ELECTRO-PHYSIOLOGY

H. M. NOAD.


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Dr. Pitman

with the authors best regards.

24th Oct 1849

ELECTRO-PHYSIOLOGY:

BEING

A POPULAR ACCOUNT OF THE RECENT RESEARCHES

OF

MATTEUCCI AND OTHERS

IN THIS DEPARTMENT

OF

ELECTRICAL SCIENCE,

INCLUDING SOME OBSERVATIONS ON THE

THERAPEUTIC APPLICATIONS OF ELECTRICITY.

BY

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ADVERTISEMENT.

For the convenience of those persons who are in possession of the Second Edition of "Noad's Lectures on Electricity," and of others interested in this particular branch of the subject, the Publishers have obtained permission to issue, in a separate form, the Lecture on Electro-Physiology just published in the new Edition of the above Work.

Foster Lane,
1849.

ELECTRO-PHYSIOLOGY.

Historical Sketch—Original experiments of Galvani—of Volta—of Humboldt—of Valli—of Aldini—of Lehot—of Nobili—The Galvanometer—The Galvanoscopic Frog—The Electroscope—Researches of Matteucci—The Muscular Electric Current—Its Laws—The Current Proper of the Frog—Its Laws—The Function of the Nervous System on the Muscular Electric Current, and on the Current Proper of the Frog—Theory of the Muscular Electric Current—Phenomena produced by the Contraction of a Muscle—Electric Discharge of the Torpedo—Its Causes—Influence of the Electric Current on Animals—Its action on the Nerves and Muscles—Causes which modify the action—Action on the Nerves of the Senses—Its action compared with that of other stimulants—Relation between the Electric Current and the unknown force of the Nervous System—Hypothetical views of the nature of this force—Therapeutic applications of Electricity—Apparatus for the medical administration of Frictional Electricity—Its use in cases of Paralysis, Tetanus, Muscular Contractions, St. Vitus's Dance, and Neuralgia—Mr. Pott's and Sir Wm. Blizzard's methods of administering Electricity in cases of Amaurosis and of Deafness—Apparatus for the medical administration of Galvanic Electricity—Acupuncturation—Observations of Marianini—Majendie and Grafengesser's methods of treating Amaurosis and Deafness by Galvanism—The Electric Moxa — Apparatus for the administration of Electro-Magnetism — Messrs. Knights' Medico-Galvanic Machine—Mr. Noad's Medico-Electro Dynamic Coil.

"It may be proved," says M. Arago, "that the immortal discovery of the voltaic pile arose in the most immediate and direct manner from a slight cold with which a Bolognese lady was attacked in 1790, for which her physician prescribed the use of *frog-broth*." There is scarcely a work on the subject of Galvanic Electricity in which this account of its origin is not given in some form or other.

The author of the article "Voltaic Electricity," in the Encyclopædia Britannica, writes thus :—"When one of Galvani's pupils was using an electrical machine, a number of frogs were lying skinned on an adjoining table for the purpose of cookery. The machine being in action, the young man happened to touch with a scalpel the nerve of the leg of one of the frogs, when to his great surprise the leg was thrown into violent convulsions."

Dr. Lardner, in the introduction to his treatise in the Cabinet Cyclopædia, after repeating the above account, adds, "This was the first, but not the only or chief part played by *chance* in this great discovery.

"*Galvani was not familiar with Electricity;* luckily for the progress of science he was more an anatomist than an electrician, and beheld with sentiments of unmixed wonder the manifestation of what he believed to be a new principle in the animal economy; and,

fired with the notion of bringing to light the proximate cause of vitality, engaged with ardent enthusiasm in a course of experiments on the effects of Electricity on the animal system. It is rarely that an example is found of the progress of science being favoured by the ignorance of its professors.

"*Chance* now again came upon the stage. In the course of his researches he had occasion to separate the legs, thighs, and lower part of the body of the frog from the remainder, so as to lay bare the lumbar nerves. Having the members of several frogs thus dissected, he passed copper hooks through part of the dorsal column which remained above the junction of the thighs, for the convenience of hanging them up till they might be required for the purpose of experiment. In this manner he happened to suspend several upon the iron balcony in front of his laboratory, when, to his inexpressible astonishment, the limbs were thrown into strong convulsions. No electrical machine was now present to exert any influence."

Dr. Thomas Young, in his Lectures on Natural Philosophy, shortly alludes to the circumstance thus:—"The first circumstance that attracted Galvani's attention to the subject of animal Electricity, was the agitation of a frog that had a nerve armed, that is, laid bare and covered with a metal, *when a spark was taken in its neighbourhood. A person acquainted with the well-known laws of induced Electricity might easily have foreseen this effect.* It proved, however, that a frog so prepared was a very delicate electrometer, and it led Galvani to further experiments."

The author of the treatise on Galvanism, in the Library of Useful Knowledge, repeats the old story of the "frog-soup," and we have done the same in the beginning of our fourth lecture. It appears, however, that we have all been guilty of considerable injustice towards Galvani, and that so far from his being unacquainted with Electricity at the time he made his important observation, he had been for many years studying it in connexion with the muscular contractions of frogs, as appears from a draft found among his manuscripts, which, with his memoirs have recently been collected by M. Gherardi, and published by the Academy of Sciences of Bologna. This draft bears date 6th November, 1780, *i. e.* eleven years before the publication of his Commentary. It is worthy of remark, that in the description of the first experiment there occur the words, "The frog was prepared as usual," which sufficiently proves that this was not his *first* experiment with frogs.

M. Matteucci devotes a considerable portion of the first chapter of his "Treatise on the Electro-physiological Phenomena of Animals," (a condensed analysis of which we are about to enter upon) to an

account of the investigations and discoveries of Galvani, derived from the recent publication of the Bolognese Academy : —

In the year 1678, the following experiment was made by *Swammerdam* before the Grand Duke of Tuscany; it will be perceived that it is identical with the celebrated experiment of Galvani, though there can be no doubt that the Bolognese philosopher was entirely ignorant of it. Into a cylindrical tube of glass was placed a muscle, the nerve of which was enveloped with a small silver wire, in such a manner that it could be raised without injury. The first wire was passed through a ring, bored in the extremity of a small copper support, soldered to a sort of piston or partition; but this small silver wire was disposed in such a manner that, on passing between the glass and the piston, the nerve could be drawn by the hand so as to touch the copper, *the muscle immediately contracted.*

In the year 1767, the sensation experienced by introducing the tongue between two plates of dissimilar metals, and then bringing them into contact, was described by Sulzer in a work entitled " General Theory of Pleasure."

From documents in the possession of the Institute of Bologna, it appears that Galvani was engaged with experiments on the contractions of the muscles of frogs at least twenty years before the publication of his famous Commentary. The story of the frog-soup may, therefore, henceforth be treated as a romance; and it is unfair to question Galvani's electrical knowledge, from the circumstance of his feeling surprised at observing the contraction of the prepared frog when a spark from the conductor of an electrical machine was drawn near it. Any other philosopher, as Matteucci justly observes, would at that time have felt surprised on witnessing the phenomenon for the first time; and, in fact, in a Latin memoir on electrical light in air of different densities, Galvani sufficiently shows his acquaintance with Electricity, both theoretically and practically; and, in a memoir " on the use and activity of the conducting arc," he suggests that the contraction of the frog may be explained by the *return shock.*

In pursuing his researches, Galvani submitted the frog to the passage of atmospheric Electricity; and it was in these experiments that he discovered that the frog properly prepared is of all electroscopes the most delicate. We cannot read, without a shudder, Galvani's account of a daring experiment made by him April 7th, 1786, whilst engaged in these investigations. He grasped in his hands the rod of an insulated atmospheric conductor at the very moment when lightning was flashing through the skies ! !

The first experiment made with a metallic arc is described in the third part of Galvani's Commentary. The note in which it is found

registered bears date Sept. 20, 1786, and contains, in Galvani's own handwriting, the words "Experiments on the Electricity of Metals."

The primary fact of the contraction of the frog suspended by a *copper* hook from an *iron* stem in the neighbourhood of an electrical machine in action was studied by Galvani with great care; in it he saw that the contraction took place when the extremities of a metallic arc, formed of two different metals, united together, touched at one point the nerves, and at the other the muscles of the frog. In two different parts of his Commentary, Galvani insists on the advantage in this experiment of employing a metallic arc, composed of two *different* metals instead of one. He also states that the contractions may be obtained by uniting with a metallic arc two capsules filled with water, in which the frog is so disposed as to have its lumbar nerves in one of the capsules and its legs in the other. Lastly, he ascertained that the metal composing the arc in this experiment should be chosen amongst the least oxidable metals, such as gold or silver, to obtain the greatest and most prolonged contractions, and he minutely describes all the circumstances which prove that the phenomenon is an electrical one.

Galvani supposes the existence of an *Animal* Electricity, a *nervous fluid* condensed in the interior of the muscle. The nerve, according to him, was only the conductor of the discharge of the two electricities contained in the muscle. The apparent homogeneity of the structure of muscle does not vitiate this hypothesis, Tourmaline presenting an analogous phenomenon. In one part of his Commentary, Galvani expressly says, that many of the contractions obtained with a metallic arc are due *to the arc itself.*

Other of Galvani's memoirs relate to the following subjects:—The use and activity of the conducting arc in muscular contractions;—the action of the arc composed of a single metal;—of water and carbon;—of water alone;—or of the human body;—of a metallic arc of unequal surface;—the contractions excited in a frog when the arc is interrupted, &c. To explain the action of the electrical current on muscular contractions, Galvani supposes that a change is determined in the parts of the brain.

In one of his memoirs on Animal Electricity addressed to *Spallanzani*, Galvani describes the fact of the contractions excited in a prepared frog by bending back its limbs, and bringing them in contact with the lumbar nerves. The perusal of this memoir impresses one (writes Matteucci) with a high sense of the merits of Galvani as an experimentalist. It commences by establishing that the contractions excited in this famous experiment cannot be attributed to anything like *irritation* of the nerve; that the experiment is more likely to succeed if the frog be previously moistened with solution of salt;

that the frog should not be operated upon till it has lost that tetanized condition which it frequently exhibits for a time after its preparation; that the contraction sometimes takes place on separating the nerves from the muscles of the leg; that it also succeeds on establishing the circuit between the nerves and legs, and morsels of muscular substance; and lastly, that contractions are awakened by touching the nerves of the prepared frog at two different points, with a morsel of muscular substance taken from a living animal.

Galvani next studied the discharge of the torpedo, and by means of a prepared frog he ascertained the instant of its discharge; he made also the first observations on the influence of the brain and circulation of the blood on the discharge of the torpedo.

The first philosopher who repeated the experiments of Galvani was the celebrated *Volta*. He admitted the existence of *animal* electricity in the muscles, and in a letter to Professor *Carmenati*, bearing date April 3rd, 1792, he relates all the experiments made by him to demonstrate the sensibility of the frog to electrical discharge; he next applied himself to Galvani's experiments with the metallic arc. He first ascertained that the contractions of the frog ensued on simply touching, with the extremities of the metallic arc, two points of the nervous filaments; he next discovered that it was possible with the metallic arc to produce sometimes the sensation of light, sometimes that of taste, by applying it to the nerves of the eye or tongue; and from all his experiments he drew the rigorous conclusion, that the muscular contractions in the experiments of Galvani and himself were produced by the irritation of the nerves; that this irritation may produce sometimes *sensations*, sometimes *contractions;* and that, lastly, this irritation by the metallic arc was occasioned by an electric current developed by that arc.

Volta imagined that by the contact of any two heterogeneous conductors an action is developed, by which the two bodies become charged with contrary electricities, which may discharge themselves across a third not possessing the same action as the other two.

When it was objected to this hypothesis of Volta, that a *homogeneous* metallic arc was sufficient to cause contractions in the frog, he replied that a very small difference in the extremities of the arc was sufficient to produce an electric current, and that a very feeble current may irritate the nerves of a frog sufficiently to excite contractions. Thus Volta found that when one extremity of a metallic arc was heated and the other *not*—one end polished the other *not*—sufficient heterogeneity was occasioned to excite a current. In vain *Galvani*, *Humboldt*, *Valli*, and *Aldini* opposed to Volta the fact that without any metallic arc the frog may be made to contract, by simply

bending back the limb, and bringing it into contact with the lumbar nerves; Volta answered that it was only to generalize his theory of electro-motive force; that it was only necessary to say that the nerves and muscles of the frog act as the two metals of the arc in order to explain the facts submitted by the partisans of Galvani.

Up to this time the development of Electricity by the contact of heterogeneous metals was only an hypothesis of Volta's. It was in the month of August 1796, that he obtained, by means of the condenser, the first signs of Electricity developed by the contact of two metals, and that he made his immortal discovery of the *Pile.*

The influence of this discovery over all the sciences, and the rapidity with which it spread, caused all opposition on the part of Galvani to fall into oblivion, and fifty years elapsed ere any one, save in an historical work, ventured to make any mention of *Animal Electricity.*

Volta discovered that the electric current, in its passage through the organs of sense, excites there corresponding sensations; he also found that the continued passage of the electric current through a frog weakened its action in the direction of the current, while it was still very strong whilst traversing the animal in a contrary direction.

Among the philosophers who occupied a distinguished rank in the celebrated controversy between Galvani and Volta, the illustrious *Humboldt* stands pre-eminent. His work entitled "Experiments on Galvanism," published in Paris in 1799, and afterwards in Germany, contains a host of excellent and important experiments. No one before him had applied the arc of *Galvani* to so great a number of different animals in various parts of their bodies. The action of the electric current on the movement proper of the intestines, and on the pulsations of the heart, was discovered by Humboldt. He had the courage to remove the skin from parts of his own body by means of blisters, and to subject the denuded parts to the action of the metallic arc. His experiments on the secretions from the wounds formed by the blisters are exceedingly curious. He proved on himself that the action of the electric current was not limited to the sole instants of the commencement and the end of its passage. He studied with great care *Galvani's discovery* of the contractions obtained by bringing the legs of a frog into contact with its lumbar nerves; and he ascertained that contractions may be obtained in the prepared frog, by touching the nerve at different points with morsels of muscular substance taken from a living frog.

Some important observations were made by *Valli* of Pisa in 1792; this experimentalist was the first to show that when an arc of two metals, *pewter* and *silver*, is employed, the most violent contractions

are obtained when the pewter is applied to the nerves, and the silver to the muscles, he ascertained that of all metals *zinc*, when applied to the nerves, has the most remarkable power of exciting contractions, and he noticed that when a frog had lost its sensibility to the passage of a current, it regained it by repose.

Aldini showed that contractions may be excited in a prepared frog by holding it in the hand, and plunging its nerves into the interior of a wound in the muscle of a living animal.

Some interesting observations on the sensations excited in animals by the passage of the electric current through them,—on the influence of cold and heat:—on the muscular irritability excited by Electricity,—on the reproduction of nervous substance,—on the action of certain poisons on the phenomena of muscular contraction, &c. were made by *Fowler*, and are alluded to in the *Bibliotheca Britannica*, May 1796.

The following is a summary of some of the contributions made by *Lehot* to the science of animal Electricity. He ascertained that in a recently killed animal, contractions are excited by the electric current in whatever direction it may be applied; but, when the vitality of the animal has become diminished, if the current be sent in the direction of the ramifications of the nerve, contractions are excited only at the *commencement* of the current: the contrary takes place when the current is directed contrary to the ramifications of the nerves, *i. e.* in this case the contractions only take place when the current ceases. By studying the sensation excited by the current on the organs of taste, *Lehot* arrived at a most important result: the current which traverses a nerve in the direction of its ramifications excites a sensation when it ceases to pass, though this influence is only exerted at the *commencement* of its passage when the nerve is traversed in a direction contrary to its ramifications: the later experiments of *Bellingeri* and *Marianini* entirely confirm those of *Lehot*.

After a long interval, during which the name of Animal Electricity was scarcely mentioned in science, the study of it was resumed by *Nobili*, who published a memoir on the subject in the Bibliotheca Universelle, 3d Nov. 1827. It is to this philosopher that we are indebted for the great improvements in the galvanometer. He prepared a frog *à la Galvani*, and plunging its two extremities (lumbar nerves and legs) into two capsules of salt water, he united the two vessels by filaments of moistened cotton; the frog as in Galvani's experiment immediately contracted: he then removed the cotton and shut the circuit by plunging into the capsules the platina extremities of his galvanometer, a deviation amounting to 10°, 20°, and even to 30° was obtained, indicating an electrical current from the *feet to the head* of

the animal. Nobili called this current the *current proper* of the frog, and he found that it remained for several hours after the preparation of the animal, and that it could be increased by disposing the animals in a pile. Nobili endeavoured to explain this current on thermo-electric principles : to an unequal temperature in the nerve and muscle occasioned by *evaporation*.

Nobili appears to have studied more closely than any of his predecessors, the contractions excited in a frog by the passage of a current through its nerves in different directions, and according to the degree of vitality remaining in the animal. His ideas of *tetanus* and of *paralysis* are well deserving the attention of medical men.

We shall now proceed to give an account of the more recent researches of Matteucci, but it will be necessary, previously, to describe as briefly as possible, the instruments that he employed in his experiments, and the precautions to be observed in manipulating with them, without attending to which no success can be expected in the repetition of his experiments.

The Galvanometer.

For electro-physiological experiments the galvanometer is better in proportion as its wire makes more convolutions around the needle. They are now constructed with 3000 convolutions. The wire is ·023 in. in diameter, and is made of very pure copper.

