity, and screwed on the projecting parts of the flanches, against a collar of leather as shewn in *fig*. 9.

* See Transactions of the Royal Society, for 1827, pt. i. p. 18.

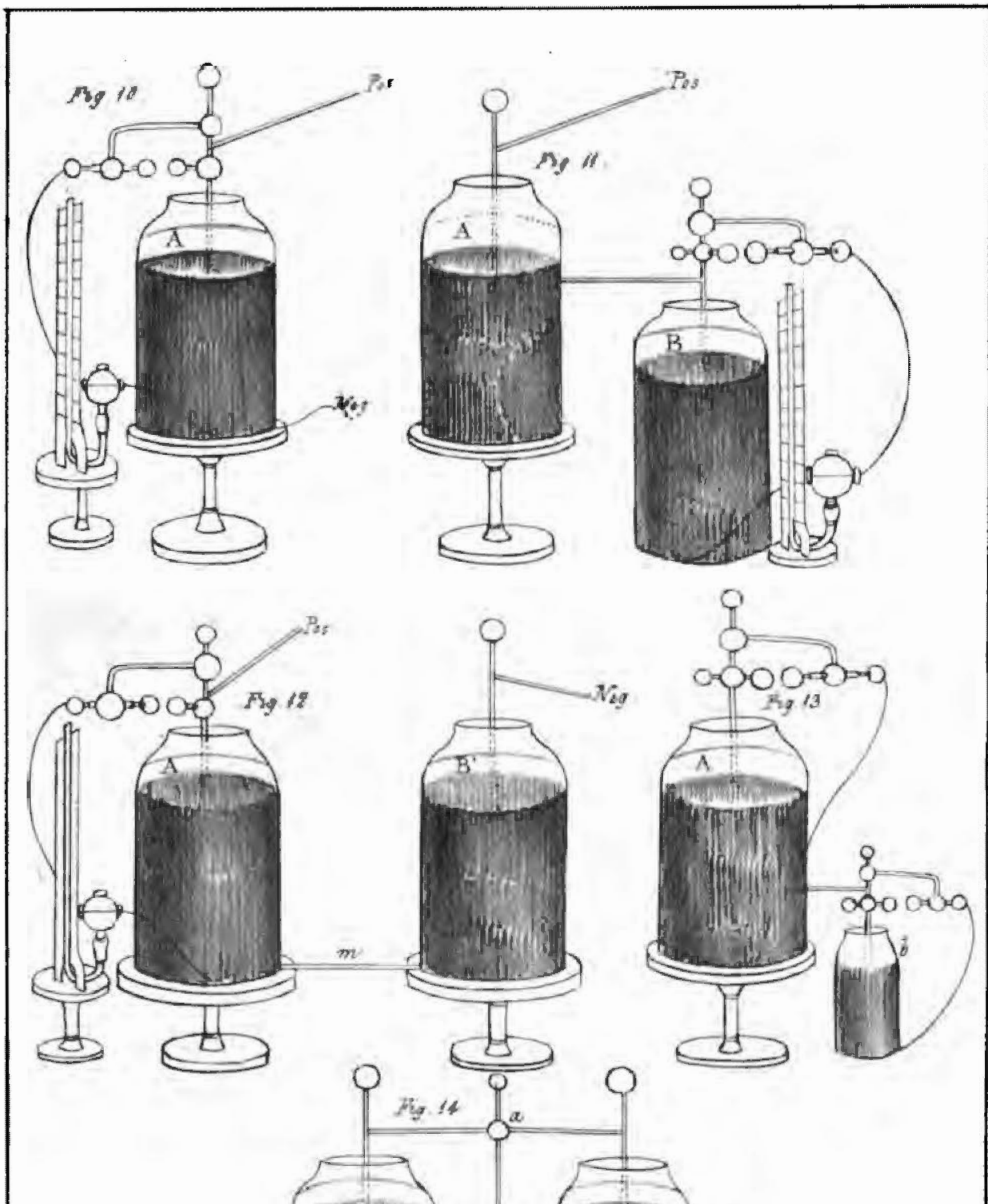
The metal best suited for measuring the force of an explosion in this way, is platinum; it is easily acted on, and not liable to oxidation. The wire may vary in diameter, between the 50th and 150th of an inch, according to the circumstances of the experiment. This method of estimating the effects of electrical explosions by their action on metals, will be found very convenient, and it is susceptible of much greater accuracy than the ordinary means by the fusion of metallic wire, which appears to be somewhat uncertain and precarious, when reduced to practice. *

9. In the detail of these inquiries, concerning the laws of electrical accumulations, our attention will be directed;—1—to the quantity of matter accumulated. 2—to the intensity, or free action of the accumulation. 3—to the extent and disposition of the surface, on which the matter has been distributed. 4—to the effects of the explosion: the quantity of matter, the surface and the intensity, being varied according to certain conditions. †

10. The relative quantity of matter may be measured by the revolutions of the electrical machine, employed to produce the accumulation; for if one revolution produces one quantity, as it assuredly does, then two revolutions should produce double that quantity, and so on, supposing the machine to be in good and uniform action, during the given time; but the precise manner in which a charge thus accumulates, not having been clearly determined, it is necessary to demonstrate, by

* Cuthbertson's Practical Electricity, p. 186.

† The immediate cause of electrical phenomena, must be considered as an agent of a peculiar kind, and if material, differing essentially from the usual forms of matter. The hypothesis of materiality, has only been assumed that we may be the better enabled to connect the results of experiment, and reason on them;—the only legitimate end for which hypothesis is at all admissible; whether electrical agency be material, or no in the ordinary acceptation of the word, I do not presume to determine.



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experiment, that an artificial electrical accumulation, on a coated surface, may be supposed to proceed, by equal increments.

There are however, a few previous experiments, requisite to be detailed, because they seem to constitute the basis on which the above conclusion rests. *

Exp. 1. (*fig.* 10) A jar, (A) containing five square feet of coated surface, being insulated; its inner coating was connected with the positive conductor, and its outer coating with the negative conductor. The discharging electrometer, *fig.* 7, was attached to the jar, and the distance between the balls, set to an interval of three-tenths of an inch. In order to estimate the effects of the explosion, the negative ball was connected with the outer coating, through the electrometer, before described; (*fig.* 8) which last, was also carefully insulated. When three turns and three quarters of the plate were completed, the explosion took place, between the balls, and passing through the wire, elevated the fluid, nine degrees of the scale.

Exp. 2. The outer coating of the jar, being connected with the ground instead of with the negative conductor, the same result was obtained; the fluid was again elevated nine degrees, and with the same number of turns of the plate.

Exp. 3. The outer coating of the jar, (A) being joined

* It may not be improper to state, that in the course of these inquiries, it has been thought desirable to submit to a rigorous examination, some few phenomena, in the science of electricity, already known, but which, nevertheless, do not appear to have undergone a very severe scrutiny, by experiment; not only because this constituted a necessary step in the investigation, but because it seemed more satisfactory to apply the same method of demonstration to facts which have been admitted, as was resorted to for the purpose of farther research.

to the inner coating of a second and perfectly similar jar,* (B) and the connection with the negative conductor, or with the ground, completed through the outer coating of this last, the machine was again put in action.—The explosion again passed at the end of the same number of turns, and again elevated the fluid nine degrees. This arrangement is represented in *fig.* 11; except, that the electrometers must be supposed to remain with the insulated jar, as seen in *fig.* 10.

Exp. 4. (*fig.* 11) The matter which had accumulated in the second jar, (B) from the outer coating of the first jar, (A) being discharged; the electrometers, were transferred to this last, in order to ascertain if the accumulation in (B) was precisely similar to that which took place in the first jar (A). The machine being put in action, the explosion again passed at the end of the same number of turns, and again elevated the fluid, nine degrees as before.

Exp. 5. (*fig.* 12) The electrometers, being again transferred to the jar, (A) as in exp. 1. *fig.* 10; the second jar, (B) was also insulated, and its inner coating connected with the negative conductor; the outer coatings of the two jars being joined by a metallic rod (m). Under these circumstances, the explosion again occured, at the end of the same number of turns, and with the same effect as before.

Exp. 6. Lastly, the electrometers being transferred to the jar, (B) charged from the negative conductor; the machine was again put in action: the discharge again passed as in the preceding cases, and again raised the fluid nine degrees of the scale. I repeated these experiments with jars,

* By a perfectly similar jar, is to be understood, a jar which will explode over a given interval with the same number of revolutions of the plate, and cause the fluid to ascend along the scale of the electrometer, *fig.* 8, the same number of degrees.

not precisely similar; by alternating them, and taking the mean results, and arrived at the same conclusions.

11. We may therefore infer: 1—that precisely the same charge accumulates on a coated surface; whether we suppose the opposite coating to be insulated and connected with one of the conductors of the machine, or whether it be in a freely uninsulated state, or otherwise, whether it operate through an intervening jar. 2—that the charge conveyed to an intervening and similar jar, is precisely equal to the charge conveyed to the first jar, in connexion with the conductor of the machine.

12. These experiments being premised, we pass on to the more immediate object of this part of the inquiry. (10)

Exp. 7. The jars and electrometers being arranged, as in *fig.* 11; the explosion again passed at somewhat less than four turns of the plate, and again raised the fluid nine degrees, as in exp. 4. The small residuum in the jar, (B) being discharged, the machine was again put in action;—the first jar, (A) connected with the conductor, remaining charged with the previous accumulation; when the same number of turns had been completed, the jar (B) discharged again, and with precisely the same effect on the wire as before.

