

XXII. *Experiments and Observations on Electricity.* By Mr. William Nicholson; communicated by Sir Joseph Banks, Bart. P. R. S.

Read June 25, 1789.

SECT. I. *On the Excitation of Electricity.*

1. A GLASS cylinder was mounted, and a cushion applied with a silk flap, proceeding from the edge of the cushion over its surface, and thence half round the cylinder. The cylinder was then excited by applying an amalgamated leather in the usual manner. The electricity was received by a conductor, and passed off in sparks to LANE's electrometer. By the frequency of these sparks, or by the number of turns required to cause spontaneous explosion of a jar, the strength of the excitation was ascertained.

2. The cushion was withdrawn about one inch from the cylinder, and the excitation performed by the silk only. A stream of fire was seen between the cushion and the silk; and much fewer sparks passed between the balls of the electrometer.

3. A roll of dry silk was interposed, to prevent the stream from passing between the cushion and the silk. Very few sparks then appeared at the electrometer.

4. A metallic rod, not insulated, was then interposed, instead of the roll of silk, so as not to touch any part of the apparatus.

apparatus. A dense stream of electricity appeared between the rod and the silk, and the conductor gave very many sparks.

5. The knob of a jar being substituted in the place of the metallic rod, it became charged negatively.

6. The silk alone, with a piece of tin-foil applied behind it, afforded much electricity, though less than when the cushion was applied with a light pressure. The hand, being applied to the silk as a cushion, produced a degree of excitation seldom equalled by any other cushion.

7. The edge of the hand answered as well as the palm.

8. When the excitation by a cushion was weak, a line of light appeared at the anterior part of the cushion, and the silk was strongly disposed to receive electricity from any uninsulated conductor. These appearances did not obtain when the excitation was by any means made very strong.

9. A thick silk, or two or more folds of silk, excited worse than a single very thin flap. I use the silk which the milleners call Persian.

10. When the silk was separated from the cylinder, sparks passed between them; the silk was found to be in a weak negative, and the cylinder in a positive state.

The foregoing experiments shew that the office of the silk is not merely to prevent the return of electricity from the cylinder to the cushion, but that it is the chief agent in the excitation; while the cushion serves only to supply the electricity, and perhaps increase the pressure at the entering part. There likewise seems to be little reason to doubt but that the disposition of the electricity to escape from the surface of the cylinder is not prevented by the interposition of the silk, but by a compensation after the manner of a charge; the silk being then as strongly negative as the cylinder is positive: and, lastly, that the line of light
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between the silk and cushion in weak excitations does not consist of returning electricity, but of electricity which passes to the cylinder, in consequence of its not having been sufficiently supplied, during its contact with the rubbing surface.

11. When the excitation was very strong in a cylinder newly mounted, flashes of light were seen to fly across its inside, from the receiving surface to the surface in contact with the cushion, as indicated by the brush figure. These made the cylinder ring as if struck with a bundle of small twigs. They seem to have arisen from part of the electricity of the cylinder taking the form of a charge. This appearance was observed in a nine-inch and a twelve-inch cylinder, and the property went off in a few weeks. Whence it appears to have been chiefly occasioned by the rarity of the internal air produced by handling, and probably restored by gradual leaking of the cement.

12. With a view to determine what happens in the inside of the cylinder, recourse was had to a plate machine. One cushion was applied with its silken flap. The plate was nine inches in diameter and two-tenths of an inch thick. During the excitation, the surface opposite the cushion strongly attracted electricity, which it gave out when it arrived opposite the extremity of the flap. So that a continual stream of electricity passed through an insulated metallic bow terminating in balls, which were opposed, the one to the surface opposite the extremity of the silk, and the other opposite the cushion; the former ball shewing positive, and the latter negative signs. The knobs of two jars being substituted in the place of these balls, the jar, applied to the surface opposed to the cushion, was charged negatively, and the other positively. This disposition of the back surface seemed, by a few trials, to be weaker the

stronger the action of the cushion, as judged by the electricity on the cushion side.

Hence it follows, that the internal surface of a cylinder is so far from being disposed to give out electricity during the friction by which the external surface acquires it, that it even greedily attracts it.