The sensibility of the galvanometer is greatly increased by employing the *astatic system* instead of a single needle as first recommended by Nobili. Two needles as nearly as possible alike in size, temper, and magnetization are fixed in a slender brass stem, or in a straw, with their opposite poles facing each other. One of the needles is placed within the coil and the other above, the system being suspended by a single filament of untwisted silk. Were it possible to obtain the two needles exactly equal in their degree of magnetization, they would evidently be insensible to terrestrial magnetic action, and such an instrument would be perfect, the most feeble electrical current causing very great deviation. Such a galvanometer would not, however, be adapted for the comparison of currents of different intensities, since the needles would remain in equilibrio in all positions, and it is necessary in making an observation to commence with the needles at zero. In constructing an astatic galvanometer therefore, one of the needles is made somewhat more magnetic than the other, so that the whole system should have a slight degree of directive force. In the most perfect instruments there is appended a simple mechanical contrivance by which the upper needle is always brought back exactly to zero.— The sensibility of a galvanometer is judged of by the slowness of the

oscillations of its magnetic system, it may be considered sufficiently delicate, if they are at the rate of *one a minute:* but it not unfrequently happens that either from too strong a current being sent through the instrument:—from the contiguity of a magnetic bar:—from the reaction of the magnetism of the two needles, or from some difference in their dimensions and the quality of the steel, the galvanometer after a time loses a portion of its sensibility. By subjecting the needles to the following treatment, the original delicacy of the instrument may be restored, but the operation requires considerable care and tact, and it is not an unusual occurrence to spend whole days in the arrangement of a galvanometer for a course of delicate experiments. The first thing to be done is to note carefully the duration of an oscillation, then to ascertain which is the weaker of the two needles, for this purpose the upper one is first removed; if now the system remain in its position, it is clear that the needle removed is more feeble than the other; if, on the other hand, the needle which remains returns of itself, it is evident that the needle taken away was the stronger of the two. The weak needle is then remagnetized by passing a small bar magnet a few times along it from end to end, taking especial care not to arrest the motion of the bar or to return it on itself: the needle is then returned to its place, and the duration of an oscillation of the system again determined, if it has become greater, a proof is obtained that the sensibility of the galvanometer has been increased: should too much magnetism have been given to the needle, a portion must be taken away by reversing the motion of the magnetising bar along it; this is a nice operation and frequently gives a good deal of trouble.

It is usual for the maker of a galvanometer to mark on the scale an indication by which the experimenter is enabled to ascertain from the direction of the deviation of the needle the direction of the current. For this purpose we find marked on the scale two letters A and B, the same two letters are also marked on the side of the two extremities of the galvanometer. By a first experiment, the operator determines once for all, by means of a single electro-motive element, zinc and copper for instance, to which letter the point of the needle is carried according as the current enters into the wire of the instrument by the extremity A or B; of course in the single voltaic pair, the current is from the copper to the zinc.

Before commencing a series of experiments, the marked indications of the galvanometer should be verified, which may easily be done by plunging the extremities of two wires, platina and copper, into distilled water, and allowing the current of Electricity thereby determined to pass through the instrument, the direction of the current is from

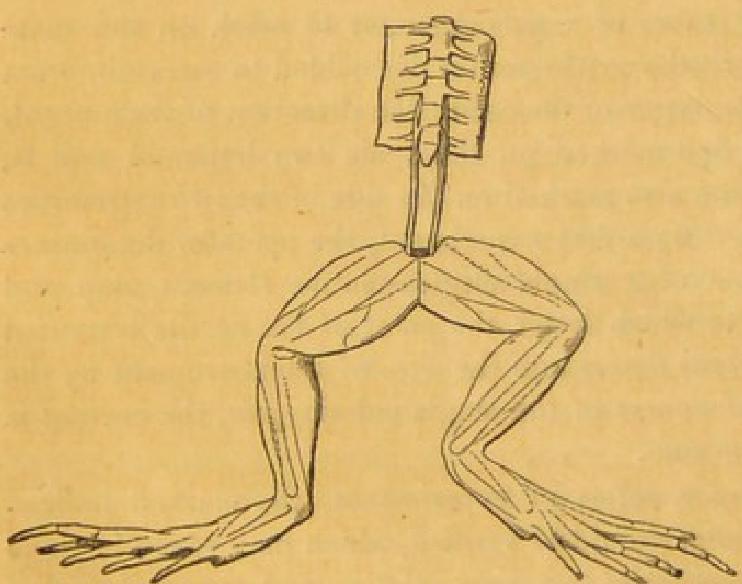
the platinum to the copper through the galvanometer. It is almost unnecessary, perhaps, to say that the operator must be careful that no iron or steel should be allowed to be near the galvanometer, and that it should be placed on a firm and even surface.

The prepared or Galvanoscopic Frog.

This, if renewed from time to time, is the most sensible apparatus that we possess; it is, moreover, very exact in its indications, if care be taken to expose the nerve well, and to close the circuit with the nerve alone, without ever including any portion of the muscle of the leg. It not only indicates the existence of the electric current, but it helps to determine its direction. When the frog is a little weakened, we almost always perceive the leg contract when the circuit is closed, and the limb remain motionless when the current is opened, provided the current be directed in the nerve from the nerve towards the leg. When these phenomena take place in a contrary direction, it is because the current is directed from the leg towards the nerve. We have only then to close the circuit with the nerve of a galvanoscopic frog, and to open it the instant afterwards, in order to establish in which of the two instants the contraction takes place. To confirm the indication of a first experiment, the position of the nerve of the galvanoscopic frog is reversed: if the first indication were exact, the leg ought to contract in the latter case, when it remained tranquil in the former.

Preparation of the Galvanoscopic Frog.

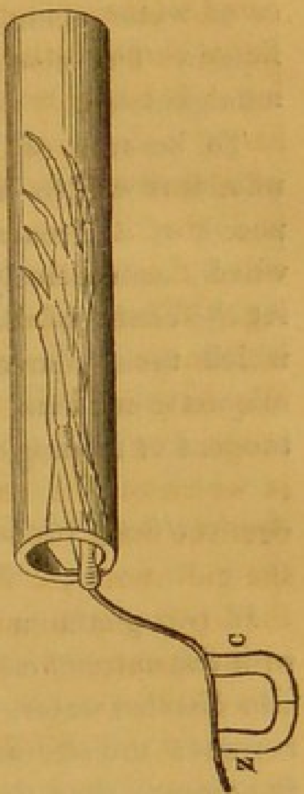
Fig. 1.



A lively animal is selected:—two-thirds of the body just below the front paws are cut off, and the hind legs and pelvis, with a piece of the spinal cord, are preserved and skinned: then, by introducing the scissors between the lumbar nerves and the pelvis, and cutting the latter in two places, we obtain the frog prepared *after Galvani's plan;* it is shown in Fig. 1.

In order to employ the frog in the study of the electric current, the latter must be passed along the nervous filament alone of the frog. For this purpose the frog, prepared after Galvani's plan, is cut in half, and by a very easy preparation, we are enabled to remove from the half frog, the bone and muscles of the thigh, preserving its nerve untouched. In this manner we end by having a frog's leg, to which is attached a long nervous filament, composed of the lumbar portion of the pelvis, and the crural portion of the thigh. We have only to introduce this leg into a tube of varnished glass, to have an instrument very sensible to the passage of the electric current. It is shown in Fig. 2. To employ this kind of galvanoscope, the glass tube is taken by the end opposite to that into which the leg of the frog has been introduced, and the nervous filament which is hanging outside the tube, is made to touch the two points of the electromotive element that we desire to study. When the nervous filament is traversed by an electric current, the leg is seen instantly to contract. Two slips of moistened paper may be placed on the two points of the electromotive element to avoid any irritation of the nerve by direct contact.

Fig. 2.



The Electroscope.

The instrument employed by Matteucci, in examinations for the existence of electricity of tension, consists of a bell-glass varnished throughout its upper part, and furnished with a hole at its centre, through which there passes a brass rod, which is secured by mastic. The end of this rod outside the bell is terminated by a small brass ball: on the other is stuck a very narrow slip of gold leaf five or six centimetres (2 or $2\frac{1}{2}$ in.) long. The bell, which is open at its lower part, rests on a wooden base, in which are fixed perpendicularly, and opposite to each other, two dry piles* arranged so as to be in connexion at their base, and to have poles of a contrary nature upwards. The gold leaf is thus suspended between two contrary poles, and remains in equilibrio by the equal and contrary action to which it is subjected. When the leaf is electrized, it moves toward the pole of one of the piles which has Electricity contrary to its own. This electroscope is extremely sensible, and very easy to manage. We

* For an account of the construction and properties of the *dry pile*, see Lectures on Electricity, page 142.

have only to notice to which of the piles the gold leaf approaches, in order to learn immediately the nature of its electricity.

Lastly, in electro-physiological experiments, we often have occasion to refer to an electric current of a certain intensity, and a constant force. The pile to be employed for the purpose may be composed, as usual, of zinc and copper plates: the copper plate must be plunged into a solution of sulphate of copper contained in a glass vessel, a kind of leather bag filled with a solution of common salt, or of water acidulated with sulphuric acid, must be placed in this liquid. The zinc plate is immersed in the bag, and it should be amalgamated.

To be sure of the constancy of the current obtained with this pile, it is well to have a tangent compass. This apparatus is composed of a circular silk covered copper ribbon, the extremities of which, conveniently bent, are immersed in cups containing mercury. At the centre of the circle is suspended a very small magnetic needle, which turns above a scale: the circle is placed in the plane of the magnetic meridian. The intensity of the current is measured by the tangent of the angle of deviation.

Application of the Galvanometer to the Study of Electro-Physiological Phenomena.

If two platinum plates, as nearly alike as possible, be connected with the extremities of a delicate astatic galvanometer, and plunged into distilled water, it is very rarely that there is no sign of an electric current; the electro-physiologist must always be on his guard against the current thus developed,—he will otherwise be led to very erroneous results. This is the more important, as in all his experiments he will have to touch with the extremities of his galvanometer animal parts composed of solid bodies, or of saline solutions which may act chemically and in an unequal manner on the plates. It is indeed extraordinary how small a mechanical difference in the surfaces of plates of silver, copper, or iron, alike in size, will determine an electrical current even in distilled water. If one plate be a little more polished than the other; if one be warmer than the other; if one be immersed after the other, a deviation of the needle of the instrument will take place which it is almost impossible entirely to destroy. The plates terminating the extremities of the galvanometer should always therefore be of platinum, having an equal extent of surface, and constantly the same; they should, moreover, be made to touch the animal parts in which an Electric current is sought at the same time, for Matteucci found that an electrical current is always determined when one plate is immersed (even in distilled water) *after* the

other: the direction of the current being from the plate immersed *last* to that immersed *first*. The terminal plates employed by Matteucci, are about one-fifth of an inch wide, and are each fixed with a handle of wood or bone. The extremities of the galvanometer wire are soldered to these two plates, and the whole of the handles and plates are covered with a coating of sealing wax varnish so as only to leave the extremity of the plate disclosed for a length of one-fifth of an inch. Two platinum plates of equal surface are thus obtained.

The following experiment made by Matteucci, will serve to show how easy it is to be led into error in making electro-physiological experiments with a delicate galvanometer. He took a lock of cotton two inches long, one-half of which he saturated with distilled water, and the other with blood taken from a pigeon, which had been agitated to prevent coagulation. He employed the lock thus prepared to form an arc of communication between two capsules, one of which was filled with distilled water, the other with the same pigeon's blood. He next so prepared the plates of his galvanometer, that they should give no current when plunged into water; this he effected by leaving them for a time immersed in a liquid similar to that about to be experimented upon, and he then closed the circuit with these plates, and obtained a current amounting to 12° directed in the lock from the blood to the water. The experiment was several times repeated with the same result.

In passing from one electro-physiological experiment to another, Matteucci also warns us to beware of the *secondary current* which is always produced, especially with platinum plates, when either the circuit is a second time closed, or when they are removed to another liquid. This current has a contrary direction to the first, and must be guarded against by leaving the plates for a certain time in the liquid before making the experiment.

The Muscular Electric Current.

Proof of the existence of an electric current circulating through the muscle of a living animal is obtained by introducing into a wound formed in the muscle of a living animal the nerve of a prepared frog, in such a manner that the extremity of the nerve shall touch the bottom of the wound, and another part, the edge; the frog instantly contracts. In this experiment the prepared frog is *insulated*, it is not, therefore, to be confounded with the previous one of *Aldini*, in which the frog was held in the hand, the contraction obtained in this case being due to the *current proper* of the frog, which circulated at the same time through the frog, the body of the observer, the earth, and the animal touched, and which did not take place at all when the

operator was insulated. The muscular electric current may be detected in animals for some time after death, but when it has once ceased, it cannot again be renewed. It is found in *warm* as well as in cold-blooded animals.

By forming a *muscular pile*, Matteucci succeeded in giving considerable deflection to the needle of his galvanometer.

The pile was thus formed. Five or six frogs were prepared and cut in half after Galvani's plan, great care being taken not to injure the muscle. The thighs were then cut in half, and so disposed that each half thigh should touch the following, the faces of each turning the same way, and the interior of one coming into contact with the exterior of the next; so that one of the extremities of the pile was formed of the interior of the muscle, while the other extremity was formed of the surface. The prepared plates of the galvanometer were immersed in the cavities of the board on which the pile was disposed, which cavities contained a liquid similar to that in which the plates had been prepared, the deviation amounted to 15°, 20°, 30°, 40°, 60°, according to the number of half thighs; and if the frogs were sufficiently active, a duration of 3° or 4° was obtained with two elements, of 6° or 8° with four elements, of 10° or 12° with six elements, and so on: the liquid in the cavities being distilled water; but when a liquid of a better conductibility was employed, the deviations were considerably greater, though always in the same direction, viz., from the interior of the muscle to the surface. On leaving the circuit closed, the needle gradually returned to zero.

Similar experiments were made with eels, cut into pieces, and so disposed that the muscular surface of one of the elements should touch the internal face of the next. With a pile of five elements, a deviation of 28° was obtained, with two elements a deviation of 10°, always in the same direction, viz., from the interior of the muscle to the surface, with a pile formed of muscular slices cut from the backs of tenches, analogous results were obtained; and by experimenting on warm-blooded animals, such as pigeons, chicken, oxen, sheep, &c., ample evidence was obtained to prove that whenever the interior of the muscle of a recently killed animal is by the aid of a conducting substance brought into contact with the surface, an electrical current is established, directed from the interior to the surface, the intensity of which varies with the animal, and is increased in proportion to the number of elements disposed in the pile.

In all these experiments, Matteucci was scrupulously careful in the management of his galvanometer: and the regular increase of the deviations with the number of elements, their uniform direction, whatever the liquid employed in the cavities, and the instantaneous

reversal of the current by reversing the disposition of the elements, are facts which fully prove the correctness of the conclusion at which Matteucci arrived, namely, that the current, whatever its source, had its origin in the muscular masses, and was not due to adventitious circumstances introduced in the manipulation.

By closing the circuit with the nerve of the galvanoscopic frog instead of the galvanometer, a more delicate and perhaps a less questionable method of detecting the muscular electric current was obtained. The return of the needle of the galvanometer to zero, on leaving the circuit closed, is easily accounted for, not only from the gradual dimunition of vitality in the muscle, but also from the *secondary current* developed in the terminal plates, which circulates in a contrary direction to that of the pile.

Matteucci next instituted a series of experiments on living animals, the general results of which were the same as those on animals recently killed, the current in all cases moving from the interior of the muscle to its surface, or more generally from the interior of the muscle to any conducting substance in communication with that surface.

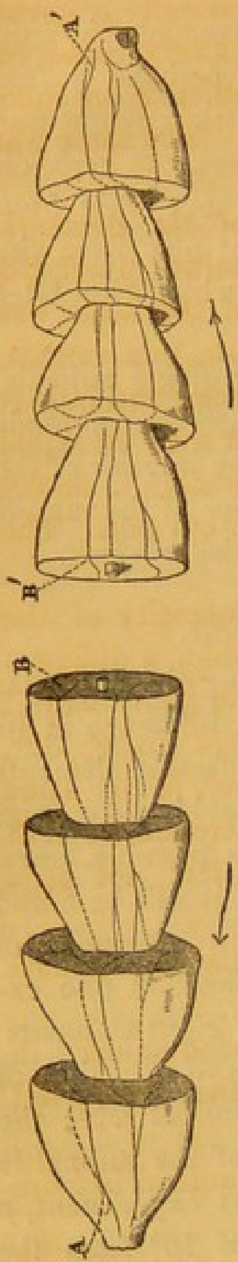
The Laws of the Muscular Electric Current.

The first thing that arrests the attention in studying the muscular current in the muscles of different animals, is the difference in its duration in different cases. If an equal number of muscular elements be prepared from different animals, frogs, pigeons, rabbits, &c., and examined one after the other with as little delay as possible, commencing sometimes with one, sometimes with another, it will be found that the deviations afforded by each, though in point of number of elements they are equal, are remarkably different: thus, in one experiment made by Matteucci, with three piles each of eight elements the pile formed of muscle of rabbit gave a deviation of 8°; that of pigeons, a deviation of 14°; that of frogs, a deviation of 22°; the current diminishing with the elevation of the rank of the animal in the scale of creation. Fifteen minutes after the first experiment, a deviation of 4° was obtained from the first pile; of 10° from the second; and of 16° from the third. One hour after the signs of the electrical current in the *rabbit* pile had entirely disappeared, from the *pigeon* pile a deviation of 2° or 3° could with difficulty be obtained; while from the *frog* pile there was still a deviation of 8° or 10°; and, even after twenty-four hours from the latter, a deviation of 2° or 3° could be made apparent.

In studying the laws of the muscular electric current, M. Matteucci availed himself of the *differential current* which is produced by causing two currents to pass through the galvanometer in inverse

directions, the deviations of the needles being of course in the direction of the strongest current. In applying this principle to the study of the varying circumstances of the muscular current,

Fig. 3.



the two piles to be compared, both consisting of the same number of elements A B, A′ B′, Fig. 3, are opposed to each other, as shown in the figure, their extremities being plunged into two cavities of the wood, and the circuit shut with the galvanometer, by dipping the terminal plates in the liquid of the extreme cavities; if any difference exist in the two piles, it will be immediately disclosed by the differential current in the direction of the strongest. In this manner Matteucci studied the influence on the intensity of the current exerted by the mass of muscle: he compared two piles opposed one to the other: one of these piles had each of its elements formed of one half thigh of a frog, whilst those of the other were formed each of two or three half thighs placed one on the other. He never obtained any very distinct signs of a differential current: the same was the case when two piles composed of muscle of rabbit were compared, one of these piles having its elements made up of large muscular slices, and the other of small slices from the same muscle. The small differential current that was obtained was in favour of the pile, the elements of which consisted of the larger quantity of muscle. Two similar piles, formed one of half thighs of frogs that had been subjected to a very low temperature, the other of an equal number of half thighs, cut from frogs in their natural state, gave a differential current of 35° to 40° in favour of the latter. The pile of cooled frogs gave from 15° to 16°, the other 45°; with warm-blooded animals the influence of temperature was less marked.

