PHILOSOPHICAL TRANSACTIONS.

XIV. *On some Elementary Laws of Electricity.* *By* W. Snow Harris, *Esq. F.R.S. &c.*

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1. A MORE perfect apprehension of those subtile agencies, the effects of which are continually present in various operations of nature, seems of paramount importance to the future advancement of science. Thus the physical causes of heat, light, electricity and magnetism, have become subjects of deep interest to the natural philosopher; little apology, therefore, may perhaps be deemed requisite for my venturing to submit to the consideration of the Royal Society an account of some inquiries, the object of which is to improve our knowledge of one of these great natural powers. As it is only by a patient and repeated induction from well investigated facts that we can hope to attain a higher degree of perfection in natural knowledge, I have thought it not altogether undesirable to inquire further into the elementary laws of common electricity: indeed, upon considering the late fine discoveries of Dr. Faraday, this seems to a certain extent requisite. The researches of this distinguished philosopher have invested electrical phenomena generally with a new interest, and exposed novel and important features in the theory of electrical action.

The investigations in this department of science, which I have now the honour of presenting to the Royal Society, will, I hope, be found to contain matter of sufficient interest to render them not unworthy of its acceptance.

2. The existence of an invisible agency in the natural world, designated by the term electricity, may be inferred from the tendency of bodies toward each other, when subjected to a peculiar kind of excitation, by means of various operations, such as by the contact of dissimilar bodies, friction, changes of temperature, of form, and the like. Many striking facts seem to warrant the supposition that this agency is dependent on an extremely subtile species of matter, either of a compound or elementary character, everywhere present, and operating according to certain laws, which it is the province of experiment and analysis to determine.

3. This hypothesis appears, upon the whole, to be not ill adapted to an easy explanation of appearances, and to the purposes for which hypothesis may be legitimately

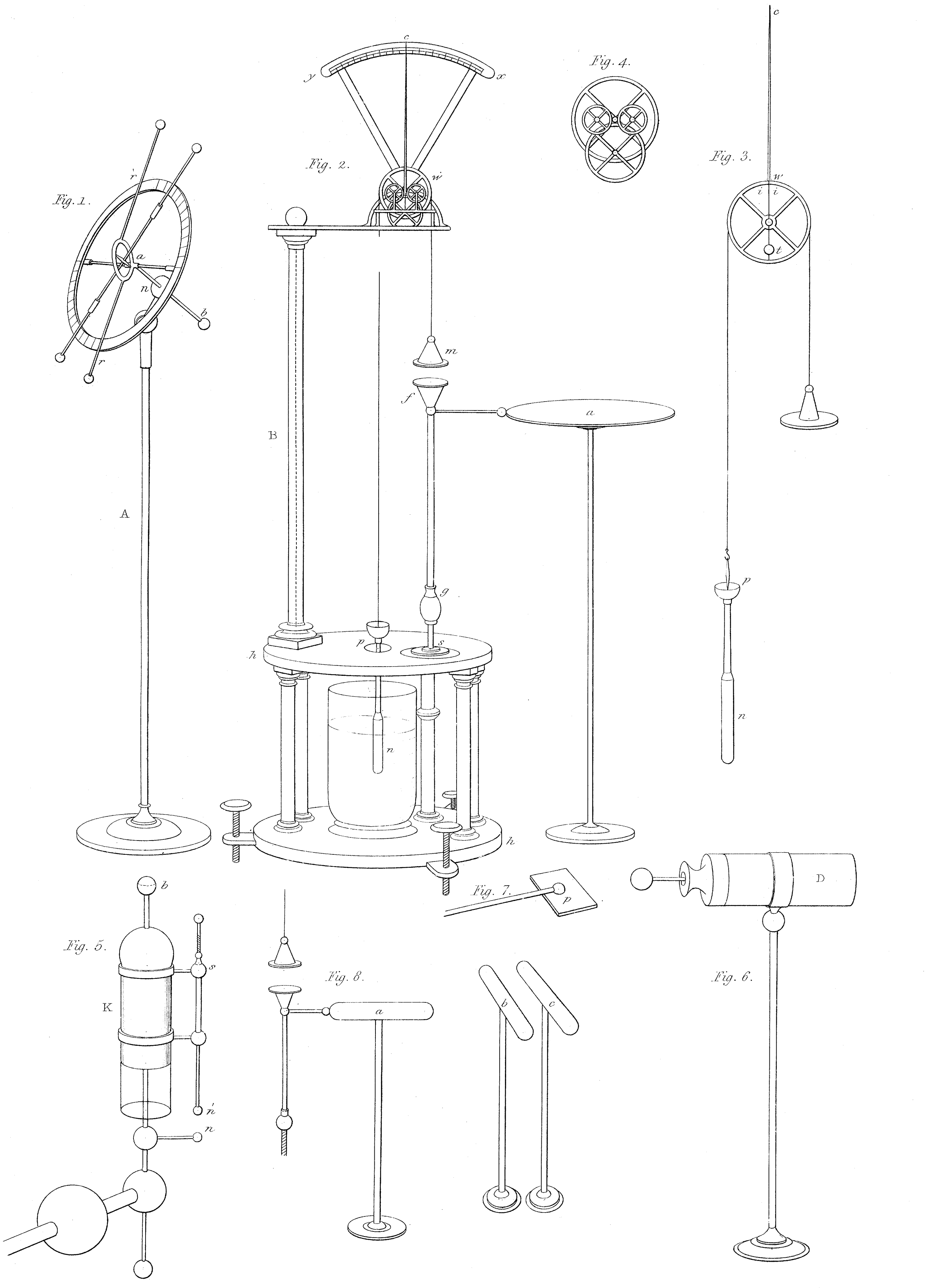
resorted to in the prosecution of physical inquiries. Accordingly, I am led to avail myself of it, but without extending it beyond the simple principle above mentioned. The properties of this subtile matter, whether of an elementary or compound character, if such should hereafter be more fully proved to exist, I leave only to be determined by adequate induction from observed phenomena.

4. Assuming, then, as an elementary principle, not upon the whole unwarranted by facts, the existence of a subtile material agent essentially involved in the constitution of ordinary matter, and known to us only through the medium of its effects, we may distinguish its presence under two different forms of what may be termed electrical excitation; that is to say, a state of excitation produced by a different relative state of the electricity possessed by a body to that which is more or less common to all bodies, in which case the quantity remains unchanged; and a state of excitation derived from an actual addition, or subtraction, of the electricity of a given substance, or of any component part of its electricity, in which case the quantity may be said to vary.

5. The latter of these states has been termed excitation by communication; and the former, when produced by the influence of this last, operating at a distance, excitation by induction.

6. A body, when excited according to either of these forms of excitation, displays apparently an attractive force, so that other bodies, when all impediments to motion are removed, tend toward it, and the accumulated electricity seeks to regain its previously existing state: a peculiar action is in this case found to obtain, either in the excited substance itself, or otherwise between it and the surrounding masses. Such may be considered, on the above hypothesis, the great characteristics of ordinary electrical action, those which were the first observed, and which, with their attendant phenomena, demand the most rigorous scrutiny.

7. In order to facilitate the progress of inquiries concerning the elementary laws of electrical action, I have been led to construct one or two new instruments, as also to resort to other electrical arrangements, which it is essential to notice. Fig. 1. A. (Plate II.) represents an electroscope which acts on the principle of divergence: a small elliptical ring of metal, *a*, is attached obliquely to a small brass rod, *a b*, by the intervention of a short tube of brass at *a*; the rod *a b* terminates in a brass ball, *b*, and is insulated through the substance of the wood ball *n*: two arms of brass, *r r'*, are fixed vertically in opposite directions, on the extremities of the long diameter of the ring, and terminate in small balls; and in the direction of the shorter diameter, within the ring, there is a delicate axis set on extremely fine points: this axis carries, by means of short vertical pins, two light reeds of straw, terminating in balls of pith, and constituting a long index A, corresponding in length to the fixed arms above mentioned. The index thus circumstanced is susceptible of an extremely minute force; its tendency to a vertical position is regulated by small sliders of straw, moveable with sufficient friction on either side of the axis. To mark the angular position of the index



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in any given case, there is a narrow graduated ring of cardboard or ivory, *r r'*, placed behind it, the divisions being distinctly legible through sight-slits cut in the reeds: the graduated circle is supported on a transverse rod of glass, by the intervention of wood caps, and is sustained by means of the brass tube *a*, in which the glass rod is fixed. The whole is insulated on a long rod of glass, A, by means of wood caps terminating in spherical ends. In this arrangement, as is evident, the index diverges from the fixed arms whenever an electrical charge is communicated to the ball *b*, as in fig. 10. This instrument is occasionally placed out of the vertical position at any required angle, by means of a joint at *n*, and all the insulating portions are carefully varnished with a solution of shell lac in alcohol.

8. Fig. 2. B. represents an electrometer which measures directly the attractive force of an electrified body in terms of a known standard of weight estimated in degrees on the graduated arc *x y*. An insulated conductor, *f*, is fixed on a varnished rod of glass, *f g*, sustained by the intervention of a wood ball on the extremity of a micrometer screw, *s*: by aid of the screw the whole may be raised or depressed, through given intervals, to within the one hundredth of an inch of any required point. A moveable and similar conductor, *m*, made of light wood, hollowed and gilded, is suspended immediately over the former from the periphery of a small brass wheel W by means of a fine silver thread attached near its vertical arm, and passing from thence over its grooved circumference, as shown in fig. 3. The conductor *m* is counterpoised by a short cylinder of wood, *p n*, figs. 2, 3, suspended in a similar manner from the opposite side of the wheel, by means of a silk thread: this counterpoise is partly immersed in water contained in the glass vessel *n*, fig. 1.

The extremities of the axis of the wheel W, figs. 2, 3, are turned to extremely fine pivots, and rest on two large friction wheels, after the manner represented in fig. 4*, by which great freedom of motion is obtained. There is a fine index of light straw, W *c*, attached to the extremity of a small steel needle inserted diametrically through the circumference, which indicates on the graduated arc *x y* the force exerted between the conductors *m f*: the weight of this index is accurately poised by a small globule of brass, *t*, fig. 3, moveable on a screw, cut in the opposite arm of the steel needle carrying the index.

The centre of the wheel W is accurately placed in the centre of the arc *x y*, which, with its radii of support, is made of varnished wood, the graduated scale being of cardboard or ivory. The arc is the sixth part of a circle; it is divided into 120 equal parts, sixty in the direction *c x*, and sixty in direction *c y*, the centre C being marked zero.

* I resorted to this method of employing friction rollers, as being more efficient than that in which the axis is allowed to rest in the angles formed between the peripheries of four smaller wheels. In this case it rolls fairly on a large circumference, and is prevented from passing off it on either side by the check wheels, either of which, when acted on, opposes little or no resistance to motion. When this machine is equipoised with 500 grains, less than the $\frac{1}{50}$th of a grain will set the whole in motion.

Fig. 3. represents the wheel W with the suspended conductor and counterpoise, the index and its balance weight, together with the lines of suspension, passing freely over the circumference, and fixed at the points *i i*.

The various wheels above mentioned, with the graduated arc, are sustained on a projecting metallic plate, which is united by a spherical nut to a metallic rod passing through a glass column B. The column is secured by means of the rod to a sort of double stand, *h h*, fig. 2, supported on three levelling screws. The interval between the plates of this stand contains the glass vessel *n* and the micrometer screw *s*; the upper plate has a circular hole, *p*, through which the cylindrical counterpoise passes into the water, *n*; the levelling screws serve to regulate the position of this counterpoise through the hole *p*, so that when it hangs in it centrally, the instrument is accurately adjusted.

