# XXXI. *Electro-Physiological Researches. On Induced Contraction.—Ninth Series.*

*By Signor* Carlo Matteucci, *Professor in the University of Pisa, &c. &c.*
*Communicated by* W. R. Grove, *Esq., F.R.S.*

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It is not without considerable regret that I am compelled to depart from my established rule of never publishing any facts relating to electro-physiology without having previously endeavoured to connect them with those already discovered, and without having succeeded in reproducing them in such a constant and unvarying manner as to remove the slightest doubt of their truth. The announcement, however, just made to the Académie des Sciences by M. du Bois Raymond of a work "*On the Law of Muscular Current, and on the Modification which that law undergoes by the effect of Contraction*," obliges me, though unwillingly, to transmit to the Royal Society the continuation of my researches on induced contraction, confining myself, for the present, to some fundamental experiments, made a long time since, for the publication of which I should have wished to await a more favourable moment.

In the Third and Fifth Series of my Electro-physiological Researches*, I studied, with all possible care, and in its minute details, the fact of induced contraction, in order to deduce the law of this phenomenon, and from thence to be led to the discovery of its cause. In the Fifth Series, principally, I was led to conclude, that, according to all the analogies, and without being in opposition to the experiments, induced contraction might be considered to be the effect of an electric discharge which takes place during the act of muscular contraction.

In a memoir published in the Annales de Physique et de Chimie, Octobre 1847, after having given an exposition of the laws of the electrical discharge of fish, and demonstrated all the analogies existing between this function and muscular contraction, I declared still more explicitly, that experiment leads to the admission that in muscular contraction there is a phenomenon analogous to that of the discharge of the Leyden phial, and which was the cause of induced contraction. Nevertheless it has been my wish that this conclusion, which I have always studiously announced with extreme reserve, should be demonstrated by direct experiment, and this object I have vainly endeavoured to attain in making use of the galvanometer.

In the memoirs above cited, are to be found a description of all the efforts made to this purpose; by forming piles with muscular elements of the frog and making these elements contract, I endeavoured, but always without satisfactory result, to obtain

* Philosophical Transactions, Part II. 1845, 1847.

from the galvanometer signs of electrical phenomena produced by the act of contraction. The variations produced in the conductibility of the circuit, by the convulsive movements of the muscles of the frogs, which alter the points of contact between the elements of the pile, the agitation of the liquid into which the platina plates of the galvanometer are plunged, are constant and inevitable causes of the production of an electric current, which involves a constant uncertainty as to the effects which may depend on contraction. These same causes of error exist in the experiment made by M. du Bois Reymond on voluntary contraction of a man's arm; I have tried a great number of experiments, following his method, increasing the number of elements which contract at the same time, without ever succeeding in obtaining an evident and constant development of electricity by muscular contraction. In the researches for the discovery of this development, I have not failed to employ, with all proper care, the galvanoscopic frog. Operating on a circle of thirty and forty individuals, who all contracted the same arm at the same time, and although the galvanoscopic frog, the nerve of which formed part of the circuit (being in contact with the two outermost fingers of this pile of men), was extremely sensitive, yet never did we obtain the slightest sign of a current from voluntary contraction. Yet the circuit, though composed of a great number of individuals, was always a sufficiently good conductor for the transmission of a current of some muscular elements, capable of producing contraction in the galvanoscopic frog.

Since, therefore, the galvanometer employed in my first experiments on induced contraction, and by means of which M. du Bois Reymond thinks that he has discovered the development of electricity in voluntary muscular contraction, never has with me led to any other but uncertain and very doubtful results, since by the aid of the galvanoscopic frog, used as a substitute for the galvanometer, I have *never obtained the slightest signs* of an electric current in the voluntary contraction of the muscles of the arms, I was authorized in concluding that the development of electricity by muscular contraction still remained to be demonstrated by experiment, and that the phenomenon of induced contraction was still that which led most directly to this result.

I will now give some new experiments on induced contraction, of incontestable evidence and certainty, and which undoubtedly lend an increasing probability to the conclusion that induced contraction is due to an electric discharge, and that muscular contraction is accompanied by a development of electricity.