13. A plate of glass was applied to the revolving plate, and thrust under the cushion in such a manner as to supply the place of the silk flap. It rendered the electricity stronger, and appears to be an improvement of the plate machine; to be admitted if there were not essential objections against the machine itself.

14. Two cushions were then applied on the opposite surfaces with their silk flaps, so as to clasp the plate between them. The electricity was received from both by applying the finger and thumb to the opposite surfaces of the plate. When the finger was advanced a little towards its correspondent cushion, so that its distance was less than between the thumb and its cushion, the finger received strong electricity, and the thumb none; and, contrariwise, if the thumb were advanced beyond the finger, it received all the electricity, and none passed to the finger. This electricity was not stronger than was produced by the good action of one cushion applied singly.

15. The cushion in experiment 12. gave most electricity when the back surface was supplied, provided that surface was suffered to retain its electricity till the rubbed surface had given out its electricity.

From the two last paragraphs it appears, that no advantage is gained by rubbing both surfaces; but that a well managed friction on one surface will accumulate as much electricity as the present methods of excitation seem capable of collecting; but

but that when the excitation is weak, on account of the electric matter not passing with sufficient facility to the rubbed surface, the friction enables the opposite surface to attract or receive it, and if it be supplied, both surfaces will pass off in the positive state; and either surface will give out more electricity than is really induced upon it, because the electricity of the opposite surface forms a charge. It may be necessary to observe, that I am speaking of the facts or effects produced by friction; but how the rubbing surfaces act upon each other to produce them, whether by attraction, or otherwise, I do not here enquire.

It will hereafter be seen, that plate machines do not collect more electricity than cylinders (in the hands of the electrical operators of this metropolis) do with half the rubbed surface; which is a corroboration of the inference here made.

16. When a cylinder is weakly excited, the appearances mentioned (par. 8.) are more evident, the more rapid the turning. In this case, the avidity of the surface of the cylinder beneath the silk is partly supplied from the edge of the silk which throws back a broad cascade of fire, sometimes to the distance of above twelve inches. From these causes it is that there is a determinate velocity of turning required to produce the maximum of intensity in the conductor. The stronger the excitation the quicker may be the velocity; but it rarely exceeds five feet of the glass to pass the cushion in a second.

17. If a piece of silk be applied to a cylinder, by drawing down the ends, so that it may touch half the circumference, and the cylinder be then turned and excited by applying the amalgamed leather, it will become very greedy of electricity during the time it passes under the silk. And if the entering surface of the glass be supplied with electricity, it will give it out at the other extremity of contact; that is to say, if insu-

lated conductors be applied at the touching ends of the silk, the one will give, and the other receive, electricity until the intensities of their opposite states are as high as the power of the apparatus can bring them; and these states will be instantly reversed by turning the cylinder in the opposite direction.

As this discovery promises to be of the greatest use in electrical experiments, because it affords the means of producing either the plus or minus states in one and the same conductor, and of instantly repeating experiments with either power, and without any change of position or adjustment of the apparatus, it evidently deserved the most minute examination.

18. There was little hope (par. 6.) that cushions could be dispensed with. They were therefore added; and it was then seen, that the electrified conductors were supplied by the difference between the action of the cushion which had the advantage of the silk and that which had not; so that the naked face of the cylinder was always in a strong electric state. Methods were used for taking off the pressure of the receiving cushion; but the extremity of the silk, by the construction, not being immediately under that cushion, gave out large flashes of electricity with the power that was used. Neither did it appear practicable to present a row of points or other apparatus to intercept the electricity which flew round the cylinder; because such an addition would have materially diminished the intensity of the conductor, which in the usual way was such as to flash into the air from rounded extremities of four inches diameter, and made an inch and half ball become luminous and blow like a point. But the greatest inconvenience was, that the two states with the backward and forward turn were seldom equal; because the disposition of the amal-

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gam on the silk, produced by applying the leather to the cylinder in one direction of turning, was the reverse of what must take place when the contrary operation was performed.

Notwithstanding all this, as the intensity with the two cushions was such as most operators would have called strong, the method may be of use, and I still mean to make more experiments when I get possession of a very large machine which is now in hand.