The gravity of the suspended conductor *m* being in the above arrangement opposed by that of the counterpoise, it may be so far considered as existing in free space devoid of weight, and will therefore become very readily moved by any new force applied to it. It may consequently be caused to approach, or recede from, the fixed conductor *f*, by the operation of forces acting in either of these directions; the motion will however be speedily arrested by the counterpoise *n*, which (becoming either further immersed, or otherwise raised in the water,) furnishes in the greater or less quantity of water displaced, a measure of the force. In this way the force may be estimated either in degrees or in grains of actual weight, since the number of grains requisite to add to either side, in order to advance the index in either direction, a given number of divisions may be immediately found by experiment, and which, as the sections of the cylinder are all similar, will increase or decrease with the degrees of the arc. Thus, if one grain advance the index in either direction five degrees, then two grains will advance it ten degrees, and so on*.

9. In the application of this instrument to electrical inquiries, the force to be measured is first communicated to the fixed conductor *f*, a free communication being established between the suspended conductor *m* and the ground, or otherwise with the negative side of the jar or battery, should the attractive force be derived from this species of accumulation; this is readily effected through the brass work of the apparatus in connexion with the rod passing through the interior of the glass column B.

For the repulsive force we connect the conductor *f* as before, and suspend *m* by a silk thread, so as to allow it to rest on *f*; it will then, after being electrified similarly to *f*, recede from it; but this method of experiment I have seldom resorted to; it is evidently more complicated than the former, and occasionally liable to objection.

10. The distance between the conductors *m f* corresponding to a given force, is easily ascertained by means of the degrees indicated on the arc *x y*. In the instrument

* The counterpoise should be free from grease or varnish of any sort, and should, previously to being used, be kept immersed in water; the insulation of the conductor *f*, also, should be made extremely dry, and occasionally warmed by a stick of burning charcoal.

above described, each degree corresponds to a variation of distance between the conductors equal to the ·01 of an inch. If, therefore, at the commencement of any given experiment, we first bring the nearest points of the conductors *m f* in contact, the index being in zero, and then depress the inferior conductor *f* a given distance, known by means of the micrometer screw *s*, then all subsequent distances may be readily determined between these points.

11. It is now only requisite to observe, that the interior of the cylindrical counterpoise *p n* is hollow, in order to weight it accurately, and cause it to hang vertically in the water; and there is a small hemispherical cup, *p*, fixed on its stem, for the reception of small adjusting weights *, by which the position of the index at 0 of the scale is regulated with great nicety. With respect to the form of the conductors *m f*, they are generally plane circular areas, backed by small cones, and are of about two inches diameter. Conductors of other forms, however, such as spheres and cylinders, may be occasionally used when the object is to experiment more particularly on bodies of peculiar forms.

Experiments with this instrument are remarkably clear, notwithstanding the subtile character of the principle we have to investigate: thus, when the insulations are perfect, and the atmosphere dry, the index immediately exhibits the amount of the attractive force, and remains stationary for a much longer time than is required to note the result.

12. Considering that electrical inquiries would be much facilitated by an accurate method of estimating comparative quantity, I endeavoured, as being essential to my purpose, to obtain a unit of measure, and at length arrived at the following methods of estimating quantity, which are simple and accurate.

According to the known laws of electrical accumulation on coated jars, the quantity accumulated on one coating is proportionate to the quantity given off by the other: hence, if instead of transmitting the electricity evolved by the machine immediately from its conductor, we communicate the charge from the outer coating of a small jar furnished with a discharging electrometer, we may estimate pretty accurately by the number of explosions, that is to say, by the number of charges which have passed the smaller jar, the quantity accumulated.

13. On this principle, I inverted a small jar, K, fig. 5, exposing about six inches square of coating, on a brass rod fixed to the conductor of the machine, or otherwise sustained on a separate insulation, and connected the jar or battery to be charged with its outer surface, through the intervention of a brass ball, *b*. In this arrangement, electricity is continually supplied to the jar, and the amount of the accumulation accurately measured by the number of charges which the unit jar has received, the charges being determinable by means of the discharging balls *n n'*. By diminishing or increasing the distance between the discharging balls, the value of the unit may be rendered as small or as great as we please: hence, if the balls be securely

* Small lead shot may be employed for this purpose.

fixed, and the distances between their points of discharge accurately measured by means of a micrometer-screw and index at *s*, comparative quantities may be always estimated and restored from time to time with a great degree of accuracy.

14. Comparative quantities of electricity may be transferred to simple conductors, by abstracting sparks from an insulated jar, D, fig. 6. charged with a given accumulation by the preceding process. The sparks may be taken immediately on the conductor, or otherwise, on an insulated transfer plate, *p*, fig. 7, of given capacity, and then deposited on the conductor, as in *a*, fig. 2. This method of estimating quantity is extremely efficient in researches with simple conductors. The following experiments in illustration of it are not unimportant:

(*a*.) An insulated metallic disc, *a*, fig. 2, electrified many times in succession by a series of sparks transferred to it from the charged jar D by means of the insulated plate *p*, was found at each transfer to be electrified to so nearly the same amount, that the differences were not apparent on the electrometer, fig. 2, or on the electroscope, fig. 1; the disc being supposed in contact with either of these instruments. It is only requisite in this case to restore the opposite coating of the jar to its previous state, after each contact with the transfer plate *.

When a portion of the charge is abstracted so as to sensibly decrease the quantity in the jar, a new point may be arrived at, from whence another series of sparks can be obtained of less magnitude, but differing extremely little in quantity as compared with each other; and this process may be continued to a low point of accumulation in the jar.

(*b*.) The quantity given off by the positive coating will depend on the dimensions of the conductor to be charged, and on the state of the negative coating: thus a conductor of a double capacity becomes charged by a single contact with a double quantity; a conductor of a treble capacity, with a treble quantity (56.); and generally, conductors varying in superficial dimensions are electrified by one contact, in such way as to exhibit precisely the same force when connected with the electrometer. The extent of this action is considerable, provided the opposite coating be placed in a sufficiently free state.

15. It would seem by these experiments, that in the discharging of a charged jar, by the successive abstraction of small sparks, series may be obtained of such slow convergence, that certain terms near each other may be taken as equal †.

* It is of no consequence to the experiment what part of the electrical conductor touches the contact ball of the electrometer; the same force is invariably indicated whether we make the contact at either of its extremities or centre.

† In the various experiments with simple conductors, described in this paper, it is essential to remark, that the most perfect system of insulation was requisite: all the glass rods were therefore as slender as possible, and were varnished with a solution of shell-lac in alcohol. The experiments also have been carried on always in a dry atmosphere, and the various insulations occasionally warmed with a stick of burning charcoal. The success of this process is not a little remarkable: the index of the electrometer remains, as it were, fixed on a given point for a comparatively long period of time; hence the results are decisive. It is, on the contrary,

16. The superficial dimensions of a given conductor, or the quantity of electricity disposed on it, being varied, considerable differences are observed to arise in the attractive force; and of these, the instruments above described (7.) (8.) are extremely susceptible: by carefully pursuing the inquiry under these conditions, I arrived at very interesting results: the most important of these are the following:

A given quantity, divided upon two perfectly similar conductors, was found to exert upon external bodies, only a fourth part of the attractive force apparent when disposed upon one of them.

When divided upon three perfectly similar conductors, the force upon either is only one ninth of the force apparent when disposed upon one of them, and so on; that is, the quantity being constant, the force is as the square of the surface inversely; or the surface being constant, as the square of the quantity directly.

17. The following experiments may be adduced as illustrative of the above laws:

(*c.*) Three or four perfectly similar and equal conductors, *a*, *b*, *c*, fig. 8, of a cylindrical form, being well insulated, a given quantity of electricity was communicated to one of them by means of the charged jar D (14.), and the attractive force measured by the electrometer, fig. 2, with the contact ball of which it was subsequently made to communicate, as in fig. 8. The electrified bodies being now reduced to a neutral state, a second equal quantity was again communicated to the same conductor as before; after which it was caused to touch one of the others, so as to divide the charge on both. In this case, each conductor was observed to be, on transferring it to the electrometer, equally charged; the force, however, after making the requisite correction for distance between the attracting bodies *m f*, fig. 2, (8.) amounted only to the one fourth of the previous force. This process, repeated with three and with four similar conductors, reduced the force to the one ninth and one sixteenth part of the first respectively. The actual results of a series of experiments, conducted under extremely favourable conditions of the air, are given in the following Table:

TABLE I.

Comparative quantity.	Force in degrees.	Distance of attracting surfaces.	Force at distance of one inch.
1	30°	1	30°
$\frac{1}{2}$	5 −	1·25	7·8 −
$\frac{1}{3}$	2 +	1·28	3·27 +
$\frac{1}{4}$	1 +	1·29	1·8 +

quite impossible to insure accuracy in a moist atmosphere, or with imperfect insulation. Flame of all kinds should be studiously removed from near the subject of experiment; the dissipation of a charge being rapid under the influence of a lamp or a candle. When, however, the system of insulation is perfect, the electricity remains stationary on the conductors for a much longer time than is requisite for patient observation; and the electricity abstracted from the charged jar, upon an insulated plate of metal, will pass off again from the plate, without dissipation, in a sharp spark.

The approximations observable in this Table to the law in question are as perfect as can be expected, which is further evident when given quantities are transferred to a plane conductor in contact with the electrometer *a*, fig. 2, as will be more fully explained hereafter (56.).

18. Similar results may also be arrived at in disposing given quantities of electricity on coated jars. By aid of the unit jar (11.), and an improved adaptation of the common balance as a measure of electrical attraction, they can be exhibited without the least difficulty. It becomes necessary that I should briefly mention here the more recent mechanical arrangements connected with these and similar experiments, as I shall have occasion to refer to them frequently.