Exp. 8. (fig. 13) A small jar, (*b*) containing about a square foot, and two-tenths, of coated surface, being substituted for the jar (B), the explosion took place, at about each turn of the plate, until the jar (A) became fully charged. Now in these instances, the jars, (B,) (*b*) being charged from the outer coating of the insulated jar, (A) their explosions became a fair measure of the relative quantities of matter, communicated by the machine. (Exp. 3 and 4) and as these explosions correspond in each case to equal numbers of revolutions, whilst the receiving jar, (A) was charging in any degree short of saturation, it follows, that the accumulation in (A,) must have proceeded by equal increments; and consequently, that equal quantities of matter were thrown on at each turn.

Exp. 9. In order to ascertain if these explosions would take place in a similar way, when two or more jars, were substituted for the jar (A.) The experiment was arranged, as represented in fig. 16; the jars and electrometers being carefully insulated—the result however remained the same; the small jar discharged as before, and in precisely the same way. The explosions of a second jar, therefore, in connexion with the opposite coating of a charging surface, whether in a divided or undivided state, may be also considered as a fair measure, of the relative quantities of matter accumulated.

Exp. 10. (fig. 12). Two equal and similar jars, (A) (B) were insulated, and connected, one with the negative, and the other with the positive conductor, as in exp. 5;—the outer coatings being joined by a metallic rod (M). In this case, as much matter as was conveyed into the positive jar, (A) was evidently taken from the negative jar, (B) and reciprocally. The effects of the accumulation in either system, estimated as before, at given intervals, were precisely the same, and corresponded to an equal number of turns of the plate: consequently, the respective quantities which continued to accumulate in the opposite system after each discharge, must have been also precisely similar.

13. These experiments relate to quantity; and they evidently shew: 1—that equal quantities are given off at each revolution of the plate, (if in a state of uniform action,) whether *to an uncharged surface, or to a surface charged in any degree short of saturation.* 2—that a coated surface, charging in any degree short of saturation, receives equal quantities, in equal times; all other things remaining the

same—whence, it may be inferred, that the number of revolutions of the electrical machine is, under the above condition, a fair measure of the relative quantity of matter. 3—That the explosions of a jar, charging from one of the coatings, are proportional to the quantity of matter thrown upon the other.—The quantity of matter may therefore be easily estimated by the number of these explosions.

14. Having determined these laws, relating to the quantity of matter accumulated, we come now to the consideration of the free action, or intensity, it evinces, under various circumstances.

When a given accumulation is disposed on a simple insulated conductor, it endeavours to fly off and discharge itself upon any body which happens to be within the sphere of its action: but if the surface of the insulated conductor on which the matter is accumulated be increased, then the tendency to discharge is lessened. To express this tendency of the accumulation to pass off in any given direction, the term intensity has been employed. Intensity therefore is but another term for what may be called free action.

But experience has shewn, that it is possible to controul the free action of a given quantity of electricity, not only by disposing it on a more extended surface, but also by opposing to the insulated conductor, a second conductor of equal and similar extent; the latter being in a freely uninsulated state, placed parallel and near to the former (fig. 19,) and the two conducting surfaces separated by some perfectly insulating medium. By this peculiar arrangement, the accumulation appears to be so determined upon the uninsulated surface, that the tendency to discharge in any other direction is diminished: the free action will therefore be more or less controlled, in some ratio of the distances of the opposed conductors.

There is however this difference in the actual condition of the two arrangements—when the matter is disposed and retained on a continuous surface, the whole of that surface is supposed to be in the same electrical state; whereas, in the latter instance, half the surface only is in a similar state; the opposed uninsulated portion being in an opposite one; this seems to be a necessary consequence of the subsequent action; and without such effect can ensue, the attractive force between the opposed conductors is not found to be so exclusive:—hence, it would seem, that, by means of the increased capacity of the uninsulated conductor, a given accumulation can be retained in this way, even with greater facility than on an extended and continuous surface.

It will be immediately perceived, that the Leyden jar is merely an arrangement of the above description; since one of its coatings is perfectly insulated, and placed near and parallel to the other; the latter being in a freely uninsulated state, and the two coatings separated by an insulating and resisting medium.

15. If therefore two conductors (*a*)(*b*) (figs. 5 6 7) be separated by a given interval, and be connected with the insulated and uninsulated coatings, as in figs. 7, 14, 15, then the free action may be estimated by means of these conductors; 1—by measuring the interval between them, which it can break through. 2—by measuring its attractive force or tendency to discharge, both of which will increase in some direct ratio of the quantity of matter, and in some inverse ratio of the controlling power of the uninsulated coating; all other things remaining the same.

16. The former of these methods will be first considered: and for which purpose we shall refer to the exploding electrometers above described, (5) and represented figs. 5 and 7.

Exp. 10. Two similar jars, each containing five square feet of surface, being connected with the discharging electrometer, (fig. 5) and with the positive conductor as represented in fig. 14. and the interval between the balls adjusted to one-tenth of an inch, the discharge took place at the end of two turns and half of the plate. The interval between the balls being now doubled, and the small residuum in the jars neutralised, the discharge passed when five turns were completed. The interval being increased to three-tenths of an inch, or treble the first distance, and the residuum discharged as before; the explosion passed at the end of seven turns and half of the plate. On increasing the interval to four-tenths of an inch, the discharge took place at the end of ten turns.

Exp. 11. One of the jars in the former experiment being removed, and the interval between the balls adjusted to four-tenths of an inch, the discharge took place with five turns of the plate. The quantity of coated surface being now doubled by adding a second and similar jar, and the interval between the balls diminished to two-tenths of an inch, the discharge again took place at the end of five turns. The quantity of coated surface being again doubled by adding two more equal and similar jars, and the interval between the balls reduced to one-tenth of an inch, or to a quarter part of the first distance, the discharge again occurred at the end of five turns of the plate.

Exp. 12. A single jar being connected as before, and the interval between the balls adjusted to two-tenths of an inch, the discharge occurred at the end of two turns and half. A second similar jar being added, the discharge occurred with five turns of the plate. A third similar jar being added, seven turns and half were required to complete the discharge: the interval between the balls remaining in each case the same.

Exp. 13. Two similar jars being connected with the conductor, and the interval between the balls adjusted to two-tenths of an inch, the discharge took place with five turns of the place. One of the jars, that is half the surface, being removed, and the interval between the balls quadrupled, the discharge occurred with ten turns of the plate, or double the former.

These results as far as I could ascertain, did not appear to be influenced by the way in which the surface was disposed; thus whether the extent of surface was made up with separate jars, or otherwise consisted of one large jar, still the same results were obtained, provided the areas of the coatings were accurately adjusted, and that the thickness of the glass did not vary.*

17. We may therefore conclude, that the free action of an electrical accumulation, as estimated by the interval it can break through, is directly proportional to the quantity of matter; (exp. 10) and inversely proportional to the surface, (exp. 11.) If therefore we increase the matter and the surface in the same ratio, the interval remains the same; (exp. 12)—and if we represent the quantity of matter by Q, the interval by I, and the surface by S, we obtain by exps. 10 and 11, the following expression $I \propto \frac{Q}{S}$ from which we get $Q \propto S\,I$; and thus derive another means of estimating the relative quantity of matter thrown upon a given surface, supposing the surface to be either in a divided or undivided state, and all other things remaining the same. Hence, if the surface be constant, the quantity accumulated is as the interval; and if the interval be constant, it is as the surface; and if as Q be increased, S be decreased, then we have $I \propto Q^2$.

* It will be necessary to keep in mind, that this relates only to the free action, and is not to be assimilated with the effects of the explosion on metals under similar conditions. (94.)

I repeated the above experiments, by insulating the jars and electrometer on the principle represented in figs. 13 and 16, so as to measure the quantity of matter by means of the explosions of a jar, charging from the outer coatings; (exp. 9,) and it is not difficult to obtain in this arrangement, such a distance between the balls of the exploding jar, (*b* fig. 13) as will accurately measure the accumulation corresponding to a given explosion of the jar (A) in which the accumulation has taken place: and thus by varying the distance between the balls of the electrometer connected with the jar A, whilst the electrometer attached to the jar *b*, is preserved the same; we may investigate the free action as before.

18. We now come to consider the second method of investigating the law of free action, as regards the attractive force or tendency to discharge.

In the application of the instrument described (6) (fig. 6) to this purpose, it is desirable, when the distances between the conductors (*a*) (*b*) require to be varied, that the opposed surfaces should be plane and parallel, (fig. 20) so that the distance between the attracting points may be every where equal; or otherwise, in employing equal spheres, it will be essential to determine, in each opposed hemisphere, a fixed point, as *a* and *b*, figs. 24 25, from which the sum of all the attractions would produce the same effect as if those attractions were exerted from every point of the hemispheres: so that when the distance between the balls is varied, the interval may be reckoned between these points, and not from the immediate point of contact.* This point will be found to fall

* We suppose here the forces to act in parallel lines, which appears to be an essential condition of this species of attraction; since the opposed surfaces being in equally opposite states of electricity, the reciprocal influence of the nearest points must be such as to neutralize each others' action, in relation to any other point more distant: the attractive forces therefore between these points becomes exclusive, and consequently, the lines of attraction are parallel. fig. 24.

within the opposed hemispheres at a distance equal to one-fifth of the radius. *

19. It may be observed, that in the application of an exploding electrometer, (fig. 5) this process is not requisite; since the explosion always passes from the nearest points, and no other; the attractive forces from the other parts of the balls do not consequently interfere with the accuracy of the result; more especially as the balls are fixed at a given interval, and cannot therefore approximate; this is essentially distinct from the case in which we seek to measure the attractive force, by opposing to it a known weight, the spheres being moveable, since in the last case, we cannot separate the attraction of one point from the whole, and must therefore take the whole into the account.