When the frogs were submitted to sudden changes of temperature, being quickly cooled and then suddenly introduced into water tolerably warm, it was noticed that they not only recovered their motion, but became even more vivacious than before, and when formed into a pile they gave a stronger current than a pile composed of an equal number of frogs that had not been submitted to alterations of temperature. During the intense heat of summer the muscular current was much more feeble, and Matteucci noticed that the frogs

were much less robust than at other seasons of the year, and their muscles less red and consistent.

It does not appear that the integrity of the nervous system has any influence either on the direction or intensity of the muscular currents, for when all the great nervous filaments were carefully removed from ten prepared frogs, no differential current, or only a very feeble one was obtained, by opposing a pile of such frogs to another of an equal number of elements from frogs in their normal state. The same was the case with pigeons, and other animals.

Again, on comparing together two piles, each of six elements, the frogs composing one having had their lower extremities paralyzed by a red-hot iron, a differential current in favour of the latter was obtained, and by submitting frogs to the action of opium, nux vomica, carbonic acid, and other narcotics, so as to stupefy them, and in that state arranging them in a pile, and comparing them with an equal number of frogs in their natural state, Matteucci was unable to detect any variation either in the intensity or direction of the current. The same results were verified with pigeons.

The influence of *sulphuretted hydrogen* on the intensity of the muscular current was, on the contrary, very remarkable, a differential current of 26° being obtained in favour of frogs in their natural condition; a pile of twelve elements of common frogs giving 30°, that of the poisoned frogs only 5° or 6°, both, however, in the same direction. The same was the case with pigeons, a differential current of 15° being obtained in favour of the bird that had not been poisoned.

Matteucci thus sums up the principal results of his experiments on the muscular current.

1°. The intensity of the current varies for cold-blooded animals in proportion to the temperature of the medium in which they have lived for a certain time.

2°. Its duration after death is so much the *less* as the animal is more elevated in the scale of creation.

3°. The intensity varies with the degree of nutrition of the muscle, and it is always strongest in those muscles which are gorged with blood and inflamed.

4°. It is altogether independent of the integrity and activity of the motor and sensorial nervous system.

5°. The influence of narcotic poisons is null, or very feeble, on this current.

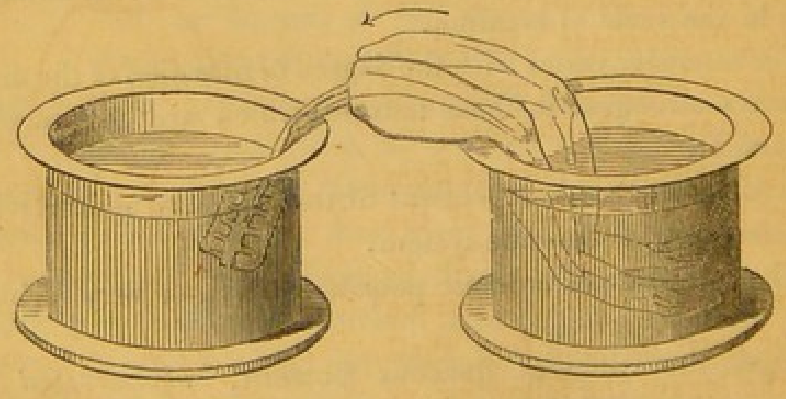
Amongst the different gazeous poisons, *sulphuretted hydrogen* alone acts in a remarkable manner in weakening the intensity of the muscular current, the direction of which is in every case the same.

More recently* M. Matteucci has added some further interesting and important information on the subject of the muscular current. He has obtained signs of tension at the two extremities of his muscular piles by the aid of the condenser. He has also obtained electro-chemical decomposition by the current; and by a great number of experiments he has established that the intensity of the current is in proportion to the activity of respiration, and that it is proportionate to the rank of the animal in the scale of creation, whilst its duration after death varies in an opposite ratio. He has further studied the influence of different gases, and has ascertained that the muscular pile acts equally in atmospheric air, in oxygen, in very rarefied air, in carbonic acid, and in hydrogen. In the latter gas the deviation of the needle of the galvanometer remains constant for several hours, a singularity not referrible to an action of the gas on the muscles, but to phenomenon of secondary polarity. The nullity of the action of the different gases named upon the intensity and duration of the muscular current proves that the origin of the current is in the *muscle itself*, whether living or taken from the animal a short time after death; and that it is in the organization of the muscle, and in the chemical actions going on within its very structure, that the current exists, is further proved from the fact that from piles formed of fibrine, separated from the blood of a recently killed ox, no signs of a current can be obtained.

The Current Proper of the Frog.

Before giving any account of the experiments of M. Matteucci in relation to this subject as described in his treatise, we may state that the results of his recent labours have led him to the conclusion that the current in question does not belong exclusively to the frog, but that it is manifested in all the muscles of all animals, provided that these muscles present at their extremities an unequal tendinous

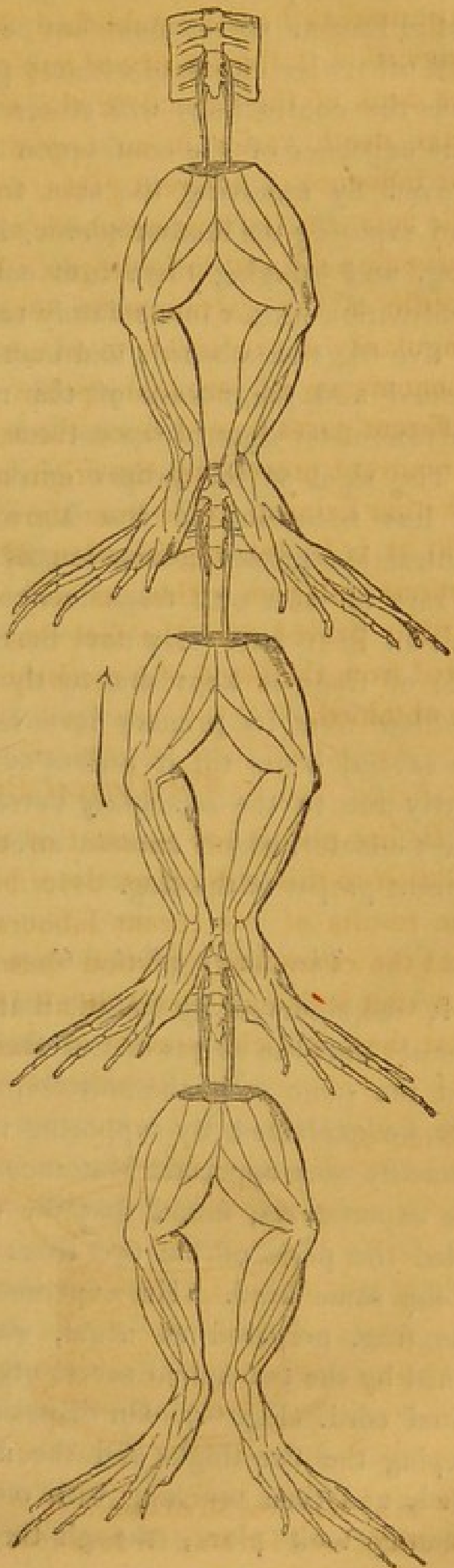
FIG. 4.



* In a letter from M. Matteucci to M. de Humboldt, "Comptes Rendus" (April 14, 1845), see Phil. Mag. for June 1845, and vol. ii. Elec. Mag.)

termination. All the muscles that have on one side the tendinous extremity more compacted, more condensed than on the other, give the current directed in the muscle from the tendinous extremity to the surface of the muscle. This result he has verified on all the muscles of the frog, on the muscles of the superior as well as those of the inferior limbs; on the muscular masses of the pigeon, rabbit, and dog. "If," says he, "I have rightly understood the latest anatomical labours made upon the structure of muscles, or their relations with the tendons and sarcolema, I cannot hesitate in regarding the proper current, or that from the tendon to the surface of the muscle, as the most simple case of the muscular current. The tendinous fibres are continued among the muscular fibres, whilst the sarcolema merely envelopes the said muscular fibres. This result is rendered still more probable when we call to mind that the same laws preside over the proper current and the muscular current.

Fig. 5.



If a prepared frog be placed, as Fig. 5, with its lumbar nerves plunged in one capsule filled with water, and with its legs in another, and the circuit completed with the galvanometer, a deviation of greater or less extent according to circumstances, is obtained, indicating an electrical current from the *feet* towards the *head* of the animal. If several frogs be so arranged on an insulated surface that the nerve of each frog shall touch the legs of the following, as shown in Fig. 5, or, still better, if they be arranged like the *couronne*

of Volta, the signs of this current, which is called the *current proper*, are increased, and at the same time the frogs are observed to contract, and this contraction Matteucci calls the *contraction proper*. Certain precautions are required to obtain these contractions proper; for instance, the pelvis of the frogs must be entirely removed, and the entire lumbar nerves must not be plunged in the liquid, the current will otherwise circulate without passing over the lumbar nerves, and thus the contractions will either not take place, or be very feeble. The existence of the contraction proper in the living animal may be proved by removing the skin from the legs of an active animal, and exposing the lumbar nerves; by then bending back the legs of the frog, and bringing them into contact with the lumbar nerves, the contraction proper immediately takes place. By extending a number of live frogs on a board, and making contact between the legs of one animal and the nerves of the next, Matteucci obtained with the galvanometer signs of the current proper.

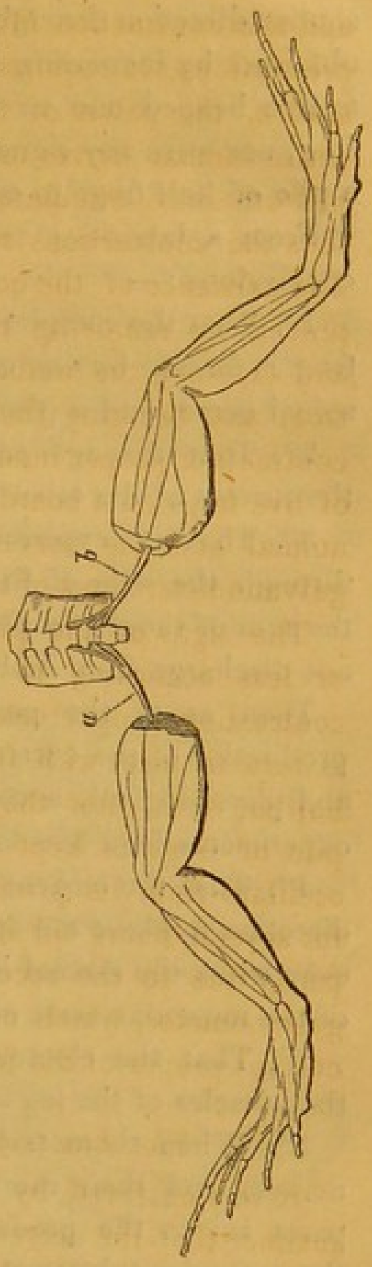
The signs of the proper current of the frog is prolonged more or less according to the degree of vitality of the animal. The contraction proper ceases usually after ten or fifteen minutes, and it is rare to meet with frogs in which the phenomena can be observed half an hour after they have been prepared. When the circuit of a pile of frogs is kept shut by the galvanometer, the needle begins to oscillate from its primary deviation, and continues gently to descend for several hours till it arrives at zero. This diminution is, however, partly due to the secondary current developed in the plates of the galvanometer, which current circulates in a contrary direction to the current proper of the frog.

The Laws of the Current Proper of the Frog.

It was observed by Nobili, that on disposing the frogs in such a manner that the nerves of one should touch the nerves of the other, and the same with the muscles, no contraction took place in either, this he explained by supposing that in this case the electro-motive elements were opposed. Matteucci, however, in repeating and varying the experiments, found that the contractions always took place provided the parts of the two frogs touched simultaneously were not of the same kind. He experimented in the following manner:— The frog, prepared as usual, was separated into two halves, but joined by the two spinal nerves organically united by a small piece of spinal cord. (Fig. 6.) On disposing this frog on an insulated plane, keeping the two thighs and the nerves attached to them well separated, and then touching with one leg the other thigh, contraction instantly took place, though they failed on touching the legs one

with the other. Still stronger contractions took place by bending back upon one leg the nerves of the other, so that the spinal cord came into contact with the muscles of the thigh. In this manner, with a very lively frog, contractions were obtained on touching one leg with the other. Frequently the contraction is observed in one of the limbs when the circuit is shut, and in the other when the circuit is opened.

Fig. 6.



By employing a galvanometer, and touching with one plate the leg and with the other the thigh, indications of a current directed from the leg to the thigh and from that by the nerve to the other thigh were obtained. If the frog was particularly lively, and experimented with as soon as prepared, it happened that on touching the muscles of one thigh with those of the other leg, contractions were awakened in the two limbs as well on opening as on shutting the circuit, but when the animal was not very lively, or was not experimented with for some minutes after preparation, the limb alone, the muscles of the thigh of which were touched, contracted on shutting the circuit, whilst the other limb remained tranquil. On opening the circuit, the contrary was the case. From these experiments, each of the limbs of the frog are considered by Matteucci as a *complete electro-motive element*, and hence it might be anticipated that the contractions would fail on touching symmetrical parts, since the two currents of the two limbs would circulate with an equal intensity, but in contrary directions. The two limbs of a prepared frog being so disposed that the nerve of one limb and the paw of the other should dip in the liquid of a small glass, and the other paw and nerve in the liquid of another glass, no signs of a current could ever be obtained by closing the circuit by a galvanometer, evidently because those portions of the currents developed in the two limbs which passed through the instrument moved in contrary directions; but if, on the other hand, the disposition of the limbs was such that in the one vessel there were plunged the two nerves and in the other the two legs, signs of a

current *were* obtained, because in this case those portions of the current which did not circulate through the animal itself took a similar direction through the galvanometer. No increased effect was obtained by increasing the number of frogs, the current from ten or twelve heaped one on the other being no greater than with a single frog, nor were any signs of a differential current obtained by opposing a pile of half frogs to one of entire frogs.

From a laborious series of experiments, M. Matteucci draws the conclusions :—

1°. That the complete electro-motive element of the current of the frog is formed by one of its limbs, that is to say, of a leg, a thigh, its spinal nerve, and a piece of the spine.

2°. That through each of the limbs of the frog there circulates the current of the other limb, whenever the two legs are made to touch.

3°. That in experiments with the galvanometer we only get, through the wire of the instrument, the current which results from the sum of those two portions of the current of the two limbs which do not discharge from limb to limb.

Then as to the parts of the frog which are necessary for the production of the current proper, and to the circumstances, anatomical and physiological, according to which its intensity varies, Matteucci's experiments lead him to the following conclusions :—

1°. That the current proper of the frog persists in its intensity and direction *without* the spinal cord, or the spinal and crural nerves, and even when the animal is deprived of all the visible nervous filaments of the muscular mass of the thigh.

2°. That the electro-motive element of this current is confined to the muscles of the leg and of the thigh organically united.

3°. When there is left in the prepared frog the spinal cord, its nerves, and their ramifications through the muscles, these nervous parts act in the production of the current in the same manner as the muscular substance of the thigh.

The influence of different gases on the current proper of the frog was next examined. Carbonic acid at first exerted no influence, but after a time it seemed to diminish the sensibility of the nerve, causing the contractions proper to cease; by exposing the animals to pure oxygen gas before preparing them no effect was produced; but Matteucci found that boiling water had the effect of extinguishing the current altogether.

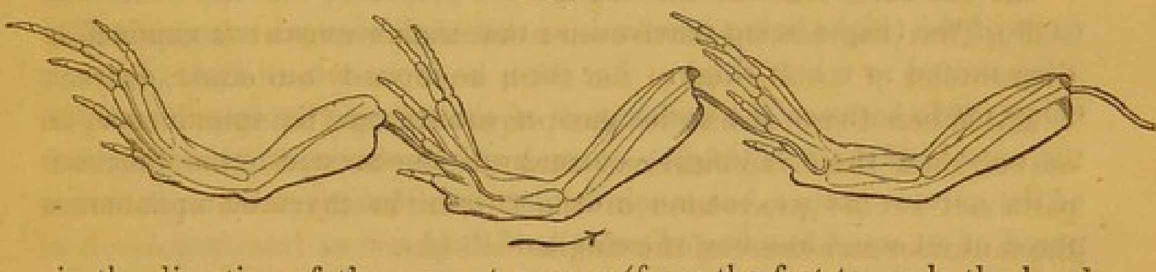
With a pile composed of legs alone, a current was produced equal to that from the same number of entire frogs; the direction of the current being from the extremity towards the head, but with a pile composed of thighs alone, sometimes with the nervous filament at-

tached, sometimes with it removed, a very feeble current only was obtained. When the tendinous surface of the limb was removed as much as possible, a current was obtained sensibly *more intense* than when the tendon was untouched, proving that the current proper may be obtained from the leg alone. Matteucci did not find with Galvani and Humboldt, that the contractions proper became feebler by removing the tendons from the muscles of leg: on the contrary, he could find no other difference in the two cases, than that the contractions were extinguished quicker when the tendons were removed. When the blood was drained from the bodies of the animals;—when they were poisoned by sulphuretted hydrogen, or stupified by nux vomica, very feeble signs of the current or contraction could be obtained. When slight wounds were inflicted on the muscles of the thighs of frogs, so that they became red and inflamed, but did not lose blood, both the current proper and the contraction proper were increased; on the other hand, the effect of *cold* was always to diminish, and frequently to destroy, both, though both were always regained by restoring the animal to its proper temperature.

The Function of the Nervous System on the Muscular Electric Current, and on the Current Proper of the Frog.