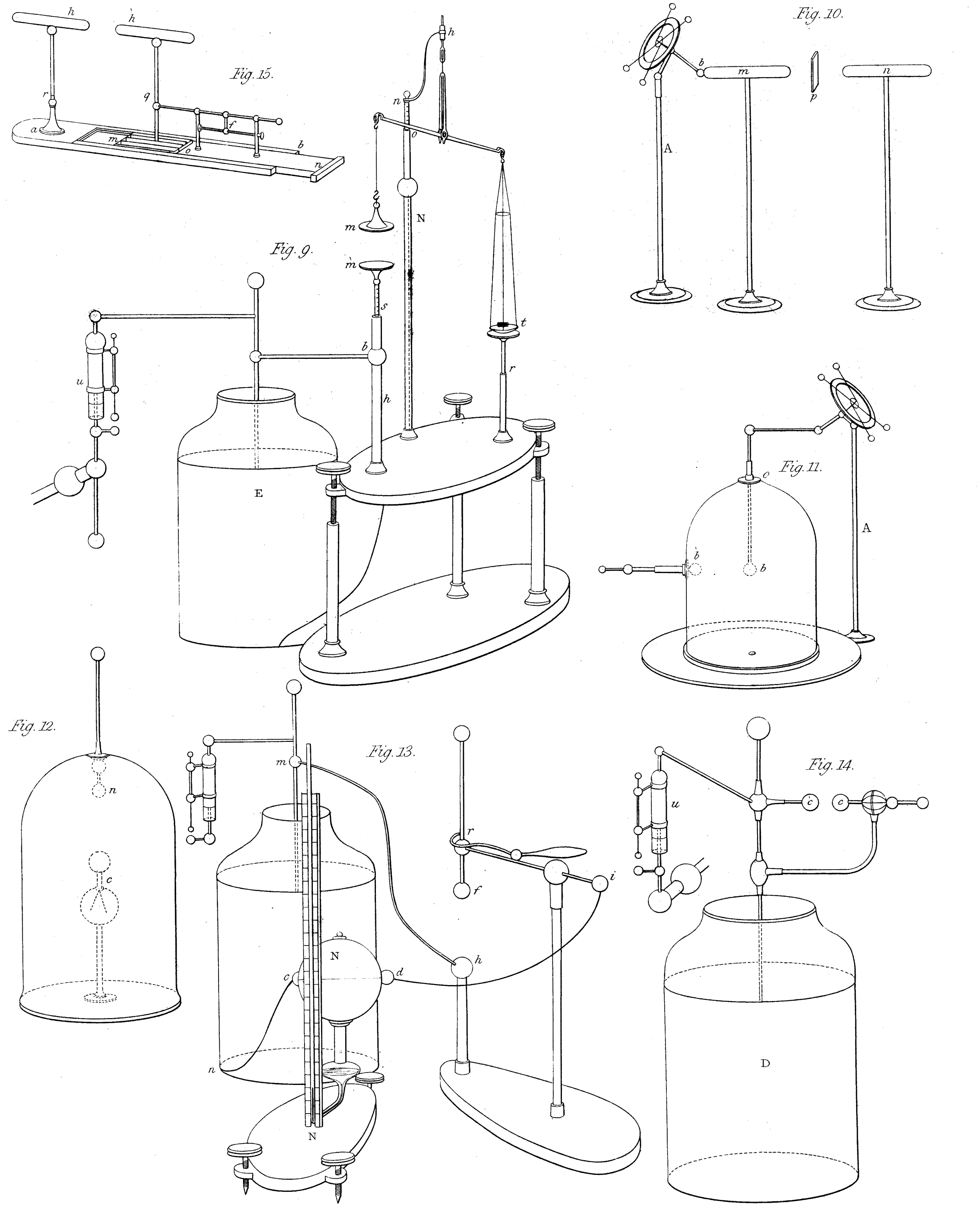
19. Fig. 9. N. represents a simple balance, suspended from the curved brass rod *n h*. It can be raised or depressed through small distances by a micrometer-screw at *h*, and can be also elevated or depressed by the graduated sliding tube *n o*: the tube *o* is screwed on a brass cap, fixed on the glass column N, through the centre of which passes a stout brass wire. A conducting substance *m*, of any required form, is suspended by a double silver thread from one of the arms of the beam: it is made of light wood, is hollow, and gilded. This body is accurately counterpoised by weights placed in the scale-pan *t*, suspended from the opposite arm. A similar conductor *m*' is fixed immediately under the former, and is supported on a graduated sliding tube *s*, insulated on the glass pillar *h*: the pan *t*, when loaded with given weights, rests on a small plate of wood, whose altitude can be easily adjusted by means of the sliding brass rod *r*: the whole is fixed on an elliptical base, furnished with three levelling screws.

When the lower conductor *m*' is connected with one side of an electrical jar E, through the substance of the ball *b*, and the suspended conductor *m* with the opposite side, by means of the suspension thread and the wire passing through the glass column N, then the attractive force arising from a given accumulation is caused to act immediately between these conductors *m m*', and may be measured, under given conditions, by weights placed in the pan *t*.

The distance between the nearest points of the conductors *m m*' is accurately estimated in the following way: The insulated conductor *m*' being raised to zero of the graduated tube, so as to touch, or very nearly so, the suspended body *m*, the points of contact are minutely found by the micrometer screw *h*. The body *m*' is now depressed a given quantity, as measured by the divisions on the slide, and hence the distance between *m m*' is accurately known. When this distance requires to be greatly increased, it is effected by raising the beam, which is easily done by means of the graduated slide *n o*; but in effecting this it is essential to raise at the same time the pan *t*, so as to preserve the index rod of the beam exactly vertical.

20. These conditions understood, the following experiments will be easily apprehended:

(*d*.) A jar, E, fig. 9, exposing about five square feet of coating, being connected



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with the unit of measure u, the number of charges was noted corresponding to an accumulation, the attractive force of which operating between the two plane surfaces, $m\ m'$, was equivalent to a force of 4·5 grains.

When the quantity of electricity accumulated was doubled, the force amounted to exactly 18 grains; three times the accumulation balanced a force of 40·5 grains, and so on.

(*e*.) When a second and precisely similar jar was connected with the former, so as to double the extent of coating, similar quantities, measured as before, only exhibited one fourth of the previous forces respectively.

With three similar jars, that is, with three times the surface, the force was only one ninth part of the respective forces first observed.

By substituting the electrometer, fig. 2, in place of the balance, the march of the attractive force may be gradually observed, so as to exhibit the above results by minute degrees, thereby furnishing very interesting experiments.

21. The physical causes of these effects are not very apparent; they seem, however, to have some connexion with the following fact. The force exerted between two given substances, is more or less diminished by the presence of a neutral or other body sharing in the attraction.

Thus, the excited balls of an electrometer tend to close when an uninsulated neutral body is brought near them.

The attractive force evinced by any description of electrometer in connexion with a charged conductor, will apparently diminish when a neutral body is presented toward the conductor.

A similar phenomenon is observable when neutral bodies are interposed between two conductors, $m\ n$, fig. 10; one, n, being permanently electrified, and influencing the other, m, by induction. An intervening plate, p, appears to operate as a screen, and to arrest, as it were, to a greater or less extent, the inductive influence; and such will also be the case when the plate p is applied near any other part of the electrified conductor n, without coming between m and n. This effect is strikingly analogous to the operation of screens in diminishing the force of a revolving magnet on metallic discs*.

It may be likewise remarked, that when a neutral conductor, m, fig. 10, is exposed to the inductive action of an excited body, n, and is at the same time touched with an uninsulated conductor, it will have its original quantity of electricity either increased or diminished according as the electricity of the excited body n is positive or negative.

Now an electroscope, A, will not indicate the change which has been effected in the conductor m so long as it remains exposed to the influence of the excited body; but if we remove the excited body, or otherwise make it neutral, then the electroscope A will immediately diverge.

It is not essential here to enter upon the theoretical explanations of these phenomena, the mere facts being alone requisite; for whatever theory may be considered

* Philosophical Transactions for 1831, p. 497.

as sufficient to account for them, it should be equally applicable under whatever peculiar form they may present themselves.

22. If these phenomena, then, be considered in reference to the accumulation of electricity on conducting bodies, there may appear some reason to conclude, that a portion of the whole force becomes, as it were, masked in respect of the electrometer. Thus, taking two terms only, the force evinced by a single quantity, by the method of experiment above explained (20.), fig. 9, amounted to three grains, whilst the addition of a second equal quantity produced a force of nine grains, making a total of twelve grains: the mean of this would be six grains; so that if, for the sake of illustration, it is admissible to reason in this way, at least one half the attractive force of which the first quantity is susceptible has been masked by the operation of some peculiar influence. Now this influence may consist in an electrical change induced by the redundant electricity in the superficial particles of the given substance, by which they exert on the accumulation, an attractive force of a greater or less extent, and hence, as in the examples above cited (21.), neutralize some of the force in respect of the electrometer. This is not altogether an hypothetical view, since the attractive force itself is evident (27. *f.*), and we know of no instance of electrical attraction unaccompanied by previous induction.

23. These considerations lead us to distinguish three elements peculiar to the conditions of electrical accumulation.

1°. The comparative quantity actually accumulated.

2°. The quantity not sensible to the electrometer.

3°. The quantity appreciable by the electrometer.

We may distinguish the first of these by the general term quantity, and the latter by the terms controlled and free quantity, or otherwise, controlled and free action.

24. We are here led to consider the more immediate acceptation of the terms tension and intensity as applied to electricity,—terms not unfrequently employed in this department of science in an indefinite sense. Tension denotes the elastic force of a given quantity accumulated in a given space, and is therefore directly as the density of the stratum; and this I apprehend should be really the true sense of the term tension in electricity on the hypothesis that electricity is an elastic fluid. It is accordingly so accepted by many profound writers in physics*.

But the term intensity, as universally understood, must be taken in a somewhat different sense to this, since it has been invariably applied to the indications of the electrometer, and is immediately referable to what we have called the free action (23.), that is, to the operation of either a part, or the whole of the total force in a given direction up to the point of discharge: thus, for example, when a double quantity of electricity is accumulated on a given extent of surface, the action in the direction of the electrometer is four times as great. We must not, therefore, confound the terms intensity and tension (except by an especial convention in language), since by the

* Haüy's Natural Philosophy.

hitherto universally received acceptation of the former, it relates especially to the indications of the electrometer, which are found by experiment, all other things being the same, to vary in certain cases with the square of the density; whereas the latter is expressive of the relation of the whole quantity accumulated to the space occupied, and is always in the direct simple ratio of the density*.

25. But in these reasonings on the probable source of electrical phenomena, we must not overlook the evidences in favour of electricity being a fluid, operating for the most part by attraction alone, without regard to its elasticity, according to the laws observable in cases of simple pressure, its peculiar property being a tendency to a state of equal action; hence it endeavours, when accumulated in given points, to flow upon surrounding masses, thereby producing currents, and the various phenomena of electrical induction.

26. It is not essential that I should here enter upon the merits of the above hypothesis; but supposing it to rest on an adequate induction of facts, then it is clear that the term tension would be ill applied, as expressing other than elastic power: we should rather employ some such term as pressure, which would be immediately associated with altitude or thickness of the electrical stratum. We might, however, still retain the term intensity as expressive of the operation of either the whole or part of the pressure in a given direction, and employ it to measure the quantity on a given surface by the aid of its known relations.

27. It has been supposed by the late Mr. Singer, in his excellent work on Electricity, that the diminished intensity observable in disposing a given quantity on an extended surface is altogether referable to the attractive force of the atmosphere, to the influence of which the electric particles become more extensively exposed: this view, however, seems inconsistent with experience.

1°. In disposing half the quantity on a given surface, we find the intensity reduced to one fourth; now the extent of the atmospheric contact is in this case unchanged.

2°. The attractive force exerted between electrified bodies and neutral non-conducting matter is inconsiderable, so as in some cases to be indefinitely small in respect of the more sensible forces under investigation: hence in experiments similar to those already described (20.), with an opposed semi-conducting or non-conducting plane *m*, fig. 9, the attractive force was found eventually to be exceedingly small.

3°. It is apparently at variance with more direct experiments, as in the following instances.

(*f.*) A brass ball, *b*, fig. 11, about two inches diameter, being placed in the centre of a large receiver, and extremely well insulated, was connected with the electroscope, A, by means of a brass rod passing airtight through a collar fixed in a glass plate and socket, *o*; a quantity of electricity was then communicated to the ball sufficient

* Should we employ the term intensity to designate any phenomenon of tension, it can only be to express its force in a given direction; we should therefore understand clearly what is expressed by the compound term intensity of the tension, as measured by the electrometer.

to diverge the electroscope forty degrees. Now this divergence remained when at least $\frac{59}{60}$ths of the air was withdrawn from the receiver. In this state of the exhaustion a similar ball, *b'*, in a neutral state, was made to approach the former by means of a similar sliding-rod and collar fixed in the side of the receiver: as the ball *b'* approached, the electroscope began to collapse, and again opened as it was withdrawn, so that at the point of contact, the divergence was permanently diminished.

