This set of pages was copied from a book by Samuel Rubin titled:

"The evolution of electric batteries in response to industrial needs"

Rubin found the pages in "Philosophical Translations of the Royal Academy for 1800.

Comments by Robert Dopp were left intact in the margins.

The Volta cell. Volta's letter to Sir Joseph Banks—Basic limitation of cathodic polarization with continuous electric current flow—Reduction of polarization by use of large-area electrodes, initiated by Cruikshank; structural changes by Pepys and Hare for supporting very large-area electrodes—Recognition by Davy of the chemistry of the Volta cell—Application of oxidizing electrolytes in contact with cathode to reduce hydrogen polarization by dual electrolytes, achieved by Davy, Grove, Bunsen, Poggendorff. Application of porous cup electrolyte separators—Mechanical means developed by Wollaston for removing electrodes from cell electrolyte when cell is not in use. Plunge-type cell of Pepys, Hare, and Grenet for removing electrode from contact with electrolyte when not in use—Reduction of local zinc corrosion by mercury amalgamation of anode, as reported by Kemp and others.

Volta had observed the reactions reported by Galvani of more energetic contractions of a frog's leg when the nerve-contacting metal arc was composed of metal dissimilar to that of a supporting rod. Rather than believing that the response of the frog's muscle was caused by an electric flow of current generated by animal electricity, he attributed the reaction to energy supplied to the responsive nerves by a potential generated by contact of dissimilar metals in a closed circuit.

He stated that the disengagement of electricity from first-class metallic conductors to second-class nonmetallic conductors, such as moist tissues, was the source of the activating potential. The bimetal arc in a closed circuit with the moist frog's leg separating the metals causes a muscular response to the extent of the galvanic

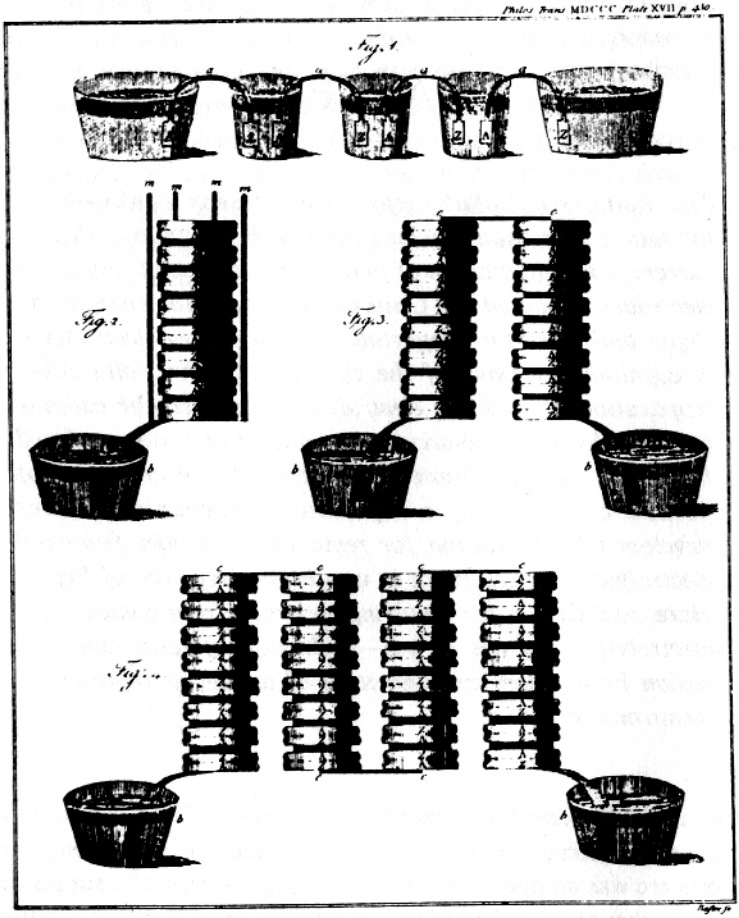

Fig. 2. Volta Pile and Cells. The illustration in Volta's letter to Banks shows four variations of the new electric battery. At the top is shown the "crown of cups" and below it variant arrangements of A (silver, for argentum) and Z, zinc discs with moist paper separators.

potential generated. This muscular reaction of the electrically charged nervous system serves to provide a sensitive electroscope that can indicate, by comparative movement, the difference in potential generated by various bimetal couples.

Volta propounded his contact theory with the principle that when two heterogeneous substances are in contact, one of them assumes a positive, and the other a negative, charge. His experimental work proved to be in the correct direction and led to his discovery of the means for generating a continuous flow of electricity by chemical action from dissimilar metals separated by an electrolyte.