From a pile of four frogs' legs, to which were left attached a long nervous filament composed of all the lumbar part and of the crural part concealed in the thigh, the nervous filament resting on the extremity of the leg of each element, (Fig. 7,) a deflection of 4° or 5°

FIG. 7.



in the direction of the current proper (from the feet towards the head of the animal) was obtained: but when in the same pile the nervous filament of each leg was bent back, and contact made between the inferior and superior extremities of the limb, a deflection of 10° or 12° was obtained. The presence of the nerve has, therefore, no other effect than that of weakening the current, which is very natural, if we reflect on the bad conductibility of the nervous substance, on the greater length of the circuit, its small diameter, &c.

Matteucci prepared eight frogs' thighs by removing the legs and leaving the lumbar nerves; he then cut the thighs nearly in half, taking care to preserve the nervous filaments, and formed them into a pile,

by connecting the nervous filament of one thigh with the muscular surface of the next half thigh. This pile gave him 12° muscular current, which in this case was directed from the interior of the muscle to the *nerve* in the animal, or rather from the nerve to the surface of the muscle. In this experiment, the nervous filament acted as the interior of the muscle in which it ramified.

The same experiment may be made with the legs of pigeons and rabbits; for this purpose the nervous filament of the limbs or the crural nerve which lies beneath the muscle must be exposed, and the pile formed by bringing the nerve of each element into contact with the surface of the muscle, the current developed is always feebler than when the nervous filament does not form a part of the circuit.

The nerve may, therefore, be considered as acting merely the part of a bad conductor, representing the electrical state of that part of the muscle nearest to it.

The following experiments confirm this: — Let a number of frogs' thighs be prepared by divesting them of their legs and lumbar nerves; let them be cut in half, removing the *inferior* half thigh instead of the *superior* as in the preceding experiment; and then let them be formed into a pile, making contact between the nerve and the interior of the muscle, a muscular current directed from the interior of the muscle to the surface (the nerve in this case) will be obtained. Here, then, we find the same direction in the muscular current relatively to the same parts, interior and surface of the muscle; as to the nerve, however, the direction of the current is reversed.

Again, let a number of half frogs be prepared, the upper half of each of the thighs being removed, so that each element is composed of a leg united to a half thigh. Let them be formed into a pile, contact being made between the under part of the leg and the interior part of the muscle of the half thigh, a current will be obtained in the direction of the current proper, but much feebler than that given by a pile composed of an equal number of entire half thighs.

This result is a necessary consequence of the existence in the animal of a current proper and a muscular current. It must be remembered, that the leg alone of the frog gives the current proper, and that the muscular current given by the half thigh is directed always from the interior of the muscle to the surface. It follows, then, that in this pile there must be *two* currents circulating in contrary directions, which necessarily mutually weaken each other, and since in this disposition a current in the direction of the current proper is obtained, it follows, that in the limbs of the frog this current is more intense than the muscular current.

The function of the nerve seems to be clearly pointed out by

these experiments, its character is always that of a feebly conducting body, which represents the electrical state of that part of the muscle which is nearest to it.

Theory of the Cause of the Muscular Electric Current.

It is a well-established fact that the muscular electric current is quite independent of the integrity of the nervous system: that it makes its appearance in the muscle, when the circuit is established by any conductor whatever, between those two parts of the muscle which differ the most in structure and function; that it is from the interior of the muscle to the surface that the current is directed, and that the signs of this current remain for a length of time, greater or less, after the death of the animal, according as the animal is lower or higher in the scale of creation, and from the influence exercised on the current by the circulation of the blood, by the redness of the muscular masses, their state of inflammation, &c. The conclusion may be drawn that, for the production of this current, the organic disposition which constitutes the muscular fibre is as necessary as the action, whatever it may be, that maintains it in such state. It is not unnatural to suppose that Electricity may be developed by the nutrition of the muscle. It is a fact well established, that the action of oxygen on arterial blood is conveyed to all parts of the living body, that all parts of the organism are constantly renewed, and that a sort of combustion accompanies this renewal, by which there is developed carbonic acid, and disengaged heat, and it cannot be denied that such chemical action cannot take place without the development of Electricity.

Let us take an example from a case in which inorganic materials are concerned.

When a metallic plate, plunged in acidulated water, is oxidized by the oxygen of that water, and then dissolved in the acid, it is admitted that during that action an enormous quantity of Electricity is developed, and as fast as the two electrical states are disengaged they recombine and become neutralized. This is not the case with those arrangements which we adopt for the purpose of obtaining the Electricity which is set free during chemical action. By joining to the dissolving metallic plate a second plate not acted on by the liquid, the circuit is established, and the electrical current circulates from the metal attacked to the other in this liquid, and from that to the first, through the metallic arc.

The metallic plate attacked is, in the phenomena of the muscular current, represented by the *fibre* of the muscle, the arterial blood is the acid. The surface of the muscle, or any other conducting body which is not muscular fibre, but which is in contact with it, represents the

second metallic plate, which does not undergo chemical action, and which serves solely to form the circuit. The direction of the muscular current is always that which it should be, supposing it due to a chemical action such as above represented as going on in the muscle.

The nervous system may thus act in two ways. First, altogether as an imperfect conductor making part of a circuit, which is not a source of the Electricity, representing the electrical state of the muscular mass, interior or surface, near to which it is situated. This first function is purely a physical one. The nervous system may act, secondly, as a preservative of the cause which disengages Electricity; for nutrition operates under the influence of this system: but since it cannot be admitted that the chemical action which takes place during nutrition is immediately arrested or suspended by cutting the nerve which ramifies through a certain part of the living body, it should follow that the muscular electric current may still remain after cutting the nerves of the muscle, and that the integrity of the nervous system is not directly necessary for the production of a muscular electric current.

These hypothetical views, which seem in a general manner to offer a satisfactory explanation of the muscular current, and which are conformable to the actual theories of Electricity, do not unfortunately extend so well to the phenomena of the current proper of the frog. There is one remarkable difference between these two currents, viz.:—the very great persistence of the current proper after the death of the animal. A pile of a certain number of half thighs of frogs ceased to give a muscular current long before another pile of the same number of entire frogs, or of frog's legs, ceased to show signs of the current proper.

Two theories have been proposed to account for the current proper of the frog. According to one, it is supposed that the current is due to the unequal temperature of the muscle and the nerve, this inequality may be occasioned by the difference of evaporation in the two parts of the animal. The current proper thus becomes a *thermo-electric current.* This theory does not however accord with facts. A current only sensible through a galvanometer with a long wire;—which traverses a tolerably thick stratum of liquid;—which is obtained by bringing muscle into contact with muscle;—which is produced by keeping the animal parts plunged in water;—cannot certainly be a current having a thermo-electric origin.

According to the other hypothesis, it is suggested that the current proper may be due to electro-chemical action, and for this it is necessary to suppose that the leg of the animal must be charged with alkali or salt, while the thigh of the lumbar nerve should contain either

acid or water less saline. But what is the chemical analysis of those parts of the frog which should authorize us to accept this hypothesis? and how are we to understand the influence exerted by sulphuretted hydrogen, the tetanic state, the state of inflammation, &c., on the current?

The cause of the current proper is, therefore, a problem as yet unsolved.

There is a sort of opposition apparent beween the muscular current and the current proper,—it is this: in the half thigh which is taken from the side of the leg, the muscular current is directed from the *head* towards the *feet*; in the half frog, or in the leg only, the *current proper* is directed from the *feet* to the *head*. Lastly, in the upper half of the thigh by the side of the pelvis, the muscular current is directed from the *feet* to the *head*.

In the first example of the muscular current, its direction seems contrary to that of the current proper; but in the example of the upper half thigh the muscular current is in the same direction as the current proper. This opposition in the direction of the two currents is only apparent; and to speak the language of facts, we must say that the muscular current is always directed in the animal from the interior of the muscle to its surface.

To refer the origin of the current proper to that which has been admitted for the muscular current, we must suppose that, by a linking which to us is unknown, and which remains, perhaps, for the anatomist to discover, the tendinous surface which composes the greater part of the leg of the frog represents the interior of the muscle; but everything at present relating to this is vague and hypothetical.

Physiological Phenomena produced by a Muscle during Contraction.

The nervous filament attached to the leg of a prepared frog being made to touch the thighs of another frog, both insulated, and the lumbar nerves of the latter being touched with a voltaic pair, contraction takes place not only in the muscles of the frog touched, but also in the leg of the other; the same happens if the lumbar nerves be irritated with a pointed instrument, contraction always taking place in the second frog, provided the contraction in the muscles of the first be sufficiently strong. The same experiment may be successfully repeated with a rabbit; but Matteucci found that when the nerve of a prepared frog's leg was laid on the bared muscle of the thigh of a living rabbit, and the latter made to contract by a pile, contraction was at the same time produced in the leg of the frog. If a thin plate of

gold, or any very thin insulating substance be interposed between the muscle and the nerve, no contractions are excited in the second frog; but they are not prevented by a layer of thin unsized paper. The phenomena cannot, therefore, be attributed to any mechanical action exercised on the leg by its nerves.

M. Becquerel, with whom M. Matteucci repeated these experiments, after satisfying himself that an insulated plate, even when extremely thin, prevented the action of the muscles from causing contraction in the nerve of another animal laid upon them, came to the conclusion that the phenomenon is only to be explained by admitting an electrical discharge during the act of contraction. At the instant that the frog contracts, he supposes that there is an electrical discharge through the extremity of the nerve of the leg when this extremity is placed on the muscle, or when it is separated from it by a band of moistened paper only: it discharges through gold leaf because this conducts Electricity better than the nerve, a fact analogous to that observed on placing a torpedo in a metal vice which is held in the hand. In this case the discharge takes place through the metal, not through the hand. All these effects can be produced only from derived currents, and we must, therefore, admit the production of an electrical discharge at the instant of the contraction of the muscle. "If," says M. Becquerel, "experiments undertaken in another direction should confirm the consequences to be deduced from the experiments of Matteucci, this philosopher will have discovered one of the most important properties of the muscles while under the empire of life, or even for some time after death."

M. Matteucci spared no pains in endeavouring to obtain a satisfactory solution of this problem; but his experiments were not attended with results that were altogether conclusive. He commenced by shutting the circuit of a muscular pile, composed of living animals, with the galvanometer, taking care that the needle was arrested at a certain deviation, and he then aroused contractions in the muscles in such a manner as to avoid augmenting directly the pre-existing current. Moreover, to avoid all chances of error, it was necessary to avoid augmenting the conductibility of the pile; indeed, if this care be not taken, it might be supposed that, although the contractions be followed by an augmentation of the intensity of the current, this second effect may be due to the better conductibility of the pile, which allows the muscular current to circulate more easily. In experimenting with muscular piles, it is found that, though the first deviation may be considerable, the needle finally rests at a comparatively very small angle. Matteucci tried in vain to compose piles of a certain number of elements, with living pigeons

fixed on a board. He then resorted to frogs, operating with the current proper. He prepared a pile of eight or ten elements, and shut the circuit with the galvanometer. The deviation, which at first amounted to 40° or 50°, settled at 6° or 8°; when the needle was nearly stationary the frogs were to be caused to contract. Here was the difficulty. His first idea was to pass an electrical current through them; but as one part of this current would pass through the galvanometer, it soon became evident that this plan would not answer. Irritation of the spinal marrow was then resorted to; but although in some cases an augmentation of the deviation, amounting to from 2° to 4°, was observed, nevertheless it proved so difficult to preserve the integrity of the circuit, owing to the violence of the contractions, that nothing like a definite result could be obtained. Chemical agents were then employed, an alkaline solution applied to the lumbar nerves gave the best results. The contractions were not so violent, and they remained longer, and they were followed by an advance of the needle of the galvanometer of 5°, 6°, and sometimes of 10°. That this was not due to an increased conductibility of the surfaces in contact between each frog, was proved by the effect failing on the second application, and the circumstance of acids and salts not augmenting the deviation; neither was it occasioned by a chemical action, exercised unequally on the nerves and muscles which it touches, giving rise to a current moving in the same direction as the current proper. This Matteucci proved by a series of well-contrived experiments. In summing up his results, however, he says, "I cannot say that the question is completely solved, and I must stop, not knowing how to proceed in the investigation."

The next six chapters of Matteucci's treatise are devoted to the history and philosophy of electric fish, especially to the torpedo. The following is a brief *resumè* of his conclusions. He alludes to the extraordinary diffusion of the electric discharge of the torpedo in a liquid. A tube, five feet across, was filled with salt water, and a torpedo held in the hand close to one side, a prepared frog being suspended at the other extremity. Every time the fish discharged, the frog contracted violently; an effect which could not be produced by a pile of very great force, especially if it be considered that a great portion of the current circulates through the hand, and that another large portion must circulate by the surface itself of the animal.

Movements, sometimes scarcely sensible, are perceived in the body of the torpedo when it gives an electric discharge, and sometimes these movements are very considerable. By the following experiment, however, it was proved that the fish can discharge without any

change in the volume of its body taking place. A moderate-sized female torpedo ($5\frac{1}{2}$ in.) was introduced into a jar of salt water, a prepared frog being laid upon its body. The jar was accurately closed, and a glass tube of small diameter was fixed into the top. After having well luted the mouth, the glass was filled with water till the fluid rose in the tube to a certain height. The torpedo from time to time gave electric discharges, and the frog contracted, but the level of the water in the tube remained unaltered.

The torpedo has not the power of directing its discharge through any particular object. When the fish is very lively, and its discharges strong, shocks are felt wherever the fish is touched; but where it has become weak the shocks are not felt over the whole body, but only in the neighbourhood of the electric organs.

By means of his galvanometer, Matteucci deduced the following general laws relating to the distribution of Electricity in the body of the torpedo.

1°. All the dorsal parts of the organ are positive to all the ventral parts.

2°. Those points of the organ on the dorsal face which are above the nerves which penetrate this organ are positive, relatively to other points of the same dorsal face.

3°. Those points of the organ on the ventral face, which correspond to those which are positive on the dorsal face are negative, relatively to other points of the same ventral face.

By passing the discharge from the torpedo through a spiral of copper wire enclosing a steel needle, the needle was magnetized in such a manner as to show the direction of the current to be from the back to the under part of the belly. To measure the intensity of the discharge, Linari employed the electro-magnetic balance of Becquerel, and on comparing with this instrument the discharge of a moderate-sized torpedo with that of a battery of nine jars, exposing a coated surface of ninety-four square inches, the former was found to be much more intense than the latter.

The same philosopher obtained marked heating effects, by passing the discharge of the fish along a thermo-electric couple.

Electro-chemical decomposition had been effected by Dr. John Davy.* Matteucci repeated his experiments with success, and, by employing an apparatus something similar to that used by Mr. Gassiot, in his experiments on the Gymnotus, at the Adelaide Gallery,† he succeeded in obtaining brilliant sparks.

* See Lectures on Electricity, page 243. † Ibid. page 248, note.

The Causes which influence the Electric Discharge of the Torpedo.

Among external causes may be mentioned the mass and temperature of the water, and the degree of irritation to which the animal is exposed. The activity of the electric function is proportional to the circulation and respiration of the animal. Matteucci found that a torpedo that was giving discharges consumed more oxygen than another that was quiet; and on introducing a small and very feeble fish, that could scarcely give any sensible shocks, under a receiver filled with oxygen gas, it became agitated, and gave five or six strong discharges before it died. When the electric organ of the torpedo is destroyed, either by the action of mineral acids or by boiling water, the fish loses its power of giving discharges, but, before its power fails, it gives several strong shocks. If one of the electric organs be rapidly separated from the living fish, the discharge may be obtained by irritating the nerves, which proves that the integrity of the circulation of the blood in the organ is not necessary for the production of the electric power.

In order to destroy entirely the power of the fish to give discharges, it is necessary to cut all four of the nerves leading to the electric organ; when one or more nerves are cut, the discharge is confined to those parts of the organ among which the uncut nerves ramify. The discharge may also be prevented by tying the nerves; but even where the nerves are cut, discharges may be obtained by irritating them, unless the nervous trunks have previously been acted on by caustic potash. Of the four lobes of the brain, the fourth only is found to actuate the electric current; it is hence called the electric lobe. Strong discharges and muscular contractions ensue on touching it; if it be destroyed, all electric power is lost to the animal, although the rest of the brain remain untouched.

The action of electric currents on the nerves of the electric organs may be thus stated:—

1°. That in the first period after death, during which the vitality of the nerves is still very great, the electric current, direct or inverse, invariably produces the discharge, both at its commencement and at its interruption.

2°. In the following period of vitality, the discharge is only produced by the commencement of the direct current and by the interruption of the inverse.

The following are the general conclusions drawn by Matteucci from the results of his researches on the torpedo:—

1°. The electric discharge of the torpedo, and the direction of this

discharge, depends on the will of the animal, which, for this function, has its seat in the brain.

2°. The Electricity is developed by the organ of the torpedo, commonly called the *electric* organ, under the influence of the will.

3°. Every external action which is directed on the body of the living torpedo, and which determines the discharge, is transmitted by the nerves of the irritated point to the electric lobe of the brain.

4°. Every irritation directed on the fourth lobe, or its nerves, produces no other phenomenon than the electric discharge. This lobe and its nerves may therefore be called *electric lobes and nerves*, as we say, *nerves of sensation*, *nerves of motion*, *nerves of organic life*.

5° The electric current which acts on the lobe or its electric nerves, produces only the discharge of the organ, and this action of the current remains longer than that of all other stimulants.

6°. All circumstances that modify the function of the electric organ act equally on the function of muscle, namely, on contraction.*

The Influence of the Electric Current on living or on recently killed Animals.

The general laws of the contractions and sensations excited by the electric current in nerves motor and sensitive.

On applying the poles of a certain number of elements to any part whatever of the body of an animal living or recently killed, we find that they are seized with convulsions, which are sometimes so violent and so general that one almost fancies that the dead animal is restored to life. We read in the annals of the science, of experiments made at the period of the discovery of the pile, which induced some savants to imagine that they had discovered the principle of life, merely from observing the grimaces produced by the electric current in the facial muscles of decapitated animals.