Since the atmospheric particles in this experiment were to a great extent withdrawn, without any change being indicated by the electroscope,—whilst, on the contrary, its divergence became instantly decreased, and again restored on withdrawing the neutral ball *b'*, or otherwise permanently diminished on contact,—we may conclude, that the atmospheric influence was indefinitely small in respect of the indications of the instrument; and that the subsequent collapsing of the electroscope was occasioned by causes altogether connected with the metallic bodies themselves.

(*g*.) An excited gold-leaf electroscope, *c*, fig. 12, inclosed in an airtight bulb of glass so as to prevent any escape of the contained air, was placed on an insulated rod, and covered by a large receiver: the divergence remained unchanged when $\frac{69}{70}$ths of the air was withdrawn. On approaching an insulated ball, *n*, to the cap of the instrument, which also terminated in a large sphere, *c*, the leaves gradually closed*.

28. The decreased intensity observable by the electrometer (16.) may be referred therefore, partly, to the change of density of the electrical stratum arising from the diminished quantity in any given point, and partly, to the influence of the electrified substance itself, by which a portion of the force on external bodies becomes more or less masked, or controlled.

29. The conditions of the controlled action, in cases of electrical accumulation on coated glass, are precisely the same as those above mentioned (28.). A coated jar may be considered as a species of compound conductor, in which the controlling effect of the insulated coating in respect of the electrometer is greatly increased by its proximity to the other in a free state; hence a much greater quantity may be accumulated on a given extent of surface with the same intensity. The difference, therefore, between electrical accumulation on coated glass and that on simple conductors is only in degree of effect; the laws incidental to the electrified substance remain the same.

30. We may infer on the principles above exposed (21.), that the controlling force of bodies when electrified, in respect of the action exerted upon their electricity by those which are neutral, would continually decrease as the quantity accumulated on a given point increases, so that at last, by the superior force of the neutral body, it would become nothing, or very nearly so; hence a discharge ensues, for the force in the

* The facility with which electrified bodies retain their charge in rarefied air, under perfect insulation, and when removed sufficiently from the influence of neutral conducting substances, is somewhat at variance with the elastic hypothesis of electricity as generally understood. Having been at first led to adopt this hypothesis in all its generality, I was not prepared for such a result.

direction of the opposed substance is continually increasing; and at length, in virtue of its connexion with the mass of the earth, if it be in a free state, indefinitely great. This reasoning applies also to the discharge of an electrical accumulation between the coatings of a jar, the force in the direction of the discharging circuit, being at the instant of the discharge indefinitely great, in respect of the controlling force exerted on the accumulated electricity by the metallic coatings, taken either singly or as acting one on the other through the intervening glass.

31. The phenomena of tension and intensity as above explained, are quite independent of the effect of the whole quantity accumulated, when discharged through various substances. Thus, the heating effect of a given quantity, discharged through a metallic wire, under the same conditions of circuit, &c., is always the same, whatever may have been its previous tension or intensity, as relating to the conductors on which the accumulation has taken place; *e. g.* a given quantity, accumulated on coated jars, always produces the same heat in a metallic wire, *c d*, fig. 13, inclosed in the bulb of the electro-thermometer N*, and discharged by means of the drop-ball *f*, whether accumulated on thick glass, or on thin, or on a greater or less extent of surface, the number of jars and the length of the circuit being the same. Dr. Faraday, in his capital researches in magneto-electricity, has further shown, that the same is true in respect of the magnetic effects produced, as also in respect of the electro-chemical effects; we have therefore arrived at a distinguishing property of quantity, of great consequence to inquiries in this branch of science.

32. The circumstances attending the transmission of a momentary electrical current between two conductors, under the form of a dense explosion, merits, in relation to the above deductions, an attentive consideration.

When the attractive force operating between two conductors can overcome the atmospheric pressure, a discharge ensues between the nearest points of the opposed surfaces. In these points the force appears to become at length indefinitely great, in respect of points more remote, so that the whole quantity accumulated, is finally determined through them. Thus, the precise points of contact between two spheres being found, and the spheres subsequently separated by given distances measured between these points, it may be shown, that the respective quantities requisite to produce a discharge will vary with the distances directly.

(*h.*) A discharging electrometer, fig. 14, was so constructed that given distances might be obtained between the nearest points of the spheres *c c*' by means of a micrometer screw, *s*. This instrument being affixed to a jar, D, exposing about five square feet of coating, it was easy to estimate very exactly by means of the unit jar *u* (11.) the quantity of electricity requisite to cause a discharge at any given distance between the balls *c c*'. Under these circumstances it is found that the number of measures indicated by the unit jar, vary exactly with the distances between the nearest points of

* For a description of this instrument I may refer to the Philosophical Transactions for 1827, p. 18; also to the Transactions of the Royal Society of Edinburgh for 1832.

the balls *c c'* of the discharging electrometer. Similar results ensue in accumulating different quantities on simple conductors, the distances through which a discharge occurs in air of the same density being directly as the quantity accumulated.

33. In order to conduct these and other experiments on electrical attraction, by means of simple conductors, with greater accuracy, I employed the mechanical arrangement represented in fig. 15. It consists of an oblong base, *a b*, a portion of which, *m n*, may be drawn out to a certain length by means of an easy groove in which it slides. There is a micrometer-screw and frame, *f*, fixed on this sliding portion, which moves the insulating glass rod *q* between the guides *m o*, either backward or forward, and by very small quantities. On the distant extremity *a* of the base *b a*, is fixed a second insulating glass rod, *r*, which passing with friction through some compressed cork in the ball *r*, may be either elevated or depressed for an inch or more. By this machine two conductors, *h h'*, placed on the glass rods *r q*, may be exactly opposed to each other in the same right line, and may be also set to any given distance within the ·01 of an inch, measured between their nearest points, a graduated circle and index being affixed to the micrometer-screw at S for this purpose. We may also charge either of the conductors *h h'* with a given quantity of electricity, without the influence of the other, by withdrawing the sliding portion of the base *m n*.

(*h.*) Two conductors, *h h'*, fig. 15, being separated by a given distance, measured between the nearest points, one of them *h'* was withdrawn, so as not to influence the quantity which the opposed conductor *h* could receive. When this last *h* had been charged, then the conductor *h'* was again restored, in an uninsulated state, to its previous position, and the precise distance at which the discharge took place observed by a final approximation with the micrometer-screw *s*. This distance being found, the same was repeated when the conductor *h* was charged with only one half the previous quantity, and so on. In these experiments the distances of discharge varied directly with the respective quantities accumulated*.

34. Comparing these results with those before arrived at (17. 20.), it may be seen, that whilst the distances of discharge between two points increase in the simple ratio of the quantity, the attractive forces increase as its square.

35. This is not only applicable to discharges produced by different quantities disposed on the same conductor, but it is also true in disposing the same quantity on many conductors precisely similar, so as to double, treble, &c., the extent of similar surface: we have in all cases the distance of discharge, in a simple ratio of the quantity contained on a unit of similar surface.

36. The distance, therefore, through which an electrical accumulation can discharge in air of a given density, is an accurate measure of the comparative quantity contained

* I do not advert to these experiments as containing any very new or unexpected results in electricity, but in explanation of the application of particular methods of research, in demonstrating more completely than has been hitherto done, a class of facts essentially involved in the subject of these inquiries.

in an unit of space, or (supposing the electrical particles to repel each other) of the tension; now the attractive force evinced by the electrometer, and which we have termed intensity, is directly as the *square* of the quantity contained in a unit of space, and cannot be taken as a measure of the tension, except under this condition.

37. On reviewing these phenomena, as connected with the discharge of electricity between conductors, we may trace an interesting and consistent relation between them. If we call the force exerted between two points $c\ c'$, fig. 14, at the instant of a discharge, unity, and we now suppose the balls to be placed with the same accumulation at twice the previous distance, then, according to the general law of electrical attraction, the force will be reduced to one fourth, since it varies in an inverse ratio of the squares of the respective distances (67.), at three times the distance it would be one ninth, and so on: hence the discharge could not occur at these distances with the same quantity. But since double, treble, &c., accumulations develop free quantities or intensities, which are as the squares of the whole quantity accumulated (16.), we have with double, treble, &c., quantities accumulated, attractive forces which exactly compensate the decreased force due to the respective increases of distance; and hence at the instant of the discharge at double, treble, &c., distances, with double, treble, &c., accumulations, the force is precisely the same; that is to say, it is in every case sufficient to overcome the atmospheric pressure at each given distance.

38. A similar result ensues when the same quantity is disposed on an increased surface of similar dimensions, where the distance of discharge (35.) becomes reduced in an inverse ratio of the surface: now in this case the intensity being as the square of the quantity contained in a given space, it decreases in the inverse ratio of the square of the surface (20. *e.*), whilst the attractive force increases in an inverse ratio of the squares of the respective distances (67.); hence in decreasing the distance between the discharging points, whilst at the same time the extent of surface is proportionably increased, we preserve the attractive force constant, and are thus enabled to overcome the atmospheric pressure at any required distance, as before.

39. It would seem to follow from this, that the resistance of the atmosphere to the passage of electricity is not really greater through any one discharging distance than through another, and is in no case greater than the existing pressure of the air; an induction which is found to correspond very completely with experiment.

40. I have examined carefully the influence of an atmosphere of variable density and temperature, in restraining electrical discharges, and have arrived at some interesting results; these are comprised in the following experiments.

(*i.*) The electro-thermometer N, fig. 13, being placed in connexion with the discharging electrometer *f*, the effects of given quantities of electricity discharged through the wire *d c* were carefully observed, the circuit *m h f r i d c n* being varied, both as to its extent and the nature of the substance, in the portion *i d*. A very few trials served to shew, that the effect on the wire decreased in some inverse ratio of the resistance to the transmission of the accumulated electricity; thus, the effect was less with a long

circuit than with a short one; and when it consisted of imperfect conductors, such as wood, or water contained in a glass tube, the instrument was scarcely at all affected.

41. When long circuits of metallic wire were employed, the effect varied in an inverse ratio of the length. Thus, with an insulated circuit of 300 feet of thick copper wire, the transmission of a given quantity through the electrometer, N, elevated the fluid ten degrees; with a circuit of 600 feet, the resistance was such that it only rose between five and six degrees; with 900 feet, rather more than three degrees.

42. This law was not so fully apparent on circuits of 50 or 100 feet, circumstances, necessarily involved in the experiment, being such as greatly to interfere with an exact result on short lengths of metal; thus the final equalization of the electricity through the metallic coatings of the battery, as also through the connecting rods and the like, seemed of little consequence when great lengths of circuit were compared, but interfered considerably in small ones, the resistance of each comparative circuit being increased by this constant.

