A TRANSLATION

of Luigi Galvani's *De Viribus Electricitatis*

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In Motu Musculari Commentarius

Commentary on the

EFFECT OF ELECTRICITY ON MUSCULAR MOTION

by Robert Montraville Green, M.D.

Emeritus Professor of Anatomy, Harvard Medical School,

Boston, Massachusetts

Part One

THE EFFECTS OF ARTIFICIAL ELECTRICITY ON MUSCULAR MOTION

I dissected and prepared a frog, as in Fig. 2, Tab. I, and placed it on a table, on which was an electrical machine, Fig. 1, Tab. I, widely removed from its conductor and separated by no brief interval. When by chance one of those who were assisting me gently touched the point of a scalpel to the medial crural nerves, DD, of this frog, immediately all the muscles of the limbs seemed to be so contracted that they appeared to have fallen into violent tonic convulsions. But another of the assistants, who was on hand when I did electrical experiments, seemed to observe that the same thing occurred whenever a spark was discharged from the conductor of the machine, (Fig. 1, B).

He, wondering at the novelty of the phenomenon, immediately apprised me of the same, wrapped in thought though I was and pondering something entirely different. Hereupon I was fired with incredible zeal and desire of having the same experience, and of bringing to light whatever might be concealed in the phenomenon. Therefore I myself also applied the point of a scalpel to one or other crural nerve at a time when one or other of those who were present elicited a spark. The phenomenon always occurred in the same manner: violent contraction in individual muscles of the limbs, just as if the prepared animal had been seized with tetanus, were induced at the same moment of time in which sparks were discharged.

But fearing lest these very motions arose rather from the contact of the point, which perchance acted as a stimulus, than from the spark, I again tested the same nerves in the same way in other frogs, and even more severely, but without any spark being elicited at that time by anyone; but no motions were seen at all. Hence it occurred to me that perhaps for the induction of the phenomenon both the contact of some body and the passage of a spark were simultaneously required. Wherefore I applied the edge of the scalpel again to the nerves and held it motionless, both at the time when a spark was being elicited and when the machine was perfectly quiet. But the phenomenon appeared only when the spark was produced.

We repeated the experiment, always employing the same scalpel: but not without our surprise, sometimes, when the spark was produced, the aforesaid motions occurred, sometimes they were lacking.

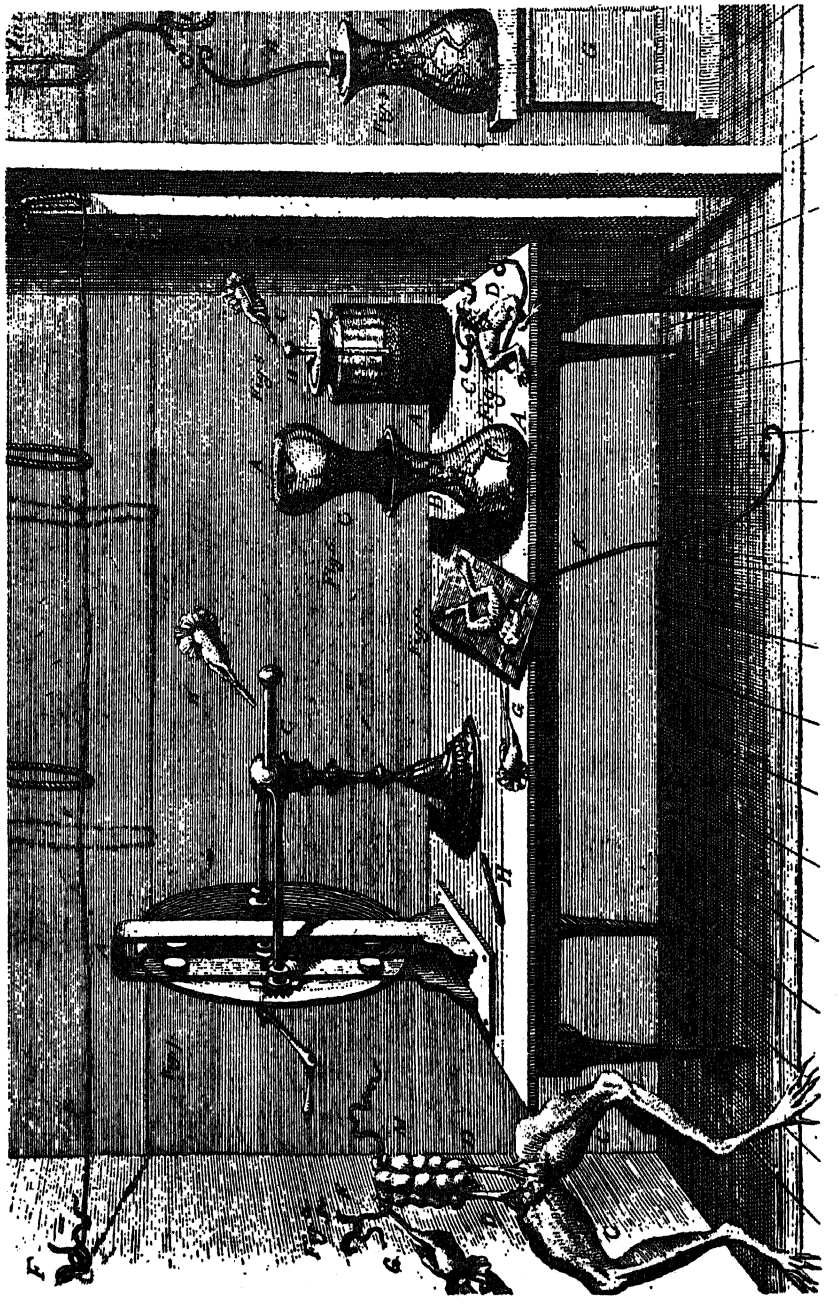
Aroused by the novelty of the circumstance, we resolved to test it in various ways, and to experiment, employing nevertheless the same scalpel, in order that, if possible, we might ascertain the causes of the unexpected difference; nor did this new labor prove vain; for we found that the whole thing was to be attributed to the different part of the scalpel by which we held it with our fingers: for since the scalpel had a bone handle, when the same handle was held by the hand, even though a spark was produced, no movements resulted, but they did ensue, if the fingers touched either the metallic blade or the iron nails securing the blade of the scalpel.

Now, since dry bones possess a non-conductile, but the metallic blade and the iron nails a conductile nature, we came into this suspicion, that perhaps it happened that when we held the bony handle with our fingers, then all access was cut off from the electric current, in whatever way it was acting on the frog, but that it was afforded when we touched the blade or the nails communicating therewith.

Therefore, to place the matter beyond all doubt, instead of a scalpel we used sometimes a slender glass cylinder H, Fig. 2, wiped clean from all moisture and dust, and sometimes an iron cylinder G. With the glass cylinder we not merely touched but rubbed the crural nerves, when the spark was elicited, but with all our effort, the phenomenon never appeared, though innumerable and violent sparks were elicited from the conductor of the machine, and at a short distance from the animal; but it appeared when the iron cylinder was even lightly applied to the same nerves and scanty sparks elicited.

Hence it appeared to us clearly established, what we had suspected to be true, that contact of a conducting body with the nerves is also required in order that the phenomenon should occur. But when both the body by which the nerves were touched, and the man who touched them, could be available, we applied the iron cylinder G to the same nerves, without touching it with our hands, that by this means it might be determined whether the phenomenon was to be ascribed to the man and the iron cylinder, or to the latter alone. When things were thus disposed, no motion of the muscles occurred when a spark was produced. Therefore, in place of the cylinder, we employed a very long wire, KK, to see whether in any way that

TABLE I



would replace the lack of the man, or not; and again there were contractions of the muscles on the passage of the spark.

From these observations it was clear to us that there is required not only the application of a conducting body to the nerves, but also a certain magnitude and extension thereof, for the production of the phenomenon. Hereafter, for the sake of perspicuity, not of brevity, let us be permitted to call such a conductor a nerve-conductor.

Moreover, we attached to the extremity of this conductor a frog by means of a small hook fixed into its spinal cord, Fig. 2, and sometimes placed the frog opposite the machine, sometimes placed its conductor so that the frog was now near the machine, now far distant from it, and therefore now the feet, now the prepared nerves, were turned towards the machine, which had the conductor now before now behind it; nevertheless contractions were always obtained equally.

We investigated moreover whether the phenomenon would be obtained in prepared animals, from a machine situated far distant, and this employing very long nerve-conductors. Moreover, the trial was so conducted that when an iron wire, 150 feet long and more, was employed, nevertheless, when a spark was produced, contractions of the muscles occurred, even at so great a distance from the machine.

We arranged an experiment in this way. We suspended an iron wire, EEE, Fig. 3, by a series of silk threads and, as the physicists say, insulated it. One end we attached similarly by silk threads to a nail driven in the wall, F; the other we conducted far from the machine the length of the wire into various other rooms. To this, at point C, we attached another iron wire, B, to whose extremity a frog was attached; and for convenience enclosed the frog in a glass jar, A, the bottom of which was filled with some conducting material, like water, for example, or very fine lead shot, whereby a better experiment resulted. But when a spark was produced from the conductor of the machine, surprisingly the headless frog moved at so great a distance and jumped vigorously about. The same thing happened if a frog outside the glass jar was attached in the same way to conductor EE, and far more quickly if there were attached to its feet some conducting body which communicated with the earth.

Having ascertained the situation in an insulated conductor, we explored what would happen with one not insulated.

For this purpose, we attached the same iron wire to various hinges of doors of chambers of our house, which were six in number, other things having been prepared as before: smaller contractions, but some in a prepared frog, appeared, when a spark was elicited.

These observations having been made, I resolved to investigate also whether the effect of such electricity would act and diffuse itself in all directions and in a circle. Therefore, having distributed various nerve-conductors circularly around the conductor of the machine at no short distance therefrom, and having attached a prepared frog to every single one of them, and having produced a spark, at one and the same time, not infrequently, the individual frogs moved, especially when the conducting body, as in the previous experiment, was attached to the feet of individual frogs, and most strongly when it was extended as far as the ground which was easily accomplished, either by a long metal wire attached to the individual feet of frogs, or if the frogs were grasped with the fingers.

But when we discovered the use and necessity of conducting bodies attached to the feet, it filled us with the desire to undertake other experiments concerning this matter; and, when these had been performed, it was determined that conducting bodies attached to muscles, for the purpose of obtaining contractions, were either sometimes alone sufficient without nerve conductors, or at least certainly with no small influence thereon; and the more, the larger they were and the more they excelled in power of conduction; but most, if they communicated with the earth; but at least they were as powerful as those we were accustomed to attach to nerves.

These conductors we will hereafter call muscle-conductors, that they may be conveniently distinguished from those which we have called nerve-conductors.

Now, indeed, we saw no contractions ensue when a spark was produced, even when we attached its conductor to each of the muscles, if the nerve-conductor, extended far from the machine, were intercepted by any non-conducting body, as if it were carefully prepared partly from conductile metal substance, partly from non-conductile substance, like glass or resin or silk, as if the conductor B, Fig. 3 were not attached to conductor EE at point C, but were suspended in a silk sling D; a new and indubitable demonstration that electricity flows through such conductors.

But we tested the fact not only by interception but also by total

interruption of the conductor, and with the extremities of the interrupted conductor placed at a minimal distance from one another: there was no manifestation of any phenomenon at all.

But we endeavored also in some other way to interrupt the free passage of electricity through the conductor. We placed a prepared animal on an insulated surface, but did not, as before, connect its nerve-conductor either with the nerves or with the spinal cord, but placed it on the same surface in such a way that its extremity was distant from them several lines, sometimes even an inch; contractions resulted when a spark was elicited, they occurred also in limbs on the conducting surface when the nerves were placed at the same distance on an insulated surface or held elevated between the fingers, whether a short or a long nerve-conductor were employed, and whether the animal were near to or far from the machine. But they were completely lacking if the nerves and their conductor, separated from them as above, lay on a conducting surface.

And we did not fail to investigate whether this, which might be electricity, freely pervading not the surface merely but the substance of the conductors, nevertheless would excite the contractions of which we have often spoken. Therefore we wholly covered and invested, except for its extremities, the iron wire which constituted the nerve conductor with an insulating material, namely common wax, or sealing wax, or pitch. But, when a spark was produced, contractions occurred, as in the free conductor.

Moreover, these individual facts having been investigated and confirmed by a long series of experiments, it was possible not only to ascribe the phenomenon of such contractions to electricity, but also to note the conditions and as it were certain laws by which it was governed.

Muscular contractions of this sort, then, seemed to us, within certain limits, to vary directly with the strength of the spark and of the animal and especially the extent of the nerve-conductors, but inversely with the distance from the conductor of the machine. Likewise these contractions generally appeared to us greater when the animal was placed on the same table as the machine and the table was covered with oily pigment, or when the animal, removed from the table, was laid on an insulating, rather than on a conducting, substance.

I have said that it had seemed to me that a direct proportion was

preserved in the contractions, but only within certain limits. For when, for example, a certain extension of the nerve-conductor has been found which is sufficient to produce the effect, if you diminish this, the contractions are not diminished but fail; but if you increase it, the contractions grow stronger, but only until you reach a certain extension, beyond which, however much you extend the nerve-conductor, they increase barely or not at all: and the same can be said of other elements of the stated proportion.

But indeed, so great was the observed capacity of the spark derived from the conductor of the machine for exciting muscular movements, that it seemed to us that much greater contractions were promised from the electric flame which breaks out when the circuit is overloaded. But the thing turned out altogether differently; for not without our amazement, in the animal prepared in the usual manner no motions ensued.