19. The more immediate advantage of this discovery is, that it suggested the idea of two fixed cushions with a moveable silk flap and rubber. Upon this principle, which is so simple and obvious, that it is wonderful it should have been so long overlooked, I have constructed a machine with one conductor, in which the two opposite and equal states are produced by the simple process of loosening the leather rubber, and letting it pass round with the cylinder (to which it adheres) until it arrives at the opposite side, where it is again fastened. A wish to avoid prolixity prevents my describing the mechanism by which it is let go, and fastened in an instant, at the same time that the cushion is made either to press or is withdrawn, as occasion requires.

20. Although the foregoing series of experiments naturally lead us to consider the silk as the chief agent in excitation; yet as this business was originally performed by a cushion only, it becomes an object of enquiry to determine what happens in this case.

21. The great BECCARIA * inferred, that in a simple cushion, the line of fire, which is seen at the extremity of contact from which the surface of the glass recedes, consists of returning electricity; and Dr. NORTH grounded his happy

* Philosophical Transactions, Vol. LVI. p. 117.

invention of the silk flap upon the same supposition. The former asserts, that the lines of light both at the entering and departing parts of the surface are absolutely similar; and thence infers, that the cushion receives on the one side, as it certainly does on the other. I find, however, that the fact is directly contrary to this assertion; and that the opposite inference ought to be made, as far as this indication can be reckoned conclusive: for the entering surface exhibits many luminous perpendiculars to the cushion, and the departing surface exhibits a neat uniform line of light. This circumstance, together with the consideration that the line of light behind the silk in par. 8. could not consist of returning electricity, shewed the necessity of farther examination. I therefore applied the edge of the hand as a rubber, and by occasionally bringing forward the palm, I varied the quantity of electricity which passed near the departing surface. When this was the greatest, the sparks at the electrometer were the most numerous. But, as the experiment was liable to the objection that the rubbing surface was variable, I pasted a piece of leather upon a thin flat piece of wood, then amalgamated its whole surface, and cut its extremity off in a neat right line close to the wood. This being applied by the constant action of a spring against the cylinder, produced a weak excitation, and the line where the contact of the cylinder and leather ceased (as abruptly as possible) exhibited a very narrow fringe of light. Another piece of wood was prepared of the same width as the rubber, but one quarter of an inch thick, with its edges rounded, and its whole surface covered with tin-foil. This was laid on the back of the rubber, and was there held by a small spring, in such a manner as that it could be slid onward, so as occasionally to project beyond the rubber, and cover the departing and excited surface

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of the cylinder, without touching it. The sparks at the electrometer were four times as numerous when this metallic piece was thus projected; but no electricity was observed to pass between it and the cylinder. The metallic piece was then held in the hand to regulate its distance from the glass; and it was found, that the sparks at the electrometer increased in number as it was brought nearer, until light appeared between the metal and the cylinder, at which time they became fewer the nearer it was brought, and at last ceased when it was in contact.

The following conclusions appear to be deducible from these experiments. 1. The line of light on a cylinder departing from a simple cushion consists of returning electricity; 2. the projecting part of the cushion compensates the electricity upon the cylinder, and by diminishing its intensity prevents its striking back in such large quantities as it would otherwise do; 3. that if there were no such compensation, very little of the excited electricity would be carried off; and, 4. that the compensation is diminished, or the intensity increased, in an higher ratio than that of the distance of the compensating substance; because if it were not, the electricity which has been carried off from an indefinitely small distance, would never fly back from a greater distance and form the edge of light.

22. I hope the considerable intensity I shall speak of will be an apology for describing the manner in which I produce it. I wish the theory of this very obscure process were better known; but no conjecture of mine is worth mentioning. The method is as follows:

Clean the cylinder, and wipe the silk.

Grease the cylinder by turning it against a greased leather till it is uniformly obscured. I use the tallow of a candle.

Turn

Turn the cylinder till the silk flap has wiped off so much of the grease as to render it semi-transparent.

Put some amalgam on a piece of leather, and spread it well so that it may be uniformly bright. Apply this against the turning cylinder. The friction will immediately increase, and the leather must not be removed until it ceases to become greater.

Remove the leather, and the action of the machine will be very strong.