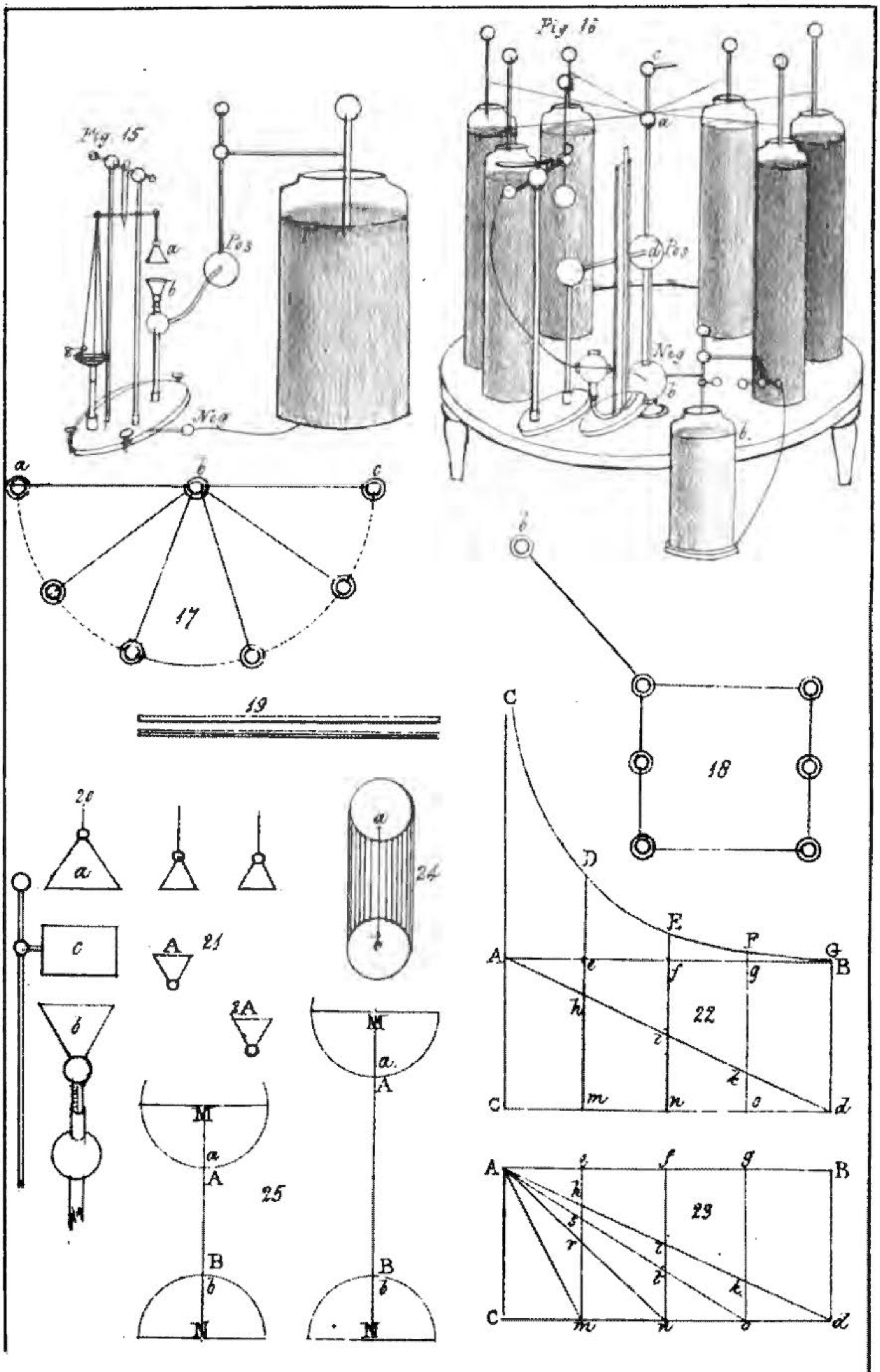
* Let M and N (fig. 25) be two hemispheres, whose diameters are two inches, and attracting each other at the distances A B $A_, B_,$ Let $a\,A = B\,b = a_, A_, = B_, b_, = x$ let A B = ,5 of an inch, and $A_, B_, = 1.4$; at which distances the respective attractive forces were found, by experiment, to be as 16 : 4 or 4 : 1.

$$\text{Then } 4 : 1 :: (a_, b_,)^2 : (a\,b)^2 :: (1,4 + 2\,x)^2 : (,5 + 2\,x)^2$$

$$\therefore 4 \times (.5 + 2\,x\ ) = (1.4 + 2\,x)^2 \text{ from which we obtain}$$

$$x^2 + \tfrac{2}{10}\,x = ,08$$

By solving this equation we shall have $x = +.3 - .1$, and consequently $x = +.2$ of an inch, or a distance equal to one-fifth of the radius; the other value of x being negative, and therefore in this case an impossible quantity. This expression will be found to be true for any two equal spheres; thus, in spheres of three inches diameter, the attractive forces were found, by experiment, to be as 4 : 1, when the respective distances A B $A_, B_,$ were 0.5 and 1.6. In spheres of 1 inch diameter, they were as 4 : 1 when A B $A_, B_,$ were 0.5 and 1.2. By substituting these quantities, in the above equation we shall have as before, x equal to one-fifth of the radius of the respective spheres. It may be further remarked, that the same results as in experiment 14 were obtained, when the opposed conductors were equal spheres, and the intervals estimated from within each hemisphere, at a distance equal to one-fifth of the radius.



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Exp. 14. A single jar, containing five square feet, being connected with the instrument already described; (6) and the connection with the negative coating completed, as represented in fig. 15, the insulated conductor *b* was depressed from contact with the suspended conductor (*a*) through an interval of half an inch, and a weight of sixteen grains placed in the small pan suspended from the opposite arm of the balance.* When five turns of the plate were completed, the attractive force was sufficient to tip the beam. The accumulation being discharged, the insulated conductor (*b*) was depressed through a second interval of half an inch, making the whole distance one inch. A weight of four grains or $\frac{1}{4}$ part of the former weight being now placed in the pan, the beam was again depressed with five turns of the plate: so that the distances being as 2 to 1, the corresponding weights were as 4 : 1. The accumulation being discharged, and the insulated conductor (*b*) depressed through a third interval of half an inch, and one-ninth part of the first weight placed in the pan; the beam was again depressed with five revolutions of the plate. We may therefore infer, *that the attractive force between the conductors varied in an inverse ratio of the square of the distance of the points of contact.*

Exp. 15. The distance between the conductors being adjusted to an interval of an inch, and a weight of four grains placed in the pan; the beam was again depressed with *five* revolutions of the plate. The quantity of matter being now doubled, that is to say, *ten* turns of the plate being allowed to accumulate, sixteen grains were requisite to balance the attractive force: the attractive force therefore, all other things remaining the same, increases directly as the square of the quantity of matter accumulated. This became further evident by placing a weight of thirty-six grains in the pan: in which case the beam was depressed with about fifteen turns of the plate.

* The position of the suspended conductor (*a*) is carefully adjusted by means of the three levelling screws attached to the base of the instrument, so that it may hang vertically and parallel over the insulated conductor (b).

20. This result is a necessary consequence of the law which seems to govern all these forces; for let two balls be connected with the opposed surfaces, and be separated by any given interval, and let the accumulation proceed until the free action can pass this interval; call the quantity at the time of the explosion 1, and the attractive force at the same instant also 1, and let the number of revolutions of the plate necessary to produce the accumulation be expressed by n. If we suppose the interval to be doubled, then the attractive force, all other things remaining the same, will be reduced to $\frac{1}{4}$, since the force varies in an inverse ratio of the square of the distance between the exploding points (exp. 14)—the discharge therefore, with the same quantity of matter, cannot occur at this new interval; but we have seen (by exp. 10) that with $2n$ turns of the machine, that is with double the matter, the explosion will again pass at a double interval. If therefore, when the interval between the balls is doubled, we double the matter, the discharge will again take place; but in this case, the attractive force must necessarily be as great at the greater interval, as it was at the lesser interval, without which the explosion could not happen, that is to say, it must have increased from $\frac{1}{4}$ to 1; or if measured at the first interval, it must be equal to 4; in either case, with double the quantity of matter, it must be four times as great, all other things remaining the same.

Exp. 16. A weight of 16 grains being placed in the pan, add the interval between the balls again adjusted to an inch, the beam was again depressed with 10 revolutions of the plate: a second equal and similar jar being added, that is to say the surface being doubled, ten revolutions of the plate were still requisite to depress the beam, when only four grains were placed in the pan: thus it may be perceived, that the same matter, disposed on a double surface only, evinces $\frac{1}{4}$ part of the free action: the distance between the balls being constant. I repeated these experiments, the apparatus being insulated, and the quantity of matter measured by the explosions of a small jar, charging from the outer coating, as already explained, (exps. 8, 9,) and obtained the same results; the interval between the balls of the exploding jar, being made very small.