But now, these experiments having been made in positive electricity, as they say, it seemed to remain for us to make similar tests also in negative. First, therefore, we insulated the electrical machine and its operator. He held in his hand an iron cylinder to which we approximated the frogs provided, as was necessary, with their conductors; the frogs were placed on a glass surface, in order that no neighboring bodies might give them any electricity. Then the operator of the machine, with the iron cylinder which we have mentioned, industriously elicited sparks from the neighboring objects: we then saw contractions occur in the prepared frogs, just as they occurred with sparks elicited from the conductor of the non-insulated machine.

Moreover, we tested negative electricity in another way, which was as follows. At a certain distance from the negative surface of a Leyden jar we placed the nerve-conductor C, Fig. 4; then we elicited sparks Fig. 5 from the charged surface, as the physicists say, or from that which was endued with positive electricity. The frogs moved in the same way as when positive electricity was employed; they moved also when the iron wire, which constituted the nerve conductor, was at some distance from the external surface of the jar, and when it was wholly enclosed in a long glass tube and the frog itself guarded in a glass jar, if the open end of this tube touched the aforesaid external surface of the jar. Moreover, the same contractions were obtained, whether the spark was elicited from the crook of the Leyden jar at the same time when the said jar, as they say,

was being charged, or in the same place in which it was charged, or elsewhere, and far removed from the machine.

These phenomena, moreover, occurred when the frogs were equipped not only with a nerve-conductor, but merely with a muscle-conductor: in a word everything was confirmed in this experiment of the jar, as in the former of the machine, if the prepared animal could receive no electricity from the external surface of the jar, or from neighboring bodies, or from any other possible source.

But we wished also in another way to test electric surfaces negatively, and by eliciting sparks from them, to investigate such contractions; therefore I placed a prepared frog on the upper surface of the square to which the electricity of the machine was constantly flowing, and elicited a spark from the inferior surface, both when the machine was quiet and when it was rotating. Rarely, though sometimes, when it was quiet, but then only from quiet of the machine; but never when rotating, did the customary contractions of the muscles fail to occur.

These experiments having been made by means of the electric machine, we also called to the experiment electricity of an electrophor, that we might omit no kind of electricity exhibiting a spark. Therefore we elicited a spark from the shield of an electrophor, and the customary phenomenon of muscular contractions presented itself, not at as great distances as when the spark was elicited from the conductor of a machine, but at very short distances; moreover the contractions themselves were very slight. Although, indeed, after so many experiments, there seemed to us scarcely any doubt about the effects of electricity, and scarcely any about the cause of the phenomenon, nevertheless nothing occurred to us more suitable for confirming the thing more and more than to apply the most delicate electrometers to animal conductors.

To these, therefore, we adapted a small electrometer constructed after the manner of the justly celebrated Volta, whose straws, that they might be more suitable for the experiment we covered on one side with very thin silver-foil: when the experiment was performed, when the insulated conductors of the machine were in rotation, the straws not infrequently were separated one from another, but they often came together again on the passage of the spark; but when they were free, not least in rotation of the machine, the straws mutually receded one from another, and on extortion of the spark pro-

duced little leaps and vibrations which seemed to indicate some passage of electricity through the conductors of the animal at the time when contractions are excited at the extortion of a spark.

Now indeed, that the thing might be put beyond all doubt, we have striven in various ways to cut off all access for electric fluid of the machine in any way acting both on the animal and on his conductors. First, therefore, I enclosed the animal in a glass jar, then in one with a perforated wall, near which was an electrical machine, and into this foramen, which pierced the entire thickness of the wall, I inserted a glass tube so that a nerve-conductor, passing through the inserted tube, so fitted the orifice of the jar, artificially closed with glue, that it passed from the opposite surface of the wall and hung down into the next room. When a spark was elicited from the conductor of the machine, muscular motions ensued.

Conversely also I placed the animal and his conductor, with the conductor in the jar where first the animal was, and the animal where first the conductor hung; then I placed everything in the same arrangement as before, and elicited a spark, and the same movements ensued.

But although by this kind of experiment every pathway for electric fluid of the machine seemed cut off, nevertheless I devised and constructed a little machine, Fig. 6, which was far simpler and more convenient than the apparatus hitherto described, and which could easily be placed at various distances from the (large) machine, and within which not only the animal, but also both the nerve-conductor and the muscle-conductor, could easily be enclosed and concealed.

Now the little machine is of this nature. It is composed of two glass jars, of which one rests upon the other. In the upper jar is the nerve-conductor, which, for the sake of convenience, can be made of small lead shot, which can serve as muscle-conductor, since the animal, standing in them with his feet, has them as it were attached to his muscles.

The animal in this situation both is easily restrained and has communication with the conductor of the superior jar through his spinal cord by means of an iron wire which both is attached to the cork stopper of the same jar, and projects in its cavity, and is surrounded and covered with lead shot.

One must beware of this kind of stopper, lest, when the upper jar is inverted, that it may be superimposed on the other, the lead

shot fall out; and lest the same jar easily become separated from the lower, and the electric fluid find a way for itself through the cracks which may easily remain between the mouths of both jars, their lips are attached and stuck together by a certain special glue made of wax and turpentine, firmly but nevertheless so that the jars can be separated and joined again in accordance with desire and opportunity.

Now when this little machine is placed on the table on which is the electric machine, at a certain distance from the conductor of the same, and a spark is produced, movements are seen, not merely the same but more vigorous than when the animal and his conductors are exposed to the open air; and the laws, which were indicated above for the muscular movements were maintained in the given proportion. These things having been observed, I would readily have forsaken my first opinion, whereby I considered the electricity of the conductor of the machine, in whatever way or manner excited in the extortion of the spark as the active origin and cause of these muscular movements, unless I had been recalled to the same opinion both by experiments previously performed and by a rising suspicion that the phenomenon was chiefly to be ascribed to electricity of the interior surface of the glass acting on the animal and its conductors at the time of discharge of the spark; in which suspicion, indeed, I was wholly confirmed not only by other experiments subsequently instituted, but also in the first by the movements of the electrometer located in the same little machine. For the very light shot and the wires, of which the electrometer was composed, changed position immediately when the machine was turned, and were restored again, when sparks were elicited, into their former position and contact.

Now, indeed, these and other things having been performed and ascertained, that seemed at last to remain which promised the greatest usefulness in our experiments, that we should institute them also in living animals.

This therefore we did with the crural nerve, not dissected inside the abdomen, lest the animals might easily die, but exposed in the thigh and separated from adjacent structures and drawn outside the muscles, and the conductor applied to it; contractions ensued on the passage of the spark in the corresponding leg alone, only less, as it seemed to us, than in the dead animal.

But since in our individual experiments, hitherto described, the

animal and the machines and conductor communicated one with another through the intervening atmosphere, we wished also to ascertain what would happen if this communication first were interrupted and then finally restored.

First I accomplished it as follows: arranged under a glass jar, as in Fig. 6, I placed a little machine along with a prepared animal and its conductors at a short distance from an electric machine; then I elicited a spark, and motions occurred according to custom.

I then placed this same jar, along with an enclosed little machine, under another much larger, and this under another still larger: again, when a spark was elicited, similar motions ensued, though feebler the greater the number of recipients and the thickness of their walls.

After this, I cut off all communication of air between the animal and the electric machine. Namely, I placed the little machine, in which was the animal, in the receiver of a pneumatic machine, in a place moderately distant from the conductor of an electric machine; I perforated the upper jar of the little machine, in order that the air might be evacuated from it by repeated exhaustions: then, sometimes when the air was exhausted, and sometimes when it was not, I elicited a spark: contractions occurred in each case, nor, as it seemed, were they appreciably dissimilar.

Now then, electricity acting through a spark having been tested in such various ways, we investigated with diligence and labor whether it exercised its control also by other effects and means on muscular motion. Sometimes it was possible to observe muscular contractions, if the nerve-conductor, B, Fig. 3, was placed as near as possible to the conductor of the electric machine, then the shield of the electrophore raised from the resinous surface, or if the same shield were transferred close to the same conductor, when the electrophore was far distant from the same conductor, without any spark being elicited.

These experiments were all performed in animals which are called cold-blooded. These things having been tested and discovered, nothing was more in my desires than to perform the same or similar experiments in warm-blooded animals, as for example in hens and in sheep. The experiment having been tried, the result was the same in the latter as in the former. But there was need of a different preparation in the latter; for it was necessary first to expose the crural nerve, not inside the abdomen, but externally in the thigh

itself, and to separate it from other parts and bring it to the surface, then apply the conductor to it, and then elicit the spark from the conductor of the machine, with the leg either attached to the living animal or resected from it as soon as possible; for otherwise, if the customary manner of preparing frogs were employed, the phenomenon was wholly lacking, perhaps because the power of self-contraction of the muscles was lacking beforehand, which that long and complex preparation can release.

But indeed, in this kind of experiments, whether in warm or in cold animals, there are some things at the end, and these peculiar and, as I think, not unimportant to note, which never presented themselves to us. One was that prepared animals were more suitable for these phenomena, the more advanced they were in age, and also the whiter their muscles were and the more they were deficient in blood, and therefore perhaps the muscular contractions were prompter and easier and could be excited much longer in cold than in warm animals; for the former, in comparison with the latter, have more dilute blood, more difficult to coagulate, and therefore flowing much more easily from the muscles: another was that prepared animals, in whom these electric experiments were undertaken, decay and rot much more quickly than those who have suffered no electric force: finally that even if the phenomena which we have described thus far as occurring did so in the way we stated, animals prepared for experiment fail differently. For if the conductors are applied not to the dissected spinal cord or to the nerves, as we have been accustomed, but are applied or even attached to the brain or the muscles, or if nerve conductors are extended or prolonged, or if nerves according to custom are in the least detached from surrounding parts, the contractions are either none or very slight. Many accepted things certainly, which we have discovered from these experiments, we refer chiefly to this method of preparing and separating nerves.

Part Two

THE EFFECTS OF ATMOSPHERIC ELECTRICITY ON MUSCULAR MOTION

Having discovered the effects of artificial electricity on muscular contractions which we have thus far explained, there was nothing we would sooner do than to investigate whether atmospheric electricity, as it is called, would afford the same phenomena, or not: whether, for example, by employing the same devices, the passage of lightning, as of sparks, would excite muscular contractions.

Therefore we erected, in the fresh air, in a lofty part of the house, a long and suitable conductor, namely an iron wire, and insulated it, Fig. 7, and to it, when a storm arose in the sky, attached by their nerves either prepared frogs, or prepared legs of warm animals, as in Fig. 20, 21, Tab. IV. Also we attached another conductor, namely another iron wire, to the feet of the same, and this as long as possible, that it might extend as far as the waters of the well indicated in the figure. Moreover, the thing went according to our desire, just as in artificial electricity; for as often as the lightning broke out, at the same moment of time all the muscles fell into violent and multiple contractions, so that, just as the splendor and flash of the lightning are wont, so the muscular motions and contractions of those animals preceded the thunders, and, as it were, warned of them; nay, indeed, so great was the concurrence of the phenomena that the contractions occurred both when no muscle conductor was also added, and when the nerve conductor was not insulated, nay it was even possible to observe them beyond hope and expectation when the conductor was placed on lower ground, Fig. 8, particularly if the lightnings either were very great, or burst from clouds nearer the place of experimentation, or if anyone held the iron wire F in his hands at the same time when the thunderbolts fell.

Moreover, the phenomenon occurred whether the animal was exposed in the fresh air, or, for the sake of convenience, had been enclosed in a suitable jar, as in Fig. 7, or kept within the room. It occurred also although the nerve-conductor was at some distance from the nerves themselves, particularly with lightnings either more violent or nearer, as we said occurred in artificial electricity when

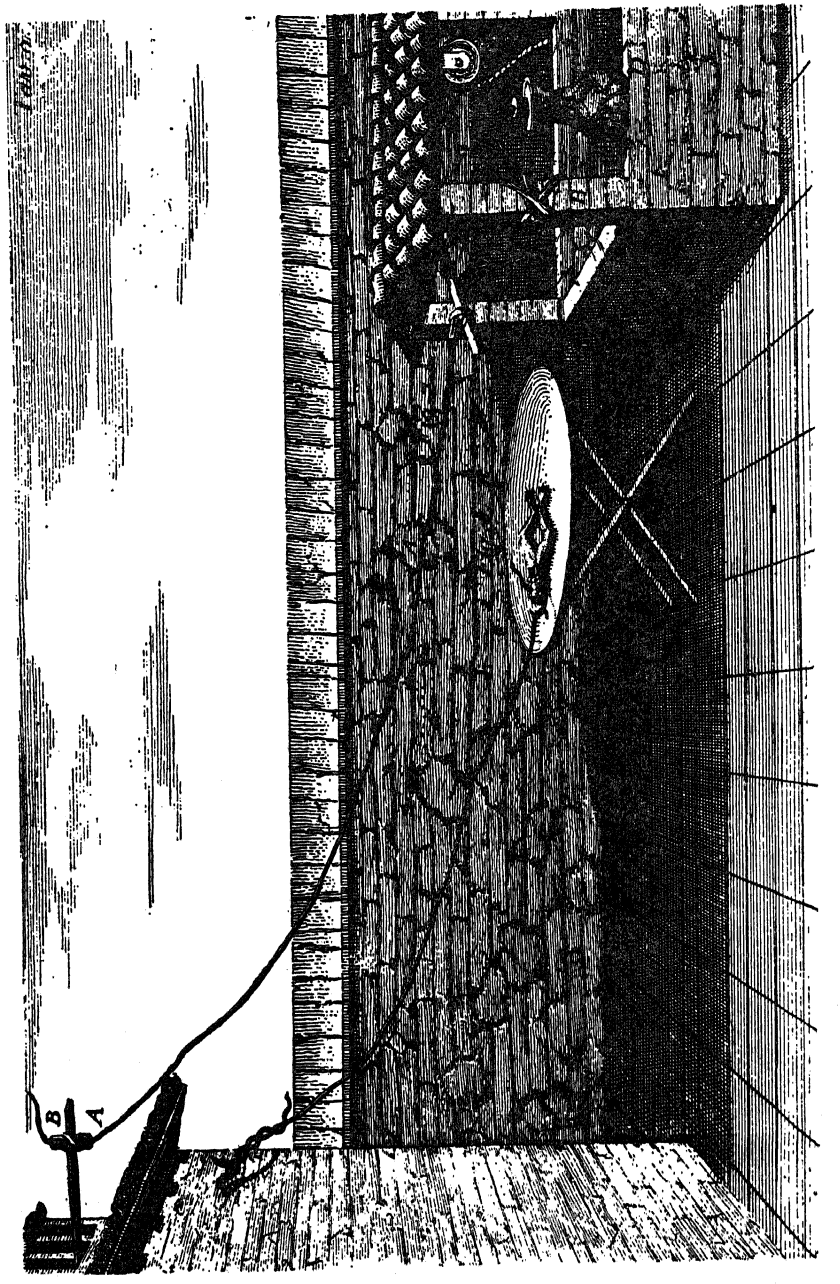
the sparks were either stronger or extorted nearer the animal. Finally that worthy of notice occurred, that not merely by one contraction of muscles was the whole thing manifested in the lightning as in the spark, but by many, succeeding one another as it were in one mutual moment of time, of which the number of thunders seemed to correspond to the number which a thunderbolt is wont to produce.