Volta had been engaged in the study of his electric pile a number of years before he presented his discovery to the Royal Society. In announcing his epochal discovery of the generation of a continuous flow of electricity, he presented his theories and the structures that reflected the state of galvanic technology of that period.

Rather than give a hindsight description of Volta's cell or pile, I reproduce Volta's informative report to Sir Joseph Banks, president of the Royal Society in London, March 20, 1800.

> "On the Electricity excited by the mere Contact of conducting Substances of different Kinds." In a Letter from Mr. Alexander Volta, F.R.S. Professor of Natural Philosophy in the University of Pavia, to the Right Hon. Sir Joseph Banks, Bart. K.B.P.R.S.*
>
> Como in the Milanese, March 20, 1800.
>
> After a long silence, for which I shall offer no apology, I have the pleasure of communicating to you, and through you to the Royal Society, some striking results I have obtained in pursuing my experiments on electricity excited by the mere mutual contact of different kinds of metal, and even by that of other conductors, also different from each other, either liquid or containing some liquid, to which they are properly indebted for their conducting power. The principal of these results, which comprehends nearly all the rest, is

*Translated from Volta's paper published in French in the *Philosophical Transactions* of the Royal Society for 1800, pt. 2. Courtesy of Burndy Library, Norwalk, Conn.

the construction of an apparatus having a resemblance in its effects (that is to say, in the shock it is capable of making the arms, &c. experience) to the Leyden flask, or, rather, to an electric battery weakly charged acting incessantly, which should charge itself after each explosion; and, in a word, which should have an inexhaustible charge, a perpetual action or impulse on the electric fluid; but which differs from it essentially both by this continual action, which is peculiar to it; and because, instead of consisting, like the common electric jars and batteries, of one or more insulating plates or thin strata of those bodies which are alone thought to be *electric,* armed with conductors, or bodies called *non-electric,* this new apparatus is formed merely of several of the latter bodies, chosen from among those which are the best conductors, and therefore the most remote, as has hitherto been believed, from the electric nature. The apparatus to which I allude, and which will, no doubt, astonish you, is only the assemblage of a number of good conductors of different kinds arranged in a certain manner. Thirty, forty, sixty, or more pieces of copper, or rather silver, applied each to a piece of tin, or zinc, which is much better, and as many strata of water, or any other liquid which may be a better conductor, such as salt water, ley, &c. or pieces of pasteboard, skin, &c. well soaked in these liquids; such strata interposed between every pair or combination of two different metals in an alternate series, and always in the same order of these three kinds of conductors, are all that is necessary for constituting my new instrument, which, as I have said, imitates the effects of the Leyden flask, or of electric batteries, by communicating the same shock as these do; but which, indeed, is far inferior to the activity of these batteries when highly charged, either in regard to the force and noise of the explosions, the spark, the distance at which the discharge may be effected, &c. as it equals only the effects of a battery very weakly charged, though of immense capacity; in other respects, however, it far surpasses the virtue and power of these batteries, as it has no need, like these, of being previously charged by means of foreign electricity, and as it is capable of giving a shock every time it is properly touched, however often it may be.

To this apparatus, much more similar at bottom, as I shall show, and even such as I have constructed it, in its form to the *natural electric organ* of the torpedo or electric eel, &c. than to the Leyden flask and electric batteries, I would wish to give the name of the *artificial electric organ:* and, indeed, is it not, like it, composed entirely of conducting bodies? Is it not also active of itself without any previous charge, without the aid of any electricity excited by any of the means hitherto known? Does it not act incessantly, and

without intermission? And, in the last place, is it not capable of giving every moment shocks of greater or less strength, according to circumstances—shocks which are renewed by each new touch, and which, when thus repeated or continued for a certain time, produce the same torpor in the limbs as is occasioned by the torpedo, &c.?

I shall now give a more particular description of this apparatus and of others analogous to it, as well as of the most remarkable experiments made with them.

I provide a few dozens of small round plates or disks of copper, brass or rather silver, an inch in diameter more or less (pieces of coin for example), and an equal number of plates of tin, or, what is better, of zinc, nearly of the same size and figure. I make use of the term *nearly*, because great precision is not necessary, and the size in general, as well as the figure of the metallic pieces, is merely arbitrary: care only must be taken that they may be capable of being conveniently arranged one above the other, in the form of a column. I prepare also a pretty large number of circular pieces of pasteboard, or any other spongy matter capable of imbibing and retaining a great deal of water or moisture, with which they must be well impregnated in order to insure success to the experiments. These circular pieces of pasteboard, which I shall call moistened disks, I make a little smaller than the plates of metal, in order that, when interposed between them, as I shall hereafter describe, they may not project beyond them.