My rubber, as before observed, consists of the silk flap pasted to a leather, and the cushion is pressed against the silk by a slender spiral spring in the middle of its back. The cushion is loosely retained in a groove, and rests against the spring only, in such a manner that by a sort of libration upon it as a fulcrum, it adapts itself to all the irregularities of the cylinder, and never fails to touch in its whole length. There is no adjustment to vary the pressure, because the pressure cannot be too small when the excitation is properly made. Indeed, the actual withdrawing of the cushion to the distance of one-tenth of an inch from the silk, as in par. 2. will not materially affect a good excitation.

The amalgam is that of Dr. HIGGINS, composed of zinc and mercury. If a little mercury be added to melted zinc, it renders it easily pulverable, and more mercury may be added to the powder to make a very soft amalgam. It is apt to crystallize by repose, which seems in some measure to be prevented by triturating it with a small proportion of grease: and it is always of advantage to triturate it before using.

A very strong excitation may be produced by applying the amalgamed leather to a clean cylinder with a clean silk. But

it soon goes off, and is not so strong as the foregoing, which lasts several days.

23. To give some distinctive criterions by which other electricians may determine whether the intensity they produce exceeds or falls short of that which this method affords, I shall mention a few facts.

With a cylinder 7 inches diameter and cushion 8 inches long, three brushes at a time constantly flew out of a three-inch ball in a succession too quick to be counted, and a ball of $1\frac{1}{2}$ inch diameter was rendered luminous, and produced a strong wind like a point. A nine-inch cylinder with an eight-inch cushion occasioned frequent flashes from the round end of a conductor 4 inches diameter: with a ball of $2\frac{1}{2}$ inches diameter the flashes ceased now and then, and it began to appear luminous: a ball of $1\frac{1}{2}$ inch diameter first gave the usual flashes; then, by quicker turning, it became luminous with a bright speck moving about on its surface, while a constant stream of air rushed from it; and, lastly, when the intensity was greatest, brushes, of a different kind from the former, appeared. These were less luminous, but better defined in the branches; many started out at once with a hoarse sound. They were reddish at the stem, sooner divided, and were greenish at the point next the ball, which was brass. A ball of $\frac{4}{10}$ inch diameter was surrounded by a steady faint light, enveloping its exterior hemisphere, and sometimes a flash struck out at top. When the excitation was strongest a few flashes struck out sideways. The horizontal diameter of the light was longest, and might measure one inch, the stem of the ball being vertical.

This last phenomenon is similar to a natural event related by M. LOAMMI BALDWIN*, who raised an electrical kite in

* Memoirs of the American Academy, Vol. I. p. 257.

July, 1771, during the approach of a severe thunder-storm, and observed himself to be surrounded by a rare medium of fire, which, as the cloud rose nearer the zenith, and the kite rose higher, continued to extend itself with some gentle faint flashes. Mr. BALDWIN felt no other effect than a general weakness in his joints and limbs, and a kind of listless feeling; all which he observes might possibly be the effect of surprize, though it was sufficient to discourage him from persisting in any farther attempt at that time. He therefore drew in his kite, and retired to a shop till the storm was over, and then went to his house, where he found his parents and friends much more surpris'd than he had been himself; who, after expressing their astonishment, informed him, that he appeared to them (during the time he was raising the kite) to be in the midst of a large bright flame of fire, attended with flashings; and that they expected every moment to see him fall a sacrifice to the flame. The same was observed by some of his neighbours, who lived near the place where he stood.

This fact is similar to another observed by M. DE SAUSSURE on the Alps, and both are referable to my luminous ball with the second kind of brush. The cloud must have been negative.

With a 12-inch cylinder, and rubber of $7\frac{1}{2}$ inches, a five-inch ball gave frequent flashes, upwards of 14 inches long, and sometimes a six-inch ball would flash. I do not mention the long spark, because I was not provided with a favourable apparatus for the two larger cylinders. The 7-inch cylinder affords a spark of $10\frac{1}{4}$ inches at best. The 9-inch cylinder, not having its conductor insulated on a support sufficiently high, afforded flashes to the table which was 14 inches distant. And the 12-inch cylinder, being mounted only as a model or trial for constructing a larger apparatus, is defective in several respects

respects which I have not thought fit to alter. When the five-inch ball gives flashes, the cylinder is enveloped on all sides with fire which rushes from the receiving part of the conductor. I never use points, but in a simple machine bring the conductor almost in contact with the cylinder. In this apparatus that cushion to which the rubber is not applied serves that purpose.