Now, indeed, such contractions were produced not merely with lightning but in a stormy sky, with clouds passing over the almost removed conductors they arose for the most part spontaneously; and when this had happened, both the electrometers gave no slight signs of electricity, and not rarely sparks could be elicited from the conductors raised high in air, differently from when contractions were obtained with lightning-flashes; for then more often no sparks were elicited, and more delicate electrometers hardly aroused any suspicion of electricity.

Now experiments of this kind were undertaken not only in dead but also in living animals, and in both the phenomenon appeared, and none of those things was omitted which we have discovered in artificial electricity, but all for the most part occurred in the same way. At first sight, indeed, it seemed that this considerable difference existed, that the prepared frogs which, with a suitable conductor, were enclosed in a little glass machine, Fig. 6, Tab. I, separated from the conductor of the electric machine by an interval, on the passage of the spark were violently disturbed, as we said, but, when lightning burst from the clouds, were wholly quiescent; perhaps either because, if any electricity were conveyed from the electric cloud to the little machine by means of the conductor, it was very slight, and occupied a very small part of its surface, so that it was not adequate for inducing contractions, or perhaps because none was carried to the same little machine; just as for the most part, for the same reason the same contractions are lacking on the passage of the spark, if the little machine is placed, not near the electric machine, but near that end of the electric conductor, EE Fig. 3, Tab. I, which is far distant from the same machine.

Upon diligent investigation of the circumstance, on this account, the manner of action appears similar between artificial and atmospheric electricity; perhaps for obtaining these contractions within the little glass machine, it is necessary that the electric atmosphere, either wholly or for the most part, should surround the same ma-

TABLE II



chine; but, from what has hitherto been stated, it seems to be far removed from the position of the little machine and from the experiment.

But not merely the phenomenon having been explored, but its laws also having been subjected to examination, we have ascertained that the same are maintained in no dissimilar manner in atmospheric, as are maintained in artificial, electricity.

Now, indeed, the effects of storm electricity, as they say, having been investigated, not of thunder and lighting alone, it occurred to us also to test what sheet lightning and northern lights would produce in animals prepared in the customary way. Therefore we adapted our animals to an atmospheric conductor not only during lightning but during northern lights. But no contractions were ever then produced, perhaps because either such coruscations do not depend on electricity or, if they do, either in too remote a place, or they occur for some very different reason than thunderbolts. But these are questions for the physicists.

Part Three

THE EFFECTS OF ANIMAL ELECTRICITY ON MUSCULAR MOTION

The effects of stormy atmospheric electricity having been tested, my heart burned with desire to test also the power of peaceful, everyday electricity.

Wherefore, since I had sometimes seen prepared frogs placed in iron gratings which surrounded a certain hanging garden of my house, equipped also with bronze hooks in their spinal cord, fall into the customary contractions, not only when the sky was lighting, but also sometimes when it was quiet and serene, I thought these contractions derived their origin from the changes which sometimes occur in atmospheric electricity. Hence, not without hope, I began diligently to investigate the effects of these changes on these muscular motions in various ways. Wherefore at different hours, and for many days, I inspected animals, appropriately adjusted therefor; but there was scarcely any motion in their muscles. Finally, weary with vain expectation I began to press the bronze hooks, whereby their spinal cords were fixed, against the iron gratings, to see whether by this kind of device they excited muscular contractions, and in various states of the atmosphere, and of electricity whatever variety and mutation they presented; not infrequently, indeed, I observed contractions, but bearing no relation to varied state of atmosphere or of electricity.

Nevertheless, since I had not inspected these contractions except in the fresh air, for I had not yet experimented in other places, I was on the point of seeking such contractions from electricity of the atmosphere, which had crept into the animal and accumulated in him and gone out rapidly from him in contact of the hook with the iron grating; for it is easy in experimentation to be deceived, and to think one has seen and discovered what we desire to see and discover.

But when I had transported the animal into a closed chamber and placed him on an iron surface, and had begun to press against it the hook fixed in his spinal cord, behold the same contractions and the same motions! Likewise continuously, I tried using other metals,

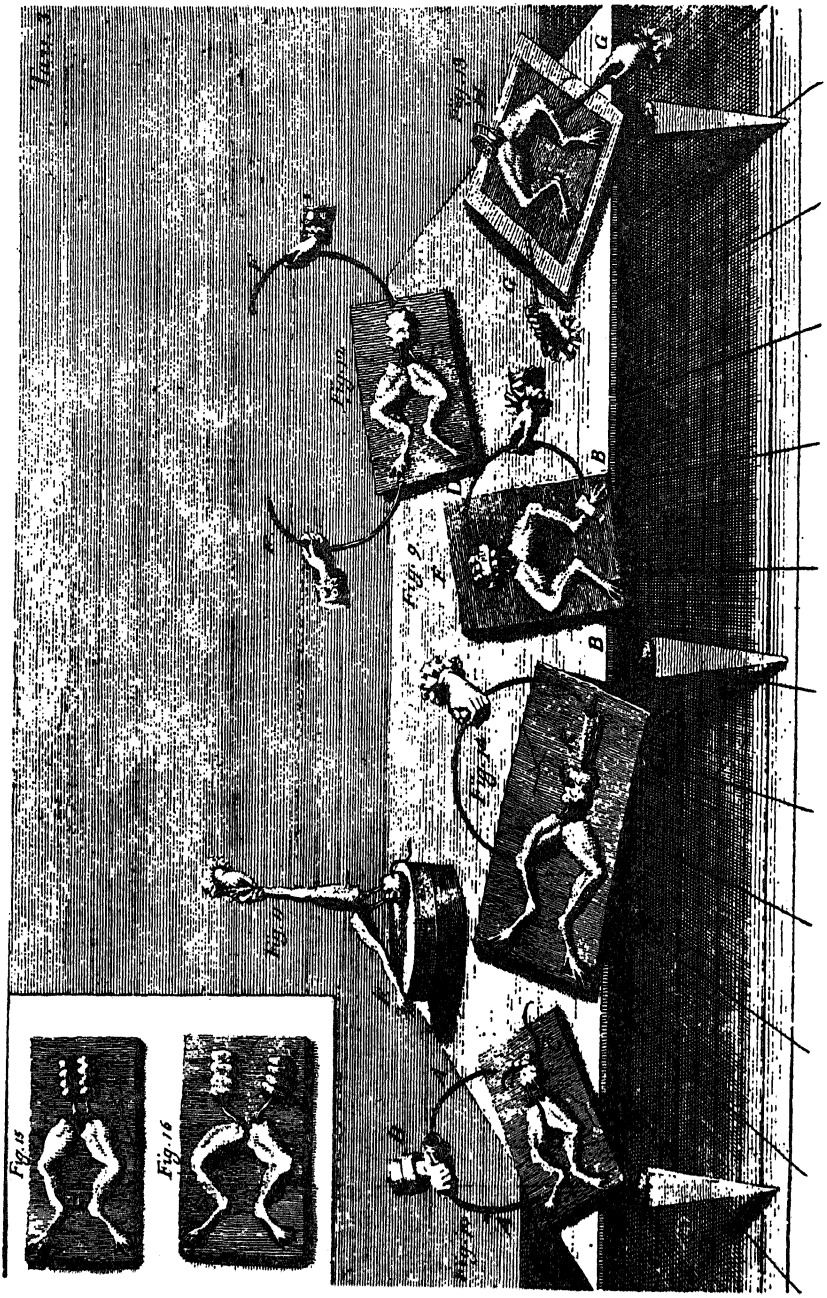
in other places, other hours and days; and the same result; except that the contractions were different in accordance with the diversity of metals, namely more violent in some, and more sluggish in others. Then it continually occurred to me to employ for the same experiment other bodies, but those which transmit little or no electricity, glass for example, gum, resin, stone, wood, and those which are dry; nothing similar occurred, it was not possible to observe any muscular motions or contractions. Results of this sort both brought us no slight amazement and began to arouse some suspicion about inherent animal electricity itself. Moreover both were increased by the circuit of very thin nervous fluid which by chance we observed to be produced from the nerves to the muscles, when the phenomenon occurred, and which resembled the electric circuit which is discharged in the Leyden jar.

For, while I myself held in one hand a prepared frog on a hook fixed in his spinal cord, and manipulated him so that with his feet he rested on a silver box, with the other hand I touched with some metal object the surface of the same box on which the frog rested with his feet, or his sides, and beyond expectation I saw the frog fall into no slight contractions, and indeed as often as I employed the same kind of device.

Having made these observations I asked Rialpus, a Spaniard, a very learned man, formerly a Fellow of the Society of Jesus, who was then rusticating with me in the villa of the most excellent and noble gentleman, Jacob Zambeccari, I asked him, I say, that as in other experiments he was very kindly accustomed, so in this he would afford me a helpful and assisting hand and hold the frog, as I myself did formerly, while I myself touched the box again, both for convenience and in order that I might change a little my mode of experimentation. But, contrary to expectation, the contractions failed; I continued the experiment as before, and performed it alone; and immediately they returned.

This moved me to hold the animal myself with one hand, as before, and with the other the hand of Rialpus and to ask him that he himself with his other hand should either touch or strike the box in which the appearance of an electric circuit was produced: immediately the same phenomenon of the contractions occurred, not without our pleasure and wonder, because it was again lacking, if we removed our hand, and appeared again if the hand were replaced.

TABLE III



But although it seemed that these things could all be demonstrated as an electric extension of the nerve fluid through the human chain, nevertheless, in order that we might more and more confirm a thing so great and concealing so much novelty, we wished that not by the clasp of hands alone but through some intermediate body, either insulating, like a glass cylinder, or conducting, like a metal cylinder, Rialpus and I should constitute the chain; but, the experiment having been made, we beheld, not without pleasure, that the phenomenon occurred when a metal cylinder was employed, but failed altogether when glass was employed or when it was touched in vain or when the box was struck with heavier blows of the conducting body; so that on this account we considered it as ascertained that electricity of this sort excites contractions, in whatever way it may ultimately do this.

But, in order that I might put the thing more in the open, it was most opportune for me to place the frog on an insulating surface, namely glass or resin; then to employ either the whole arc or the conducting arc or in part the non-conducting arc, one end of it with a hook fixed to the spine; the other end applied either to the muscles of the leg or to the feet. But when the experiment had been done, we saw the contractions performed when the conducting arc was employed, Fig. 9, but fail completely when we used the arc partly conducting and partly insulating, as in Fig. 10. The conducting arc was of iron wire, but the hook of brass wire.

These things having been observed, it seemed to us that the contractions which we have said occurred in frogs placed on a metal surface when a hook in the spinal cord was pressed towards the same plane, ought to be repeated by a similar arc whose ends should be borne in some way by a metallic plane, and hence it should result that contractions should not be excited in frogs placed on any insulating surface, provided the same devices were employed altogether.

This opinion of ours, if I judge correctly, was clearly confirmed by a not inopportune phenomenon casually observed: for if a frog is held in the fingers so suspended by one leg that a hook fixed in the spinal cord touches a silver surface and the other leg freely falls into the same plane, Fig. 11, Tab. III, as soon as this same leg touches the surface itself immediately the muscles contract, wherefore the the leg rises and is drawn up, but soon relaxes of its own accord and

again falls to the surface, and as soon as it comes in contact with it, is again elevated for the same reason, and so it continues thereafter to rise and fall alternately, so that, like an electric pendulum, the same leg seems to imitate the other, not without admiration and pleasure on the part of the beholder.

It is easy to see how conveniently and aptly this phenomenon can be repeated, taking turns on the supporting surface with each arc most fit for the aforesaid circuit, while it calls the free leg to the same surface, but to the circuit wholly different, at the same time that the other leg recedes from it. These are neither doubtful nor obscure signs of the metallic surface bearing alternate arcs.

But it can hardly be said what is the capacity and aptitude of this surface for exciting muscular contractions, that namely whereby contractions may be obtained, both great and frequent, sometimes even constant for a long time, not only if the hook fixed in the spinal cord is either pressed against the metallic surface itself, or rubbed against it, but also at the same time that the hook itself touches the same surface, and if it afterwards touches it, some of its contacts with the surface are changed, as if you lightly strike either the surface on which the animal is, or the bodies on which the same plane rests. But concerning the kind of arc which the metallic plane carries, so much for the present.