Having all these pieces ready in a good state, that is to say, the metallic disks very clean and dry, and the non-metallic ones well moistened with common water, or, what is much better, salt water, and slightly wiped that the moisture may not drop off, I have nothing to do but to arrange them, a matter exceedingly simple and easy.

I place then horizontally, on a table or any other stand, one of the metallic pieces, for example one of silver, and over the first I adapt one of zinc; on the second I place one of the moistened disks, then another plate of silver followed immediately by another of zinc, over which I place another of the moistened disks. In this manner I continue coupling a plate of silver with one of zinc, and always in the same order, that is to say, the silver below and the zinc above it, or vice versa, according as I have begun, and interpose between each of these couples a moistened disk. I continue to form, of several of these stories, a column as high as possible without any danger of its falling.

But, if it contain about twenty of these stories or couples of metal, it will be capable not only of emitting signs of electricity by

Cavallo's electrometer, assisted by a condenser, beyond ten or fifteen degrees, and of charging his condenser by mere contact so as to make it emit a spark, &c. but of giving to the fingers with which its extremities (the bottom and top of the column) have been touched several small shocks, more or less frequent, according as the touching has been repeated. Each of these shocks has a perfect resemblance to that slight shock experienced from a Leyden flask weakly charged, or a battery still more weakly charged, or a torpedo in an exceedingly languishing state, which imitates still better the effects of my apparatus by the series of repeated shocks which it can continually communicate.

To obtain such slight shocks from this apparatus which I have described, and which is still too small for great effects, it is necessary that the fingers, with which the two extremities are to be touched at the same time, should be dipped in water, so that the skin, which otherwise is not a good conductor, may be well moistened. To succeed with more certainty, and receive stronger shocks, a communication must be made, by means of a metallic plate sufficiently large, or a large metallic wire, between the bottom of the column (that is to say, the lower piece of metal,) and water contained in a bason or large cup, in which one, two, or three fingers or the whole hand is to be immersed, while you touch the top or upper extremity (the uppermost or one of the uppermost plates of the column) with the clean extremity of another metallic plate held in the other hand, which must be very moist, and embrace a large surface of the plate held very fast. By proceeding in this manner, I can obtain a small pricking or slight shock in one or two articulations of a finger immersed in the water of the bason, by touching, with the plate grasped in the other hand, the fourth or even third pair of metallic pieces. By touching then the fifth, the sixth, and the rest in succession till I come to the last, which forms the head of the column, it is curious to observe how the shocks gradually increase in force. But this force is such, that I receive from a column formed of twenty pairs of pieces (not more) shocks which affect the whole finger with considerable pain if it be immersed alone in the water of the bason; which extend (without pain) as far as the wrist, and even to the elbow, if the whole hand, or the greater part of it, be immersed; and are felt also in the wrist of the other hand.

I still suppose that all the necessary attention has been employed in the construction of the column, and that each pair or couple of metallic pieces, resulting from a plate of silver applied over one of zinc, is in communication with the following couple by a sufficient

stratum of moisture, consisting of salt water rather than common water, or by a piece of pasteboard, skin, or any thing of the same kind well impregnated with this salt water. The disk must not be too small, and its surface must adhere closely to those of the metallic plates between which it is placed. This exact and extensive application of moistened disks is very important, whereas the metallic plates of each pair may only touch each other in a few points, provided that their contact is immediate.

All this shows that, if the contact of the metals with each other in some points only be sufficient (as they are excellent conductors) to give a free passage to a moderately strong current of electricity, the case is not the same with liquids, or bodies impregnated with moisture, which are conductors much less perfect; and which, consequently, have need of more ample contact with metallic conductors, and still more with each other, in order that the electric fluid may easily pass, and that it may not be too much retarded in its course, especially when it is moved with very little force, as in the present case.

In a word, the effects of my apparatus, that is to say, the shocks felt, are considerably more sensible in proportion as the temperature of the ambient air, or that of the water or moistened disks which enter into the composition of the column, and that of the water even in the bason, is warmer, as heat renders the water a better conductor. But almost all the salts, and particularly common salt, will render it a still better. This is one of the reasons, if not the only one, why it is so advantageous that the water of the bason, and, above all, that interposed between each pair of metallic plates, as well as the water with which the circular pieces of pasteboard are impregnated, &c. should be salt water, as already observed.