21. We may therefore conclude, 1—that the attractive force varies in an inverse ratio of the square of the distance; all other things remaining the same. 2—if the surface be constant, and the matter increased, the attractive force is directly as the square of the quantity of matter. 3—if the matter be constant, and the surface increased, the attractive force is in an inverse ratio of the square of the surface. 4—if both the surface and the matter be increased in the same proportion, the attractive force is constant; and if we represent the attractive force by A, the quantity of matter by Q, and the surface by S, we have (exps. 15, 16) the following expression: $A \propto \frac{Q^2}{S^2}$ from which we deduce $Q \propto \sqrt{AS^2}$ or $Q \propto S\sqrt{A}$ and thus derive other expressions for estimating the relative quantity of matter; hence if the attractive force be constant, the quantity of matter is as the surface; and if the surface be constant, it is as the square root of the attraction; and if, as Q be increased, S be decreased, then we have $A \propto Q^4$

The want of a correct knowledge of these laws, has I apprehend, occasioned much uncertainty, in the results of many electrical inquiries. Thus in employing the well known and ingenious balance, or steel-yard electrometer, of Mr. Cuthbertson, in which the force of the free action is opposed by a known weight; it has been assumed,* that when the slider has been set to 15 and 30, so as to measure separate charges, the surface being constant, that the corresponding

* Cuthbertson's Practical Electricity, p. 175, 178, 179, 180.

accumulations, are in the same ratio, that is to say, as 2 : 1; whereas, in order to obtain a double accumulation, the slider should be set to sixty grains, instead of thirty; since the opposing forces should be to each other as 4 : 1.

22. Having determined the relations which subsist between the quantity of matter, and the free action of a charged surface, and shewn how these last may be measured; we come now to investigate the effects of the explosion: the quantities we have been considering being varied, according to certain conditions.

Exp. 17. (*fig.* 10) A single jar, containing two square feet and half of coated surface, being connected with the conductors, and with the electrometers before mentioned, (5) (7) and the distance between the balls adjusted to eight-tenths of an inch, the explosion took place with five revolutions of the plate, and elevated the fluid eighteen degrees.

Exp. 18. A jar, containing five square feet, or double the former surface, being substituted for the jar in the last experiment, and the distance between the balls adjusted to four-tenths of an inch, the explosion again passed with five revolutions of the plate, and again elevated the fluid eighteen degrees.

Exp. 19. A second equal and similar jar, being connected so as to double the last surface, and the distance between the balls diminished to two-tenths of an inch, the discharge again passed with five revolutions of the plate, but only elevated the fluid to twelve degrees, or about two-thirds of the former.

Exp. 20. The two larger jars being removed, and two jars containing each two square feet and half substituted, that is to say, half the former surface, divided into two equal and similar parts, and the interval between the balls again increased to four-tenths of an inch, the explosion again passed with five revolutions of the plate, and again elevated the fluid twelve degrees.

Exp. 21. A series of six jars being selected, differing in thickness, and the areas of whose coatings varied from one to five square feet; each jar was connected in succession with the conductor and electrometers, and two turns of the plate thrown on it: the discharge being effected by means of the discharging electrometer; (*fig.* 4) the fluid was in each case elevated to eighteen degrees. *

I repeated these experiments, by insulating the apparatus; the quantity of matter being measured by the explosions of a jar, charged from the outer coating, (as in *fig.* 16;) and the discharge effected as in the last experiment, and obtained the same results. We may therefore conclude, 1—that the effect of the explosion depends exclusively on the quantity of matter, without reference to the free action; (exps. 17, 18, 21.) and, 2—that in disposing the same quantity of matter, on the same surface, divided into two equal and similar parts, about one third of its effect is lost. (exps. 19, 20.)

23. Exp. 22. A single jar containing five square feet, being connected as before, (*fig.* 10) and the distance between the balls adjusted to two-tenths of an inch, the explosion passed with two revolutions and half of the plate, and raised the fluid four degrees and half of the scale. The small residuum being discharged, and the distance between the balls adjusted to four-tenths of an inch, the explosion passed at five revolutions of the plate, and raised the fluid eighteen degrees. The dis-

* In this last experiment, it was necessary to employ a much finer wire, than in the preceding cases, in order to render the effect more apparent; the quantity of matter being small.

tance between the balls being now adjusted to six-tenths of an inch, and the residuum neutralized as before, the discharge passed between the seventh and eighth revolution of the plate, and raised the fluid to about forty degrees.

The same results were obtained, by insulating the apparatus, and measuring the quantity of matter, by means of the explosions of a jar, connected with the outer coating. *It may therefore be inferred, that the effects of an electrical explosion on a metallic wire, all other things remaining the same; is directly as the square of the quantity of matter.*

This law did not appear to be influenced by disposing the accumulation on a divided surface; for although the magnitude of the corresponding effects was reduced, as in exp. 19, yet the surface being constant, the subsequent results were directly as the square of the quantity of matter.

24. Having thus found, (23) that the effect of the explosion on a metallic wire, is directly as the square of the quantity of matter: all other things remaing the same—and (exp. 19) that in disposing the same quantity of matter, on the same extent of coated surface, divided into two equal and similar parts, about one-third of its power is lost; it seems a point of some interest, to pursue this investigation a little further, in order to ascertain what subsequent decrements in the effect take place, by a still greater division of the surface; the quantity of matter remaining constant.

With this view, six jars were selected, each containing about a square foot, and four-tenths of coated surface: they did not materially differ in their electrical capacities; and since the investigation related exclusively to the quantity of matter and the surface, the excitation of the machine, was tested by an exploding jar, and the quantity of matter measured, both by means of the revolutions of the plate, and the explosions of a jar charged from the outer coatings; the discharge being effected by means of the discharging electrometer *fig.* 4. The general arrangement is represented in *fig.* 16.

Exp. 22. A single jar being connected with the conductor, and charged with two revolutions of the plate, the effect on the wire was observed and noted. A second jar was now examined in a similar way; the respective effects did not greatly vary, but the mean result amounted to just sixteen degrees. The two jars being now combined, and the same quantity of matter disposed on them, the resulting effect was only eleven degrees, the loss being about one third. This process was repeated, with the same quantity of matter disposed on three jars; the mean result of the three, taking each separately, being first determined, and then the result of their combination—in this case, the loss amounted to somewhat less than one half—a similar process with four jars, gave a loss rather greater than one half—with five jars, it amounted to nearly two-thirds, and with six jars to about four-fifths. The results are given in the following table.

TABLE I.

REVOLUTIONS OF THE PLATE.	NUMBER OF JARS.	EFFECT.
2	1	16
2	2	11
2	3	9
2	4	7
2	5	5
2	6	3

It might therefore be supposed, that by increasing the number of jars, the effect would at length be reduced to zero, and such was found to be the case; for on disposing the same matter on a great number of jars, the effect on the wire became insensible.

25. As a further extension of the preceding investigation, the quantity of matter was made to increase as the number of jars, and to obviate any error which might be supposed to arise from slight differences in the jars, each jar was first examined separately, and a mean result obtained; they were then combined in pairs, the matter being doubled, then each three jars were combined; the matter being tripled, and so on to the last combination, in which the whole six were combined; the matter being six times as great as in the first instance. The mean results of each respective series of combinations are given in the following table. *

TABLE II.

REVOLUTIONS OF THE PLATE.	NUMBER OF JARS.	EFFECT.
2	1	11
4	2	26
6	3	50
8	4	73
10	5	85

It is easy to reduce the above results, to the same form as in the preceding table, so as to obtain the relative effects of the same quantity of matter disposed on a given number of

* In these experiments, it became necessary to employ a larger wire in the electrometer, than in the preceding, in order to resist fusion; the quantity of matter being greatly increased.

jars; since the effect (23) is directly as the square of the quantity of matter. Thus to havè the effect of the matter disposed on two jars, as compared with the same quantity disposed on one, we divide the effect on two jars by four: to obtain the effect on three jars as compared with the same quantity on one, we divided the effect with three jars by nine, and so on. The results thus reduced are given in the following table; and it will be observed, that they do not considerably differ in their relation to each other, from those before obtained. (exp. 22.) Table I.

TABLE III.

REVOLUTIONS OF THE PLATE.	NUMBER OF JARS.	EFFECTS.
2	1	11, 0
2	2	6, 5
2	3	5, 5
2	4	4, 5
2	5	3, 4

26. In referring to table II, it may be observed, that when the quantity of matter and the number of jars are both increased together, the full effect of the respective accumulations is not obtained; since double the matter disposed on two jars, only equals about two and half times the first effect, instead of four times, which it should do if disposed on one. (23) By disposing three times the quantity of matter on three jars, we only obtain about four and half times the first effect, instead of 9 times, and so on, untill at last in increasing the number of jars, the differences in the respective effects become less and less, so that a limit appears to obtain, in which the advantage derived from an increased quantity of

matter, becomes neutralized by the opposite effect of the increased number of jars.

These results are very analogous to those arrived at in the extensive investigations of Mr. Children with his large voltaic battery, in which an intense deflagrating power was obtained by accumulating the electric action on as great an extent of undivided surface as possible;* and also with those of Sir H. Davy,† in which the relative powers of ignition with an extensive voltaic series appeared to decrease after a certain limit, beyond which there is a loss of power; which is precisely what happens when the number of jars and the quantity of matter are both increased together, and in the same proportion.