24. These marks exhibit the intensity as deduced from simple electrifying. I will now mention the rate of charging, which was nearly the same in all the three cylinders.

A large jar of 350 square inches, or near $2\frac{1}{2}$ square feet, with an uncoated varnished rim, of more than four inches in height, was made to explode spontaneously over the rim. The jar, when broken, proved to be 0.082 inches thick on an average; and the number of square feet of the surface of the cylinder which was rubbed, to produce the charge of one foot, was, when least, 18.03, and when most, with good excitation, 19.34. The great machine at Harlem charges * a single jar of one foot square by the friction of 66.6 square feet, and charges its battery of 225 square feet at the rate of 94.8 square feet rubbed for each foot. The intensity of electricity on the surface of the glass is therefore considerably less than one-fourth of that here spoken of; but if we take the most favourable number 66.6 at the commencement of turning, and halve it on account of the unavoidable imperfection of a plate machine (as shewn in par. 14.), it will be found, that the management applied to that machine would cause a cylinder to charge one square foot by the friction of $33\frac{1}{2}$ square feet. It must be observed, however, that M. VAN MARUM'S own machine, con-

* To explode from the central wire, which, from some trials, I find to require less force than from coating to coating at equal distances.

sisting of two plates, 33 inches diameter, has only half the intensity, though he reckons it a very good one. This machine is about equal in absolute power to my 9-inch cylinder, with its short rubber; but it is near thirty times as dear in price. In all these deductions I omit the computations, for the sake of brevity, and because they are easily made. The *data* are found in the description of the Teylerian machine, and its continuation published at Harlem in the years 1785 and 1787.

I shall here take the liberty of observing, that the action of the cylinder, by a simple cushion or the hand, which excited the astonishment of all Europe, in the memory of our contemporaries, was first improved by the addition of a leathern flap; then by moistening the rubber; afterwards by applying the amalgam; and, lastly, by the addition of a silk flap. Now, I find, by experiment, that we at present obtain upwards of forty times the intensity which the bare hand produces; and consequently that, since eighteen times our present intensity will equal the utmost we can now condense on strong glass even in the form of a charge; we have a less step to take before we arrive at that amazing power, than our immediate predecessors have already made.

My 9-inch cylinder, when broken, proved to be $\frac{1}{21}$ of an inch thick.

SECT. II. *Upon the luminous Appearances of Electricity and the Action of Points.*

25. Some of the luminous appearances, with balls in the positive state, have been slightly noticed as criterions of intensity. I shall here add, that the escape of negative electricity from a ball is attended with the appearance of strait sharp sparks with a

hoarse or chirping noise. When the ball was less than two inches in diameter, it was usually covered with short flames of this kind, which were very numerous.

26. When two equal balls were presented to each other, and one of them was rendered strongly positive, while the other remained in connection with the earth, the positive brush or ramified spark was seen to pass from the electrified ball: when the other ball was electrified negatively, and the ball, which before had been positive, was connected with the ground, the electricity (passing the same way according to FRANKLIN) exhibited the negative flame, or dense straight and more luminous spark, from the negative ball; and when the one ball was electrified *plus* and the other *minus*, the signs of both electricities appeared. If the interval was not too great, the long zig-zag spark of the *plus* ball struck to the straight flame of the *minus* ball, usually at the distance of about one-third of the length of the latter from its point, rendering the other two-thirds very bright. Sometimes, however, the positive spark struck the ball at a distance from the negative flame. These effects are represented in Plate IV. fig. 1, 2 and 3.

27. Two conductors of three-quarters of an inch diameter, with spherical ends of the same diameter, were laid parallel to each other, at the distance of about two inches, in such a manner as that the ends pointed in opposite directions, and were six or eight inches asunder. These, which may be distinguished by the letters P and M, were successively electrified as the balls were in the last paragraph. When one conductor P was positive, fig. 5. it exhibited the spark of that electricity at its extremity, and struck the side of the other conductor M. When the last-mentioned conductor M was electrified negatively, fig. 4. the former being in its turn connected with the earth,

the sparks ceased to strike as before, and the extremity of the electrified conductor M exhibited negative signs, and struck the side of the other conductor. And when one conductor was electrified *plus* and the other *minus*, fig. 6. both signs appeared at the same time, and continual streams of electricity passed between the extremities of each conductor to the side of the other conductor opposed to it. In each of these three cases, the current of electricity, on the hypothesis of a single fluid, passed the same way.

