Physics 4

Fig. 29

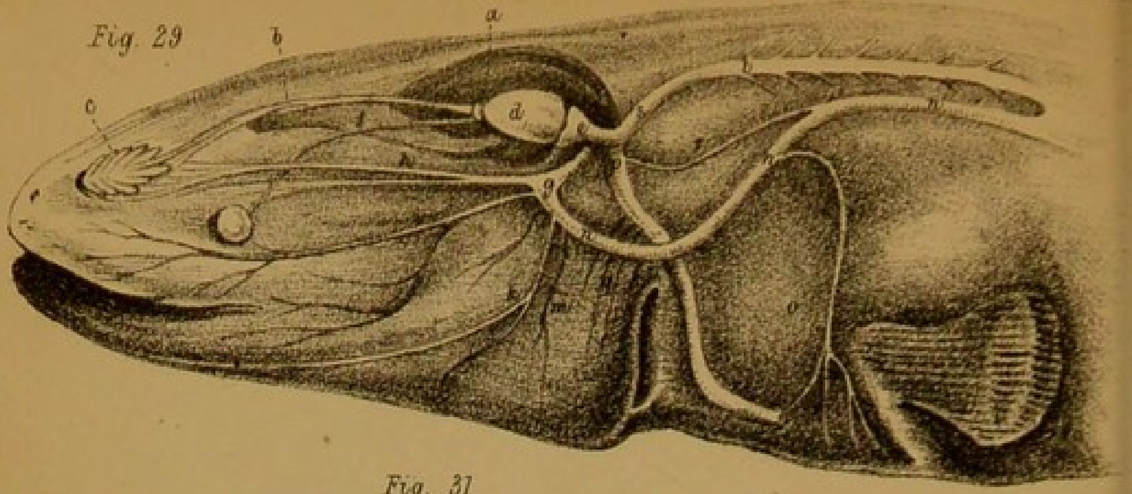


Fig. 31

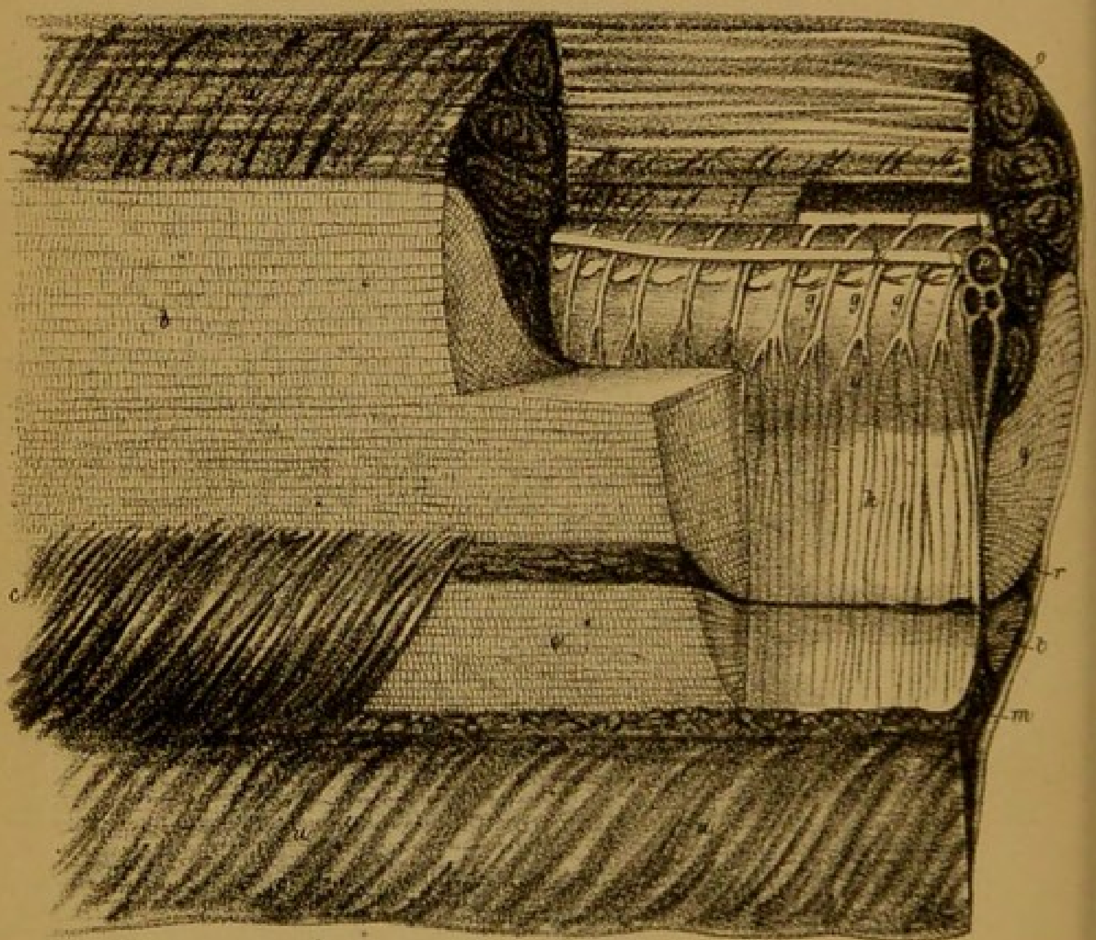
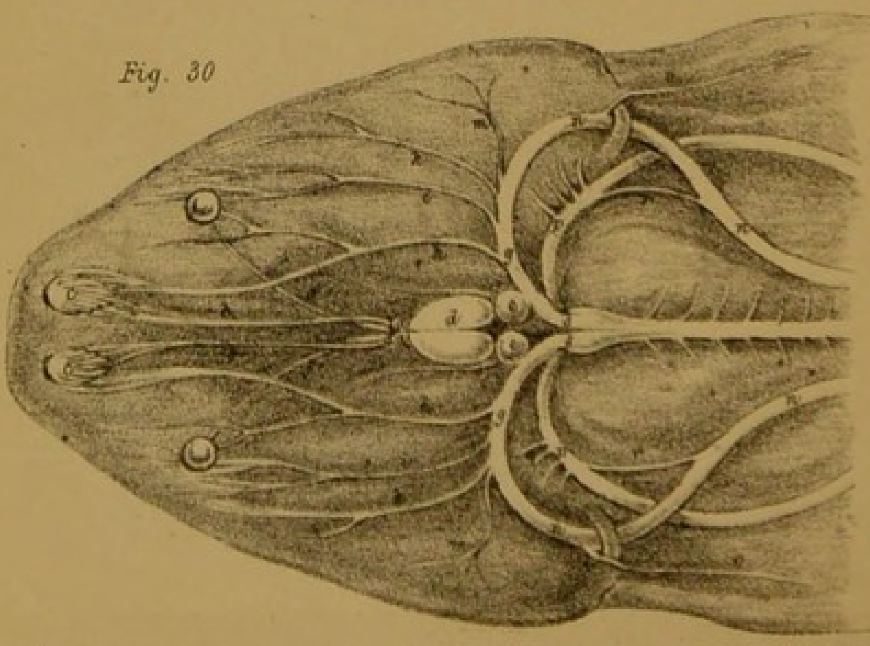