But all these means and all these attentions have only a limited advantage, and will never occasion your receiving very strong shocks as long as the apparatus consists but of one column formed only of twenty pairs of plates, even though they may consist of the two metals properest for these experiments, viz. silver and zinc; for if they were silver and lead, or tin, or copper and tin, the half of the effect would not be produced, unless the weaker effect of each pair were supplied by a much greater number. What really increases the electric power of this apparatus, and to such a degree as to make it equal or surpass that of the torpedo or electric eel, is the number of plates arranged in such a manner, and with the attention before mentioned. If to the twenty pairs above described twenty or thirty others be added disposed in the same order, the shocks which may be communicated by a column lengthened in this manner will be

much stronger, and extend to both arms as far as the shoulder; and especially of that, the hand of which has been immersed in the water; this hand, with the whole arm, will remain more or less benumbed, if by frequently renewing the touches these shocks be made to succeed each other rapidly, and without intermission. This will be the case if the whole hand, or the greater part of it be immersed in the water of the bason; but if only one finger be immersed, either wholly or in part, the shocks being almost entirely concentrated in it alone, will become so much the more painful, and so acute as to be scarcely supportable.

It may readily be conceived that this column, formed of forty or fifty couples of metals, which gives shocks more than moderate to both the arms of one person, is capable of giving sensible shocks also to several persons, holding each other by the hands (sufficiently moist) so as to form an uninterrupted chain.

I shall now return to the mechanical construction of my apparatus, which is susceptible of several variations, and describe not all those which I have invented or made, either on a small or a large scale, but only a few, which are either curious or useful, which exhibit some real advantage, as being easier or sooner constructed, and which are certain in their effects, or can be longer preserved in good order.

I shall begin by one which, uniting nearly all these advantages, differs most in its figure from the columnar apparatus above described, but which is attended with the inconvenience of being much more voluminous. This new apparatus, which I shall call a *couronne de tasses* (a chain of cups), is represented Plate VIII.

I dispose, therefore, a row of several basons or cups of any matter whatever, except metal, such as wood, shell, earth, or rather glass (small tumblers or drinking glasses are the most convenient), half filled with pure water, or rather salt water or ley; they are made all to communicate by forming them into a sort of chain, by means of so many metallic arcs, one arm of which, Sa, or only the extremity S, immersed in one of the tumblers, is of copper or brass, or rather of copper plated silver; and the other, Za, immersed into the next tumbler, is of tin, or rather of zinc. I shall here observe, that ley and other alkaline liquors are preferable when one of the metals to be immersed is tin; salt water is preferable when it is zinc. The two metals of which each arc is composed, are soldered together in any part above that which is immersed in the liquor, and which must touch it with a surface sufficiently large; it is necessary therefore that this part should be a plate of an inch square, or very little less; the rest of the arc may be as much narrower as you choose, and even

shall relate only a few which are no less instructive than amusing.

Let three twenties of these tumblers be ranged, and connected with each other by metallic arcs, but in such manner, that, for the first twenty, these arcs shall be turned in the same direction; for example, the arm of silver turned to the left, and the arm of zinc to the right; and for the second twenty in a contrary direction, that is to say, the zinc to the left, and the silver to the right; in the last place, for the third twenty, the silver to the left, as is the case in regard the first. When every thing is thus arranged, immerse one finger in the water of the first tumbler, and, with the plate grasped in the other hand, as above directed, touch the first metallic arc (that which joins the first tumbler to the second), then the other arc which joins the second and third tumbler, and so on, in succession, till you have touched them all. If the water be very salt and luke-warm, and the skin of the hands well moistened and softened, you will already begin to feel a slight shock in the finger when you have touched the fourth or fifth arc (I have experienced it sometimes very distinctly by touching the third), and by successively proceeding to the sixth and the seventh, &c. the shocks will gradually increase in force to the twentieth arc, that is to say, to the last of those turned in the same direction; but by proceeding onwards to the 21st, 22d, 23d or 1st, 2d, 3d of the second twenty, in which they are all turned in a contrary direction, the shocks will each time become weaker, so that at the 36th or 37th, they will be imperceptible, and be entirely null at the 40th, beyond which (and beginning the third twenty, opposed to the second and analogous to the first) the shocks will be imperceptible to the 44th or 45th arc; but they will begin to become sensible, and to increase gradually, in proportion as you advance to the 60th, where they will have attained the same force as that of the 20th arc.

If the twenty arcs in the middle were all turned in the same direction as the preceding twenty and the following twenty, that is to say, if the whole 60 conspired to impel the electric fluid in the same direction, it may readily be comprehended how much greater the effect will be at the end, and how much stronger the shock; and it may be comprehended, in general, to what point it must be weakened in all cases where a greater or smaller number of these forces act contrary to each other by an inverted position of metals.