But before our discussion leaves the use and capacities of the arc, we do not wish to omit this about its capacity and I almost said necessity for demonstrating this kind of muscular contractions as conveniently as possible, that the same are obtained, and often, more clearly and promptly not merely with one but with two arcs also, disposed and employed in such a way that one extremity of one arc is applied to muscles, one extremity of the other arc to nerves, and the two remaining extremities are brought to mutual contact, or if necessary are touched alternately, Fig. 12. In which this peculiarity is observed: that electricity of this sort, incuding contractions, is not to any appreciable degree diffused or dissipated either by contact of the hands with either arc or by repeated contacts of the arcs with parts of the animal.

But that is also peculiar and worthy of notice when the strength, particularly of prepared animals, languishes, around the arc-conductors or conducting surfaces, it befell us very often to observe that various and multiple metal substances are very effective both

for obtaining and for increasing muscular contractions, and indeed far more than one and the same metallic substance. So, for example, if the whole arc were iron, or the hook iron and the conducting surface likewise iron, very often the contractions will either fail or will be very scanty. But if one of them were iron, for example, and the other bronze, much more if it were silver (for silver, in comparison with other metals, seems to us preferable for conducting animal electricity), contractions will occur continuously and far greater and far longer. The same thing happens when one surface of an insulating plane is separated in two places, and equally covered with dissimilar metal foil, as for example, if, in one place, you employ tinfoil, in another, brass-foil, contractions will occur as much greater as possible than if each place were covered, or, as they say, armatured, with one and the same metal, even silver-foil.

But, indeed, this sort of a circuit of nervous fluid, like electric fire, having been detected, this seemed the twofold consequence, that both this or a dissimilar, or rather contrary electricity produces this phenomenon, as it were duplex, either in a Leyden jar or that electricity in the charged arc through which it discharges its electric fluid like a circle; for the movement of electricity cannot be held as a circuit by the demonstrating physicists, except in restoration of equilibrium, and either solely or chiefly between contrary electricities. Moreover, in one and the same metal there lay concealed those opposite by nature which seemed contrary to observations: therefore it remained that each resided in the animal. Nor did I have any suspicion in experimenting that any kind of electricity could have been ascribed to animals, I attached the bronze arc covered with silver leaf to the glass cylinder, which I held in my hands, when I applied the arc itself to animals; when this precaution was employed, contractions nevertheless occurred.

These experiments having been performed in the fresh air, the thought entered my mind, what would happen to the electricity of an animal, if I should submerge the animal himself under water: this therefore I did, and according to custom applied to him the extremities of an arc, one with an iron hook to the spinal cord, the other to the feet: contractions occurred just as in the fresh air.

But this peculiarity presented itself to me in this experiment, that if either with the same arc or with any other conducting body I merely touched the hook in the spinal cord of the animal lying

under the water, immediately contractions occurred; which I myself referred to the water transmitting the arc in turn. Therefore I immersed the animal not in water as before, but in oil, to see whether contractions occurred just as under water, or were wholly lacking. Then I applied the same conducting body to the hook in the spinal cord as before; the contractions wholly failed, the oil being wholly unequal to taking turns with the conducting arc, a thing which confirmed me not a little in my preconceived opinion.

These things having been ascertained and noted, it seemed to me that I could best proceed without any delay to find that double and opposite electricity in the prepared animal itself, and that either one has its location in muscle, the other in nerve, or both in either, as the physicists affirm in the Tourmaline Stone. With all zeal, therefore, I began to seek and investigate this location; and first what kind of electricity nerves present. Therefore to the spinal cord of one of the headless frogs, which I had recently prepared in as large number as possible, having been killed for experiment, I closely applied a cylinder, now glass, now made of sealing-wax; but never at first application did muscular movements occur; but they were observed when another was employed, generally at a distance of four or more lines, provided the vertebral tube and had been covered with tin-foil, as we shall say below. In place of the glass cylinder, we often used the disc of the electric machine, driven by numerous revolutions, in order that we might ascertain whether the greater supply of electricity which was collected in the disc would excite those muscular contractions which the cylinder could not, but the experiment had the same result; not the slightest motions occurred in the muscles.

Therefore the nerve-electricity in the experiments will be positive since the physicists demonstrate that only between opposite electricities can known effects and motions be obtained.

Then we turned our mind to investigating the electricity of muscles: therefore we undertook the same experiments in these as in the former; but it was not possible to observe any movements in the muscles when either positive or negative electricity was employed.

Therefore we returned again to nerve-electricity, which was conforming to our experiments; and in exploring the same with sealing-wax we used the same devices, whereby we were burned while we tested it with the extortion of a spark. Nearly the same phenomena

of contractions appeared, except that those were much less which were produced with sealing-wax, than those with a spark, corresponding to the strength of the electricity. The utility of the conductors was the same also, and their laws the same, and clearly the muscular motions appeared in the same way.

But since nothing seemed to be more suitable for discovering so obscure and difficult a thing, namely the location of each electricity, than to increase and apply the electricity, I therefore began to meditate sedulously concerning the method of accomplishing this, and, following analogy, this method presented itself first, that I should cover the nerves in which electricity seemed to prevail, and whose nature we had ascertained, with some metal foil, preferably of tin, no less than the physicists are accustomed to accomplish in their magic square and Leyden jar, Fig. 9, Tab. III.

With a device of this sort, it is amazing how much stronger muscular contractions grow, so much, indeed, that even without an arc, but with a single contact of a body of any nature, either conducting or even non-conducting, with armatured nerves, contractions appeared, provided only that they had been recently prepared and that their strength was maintained; so that the arc, and the strength and utility of other devices, proved far greater; that finally contractions became more violent and longer and fairly constant in animals vigorous before section, even if either the arc is removed or the body whereby the armatured nerves are touched.

What more? Such was the power and capacity of this device in increasing and augmenting the strength of this kind of electricity, that a circuit which barely, and not even barely, appeared when hooks and an arc were employed, emerged happily and promptly in a tadpole, not only through two men, but even sometimes through three and more, constituting, as it were, an electric chain, and muscular contractions were excited, especially in summer time, in older animals with pale muscles, and when a storm threatens in heaven. Moreover, in prepared animals, if the denuded cerebrum and denuded spinal cord are covered in some part with the same metal foil, when the arc was employed according to custom, contractions both vigorous and prompt then began to appear, which, however, without this kind of device, I had previously striven in vain to excite with the arc or in any other way.

Moreover, the effect of tin-foil applied to nerves having been

found so great in augmenting animal electricity, I decided to try also what the same foil would do in muscles; but contractions were not seen to assume much increase, nay even, when the thing was tested more often, we finally noticed this, that some increase of contractions occurred if only with these parts, the muscles also were covered with the same layer of tin, and the arc applied to the armatured places.

Not only were the contractions extended by metal foil applied to the denuded spinal cord, but also by having the vertebral column covered with the same, applied not only externally in the back to its muscles, but internally in the abdomen, and especially in the region where the nerves emerge. And it did not matter if at first you had covered those parts and the nerves with much foil or with little, for it was sufficient if you should cover it with any, and should apply one extremity of the arc to it and the other to the muscles. But in place of the metal foil we employed with equal utility an electric amalgam, or sprinkled the nerve with its powder, or applied to the nerve a pastille made of the same powder with oil. But if we used any other metallic powder, iron, for example, or brass, even in the same way, there was scarcely any increase of muscular motions.

Now, indeed, having found the reason why this sort of electricity assumed so much increase, we then sought its location with more eagerness and confidence. Hence now a nerve, now a muscle being covered with the same foil, we drew out from the animal first the muscle with the corresponding nerve and placed it on an insulating surface, and applied an arc to it according to custom; we likewise did the same both in an intact muscle, and in a divided muscle, namely we enclosed one part of it in metal foil, then applied one extremity of an arc to the armatured part of the muscle, the other extremity to the bare muscle; but barely, and not even barely, were we permitted by these attempts to arrive at any of those things which we were seeking.

This only we noticed: in the muscle with its nerve brought outside the animal, far fewer contractions took place than if they had remained in their natural positions; moreover, in the intact muscle, though they were scanty hitherto, that they became much slighter, nay, hardly occurred at all; but nevertheless not rarely some, if one extremity of an arc were applied to an armatured place on a muscle, the other to an adjacent and bare surface of the same muscle; but

when the experiment was tried otherwise, none occurred: also that it likewise happened, but with much more difficulty, in the internal substance of a muscle; but that contractions arise far more easily and promptly if the arc were applied in the same way to an armatured nerve; nay, if the small extremity of an arc, in place of any other conducting body, were called into use, and partly an edge of metal foil and partly a bare nerve were touched by it.

These tests we made concerning the investigated location of animal electricity, by which it is established that the fact, which could not be sufficiently illustrated by experiments, must be largely committed to conjecture.

Now let us pursue some matters which, as we diligently investigated this kind of electricity, presented themselves to us as worthy of attention; among which this was foremost: that that excited by common electricity always acts, as we have warned, at a distance of several lines, but by itself alone not even at the shortest distance, but always requires actual contact in order that it may exercise its effect. But we see that greater contractions can often be obtained more certainly and promptly, if the extremity of the arc is applied to the very edge of a metallic layer covering nerves or muscles, than if to the flat surface thereof; likewise if to the extremity of a hook than if to the other parts thereof: whereby it appears that animal electricity does not exactly imitate common, ordinary electricity, whose peculiar nature it is to choose and follow angles and points.

These facts, so obvious and clear, to my judgment, about electricity in muscles and nerves, gave us additional courage that we should more studiously investigate more and more data about the same. Hence first, in place of the aforesaid metal foil, we covered both nerves and muscles in some part with insulating material, namely silk-web, oil in which pitch was dissolved and wholly imbued, to see whether contractions would be wholly lacking, when the arc was employed, or not: they failed completely. But it was necessary to employ the silk web, and to prepare it in such a way that it was adequate to insulate contractions, because easily, in the conducting animals, it became imbued and moistened with lymph, and not oil alone, because it so yielded place to the extremity of the arc that it came into altogether absolute contact with the underlying part.

Then we investigated whether this kind of electricity followed the

theory and nature of common electricity in this, that it made itself an easier way through certain conducting bodies, and through others a more difficult one.

But we see it follows almost exactly; and first, as the former, so the latter makes its way more happily through metals than through wood, but among metals most happily through gold and silver, more feebly through lead and iron, particularly if the latter is corroded with rust, so that if either an arc, or surfaces substituting for an arc, were plated, and particularly with silver, or, which is more convenient, covered with very thin silver-foil, the phenomena of contractions would appear both far more clearly and far more promptly than if the same had been constructed either of lead, for example, or even of iron.

But having investigated the power of conduction in solid bodies, we also explored the same in fluids, and the thing came out the same way; namely we found that this kind of electricity makes its way very readily through aqueous fluids, but is wholly blocked and retarded by oily fluids. In order that we might investigate this, we used small glass tubes, which we closed at one end with some material through which we passed a metal wire, namely silver or brass, and passed it so covered with tin-foil that by one part it would be free inside the cavity of the tube, and by the other would be prolonged far from it; but the tubes we filled with material suitable for the experiment, namely sometimes aqueous, sometimes oily, and by a similar device closed them at the other extremity, and equipped them in the same way with a similar metallic wire. Things being thus arranged, we used tubes of this sort so that they constituted either a whole arc, by bending the metallic wires, or part of an arc whose extremities, according to custom, were applied to an animal. When these tubes were employed, Fig. 14 Tab. III, no contractions occurred when they had been filled with oil, but only when they had been filled with water.

Now, nothing seemed to conduce more to deriving utility from these experiments than to investigate diligently also the faculty of insulation or of conduction in different parts of animals. The experiment having been made we have ascertained that all parts of dissected animals freely conduct and transmit conveniently this kind of electricity, perhaps on account of the moisture by which they are washed, either by nature or in sections and preparations;

for if various and recently dissected parts, such as muscle fibers, cartilages, nerves, bones, membranes; or fluids, as blood, lymph, serum, urine, received on a glass plate, or enclosed in the aforesaid tubes, are applied to preparations, and especially to armatured nerves, and then to the same parts one end of an arc is adjusted, and muscles are touched by the other, then contractions as surely occur as if the same arc-end had been applied to the nerves themselves. Moreover, we ascertained that the same thing happens if things are arranged as it were in the opposite way, and the experiment undertaken with the aforesaid parts, not nerves but muscles being fitted, but with one extremity of the arc adjusted to the same parts, and the other to the armatured nerves. But we see the thing is otherwise, particularly if those solid parts have not recently been dissected, but are dry by nature or by art. And indeed the phenomenon does not appear solely in those parts artificially arranged, but also in the same either located hitherto by nature in the animal, or by reason certainly deviating little from the natural; for if one extremity of an arc is applied to insulated nerves, particularly armatured, and the other touches any other part of the body, intactly and naturally constituted, which ultimately responds to muscles supplied by the same nerves, the phenomenon almost always occurs, just as if the same extremity of the arc were applied to the muscles themselves; but not without some surprise we saw the same thing occur, both with nerves and with muscles first cut and separated from the circuit, then joined again in some artificial way. For if frogs are prepared in the customary way, and their vertebral column covered with tin-foil and their limbs divided with a knife so that each limb remains joined only to its own corresponding nerve, and then one limb removed far from the other, Fig. 15, Tab. III, then one extremity of an arc applied to the same vertebral column, the other to muscles, or only to the foot of one leg, then only the muscles of the same leg will move and contract.

