XIV. *Electro-Physiological Researches.—Sixth Series. Laws of the Electric Discharge of the Torpedo and other Electric Fishes—Theory of the production of Electricity in these animals.*

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Received May 20,—Read June 10, 1847.

THE present memoir is not a mere description of a certain number of facts lately discovered on the electricity of electric fishes; besides this, and more than this, it contains the laws and theory of these phenomena. Consequently the order of exposition of the facts in this memoir will be the same as that which a scientific arrangement of the subject would dictate.

It is needless to remind the reader that the discharge of the electric fishes is subject to the will of the animal.

On irritating any point of the body of an electric fish, it is easy to demonstrate by experiment that this irritation is transmitted by the nerves to the fourth lobe of the brain, and that then only the discharge takes place. If the spinal marrow be divided at any part of its length in a living torpedo, every kind of irritation below the point of section fails to produce any effect.

It is equally easy to prove that the nervous action by which the discharge is determined under the influence of the will, resides in the fourth, or *electric lobe* of the brain; in effect, after the three superior cerebral lobes have been extracted, the torpedo can still give the shock either voluntarily, or from external irritations.

We also know that if one of the electric organs of a living torpedo be rapidly detached, we can still obtain the discharge on irritating one of the nerves ramified within the organ.

We have also shown, some time ago, that on acting upon these nerves with the electric current, we obtain the discharge under the same conditions and the same laws as those under which we have muscular contraction on acting upon the mixed nerves. Hence the remarkable analogy found to exist between muscular contraction and the electric discharge of fishes.

The most singular and the most important fact in a theoretical point of view is the discharge which we obtain when we take a very small part of a prism of the electric organ of the torpedo, and irritate it in any manner. Electric discharges always take place, as is shown by the contractions of the galvanoscopic frog.

I have very lately repeated this experiment in a variety of ways, and have always found that, on irritating one of the small nervous filaments distributed to the organ,

we obtain the discharge from that small portion of the organ into which the nerve penetrates. We have thus every reason to conclude that the electric organ of the torpedo and of all the electric fishes is composed of a great number of elementary organs, and that the elementary organ is nothing else but a nervous fibril in contact with a small cell filled with albumen. And since this cell gives an electric shock when it is subjected to nervous action, we are compelled to admit that under nervous influence the two opposite electricities separate to be instantaneously re-united.

This relation between nervous influence and electricity is, without doubt, of the same nature as that which exists between heat and electricity, between the electric current and magnetism. It is in studying the production of electricity in the different electric fishes, together with the distribution of nervous filaments in their electric organs, that we arrive at a better understanding of this relation between nervous influence (la force nerveuse) and electricity. Thus we see in the torpedo and gymnotus—the two electric fishes best known physically and anatomically—that the nervous filament always ramifies in the electric organs of these fishes perpendicularly to the axis of the prisms of these organs. Besides which we know that the extremities or poles of the electric organs in these two fishes are situated at the extremities of the prisms: in effect, in the torpedo these poles are the ventral and dorsal surfaces, while in the gymnotus the poles are at the head and tail of the animal.

It will be seen from this, that in this action of the nervous force, as exercised in the electric organs of these fishes, it follows the same law in developing electricity as does the electric current upon magnetic bodies. In effect, each prism of these electric organs cannot be considered otherwise than as a pile of elementary organs, upon each of which a nervous filament is spread normally to the axis of this pile. Now a cylinder of cast iron enclosed in a helix of metallic wire, and traversed by the electric current, is evidently an apparatus analogous to a prism of the electric organ of the fish at the moment when the nervous influence excites the discharge.

On one side we have the two opposite states of electricity, the tension of both of which must increase at the extremities of each prism in proportion to the number of elementary organs of which it is composed; on the other hand, we have opposite magnetic states, the strength of which at the poles is also proportional to the number of magnetic elements of the cylinder.

Experience has in fact shown, both in the torpedo and in the gymnotus, that the strength of the current obtained during the discharge is proportional to the length of the prisms included in the circuit closed. I have frequently seen, on dividing the electric organ of the living torpedo in a plane parallel to the surface of the organ, that the sum of the currents given by the different slices of the organ were approximatively equal to the current given by the entire organ. These same facts are verified also by including different points of the electric organ of the torpedo in the circuit; we know, in effect, that the current is stronger when points near the median line of the animal are touched, than when more remote points are. Nothing is easier than

to verify upon the gymnotus the fact that the strongest discharge is that obtained on including the entire length of the animal within the circuit.

In comparing the discharge of the torpedo with that of the gymnotus, so far as it is possible to do so, it is somewhat surprising to see that the two discharges are not so far different as they should be to be in proportion to the length of the prisms in the two animals.

But anatomy furnishes us with the key to this apparent anomaly, and shows us that the length of the prisms in the torpedo may be considered equal to that of the gymnotus, inasmuch as the number of elementary organs in the former is at least ten times as great as in the latter.

As regards the constancy in the direction of the current in the discharge of the electric fish, it results necessarily from the unvarying direction in which nervous influence is propagated through the nerves of the electric organs.

Experience has clearly shown that these nerves are charged with the sole function of exciting the discharge, so that the nervous action must constantly be propagated in a direction from the brain to the nervous extremities; the direction in which the separation of the two opposite states of electrical excitement ought to take place in the electric organ, must also necessarily be constant.

Finally, it results from all that has been said above, and it is proved by a vast number of experiments, that there exists between the nervous force and the electric states developed in the electric organs of fishes, that same relation or degree of intensity which always exists between two phenomena of which one is the cause of the other, such as exists between the electric current and the magnetism which it gives rise to.

In effect, without stopping to insist too much on what may be but vague in the physiological data, I cannot but admit that the nervous force increases independently of the will, with every increase in the activity of the functions of circulation and of respiration, and of every act of nutrition, as also under the influence of certain agents introduced into the organism. A great many experiments have fully convinced me that the electric shock of the torpedo increases with these same vital actions. Thus the torpedo in water, a little above the ordinary temperature, produces stronger discharges; the effect is precisely opposite if the respiration or the circulation of the blood of these fishes be hindered. The torpedo and the gymnotus give discharges decreasing in strength in proportion to the number given, and they reacquire their faculty of giving more powerful shocks after an interval of repose. The torpedo, over-excited by nux vomica, gives shocks more powerful than usual. This last and the preceding facts establish the connection between the intensity of the nervous force and that of the electric discharge of fishes.

I trust that I have demonstrated in this memoir, which contains the summary of my numerous researches upon the phenomena of electric fishes, that there exists in the electric organs of these fish a very simple case of relation between nervous force and electricity, established by well-determined laws.

Pisa, January 1847.