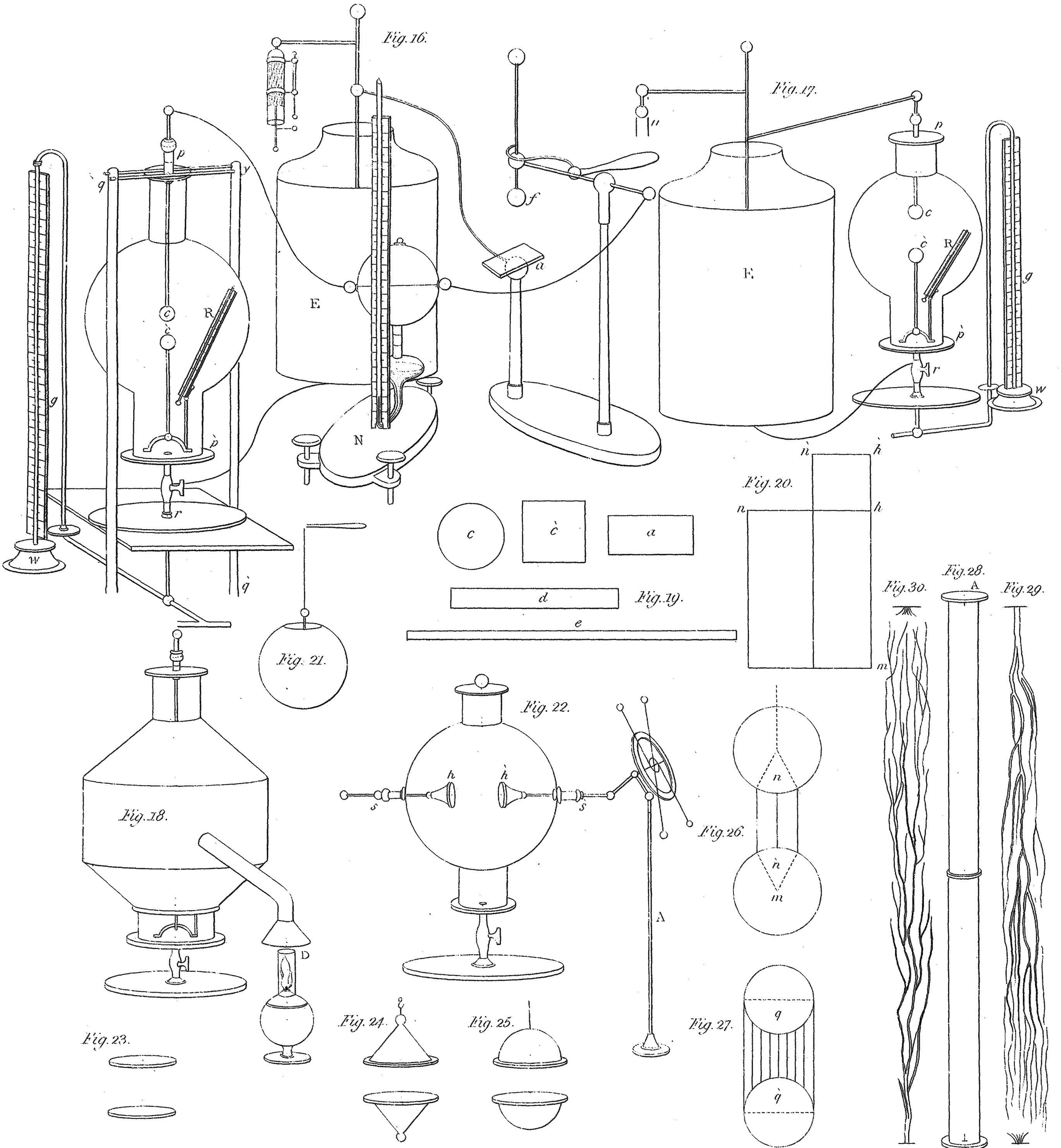
43. These experiments on the resistance of conducting substances to the transmission of electricity through them, will enable us better to appreciate the kind of resistance arising from a non-conducting medium, such as air, as in the following cases.

The electro-thermometer N, fig. 16, (Plate IV.) was placed in connexion with the opposed spheres *c c'* in the receiver R; the spheres were separable to a greater or less extent by means of a brass rod sliding through an airtight collar on the glass plate *p*, the distance being regulated by a micrometer-screw and index at *p*: the receiver was connected with a good air-pump at *r*, furnished with a long mercurial gage, *g*, and had within it a thermometer, R, to indicate the temperature of the contained air. The temperature could be raised considerably, when required, by means of a metallic envelop, fig. 18, and a powerful lamp at D: this envelop was so contrived as to be easily removed at the time of experiment, without disturbing the fixed pieces *q q'*, fig. 16, and cross-bars of glass *q y*, by which the expansive effect of the heated air on the plates *p p'* was effectually resisted.

(*j*.) A given quantity being accumulated in the jar E, it was discharged between the balls *c c'*, placed at different distances apart, within the extreme limit of the distance at which the accumulated electricity could of itself escape. In order to effect this, the jar was discharged by the drop-ball *f*, which was allowed to fall with force on a small plate of varnished glass *a*, placed on the opposed ball *a* in connexion with the positive coating: by this the transmission of the electricity became impeded up to the point of fracture of the glass, as appeared by the retention of the charge, when the ball *f* rested on *a*. The results of thirty successive experiments gave an invariable effect on the wire *c d*, at whatever intermediate distance the balls *c c'* were placed within the limits of the whole discharging distance.

By diminishing the density of the air, the discharging distance could be extremely increased: the effect, however, on the instrument remained the same.

44. The ball *c* being connected with the positive coating, and *c'* with the negative



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coating, fig. 17, given quantities of electricity were accumulated, and the distances at which the discharge occurred in air varying in density observed, this series of experiments led to the following results:

(*k.*) 1st, The respective quantities requisite to pass a given interval, *c c'*, varied in a simple ratio of the density of the air. When the density was one half as great, the discharge occurred with one half the quantity accumulated; that is to say, with one fourth of the intensity or free action (16. 20.).

(*l.*) 2ndly, The distance *c c'* through which a given accumulation could discharge, was found to be in an inverse simple ratio of the density of the air, the intensity or free action being supposed constant. In air of one half the density, the discharge occurred at twice the distance.

45. These results are in complete accordance with the conclusion already derived (37.), since the attractive force between the points of discharge *c c'* was, 1°, varied by varying the whole quantity accumulated; 2°, by varying the distance: the force, therefore, was in each case the same (20. 67.), that is, as the square of the density of the air directly.

46. By diminishing the density, and increasing the distance between the points of discharge, we may very completely represent the beautiful phenomena of summer lightning: the electrical explosion approaches nearer and nearer to the state of a diffuse luminous flash without noise: and this also happens when the distance between the discharging points is the same, the quantity accumulated becoming continually reduced. We may hence infer, that in atmospheric discharges between clouds opposed to each other in air greatly rarefied, either by heat or by diminished pressure (44. *l.*, 50.), the electrical accumulation never proceeds beyond a certain limit; so that discharges in diffuse flashes, without noise, repeatedly occur, whilst the exciting cause of the electrical accumulation continues to operate.

47. The resistance of a column of non-conducting matter, such as air, to the passage of an electrical discharge, appears by the foregoing results (43.) to produce a somewhat different result to that of conducting bodies; the resistance in the former arising solely from the pressure of non-conducting particles, by which the whole accumulation is restrained within given limits. Now when the attractive forces are sufficiently great to remove the atmospheric column interposed between the points of discharge, the accumulated electricity escapes in a dense form between those points, without any regard to the distance traversed; and without any intermediate operation on the force of the electrical current, as in the case of electricity passing through an interposed circuit of metal of greater or less extent (40.).

48. I endeavoured to find, by varying the temperature of a given volume of air forcibly retained within the receiver R, figs. 16, 18, so as to prevent expansion, whether the influence of heat was such as to impair its insulating property. It may be here remarked, that the numerous experiments hitherto instituted, in order to show the conducting power of heated air, are by no means conclusive. The great source

of fallacy appears to consist in a neglect of a very important element,—the density of the air immediately operated on,—and which has great influence in the restraining of electrical discharges (44.). By means of the arrangement above described (43.), this source of fallacy is altogether avoided, and we are enabled to experiment on a constant volume of air of variable temperature.

(*m.*) The experiment being disposed as above stated (44.), an accumulation was effected sufficient to discharge through a certain interval of air of a given temperature, and whose volume was fixed by closing the cock *r*, fig. 16. This being ascertained, the temperature was varied from between 50 to 300 degrees of Fahrenheit, but without in the least affecting the result; the discharge invariably occurred when the same quantity was accumulated. The influence of heat was therefore evidently not in any way opposed to the restraining power of the air,

(*n.*) The heated air was now permitted to expand, by opening the cock at *r*, and allowing an escape through the long gage *g*, from under the surface of the mercury in the cistern *w*: when the full expansion had taken place, the cock was again closed. The thermometer within now stood at about 280 degrees. This preparation being accomplished, the quantity requisite to cause a discharge between the balls *c c'* was again determined; but although greatly reduced, it was found to remain the same through each succeeding decrease of temperature, as the whole gradually acquired the temperature of the room. When this was attained, the cock at *r* was again opened, in order to admit of the ascent of the mercury in the gage, and by which the density of the air in the receiver could be sufficiently well estimated. The comparative accumulation, as in the preceding cases (44.), was then found to be as the diminished density directly, or nearly so.

49. These experiments on the power of heated air to restrain electrical discharges, were varied in the following way: A portion of the air within the receiver R, fig. 17, was first withdrawn, so as to raise the mercury in the long gage *g* about five or six inches; a given accumulation was then effected, sufficient to produce a discharge between the opposed spheres *c c'*. The receiver was now heated as before, and the descent of the mercury in the gage observed. By this method the actual tension of the air within could be estimated, whilst the expansive force on the plates *h h'* terminating the receiver, was efficiently resisted by the atmospheric pressure from without, so that the plates did not require further support. The results were the same as those before arrived at. The insulating power of the air was found to be quite independent of its temperature, and to depend only on the density.

50. We may conclude from these experiments,—1°. That heated air is not, as frequently stated, a conductor of electricity, and that heat does not facilitate electrical transmission through air in any other way than by diminishing its density;—2°. Supposing heat to be material, it is a non-conductor of electricity; because the incorporation of a conducting with a non-conducting substance is found to impair the insulating power of the latter, as in the case of air charged with free vapour;

whereas, in the intimate union of two non-conductors, the insulating power remains perfect. Since, then, heat does not impair the insulating power of a given volume of air, heat, if a substance, should necessarily have non-conducting properties.

51. The converse of this reasoning furnishes additional evidence in favour of the above conclusion; it is a well-known fact, that the excitation of heat in good conductors, such as the metals, is inimical to their conducting power. This result always ensues in mixing a conducting with a non-conducting substance, and is also evident in amalgamating a good conducting metal with an inferior one *.

This curious effect of heat in impairing the conducting power of metals, has been clearly and beautifully illustrated by Sir HUMPHRY DAVY †. I have also arrived at similar results ‡, and find, as stated by him, that heat in any way excited in metallic conductors, whilst transmitting an electrical current, tends to impair their conducting power. Mr. CHRISTIE, likewise, has observed the same fact, as appears in his last interesting paper on the Laws of Magneto-electric Induction §.

52. Although the experiments in evidence of this influence of heat or metallic conductors are numerous and very conclusive, yet opposite views have been advanced by Dr. RITCHIE in his paper on Electric Conduction ||. Dr. RITCHIE's principal experiment consists in transmitting common electricity over a forked iron rod, one of the legs of which he heated to redness: he finds, under these circumstances, that the electricity will rather pass from the heated side, than from the cool side; but this result cannot be taken in evidence of the superior conducting power of the heated iron, so long as the experiment is made in air, since, as has been just shown (48.), air rarefied by heat, loses to a greater or less extent, its restraining power. Now the air immediately in contact with an iron rod heated to redness, is necessarily in an extremely rare state: hence the impaired conducting power of the metal becomes more than compensated by the diminished resistance on its surface; so that the conducting power of the metal, together with the greatly diminished density of the air on the one side, may still afford an easier passage to the electricity than the conducting power of the metal alone on the other (44.). It is hence essential, in such an experiment as that proposed by Dr. RITCHIE, to place the bent iron rod in a well-exhausted receiver before any fair conclusion can be drawn as to the influence of heat on its conducting power. Of this the talented author of the paper alluded to seems to be in a great measure aware, as appears in his account of his seventh experiment. Dr. RITCHIE has, however, taken an objection to one of the many phenomena so decisive of this important question: he appears to think that the effect of a heated wire would be a species of electrical evaporation from its surface; but it will be immediately perceived that this notion is purely hypothetical. Electricity is never found to escape from a

* Philosophical Transactions, 1827, p. 18.