28. In drawing the long spark from a ball of four inches diameter, I found it of some consequence that the stem should not be too short, because the vicinity of the large prime conductor altered the disposition of the electricity to escape; I therefore made a set of experiments, the result of which shewed, that the disposition of balls to receive or emit electricity is greatest when they stand remote from other surfaces in the same state; and that between this greatest disposition in any ball, whatever may be its diameter, every possible less degree may be obtained by withdrawing the ball towards the broader or less convex surface out of which its stem projects, until at length the ball, being wholly depressed beneath that surface, loses the disposition entirely. From these experiments it follows, that a variety of balls is unnecessary in electricity; because any small ball, if near the prime conductor, will be equivalent to a larger ball whose stem is longer.

29. From comparing some experiments, made by myself many years ago, with the present set, I considered a point as a ball of an indefinitely small diameter, and constructed an instrument consisting of a brass ball of six inches diameter, through the axis of which a stem, carrying a fine point, was screwed. When this stem is fixed in the prime conductor, if the

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the ball be moved on its axis in either direction, it causes the fine point either to protrude through a small hole in its external surface, or to withdraw itself; because by this means the ball runs along the stem. The disposition of the point to transmit electricity may thus be made equal to that of any ball whatever, from the minutest size to the diameter of six inches. See fig. 7. let. A.

30. The action of pointed bodies has been a subject of discussion ever since it was first discovered, and is not yet well explained. To those who ascribe this effect to the figure of electric atmospheres, and their disposition to fly off, it may be answered, that they ought first to prove their existence, and then shew why the cause which accumulated them does not prevent their escape; not to mention the difficulty of explaining the nature of negative atmospheres. If these be supposed to consist of electrified air, it will not be easy to shew why a current of air passing near a prime conductor does not destroy its effects. The opinion, supported by the celebrated VOLTA and others, that a point is the coating to an infinitely small plate of air, does not appear better founded: for such a plate must be broken through at a greater distance only because higher charged; whence it would follow, that points should not act but at high intensities. I must likewise take notice, as a proof that the charge has little to do here, that if a ball be presented to the prime conductor, at the same time that a point proceeds from the opposite side of the ball, the electricity will pass by the point, though it is obliged to go round the ball for that purpose; but it can hardly be doubted, that whatever charge obtains in this case is on the surface of the ball next the conductor, and not on the remote side to which the electricity directs its course.

31. ACHARD'S experiments with a number of pointed cones, screwed in a plate of metal, and likewise the pointed apparatus described (par. 29) shew that the effect of points depends on the remoteness of their extremities from the other parts of the conductor. This leads to the following general law.

In any electrified conductor the transition or escape of electricity will be made chiefly from that part of the surface which is the most remote from the natural state.

Thus in the apparatus of the ball and stem, the point having a communication with the rest of the whole conductor, constantly possesses the same intensity; but the influence of the surrounding surface of the ball diminishes its capacity. This diminution is less the farther the ball is withdrawn, and consequently the point will really possess more electricity, and be more disposed to give it out when it is prominent than when depressed. The same explanation serves for negative electricity.

32. The effect of a positive surface appears to extend farther than that of a negative: for the point acts like a ball when considerably more prominent if it be positive than it will if negative. This property was used by me some years ago for the construction of an instrument to distinguish the two electricities*.

For the sake of conciseness I pass over many facts which have presented themselves in the course of my experiments on the two electricities, and content myself with observing, that there is scarcely any experiment made with the positive power which will not afford a result worthy of notice, if repeated with the negative.

* Introduction to Natural Philosophy, Vol. II. p. 320.

33. When we consider that our machines can cause a ball of an inch and half diameter to act like a point, and that our apparatus makes a point act like a ball; if at the same time we remark the small elevation of our conductors for lightning above the extended surface of the ground, and the small size of the balls proposed by some to be used as terminations; the dispute, which was so much agitated respecting them, will perhaps be found to relate to a very minute circumstance, among the many which govern the great operations of nature. It does not seem probable, that any conductor would act silently if the main course of the electricity of a negative cloud were to pass through it, and many would probably receive the stroke from a positive cloud. It does not, however, follow from this, that they might not conduct it with safety.