27. It may be proper to observe, that the above results are somewhat at variance with the conclusions arrived at, in Mr. Singer's excellent work on electricity; he infers, p. 179 that the same quantity of matter, will fuse the same length of wire, whether it be disposed on two jars, or on one: but it may be shewn, that in the immediate experiment from which this conclusion has been drawn, the quantity of matter greatly varied. In the experiment alluded to, eight inches of wire had been previously fused, by a single jar, charged to thirty grains; it was likewise fused by two jars, charged to fifteen grains,‡ and it is inferred, that the quantity of matter was in each case the same; whereas, in the latter instance, it must have been greatly increased, for it will be remembered, (15) (20) that by the expression charging a single jar, or otherwise, two jars to any degree, say fifteen or thirty grains, we thereby mean, that certain relative measures of the free action of the accumulation have been obtained, as indicated by its attractive force; the surface on which the matter is disposed

* Elements of Chemical Philosophy, p. 159. † Ib. p. 156.

‡ Exp. 77, page 177.

being given. Now it has been shewn, (exp. 16) that supposing the same quantity of matter to be disposed on a double surface, the intensity or free action, as indicated by its attractive force, would be reduced to one quarter; consequently, the intensity corresponding to the previous quantity of matter on the single jar, would when both jars were employed, only amount to seven grains and half; that is to say, to the one quarter part of thirty grains; the previous intensity on the single jar, supposing the jars to be precisely equal and similar. But in the experiment above-mentioned, the intensity on the double surface, was double this amount, or fifteen grains; therefore the matter accumulated, by a very simple calculation, must have been greater than in the previous case with the single jar by nearly one half; for the surface being constant, the quantity is directly as the square root of the attractive force. (21)

It is easy from the preceding investigations, to observe the relations which subsist between the interval which the free action can break through, the attractive force it exerts, and and the resulting effect of the explosion. For since $I \propto Q$ (18) and $A \propto Q^2$ (21) and $E \propto Q^2$ (22) the effect being represented by E; therefore the effect and the attractive force must vary together, and each must vary as the square of the interval—all other things remaining the same.

28. It has been my endeavour hitherto, in the course of these inquiries, to confine my observations as much as possible to matters of plain experimental evidence, in order that they might not be embarrassed by theoretical speculations, which would be a source of serious objection. I have therefore, avoided entering upon any explanation of the curious phænomena, that the interval which the free action of an electrical accumulation can pass, is directly as the quantity of matter accumulated; (exp. 10) whilst the attractive force is as the square of the quantity. (exp. 15.) I have only endeavoured

to shew, (20) * that these phænomena are perfectly consistent with each other, and involve no sort of contradiction. A few additional observations concerning these laws of electrical action, more especially as relating to the attractive force of the accumulation, may not however, be now altogether out of place, keeping in view an established principle in experimental science, that we are said to explain any phænomenon when we shew it to be necessarily included in some other phænomenon, or fact already known.

29. It is reasonable to infer, that in every case of duplicate proportion, two equal and concurring causes are present; for as observed by the learned Dr. Clarke, to suppose any effect whatever, to be as the square, or the cube of its cause, is to suppose that such effect arises partly from its cause, and partly from nothing. Thus in the case of the free action of an electrical accumulation, as estimated by means of its attractive force operating between two conductors, *(a) (b) fig.* 15. there are, as already observed (15) two separate causes to be considered; the quantity of matter accumulated, and the controlling power of the uninsulated coating; and it has been observed (14) that the free action will be in a direct proportion to the quantity of matter, and in an inverse proportion to the controlling power. If, therefore, as the quantity of matter is increased the controlling power of the uninsulated coating should from any cause be diminished, and in an inverse ratio, then the free action must necessarily be in a duplicate proportion; and such a conclusion is by no means unwarranted by known facts.

We have already had occasion to remark, (14) that when an insulated and uninsulated conductor are directly opposed to each other, and are separated by a non-conducting interval, the capability of the former to retain a given accumulation is,

* See page 64.

all other things remaining the same, considerably increased; for the accumulation being determined by the proximity of the two conductors, immediately upon the uninsulated one, a portion of the natural electricity of the latter becomes displaced, and thus it appropriates to itself, a great part of the resulting action. In the operation of the Leyden jar, however, the natural electricity of the insulated coating, not having the same unlimited room to recede, in consequence of the intervening glass, the effect of the inductive influence in controlling the free action is not proportionate to the quantity accumulated. Hence, the respective quantities set free, as arising from this cause alone, must continue to increase in a simple ratio of the accumulation.*

But in order to estimate the whole amount of the free action, we have also to take into the account, the simultaneous influence of the matter thus set free, on the outside of the jar, by which the controlling power is at length destroyed, and the whole accumulation caused to pass in the form of an explosion; by increasing the quantity accumulated, we have, therefore, not only an increased quantity set free; but also an increased neutralizing influence, which operating upon the negative coating, either immediately through the balls of the electrometer, or otherwise through the surrounding medium, as in the case of a spontaneous explosion over the uncoated interval; the exclusive action between the coatings in the direction of the intervening glass, will be necessarily diminished, that is to say, the controlling influence in the latter direction, *will be more or less neutralized by a similar and opposite force.*

* It is quite immaterial in this investigation, whether we consider an artificial electrical accumulation, to commence first from the negative coating, which may be supposed to happen in charging a jar, by the transfer of its own electricity, (exp. 1.) or otherwise from the positive coating, as may be supposed to occur in charging an uninsulated jar, (exp. 2.) In either case, the quantities set free will be precisely the same; since, in the one instance, the quantity displaced may be supposed to *precede* the quantity accumulated, in the other, to *succeed* it.

It is further to be observed, since the tendency to a state of equal distribution, in the direction of the balls of the electrometer may be supposed to increase, not only with the quantity accumulated, but also with the displacement from the opposite coating: we may likewise estimate the quantity set free, under these conditions, and consider merely the power of controlling the free action, as depending on these two causes taken together. In which case, this power will continually decrease, in an inverse ratio of the square of the quantity accumulated, (exp. 4), until it vanishes at the instant of the explosion; whilst the indicated attractive force will consequently *increase* in a direct ratio of the square of the same quantity, and the effect is still proportionate to its cause; that is to say, to the quantity set free.

This duplicate proportion will not, however, become apparent in the interval which the accumulation can pass; since by increasing the intervals between the exploding points, we diminish the attractive force; the quantity of matter being constant, in the inverse ratio of the squares of the respective distances, as already explained. (20.) The attractive force therefore of the free action, considered as a constant quantity, is at a double interval, reduced to one-fourth, and the explosion cannot pass at a double interval, until an equivalent attraction is obtained, that is to say, until four times the quantity is set free, which will be when double the quantity is accumulated.

30. In disposing the same quantity of matter on double the surface, we have also a duplicate proportion indicated by the decrease of the free action; as observed (exp. 16); in this instance, we may also trace the joint effects of these two concurring causes. It will be readily perceived, that to dispose the same quantity of matter on a double surface, is the same thing as regards the attractive force of the free action, as disposing half the quantity on the same surface; for

let the double surface be supposed to be divided into two parts, each equal and similar to the single surface, then the quantity will be divided in the same proportion, one half remaining with one part, and the other half with the other. We have only therefore, to determine the resulting attractive effect, for one of these portions, and we obtain the indicated attraction of both, (21) since the attractive force of the free action is the same with one jar, as with any given number, when the quantity of matter is made to vary with the number of jars. (exp. 11.) Now by disposing half the quantity on the same surface, that is by diminishing the quantity one half, we at the same time double the controlling power of the uninsulated coating, since the latter is increased as the difference from a state of equal distribution is decreased: and hence, by the joint action of these concurring causes, we have only one-fourth part the attractive force.

This duplicate proportion, will not however become apparent in the interval which the explosion can pass; (exp. 11) for as already observed, (20)* the attractive force being in an inverse ratio of the square of the distance, the explosion can with the same quantity of matter still pass at one half the interval; since by diminishing the distance between the balls one half, we quadruple the attractive force; the quantity of matter being constant.

The converse of this reasoning will be readily admitted, in its application to the duplicate proportion observable in accumulating the same quantity of matter, on half the extent of coated glass, the one being the reciprocal of the other, and is included in the general expression $A \propto \frac{1}{S_2}$ (21); taking care to remember, that by s, we denote the extent of coated glass, considered as a simple quantity without reference to its two surfaces.

* See page 64.

31. The various instruments, employed as measures of these different states of the free action, which we have been just considering, have been supposed merely to indicate the deviation of the accumulated electricity, from a state of natural distribution; and to have no relation to the quantity accumulated;* but such a conclusion must be taken with considerable limitation. It is true, that as much free action may be evinced by a jar containing only a square foot, as by a jar containing ten square feet, or by a battery containing one hundred. But when we take into the account the laws above mentioned, (21) we immediately perceive that there is an important connection existing between the indicated attractive force, the quantity of matter set free, and the relative quantity accumulated. Thus if a given quantity of matter be accumulated on a square foot of coated glass, and it indicate an attractive force, which we will call 1, then supposing the same quantity to be disposed on ten square feet, its free action will be reduced to one hundredth, (21) that is to say, there will be only the one-hundredth part of one-tenth of the whole set free from each jar, since the matter is disposed on ten jars. (30) If therefore, the free action should become the same as before, then one hundred times the above quantity will be set free from each jar; and ten times the original quantity of matter will be accumulated on the whole.