Exp. 1. I prepare a frog in the usual manner, and I lay on the muscles of its thighs, legs, and on the articulations of its claws, the nerves of highly sensitive galvanoscopic frogs: on provoking the contraction of the muscles of the first frog by irritating its lumbar nerves, the galvanoscopic frogs contract, and when these first contractions are very violent, induced contraction may be seen to take place on contact even with the extremities of the limb of the entire* frog. The signs of in-

* I apply the word entire to the frog fastened on the glass tubes: see figs. 1 and 3.

Fig. 1.

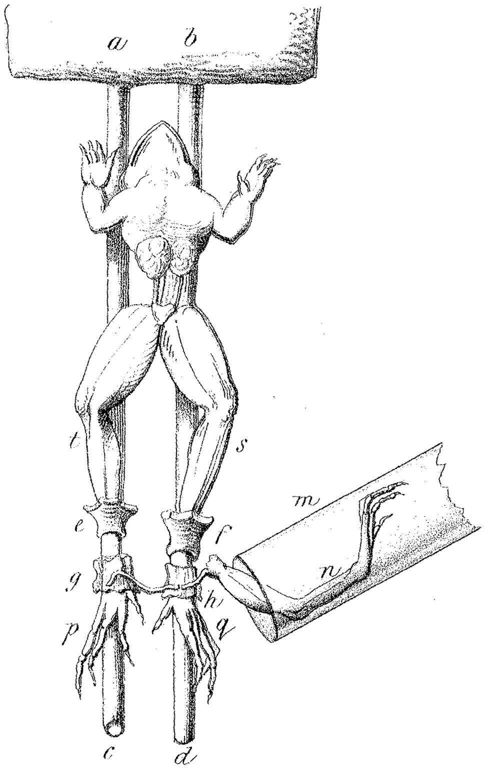



Fig. 3.

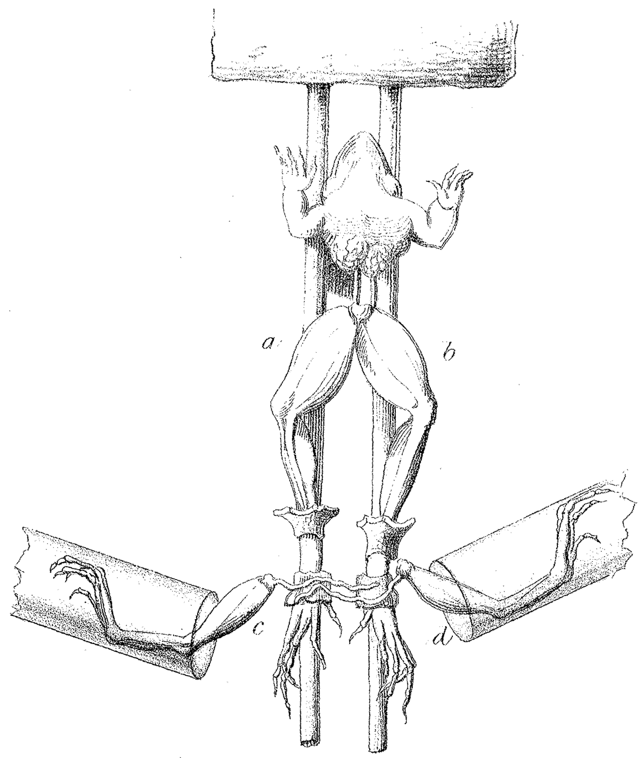



Fig. 2.