SECT. III. *Of compensated Electricity.*

34. It is unnecessary to insist upon what is called the equilibrium of an electrical charge, because Dr. FRANKLIN has admirably explained it according to his hypothesis. But there is another important particular, which has been almost entirely overlooked, namely, the uncompensated electricity which is as essential to the charge as that which is in equilibrium. Whenever a jar is charged, the greatest part of the electricity becomes latent on account of the compensation; but there is a certain proportion which remains on the insulated side, and exerts its force to prevent the electricity from returning to the outer surface. In moderate intensities, this will explode, and carry the charge with it, to distances which are in proportion to the quantity of the charge itself; but in greater intensities the distances greatly exceed that proportion. With glasses of different thicknesses, this intensity,

as measured by the explosive spark, is as the thickness, when the charges are equal, as Mr. CAVENDISH has determined, and I find likewise by experiments with thin substances; but when the thicknesses are greater, it increases in a higher proportion, as is found by the explosion which takes place between the electrophore and its plate, as well as by other experiments.

35. This uncompensated part of the charge (which is commonly in proportion to the quantity of latent or compensated electricity, or to the distance at which it exerts its action) was found to be greatly increased when a series of jars were made to charge each other. If a jar be insulated and made to explode by LANE's electrometer at a determinate number of turns; and another jar be then connected with its external coating so as to become charged by that means, the explosion, from the outside of the last to the inside of the first, will take place at the electrometer (unaltered) with much fewer turns. Or if the electrometer be altered till the explosion takes place at the original number, the distance will be much greater than before. Hence we see, that the intensity of the uncompensated part must be greater when there is a greater charge to be maintained, whether it be on one surface only, or on two surfaces successively connected. I have not yet made the experiments necessary to ascertain the law of this last action.

36. It is evident, that the breaking of jars is not effected by any attraction between the electricities which form the charge, but by this necessary surplus: for thicker glasses require much less electricity to produce an intensity which breaks them than thinner do; and I found a piece of Muscovy talc, one hundredth of an inch thick, to bear a charge consisting of ten times the quantity of electricity which was sufficient to have charged an equal surface of common glass so as to break it.

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But the intensity of the very dense charge on the talc was so low as to afford an explosion of no more than about one-tenth of an inch, while that of the glass jar it was compared with exploded through about five inches.

The perforation of glass by the long spark, or by the spark through oil or cement, seems to depend on the very great intensity of the electricity which has not time to diffuse itself, but charges a minute part of the surface very high.

37. Muscovy talc * being a very perfect non-conductor, and capable of being divided into plates of less thickness than one two-hundredth part of an inch, I made many experiments with it, which are too numerous to enter into this Paper. In consequence of its great capacity it gives very strong shocks. Contrary to the assertion of BECCARIA, I found that its laminæ are naturally in strong opposite states of electricity, and flash to each other when torn asunder in the dark. A large piece being split in two, the parts were found to be in opposite states. The greatest care was taken in these experiments to avoid friction, and to use such pieces as had never been excited, nor brought near the machine.

38. The most plausible objection against the probability of danger from the returning stroke of the Earl of STANHOPE is, that the quantity of electricity in an animal is too small to produce any mischievous effect. This the noble author has answered by remarking, that the quantity has not been shewn to be small †. My experiments with talc shewing that it naturally possesses much electricity, led me to investigate the quantity which a man may contain. I melted sealing wax upon BENNET's electrometer with a burning glass, and found it pro-

* I am not certain whether HENLEY or BECCARIA first used this substance; but little attention was paid to it by either. † Phil. Trans. Vol. LXXVII. p. 143.