32. The duplicate proportion observable in the general law of electrical attraction, already noticed, (20) will be found to involve a similar concurrence of two equal causes; since it may be shewn by a very easy experimental analysis, that the whole attractive force depends, first, on the force induced in the attracted body, and secondly, on the distance at which the force so induced is caused to act. If therefore, whilst we diminish the distance one half, it should be found that the force induced in the attracted body is doubled, then we have neces-

* Singer's Electricity, p. 139.

sarily four times the attraction. If the distance be diminished to one-third, and the force induced in the attracted body be tripled, then we have nine times the attraction, and so on. There are a few very simple experiments to be adduced in support of this view of electrical action.

Exp. 24. A large jar, containing about five square feet, was connected with the insulated conductor of the electrometer, (*fig.* 6) and with the conductor of the machine, as in *fig.* 15; the whole being insulated, and the quantity of matter measured by the explosions of a small jar, charging from the outer coating, on the principle already explained, (12) and represented in *figs.* 13 and 16. A third conductor, (*c*, *fig.* 20) with flattened surfaces, was now carefully insulated, and interposed between the insulated and suspended conductors; (*a*) (*b*) under these conditions, the weight requisite to balance the attractive force, measures the force induced in this intermediate conductor, (*c*) at different distances from the insulated conductor, (*b*) the distance (*a c*) between the suspended and interposed conductors, remaining in each case the same. Now the induced force, was found *within certain limits* to vary in a simple inverse ratio of the distance (*c b*) between the insulated and interposed conductor. Thus the insulated conductor (*b*) being depressed from contact with the interposed conductor, (*c*) through an interval of two-tenths of an inch, and an accumulation caused to take place, expressed by twenty explosions of the small jar; the weight requisite to balance the attractive force, amounted to eight grains; the distance from the suspended conductor being about two-tenths of an inch; the interval (*c b*) being now doubled, by depressing the lower insulated conductor (*b*) another two-tenths, the attractive force amounted to four grains; the interval (*c b*) being increased to six-tenths, the attractive force amounted to about two grains and half; the induced attraction therefore, varied in an inverse simple ratio of the distance, (*c b*) all other things remaining the same. By a further extension of this experiment, it became also apparent, that the induced force so long as the inductive action could proceed with facility, was directly as the force of the free action; for by increasing the quantity of matter accumulated by about half as much again, so as to double the free action, according to the laws already determined. (20) The induced attractive force at a certain distance was also doubled; the free action being quadrupled by doubling the accumulation, the induced force was also quadrupled. (21) This law however, as the disturbance in the interposed conductor became considerable, began to vary; the state of unequal distribution not being equally susceptible of further change.

Exp. 25. The interposed conductor (c) being removed, and the attractive force at a given distance (*b d, fig.* 15) being determined, a second accumulation was caused to take place, so as to give at the same distance, a force double the former. This double force, being caused to operate on the suspended conductor at a double interval, the respective attractive forces were found to be reciprocally proportional to the distances between the insulated and suspended conductors. (*a*) (*b*) Now in these instances, the induced force in the suspended body (*b*) must have been the same, since a double inductive force 2 A *fig.* 21, acting at a given distance, will be equivalent to a single inductive force, (A) acting at one half that distance—the inductive effect being as just shewn, (exp. 24) inversely as the distances. This result although a necessary consequence, when we assume, that the force of electrical attraction, varies in an inverse duplicate ratio of the distance, still involves the important fact, *that the induced force being constant, the attractive force varies in an inverse simple ratio of the distance between the attracting bodies.* These results therefore, go to prove, that the duplicate proportion observable in the general law of electrical attraction, may be referred to the operation of two concurring and equal causes; that is to say, to the induced force, and to the distance at which the force so induced acts.

when therefore, these vary together, and in an inverse proportion, we have the inverse duplicate ratio above mentioned.

It may not be uninteresting to remark, that similar effects are observable in the action of a magnet on a mass of iron; the attractive force being directly as the force induced in the iron, and inversely as its distance from the magnet, whilst the inductive effect is directly as the power of the magnet, and inversely as its distance from the iron: and it is also demonstrable, that when the inductive effect on the iron can no longer proceed, the attractive force is not in an inverse duplicate proportion, but in an inverse simple ratio of the distance, as I have endeavoured to shew elsewhere.*

33. The reasoning which has been advanced (29. 30) in explanation of the duplicate proportion observable in the attractive force of the free action, admits of much useful elucidation, when the quantities are represented by analogous geometrical magnitudes; a method which frequently enables us to demonstrate theorems relating to such quantities, with great readiness and precision; and developes many important facts which otherwise would not so readily appear.

Since the quantity of matter accumulated on a charged surface may be supposed to proceed by equal increments (13) therefore it may be represented by any magnitude supposed to flow uniformly. Let, therefore, the line A c, *fig.* 22. move parallel to itself upon the line (c d,) and generate the equal spaces c e, m f, n g, &c. then the rectangular space A, B, c d, may stand for and represent the whole quantity accumulated; and because, as we have endeavoured to shew (29) the controlling power is constantly decreased, as the quantity of matter is increased, until it vanishes at the time of the explosion; therefore, it may be represented by any magnitude

* Experimental Researches, on the Laws of Magnetic Action.

supposed to flow; and at the same time continually decrease as the accumulation increases. Let therefore the line A c, also move parallel to itself, in the direction c d, and continually decrease by the quantities e h, f i, g k, &c. which are proportional to the lines A e, A f, A g, &c. that is, to the respective quantities of matter, and so generate the diminishing triangular space A d c, which may consequently stand for, and represent the whole of the controlling power: then the quantity of matter first accumulated being represented by the space c e, the quantity controlled will be represented by the space c h, and the quantity set free by the triangle, A e h; in the same way, a double quantity of matter will be represented by the double space c f, the quantity controlled by the space c i, and the quantity set free by the triangle, A f i, and so on. But the triangles A e h, A f i, are to each other as the square of A e, to the square of A f; and since A f, is double of A e, these triangles are to each other as four to one. In the same way it may be shewn, that the triangles A e h, A g k, are to each other as nine to one, and so on: and as these triangles stand for the free action, whilst the sides A g, A f, A e, are proportional to the respective quantities of matter accumulated; it is so far demonstrable that the free action of any given accumulation, is, all other things remaining the same, directly proportional to the square of the quantity of matter.

In a similar way, if the lines A e, A f, stand for the intervals which the force of the free action can pass, and the relative quantities set free, be represented by the triangles A e h, A f i, &c. as before, then in drawing a curve line C, D, E, F, G, so that the ordinates D e, E f, &c. may vary in an inverse ratio of the squares of their distances from the point A; these ordinates D e, E f, &c. may stand for the relative attractive force of any given quantity of matter at the respective distances A e, A f, &c. (20. exp. 14.)

If therefore, when the quantity set free is A e h, the explosion takes place, the interval being A e, and the attractive force

D e, then, in supposing the interval A e to be made twice as great, that is to become A f, the attractive force of the same quantity of matter would be represented by E f, and the explosion could not occur at this interval with the same quantity accumulated; but in doubling the accumulation, the quantity set free would be represented by the triangle A f i, that is, it would be four times as great, and the magnitude of the whole attractive force, would become equal to four times E f, that is, it would be equal to D e, as before, and the explosion must then again take place. In a similar way, it may be shewn, that when the interval A e, is extended to A g, the attractive force D E, of the same quantity of matter A e h, is reduced to one-ninth of D e, that is, to F g, whilst the quantity set free, when three times the matter is accumulated, being represented by the triangle A g k, becomes nine times as great; the explosion will therefore again pass at this interval, for the whole attraction will become nine times F g, that is, D e as before, and so on;* hence the interval which the explosion can pass, will be directly as the quantity *accumulated*. (20)

34. The duplicate ratio observable in comparing the effects of the explosion, (23) would seem to be of a more intricate character, the concurring causes by the joint action of which it is produced not being very apparent. We might indeed be led to conclude, from the circumstance of the effect being as the quantity of matter set free, (29) that it depended exclusively on the state of the free action; which we have seen is as the square of the quantity accumulated. (21) But such a conclusion is not warranted by the subsequent phænomena, for the same quantity of matter is always equivalent to the same effect, whatever be the area of the coating, or the thickness of the glass, provided the surface be in an undivided state, and all other things remain unchanged. (exp. 21.) Since therefore, the same accumulation, disposed on jars, varying in size and thickness, exists in very different states of controlled

* That is: equal to D e, at a double, triple, &c. distance—see page 64.

action, the effect must have reference only to the quantity of matter *accumulated.*

This question however, may possibly admit of much elucidation, by taking into consideration, not only the quantity of matter accumulated, but the velocity with which it passes from the positive to the negative coating. Now it is not unreasonable to suppose, that the latter will be as the attractive force, exerted between the opposite electrical states; which being an effect proportionate to a given cause, must necessarily be as the deviation from a state of equal distribution; that is as the quantity accumulated: and hence, a double quantity of matter, will exert a double attractive force; and consequently, pass with a double velocity—it will therefore, have *four times the momentum.* For a similar reason, a triple quantity of matter, would have three times the attractive force, and consequently pass with a triple velocity; and hence, have nine times the momentum.*