If the chain be in any part interrupted, either by one of the tumblers being empty of water, or one of the metallic arcs being removed or divided into two pieces, you will receive no shock when you immerse your finger into the water of the first and another into that of the last vessel; but you will have it strong or weak, according

to circumstances (leaving these fingers immersed), at the moment when the interrupted communication is restored; at the moment when another person shall immerse into the two tumblers, where the arc is wanting, two of his fingers (which will also receive a slight shock), or rather, when he shall immerse the same arc which has been taken away, or any other; and in the case of the arc separated into two pieces, at the moment when these pieces are again brought into mutual contact (in which case the shock will be stronger than in any other); and, lastly, in the case of the empty tumbler, at the moment when water poured into it shall rise to the two metallic arms immersed in this cup which before were dry.

When the chain of cups is of sufficient length, and capable of giving a strong shock, you will experience one, though much weaker, even though you keep immersed two fingers or the two hands, in one bason of water of pretty large size, in which the first and last metallic arcs are made to terminate; provided that either of these hands thus immersed, or rather both of them, be kept respectively in contact, or nearly in contact, with these arcs, you will, I say, experience a shock at the moment when (the chain being interrupted in any part) the communication is restored, and the circle completed in any of the ways before mentioned. One might be surprised that in this circle the electric current having a free passage through an interrupted mass of water, that which fills the bason, should quit this good conductor to throw itself and pursue its course through the body of the person who holds his hands immersed in the same water, and thus to take a longer passage. But the surprise will cease if we reflect, that living and warm animal substances, and above all, their humours, are, in general, better conductors than water. As the body, then, of the person who immerses his hands in the water, affords an easier passage than this water does to the electric current, the latter must prefer it though a little longer. In a word, the electric fluid, when it must traverse imperfect conductors in a large quantity, and particularly moist conductors, has a propensity to extend itself in a larger stream, or to divide itself into several, and even to pursue a winding course, as it thereby finds less resistance than by following one single channel, though shorter; in the present case it is only a part of the electric current, which, leaving the water, pursues this new route through the body of the person, and traverses it from the one arm to the other; a greater or less part passes through the water in the vessel. This is the reason why the shock experienced is much weaker than when the electric current is not divided when the person alone forms the communication between one arc and another, &c.

From these experiments one might believe, that when the torpedo wishes to communicate a shock to the arms of a man or to animals which touch it, or which approach its body under the water (which shock is much weaker than what the fish can give out of the water), it has nothing to do but to bring together some of the parts of its electric organ in that place, where, by some interval, the communication is interrupted, to remove the interruptions from between the columns of which the said organ is formed, or from between its membranes in the form of thin disks, which lie one above the other from the bottom to the summit of each column; it has, I say, nothing to do but to remove these interruptions in one or more places, and to produce there the requisite contact, either by compressing these columns, or by making some moisture to flow in between the pellicles or diaphragms which have been separated, &c. This is what may be, and what I really conclude to be, the task of the torpedo when it gives a shock; for all the rest, the impulse and movement communicated to the electric fluid, is only a necessary effect of its singular organ, formed, as is seen, of a very numerous series of conductors, which I have every reason to believe sufficiently different from each other to be *exciters* of the electric fluid by their mutual contacts; and to suppose them ranged in a manner proper from impelling that fluid with a sufficient force from top to bottom, or from the bottom to the top, and for determining a current capable of producing the shock, &c. as soon and as often as all the necessary contacts and communications take place.

But let us now leave the torpedo, and its *natural electric organ,* and return to the *artificial electric organ* of my invention, and particularly to my first *columnar apparatus*, that which imitates the first even in its form (for that composed of tumblers is different in that respect). I might say something also in regard to the construction of the said apparatus with tumblers or a *chain of glasses;* for example, that the first and last tumbler should be of such a size that, when necessary, the whole hand might be immersed in it, &c.: but, to enter into all these details, would require too much time.

In regard to the columnar apparatus, I endeavoured to discover the means of lengthening it a great deal by multiplying the metallic plates in such a manner as not to tumble down; and I discovered, besides others, the following, which are represented in the annexed figures. (Plate VIII. fig. 2, 3, 4)

In Fig. 2, mmmm are rods, three, four, or more in number, which rise from the bottom of the column, and confine, as in a cage, the plates or disks, placed each above the other in such number and to

such a height as you choose, and which thus prevent them from falling. The rods may be of glass, wood, or metal, only that, in the last case, you must prevent them from coming into contact with the plates; which may be done either by covering each of them with a glass tube, or interposing between them and the column a few stripes of wax cloth, oiled paper, or even plain paper, and, in a word, any other body that may either be a *cohibent* or a bad conductor; wood or paper will be sufficiently so for our purpose, provided only that they are not very damp or moist.