But if the same limbs are carefully joined again so that they come into mutual contact, and the arc applied in the same way and to the same leg, then all the muscles of each leg will move and contract. Moreover exactly the same thing happens when the vertebral column is split, with the spinal cord along its axis, and then the parts of the divided column spread apart with their corresponding nerves, but the limbs joined as they are by nature; the muscles of only one

limb fall into contractions when one extremity of an arc is applied to only one of the aforesaid parts of the vertebral column, the other to the corresponding leg; but the muscles of each leg fall into contractions when the parts of the divided spinal cord are again joined artificially, and the arc applied by one of its extremities to either limb, and the other to the same conjoined parts: finally exactly the same phenomena occur either with the intact trunk of a prepared animal, or with the trunk divided through the middle sagitally from top to bottom, provided the divided parts are artificially and carefully joined and brought into mutual contact, Fig. 16, Tab. III.

It does not seem that these phenomena can be sufficiently fitly explained except by the interposed moisture of the parts affording access and passage to the outflowing animal electricity. Will they be able to throw any light on the hitherto obscure cause and reason for the coöperation of nerves? Would that wiser physiologists would investigate this sometime! But perhaps nothing is more suitable for demonstrating powers of coöperation than if the crural nerves are prepared according to custom, and the spinal cord and head remain intact, and the upper limbs intact in nature and position.

For then, if either the crural nerve or the vertebral column is armatured, and the arc applied partly to the armatured part of the crural nerve and partly to the corresponding limb, not only the lower limbs contract, but the upper ones move also, the eyelids move, and other parts of the head move, so that on this account, the electric fluid, aroused by nervous contact of the arc, for the most part flows from the indicated place of the nerves to the muscles, but partly also through the nerves seeks the higher regions and is carried as far as the brain, and seems to carry such effect into it that thence, for whatever reason, motions of other muscles are excited.

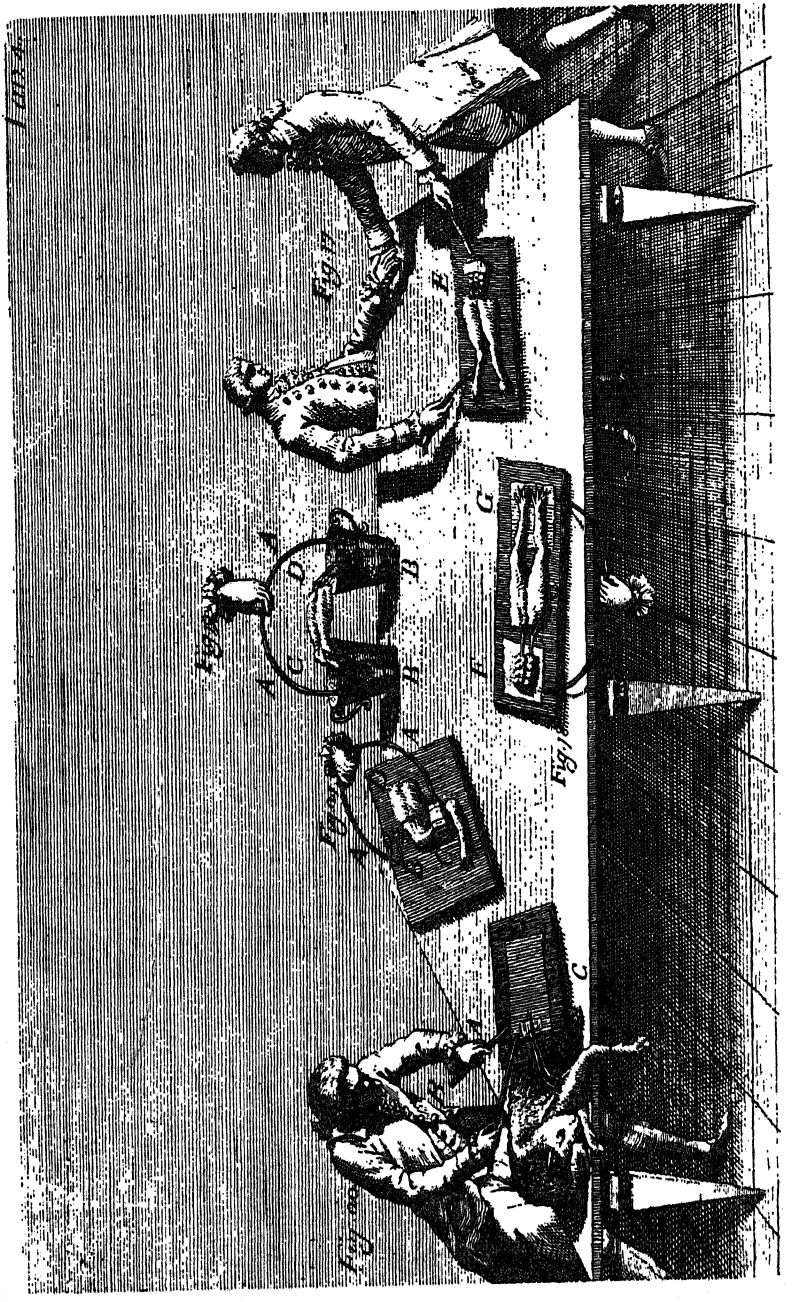
But truly, although it would hardly seem permissible to doubt about animal electricity, confirmed both by experiments and by factors of analogy and reason, or about its presence and motion in nerves and in muscles, or about its exit either from the former, or from the latter, or from both, and about its free excursion through applied conducting bodies; and although we realize that fortune and industry have granted us no small fruit of our experiments, in that to us first perhaps they have revealed whereby to place the said electricity clearly before the eyes and to derive it from the animal and, as it were, to handle it with our hands; nevertheless, to

confess the truth, the thing is not yet completely demonstrated and absolute in all respects, nor does it seem to us to have passed sufficiently out of the realm of opinion, unless we might be permitted also to ascertain the mode and reason, way and manner, whereby the same phenomena of contractions might be obtained without either nerves or muscles being touched in any way or by any substance.

We feared lest perhaps these phenomena might in some way be ascribed to some mechanical irritation either of the arc or other instruments, and that therefore it was not sufficiently established by these experiments themselves concerning the very tenuous electric fluid flowing out through nerves and inducing muscular contractions. Moreover, it occurred to me to try whether, with the nerves attached to one surface of the magic square, as the upper for example, and the muscles to the lower, Fig. 20, or the opposite, as in Fig. 13, and with one extremity of the arc applied to the former, the other to the latter, surface, in a place far removed from the displaced parts of the animal, contractions would occur or not. For by this sort of experiment I easily learned whether the fluid flowing out along the nerves had been electrical and the contractions had originated and started from its passage from the nerves to the muscles, whether it was the same as if I had applied the arc to muscles and nerves without its being possible for any suspicion to arise about mechanical stimulus being applied to them. But, the experiment having been made, we saw, not without some delight, that contractions occurred, without occurring by the same method, if glass or resinous surfaces armatured after the fashion of the physicists had been placed in one and the same plane, provided they had been separated by some distance from one another, so that the nerves were in one of those surfaces, the muscles in the other, and there had been no communication between them through an intermediate conducting body, Fig. 18. Moreover we observed that by this device contractions occurred without either nerves or muscles having been covered with metal foil in the customary method; and we finally noticed that they occurred if, for example, the spinal cord or the nerves were placed under water in one jar, the feet in another, and then, according to custom, the arc applied by its extremities to both surfaces of water, Fig. 19.

This moreover, furnished us occasion to investigate what would

TABLE IV



happen, if the muscles were placed on an armatured glass surface, the spinal cord in its own tube and joined to its nerves on a conducting surface, either connected by a hook or else armatured according to custom; what then would happen, if the experiment were otherwise arranged, namely with the spinal cord placed on the glass plate, conducting to the muscles, and the arc, as in the preceding experiment, applied to two opposite places, of which one should look towards the spinal cord, the other towards the muscles; what, finally, if both the cord and the muscles should be laid out on one and the same armatured surface. Truly the contractions were more languid, and were excited with more difficulty, when the muscles lay on the glass surface and the spinal cord on the conducting plate; but on the contrary they became more violent when the spinal cord was placed on the glass plate and the muscles on the conducting plate; but sometimes of their own accord they became far more vehement and longer, appearing without any use of the arc, and as if recurring, if both muscles and nerves had lain on the same armatured glass surface, especially if either light percussion or motion had been made on the armatured glass surface, so that those trunks of animals were seen to have fallen into the severest spasticity.

But if anyone compares these phenomena with those which we said occurred at first, when namely the muscles and the spinal cord were located on one and the same conducting plate, and contractions were excited either by pressure of a hook against the same plate or by other indicated means, he will easily understand that these were then far less than when similar ones were produced on an armatured glass surface: truly no trifling argument that animal electricity is dissipated less by conducting bodies than is common, ordinary electricity; nevertheless that it is dissipated, and that it is restrained and accumulated by insulating bodies no less than the former, which, if I judge correctly, will appear far more clearly in the subsequent experiments.

For before removing my hand and solicitude from these experiments, I wished to investigate whether the same phenomena of contractions would occur not only on glass or resinous but also on marble or highly polished surfaces, that I might forsooth remove that doubt which was often observed in my mind, whether the contractions, which I myself used to repeat with animal electricity, proceeded rather from the electricity of an armatured glass or resinous

surface. Therefore the same experiments were undertaken with armatured marble surfaces as with glass and resinous, and all turned out the same way, but more languid contractions occurred, so that those devices had to be employed whereby the effects of animal electricity exciting contractions are augmented. Hence it was often necessary to equip one surface of one marble plate, or part of it, (for it is the same, whether you employ two plates, or one divided into parts by means of armatures), with one metal, tin for example or silver, and the other with bronze or gold-leaf, in order that contractions might occur; perhaps because animal electricity, like common and ordinary, is wont to be checked less readily by marble than by vitreous or resinous substances.

But this ought not to be passed over in silence, because if the arc should have one extremity of insulating material, and then that should be applied, as above, to the armatured plates, it excites no contractions at all; but they are excited, if either the same extremity, or other insulating body, be applied to armatured nerves, or to the spinal cord, as we have already suggested.

But having observed the phenomenon in dead frogs and in dissected nerves, we were impelled to try the same in living frogs also, both with intact and with dissected nerves. Therefore, the integument having been reflected and the crural nerve exposed and armatured, where it advances completely bare, namely below the place of the leg which can be compared to the ham, we applied the arc as usual both to the same nerve and to the muscles of the leg; contractions occurred not infrequently; but they always occurred when the nerve was dissected and armatured and laid on an armatured glass surface, and then the arc applied either to the nerve, or only to the same surface, and to the muscles, in the same way as before; but contractions were lacking, wholly or in great part, if the plate on which the nerve lay was conductile and had been insulated in no way: so that it seemed thence to be established that the mode of action of animal electricity is exactly the same both in living and in dead animals.

Having had so many, and I think not obscure, indications of the effects of animal electricity, I wished to find out whether, as we noted to occur in ordinary and extrinsic electricity, the customary preparation of nerves and their diligent separation from other parts contributed anything to collecting and manifesting its powers.

Moreover I found that it contributes a great deal. For if with only the cranium or the vertebral column opened, and the rest of the animal intact, the cerebrum or the spinal cord was covered with its own tinfoil, and then one extremity of an arc was applied to an armatured portion and the other to a leg, some contractions occurred in the upper limbs, but none or scarcely any in the lower; but imperceptibly and gradually others appeared, according as the animal was denuded and exenterated, and nerves were more and more separated from adjacent parts, until finally, when all the nerves were isolated and free and surrounded only with bronze-foil, they appeared great and violent, with the same arc and the same method employed, so that it seemed established thence that perchance paths and some access lie open for animal electricity from the nerves to the contiguous parts either through moisture or through lymphatic or blood-vessels accompanying the nerves; and when these are dissected, the nerves are free, and while they remain insulated, electricity prepared for motion, flowing to the armatured place, either wholly or in great part, and completing its circuit through muscles and nerves by means of the arc, produces the contractions far greater than before their preparation.

But that a new phenomenon of this sort exists seems no slight argument for animal electricity: and perhaps some suspicion may arise thence that the acceleration of blood and circulation of humors in the muscular motion depend either principally or in some part on electricity itself, flowing from the nerves to the vessels and making inroad into their humors: and surely, if there were room for this conjecture, perhaps some explanation might emerge thence why in old men, in whom many vessels coalesce, i.e. become occluded from arteriosclerosis, the electricity, hastening more abundantly along the nerves directly to the cerebrum, not infrequently injures the latter seriously, and for this reason also renders old age more susceptible to both paralysis, and apoplexy, and other diseases of this sort. But of these we will speak elsewhere.

But nothing seemed to us to conduce more to deriving some utility from our experiments than diligently to transfer to warm-blooded animals also those which had hitherto been tried in the cold-blooded.

For I readily realized, if those things which I had discovered had pertained only to cold-blooded animals, that I had discovered only

certain of their properties, perhaps hardly associated with any utility: but if the same things could be found also in the warm-blooded, I was shown great hope that the result would be that I might accomplish not a little towards a little more revealing, if not clearly explaining, the essence and nature of muscular and nervous powers; which perhaps without some increase could not be of utility both to physiology and to medicine.

Moreover, the experiments having been performed, in birds and in quadrupeds, not once but again and again, not only the principal phenomena appeared, according to desire, as in cold-blooded animals, namely frogs and turtles, but they both appeared more easily and were far more conspicuous. It was possible also to observe this peculiarity in both the living and the dead animal, Figs. 20 and 21, for example that in a lamb or a chick, with a crural nerve dissected and covered with metal foil and extended on an armatured glass surface, contractions were obtained without the device of an arc, but solely by the contact of some conducting body with the same surface; but they are never obtained when the nerve is extended on a metallic surface, unless an arc is applied to the animal according to custom.