† Ibid., 1821.

‡ Transactions of the Royal Society of Edinburgh, 1832.

§ Philosophical Transactions, 1833.

|| Philosophical Transactions, 1828, p. 373.

body, even *in vacuo*, except to flow upon some other body towards which it tends: thus, in the experiment of charging a jar under an exhausted receiver, the electrical current invariably flows from one coating to the other. If the rod of a charged jar be caused to project into the middle of a large receiver, the charge will not leave the jar; for the ball in which the rod terminates is still without the influence of the points of attraction toward which the electricity would otherwise tend. In short, electrical currents generally, may be shown to be almost exclusive actions between given points (74. 78.). Independently, however, of these considerations, it is evident, that the excitation of heat is the sole cause of the less effective transmission of the electricity. Thus, a fine wire passed through an exhausted receiver, has its conducting power impaired when heated: now in this instance the atmospheric pressure is extremely diminished, as well for the wire in its cool state, as when subsequently heated. Moreover, the converse of this experiment, the increased conducting power by the application of cold to the wire, is equally demonstrable: thus, a wire under the ordinary atmospheric conditions has its conducting power greatly increased by evaporating ether from its surface *.

53. Although the disposition of electricity on insulated conductors is subject to the laws above deduced (16.), and which are invariable when the surface remains the same, or is perfectly similar in respect of dimensions and form, yet these laws do not appear, under every condition, incidental to the conducting surface. It has been already observed by VOLTA, that extension in length greatly contributes to increase the capacity of a conductor; so that of two plane surfaces of equal area, that which has the greatest extension has also the greatest capacity for electricity. I have pursued this interesting fact, and have arrived at some further results which seem of importance.

(*o*.) Having procured some rectangular plates of equal area, such as represented in fig. 19, whose figures varied from a circle, through a square, up to a long parallelogram, I submitted them to experiment, according to the methods already described (14.). Each plate was placed in connexion with the electrometer *a*, fig. 2, and a given quantity of electricity transferred on it, from a jar charged to a known extent, by means of a small insulated transfer plate. After a few trials it became evident that the intensity varied in an inverse ratio of the perimeter of the respective plates, the differences being inconsiderable between the circle and square, but more decided as the area became extended in length. Thus, in the parallelograms *a*, *d*, *e*, fig. 19, the intensities, as corresponding with the dimensions, were as in the following Table: these intensities have been calculated for a distance = 0·5 of an inch between the attracting surfaces (10.); and it may be observed, that in these instances, the numerical agreements are sufficiently near.

* Transactions of the Royal Society of Edinburgh, 1832; also Philosophical Transactions, 1821, p. 425.

TABLE II.

Area = 75 square inches.

Dimensions.		Perimeter.	Intensity.	Parallelograms.
Length.	Breadth.			
		Inches.	°	
12·5	6	37	9	*a*
25	3	56	6	*d*
54·5	1·4	112	3	*e*

54. At first, these results led me to believe, that the diminished intensity was caused by the increased extent of edge acquired by the plate, when its area was extended in length; but after a careful inquiry I found this was not the case: the same plates formed into cylinders, either in the direction of their lengths or breadths, evinced with the same quantity, precisely the same intensity, which may be considered as a somewhat novel result. The intensity of a sphere also, was found to be the same as that of a plane circular area of the same superficial extent; neither did any differences arise in turning the plates into other figures approaching cylinders, such as triangular and hexagonal prisms. The mere circumstance of the extent of edge, therefore, has evidently no influence on the intensity: hence the increased capacity would seem to arise from some peculiar disposition of the electricity depending on the form of the conductor; it has accordingly been considered by VOLTA, to consist in the removal of the electrical particles further without the sphere of each other's influence. On reviewing these phenomena, we must therefore consider the perimeter as being merely a function of the peculiar kind of extension to which the given area has been subjected, and by which the electrical particles have become so placed in respect of each other, that their operation on external bodies is diminished. For the sake of clearness, therefore, and to avoid a direct association of the cause of the diminished intensity with the extent of edge acquired by the plate, it may be perhaps advisable to consider the intensity as more immediately dependent on the form of the respective plates, the area being constant; which equally well coincides with the results before deduced.

55. The greatest intensity of a given quantity of electricity, disposed on a given area, will appear, therefore, when the area is contained under a circle *c*, fig. 18; and the least, when expanded into an indefinite right line, as is shown also by experiment.

56. The intensities of conductors being inversely as their perimeters, when the area is constant, I thought it not unlikely that the intensity might also vary in an inverse ratio of the area, when the perimeters remained the same.

(*p*.) With a view of ascertaining this, I procured some additional plates, such as *m n*, *m n'*, fig. 20, which were so constructed, that their perimeters did not materially differ, whilst their areas greatly varied: these being submitted to experiment, as

before (14.), the respective capacities were found to be in a simple inverse ratio of the areas. Thus, when the area $m\ n'$, fig. 20, was doubled, so as to become equal area $m\ n$, whilst at the same time $m\ h + h\ n$ equalled $m\ h' + h'\ n'$, the intensity was only one half as great.

57. Since, then, the intensity of a rectangular plate, is inversely as its perimeter when the area is constant, and inversely as its area, when the perimeter is constant, it follows that the intensity must vary inversely with those quantities jointly; or calling I the intensity, A the area, and P the perimeter, we have

$$I \propto \frac{1}{A\,P}$$

This, however, is on the supposition that the quantity of electricity is constant; but if the quantity varies, whilst the form and size of the conductor remain the same, then from the results obtained (20.) the intensity, is as the square of the quantity; therefore, if x represent the number of measures of electricity (12.), we have

$$I \propto \frac{x^2}{A\,P}$$

Now the *capacity* of a conductor, is measured, by *the quantity* of *electricity* it *can receive under a given intensity*; and from the above formula we have

$$x^2 \propto I\,A\,P$$

If, therefore, we take the intensity constant, x will represent the capacity, and we shall have

$$\text{Capacity} \propto \sqrt{A\,P}$$

To obtain, therefore, rectangular plane conductors, having capacities, double, treble, &c., of a given conductor, we must construct them so, that the areas and perimeters shall be also, double, treble, &c., of the first respectively; a deduction which is in a great measure confirmed by the following experiments.

(*q*.) A circular plate *a*, fig. 2, being placed in connexion with the electrometer, a given quantity of electricity was transferred on it by means of a well insulated plate of given dimensions. The intensity being observed, a second equal quantity, transferred as before, was added to the former, when, according to the general law (16.), the resulting intensity amounted to just four times the first.

The electricity of the different bodies was now neutralized, and a transfer-plate applied to the jar, the *area* and perimeter of which, was just double that of the former. This plate being deposited on the circular area in contact with the electrometer, the intensity was found to be exactly the same as that produced by two contacts of the first plate (14. *b*.). In a similar manner, a transfer-plate of a treble area, and treble linear boundary, abstracted from the jar as much electricity at one contact, as the first did by three successive contacts; but this result could not be obtained under any other disposition of the areas of the respective plates.

It may perhaps be requisite to observe, that slight differences may occasionally

arise when the same transfer-plate is employed for successive transfers of the electricity, in consequence of again withdrawing a small portion of the charge deposited on the circular plate; commonly, however, this is of little consequence, the capacity of the large plate being very considerable in respect of the capacity of the smaller one. We may, however, avoid the discrepancies by means of two or three small plates, precisely equal, so as to place each in succession on the larger one.

(*r.*) Two plane conductors being alternately connected with the electrometer, whose areas and perimeters were, in one, double of the other respectively, the intensity of a given quantity, when disposed on them, was, according to the general law (16.), in an inverse ratio of the square of the surface. This law, however, did not obtain when the area only was double, without regard to the perimeter. Thus, in two circular plates or parallelograms, in which the area of one plate, was double of the other, the lengths of the latter being in the ratio of 2 : 1, the respective intensities were found to be very nearly in an inverse ratio of the areas; a somewhat remarkable fact.

58. We may conclude from these phenomena, that the intensity does not vary in an inverse ratio of the square of the surface, according to the general law (16.), except when the areas are so disposed; that the whole perimeter of the various plates, is as the respective surfaces; a result which applies also to cylindrical conductors, the electrical capacities of these being the same as the plane areas, into which we may conceive them to be expanded (54.).

59. The curious fact, that the capacity of a sphere or cylinder is the same as that of the plane area into which it may be supposed to be rectified, seems to afford some new views in electricity. We find in the case of electricity accumulated on a hollow sphere, that a conducting substance, insulated and placed entirely within the sphere, remains in a neutral state; from which it has been inferred that the charge resides only on the exterior surface. Now the intensity of a sphere being the same as that of a plane circle of equal area, it should follow that the distribution is in each alike, since it is difficult, from any known fact, to suppose a given quantity of electricity expanded over twice the surface, as may be inferred in the latter case, and yet maintain the same intensity: the redundant electricity, therefore, if the above deduction be true, should be also disposed on one side of the plate only, notwithstanding that it may be determined to either when operated upon by a neutral body.

60. The great difference in the condition of an electrified sphere and that of a plane of equal area, seems to consist in the difference of the relation of one of the surfaces of the sphere in respect to neutral bodies. It may be observed, in the case of a neutral body becoming electrified from either side of the plane area, that some portion of the body is always elevated without the surrounding plane; and if a similar condition be fulfilled in respect of the interior surface of a sphere, there will remain no difficulty in obtaining electricity from that surface, and as readily as from the other: thus, a substance insulated within the sphere, at the extremity of a conducting rod, projecting in

the least beyond the interior, as in fig. 21, becomes immediately electrified when the sphere is charged with electricity.

61. We have yet to notice another seeming exception to the general law (16.) observable in accumulating variable quantities of electricity on insulated conductors, and which is found to occur in that peculiar kind of accumulation induced in a body by electrical influence.

Many striking facts lead us to conclude, that excitation by induction, as above stated (4. 5.), is the immediate effect of a tendency of accumulated electricity to a given state, or mode of existence: hence an electrified substance is observed to exert a peculiar kind of influence upon surrounding bodies. The immediate result of this influence, is a sort of temporary change, or displacement, of the electricity which these bodies already possess; so that if they be insulated, a species of accumulation is apparent in certain parts of them, depending upon a new disposition or state of their own electricity. Now the attractive force thus induced in a neutral substance, by the immediate influence of a charged conductor, appears to be as the quantity of the free electricity in operation directly, that is, as the intensity or exciting cause; and as the simple distance between the points of the opposed bodies inversely, which may be gathered from the following experiments.

(*s.*) Two conductors, *h h'*, fig. 15, terminating in plane surfaces, as in fig. 22, being insulated on the stand fig. 15. above described (33.), one of them, *h*, was connected with the electrometer, fig. 2, and the other charged with a given quantity (14.), whilst withdrawn from the influence of the former. These two conductors were now placed within a known distance of each other, and the induced force in *h* observed: after numerous repetitions of this experiment, the distances between the conductors being varied, I found, that the force induced in the distant extremity of *h* was in the simple inverse ratio of the distances between the opposed surfaces.