But the best expedient, when you wish to form an apparatus to consist of a great number of plates, above 60, 80, or 100 for example, is to divide the column into two or more, as seen Fig. 3 and 4, (Plate VIII), where the pieces all have their respective positions and communication as if there were only one column. Fig. 4, as well as Fig. 3 may indeed be considered as a bent column.

In all these figures the different metallic plates are denoted by the letters S and Z (which are the initials of silver and zinc); and the *moistened disks* (of pasteboard, skin, &c. interposed between each pair of metals), are represented by a black stratum. The plates of metal may either be laid simply upon each other and so brought into union in an indefinite number of points, or they may be soldered together. It is altogether indifferent which ever of these methods be followed. cc, cc, cc, are the metallic plates which form a communication between each column, or section of a column, and another; and bb, bb, bb, are the basons of water in communication with the lower part or extremities of these columns.

An apparatus thus prepared is exceedingly convenient without being bulky; and it might be rendered portable, with still more ease and safety, by means of circular cases or tubes, in which each column might be inclosed and preserved. It is only to be regretted that it does not long continue in a good state; the moistened disks become dry in one or two days to such a degree that they must be again moistened; which, however, may be done without taking to pieces the whole apparatus, by immersing the columns, completely formed, in water, and wiping them, when taken out some time after, with a cloth, or in any other manner.

The best method of making an instrument as durable as can be wished, would be, to inclose and confine the water interposed between each pair of metals, and to fix these metallic plates in their places by enveloping the whole column with wax or pitch; but this would be somewhat difficult in the execution, and would require a great deal of patience. I have, however, succeeded; and have formed

of pricking and pain are stronger and sharper, every thing else being equal, when the part of the body which is to feel them is towards the negative electricity; that is to say, placed in such a manner in the conducting circle, that the electric fluid traversing that circle is not directed towards that sensible part, does not advance towards it, and enter from the outside inwards, but takes its direction from the inside outwards; in a word, that it issues from it: in regard to which it is necessary to know, of the two metals that enter by pairs into the construction of the machine, which is the one that gives off to the other. But I had already determined this respecting all the metals by other experiments, published a long time ago at the end of my first memoirs on galvanism. I shall therefore say nothing further here, than that the whole is completely confirmed by the experiments, equally and still more demonstrative and striking, with which I am at present employed.

taste

In regard to the sense of taste, I had before discovered, and published in these first memoirs, where I found myself obliged to combat the pretended animal electricity of Galvani, and to declare it an external electricity moved by the mutual contact of metals of different kinds,—I had discovered, I say, in consequence of this power which I ascribed to metals, that two pieces of these different metals, and particularly one of silver and one of zinc, applied in a proper manner, excited at the tip of the tongue very sensible sensations of taste; that the taste was decidedly acid, if, the tip of the tongue being turned toward the zinc, the electric current proceeded against it, and entered it; and that another taste, less strong but more disagreeable, acrid, and inclining to alkaline, was felt, if (the position of the metals being reversed) the electric current issued from the tip of the tongue; that these sensations continued and received even an increase for several seconds, if the mutual contact of the two metals was maintained, and if the conducting circle was nowhere interrupted. But when I have said here, that exactly the same phenomena take place when you try, instead of one pair of these metallic pieces, an assemblage of several of them, ranged in the proper manner; and that the said sensations of taste, whether acid or alkaline, increase but a little with the number of these pairs, I have said the whole. It only remains for me to add that, if the apparatus put in play for these experiments on the tongue be formed of a sufficiently large number of metallic pairs of this kind, for example, if it contain 30, 40 or more, the tongue experiences not only the sensation of taste already mentioned, but, besides that, a blow which it receives at the moment when the circle is completed, and which occasions in it a pricking more or less painful, but

fleeting, followed some moments after by a durable sensation of taste. This blow produces even a convulsion or agitation of a part of or the whole of the tongue, when the apparatus, formed of a still greater number of pairs of the said metals, is more active, and if, by means of good communicating conductors, the electric current which it excites be able to pass every where with perfect freedom.