What more fitting, what more certain, than that it should be demonstrated that animal electricity is diffused to contiguous bodies by the nerves, and, not otherwise than common and ordinary electricity, is accustomed to be arrested by insulating and dispersed by conducting substances? These are the things which we have ascertained by experiment.

But finally we wish the reader warned that animal electricity, discovered by us, just as in many other properties, so chiefly in its inconstancy, variety, and as it were renewal after a certain time, corresponds not a little with common electricity. For the contractions differ greatly, particularly those occurring in this last part of the experiments, not only in accordance with the different kind of animals, but in accordance with the varied nature, age, condition, and strength of each of them; so that in some they occur very strong and promptly, feebly in others, and hardly perceptible: they differ likewise in accordance with varied seasons of the year, and even with the condition of the sky itself.

For in summer time and with a sky threatening thunder and lightning, the contractions are accustomed to be stronger and prompter,

than in winter and with a calm sky, although then we have observed that the force with which they are excited in the animal is extinguished more quickly; they are stronger likewise and prompter in the older than in the younger; in the more active than in the more sluggish animal; finally in the exsanguinated and pale than in those filled with blood, and with red muscles.

Moreover, in one and the same prepared animal, there are contractions now scanty, now strong, sometimes even none; and sometimes they occur at initial experiments; sometimes after many trials. Moreover this so great variety of effects or contractions occurs not only at great but also at brief intervals of time.

Finally, diminished after a certain time and certain respite, contractions augment, sometimes as if voluntarily, and grow stronger, nay failing they are also restored as if voluntarily, when other external causes and associated phenomena are barely or not even barely changed, as it appears, not otherwise than as the electricity seems to be refreshed and restored through rest and quiet at a certain time in the magic quadrant or Leyden jar, dissipated by repeated experiments.

But that those who have devoted themselves to this kind of experiments may the better recognize the use and utility of the arc, it aids to note this, that with failing contractions which, especially with armatured nerves, are sometimes excited at the outset by the sole contact of any conducting body, if then they have recourse to the use of the arc, they will see the contractions restored anew; but if they wish to adapt the same arc to the armatured surfaces of a plane, then let them call it into use either continuously or a little after the preparation of the animal.

Moreover, we give this advice with this purpose, lest anyone, in repeating these experiments of ours, in estimating the force of contractions and of electricity, should either deceive himself or think that we have been deceived; for if these same experiments are tried many times, he will find out many times also the phenomena which we have produced by trial and experience.

Part Four

CONJECTURES AND SOME CONCLUSIONS

From what is known and explored thus far, I think it is sufficiently established that there is electricity in animals, which, with Bartholinus and others, we may be permitted to call by the general name of animal electricity. This, if not in all, yet is contained in most parts of animals; but manifests itself most conspicuously in muscles and nerves. The peculiar and not previously recognized nature of this seems to be that it flows from muscles to nerves, or rather from the latter to the former, and that it traverses there either an arc or a series of men or any other conducting bodies which lead from nerves to muscles by a shorter and quicker way, and flows most speedily through them from the former to the latter.

From this, moreover, two consequences seem chiefly to ensue, namely, that the electricity in these parts is, one positive, as we may believe, the other negative, and that one is wholly distinct in nature from the other; for when equilibrium is established, there is no motion, no excursion of electricity, no phenomenon of muscular contraction.

But forsooth, it is difficult to define in which of the designated parts one electricity resides, in which the other; whether, for example, one in muscle, the other in nerve, or both in one and the same muscle, and from which part it flows. In this obscurity of things, however, if it is permissible to have an opinion, my mind inclines towards placing the location of both kinds of electricity in muscle.

For to obtain muscular contractions grant that it is generally necessary to apply one extremity of the arc outside of muscles, the other to muscles, as we have said; but it does not seem to follow thence, because nerves are rich in intrinsic electricity, that therefore one kind has its seat in them and the other in muscles; just as in a Leyden jar, although it is customary that one extremity of the arc should be applied to the external surface thereof, the other to its conductor, in order that the excursion of electricity may be made from one to the other, nevertheless it cannot be inferred therefrom that the electricity which is produced in the conductor is peculiar, and unlike that which collects within the bottom of the jar; nay

even it is established that that looks altogether towards the internal and charged surface, and that both electricities, although contrary, are contained in the same flask.

Wherefore, if the great number of contractions obtained in the prepared animal be considered, for which surely the small quantity of electricity contained in the small part of the nerve remaining in the prepared muscles is adequate; if, moreover, the many arguments be considered which are sought from the animal functions, which openly declare that the nerve fluid, already demonstrated by us is electric and flows freely and swiftly through the nerves; if finally the obvious and simple explanation of the phenomena from each electricity be sought residing in the muscle itself: it will not seem beside the point, as we shall show hereafter, that the muscle should be the proper seat of the electricity investigated by us, but that the nerve performs the function of a conductor.

These things being admitted, it would perhaps be a not inept hypothesis and conjecture, nor altogether deviating from the truth, which should compare a muscle fibre to a small Leyden jar, or other similar electric body, charged with two opposite kinds of electricity; but should liken the nerve to the conductor, and therefore compare the whole muscle with an assemblage of Leyden jars. Moreover that a double and opposite electricity can occupy one and the same muscle he will readily grant not contrary to the truth who has considered that a muscular fibre, although at first sight very simple, nevertheless is composed of diverse solid and liquid parts, which produce in it no slight variety of substance: certainly the sensation which is present at every point of the fibre warns us clearly that nerve substance is found in it altogether different from muscle. And indeed, although, at whatever point of the fibre, this nerve substance neither constitutes the nerve, nor is obvious to the eyes, but is diagnosed by sensation alone, what prevents us from conjecturing that it is in some part different from the substance of visible nerve, or disposed in a different way, and that therefore it has an electrical nature; but that it is extended as a conducting nerve beyond the muscle fibre? But perhaps this will appear more clearly from that which we shall say a little later about nerves.

But much less easily could he deny double electricity in one and the same muscular fibre who should see that it is neither difficult nor without some sort of truth that the same fibre should have

external and internal surfaces opposite one another, either having observed a cavity, which some assign to it, or from diversity of substances, of which we have said it is composed, which cannot be without various holes and surfaces of the muscular substance.

Finally, if anyone turns his mind even for a short time to the tourmaline stone, in which recent discoveries seem to suggest that a double and opposite electricity is found, he will perceive a new reason derived from analogy, whereby a hypothesis of this sort is rendered not altogether vain. But, however the circumstance is, we have seemed to observe so much agreement of causes and of phenomena between the eruption of electric fluid from a Leyden jar and our contractions, that from this hypothesis and comparison we have barely and not even barely been able to withdraw our mind and restrain ourselves from deriving both the former and the latter from a similar cause.

For particularly by employing three devices, electricity breaks from the internal surface of a Leyden jar; namely by the contact of its conductor with some highly conductile body, by the apposition of an arc, and by the production of a spark from the conductor of an electric machine, as we have most recently observed.

Moreover, with these three devices we have already seen contractions of muscles obtained: namely by contact of an armatured nerve which we have made a muscle conductor; by the application of an arc by its extremities both to the same nerve, and to the muscle; and finally by the passage of a spark.

But just as among those devices, more apt and stronger than all for promoting the eruption of electricity from a Leyden jar is the arc, so we have already seen that it is more suitable than all for exciting muscular contractions: likewise, just as, unless the conductor projects beyond the orifice of the jar, and especially extends beyond that on which rests and in which is contained the conducting material inside the jar, the use of the arc can do hardly anything to induce these muscular contractions, if the nerves were resected close to the muscles; as we have already demonstrated.

But now with respect to the production of a spark, the similarity proceeds even farther than we have hitherto explained; but in order that it may be rightly understood, we have noticed that, when by chance it was made dark, we have observed a luminous pencil to gleam continuously from the pointed conductor of a charged Leyden

jar and then after some time to fail spontaneously. But after it failed, if the jar were placed at a certain distance from the conductor of the machine and a spark elicited from the same conductor, again the same pencil appeared at the very moment of time when the spark was produced, but soon vanished, and so the produced spark alternately arises and is extinguished. It is a pencil of this sort which, tested and investigated by us in various ways presented a new and not inconsiderable argument for the analogy already proposed.

For as a pencil of this sort appears at the passage of a spark, contractions are excited, as we suggested; moreover, just as if a conducting body, especially one communicating with the earth, be applied to the external surface of the jar just at the time when the same pencil either fails or languishes at the passage of the spark, the spark, again elicited, continuously revives and is restored; so, if the same conducting body be applied to muscles, we have already suggested that the contractions of muscles were either restored when failing or augmented when languishing, while sparks were being elicited. Likewise, in order that that pencil may appear, when a spark is produced, whether the conductor faced the machine of the jar or were in the opposite region; so then, as we have said, contractions occur, whether the nerves and their conductors were from the region of the machine, or in the opposite direction. But when the tube is either glass or resinous, if that part of the conductor be occluded, which projects beyond the orifice of the jar, the pencil fails at the passage of the spark, not otherwise than as contractions fail when nerves are enclosed in the same tube, although the rest of the animal is freely exposed to the air.

Moreover, just as, if the jar is placed inside another glass vessel covered externally with metallic foil, a failing pencil is restored and revived, when languishing, by sole contact of the exterior of this vessel, while a spark is being elicited; so if the jar, in which is the animal, be placed within the same vessel, as in Fig. 3, Tab. I, contractions languishing, at the passage of a spark, revive by contact of the same vessel; and if they cease, they arise again.

But as all appearance of that electric pencil vanishes at the passage of a spark, either if the conductor of the internal surface does not project, or even if it does, if another conductor is added to it, and this is extended as far as to the external surface of the jar; so,

as we have stated, contractions cease on the passage of a spark, if either the nerve does not project beyond the muscles corresponding to it, and the contiguous parts, or if it does project, if another conductor be applied thereto, which is directed as far as to the muscles or to their conductors.

But indeed, although this hypothesis and comparison present no slight appearance of truth, nevertheless there are some things which seem not slightly to oppose them. For either nerves are of an insulative nature, as some surmise, and cannot then perform the function of conductors; or they are conductive: and how then could it be that the electric fluid should be contained within them and not be permitted to escape and diffuse to neighboring parts, not without great detriment surely of muscular contractions?

But this inconvenience and difficulty will easily be met by him who imagines the nerves so constituted that they are hollow within, or composed of some material suitable for conveying electric fluid, but externally they are either oily or are fused with some other substance which prevents the effusion and dissipation of the said electric fluid running through them. Such a structure indeed, and that composition of the nerves, will bring it about that they can perform both functions, namely of conducting the neuro-electric fluid and at the same time of avoiding the effusion thereof, and will be admirably accommodated both for the animal economy and for experiments; if indeed the animal economy seems always to demand animal spirits forced within the nerves; but experiments demonstrate that the nerves consist chiefly of oily substance.

For not only a large amount of oil is obtained by distillation from nerves, and far greater than from muscles, but as a greater quantity of inflammable gas was produced from them by us by a newer method than it was ever possible to elicit from any other part of the animal, and this gas was of such a nature that, when ignited, it emitted a more vivid, purer, and long-lasting flame than the inflammable gas derived from other parts is wont; surely this is no slight indication of more abundant oily substance in nerves.

Nor indeed will this non-conducting substance in nerves, which seems to be a safeguard lest the electric nerve fluid should be dispersed, not without severe detriment, be an impediment lest the same fluid, running out through the intimate conducting substance of nerves, when there is need, should go out from the same nerves,

for the accomplishment of contractions, and should be transferred very swiftly through the arc to the muscles according to its custom and nature.

For just as, although the conductor of a Leyden jar is covered with wax, nevertheless, if an arc is applied to it, an explosion is obtained, if either the layer of wax were thin, or, though thicker, were yet covered with a thin metallic foil, provided it does not pass certain limits of thickness, as we have often found; so, from a nerve made in the same way by nature and armatured by art, electric fluid can escape and produce contractions.

Let us therefore be permitted to follow a not improbable hypothesis of this sort, which however we will immediately discard, as soon as either learned men dissent from it, or the discoveries of physicists or new experiments undertaken in respect to it have demonstrated another more suitable.

Now a few things about the nature of animal electricity chosen from those which it is permissible to infer from the described experiments. This electricity, then, has some things in common with artificial and with ordinary electricity, some things with that of the torpedo and other animals of this class.

Things in common with ordinary electricity are: First, free and easy passage through the same bodies through which common electricity is accustomed to pass, namely through metals, among the foremost, and, among these, through the more perfect and nobler, such as gold and silver, then through the less noble, namely copper, iron, tin and lead, moreover through the imperfect metals, such as antimony, and finally through minerals; likewise free and easy passage through water and moist bodies; more difficult passage through stones, earth, and wood; finally, interrupted and completely cut off through glass, resin, and oily substances: wherefrom it results that if metals are laid on an insulating plane, it is inevitable that common and artificial electricity should accumulate in them, and they would be wont to produce far greater effects, namely to excite more violent and longer contractions, than if the same metals communicated freely with other conducting bodies.

Second, the choice, in excursion, of a shorter and quicker way, an arc, for example, or angles, or points.

Third, a double and opposite nature, namely one positive, the other negative.

Fourth, daily and hourly constant attachment to muscles not otherwise than common electricity is wont by nature to electric bodies.

Fifth, spontaneous restoration, not lasting a short space of time.

Sixth, distinct increase of power by employment of the device of a so-called armature made of the same metal with which the physicists are accustomed to surround resinous and vitreous bodies.

Properties in common with electricity of the torpedo and other animals of this class are chiefly these:—

Namely, as it were, a sort of circulation of electricity from one part of the animal to another, and this either through an arc or through the fluid itself of the arc alternately, as the physicists have observed. Whereby forsooth it is established that such a circulation is characteristic, not of the torpedo alone or of similar animals but perhaps of animals generally when our devices are employed. Moreever, as in the latter so in the former, there are absent both sensation of a relatively gentle breeze, and attraction or repulsion of very light bodies, and finally indications of the slightest motion in electrometers hitherto invented.