Happily for science this infatuation did not last long, and men betook themselves, on the contrary, to a serious study of electro-physiological phenomena. To commence with a general exposition of these phenomena. When a pile of from fifteen to twenty couples is made to act on the living animal, taking care to include a portion of the nervous system, it contracts, crooks its back, and utters a cry. If the current be very strong, these phenomena persist when the circuit is kept closed; but usually it is only when the circuit is formed and interrupted that they occur. By operating on animals

* For an account of Faraday's Experiments with the *Gymnotus*, or Electrical Eel, see Lectures on Electricity, pp. 246, *et seq.*

recently killed, the same phenomena, with the exception of the signs of suffering, take place, and of all animals the prepared frog is the most sensible to feeble electrical currents.

According to Nobili, the vitality of the nerve of a recently killed animal may be divided into *five periods*, in each of which the action of the electric current differs. In the *first period*, the *direct* current—*i. e.* that directed from the brain to the extremities of the nerves—produces contractions in the inferior muscles when it *commences* and when it *ceases* its passage: the same phenomena are produced by the *inverse* current. In the *second period*, when the nerve begins to be less sensitive, the *direct* current produces contractions at its commencement, while they become very feeble at the instant it ceases to pass. The *inverse* current does not produce contractions on entering, but always on ceasing. In the *third period*, contractions are only produced at the *commencement* of the *direct*, and at the interruption of the *inverse* current. In the *fourth period*, there is only contraction when the direct current commences; and in the fifth and last period, the action of the current on the nerves is in every case null.

According to *Marianini*, the electric current transmitted through a nervous trunk well insulated, produces contractions in the inferior muscles in two cases only, viz., when the *direct* current commences, and when the *inverse* current is interrupted. The same philosopher, by repeating with extreme care the experiments of *Lehot* and *Bellingeri*, has come to the conclusion, that the direct current produces a sensation when it is interrupted, whilst the same phenomenon is developed by the inverse current the instant it commences. The following table may, therefore, very simply express the general law of the action of the current on a living or recently killed animal, as deduced by Marianini:—

Direct current	when it commences,	contraction of the inferior muscles;
	circuit closed,	nothing;
	when it ceases,	sensations;
Inverse current	when it commences,	sensations;
	circuit closed,	nothing;
	when it ceases,	contractions in the inferior muscles.

Matteucci experimented on a rabbit in the following manner:—The animal was secured on a board, and about an inch of its sciatic nerves laid bare and well insulated; it did not appear to suffer much pain, and there was very little hæmorrhage. Underneath the isolated portion of the nerves a long piece of varnished silk was placed, and the nerves were then wiped with unsized paper, to be certain that

they were perfectly insulated; one nerve was then submitted to the direct, and the other to the inverse current, the length comprised in the circuit being about two-thirds of an inch. A single pair of zinc and copper, or of zinc and platina plates was employed; but with the current from this battery, Matteucci was never able to obtain any well-marked signs of suffering, nor of contractions in the muscles above the irritated nerve, but contractions always took place in the inferior muscles on shutting or on opening either the direct or the inverse current. By continuing for a certain time the action of this current on the same points of the nerve, it was found that contractions of the inferior muscles only takes place at the commencement of the *direct* current, and at the interruption of the *inverse*.

In these kind of experiments it is important not to submit the same nerve to the passage of two contrary currents, one after the other, the passage of an electric current along a nerve being found to modify in some way its excitability, for a current passed in the contrary direction.

When a battery of ten pairs was employed, the rabbit exhibited distinct signs of suffering: at the commencement of the direct current, all the inferior muscles contracted, the rabbit squeaked, contorted its back, and agitated its ears; the same occurred on operating with the inverse current, and always took place at the instant when the two currents ceased. By repeating this experiment on several individuals, it was found in general that the signs of suffering were strongest when the *inverse* current commenced, and that the greatest muscular contractions were those produced at the commencement of the *direct* current. The commencement and interruption of an electrical current of a certain intensity, acting on a certain portion of the nervous system, are then followed by the same phenomena, whatever may be the direction of this current through the nerve. By continuing to operate on the same animal, it is easy to see that the phenomena do not always take place in the same manner. The variations which occur commence after a certain time, which is so much the shorter, as the current employed is more intense.

By prolonging the action of the current on the living animal, the following differences were noticed:—When the direct current was interrupted, the contractions of the inferior muscles became more feeble; whilst they continued in the muscles of the back, the ears were agitated, and the animal frequently uttered cries; when the direct current commenced, the effects were limited to contractions of the inferior muscles. In the inverse current, the contractions of the muscles of the back, the agitation of the ears, and the cry, took place at the commencement, whilst the contractions of the inferior muscles

were hardly perceptible. At the interruption of this current the contractions of the inferior muscles took place, while those of the back and ears, and also the cry, entirely disappeared.

Thus, then, the action of the electric current, which excites the nerves of a living animal, may be reduced to two periods only. In the first period, the excitation of the nerve is transmitted in every direction to its periphery as well as to its centre, at the commencement of the excitation as well as at its interruption, and that independent of the direction of the current in the nerve. In the second period, the excitation of the nerve is conveyed towards its extremities by the direct current at its commencement, or by the inverse current at its interruption: on the contrary, the excitation of the nerve is transmitted towards the brain when the direct current is interrupted, or when the inverse current commences.

These results may perhaps be expressed in simpler terms: the current during the second period acts in the sense of its direction when it commences, or in the contrary sense when it ceases.

But in what way does the electric current produce contractions in the muscles of the back and head, when this current acts on a nerve which does not ramify through these muscles? How happens it that, in opposition to the generally received idea, muscular contractions should be produced by the excitation of a nerve in a backward direction?

Matteucci answers this question by a very simple experiment. He cut the spinal cord of a rabbit arrived at the second period, and found that the contractions of the muscles above the excited nerve only affected those below to the point where the cord had been cut, and which were consequently comprised between the point excited and the point where the nerve was cut. If the spinal cord be cut altogether at its extremity, there will no longer be found contraction at any point above the excited nerve. The phenomena produced by the passage of the electric current are reduced then to the contraction of the inferior muscles, which takes place at the commencement of the direct current, and at the interruption of the inverse current.

It had been shown by Valli that after an animal had ceased to exhibit contractions by the prolonged action of an electric current through its nerve, the contractions may be renewed by causing the current to traverse a portion of the nerve further removed from the brain and nearer the extremities than before. Matteucci verified this with several animals, proving the generality of this principle, viz., that property of a nerve to excite contractions in the muscles through which it ramifies by the passage of a current, retires towards

the extremities of the nerve in proportion as its sensibility diminishes.

By operating with the inverse current, it was found that, in proportion as the sensibility of the nerve became diminished, it became necessary, in order to produce signs of suffering and contractions of the superior muscles, to make the current traverse portions of the nerve *nearer the brain* and further from the extremities; hence the conclusion that the portion of the nerve which, at the introduction of the *direct* current, excites contractions in the muscles, is so much *further* from the central system as the vitality of the nerve becomes less; on the other hand, that the portion of the nerve which, at the introduction of the *inverse* current, excites painful sensations approaches *nearer* the central system as the vitality of the nerve becomes less.

When recently killed rabbits were submitted to the action of a single couple, the inferior muscles contracted at the commencement of the direct current, and at the interruption of the inverse, whatever the direction in which it was applied, but if the current were continued, those contractions alone were obtained which were due to the commencement of the direct and the interruption of the inverse current.

By numerous experiments on frogs, Matteucci has convinced himself that the electric current acts only on the nerves, and that there are not, as Marianini has objected to Nobili, currents which run at the same time directly, and in an inverse direction following the ramification of the nerve.

It has been demonstrated by Marianini that contractions of the muscles may be obtained at the interruption of the current without the production of those due to its commencement. He has also shown that the contraction due to the interruption of the current may be obtained without destroying the circuit, but by diverting it from the body of the animal by a better conductor; he has also ascertained that this contraction, which takes place at the interruption of the current, is stronger in proportion as the circuit has been closed a longer time: from his experiments he has drawn the conclusion that during the passage of a current through a nerve in the direction of its ramification, there is one portion of the Electricity which accumulates in this nerve, which at the instant of the interruption of the circuit discharges itself, traversing the nerve in a contrary direction, thus giving rise to the contraction produced by the inverse current at the moment of its interruption. Matteucci, however, objects to this hypothesis, which he thinks inconsistent with the knowledge we possess of the conducting power of nervous substance, and of the manner in which it propagates Electricity through the muscles.

The Action of the Electric Current during its passage across the Nerves and Muscles at the same time on living or recently killed Animals.

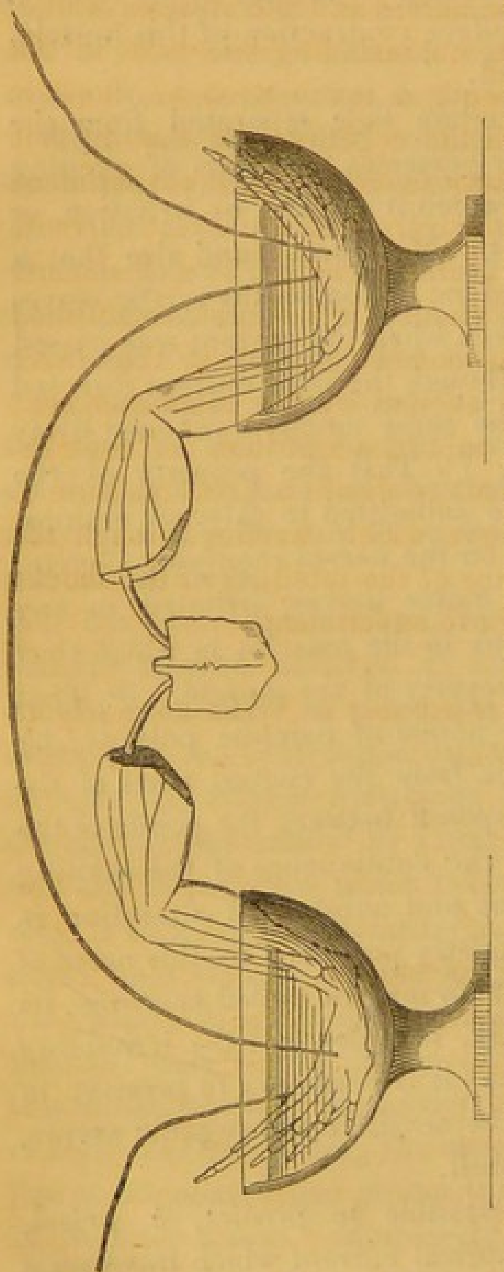
If it were possible entirely to deprive muscle of all nervous filaments, we might hope to discover the action of the electric current on muscular fibre, and thus resolve the question which, since Haller's time, has agitated physiologists; viz., whether muscular fibre of itself, independently of all external action conveyed through its nerve, is capable of undergoing contraction, and whether the excitation of the nerve is merely one cause of awakening irritability of the muscle, or if, on the contrary, in order to produce contraction of this muscle, its nerve should be previously irritated.

When a nerve has been for a certain time separated from the central nervous system, it no longer possesses the power of exciting contractions in the muscles through which it ramifies by irritation, or by the action of an electrical current. Matteucci found also that a pile of eight or ten couples produced no action on the sciatic nerves of frogs poisoned with nux vomica, even when the current was passed along the extremities of this nerve, although the same current directed through two points of a muscle of the same animal awakened lively contractions. He hence concludes, 1°. That the property of the living muscular fibre to contract when submitted to external actions, whether directed on the fibre itself or on the nerves ramifying therein, is inherent in itself. 2°. That the motor nerves, irritated in any manner whatever, produce contractions in the muscles in which they ramify, by awakening this inherent property of the muscle. 3°. That these nerves lose this property by the action of narcotic poisons; by their separation at a suitable distance from the central parts of the nervous system; by a ligament interposed between the points of the irritated nerve and the muscles; by the continuance of the exciting action, independent of any permanent and substantial alteration in the nerve, which is proved by the property possessed by this nerve of recovering by repose, or by actions which may be called *contrary*, its primitive faculty. 4°. And that lastly, in order that the irritability of the muscular fibre should continue, it is necessary to preserve in this fibre the simultaneous action of the sensitive and organic nerves, and of the blood by which it is nourished.

From these principles, it seems possible to predict, *à priori*, what should be the direction of an electrical current which traverses a mass of muscle, and at the same time all the nervous filaments ramifying therein. If this muscular mass be traversed by the current in a direction parallel to that of the principal nervous trunks distributed therein, it seems evident that the resulting contraction should be

stronger than that produced by the same current transmitted in a direction normal to that of the nervous trunks. Indeed, the contraction obtained in the first case is due to that which is proper to the muscular fibre, and to that which is caused in this fibre, by the excitation of the nerves which are traversed by one portion of the current. At the same time, it results that the laws of the contractions excited by the current which traverses a muscular mass, should not, especially while the vitality is still great, differ from that found to belong to the action of a current limited to the nerve.

Fig. 8.



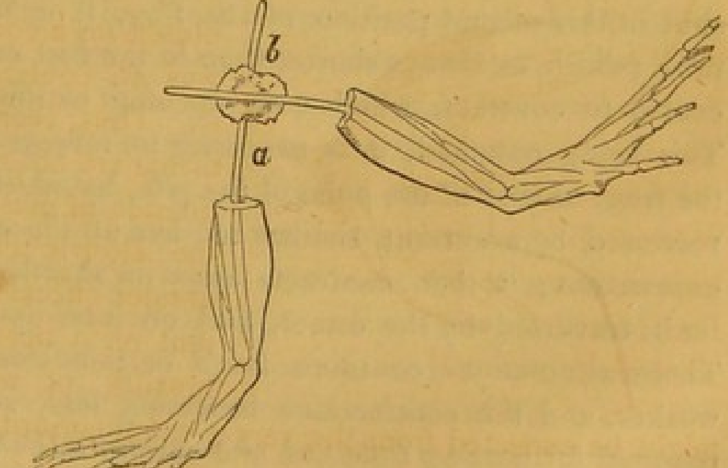
Matteucci carefully removed all the visible nervous filaments from the thighs of rabbits, from the breasts of pigeons, and from the hearts of several other animals; in this state he passed through them a current from twenty or thirty pairs, and he found that the muscles always underwent contraction when the circuit was closed. The contraction only lasted for a moment, and seemed to consist in a sort of shortening of the fibres which caused them to oscillate and knit up; on keeping the circuit closed, the fibres regained their original condition, but again contracted, though more feebly than before, on interrupting the current. The direction of the current had no influence on the result, and if the circuit was kept closed for a considerable time, there was no contraction on interrupting it. Thus, then, vsible nervous filaments are not necessary for the production of muscular contractions by the electric current, though much greater effects are produced by a current on a nerve than on a similar breadth of muscular fibre which might be expected from the very great superiority of conducting power possessed by the muscle.

When an electrical current is passed through a prepared frog arranged as shown in Fig. 8, where the current is direct for one of

the legs, and inverse for the other, the following phenomena are observed. At the commencement of the experiment, when the animal is very active, both legs contract, at the commencement as well as at the interruption of the current. As vitality diminishes, only one of the legs contracts ; that which is traversed by the direct current contracts at the commencement, and that traversed by the inverse current at the interruption. These results are analogous to those obtained by operating with the current on the nerve alone, and it is principally to the action of the current which traverses the attached nerve, and ramifies through the muscle, to which the action of the current which traverses at the same time the nerves and the muscles is due. It had been noticed by Marianini that, on including two arms in the circuit of a pile of forty or fifty elements, a much stronger shock is experienced in the arm in contact with the negative pole than in that in contact with the positive ; now it is easy to see that in this experiment the great nervous trunks of one arm are traversed by the direct current, and those of the other by the inverse current, and as, by experiments on the nerve during its first period of vitality, it has been established that the contractions excited by the commencement of the direct current are always greater than those excited by the commencement of the inverse, it seems that we have only to admit that the contraction produced in a muscle by a current is due in a great measure to the action of this current on the nerve which ramifies through the muscle, in order to explain the difference of the intensity of the shocks experienced in the two arms in the above experiment.

The Action of an Electric Current traversing a Nerve normally to its length.

FIG. 9.



Matteucci made the following experiments : — Two frogs' legs were prepared, their nervous filaments being preserved, and arranged on an insulated surface, in such a manner that the two nervous filaments crossed at right angles, as shown in Fig. 9, one of the nerves was cut in half, and the two

newly formed extremities were removed about an inch, or an inch and a quarter distant from the nerve of the other leg: the surfaces of the divided nerve were then united by a drop of distilled water. Thus arranged, the points *a* and *b* of the cut nerve were touched with the extremities of a pile composed of a certain number of elements: the current necessarily traversed not only the water but the interposed nerve also; nevertheless it was only the leg, the nerve of which was touched by the extremities of the pile, that contracted, the other leg, the nerve of which was traversed normally by the current, remained at rest; and although, when a great number of couples was employed, contractions were obtained in both legs, the experiment distinctly proves that an electric current which traverses a nerve *normally* to its length, has less power of arousing contractions in the muscles through which it ramifies, than the same current when it traverses the same length of nerve longitudinally.

The Causes which modify the Action of the Electric Current on the Nerves.

1st. *Alternations of the Current.*—If the current from a certain number of couples be allowed to pass during the twenty-five or thirty minutes through a frog arranged as in Fig. 8, it is found that on interrupting the circuit, and immediately shutting it again, the animal undergoes no contraction in either case. The time required to produce this effect varies according to the force of the pile, and the vitality of the frog. When the animal is reduced to the point at which it ceases to contract, if the poles of the pile be reversed, or if the frog be turned over, so that the current may be transmitted through the limbs in a contrary direction, contractions are obtained anew on shutting the circuit for the limb in which the current is direct, and on interrupting it for the other. If the current be left shut in this second position of the frog, it is found after a certain time (which is always shorter than in the first case) that the animal ceases to contract, whether on opening or on shutting the circuit. This being obtained, it is necessary to reverse anew the position of the frog, or that of the poles of the pile, by which the animal becomes traversed by a current similar to that at the commencement of the experiment; it then contracts anew on shutting the circuit for the limb traversed by the direct, and on interrupting it for the other. These alternations continue for a certain time, growing gradually weaker, and the contractions becoming less, according to the time required for passing from one alternation to the other.