35, The attractive force, exerted between the opposite electrical states, will necessarily be independant of all those indications developed by the uncontrolled action; even those resulting from the area of the coating, or thickness of the glass: it must in fact be considered, as the disposition or tendency of a certain natural power, or powers, to a state of equal

* In assuming the attractive force to be proportional to the quantity accumulated, we have to consider the immediate force exerted between the opposite electrical states, at the instant the circuit is made complete, and not the attractive force of the free action, in relation to the quantity accumulated, which as already observed, is proportional to the square of the accumulation. We have already shewn, (29) that this effect results from an increased quantity of matter, and a decreased controlling power; so that if with a double accumulation, there is evinced four times the attractive force, it is because there is four times the quantity of matter set free; and the attractive force is still proportionate to the quantity of matter in action, as we have just assumed.

distribution, through a given circuit. For although we sometimes observe, that the attractive force exerted between the opposed coatings, is sufficient to break down the intervening glass, when accumulated on a small extent of coating, which does not happen on a more extended surface; yet, we must not from this effect conclude, that the mutual attraction of the opposite electrical states, through a given circuit, is on this account either increased, or otherwise diminished. The tendency to an equal distribution, cannot be in any other proportion than that of the variation from the natural state, that is to say, of the quantity accumulated. The power indicated by a spontaneous explosion, through the sides of a glass jar, depends exclusively on the number of points, to which the attractive force is confined, so that on a great extent of coating, there is less action in any given direction. But the absolute quantity of attractive force, as relating to the deviation from the natural state, remains unchanged; the accumulation, whilst in the act of passing through a given circuit *(a b,) fig.* 14, being drawn from every point of the intervening glass through the medium of the opposed coatings, and finally concentrated upon what may be considered as two centres of action *(d) (b.)* So long as the circuit, and the quantity of matter therefore, remain unchanged, the same attractive force at the instant of the explosion will be in action; whether the matter shall have been previously diffused over a large surface, or a small one; or otherwise, whether it be disposed on thick glass or on thin.

We are hence led to infer, that when the circuit is made complete, that is, when all distance between the opposed coatings, is, as it were, annihilated; it is no longer the attractive force, as exerted through the intervening glass, or the extent of coated surface, or the indications of the free action which we have to consider. Every thing relating to these, at once vanishes; for the great condition upon which their observed influence rested, that is to say, the separation of the opposite states, by the intervening glass is destroyed; and we have now only to look to the variation, from the natural state of distribution, that is to the quantity of matter accumulated, and to its attractive force through a given circuit, that is to the relative velocity with which it passes; and therefore, it is not unreasonable to infer, that the duplicate proportion observable in the explosive effect of the accumulation on a metallic wire, (23) may depend on these two causes, taken together; so that when the matter is doubled, and the velocity also necessarily doubled, the effect must be quadrupled; or, in other words, *it must be proportionate to the momentum, with which the given quantity of matter pervades the metal.*

36. These views derive much support from a few admitted and important facts—thus, when a given charge is caused to pervade a great extent of circuit, much of its power is lost, and the explosion of the battery at other times remarkably loud, is then scarcely audible,* and to fuse any quantity of metal with a given charge, we make the circuit as short as possible; the effect of the explosion on the wire of the electrometer, *fig.* 8, is found to be greatly diminished by increasing the length of the circuit, that is to say, by retarding the velocity of the charge, and the effect seems to decrease in an inverse ratio to the obstacle to be overcome, so that in transmitting the charge through imperfect conductors, such as water contained in glass tubes, the velocity of the explosion is so much diminished, that the effect, otherwise considerable, is no longer to be appreciated.

It is not improbable, but that the decreased effect of the explosion observed in disposing the accumulation on a divided surface, (22) arises in a great measure, from this cause; since, in employing many jars, we necessarily increase the number of charging and connecting conductors; indeed, the results given in Table I, seem to warrant such a conclusion; for supposing the number of jars to stand for the respective increase

* Singer's Electricity, p. 178.

of conductors, the corresponding decrements in the effect, will be nearly in a direct proportion to the number of conductors.

87. In the analysis which has been given of the progress of an electrical accumulation, (33) it may be inferred from the equality of the triangles A *d* c, A *d* B, that at the instant of the explosion, the free action is equal to the controlled action; which may be readily conceived to be the case—for at this instant, the tendency of the free action through the balls of the electrometer (*a*) (*b*) *fig.* 14, being equivalent to neutralize all the controlling power, the whole accumulation is set free in the act of exploding, and a state of equal distribution ensues.

If therefore, we suppose the explosion to occur with a single quantity of matter *c e* at the interval A *e*, *fig.* 23, then the free action will be represented by the triangle A *e* m, and the controlled action by the triangle A *m c*; when the interval is increased to A *f*, and the quantity of matter to *c f*, then the free action is represented by the triangle A *f* n, and the controlled action by the triangle A n c, and so on; it is only necessary to observe, that in estimating the free action by its attractive force, as indicated by a moveable electrometer, the free action of the first quantity of matter *c e* will no longer be represented by the triangle A *m e*, when the interval A *e* is doubled, but by the triangle A *e r* or one-half of the former—that is by one-quarter part of the triangle A *f* n; since to obtain a double accumulation, by means of a moveable electrometer, we must oppose to the attractive force of the free action at the time of the explosion, four times the weight (exp. 15.); when, therefore, the interval is doubled, the respective quantities set free will be represented by the triangles A *e r*, A *f* n; when the interval is tripled by the triangles A *e s*, A *f t*, A *g o*; when the interval is quadrupled by the triangles A *e h*, A *f i*, A *g k*, A B *d*. The free action being as the square of the quantity accumulated as already observed (21.)

I have ventured on these theoretical observations, more with a view of tracing the connection which necessarily subsists between these interesting phænomena, and of applying general principles to the explanation of particular facts, than with any intention of having such observations considered as incontrovertible. The theory which they include, must rest on observation and experiment, and its evidence must therefore increase or decrease with the number of facts to which it can be applied, and the precision with which it explains them.

38. It may not be improper, before concluding this paper, to notice some circumstances connected with electrical investigations, which appear calculated to involve them in some uncertainty; on which account they merit particular attention.

In the application of electrical jars to the purposes of investigation, it is quite essential in certain experiments requiring great precision, not only that they expose the same extent of coated surface, but that they be in every other respect precisely similar. Now there are many circumstances affecting the identity of coated jars—it is already known, that the charge which a jar can receive as estimated by its attractive force, is in some direct ratio of the area of the coating, and in some inverse ratio of the thickness of the glass. A thin jar, having the same extent of coated surface, will therefore, with the same attraction, always ignite more wire than a thick one: it must be remembered however, that this is not in consequence of the difference in the thickness, but because there is absolutely more electricity accumulated with a given attractive force. (14) It was shewn (exp. 24) that the quantity of matter being the same, the effect does not vary whatever be the thickness of the glass, or even the area of the coating, provided the jar can receive the given accumulation. The way in which the coating is applied, is another circumstance which will also materially influence the action of a jar; so that although the thickness of the glass, and the area of the coating be the same, the quantity of matter corresponding to a given attractive force, shall greatly vary; and the quantity of matter being the same, the effect shall no longer be identical. This is the case when a layer of paper is interposed between the coating and the glass; which is sometimes resorted to in order to diminish the chance of fracture.* Thus in selecting some jars from a battery constructed by Mr. Cuthbertson, it was observed, that one of them materially differed from the rest; it would admit of a much greater quantity of matter being disposed on it, with a given intensity—but the quantities of matter being equal, the action of this jar was less than either of the others by nearly one half. On examining the jar attentively, a layer of writing paper was found to be interposed between the outer coating and the glass; this being removed, and the coating restored, the jar acted in every respect like the others. The paper therefore being an imperfect conductor, impedes the free transmission of the accumulation upon the surface of the glass; and hence the force of the explosion becomes diminished: for the same reason it keeps down the tendency of the accumulation, through the balls of the electrometer, by which the controlling power is increased, as before explained (29.): every species of cement employed to attach the coating to the glass, will consequently operate more or less to the disadvantage of the action of the jar, according as it has a greater or less insulating power, and is applied in greater or less quantity.

39. It is therefore essential, where great accuracy is required, to ascertain in some investigations, the action of each jar separately. If two jars, with the same quantity of matter, explode over a given interval, or exhibit the same attractive force, or produce the same effect as estimated by any of the foregoing methods, (13, 15, 7) then they may be con-

* Singer's Electricity, p. 180.

sidered as identical; if not, the separate effects due to each should be noted, and the mean result taken.

40. The way in which a series of jars are arranged, may also affect our results; when for instance, we increase the number of jars, and instead of arranging them about a common centre, as in *fig.* 17, in which case, each jar may be supposed to operate, as if disconnected with the others; we dispose them as in *fig.* 18, one jar only being connected with the conductor, and the remaining jars with each other; there appears to arise in the latter arrangement, a greater impediment to the free transmission of the accumulation, and although the difference is not considerable when two or three jars only are employed, yet in an extensive series it is of great importance. I arranged a battery of five jars, each jar containing five square feet, (according to these methods,) and having charged it in both cases alike, the corresponding effects on the wire of the electrometer amounted to 56° and 70°; the loss being by the arrangement in *fig.* 18, about one-fifth. This circumstance may also arise from the increased number of conductors, which the accumulation has to traverse; since each jar, except the first, instead of discharging through the line *(a b)*, has to discharge through that line, and its connexion with the first jar.