I must often recur to, and insist on, this last condition, because it is essential in all experiments when you wish to obtain sensible effects on the body, or commotions in the limbs, or sensations in the organs of the senses. It is necessary, therefore, that the non-metallic conductors which enter into the circle should be as good conductors as possible, well moistened (if they are not themselves liquid) with water, or with any other liquid that may be a better conductor than pure water; and it is necessary, besides, that the well moistened surfaces by which they communicate with the metallic conductor, should be sufficiently large. The communication ought to be confined or reduced to a small number of points of contact only in that place where you wish to concentrate the electric action on one of the most sensible parts of the body, on any of the sensitive nerves, &c. as I have already remarked in speaking of the experiments on feeling, *viz.* those by which acute pains are excited in different parts. The best method which I have found for producing on the tongue all the sensations above described, is, to apply the tip of it to the pointed extremity (which, however, must not be too much so) of a metallic rod, which I made to communicate properly, as in the other experiments, with one of the extremities of my apparatus, and to establish a good communication between the hand, or, what is better, both the hands together, and the other extremity. This application of the tip of the tongue to the end of the metallic rod, may either exist already, when you are going to make the other communication to complete the circle (when you are going to immerse your hand into the water of the bason), or be made after the establishment of this communication, while the hand is immersed; and in the latter case I think I feel the pricking and shock in the tongue, a very short time before actual contact. Yes; it always appears to me, particularly if I advance the tip of my tongue gradually, that, when it has arrived within a very small distance of the metal, the electric fluid (I would almost say spark), overcoming this interval, darts forward to strike it.

In regard to the sense of sight, which I also found might be affected by the weak current of the electric fluid, arising from the mutual contact of two different metals in general, and in particular, of a piece of silver and one of zinc, it was natural to expect that the

sensation of light, excited by my new apparatus, would be stronger in proportion as it contained a greater number of pieces of these metals; each pair of which, arranged in the proper manner, adds a degree of force to the said electric current, as all the other experiments show, and particularly those with the electrometer assisted by the condenser, which I have only mentioned and which I shall describe on another occasion. But I was surprised to find that with 10, 20, 30 pairs, and more, the flash produced neither appeared longer and more extended, nor much brighter than with one pair. It is true, however, that this sensation of weak and transient light, is excited by such an apparatus much easier and in different ways. To succeed, indeed, with one pair, the following are almost the only methods; *viz.* that one of the metallic pieces should be applied to the ball of the eye, or the eye-lid well moistened and that it should be made to touch the other metal applied to the other eye, or held in the mouth, which produces a flash much more beautiful; or, that this second metallic piece should be held in the moistened hand and then brought into contact with the former; or, in the last place that these two plates should be applied to certain parts of the inside of the mouth, making them communicate with each other. But with an apparatus of 20 or 30 pairs, &c. the same flash will be produced by applying the end of a metallic plate or rod placed in communication with one of the extremities of the apparatus, to the eye, while with one hand you form a proper communication with the other extremity; by bringing, I say, this plate into contact not only with the eye or any part of the mouth, but even the forehead, the nose, the cheeks, lips, chin, and even the throat; in a word, every part and point of the visage, which must only be well moistened before they are applied to the metallic plate. The form as well as the force of this transient light which is perceived varies a little, if the places of the face to which the action of the electric current is applied, be varied, if it be on the forehead, for example, this light is moderately bright, and appears like a luminous circle, under which figure it presents itself also in several other experiments.

But the most curious of all these experiments is, to hold the metallic plate between the lips, and in contact with the tip of the tongue, since when you afterwards complete the circle in the proper manner, you excite at once, if the apparatus be sufficiently large and in good order, and the electric current sufficiently strong and in good order, a sensation of light in the eyes, a convulsion in the lips, and even in the tongue, and a painful prick at the tip of it, followed by a sensation of taste.

I have now only to say a few words on hearing. This sense, which

I had in vain tried to excite with only two metallic plates, though the most active of all the exciters of electricity, *viz.* one of silver or gold, and the other of zinc I was at length able to affect it with my new apparatus, composed of 30 or 40 pairs of metals. I introduced, a considerable way into both ears, two probes or metallic rods with their ends rounded, and I made them to communicate immediately with both extremities of the apparatus. At the moment when the circle was thus completed I received a shock in the head, and some moments after (the communication continuing without any interruption) I began to hear a sound, or rather noise, in the ears, which I cannot well define; it was a kind of crackling with shocks, as if some paste or tenacious matter had been boiling. This noise continued incessantly, and without increasing, all the time that the circle was complete, &c. The disagreeable sensation, and which I apprehended might be dangerous, of the shock in the brain, prevented me from repeating this experiment.

There still remains the sense of smelling, which I have hitherto tried in vain with my apparatus. The electric fluid, which, when made to flow in a current in a complete circle of conductors, produces in the limbs and parts of the living body effects correspondent to their excitability, which stimulating in particular the organs or nerves of touch, taste, sight and hearing, excite in them some sensations peculiar to each of these senses, as I have found, produces in the interior of the nose only a pricking more or less painful, and commotions more or less extensive, according as the said current is weaker or stronger. And whence comes it, then, that it does not excite any sensation of smell, though, as appears, it stimulates the nerves of that sense? It cannot be said that the electric fluid of itself is not proper for producing odorous sensations, since, when it diffuses itself through the air in the form of aigrettes, &c. in the common experiments made with electric machines, it conveys to the nose a very sensible smell resembling that of phosphorus. Taking similitude into consideration, and reasoning from its analogy with other odoriferous matters, I will say, that it must completely diffuse itself throughout the air to excite smell; that it has need, like other effluvia, of the vehicle of the air to affect that sense in such a manner as to excite the sensations of smell. But in the experiments of which I speak, that is to say, of an electric current in a circle of conductors, all contiguous, and without the least interruption, this absolutely cannot take place.