But even our animal electricity has this in common with this kind of electricity, that it requires no previous device, friction for example, heat or other things of this sort, by which it should be excited, but it is ready as if by nature and continually prompt, and is produced on contact alone.

Nay, so great promptness for action is in this electricity of animals, which we have experienced, that if the vertebral column is allowed to be touched by an insulating body in a place where it is armatured, not rarely contractions are produced, particularly if the animal has been recently slaughtered and prepared. Moreover, they often occur if the same insulating body is so pressed against metallic foil that the contact of the foil with the nerve emerging from the vertebral column is either augmented or changed, but I know not whether this can be affirmed concerning the torpedo's electricity.

Moreover, this one thing seems particularly proper and peculiar of the torpedo and cognate animals that at their will and pleasure they can direct electricity outside the skin, and expel it so that it completes its circulation outside the body, and with such quantity and force that it exhibits a spark, if we heed the physicists, so that it produces a concussion and violent sensation and sometimes makes

such an impact on the animalcules that fall into the path of its circulation, that it either kills or stupefies and terrifies them. But perhaps in animals of this class this indicates more abundant quantity and force, not really a different nature; and perhaps some time, devices can be found whereby effects of this sort can be obtained in other animals also.

Moreover, electric circulations of this sort, discovered and described by us in other animals, not only their strength and relations but also their ways and instruments, perhaps will be able to shed some light on the same circulation in the torpedo and cognate animals, and again from more diligent discussion and observation of these animal organs which are fitted for this function, these of ours will be able to receive light. The instruments perhaps will be similar, and the terminals of the electric circuit, namely muscles and nerves, the same.

These things concerning the nature and character of animal electricity: now a few things concerning its source. This I should think to be not dissimilar from that which physiologists, up to the present time, have indicated for animal spirits, namely the cerebrum. For though we have indicated that electricity is inherent in muscles, yet we do not concur in the opinion that it emanates from them also, as from its proper and natural source.

For since all nerves, both those to the muscles and those which go to other parts of the body, seem to be altogether the same, as in kind so in nature, who will rightfully deny that all carry fluid of the same nature? But already we have shown above that electric fluid is carried through the nerves of muscles; therefore it will be carried through all: therefore from one common source, namely the cerebrum, they will drain it, from the source and origin of all: for otherwise there would be as many sources as there are parts in which nerves terminate; and although these are very different in nature and construction, they do not seem suited for the elaboration and secretion of one and the same fluid.

Therefore we believe it equally true that electricity is prepared by action of the cerebrum, and that it is extracted from the blood, and that it enters the nerves, and that it runs through them within, whether they are hollow and free, or whether, as seems more probable, they carry a very thin lymph, or some other peculiar similar thin fluid, secreted, as many think, by the cortical cerebrum. If this

prove so, the obscure nature of animal spirits, long sought in vain, may perhaps appear clearly. But as things are, certain no one of those hereafter, I think, after these experiments of ours, will call electricity into doubt. And although, led merely by reason and by some observations, we first brought this into our public Anatomical Amphitheater, and many illustrious men had already mentioned it before, yet never might we think fortune sufficiently favorable to us to grant to us perchance first to handle it, as it were with our hands, lurking in the nerves, and to draw it out of the nerves, and almost to place it under our eyes.

With these premises and indications, I now turn for the first time to those things which pertain to some explanation especially of the muscular contractions which are obtained by our experiments, thence to bring forward those which pertain not only to natural and voluntary motions, but also to involuntary and pathological, in order that some approach may be opened to utility of our observations, if indeed it may be permissible to transfer these data of ours, as not without cause we think, from animals, and especially from the warm-blooded, to man.

Now from the experiments performed, this fact emerges without difficulty, that there is a swift and violent excursion of neuro-electric fluid through the muscle to that nerve whereby chiefly muscular contractions and motions are excited.

But in what way an excursion of this kind of electricity causes and induces contractions, whether, for example, by some mechanical irritation and stimulus striking either the nerves or the muscle fibre and, as they say, exciting the irritability thereof, or, by the custom and character of common electric vapor, exciting a peculiar and violent attraction between the particles composing, for example, a muscle fibre, by its swift excursion through it, so that, as they mutually approach one another, the fibre becomes shorter; or whether, as is easier to believe, it is acting for some other reason not yet understood, is a very difficult thing to be known, and very much involved in darkness. More and more experiments undertaken on this subject may perhaps bring some light some time. But now that first comes into question, in what way and from what causes does such an excursion of electricity from the muscles to the nerves occur in the experiments described, which will not be difficult to find under the hypothesis previously described.

In the first place, therefore, I should wish it carefully noted that two things are either chiefly requisite, or certainly highly conducive to exciting muscular contractions, about which we have heretofore discussed.

First, namely, something which shall attract the neuro-electric fluid from the muscle to the nerve and instigate it to exit; then something which shall receive it as it goes out from the nerve and either take it back and as it were restore it to the muscles or conduct it elsewhere and dissipate it. Indeed, if one or the other of that conditions is lacking, the phenomenon of contractions will be lacking also.

Now the things which invite and as it were force neuro-electric fluid from the muscle to the nerve seem to be chiefly these: namely, the suddenly removed equilibrium between the internal electricity of muscles and nerves and the external electricity of bodies communicating chiefly with nerves; moreover, irritation of the same nerves; contact of some body, principally conducting, either with the same nerves themselves or with conducting bodies communicating with the same nerves; finally, as it were, some disturbance of the substance, or friction of the slightest sort, as when, by simple percussion of the plane on which the prepared animal is lying, contractions are excited.

Moreover, it is clear that stimuli of this sort can finally be referred partly to disturbed equilibrium, partly to some kind of impulse into nerves, even if very slight.

But the electric fluid, running to a nerve for these reasons, will be received by some conducting body, which will transfer it from the nerves to the muscles, if it was produced from the former to the latter by use of the electric arc; but it will convey it elsewhere, if it has communicated with nerves alone, or with bodies touching nerves, and if it has a certain magnitude.

But, these things having been noted and determined, I come to the explanation of the muscular motions which we have observed, and first of those which are obtained at the extortion of a spark.

For at the passage of a spark, electricity breaks out both from the layers of air surrounding the conductor of the machine and from the nerve-conductors communicating with the same layers; and negative electricity results on account of them. Hence the intrinsic positive electricity of muscles runs to the nerves both with its own strength

and with strength from extrinsic electricity, more abundant whether you borrow it from artificial or natural, as received from their conductors, and flowing through them, failing both in them and in the shortly hitherto mentioned layers of air, it will renew the electricity, and establish itself at equilibrium therewith; not otherwise than as, in a Leyden jar, the positive electricity of the internal surface in the production of a spark, flows more abundantly to the conductor of the former, for the same reasons, and goes out therefrom, just as the form of a luminous electric pencil openly declares.

Hence it is understood without difficulty whether there is utility or necessity in the nerves of conductors for receiving and transferring electricity and their constant ratio and proportion with muscular contractions.

Similar seem to be the cause and reason of the muscular contractions which are obtained, on the passage of a spark, in an animal enclosed in our little glass machine: for the intrinsic electricity of the muscles seems to flow to the internal surface of the glass through the nerves and their conductors on account of the same law of equilibrium, so that forsooth as much electricity collects at the internal surface of the glass as had been removed from the external surface by passage of the spark.

The reason and cause of the phenomenon seems the same also in the contractions which occur when the conductors of prepared animals are applied to the external surface of a Leyden jar, or near it, when a spark is elicited from the conductor of the internal surface.

Indeed, so aptly and clearly is the phenomenon explained by this law of surfaces and of equilibrium, that I should not easily blame him who explained also by the same law those contractions which are obtained in the extortion of a spark from the conductor of an electric machine, and who should consider the same conductor as a double surface in the surrounding layers of air, one an internal conductor, the other external as regards the animal.

But whether it happens for this or that reason, or any other, not yet known, no one will doubt that the causes and reasons of the phenomenon are the same in those contractions which we said occur in thunderstormy weather; for at the cast of thunderbolts the same thing is seen to befall the layers of air surrounding the electric cloud as befalls those which surround the electric machine.

Finally, there is no one who does not see that, from the same law

of equilibrium between the positive electricity of muscles and the negative electricity of sealing-wax, those contractions easily take their origin which we said occur when the same rubbed wax is applied to nerves, but fail when rubbed glass is applied; likewise that from the same law of equilibrium those contractions also derive which we have already warned will occur when the shield of an electrophore is raised from its resinous surface.

But I come now to those contractions which are excited either by an arc, or by the contact of conducting bodies with nerves, or by irritation of the same nerves, or in other ways which we have indicated above; and indeed no one has even briefly considered what of animal electricity pertains to them, how we have referred its nature and character, without easily understanding how those are devices suitable and adapted for attracting the positive internal electricity of the muscles to the nerves, and receiving it and, as we have stated, for negatively transferring it to the external electric part of muscles.

But, these things being once admitted, it may be enquired how it is that, if a nerve is even touched briefly by some insulating body, as happens sometimes if it were armatured, it is irritated by the same or, if you prefer, by artificial electricity, nevertheless contractions appear.

For then indeed there is present both contact and impulse which, though perhaps slight, could recall neuro-electric fluid to the exterior of a nerve: but the body which should receive the same fluid and either conduct it elsewhere for the sake of equilibrium, or restore it much more to the muscles, seems to be wholly lacking.

But if the phenomena described are accurately weighed, and the nature and character of neuro-electric fluid considered, which is accustomed to find free access and a ready way for itself only through conducting bodies, and to hasten swiftly from nerves to muscles, perhaps not even then will the conducting body of an arc seem necessary as an alternate; forsooth, the fluid and moist external parts of nerves, or particularly their thick and hard membranes, or both, will be able to perform this function. Hence perhaps with the cranium open and the cerebrum exposed, and likewise the spinal cord removed from its vertebral column and bare, no contractions of muscles, as we have said, are excited, even if an arc be applied; but they are excited, if the same be equipped with metallic foil, which goes far towards taking the place of the missing membrane;

but it happens otherwise, as we have warned in nerves which, although nature has covered them with thick membranes outside the cerebrum, it is always useful, though not necessary, to provide with metallic foil. But if you compare the metallic foil, with which we are accustomed to cover nerves, as it were to part of the arc, and recall to mind what we reported concerning the utility of multiple arc substance in augmenting contractions, perhaps those of the contractions which, as we have already said, seemed to occur only on contact, you will generally repeat from the arc also which is as it were composed partly of metallic foil, partly of the already mentioned conducting substances of nerves.

But if these things be granted, perhaps some approach will be opened to explaining the muscular motions which occur in the living animal, and which we now advance to consider. For what pertains to voluntary motions, perhaps the mind, with its marvelous power, might make some impetus either into the cerebrum, as is very easy to believe, or outside the same, into whatever nerve it pleases, wherefrom it will result that neuro-electric fluid will quickly flow from the corresponding muscle to that part of the nerve to which it was recalled by the impetus, and when it has arrived there, the insulating part of the nerve substance being overcome through its then increased strength, as it goes out thence, it will be received either by the extrinsic moisture of the nerve, or by the membranes, or by other contiguous conducting parts, and through them, as through an arc, will be restored to the muscle from which, as we are pleased to think, it previously flowed out, from the positively electric part of the same, through impulse in the nerve.

Perhaps in no dissimilar, though less difficult way, if I am any judge, the occurrence could be hastened in involuntary and unusual movements, namely if sharp and stimulating agents irritate the nerves, or the spinal cord, or the cerebrum, and at the same time summon the neural fluid, so that, having been received by the conducting parts, it is finally restored to the muscles as if through an arc.

But in accordance with the different power and faculty of the acid humors for stimulation and conduction, the contractions also will be dissimilar; likewise in accordance with the different location which they will occupy in the nervous parts.

For it is easy to understand, when humors of this sort are poured

out of the vessels and subside between the surface of the nerve-substance and its investments, that contractions then ought to become more violent and longer; because then, forsooth, the effused and the stagnant acid humors will not only irritate the nerve more severely, but will also constitute, as it were, a more suitable kind of armature and arc for the neuro-electric fluid.

Hence, in the more severe rheumatic affections, and particularly in nervous sciatica, in which, according to Cotunius, the humor stagnates between the sheath and the surface of the nerve, not only are the pains more severe, but there are wont to be severe and constant contractions of the muscles of the affected joint, so that often the said joint may remain either long or permanently contracted.

Hence perhaps even such violent, such long, so readily and at brief intervals recurrent, and generally fatal contractions of the muscles, or convulsions occur when acid and perverted humors stagnate either within the cerebrum and the pia mater, or within the pia mater and the dura mater, or within the cerebral ventricles, or within the surface of the spinal cord or of the nerves and their investments, as generally happens in tetanus, in which disease it becomes chiefly noteworthy that at first nearly all the muscles fall into very severe tonic contractions, although sometimes only one nerve may be affected for a short time, as in the tetanus which sometimes follows the puncture of a nerve; then it is noteworthy that the muscles relapse into the same contractions, both spontaneously and often only and when by a slight tremor or percussion of the bed, or surface on which the bed of the patient is resting. But we have already seen something similar happen, in prepared and armatured animals in whom it is permitted that an arc should be applied briefly to one crural nerve, nevertheless all the muscles not only of one limb, but of both, fell into tonic contractions, and sometimes recurred into them spontaneously, either from a mere tremor, or from percussion, of the surface on which the animals were lying, so that on this account these experiments of ours on this disease and its peculiar symptoms seem, if not to have discovered the cause and reason, at least to have injected some suspicion into the doctors.