41. The usual method of estimating the quantity of matter by the fusion of wire being very uncertain in practice, our results may be rendered unsatisfactory from this circumstance; indeed it is admitted, by many careful experimentalists, that wires may become fused, with but slight variations in appearance, when very different quantities of electricity are passed through them:* beside which, the difficulty of ascertaining with precision, the point at which the fusion takes place, so that the wire may be just made red through its whole length, and then drop into balls, is very considerable; and we seldom

* Singer's Electricity, p. 190.

feel assured, that the given charge is not adequate to a somewhat greater effect: this in many investigations, is of material consequence; since the quantity of wire fused, varies in a duplicate ratio of the quantity of electricity passed through.

On this subject, Mr. Cuthbertson has the following observations; he says, alluding to some experiments by Dr. Van Marum, "That he, (Dr. Van Marum) might not have been aware of the different degrees of ignition, caused by electrical discharges, but only judged of the force, by the wires being converted into balls, by which great mistakes will happen; for if a wire be taken, eighteen inches long, and of such a diameter, that when a jar or battery is charged to such a height, as just to cause it to run into balls, much shorter lengths of the same wire, may be subjected to the same force, and still be only converted into balls. If only seven inches were taken, nothing but balls appear; the only difference will be that the balls will be smaller, and dispersed to a greater distance; which may be easily overlooked." He concludes by observing, "That the *lowest* degree of ignition must be had, so that when the charge is passed, the wire shall be red hot through its whole length, and then fall into balls."*

42. The method sometimes resorted to by electricians, in order to increase the capacity of a coated jar, by breathing or damping the uncoated interval on the inside, is also calculated to change materially the conditions of the experiment. Mr. Cuthbertson happened casually to discover, that a coated jar, when it was a little damp on the inside, would take a higher charge, than it would do after it had been coated for some time, and was quite dry on the inside. From this he says, "It appeared evident to me, that if I could by any means render the inside of the jars regularly damp, it would answer the same purpose. Breathing into a jar was tried, and the success was such, that it would receive and retain nearly double the

* Cuthbertson's Practical Electricty, pa. 180, 185, 186.

quantity of electricity it could retain when dry; and in trying to ignite wire with the charge of one jar in a dry state, no more than five inches could be ignited; though after breathing into it, twelve inches were fused."* Hence, it is evident, that by damping the inner surface, we completely change the relative operation of the jar: it is in fact, little more than an ingenious method of increasing the inner coating, but in such way as to extend the surface, by means of an imperfect conductor, over which the electricity is diffused, and so increase the quantity; the attractive force of the free action remaining the same. If we consider the intensity therefore, in relation to the quantity of matter, it may be said to be diminished; more especially at that point, from which it has the greatest tendency to explode: in the application of this method to the purposes of accurate investigation, we are consequently exposed to great uncertainty.

Thus, in experiments 146 and 147 of Mr. Cuthbertson's useful work, it may be observed, (exp. 146) that two inches of wire became fused, by a charge of fifteen grains; and in exp. 147, eight inches became fused, with a charge of thirty grains: but in the latter case it was necessary to breathe into the jar, so as to accumulate a given quantity of matter, which must have been more than equivalent to an attractive force of thirty grains; every thing remaining as in the previous experiment. To have been accurate in these experiments, the jar should have been damped in each case alike; by which it would have been placed under the same circumstances when a charge of fifteen grains was accumulated, as those under which it was placed when a charge of 30 grains was accumulated; and then the result as before observed by Mr. Cuthbertson, would have been widely different; for the jar in the former case, would have been adequate to a much greater effect, so that from these experiments we cannot arrive at any just conclusion, respecting the relation which subsists

* Cuthbertson's Practial Electricity, p. 170.

between the quantity of wire fused, and the intensity of the accumulation; which from the investigations already detailed, (21, 23) may be easily determined: since the quantity of matter is as the square root of the attractive force; (21) and the effect is as the square of the quantity of matter; (23) The effect, and the indicated attractive force, should therefore vary together; all other things remaining the same, and consequently the charge of thirty grains, should only have fused twice the length of wire.

It is rather important to notice the circumstance, that such would actually have been the case, or very nearly so, provided the jar had been damped in the previous instance, when a charge of fifteen grains was accumulated; according to what is previously stated by Mr. Cuthbertson, and which has been just detailed; since the same proportionate increase of capacity as that above-mentioned, must have taken place, even with the same intensity; that is to say, the jar being damped, could have received with the given intensity of fifteen grains, an additional quantity of matter. Now the effect being as the square of the accumulation, it would only have required the addition of about half as much more matter, with the same intensity, in order to have doubled the quantity of wire fused; which, considering the influence of the increased capacity, might have been soon effected. Indeed, if we suppose the ratio of 12:5 already stated, which is nearly as 2 : 1, to express the increased capacity with a given intensity, then the result would correspond, or very nearly so. When the difficulty of ascertaining the precise quantity which the respective charges could fuse is taken into account, the difference will not appear to be very considerable.*

* There does not seem to be any difficulty in accumulating the requisite charge in a jar, provided the positive coating is furnished with a paper band, as ingeniously recommended by Mr. Singer, and the jar freed from a cover: and in order to preserve the state of the jar invariable, all the uncoated interval both inside and out, should be carefully varnished—in this case the action of the jar may be depended on.

43. The various circumstances which we have detailed being duly considered, it will not seem extraordinary, that many well contrived experiments should have been productive of unsatisfactory results; and that the conclusions arrived at by practical electricians should have been different. Thus Dr. Van Marum found his batteries to increase in power only, in the same proportion as the coated surface: viz. that a double surface of coated glass could only ignite double lengths of wire, of the same diameter, which Mr. Cuthbertson considers to be erroneous, because he found by his method of experiment, that double quantities of electric fluid in the form of a discharge, will ignite four times the lengths of wire, that is to say, he found the effect, in this instance, to be as the square of the quantity of matter. Yet we find p. 182, exp. 149, that this result varied; and p. 185 we observe, that when the quantities of matter were as 3 : 2, this law was no longer apparent; for exps. 150 and 151 shew, that in this case, the lengths of wire ignited, instead of being as 9 : 4, were as 6 : 2; that is, as 3 : 1. No general conclusion therefore could be arrived at, concerning this law of electrical action on wires, which we have found (23) is always directly as the square of the quantity of matter, all other things remaining the same.

44. Much uncertainty in electrical investigations may be avoided, by measuring the quantity of matter accumulated by means of the explosions of a small jar charging from the outer coatings, as already explained *fig.* 16, the discharge being effected by means of the discharging electrometer, represented in *fig.* 4. In this case, the electrometers usually employed to measure the charge by its attractive force, may be dispensed with; thus the experiment is placed under the simplest form, since the same quantity of matter so estimated, is always equivalent to the same effect, the surface being constant, whatever be the thickness of the glass, or the area of the coating, exp. 21, whilst the measure we employ may be considered as invariable—the jar and the discharging electrometer affixed to it always remaining the same.

In referring to the works of Mr. Cuthbertson and Mr. Singer, my object has been solely to elucidate an intricate, but interesting, philosophical inquiry; and I hope it will be understood that in so doing, it is my wish to preserve every proper respect for the exertions of two able and ingenious men, whose loss the scientific world has so much to regret.

45. I shall now conclude with a short recapitulation of a few facts, which seem to be established by the preceding inquiries:

1—An electrical accumulation may be supposed to proceed by equal inrements.

A coated surface charging in any degree short of saturation, receives equal quantities in equal times, all other things remaining the same.

The quantity passing from the outer coating, is always proportional to the quantity added to the inner.

2—The quantity of matter accumulated, may be estimated by the revolutions of the plate of the electrical machine, supposing it in a state of uniform excitation; or it may be measured by the explosions of a jar connected with the outer coatings.

It is as the surface multiplied by the interval which the accumulation can pass:

When the surface is constant it is as the interval:

When the interval is constant it is as the surface.

It is also as the surface multiplied by the square root of the free action.

When the surface is constant, it is therefore as the square root of the attractive force.

3—The interval which the accumulation can pass, is directly proportional to the quantity of matter, and inversely proportional to the surface:

It is as the quantity divided by the surface:

If the matter and surface be either increased or decreased in the same proportion, the interval remains the same:

If as the matter be increased, the surface be decreased, the interval will be as the square of the quantity of matter.

4—The force of electrical attraction varies in the inverse ratio of the square of the distance between the points of contact of the opposed conductors, supposing the surfaces to be plane and parallel; or otherwise between two points, which fall within the respective hemispheres, at a distance equal to one-fifth of the radius, supposing the opposed surfaces to be spherical.

5—The free action is in a direct proportion to the square of the quantity of matter, and in an inverse proportion to the square of the surface.

It is directly as the effect of the explosion on a metallic wire, all other things remaining the same.

If the matter and the surface increase or decrease together, and in the same proportion, the attractive force remains the same.

If as the matter be increased, the surface be decreased, the attractive force is as the fourth power of the quantity of matter.

6—The effect of an electrical explosion, on a metallic wire, depends exclusively on the quantity of matter, and is not influenced by the intensity or free action.

It is diminished by accumulating the matter on a divided surface.

It is as the square of the quantity of the matter.

It is as the square of the interval which the accumulation can pass.

It is directly as the attractive force of the free action, all other things remaining, in each case, the same.

It is as the *momentum* with which the explosion pervades the metal.

Plymouth, November 17, 1825.