These facts may be simply expressed thus:—The current which traverses a motor nerve in a living or recently killed animal, and

which continues to pass along this nerve for a certain time, so modifies its excitability as to render it insensible to its passage as long as it traverses in the same direction, but the excitability of the nerve recovers under the influence of the same current directed in a contrary way: when, then, a nerve has been thus modified by the passage of a current, we may restore to it the excitability it has lost by sending through it for a certain time a current directed in a contrary way from that which destroyed its excitability. It has been shown by Marianini that the phenomena above described may be referred entirely to the weakening of the action of the current directed in a certain direction through the nerves, and to a restoration of this action by a current directed in a contrary way. It seems, then, that there exists in the living animal a force which wrestles continually against the property of an electrical current, to weaken the excitability of a nerve through which it traverses in a given direction. It is this force which, in the living animal, is capable of re-establishing the excitability which the nerve has lost, provided it be left for a certain time unacted upon by the current. This has been well established by the experiments of Marianini, and it is an ascertained fact, that *repose* produces in a living animal, the nerves of which have lost their excitability by the action of an electrical current, the same effect as the passage of a current through the nerves in a contrary direction. That the phenomena of alternations are produced entirely by the action of the current on the *nerve* was proved by Matteucci, by passing a current through a piece of muscle, deprived as much as possible of all nervous filaments; he never found, on reversing the position of the extremities of the pile, that the lost power of contraction was regained.

The alternation which is produced in a nerve by the passage of an electrical current, is not independent of its direction relatively to the ramification of the nerve. The direct current destroys the excitability of the nerve much more quickly than the inverse current. The following experiment confirms this. A prepared frog was cut at the union of the two bones of the thigh; it was then placed with its paws in two basins of water, Fig. 8, and a current from sixty to eighty couples was passed *directly* for one limb, and *inversely* for the other. In performing this experiment care must be taken that the frog does not leap out of the basins. The contractions continued for some seconds after the closing of the circuit, and it was remarked that the limb traversed by the direct current palpitated for a certain time. After fifteen, twenty, twenty-five, or thirty minutes, according to the degree of vitality in the animal, the water in the two basins were united by a metallic arc, by which a great portion of the current

was caused to leave the animal, and the limb traversed by the *inverse* current was found to contract. On removing the arc, the contraction ceased. The experiment was repeated several times with a similar result. In order to be still better assured that the nerves of the two limbs have become differently excitable, the frog may be arranged with its nerves in one glass, and its two feet in a second. Then, on passing the current, one of the limbs is seen to contract, sometimes at the commencement, sometimes at the interruption, according as the current is direct or inverse. In both cases the limb which contracts is always that which has been traversed by the inverse current in the first experiment. When, by the continued passage of the current only, one of the limbs of the frog has become capable of contraction, the direction of the current may be reversed, so that the limb before traversed by the inverse current shall now be traversed by the direct, and *vice versâ*. It is then found that, by continuing the current for a certain time, the limb which had lost the power of contraction has regained it, although this property has ceased in the other.

It may then be concluded, 1°. That the passage of an electric current across a nerve weakens its excitability in a different manner, according to its direction. 2°. That the passage of the direct current renders the nerve *less* excitable by this same current than the passage of the inverse current.

On submitting two frogs, similarly prepared, for from ten to fifteen minutes, one to the passage of a continuous current of forty-five couples, and the other to the current of a similar pile, the action of which was broken and renewed at short interval, Matteucci found that the nerves of the animal that had been subjected to the interrupted current were much more weakened than those of the other, and it required a stronger power to excite the former than the latter. Marianini also remarked that of two frogs, one traversed by a continuous current always in one direction, the other by a similar current sent sometimes in one direction and sometimes in the other, the first suffered least in loss of excitability.

2nd. *Ligature of the Nerve.*—It is a well-known fact, that when in a living or recently killed animal, a nerve is tied and irritated *above* the ligature, *i. e.*, towards the brain, no contractions ensue, but the animal exhibits signs of suffering; and on the other hand, that when the nerve is irritated below the ligature, strong contractions of the inferior muscles ensue, without any signs of suffering being evinced. The same general results are obtained when the electrical current is the stimulant employed, but in this case the ligature must

be tied tightly, and care must be taken perfectly to insulate the animal operated upon.

3rd. *Poisons.*—Carbonic acid gas, nitrogen, and chlorine do not weaken the excitability of a nerve submitted to an electrical current; the same may be said of sulphuretted hydrogen. Hydrocyanic acid, on the other hand, possesses a remarkable power of weakening the excitability. It begins by exciting tetanic convulsions in frogs exposed to its influence; and if they are prepared in this state, and submitted to the action of an electric current they still contract, especially if the current traverses the nerves and muscles at the same time, or the muscles only. But if the frogs poisoned by this acid be submitted to an electrical current, after they have ceased to exhibit tetanic convulsions, it is very rarely that contractions can be obtained with the current from a single pair passed along the lumbar nerves. A very strong current only produces very feeble contractions, and the excitability altogether disappears after some seconds.

Death by the electric discharge destroys almost entirely the excitability of a nerve by an electric current, but the muscles of the animal do not lose their irritability, for the current still excites contractions in them.

The action of narcotic poisons is curious. The animals are first brought to a state in which the most feeble contraction suffices to agitate their whole frame; they then assume the tetanized condition, during which their limbs become completely stiffened, and after a few minutes all movement ceases. When a frog was submitted to the action of a current in the first of these conditions, contractions were obtained as usual, both at the commencement and at the interruption of the circuit, whatever its direction. During the second period the following phenomena were observed. By operating on the nerve alone its excitability was found to be weakened. Sometimes the tetanic convulsions were prolonged for some seconds, although the spinal cord was cut. But if, instead of preparing the frog thus tetanized, it was submitted to the passage of a current from a pile of thirty or forty pairs directed along its body, the frog, which an instant before was quite rigid, experienced a smart shock at the commencement of the current, and then, by leaving the circuit shut, the tension of the muscles relaxed. Matteucci in this experiment remarked one difference between the direct and the inverse current. The current directed from the feet to the head excited at the commencement a shock which was weaker than that produced at the commencement of the direct current. This difference between the action of the two currents is in accordance with the general laws already detailed.

Lastly, during the third period of the narcotic poisoning the

excitability of the nerve was found either null or nearly so, while the muscular fibre still exhibited contractions when submitted to the electric current.

The Action of the Electric Current on the Nerves of the Senses, and on the Great Sympathetic Nerve.

All the researches in Electro-physiology that have been undertaken from the commencement of the science of galvanism to our own time, have proved that the current acting on the nerves of the senses only brings into play the special action appertaining to each of these nerves, a proof that the electric current acts merely as other stimulants.

It was Volta who first demonstrated the existence of a sensation of light when the electrical current traverses any point of the optic nerves. The experiment is easily made by touching with an elementary couple the eye or eyelid and the tongue. Whatever may be the intensity of the current, it is only the sensation of light that is perceived. If we reflect that this sensation may be produced by a very feeble current, and one certainly incapable of exciting a muscular contraction sufficiently strong to shake the eye, it must be admitted that the effect is really to be ascribed to the excitation of the optic nerve. An analogous phenomenon is produced when the current is made to act on the auditory nerves. Volta, on applying the two poles of a pile to his two ears, experienced a *hissing*, a sort of *jerking* noise, which continued all the time the circuit remained closed. According to Ritter, the sensation is only experienced at the commencement of the current, and the noise is sharper at the negative pole.

Again, in the experiment of Sulzer, a taste is experienced when the tongue is traversed by an electrical current. This taste is sourish when a plate of zinc is placed at the base of the organ and a plate of silver on the surface, the two plates being brought into contact; by reversing the position of the plates the taste becomes alkaline, but this feeble intensity current could not certainly be supposed to decompose the salts dissolved in the saliva. A similar sensation was experienced by Volta by taking in his hand a goblet of pewter filled with a moderately alkaline solution, and bringing the base of the tongue into contact with the liquid. It must be remarked that the taste was *sour*, which excludes entirely the idea that it was occasioned by the contact of the alkaline liquor with the tongue. It seems evident, therefore, that the taste excited by the electric current must be owing to the special excitation of the gustatory nerves. In general, then, the effect of a current acting on the nerves of the senses is to awaken the special function of those nerves.

The passage of an electric current through the cardiac and

splanchnique nerves of a living or recently killed animal increases or arouses the proper motion of the heart and intestines; but what is very remarkable, the phenomenon due to the passage of the current, instead of commencing at the very instant the circuit is closed, only begins after a certain time, and continues for some time after the current has ceased. It must not be forgotten that all other stimulating agents, viz., alkalies, mechanical irritation, heat, applied to the ganglion nerves act in the same manner as the electrical current. The direction of the current is of no consequence in these experiments.

The Differences between the Action of the Electric Current and that of other Stimulants.

It is known that heat, alkalies, or mechanical irritation applied to the motor or sensitive nerves of a living animal occasions at the same time sensation and contractions in the inferior muscles, the excitation of the nerve is then transmitted at the same time to the centre and to the extremities. When, by the continued application of these stimulants, the excitation of the nerve is prolonged, the effects grow weaker, or disappear altogether according to the duration or the intensity of their action.

The electrical current produces the same effects, which, however, very shortly cease; and an animal may have its nerves traversed by a current for a very long time without exhibiting the least signs; but the moment the current ceases, the phenomena reappear. In proportion as the vitality of the animal becomes weakened, and as the current continues to pass, the resulting phenomena cease to exhibit any analogy to those produced by other stimulants. We have seen that the action of the current differs according to its direction relatively to the ramification of the nerves. Thus the animal experiences a sensation when the *inverse* current commences, and a contraction when it ceases, and the contrary for the *direct* current. It is also known that whatever the stimulant applied to a nerve, it only excites contractions in those muscles through which its branches ramify.

The electrical current, as we have seen, produces in some cases contractions in the superior muscles, and thus exercises an action that may be called retrograde. It has been proved that these phenomena depend on a reflex action through the spinal cord, which only becomes manifest with other stimulants when the animal is placed in particular and abnormal conditions.

A difference even more remarkable than that above cited between the action of stimulants, heat, mechanical and chemical irritations, &c. and that of Electricity, consists in the power possessed by

the current of preserving for a longer time than other stimulants, the excitability of the nerve, and indeed of re-establishing in certain cases the excitability it has lost.

The electrical current may traverse for a long time the nerves of a living or a recently killed animal, without destroying in these nerves the excitability brought into play by a current sent in a contrary direction, and when the nerve by the prolonged action of the current has lost this faculty, it may again be restored by the passage of a contrary current.

In whatever manner stimulants may be applied to a nerve, its excitation never fails, and contractions and sensations always follow. The only difference is one of degree, depending on the intensity of the action of the stimulant, and the extent of the nerve submitted to it. The electrical current is alone incapable of exciting a nerve merely by traversing it; this takes place when the current is transmitted normally to the length of the nerve.

If we compare the excitability of the nervous system in a narcotized animal, we find that, of all stimulants, the electric current is the last to lose the property of awakening the excitability of a nerve, however feeble it may be.

The principal differences indicated by experiment between the action which is excited on the nerves by the electric current, and that excited by other stimulants may be summed up thus :—

1°. The electrical current, according to the direction in which it traverses a nerve, has *alone* the power of exciting separately, sometimes contractions, sometimes sensations.

2°. The electrical current *alone* whilst traversing a nerve transversely, produces none of the phenomena due to the excitability of the nerve.

3°. The electrical current *alone* produces no effect when its passage through a nerve is continued.

4°. The electrical current *alone* occasions the continuation of the excitation of a nerve, after its action upon it has ceased.

5°. The electrical current *alone* possesses the power of re-establishing the excitability of a nerve when it is transmitted in a direction contrary to that of the current which had destroyed or weakened this excitability.

6°. The electrical current is of all stimulants that which possesses for the longest time the property of arousing the excitability of a nerve, however weak it may be compared with other stimulants.

The Relation between the Electric Current and the unknown force of the Nervous System: hypothetical views of the nature of this force.

From the conclusions deduced in the last section, it appears that the mode of action of the electric current on the nerves more simple than that of other stimulants, is at the same time in some measure analogous to the unknown force which works in the nervous system. But can we hence conclude that this unknown force is none other than the electric current? We must be very careful in drawing this conclusion, which unfortunately has been so often readily embraced.

Is there an electrical current in the nerves of a living animal? and can it be applied to the explanation of the functions of the nervous system?

The muscular electric current is a phenomenon which has been proved to derive its origin from chemical actions constituting the nutrition of the muscle. It has also been seen that this current, altogether analogous to that which is produced during the combination of two bodies only exists between the molecules, and never circulates in these bodies but in particular cases, which have been realized in the muscles of living or recently killed animals. The nerves have not a direct influence on the existence of this current, and they play no other part than that of a bad conductor, which communicates with certain parts of the muscle.

Matteucci has sought unsuccessfully for an electrical current in the nerves of a living animal. He introduced steel needles into the muscles of living frogs, rabbits, and dogs, in various directions relatively to the muscular fibre, and connected them with the terminal plates of his delicate galvanometer, but could obtain no indications of an electrical current, nor was he more successful with the galvanoscopic frog; he subsequently tried the experiment on the sciatic nerve of a living horse, but without obtaining any trace of an electric current. Indeed, from what is known of the properties and laws of propagation of electricity, it seems impossible to conceive the existence of an electrical current included in the nerves; in order to admit it, such a disposition in the structure of the nervous system as would suffice to form a closed circuit must be proved, but this anatomists have not yet done. Matteucci made the following experiment, in order to ascertain, in an indirect manner, whether the nervous system might readily form a closed circuit for the electric current. He laid bare, in two different points of its length, as far from each other as possible, the sciatic nerve of a living animal: viz. above the thigh to the extremity of the leg. He introduced the limb into a spiral in connection with

a smaller spiral containing an iron wire; he then touched the points of the uncovered nerve with the extremities of a pile, in order to send a current through it, but no satisfactory indication of an induced current could be obtained.

The electric current, then, does not exist in the nerves of a living animal: the laws of its propagation require conditions which are not found in the nervous system, and it is certain, that the nervous force, whatever it may be, is not *Electricity*. What relation, then, is there between these two forces? Matteucci's laborious electro-physiological inquiries lead him to the following conclusions. There exists between the electrical current and the unknown force of the nervous system an analogy, which, if it be not susceptible of the same degree of evidence, is, however, of the same kind as that existing between heat, light, and electricity. In all the phenomena of electric fishes, the faculty of producing electricity, with which they are endowed, is under the direct dependence of the nervous system; and there is in these animals a structure, a certain disposition of particular parts of their organism, which, by the agency of the unknown force of the nervous system, enables them to disengage electricity. The parallelism which has been clearly shown to exist between muscular contraction and the electric discharge of fishes, proves distinctly that the two functions depend immediately on those of the nervous system.

The development of Electricity by a crystal of tourmaline when heated, clearly proves the relation between heat and Electricity: a similar relation between the nervous force and Electricity is demonstrated by electric fishes. Electricity is not, however, the nervous force, any more than *heat* is Electricity: the one changes into the other in the one case, by the form of the integrant molecules of the crystal; and in the other, by the structure of the electric organs. In physics we are daily advancing towards a simplification of our hypothesis, or more exactly, towards a single hypothesis serving to explain all the phenomena of heat, light, and Electricity. "What hypothesis, indeed," says Matteucci, "is more worthy of the rank to which it is sought to be elevated than that of a body which is capable of a variety of different movements, susceptible of transformation from one into the other, and so representing phenomena very different from each other?" The most essential characters of this body, such as the immense rapidity in the propagation of its motions, the transformation of one motion into another, &c., belong to the unknown force of the nervous system, as to Electricity, light, and heat. The relation between two of these movements of *ether*, motions which we have been accustomed to call *imponderables*, becomes much more intimate when not only one of these bodies can be transformed into another, but when each in its turn can be transformed into the first.

Have we this reciprocity between the unknown force of the nervous system and the electrical current? In a word, is the electrical current transformed into the unknown force of the nervous system?

We know, by experiment, that a nerve traversed by an electric current, in the direction of its length, is excited *in such* a manner as to produce either contraction or sensation. It is necessary for this purpose that the nerve be traversed in the direction of its length; that it shall not have been long separated from the central parts of the nervous system, and that it be not submitted for too long a time to the passage of the current, or to the action of other stimulants.

Heat, mechanical or chemical action, may, like the electric current, arouse the excitability of a nerve, and thus produce contraction and sensation. Are we hence to conclude that these chemical, mechanical, and calorific actions are transformed into an electric current, which alone has the power of exciting a nerve? We should be by no means warranted in drawing such a conclusion, and as it has been proved that the unknown power of the nervous system is not electricity, so we have no reason to believe that stimulants—viz., heat, chemical or mechanical action—act by producing an electrical current when applied to a nerve.

We may conclude, then, with Müller, that the electrical current, which under certain conditions traverses a nerve, determines in it a change similar to that produced by the unknown force of the nervous system, when it is there excited by external actions, or by the action of the will.

It seems, however, natural and just to suppose that this change effected in the disposition of the elementary organs of a nerve, whether by the act of the will or by the electric current or other stimulants, is accompanied in every case by a species of current of the unknown force of the nervous system. This force Matteucci denominates *Ether*, in order to explain by one hypothesis all the phenomena of imponderables, and the analogy of the nervous force with these other forces.

All philosophers agree in the impossibility of explaining the immense rapidity of the propagation of light, of radiant heat, of electricity, without having recourse to *vibratory motion*. The unknown force of the nervous system is not less rapidly propagated. Ether distributed through all points of the nervous system, as through the whole universe, takes the character of the nervous force, through the modifications introduced in the relative disposition of the molecules by the organization of the nervous substance. The different structure of the nervous fibres, and especially that of their origin and extremities, such

as the microscope is now unfolding, may serve to explain why the molecular change of the nerve which constitutes its excitable state, is less rapid in the ganglionic system than in the other nerves, and why, in certain nerves, the excitability is propagated only in a certain direction.

The nervous fluid in this hypothesis is what we suppose heat, electricity, and light to be, viz., a peculiar vibratory motion of ether.