All the facts which I have related in this long paper in regard to the action which the electric fluid excited, and when moved by my apparatus, exercises on the different parts of our body which the

current attacks and passes through—an action which is not momentaneous, but which lasts, and is maintained during the whole time that this current can follow the chain not interrupted in its communications; in a word an action the effects of which vary according to the different degrees of excitability in the parts, as has been seen;—all these facts, sufficiently numerous, and others which may be still discovered by multiplying and varying the experiments of this kind, will open a very wide field for reflection, and of views, not only curious, but particularly interesting to medicine. There will be a great deal to occupy the anatomist, the physiologist, and the practitioner.

It is well known, by the anatomy which has been made of it, that the electric organ of the torpedo or electric eel, consists of several membranaceous columns, filled from one end to the other with a great number of plates or pellicles, in the form of very thin disks, placed one upon the other, or supported at very small distances by intervals, into which, as appears, some liquor flows. But we cannot suppose that any of these laminae are of an insulating nature, like glass, resin, silk, &c. and still less that they can either become electric by friction, or be disposed and charged in the same manner as the small Franklinian plates or small electrophores; nor even that they are sufficiently bad conductors to perform the office of a good and durable condenser, as Mr. Nicholson has supposed. The hypothesis of this learned and laborious philosopher, by which he makes of each pair of these pellicles, which he compares to leaves of talc, as many small *electrophores* or *condensers,* is indeed very ingenious, and is, perhaps, the best theory that has been devised to explain the phenomena of the torpedo, adhering to the hitherto known principles and laws of electricity. For, besides that the mechanism, by which, every time that the fish intended to give a shock, the respective separation of the plates on the whole or a great number of these electrophores or condensers ought to be effected all at once, and ought to establish on the one hand a communication between themselves of all the plates electrified *positively,* and on the other a communication between all those electrified *negatively,* as Mr. Nicholson supposes—besides, that this very complex mechanism appears too difficult, and a little agreeable to nature;—and besides, that the supposition of an electric charge originally impressed, and so durable in these pellicles performing the office of electrophores, is altogether gratuitous,—such a hypothesis falls entirely, since these pellicles of the organ of the torpedo are not, and cannot be, in any manner insulating or susceptible of a real electric charge, and much less capable of retaining it. Every animal substance, as

long as it is fresh, surrounded with juices, and more or less succulent of itself, is a very good conductor. I say more, instead of being as cohibent as resins or talc, to leaves of which Mr. Nicholson has compared the pellicles in question, there is not, as I have assured myself, any living or fresh animal substance which is not a better *deferent* than water, except only grease and some oily humours. But neither these humours nor grease, especially semi-fluid or entirely fluid, as it is found in living animals, can receive an electric charge in the manner of insulating plates, and retain it; besides, we do not find that the pellicles and humours of the organ of the torpedo are greasy or oily. This organ therefore, composed entirely of conducting substances, cannot be compared either to the electrophore or condenser, or to the Leyden flask, or any machine excitable by friction or by any other means capable of electrifying insulating bodies, which before my discoveries were always believed to be the only ones originally electric.

To what electricity then, or to what instrument ought the organ of the torpedo or electric eel, &c. to be compared? To that which I have constructed according to the new principle of electricity, discovered by me some years ago, and which my successive experiments, particularly those with which I am at present engaged, have so well confirmed, *viz.* that conductors are also, in certain cases, exciters of electricity in the case of the mutual contact of those of different kinds, &c., in that apparatus which I have named the *artificial electric organ,* and which being at bottom the same as the natural organ of the torpedo, resembles it also in its form, as I have advanced.

Volta experimented with various metals to determine the maximum electromotive force developed between dissimilar metals. He found that the couple having the greatest potential difference was zinc and carbon, but it was not as practical to use in a pile as a couple of zinc and copper or silver. He later suggested an electromotive series of the elements, such as zinc, tin, lead, iron, copper, silver, gold, platinum and carbon, and noted that the further apart these elements were positioned in the series, the greater would be the electromotive force developed. Ritter independently devised a similar series at the same time. In later years this electrochemical series would be greatly expanded by the work of Faraday, Nernst, and others.