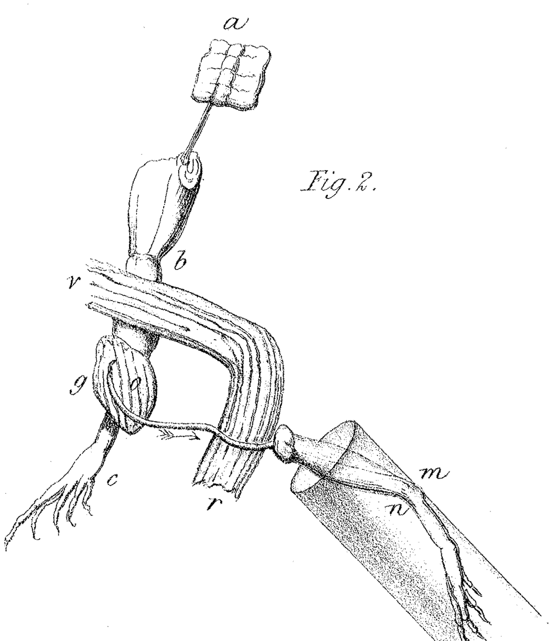
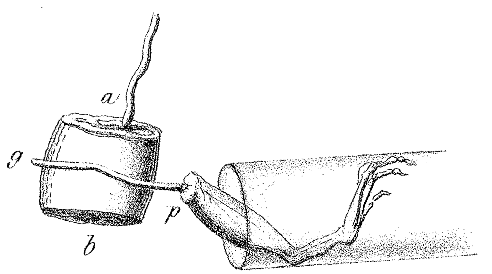



Fig. 4.




J. Basire, lith.

duced contraction are always obtained stronger and more durably on the muscles of the thigh and leg, than on the other parts of the frog.

Exp. 2. Induced contraction is very evident at the moment when the muscle itself, on which is laid the nerve of the galvanoscopic frog, is divided. This experiment is perfectly analogous to that which is made by cutting, in different directions, a very small piece of the organ of the torpedo, upon which a nerve of the galvanoscopic frog has been placed.

Exp. 3. Induced contraction is produced in the same manner, and with equal intensity, whatever may be the direction in which the nerve of the galvanoscopic frog is extended, in respect to the muscular fibres.

Exp. 4. If we interpose between the nerve of the galvanoscopic frog and the surface of the thigh of the entire frog several layers of wet paper, we cease to obtain induced contraction: if there is only a layer or two of very thin paper, induced contraction continues to be produced.

Exp. 5. We dispose a prepared frog, as in Plate L. fig. 1; *a c* and *b d* are two glass tubes covered with varnish, upon which the frog is fixed by means of Indian rubber rings, *e* and *f*; *g* and *h* are two bits of linen, or of thick paper moistened with salt water. If we touch separately the point *g* or the point *h* with the nerve of the galvanoscopic frog, there is no sign of induced contraction; but if the nerve of the galvanoscopic frog be disposed as in fig. 1, so that the nerve touches at the same time the points *g* and *h*, we have immediate contraction in the galvanoscopic frog, exciting contractions in the muscles of the entire frog. This takes place in whatever manner the contractions are provoked, whether by wounding or cutting the spinal marrow, or in passing an electric current from a small pair of zinc and platina along the lumbar nerves.

Exp. 6. If, while making the preceding experiment, a communication be established between the two legs of the frog, by placing a wetted cotton wick over the points *t s* or *p* and *q*, or over all the intervening points, the contractions of the galvanoscopic frog cease instantly, although the members of the entire frog are in contraction: we have only to remove the cotton wick and the phenomenon reappears. These alternatives are constant, and are always reproduced in the same manner.

Exp. 7. The results of the preceding experiments are obtained whether the legs of the entire frog are brought into contact or whether they are kept separate. We see from this the advantage of the arrangement adopted in these experiments in order to avoid placing the frog on a plane, which would soon become moistened and serve as a conductor.

Exp. 8. By means of a solution of the extract of nux vomica, I produce a state of nervous superexcitation in the frogs. While in this condition these animals are subject at intervals to violent contractions, which may also be excited by the slightest contact. I place a frog in this condition on the apparatus, fig. 1. The galvanoscopic frog rarely gives signs of contraction, while the entire frog contracts violently. *One*

*of the lumbar nerves ought now to be cut*; this being done, we are certain to obtain contractions in the galvanoscopic frog, at each contraction of the entire frog; these contractions cease if the two legs are brought into communication with the wetted cotton, as in the preceding experiment.