To sum up in a few words these hypothetical views :—There is in all parts of the nervous system, as in all bodies in the universe, a *diffused ether*, which in this system may have a particular arrangement, as it is admitted to have in certain crystalline bodies. When the organic molecules of the nerves are from any cause deranged, the ether, or more properly the nervous fluid, is put into a certain motion, which reaching the brain produces sensation, and arriving at the muscles determines contraction. This derangement may be produced by the electric current, by heat, by chemical and mechanical action, as it is naturally by the will; the propagation of the motion will be materially interfered with by any alteration whatever in the structure of the nerve.

Matteucci concludes by offering the following explanation of the action of the electric current on the nerves :—

Let it be admitted that the electrical current, which traverses a nerve in the direction of its length, determines a derangement in the direction of this current, as the experiments of Porrett and Becquerel have proved; let it be admitted that this derangement is accompanied by vibratory movements of the nervous fluid, which are propagated to the extremity of the nerve parallel to the direction of the organic derangement. This current of the nervous fluid produces *sensation* if directed from the extremities towards the brain, and *contraction* if directed from the brain towards the extremities. From this it follows that an electric current traversing a nerve *normally* can produce no phenomenon. The direct current produces contraction when it enters, and sensation when it ceases. The inverse current, on the other hand, produces sensation when it enters, and contraction when it ceases. The phenomena observed during the first period of the vitality of the nerve show that when the organic disposition of the nerve is perfect, its molecules are deranged in every direction by the application of any kind of stimulant, but always more so in the direction of the electric current than in the opposite direction. In proportion as the structure proper of the nerve ceases to be perfect, the phenomena produced by the current are those which take place in the direction in which this force acts with most intensity. Other stimulants produce in the structure of the nerve a derangement of a more permanent

nature, and which, unlike that produced by the electric current, does not cease till the exciting cause is removed. An electrical current which traverses a nerve for a certain time, finishes by permanently deranging its molecules, hence the reason why the prolonged action of the same current ceases after a time to produce its peculiar action on a nerve. A current in the contrary direction will bring back the molecules of the nerve into their former condition, and restore to them their capability of being excited by a current in the same direction as the first. The passage of an electrical current through a nerve in a different direction, the successive interruption of this current, and its greater intensity are the causes most likely to produce a permanent derangement in the structure of a nerve.

Therapeutic Applications of Electricity.

The application of electricity in the state of tension and in that of the pile has hitherto been made either with blind confidence, or with a faithlessness equally inconsiderate. From the first researches it might have been seen that electricity must not be expected to produce instantaneous or general cures, and that the empirical use of it should be rejected. Electro-physiology should first be studied, and a thorough acquaintance with its principles obtained.

Let us see what grounds we have for applying the electric current to the cure of paralysis.

We have seen that the passage of an electric current continued for a certain time along a nerve destroys its sensibility; its contractions cease. On making the experiment on a living animal, we find that the limb, the nerve of which has been for a certain time subjected to a current of a certain intensity, is rendered incapable of motion; it is then paralyzed, having lost the power of obeying the force of the voluntary nervous system. On allowing the animal to rest, it is found after a certain time, according to the intensity of the current, that the nerve has become again excitable by the electric current, and again capable of obeying the voluntary nervous system.

Suppose, then, a current be passed along a nerve of an animal until it has lost its sensibility; on passing along the same nerve a contrary current, we know that the nerve again becomes excitable by the direct current. This is the phenomenon of voltaic alternations. But at the same time that the nerve which by the passage of the contrary current has regained its sensibility, it becomes again capable of obeying the nervous force. The limb paralyzed by the passage of a certain current, ceases to be so by the passage of a contrary current. In this manner, by the aid of an electric current directed as above, we may

be enabled to bring about in a short time that which without it would have taken a much longer time.

It has also been seen that if the nerves of a living animal be submitted to an electric current renewed at short intervals, it arouses in the animal tetanic contractions; on prolonging this treatment, after a certain time the nerves entirely lose their sensibility. These, then, are the facts which, independent of theory and apart from any hypothesis respecting the nervous system, may guide us in the therapeutic application of electricity in cases of paralysis.

In some cases of paralysis, it must be allowed that the nerves of the diseased limb are altered in a manner analogous to that which would be produced by the continuous action of the electric current; and as, to restore to a nerve the sensibility it has lost by the passage of a current, we must act on it with a current in a contrary direction, so, to restore a paralyzed limb, we must pass along it a current in a contrary direction to that which occasioned its paralysis. If the disease be *paralysis of motion*, it is the *inverse current* that should be applied; if *paralysis of sensibility*, the *direct current*. In cases of complete paralysis, it seems immaterial whether the current be direct or inverse. Another rule which theory teaches us, is never to prolong the passage of the current beyond a certain time, lest we increase the disease we are endeavouring to cure. The more intense the current, the shorter the time it should be applied.

Theory teaches us to apply the current of an intensity varying with the degree of the disease, and to pass it during two or three minutes at intervals of some seconds. After two or three minutes, during which time from twenty to thirty shocks may have been given, the patient should be left for a while, after which the treatment may be renewed. Marianini, a physician who has greatly distinguished himself in the study of electro-physiology, has described a variety of cures of paralysis, which, without doubt, were brought about by the use of electricity. In reading the history of these cases, we see the patience which is required in order to arrive at satisfactory results. Marianini has in some cases continued the application of the electric current during several months, and in two cases the cure was not entirely effected till after 2,500 shocks had been given to the paralyzed limb.

Majendie has also occupied himself for some time with this subject, and has reported several remarkable cures. Matteucci mentions the case of an individual who was brought into the clinical hospital of Pisa with both limbs paralyzed; power of motion was restored to both legs by the application of electricity. In this case acupuncturation was resorted to, in order to convey the current as near as possible to the affected nerves.

These results are surely of sufficient importance to induce physicians to make a serious study of electro-physiological phenomena, in order that by persevering efforts science may be advanced, and a therapeutic method discovered applicable to the cure of a disease which unfortunately has hitherto resisted every other form of treatment.

Another disease in which electricity judiciously applied is likely to be successful is *tetanus*. The grounds on which we should proceed are these :—It has been seen that when the passage of an electric current along the nerves of a living or recently killed animal is renewed many times in succession, at short intervals, the limbs became tetanized; it is also known that on the contrary the limbs are paralyzed when the current is prolonged without interruption for a certain time; the effects of the current being very different according as it is continued or interrupted. It may be imagined, therefore, that the continued passage of the electric current along a tetanized limb would destroy this state and bring on a state of paralysis; indeed, the truth of this conclusion is sufficiently demonstrated by experiments with the narcotic poisons, such as opium and nux vomica, which, if administered to frogs, begin by stupifying these animals, afterwards they over-excite them, and lastly, some time before death, the animals become seized with very strong tetanic convulsions. If, while in this last state, an inverse electric current of a certain intensity be passed through the animals, the stiffening of the limbs may be observed to diminish and the spasms to disappear. The frogs die after a certain time, but without giving signs of tetanus.

The application of the electric current to an individual suffering from tetanus, an account of which was published by Matteucci in the *Bibliothèque Universelle*, May 1838, seems to prove the reality of these conclusions. The patient during the time he was under the influence of the electric current did not suffer such violent spasms as before, he was able to open and shut his mouth, and circulation and respiration appeared to be re-established; unfortunately, these signs of improvement were only transient,—the disease was occasioned by an injury of the muscles of the leg. It can perhaps, as yet, hardly be predicted that a general cure for this dreadful disease will be found in the electric current; it is, nevertheless, a well-founded belief that during the passage of an electric current through the limbs of a patient afflicted with tetanus, his sufferings may be greatly alleviated.

A proposition has recently been made to apply the electric current to the removal of the opacity of the crystalline lens. This is founded on the phenomena produced during the passage of the electric current through dissolved albumen. On passing a current through white of egg, the albumen coagulates round the positive pole; but none collects round the negative pole, unless the current be too strong. This coagu-

lation is evidently due to the chemical action of the acids, which are separated at the positive pole by the action of the current; at the negative pole, on the contrary, alkali is separated, which, as is well known, dissolves albumen. It has been thought that by applying the negative pole of a pile to the crystalline lens, darkened by the coagulation of its albumen, the alkali separated might dissolve the albumen. Matteucci made experiments to ascertain whether this might be done with feeble currents, which alone could be employed without causing inflammation of the eye. For this purpose he passed a current through white of egg, and when the albumen was coagulated round the positive pole he reversed the position of the poles, but with a pile of forty couples he could never succeed in dissolving with the alkali separated at the negative pole the albumen coagulated round the positive, though the current was continued for an hour. Thus, then, a cataract may be *brought on* by the electric current, but not cured.

The electric current has likewise been proposed for the dissolution of urinary calculi, but unfortunately hitherto without success; the fact is, that calculi are generally formed of insoluble substances, which will not yield to an electric current, unless it be of great intensity and continued for a long time.

The apparatus required for the medical administration of frictional Electricity is very simple, viz., a pair of directors, one curved and one straight, and surmounted either with brass balls or blunt wooden points, a few yards of brass chain, and an insulating stool, or, what is sometimes very convenient, a common arm chair, the legs of which rest in four stout glass cups, somewhat resembling salt-cellars, and a Leyden vial, provided with a Lane's discharger (see Lectures on Electricity, Fig. 44, p. 53), for regulating the strength of the charge, are all that is required. The machine may be either the cylinder (Fig. 14) or the plate (Fig. 15); if the former, it should not be less than eight inches in diameter; if the latter, from eighteen inches to two feet.

In the *Philosophical Transactions*, and in the pages of the *London* and *Dublin Medical Journals*, those interested in the therapeutical applications of this form of Electricity may find a large collection of cases, in which decided relief, and in some instances perfect cures, have been effected in *paralysis*, *tetanus*,* *muscular contractions*, *St. Vitus's dance*, *neuralgia*, *amaurosis*, and *deafness*. On reading the histories of these cases, it will be seen that in some, shocks from the vial were found most effectual, while in others relief was best obtained by sparks drawn from the parts effected, the patient being placed on the insulating chair. In cases of *chorea*, Dr. Golding Bird, who has

* This case, communicated by Dr. Watson, is to be found in the 53rd vol. of the *Phil. Trans.* p 672. It deserves the most attentive consideration of medical men.

treated between thirty and forty cases, states that he never found any good to follow the transmission of shocks; but by taking sparks from the spine, the results were on the whole *very satisfactory*.

The treatment of *amaurosis* and *deafness* by Electricity, requires to be conducted with great care, and should never be attempted by those unacquainted with the minute anatomy of the delicate organs in which these diseases lie. Mr. Pott, who treated successfully a case recorded in the *London Medical Journal*, vol. ix, proceeded thus:—The patient was placed on the insulating chair, and connected with the prime conductor, which was put in connection with a very large jar exhibiting *four feet* of coated surface. When the jar was fully charged, the operator drew off the charge through the orbit of the eye by a *wooden point*, until an attached Henley's electrometer stood at 3°, the remainder of the charge was then drawn off through the temples; sight was restored after *thirteen* applications. In cases of deafness, Sir William Blizzard's plan was the following:—A Leyden jar, connected with the prime conductor, was placed within the proper distance of a discharging electrometer, so that when the jar was sufficiently charged, its charge would strike the electrometer and pass along a chain terminating in a wire placed in the *meatus auditorius externus;* another chain, placed at the bottom of the jar and joined to a silver wire, was passed through the nose into the Eustachian tube; a process which, if carefully done, does not occasion pain. The shocks passed must be very weak at first, but may be gradually increased; and it must particularly be borne in mind, that should pain in the head or uneasiness be produced, the treatment must not be persevered in.

For the medical application of Voltaic Electricity, the simplest, and on the whole the most convenient, form of battery is the old *Cruickshank* trough (see Lectures on Electricity, Fig. 99); the exciting agent being dilute sulphuric acid. The mode of application may differ in different cases; when it is to be applied on the surface, the current may be transmitted through the medium of *sponges;* or, what is perhaps more convenient, by means of saddles of thin sheet copper covered with thick flannel, and saturated with brine, the surface of the skin being also well moistened with salt and water; it is sometimes, however, desirable to act on parts deeply seated below the surface; in such cases, the following method of M. Sarlandière may be adopted:—Needles of steel or platinum are introduced, as in the process of acupuncturation, the needles being connected respectively with the two opposite ends or poles of the battery. Becquerel considers this to be the most efficacious mode of applying Electricity, since it permits the operator to act directly on the diseased part.

It was first noticed by Marianini that the force of the shock

differs considerably, according as the current goes in one direction or another; thus, if a person grasp two conductors connected with the poles of an extensive voltaic battery in vigorous action, he will experience a much more powerful muscular contraction in the arm which is in communication with the *negative*, than in that connected with the *positive* end; so also, if the current be passed down the arm from the shoulder to the hand, the latter being immersed in a basin of salt water, a powerful contraction is experienced; if, however, the current be passed from the hand to the shoulder, the contractions are much less violent, and the difference is observed most strikingly in paralytic patients.

The following explanation of these differences is offered by Marianini: — The action of Electricity on the muscles and nerves produces two distinct kinds of contractions; the first, which he calls *idiopathic*, are the result of the immediate action of the current on the muscles; and the second, which he calls *sympathetic*, arise from the action of Electricity on the nerves which preside over the motions of the muscles. Now, *idiopathic* contractions are necessarily produced in whatever direction the current of Electricity passes; but the occurrence of *sympathetic* contractions must be governed by the direction of the passing current—they can only take place when the Electricity is transmitted in the direction of the ramification of the nerves; the shocks then experienced when the current is transmitted from the shoulder to the hand are more powerful than those passed in the reverse direction, because in the former case the Electricity is transmitted in the direction of the ramifications of the nerves, and in the latter in the contrary direction. These facts, which the researches of Matteucci confirm and illustrate in a satisfactory manner, will serve as a valuable guide to the Electrician in his treatment of cases of paralysis by this form of Electricity.

Majendie and Grapengresser have paid much attention to the curative effects of Galvanism in *amaurosis* and *deafness;* the same observations which we made above respecting the care and anatomical knowledge requisite for treating such diseases by frictional Electricity, apply also here, and perhaps even with greater force. Majendie's usual plan was to employ acupuncturation, making the electrical current act directly on the nerves of the orbit of the eye; and in this way he accomplished some remarkable cures. Grapengresser proceeded in a different manner. He introduced into the nose a silver probe connected with the positive end of the battery, and touched the region of the frontal nerve, previously well moistened, with a wire connected with the negative end. In cases of deafness, he used two silver wire conductors, each bent at one end, exactly in the direction of the *meatus auditorius*, and terminating in a small knob exactly fitting the auditory

canal, which was covered with linen and moistened. The current, running through the nerves with great rapidity, is communicated to the auditory nerve, and generally occasions the sensation either of a loud noise or of a tinkling sound. A feeble power must be employed in these cases, and be continued for only a few minutes at a time; as a general rule, the operator should in all cases commence with a weak battery, gradually increasing its strength as the case progresses: in cases of paralysis, the battery power required frequently rises to 100 pairs.

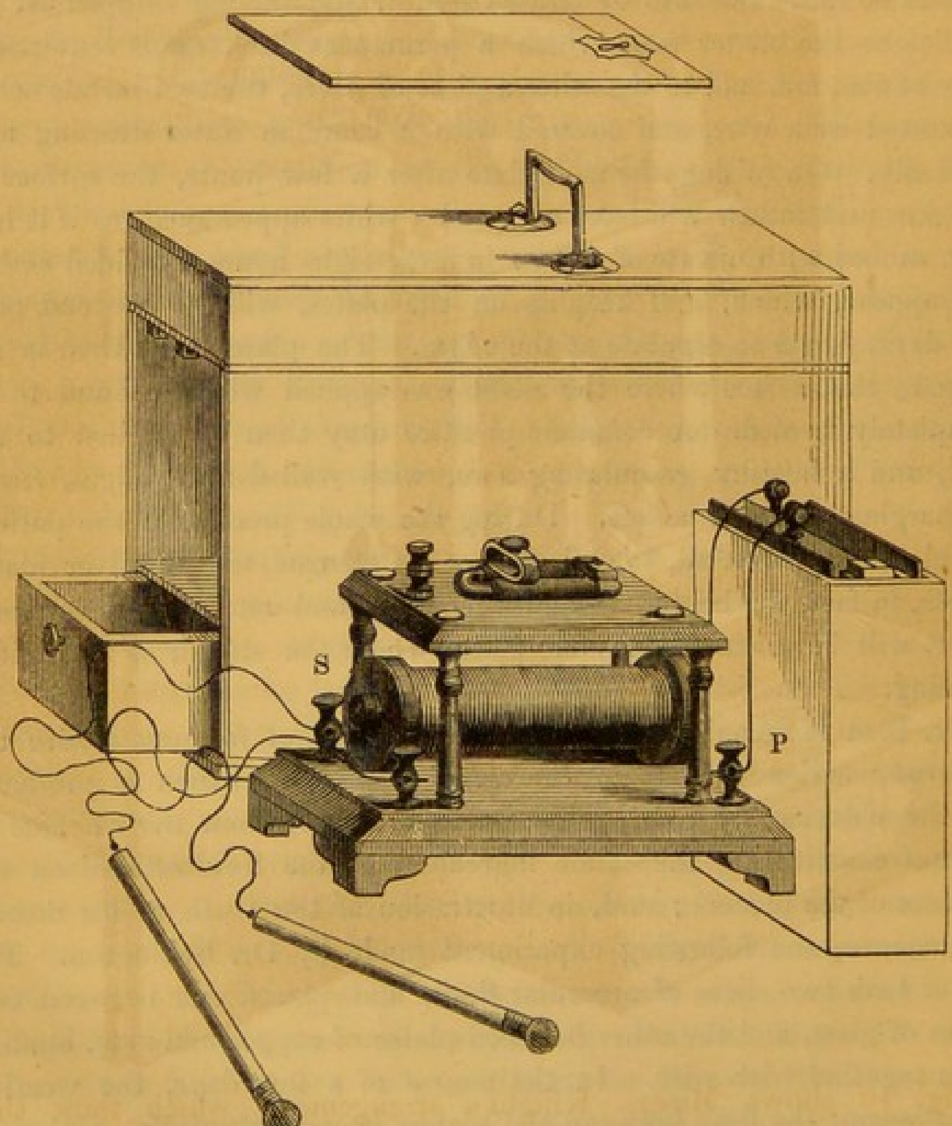
The observation was made long since by Humboldt, that a very weak galvanic power was capable of exercising a remarkable influence on the secretions from wounds; he found that when a simple arc was applied to a blistered surface, the part exposed to the most oxidable metal was more irritated than that to which the negative plate was applied. Dr. Golding Bird has made an ingenious application of this singular fact to the production of *puriginous* sores, in the place of the *issue* and *seton*. His plan is the following:—By means of small blisters he raises the skin by effused serum, and having snipped it, he applies to the blister from which a permanent discharge is required a piece of zinc foil, and to the other a piece of silver, the two metals being connected by a wire, and covered with a common water dressing and oiled silk. On raising the zinc-plate after a few hours, the surface of the skin underneath will have assumed a white appearance, as if it had been rubbed with nitrate of silver: in forty-eight hours a decided *eschar* will appear, which, still keeping on the plates, will, at the end of a few days, begin to separate at the edges. The plates may then be removed; the surface where the silver was applied will be found to be completely healed. A common poultice may then be applied to the part, and a healthy granulating sore, with well-defined edges, freely discharging pus, will be left. During the whole process, if the patient complain of pain at all, it will always be referred to the silver plate, where, in fact, the blister is rapidly healing; and not the slightest complaint will be made of the zinc-plate, where the slough is as rapidly forming.