duced no electricity either in heating or cooling. I also placed a piece of red-hot glass upon the same instrument, and it cooled without affording electric signs. These experiments shewed, that the natural quantity of electricity is the same in these bodies, whether they be in the conducting or non-conducting state; and consequently, if it can be proved, that an electric contains a large quantity of electricity, the inference may be fairly extended to non-electrics. And it will not be disputed, upon any hypothesis, but that a non-conductor, or its coating, contains as much of what we call electricity as can be driven out of it in the act of charging. Two square inches of talc, of the thickness of 0,011 inch, were repeatedly charged and made to explode over the uncoated part, by each turn of a seven-inch cylinder. The intensity of the excitation was such, that a conductor, of three feet long, and seven inches diameter, gave a dense spark of 9 inches long at each turn. Now, in round numbers 45 such plates of talc, laid upon each other, would have formed a solid inch of matter; and from this, if fitted up as a BECCARIA'S battery, we could with our machine drive out electricity enough simply to charge a conductor 45 times as long (neglecting the ends); that is to say, we find that one solid inch of talc contains electricity enough to charge a conductor of 7 inches diameter, and 135 feet long, so high as to give a nine-inch spark at least, but how much more it contains we know not.

If it be here objected, that the talc does nothing more than separate the coatings, we may make use of gold leaf for our coating; which substance being (as I find by weight and measurement) no more than $\frac{1}{282000}$ of an inch thick, would increase the result near three thousand times.

Without

Without referring to the intense electricity of a cloud, or the bulk of a man, it may be observed, that such a spark would be very painful. But to pursue our computation. The cylinder charged a square foot of glass, of about 0.08 thick, in 15 turns so as to explode over a rim above four inches high. Fifteen of the pieces of talc would therefore possess as much electricity as makes the charge of a jar of one foot square, and the 45 pieces or solid inch would contain enough to charge three square feet. If we suppose the bulk of a man to be only 3 solid feet or 5184 solid inches, the natural electricity of this mass, as deduced from the foregoing facts, will be equal to the charge of a battery of upwards of 15,000 square feet.

I beg leave to observe, in concluding this Paper, that I have been very careful in repeating the experiments with many precautions which the experienced in this branch of natural philosophy will perceive the necessity of; though, in order to keep this communication within proper limits, I have here avoided a minute description of them. With the same view I have likewise forbore to speak either of theory, or of a number of other experimental researches I have made during the course of this enquiry. Dates are entirely omitted from a conviction that the priority of accidental discovery is not worth contending for, and that no disputes ever arise about that general tenor of conduct in the cultivation of science, upon which the rational part of mankind ground their approbation or censure.

New North-street,
May 14, 1789.

P. S. Since the above was written, the *Journal de Physique* for April, 1789, has arrived. It contains an excellent Paper of M. VAN MARUM, giving an account of some very considerable amendments of the rubber, and of the manner of applying it to plate machines. The chief improvement consists in fixing the silk to the posterior part of the rubber, so that it covers the whole face, and has the amalgam applied upon it. I cannot, however, avoid expressing my surprize, that this improvement, which has been in common use in England for upwards of twelve years past, should now be offered as a discovery by so experienced a philosopher. With his new rubbers M. VAN MARUM excites his plates of 33 inches diameter so strongly as to produce nearly two-thirds of the former effect of the Teylerian machine, though the rubbed surfaces of these machines are now as 691 to 2409. This power would charge the single jar by the friction of 28.6 square feet, or the battery by rubbing 36.2 feet, instead of the numbers 66.6 and 94.8, as given in par. 24. This is a vast acquisition of intensity; but still little more than half that of the surface of a cylinder, as mentioned in the same paragraph. But if par. 14. be admitted to prove that plate machines gain nothing by the friction of the back surfaces, it will follow, that M. VAN MARUM'S management, if applied to a cylinder, would do better than mine.



Fig. 1



Fig. 2

Fig. 3



Fig. 5

Fig. 4

Fig. 6

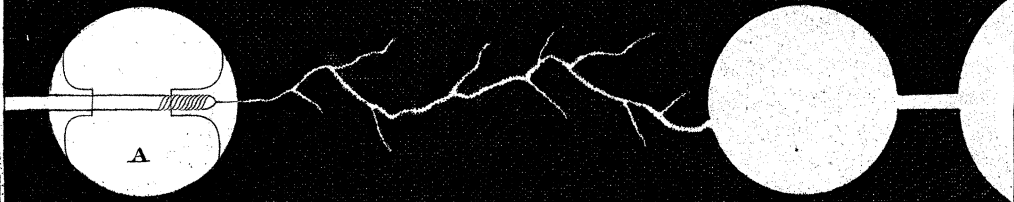


Fig. 7