(*t.*) When the distance was constant, and the accumulated quantity in *h'* variable, then the induced force in *h* varied with the square of the accumulation in *h'* directly.

62. I repeated these experiments with the balance, and with an electrical jar, according to the method already explained (19.), fig. 9, and found the result invariable. In this latter case the conductor *h* was immediately connected with the jar by a straight wire, and *h'* with the insulated ball *b*, so as to interpose the conductors between the jar and the balance, the distance between the opposed surfaces being adjusted by the micrometer-screw *f*, fig. 15.

63. Assuming in these experiments, what is quite consistent with strict philosophical reasoning, that every effect is directly proportionate to its cause, we have additional evidence of the law already deduced (16.); since to excite an attractive force in a distant body, varying as the square of the quantity of electricity accumulated in the exciting conductor, the free quantity, or intensity, in the latter must at least vary in the same ratio; hence it follows that with a double quantity accumulated there is four times the intensity, or free action.

64. Upon considering attentively the march of the attractive force in the body *h* excited by induction, it would appear that the intensity of the induced accumulation is not subject to the same law as observed in permanently electrified bodies (16.), the force in the one case being as the induced accumulation simply, in the other as the square of the quantity communicated.

The cause of this difference may possibly be traced to an essential difference in the nature of the respective accumulations. In the induced accumulation, the attractive force arises from the change effected in the electricity originally possessed by the body itself: hence the accumulation by induction may be considered rather as a species of electrical development in the neutral body. Now the quantity of developed electricity being altogether a free quantity, it must consequently be always as the exciting cause directly, all other things being the same; the induced action on the neutral body will therefore be always as the free action of the electricity accumulated on the charged conductor, as is shown by experiment (*s.*).

65. This influence of free electricity on a neutral conductor which we have been just considering, is quite independent of atmospheric pressure, it being precisely the same in a partially exhausted receiver as in air. I examined the effects of electrical influence in a rarefied medium, by means of two conductors, *h h'*, attached to rods, passing through the sides of a spherical receiver, as represented in fig. 22. These conductors were separable to a greater or less extent by micrometer-screws, *s s'*, acting on the rods, by which the conductors were sustained, the rods being moveable through airtight collars.

(*u.*) By connecting one of the rods with the electroscope A, fig. 1, or with the insulated ball *b* acting on the balance, fig. 9, or with the electrometer, fig. 2, and the opposite rod with a charged conductor or jar, as in the previous cases (17. 18.), the induction between the opposed bodies *h h'* under different atmospheric pressures was easily observed.

The results of numerous experiments led to the conclusion, that the operation of electricity on distant bodies by induction, is quite independent of atmospheric pressure, and is precisely the same in vacuo as in air; a result which was demonstrable when three fourths of the air was withdrawn from the receiver, the charge employed being such as could be retained on the conductor *h* under the influence of *h'* placed at three inches' distance.

66. These experiments were varied by giving the neutral body *h'* a temporary connexion with the ground, whilst exposed to the inducing action of *h*: in this case, as in that above described (21.), the induced effect upon the neutral body is not sensible so long as the accumulation remains on the charged conductor; but on reducing this last to a neutral state, the divergence of the index of the electroscope, or otherwise the attractive effect as indicated by the electrometer (A), or the balance (N), fig. 9, is immediately apparent.

The general result by this method was the same precisely as in the preceding ex-

periments, the subsequent effect on the electrometer being quite independent of the presence of the air.

67. The law according to which the force of electrical attraction varies, when exerted between bodies at different distances, has been justly considered by many profound philosophers an important object of physical research: it may be satisfactorily arrived at by the methods of experiment so frequently referred to in the course of this paper (20.). The results are for the most part of an extremely simple kind, without any complication; and being strikingly illustrative of an influential law, applicable to many forces in nature, they may not be altogether undeserving of attention.

(*v.*) A weight of eighteen grains being placed in the pan *t*, fig. 9, the parallel and even surfaces of the opposed bodies *m m*' were placed at 0·5 of an inch distant. A given quantity of electricity was now accumulated in the jar E, the attractive force of which just balanced the given weight, the quantity being determined by means of the unit jar *u*. The distance between the bodies *m m*' being now increased to an inch, that is, to twice the former distance, and the same quantity again accumulated in the jar, the attractive force was found equivalent to 4·5 grains precisely. In like manner a weight of two grains exactly balanced the former force, when the distance between the bodies was increased to 1·5 inch, or three times the first.

In these experiments, the attractive forces varied as the squares of the respective distances inversely with great precision; a law of much importance in its consequences, but which has received but comparatively little elucidation from methods of research not involving complicated conditions.

68. By substituting the electrometer, fig. 2, for the balance, the same law is immediately arrived at, either with simple electrified conductors, in the way already described (14.), or otherwise by means of a coated jar, as in the preceding case. When the electrometer is employed, we may compare readily the force in degrees with the distance between the attracting surfaces, the quantity being constant, and hence, as before, arrive at results which present nothing but the mere effects of the law under investigation, as given in the following Table.

Table III.

Distance.	Force.
Inches.	°
0·5	20
0·8	8—
1·0	5
1·2	3·5—
1·5	2+

The approximations in the above Table are so close, that the numerical results may be taken as exact.

69. The law observable in the preceding investigations is immediately apparent

when the opposed surfaces are parallel planes or rings; but in the case of spheres or bodies of other forms, the experiment assumes a somewhat complicated character. I have succeeded, however, in reducing it to extremely simple conditions, by the aid of some further inquiries into the peculiar mode of action of the attractive force, the results of which merit an attentive examination.

1°. The attractive force exerted between an electrified and a neutral uninsulated conductor, is not at all influenced by the form or disposition of the unopposed portions. The force is precisely the same, whether the opposed bodies are merely circular planes, as represented in fig. 23, or are otherwise backed by hemispheres or cones, &c., as in figs. 24, 25; hence two hemispheres were found to attract each other with precisely the same force as the spheres.

2°. The force is as the number of attracting points in operation directly, and as the squares of the respective distances inversely (67.); hence the attractive force between two parallel plane circles being found, the force between any other two similar planes will be given.

3°. The attractive force between two unequal circular areas, is no greater than that between two similar areas, each equal to the lesser.

4°. The attractive force also of a mere ring and a circular area on each other, is no greater, than that between two similar rings.

5°. The force between a sphere and an opposed spherical segment of the same curvature, is no greater than that of two similar segments, each equal to the given segment: thus, the attraction between the sphere *m* and the uninsulated segment *n*, fig. 26, is the same as that of the similar and equal segments *n n'*.

These results have been arrived at by the same methods of research as those above given (19.), figs. 9, 2. The intensity in the different experiments is supposed to be the same, the electrified body being connected with a charged jar of such capacity that trifling differences in the dimensions of the conductors connected with it may be considered as indefinitely small.

70. A careful induction from the above facts, led me to consider the attractive force exerted between a charged and neutral sphere of equal diameters, as being made up of a system of parallel forces, operating in right lines between the homologous points of the opposed hemispheres, a conclusion quite in accordance with what has been already shown (21.); for these being in exactly equal and opposite electrical states, and similarly placed, each two corresponding points should exactly neutralize each other's action in respect of points more distant. The whole force also may be further considered to be as the number of attracting points directly (69.), and as the squares of the distances inversely (67.), and to be no greater than that arising from the opposed hemispheres (69.).

71. These simple conditions, enable us to determine a point *q q'* within each hemisphere, in which the whole attractive power may be supposed to be condensed, and to exert the same force as if emanating from every point of the hemisphere. The exact

position of this point within the surface, will depend on the distance between the nearest points of the spheres, and may be readily found by the expression $z = \frac{(a^2 + 2ar)^{\frac{1}{2}} - a}{2}$, a being the distance between the nearest points of attraction, and r the radius.

The points $q\ q'$ being thus determined for given distances between the spheres, the whole force should vary between them, according to the general law (67.), and also as $\frac{1}{a(a+2r)}$, that is, inversely as the distance between the nearest points, multiplied into the distance between the centres, as shown in sec. (72.)*.

72. These deductions accord very completely with experiment, so nearly, indeed,

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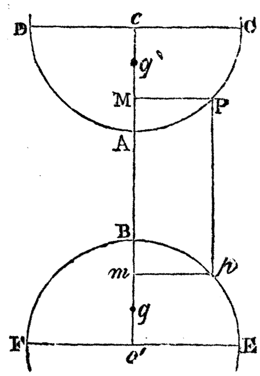

* Let C A D E B F be two hemispheres, attracting each other at distance A B.
Let $AB = a$, $AM = x$, $PM = y$, $AP = s$, r = rad., and $\pi = 3{\cdot}14159$.
μ = absolute force exerted by a unit of force at a unit of distance.
$Pp = Mm = (a + 2x)$.

Then unit of force at distance $Pp = \frac{\mu}{(a+2x)^2}$.

Now circumference whose radius = P M is $= 2\pi y$,

And annulus, whose breadth $= ds, = 2\pi y\, ds$;

$\therefore$ Force exerted by an indefinitely small annulus at P on a corresponding annulus at $p = 2\pi y\, ds \times \frac{\mu}{(a+2x)^2}$.

But in circle $y\, ds = r\, dx$;

$\therefore$ Force of annulus P on annulus $p = \frac{2\pi\mu r\, dx}{(a+2x)^2}$, the corrected sum of which = total force from A to P.

Now

$$\int \frac{2\pi\mu r\, dx}{(a+2x)^2} = -\pi\mu r \frac{1}{a+2x} + \mathrm{C}.$$

If $x = 0$, we have

$$-\pi\mu r \frac{1}{a+2x} + \mathrm{C} = 0, \text{ and } \mathrm{C} = \pi\mu r \frac{1}{a}.$$

$$\therefore\ -\pi\mu r \frac{1}{a+2x} + \mathrm{C} = \pi\mu r \left(\frac{1}{a} - \frac{1}{a+2x}\right), \text{ when } x = 0.$$

When $x = r$, this expression becomes $2\pi\mu \frac{r^2}{a(a+2r)}$ = the force upon the whole hemisphere.

Now area of hemisphere $= 2\pi r^2$, and if $q\ q'$ be the points in which we may suppose the whole force of each hemisphere to be concentrated, we have, putting $Aq' = Bq = z$,

$$\frac{2\pi\mu r^2}{(a+2z)^2} = \frac{2\pi\mu r^2}{a(a+2r)}, \text{ or } \frac{1}{(a+2z)^2} = \frac{1}{a(a+2r)},$$

that is, $(a+2z)^2 = a(a+2r)$,

$$\therefore\ a + 2z = \sqrt{a(a+2r)} = (a^2 + 2ar)^{\frac{1}{2}},$$

$$\text{and } z = \frac{(a^2+2ar)^{\frac{1}{2}} - a}{2}.$$

When both hemispheres are equal, as we have supposed, and the distances variable, the attractive forces will vary as $\frac{1}{a(a+2r)}$.

that the weight requisite to balance the force exerted between two equal spheres at given distances may be invariably predicted with extraordinary precision.

The following Table exhibits the results of a few experiments with two equal spheres, obtained by the method already given (19.), the radius of the spheres being each = one inch.

TABLE IV.