Exp. 9. I take a half frog, and instead of the other half, I employ a wick of cotton, *v, r* (fig. 2), one end of which touches the upper part of the leg or thigh, and the other the nerve of the galvanoscopic frog, *g p n*. The other extremity of this nerve rests on the lower part of the leg of the half frog, a thick stratum of wetted paper (*o*) being placed between the nerve and the leg. Every time that the half frog contracts the galvanoscopic frog contracts also; the latter ceases to contract if one removes the upper end (*v*) of the cotton wick from its contact with the upper part of the leg. It ought to be observed, that in this arrangement of the experiment we obtain the contraction of the galvanoscopic frog at the instant that we place the nerve in this sort of circuit.

This experiment has been tried with equal success operating on the limb of a living rabbit.

Exp. 10. Instead of one galvanoscopic frog I dispose two, as in fig. 3, and by irritating first one lumbar nerve and then the other, I produce contractions in each limb separately. During the first moments the two galvanoscopic frogs, *c* and *d*, contract, whichever may be the limb of the entire frog which contracts. Afterwards, when the galvanoscopic frogs begin to be less sensitive, we are sure to obtain contractions in the galvanoscopic frog, *d*, only when the limb *a* contracts, and the contraction in the galvanoscopic frog *c*, when it is the limb *b* which contracts. We obtain the same result by employing the arrangement adopted in fig. 2, representing the non-contracting limb by the wet cotton wick, disposed in the manner already described. Thus, if instead of having the nerve, *g p*, disposed as in fig. 2, we reverse the position of the nerve of the galvanoscopic frog in such a manner as to touch the cotton wick with its upper part, and the point, *o*, superposed on the limb with its lower part, either no contraction at all is obtained, or it soon ceases.

Exp. 11. I cut the thigh of a frog, above and below, so as to form a piece, *a b* (fig. 4), similar to a portion of a cylinder the two circular bases of which are the interior surfaces of muscle. The nerve of the galvanoscopic frog, *g p*, is disposed on the surface of this cylinder so as to be exactly parallel with the two bases. If we irritate the point *c* there are signs of induced contraction.

It is impossible for me to confine myself to the simple description of these experiments without deducing from them some conclusions, the most evident of which appear to me to be the following:—

1. The cause of induced contraction, according to all analogies, is the same as that which produces contraction of the galvanoscopic frog in the *sixth* and *following* experiments.

2. The cause of these contractions is evidently an electrical phenomenon developed

in the act of contraction, and which consists in a different state of electricity in the different points of the contracted limb.

3. This electrical phenomenon, like the contraction which produces it, lasts only for an instant.

4. These electric states, developed by contraction, tend to produce electrical currents which circulate in opposite directions across a conducting arch interposed between the two limbs, which contract at the same time.

5. The tenth experiment proves the existence of these currents and their directions; here we should remember that the galvanoscopic frog is more sensitive to the passage of the current when that current traverses the nerve in the direction of its ramification. Thus the contraction of the galvanoscopic frog, *d* (fig. 3), during the contraction of the limb, *a*, proves the existence of the electrical current, which goes from *a* towards *d*. The contraction of the galvanoscopic frog, *c*, during the contraction of the limb, *b*, proves, in the same manner, the existence of an electrical current going from *b* towards *c*.

Whatever the theory of these phenomena may be, it is certain that they demonstrate the production of an electrical *disequilibrium* in the act of muscular contraction.

In the experiments which have been described, this electro-physiological phenomenon may consist in a species of discharge, propagated in muscles in the direction of the ramification of the nerves. Is the cause of this discharge a phenomenon analogous to that of electrical fish, or does it consist in a change in the natural conditions of the muscular current, produced by contraction? In the present state of science it is impossible for us to answer this question. According to all the analogies, and according to our present experimental knowledge, we lean to the former of these two explanations; but we wait the light of new experiments to proceed safely further in this difficult field of science.

*Pisa, April* 1, 1850.