Dr. Bird is of opinion, that in this method of forming a sore the *escharotic* action is that of the *chloride of zinc*, which is produced by the chlorine set free by the galvanic action from the *chloride of sodium* constituting the saline ingredient of the fluid effused on the surfaces of the blisters; and, in illustration of the truth of his theory, he instances the following experiment made by Dr. Babington. The doctor took two slices of muscular flesh, and placed one between two plates of glass, and the other between plates of copper and zinc, binding them together with wire. In the course of a few days, the weather being warm, the flesh between the glasses began to putrefy, and soon

afterwards was full of maggots; while that between the metallic plates remained free from putrescency. A remarkable change had, however, occurred; for on taking off the plates the side opposite the zinc-plate was hard, as if it had been artificially dried; while that opposed to the copper had become covered with a transparent substance resembling jelly; in fact, observes Dr. Bird, the result of the experiment evidently was, that the chloride of sodium existing in the flesh had been decomposed, the zinc had been acted upon, and a dry, hard compound of chloride of zinc and albumen formed on one side of the piece, whilst the soda set free on the other side had become converted into *albuminate of soda*, in the form of a gelatinous mass.

In our ninth lecture, we have entered so fully into the rationale of the action of the *Electro-Magnetic Coil Machine*, and have described so many arrangements of the apparatus, that a very few additional observations are necessary here to convey to our readers

FIG. 10.



all the information they will require respecting the application of this interesting form of Electricity to therapeutic purposes.

In addition to the various forms of the coil already described, we here insert engravings and descriptions of two new modifications of the instrument, one (Fig. 10) designed by the publishers, and the other (Fig. 11) by the author of this treatise; both will be found to possess a decided superiority over the previous machines, and each to have its own distinctive feature.

FIG. 11.

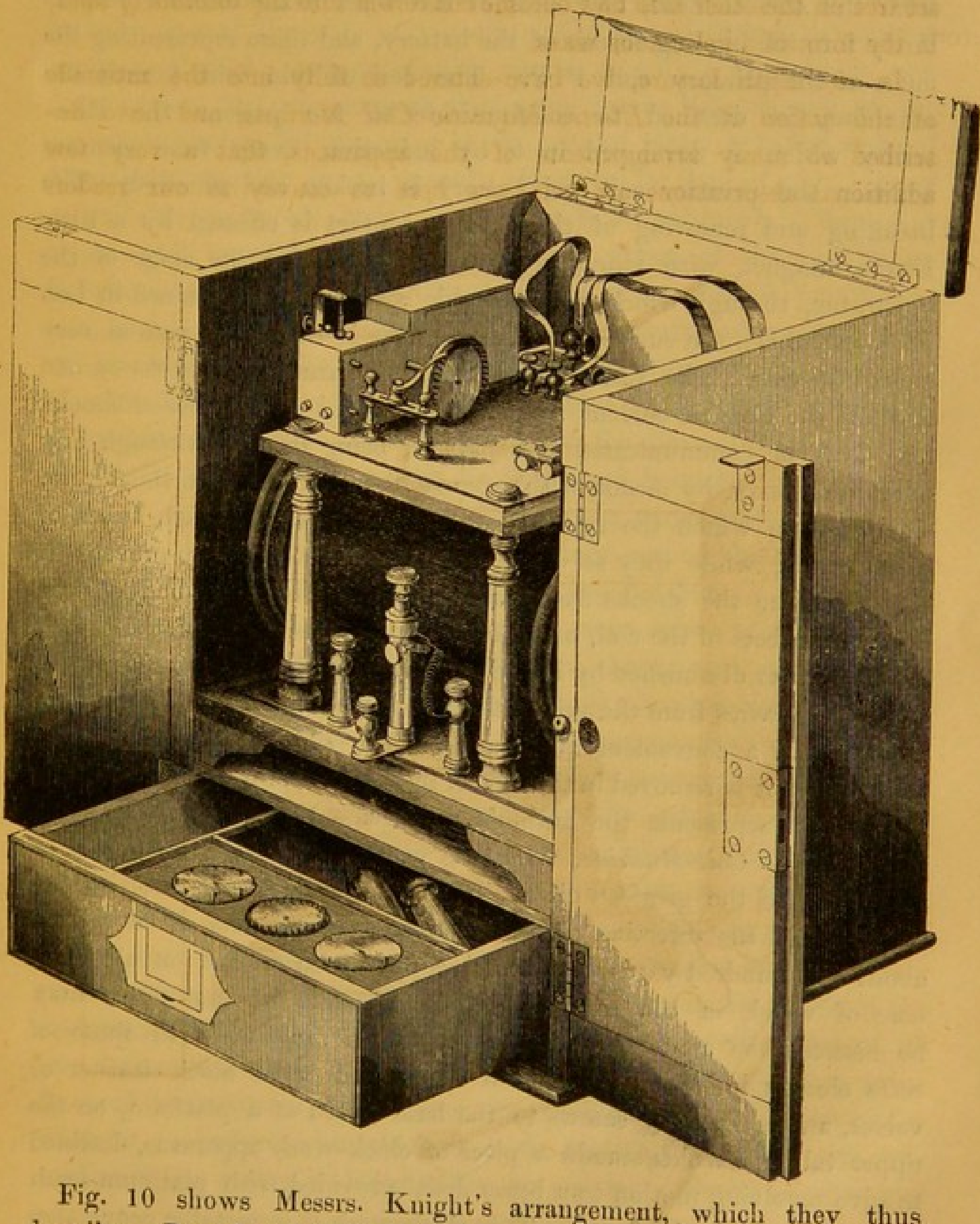


Fig. 10 shows Messrs. Knight's arrangement, which they thus describe. Round a hollow cylinder of wood, a considerable length

of stout copper wire, covered with cotton thread for the purpose of insulation, is wound. The two ends of this coil are metallically connected with the binding screws P P on the base board of the apparatus (one of these is not seen in the cut); over this coil a very considerable length of much finer copper wire, also insulated, is wound. The two ends of this second coil are metallically connected with the binding screws S S. The coil of thick wire is called the *primary:* through it the current from the battery circulates, to which it is connected by means of two stout copper wires, one proceeding from the silver and the other from the zinc element, two ends of the wires being inserted respectively into the binding screws of the battery, and those representing the ends of the primary coil P P. The coil of thin wire termed the *secondary* is destined to communicate to the patient the Electricity which is developed in it by induction every time contact between the primary coil and battery is broken and renewed. The breaking and renewing of the battery contact is effected by a little Electro-magnet, with vibrating armature, placed on the stage of the apparatus, through which, by a suitable contrivance (explained in Lec. Elec. par. 694), the current from the battery is caused to pass at very short intervals. The vibrating motion of the armature throws on and cuts off the Electric current from the coil, and a rapid series of shocks may thus be communicated to a patient, being directed through any part of his body, by means of the sponge directors shown in the figure. The wires to which the sponges are attached pass through tubes of glass which, while they serve as handles for the operator, prevent at the same time the shocks from passing through his own body. The inductive effects of the coil, or, in other words, the power of the shock, is increased or diminished by introducing into or withdrawing the bundle of soft iron wires from the axis of the wooden cylinder. The apparatus is packed in a convenient mahogany box, in which it is worked, but from which it is removed in the figure, in order to show its construction.

Fig. 11 represents the author's arrangement of the *Medico-Electro-Dynamic Coil-Machine*, which is constructed with the object of regulating to the greatest nicety, not only the strength, but also the frequency in the direction of the shocks. It consists of a coil of about one hundred yards of covered copper wire wound on a hollow core of wood, in the axis of which a bundle of iron wires may be inserted, so as to combine the effects of *magneto* with those of *volta* electric induction. The coil is covered with black leather or velvet, and is fixed by screws to the base board of a platform, on the upper table of which stands a piece of clock-work apparatus, destined to give revolving motion to a brass disc, provided with platinum teeth or cogs, as seen in the figure. This clock-work is in metallic connection

with one of the poles of the battery, which consists of two cells on Mr. Smee's plan; the other pole of the battery is metallically united through the coil with a small brass stage, to which is adapted a piece of steel spring tipped with platinum, and which is so arranged as to come into contact with each tooth or cog of the disc during its rotation; by means of a screw, the degree of force with which it presses on the cogs is readily adjusted.

The manner in which this machine acts will be clearly understood by reference to the general principles of *volta-inductric action*. When the battery circuit is completed through the coil, and contact established between one of the cogs of the disc and the steel spring, the current traverses the coil, and no sensible spark, or only a very feeble one, is perceived; but the moment the spring leaves the cog, and on the consequent return of the wire to its natural state, a *reflex wave* of Electricity, moving in a *contrary direction* to that of the battery current, is generated, and a bright spark is produced. Now this bright spark is not occasioned by any direct action of the battery, as Faraday has shown,* but by a force exerted in the wire of communication, that is, in the coil; and if two wires, connected respectively with either extremity of the coil, be brought almost into contact, at the very moment that contact with the battery is broken, the spark will appear at the interval between them, while that at the disc will be very feeble, so also, if a fine platinum wire be interposed between the two cross wires, it will remain unaffected as long as the spring and the disc are in contact, but the moment the former leaves one of the teeth of the latter, the platina wire either fuses or becomes red-hot.

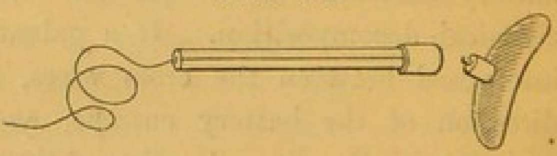
The spark which passes between the cross wires is one of great intensity, and if the body be interposed, a shock, more or less violent according to the size of the coil, is experienced; if a bundle of iron wires be thrust into the axis of the coil, it becomes insupportable. That this *induced* current does really move in a direction *contrary* to that of the battery current, may be proved both by the galvanometer and by chemical decomposition. If a galvanometer of no great delicacy be interposed between the cross wires, it will show a current in the direction of the battery current, as long as the spring remains in contact with the disc, a portion of the electricity excited by the battery, passing through the wire of the galvanometer; but if the needle of the instrument be forced back by pins applied upon opposite sides of its two extremities, so as to retain it in its natural position, when uninfluenced by a current, and if then the spring be caused to leave the tooth of the wheel with which it is in contact, the needle will immediately be strongly deflected in an opposite direction, showing,

* See his Experimental Researches, par. 1,078, *et seq.*

evidently that the induced current follows a course *contrary* to that of the battery. Again, if two platinum discs be covered with bibulous paper, moistened with iodide of potassium, and attached respectively to the ends of the two cross wires, a feeble evolution of iodine is *sometimes*, though rarely, obtained during the maintenance of contact, but the moment the spring leaves the cog the salt is decomposed in such a manner as to show the passage of a current in the reverse direction to that of the battery.

From these facts, it will be seen at once that we have in this arrangement of the coil, a ready method of administering to a patient, either *direct* or *inverse* shocks at pleasure. In the front of the lower platform in the figure, and between the two supports of the upper stage, will be seen a small water regulator This is interposed in the circuit of the coil, and by raising or depressing the upper wire, which is done in the most gradual manner by making it a screw, the intensity of the shocks may be modified to any required degree, and such perfect command does this simple arrangement give us over the power of the induced shock, that we are enabled by means of it to apply this form of Electricity to so delicate an organ as the eye, or to administer shocks sufficiently severe to bring a stout man to his knees. The method of connecting the water regulator with the coil, will be understood by the slightest reference to the figure. The clock work is so contrived as to give the disc one revolution per minute. Several of these discs are provided each with a different number of cogs, and we have thus a convenient method of regulating the frequency of the shocks. The binding screws are marked respectively A and B, A representing the positive and B the negative pole of the battery, at the moment of making contact, and during the time the current is circulating, not the slightest shock is experienced; but the instant the spring slips over one of the teeth of the disc, the shock passes from B to A. If, then, we wish to administer *direct* shocks to a paralytic limb, say the leg, we apply a sponge director or saddle, moistened with salt water, and connected with B to the hip, a metallic plate in connection with A being placed in a basin of salt water, and the foot of the patient laid upon it; if, on the other hand, we wish to apply *inverse* shocks, we merely reverse the disposition of the conductors.

FIG. 12.



The apparatus for the therapeutic application of Electricity is now so commodious and simple, that it is much to be desired that the knowledge with which we have been furnished by the beautiful Electro-physiological researches of Matteucci should receive a more extended

practical application in this country, than it hitherto has had. Our hospitals furnish ample opportunities for studying the effect of Electricity in almost every form of disease. "Hitherto," observes Dr. Golding Bird,* "it has been by no means fairly tried; for it has either been exclusively recurred to when all other remedies have failed, or its administration has been carelessly directed, and the mandate, 'Let the patient be Electrified' merely given, without referring to the manner, form, or mode of the remedy."

* In a Lecture lately delivered before the College of Physicians.

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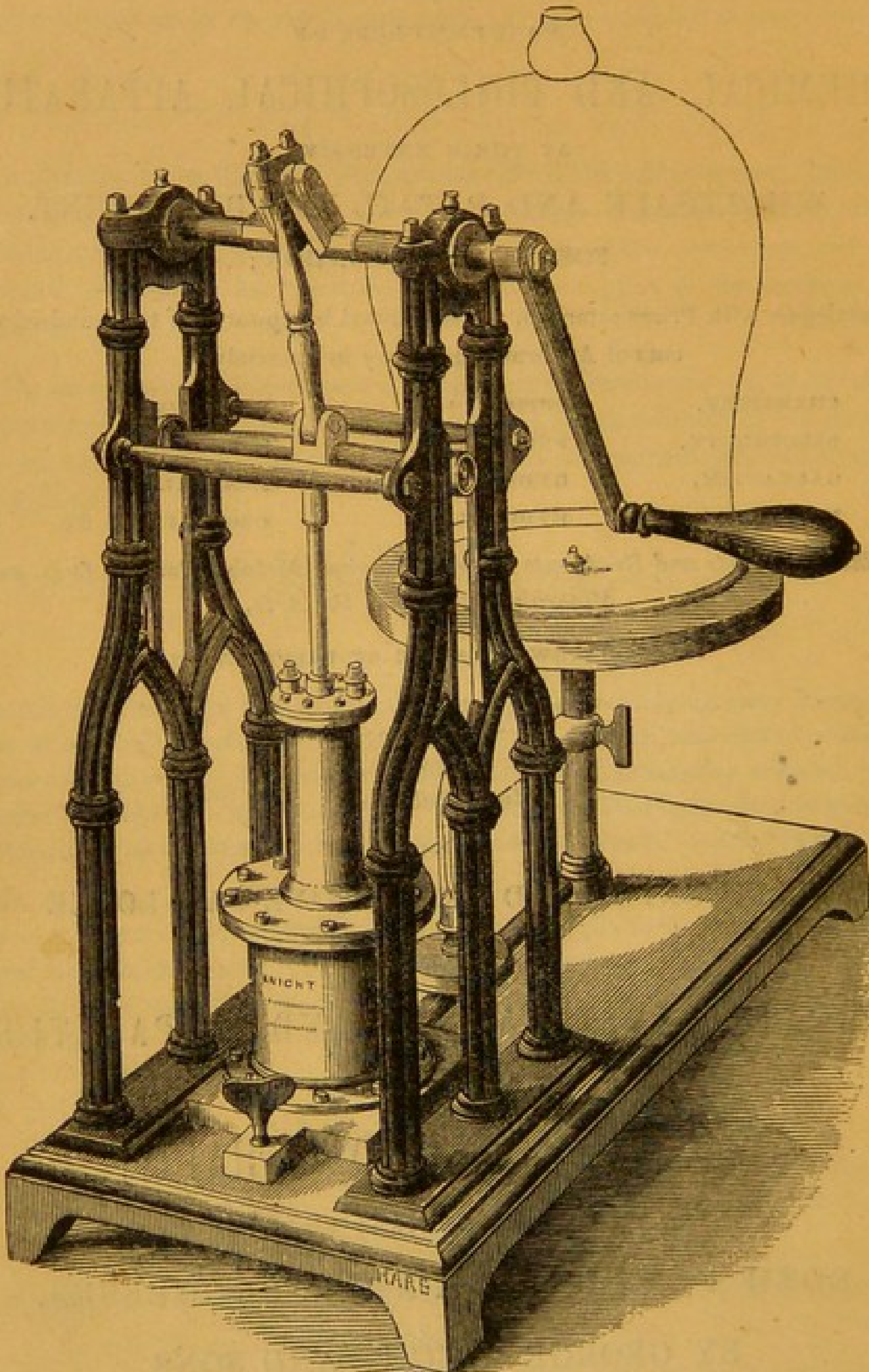

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