Now, indeed, these theories concerning contractions of muscles, both gentle and natural, more violent, and pathological, having been postulated and considered, it was inevitable that there should be presented to my mind as it were a new cause and reason for the

opposite faults, namely paralysis and others, namely the already explained arrested circulation of neuro-electric fluid, either from muscle to nerve, or from nerve to muscle.

First, perhaps, it might happen, if a substance of oily or other insulating nature should beset part of the nerve; second, if a similar material should involve either the external moisture of the nerve, or the membranes themselves, or some other parts, through which the neuro-electric fluid performs its already indicated circulation; but if the effusion and congestion of this material is promoted by acid and especially by corroding agents, the substance and texture both of the nerves and of the cerebrum may be injured. But although perhaps it seems possible that these things may have some truth, particularly in those paralyses and apoplexies which invade patients slowly and step by step, yet, in those which attack them in a moment of time, it seemed that a far different cause of the phenomenon must be considered.

While I was revolving these and similar ideas in my mind, there was presented to me as it were a new cause not only of apoplexy but of epilepsy, derived chiefly from those things which are often observed to occur when artificial electricity is employed in animals.

For just as when artificial electricity is industriously directed either against the cerebrum, or against the nerves, or against the spinal cord, for example by means of the conductor of a Leyden jar, if it rushes into those parts with a certain quantity and force, it irritates them and throws the animals into violent convulsions; but if it injures and violently impairs their substance with a far greater quantity, it renders the same animals paralytic or apoplectic, or, if it were more violent, destroys them: so I conjectured that animal electricity could do the same or similar things in man, especially if, as common electricity is wont, especially if it should seize and promptly add to itself those delicate elements whereby far greater power might be added to it; of which sort would be what come under the name of acid elements, whatever those might be; and so I thought that now epilepsy, now apoplexy could be induced by thus contaminated animal electricity hastening through the nerves either from the muscles or from other parts to the cerebrum and rushing into it, according as its force and impetus into the substance of the cerebrum were more or less, and its contamination more or less

severe. For it seemed that the excursion and impetus of animal electricity could be violently summoned through the nerves to the cerebrum by the quantity and quality of the depraved humors stagnating in the said brain, and stimulating and injuring the brain itself or the nerves, or finally, to pass over other things, by any great and sudden mutation of atmospheric electricity, especially if its conversion from positive to negative is made abruptly, perhaps not unlike that which we conjecture both the conductor of the electric machine and the electric cloud to produce in the surrounding atmospheric layers, either at the extortion of a spark, or at the crash of a thunderbolt.

Now thus far I assumed that no one failed to see how the causes reviewed could exercise their forces more violently, promptly and easily, if acid and stimulating materials were clinging in the cerebrum, than if in the nerves; for in the former they may well designate those diseases as idiopathic, but in the latter as symptomatic: and moreover diseases of this sort will be also far more severe, and will occur more readily, if animal electricity, and contaminated at that, is in excess in the body and particularly in the muscular and nervous parts. Hence I reflected that diseases of this sort are particularly prevalent in old men, because in them a more abundant supply of contaminated animal electricity seems to accumulate, both on account of their intermitted labors and exercises, and because of the dryness of the parts induced by old age, and primarily the density of the oily substance of nerves, and finally because of the diminished insensible perspiration by which so great an amount both of electricity and, of acid and delicate principles is carried outside the body; so also I conjectured that these fatal diseases prevail for the same reason especially when those more severe storms and changes of weather are threatening, in which there is wont to be a greater quantity of electricity in the atmosphere, or a little afterwards; for at that time more electricity is found in animals, so that the contractions described, then occurring more often and more promptly and more violently, seem clearly significant. For these and for other reasons, then, immoderately increased and contaminated animal electricity seemed with such force and impetus to be able to rush and flow into the substance of the cerebrum in a moment of time that in the same moment of time it injured its structure severely,

and ruptured vessels, whence both paralysis constantly and easily followed and humors were poured out, and having been shed and stagnating, as often happens, were found in sections of corpses.

These and other things used to come into my mind about the cause and the manner of invasion of these diseases; but at the same time I realized that hypotheses of this sort could incur many and grave difficulties among learned men and perhaps their reprehension for many reasons, and particularly because they oppose the opinion, common and accepted in the schools, namely that muscular motions are performed by an excursus of nerve fluid from the cerebrum to the muscular parts, not from the latter to the former. But if anyone among other things should recall to mind that aura, as it were, which, ascending to the cerebrum either from the lower limbs, or from the stomach, or from the lower abdomen, epileptics easily and very often feel and accuse at the moment when they are seized with convulsions; if then he should consider that sometimes the progress of this disease is arrested, if a noose or tourniquet is applied to the leg, which, as it were, impedes and intercepts the way: if anyone, I say, turns his attention to all these things and to our experiments, he will easily pardon us, if we have descended to these conjectures. But these things, as I was saying, I was, as it were, imagining in my mind, chiefly with this purpose, that they might be recalled to consideration by the most learned scholars.

A cause having been suggested, not only of natural but also of pathological contractions, and the cause of paralysis having been sought chiefly in the ascertained nature of animal electricity, there seem to remain some things which should be touched on concerning the treatment of these diseases.

And in the first place it seems that this can be derived from our experiments, that, whatever remedies are employed for removing those diseases, and even electricity itself administered externally, all these things, if they are going to do any good ought to exercise their effect chiefly on animal electricity, and either increase or diminish it or change it in some other way. Which electricity, therefore, and its status the doctor should have chiefly before his eyes in treatment.

Therefore, omitting other remedies, whose effect on electricity of animals diligent investigation and use will reveal and disclose some day, I immediately turn to the administration of external electricity,

and, in order that the thing may proceed more clearly, I will consider it first in convulsive and rheumatic contractions of muscles, then in paralysis.

But before all, a threefold faculty and function in applying artificial electricity to the human body, in my judgment at least, comes under consideration; first, namely, that which can be called, as it were, extemporaneous, and which continuously exerts action on parts of the human body which are exposed to it, as when it acts through a spark, and especially through an electric thunderbolt, as it were, when a Leyden jar is discharged; second, when electricity produces its action not continuously but successively and with the passage of time, combined perhaps, and almost I had said with chemicals, combined especially with the fluid parts of the animal body, as that electricity which the younger physicists call balneal; finally at length that which draws electricity from the animal, as when negative electricity, as the same physicists call it, is employed.

Let us now consider briefly these individual functions in the diseases mentioned. Now as for what pertains to convulsive contractions of muscles, anyone easily sees that, in our hypothesis, these generally derive either from exuberant and contaminated animal electricity in the muscles, which, for most trivial causes is summoned from the muscles to the nerves and to the cerebrum, or particularly from acid and stimulating principles striking either the brain or the nerves, or, as often happens, from both causes. If the first, it seems that positive electricity, as they say, could scarcely, and not even scarcely, afford any benefit, but rather more injury, in whatever way administered; but negative electricity, as is obvious, might be of no slight advantage. But if it were the second, the physician can promise himself some benefit from positive electricity, if this is artificially directed to the affected nerves; for this can, by its own power, repel and remove acid principles from the nerves.

On account of these things, the differential diagnosis of convulsions and their causes should be diligently attended to and investigated by the physician: and although perchance both causes may often be present, nevertheless it should be sedulously considered which of them is more powerful, and although this is difficult, yet not all hope is to be abandoned that sometime we may be able at length nevertheless to accomplish this. Since, for example, there

ent or slightly previous amount of electricity in the atmosphere, and our experiments prove how much this augments the powers and effects of electricity.

Moreover a quantity of this sort can be explored and diagnosticated by the device of atmospheric electrometers, and also by the appearance of the clouds, by the time and season of year, by the tempests of heaven, by the qualities of winds, by the phases of the moon, and by other signs handed down by illustrious physicists, and foremost by Bartholinus and Gardiner. Besides these, an excess of electricity in us can also be indicated by a certain unwonted speed and alacrity of motions, especially of the eyes, deriving from no other obvious cause, combined with the greatest variety and inconstancy.

Likewise perhaps suspicion might be moved by those very mutations which artificial electricity is accustomed to produce in us, namely unwonted internal warmth, increased secretions and excretions, as of bowels, urine, saliva, sweat, insensible perspiration, rapidity, magnitude and vibration of the pulses, moreover the use of foods in which the idioelectric or insulating principles are contained, as of aromatous, oily, and spirituous liquors, especially if perhaps no other causes of these mutations are apparent. Certainly these are generally accustomed to precede especially the more severe convulsions, and other affections of the nerves, such as epilepsy, mania, and others similar.

Moreover, the opposite could warn us clearly of negative or deficient electricity. But, indeed, if there were any indications of perverted or contaminated electricity, they will perhaps be furnished by some of the discomforts of patients and symptoms of diseases, which to the doctors are wont to signify the power and prevalence of acid principles. But let it suffice to have touched upon these, that another way may be open to investigate and diagnose the varied status of animal electricity.

But as for what pertains to rheumatic contractures of the muscles, since these generally take their principal origin from acid and stimulating material settling in nerves, it is easy to surmise that in them almost individual methods of administering positive electricity could be useful, employed, however, in the following order and plan; that first that method should be employed which is called "through the bath", for collecting more abundant electricity in the muscles; then that which is administered through sparks; finally that which is

administered through concussion; so that first, forsooth the stagnating humors may be attenuated by the mechanical and repellent force of electricity, and then more easily removed from the affected part by increased impulse.

And no less, for the same reason, could negative electricity also be advantageously applied in the affected part, particularly by our method, namely by the extortion of a spark either from the conductor of an electric machine or from a Leyden jar, particularly if the affected part is applied to its conductors, of which some incline to the machine, others communicate with the ground, which method could perhaps be rendered more useful, if either large Leyden jars were employed, or many of them attached to one common conductor, or larger electric machines, such as in our times are constructed without difficulty; or much more, if a way should be found whereby it is possible to direct and impel animal electricity from certain muscles to certain nerves. For it escapes no one that, of those which we have suggested, by this method a more vigorous excursion of animal electricity is promoted particularly through the affected nerves, most suitable, as it seems, above others, as an aid for dislodging, dissolving, and expelling from the nerves principles stagnant and impacted in them. Hence perhaps muscular motions, which, as we have said, perhaps arise from the excursion of electricity from a muscle to the nerves, are accustomed to afford no little benefit and relief in rheumatic affections, and the more, the more vigorously the affected parts are moved, even if with some inconvenience and pain.

But if this new method of administering negative electricity should be combined with some utility, either in these diseases or in others, how much greater benefits shall we be able to promise from atmospheric electricity, if, as we have suggested in artificial electricity, the affected parts by their own conductors are cautiously and prudently adjusted, for example, to the raging thunderbolts and lightnings: was this perhaps the reason why limbs, either contractured from an early age or paralyzed by disease, have recovered their natural flexibility, strength, and power of spontaneous motion after thunderbolts have fallen not far from the patients?

But as to what concerns the treatment of paralysis, I see the subject full of difficulty and danger; for it is difficult to diagnosticate whether a disease arises from damaged and impaired structure of

nerves or of brain, or from insulating material blocking either the internal parts of a nerve or others whereby we think that the circulation of electricity in us is performed. If it can do little good, and perhaps artificial electricity could do much harm, in whatever way administered; if the latter, it seems that it could afford some utility, either for dislodging insulating material, or for augmenting the strength of animal electricity. But some time perhaps use and experience will reveal the whole subject. But now in closing let us touch on some neither trivial nor useless conclusions from our experiments.

From these, then, it seems to be established that both artificial and atmospheric electricity have far greater power over muscles and nerves than was hitherto recognized; and that from their strength especially as great a faculty passes into animal electricity as in our experiments it was seen that animal electricity has for motion and to promote its exit from the muscles and its speeding passage along nerves, and to excite violent contractions of the muscles.

Moreover, with these things recognized, there is perhaps greater access than it before seemed could lie open for newly discovered and more useful methods of administering electricity than those hitherto ascertained, or for disclosing the causes of agreement between the vicissitudes of atmospheric electricity and of our own health, and between some diseases and the sudden changes of the former.

Moreover such experiments seem to suggest that, in the passages of thunderbolts and of sparks, not only atmospheric, but perhaps also terrestrial, electricity flows back towards heaven. Or indeed does it result from this reflux that, when great storms arise in heaven, mutations and vicissitudes occur in the atmospheric air, not only on account of principles of diverse kind which it transfers from various regions of heaven, but also on account of those which it transfers with itself from earth into the air, if the electric fluid possesses this property, which very many physicists concede to it, that, of the bodies through which it passes, it expels and dissipates some of the more subtle principles, but removes others and joins them to itself? But let the physicists chiefly attend to these matters!

But when such a reflux of terrestrial electricity into the atmosphere occurs, it could claim for itself either a large, or certainly no mediocre part in those swifter and great increases of plants which

the illustrious Gardiner observed after lightning and thunder, and ascribed particularly to atmospheric electricity associated with vapors.

Finally, since such contractions of muscles which we have said occur under storms in heaven afford, as it were, a new and not uncertain indication of atmospheric electricity and its effects on the animal economy, these could perhaps conduce no little towards revealing, not so much causes for earthquakes, as effects in the same economy; so that on this account it seems not useless to investigate these same things when earthquakes are raging.

But let there be a limit to conjectures! And now the end.

These were chiefly the things which I communicated to the most learned men as ascertained about the effects of both artificial, and atmospheric, and tempestuous, and natural, electricity on muscular motion which is subject to the will, in order that they might some time bring about that utility which has been most in our desires.

But what things pertain to the effects of these electricities on natural motions, on circulation of the blood and secretion of the humors, these things we will publish as soon as possible in another commentary, when we have found a little more leisure.