Dist. of Centres $= c\,c' = a + 2\,r$.	Dist. of nearest points = A B = a.	Dist. of Points $q\,q'$.	Force in Grains.
2·3	0·3	0·83	15
2·5	0·5	1·11	8·25 +
2·8	0·8	1·49	4·6 +
3·0	1·0	1·73	3·5 —

73. With a view of verifying the above results, I obtained two circular areas, each equal to the area of the given hemisphere expanded into a plane: these were opposed as before, and were placed at the distances $q\,q'$ given in the above Table, so as to pass through the points $q\,q'$. The experiments being repeated with the planes, the attractive forces were extremely near those deduced by the hemispheres; indeed, upon a mean of five observations for each distance, there did not arise any sensible difference.

The various planes, spheres, and other conductors employed, were constructed of light wood, neatly covered with gold-leaf: those intended to be suspended from the balance were made hollow. I repeated the experiments with the electrometer B, fig. 2, and arrived at similar results.

74. Upon a due consideration of these, and the preceding experiments in air of diminished density, we are led to conclusions of no inconsiderable consequence to our views of electrical action. By the latter, (45.), it is demonstrated, that the resistance of the air to the passage of electricity, is as the square of the density directly, so that a given quantity, having a given intensity, and about to discharge or flow upon a given point, will remain in the same relative state in air of half the density, if the distance between the points of discharge be doubled (44. *l.*); or generally, if as the density of the air be decreased, the distance between the points of action be increased, the electrical accumulation will still remain complete. If, therefore, the density of the air be indefinitely diminished, and the distance between the points of action indefinitely increased, we shall have eventually the same relative electrical state continued, without dissipation; so that if we imagine the opposed body c', fig. 17, to become nothing, then the accumulated electricity will not tend to leave the electrified body c at all, supposing it to be without the influence of all other substances. Discharges of electricity under a diminished atmospheric pressure, therefore, do not seem to occur so much in consequence of a tendency of the electric principle to evaporate, as it were, in all directions into space, but rather in consequence of the removal of the non-conducting

particles interposed between the points, *from* and *toward* which, the accumulated electricity tends to flow. It is hence extremely doubtful, whether a general distribution of electricity in mere space would ever occur, supposing the electrified substance to be the only existing body in the universe: directly, however, that we assume the existence of another body, then in a space devoid of resistance, the resulting induction would generate an attractive force, which, however small, would cause an electrical current to flow through a distance, however great.

75. In accordance with this deduction, it may be shown, that an electrified sphere having an extremely perfect insulation, and projecting within the centre of a very large receiver, retains its electricity more completely under a diminished pressure, than in the atmosphere; especially under ordinary conditions of aerial currents, imperfect insulation arising from extraneous bodies, and the like. This fact seems to have hitherto escaped detection, and therefore, the notice it merits; and I am inclined to believe, that we may eventually find it requisite to modify, to some extent, our views of the cause of electrical dissipation. The following experiment is of singular interest as bearing upon this point.

(*w*.) A small brass sphere of about two inches in diameter *b*, fig. 11, was placed immediately in the centre of a very large globular receiver, by means of a brass rod projecting into the receiver, and cemented airtight by an appropriate flanche of brass and sealing-wax. The exterior extremity of the rod was connected with a delicate electroscope, and the sphere charged with a given quantity of electricity. Under these circumstances the air was gradually withdrawn from the receiver, but no sensible collapse of the electroscope had occurred when $\frac{59}{60}$ths of the air was withdrawn.

76. Common electricity traverses with greater or less facility, under an *adequate attractive force*, the surface of any substance relieved from the pressure of a non-conducting medium. If a glass rod, or a rod of wood, be passed through a tall receiver, and be opposed to a point projecting from the conducting plate covering its upper extremity, then on exhausting the air and continuing to electrify the insulated plate, we shall eventually perceive electrical streams flowing over the rod; and if we substitute a small wire for the rod, the same thing happens, except that the streams do not usually appear in the surrounding glass, presenting in each very beautiful phenomena.

77. Discharges of common electricity are transmitted in this way more readily on the surface of bodies, in an exhausted medium, than voltaic currents, the latter requiring but little comparative insulation: it is difficult to fuse a fine wire in an extremely exhausted receiver by ordinary electricity, whilst voltaic electricity will soon heat it to redness. I have discharged upwards of twenty-five square feet of coated glass upon a fine wire of iron, inclosed in a well exhausted receiver, without in the least affecting it; the redundant electricity appeared to find an easier passage through the rarefied air on its surface, producing an extremely brilliant effect; whereas on ad-

mitting the air, the wire was immediately fused by only a single jar, exposing not more than five square feet of coating.

78. It would therefore seem impossible to prevent the flow of electricity between bodies in a space altogether void of resistance, so long as the least attractive force is exerted between them, or otherwise to restrain a similar current, in a less perfect void, with an attractive force between the bodies proportionate to the square of the density of the resisting medium. I have succeeded, by means of a very powerful electrical machine, in the transmission of continuous electrical streams through long exhausted tubes of above four inches in diameter and upwards of six feet in length. The phenomena, beside being very instructive, were of peculiar beauty. The extremities of the tubes were ground airtight to brass plates, A *a*, fig. 28, each plate being furnished with a projecting point. When this long receiver was moderately exhausted, and the plates connected with the positive and negative conductors of the machine, luminous streamers ensued, branching upon the sides of the receiver toward the negative plate. When the upper plate A was connected with the positive conductor, and *a* with the negative, the currents appeared as in fig. 29; and when these connexions were reversed by connecting A with the negative conductor, and *a* with the positive, the currents appeared as in fig. 30. If either of the plates had its connexion with the negative conductor removed, so as to leave it insulated, then the flowing from the opposite plate ceased. As the exhaustion was more complete, the distinctions of the branches gradually became less, so that finally the whole interior surface of the glass was covered with a continuous mass of white light.

In no case did the electricity appear to be transmitted through the intermediate space, except in the act of flowing from the points upon the interior surface of the glass: when it is possible, however, to cause the electric matter to pervade the partially exhausted space, it is frequently attended by a sort of beautifully luminous glow.

79. Much discussion has occasionally arisen in this department of science respecting the conducting power of a vacuum; but surely this must be regarded as a somewhat anomalous form of expression. If by a vacuum we are to understand the absence of all matter, and to consist in mere vacant space, it seems unphilosophical to suppose it endowed with any positive quality whatever. It cannot, therefore, have either conducting or insulating properties, but must be a mere passive condition, under which an electrified substance may be imagined to be placed. Hence, as already stated (74.), an attractive force, however small, exerted between two bodies so circumstanced, must cause electrical currents to flow through a distance however great; the only difference would probably be the absence of the electric light usually observed in transmitting electricity through an imperfect void, as may be gathered from the fine researches of Sir Humphry Davy on this subject*.

80. With a view of accommodating the phenomenon of electrical divergence to the

* Philosophical Transactions, 1822, p. 64.

hypothesis of Franklin and Æpinus, many acute inquirers have contended, on the authority of the Earl of Stanhope *, that the recession of electrified bodies is dependent on atmospheric attraction, and that such recession would not occur in a void; whilst others, in accommodating electrical divergence to the hypothesis of the French philosophers, endeavour to show, that although greatly dependent on the presence of an atmospheric medium, it still arises out of a repulsive force existing in the elements of the electrical principle itself †. It was upon the above statements that I adopted, by way of precaution, the method of using the gold-leaf electrometer in experiment (*f.*), fig. 12. My subsequent researches, however, with electrified bodies in receivers, more or less exhausted of the contained air, led me to investigate this point very rigorously; and I am inclined to think that the following fact, taken in connexion with the preceding (44. 74. 75.), will go far to show, that any explanation of the phenomenon of electrical divergence involving the necessity of an atmospheric action, upon any principle of mechanism whatever, is likely to be quite fallacious.

(*x.*) Two gold-leaves were suspended in free space from a stout brass wire supported horizontally on a long insulating stem of glass: these being electrified so as to diverge freely, were covered by a capacious receiver, made extremely dry, and somewhat warm within; the insulating glass stem also being varnished, was warmed with a stick of burning charcoal. The leaves did not, under these circumstances, cease to diverge when the receiver was exhausted of its air to the greatest extent which could be effected by a moderately good air-pump of the common kind. Dr. Turner has been so good as to repeat the experiment with a more perfect apparatus, and he finds the divergence equally perfect when only $\frac{1}{300}$th part of the air remains in the receiver.

81. Experiments of this kind, *demand the most perfect manipulation* and the most rigorous mode of investigation, without which we are extremely liable to be deceived by appearances: thus, the slightest deposition of moisture on the insulations becomes fatal to a delicate experiment in vacuo, as also the proximity of conducting bodies (44.). Two bodies also will frequently seem to open by a sort of flotation, on admitting air into the receiver, however carefully the operation be managed; whilst, in the electrization of bodies suspended from rods passing into receivers through brass plates, the electricity is liable to dissipation from the causes above assigned (78.).

82. Upon a careful review of these inquiries, it would seem, that the more immediate cause of electrical phenomena may be traced to certain peculiar states or conditions under which common matter may become placed in respect of an extremely subtile and universally pervading agency; from which results an attractive force, and, in the absence of an equivalent resistance, electrical currents. When these states, which, for distinction sake, we may term electrical, are incomplete, they are made perfect by the process termed induction; in which case the attractive effect immediately ensues: when they already exist, they become still further increased by the same process, and a similar result happens. When the tendency to produce these

* Singer's Electricity, p. 24.

† Haüy's Philosophy.

peculiar states is exerted between bodies whose electrical conditions are such as to be subversive of the inductive influence, then the bodies recede from each other. Such is, in plain terms, the amount of our experience of the nature of electrical attraction and repulsion; and every hypothesis of a more refined and extended character must include these elementary actions.

83. Electrical divergence is, unquestionably, an extremely intricate phenomenon. If it be assumed to depend on a repulsive force immediately impressed upon the molecules of certain kinds of matter, then it must be admitted to be a species of repulsive action essentially different from any repulsive agency in nature of which we have the least experience. Its operation is at great distances, and is exerted between distinct and concentrated accumulations of the repulsive matter disposed on the surfaces of bodies; and whilst thus exerted at sensible distances, the assumed force of repulsion is between the molecules themselves at insensible distances, either altogether controlled by some other force, or otherwise so feeble as to be incapable of producing an electrical diffusion by expansion, under an extremely diminished atmospheric pressure (75, *w*. 80, *x*.).

84. Many of the phenomena treated of in the course of this paper do not seem to have been contemplated in the more perfect theories of electricity: they may not, however, on that account be the less deserving of consideration; indeed, it is extremely uncertain whether any views of electricity hitherto adopted have been so completely verified as to render all doubts of their accuracy unpardonable. The conditions of electrical action generally assumed as the basis of calculation, do not unfrequently give rise to equations extremely complicated—in some cases very impracticable; and although the highest efforts of genius have been exerted in vanquishing the difficulties, it remains yet to be seen, whether, by an extended induction of facts, we may not succeed in arriving at easier views of electricity, and hence bring this department of science more completely under the dominion of analysis.

Plymouth,
December 1, 1833.

CORRIGENDA.

P. 214, line 7, *for* essentially involved, &c. *read* intimately associated with the molecules of....
P. 214, line 4 from the bottom, *for* A *read* *a*
P. 215, line 23 from the top, *for* fig. 1. *read* fig. 2.
P. 218, Experiment *b*, *for* (56.) *read* (57.)
P. 220, line 4 from the top, *for* (56.) *read* (57.)