Fig. 30



E. M. Williams, lith. 144, Fleet St.

H. Letheby, ad nat. d.

Fig. 32

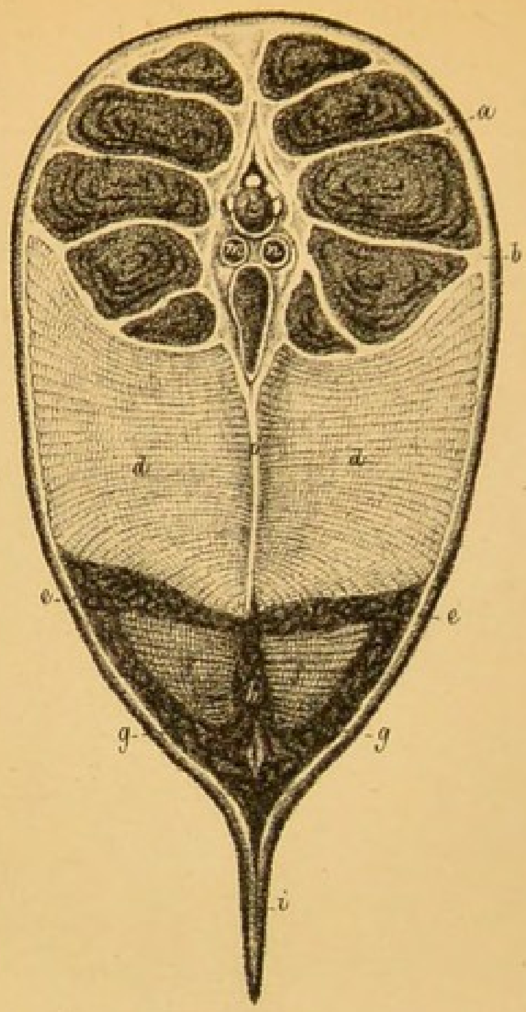


Fig. 33.

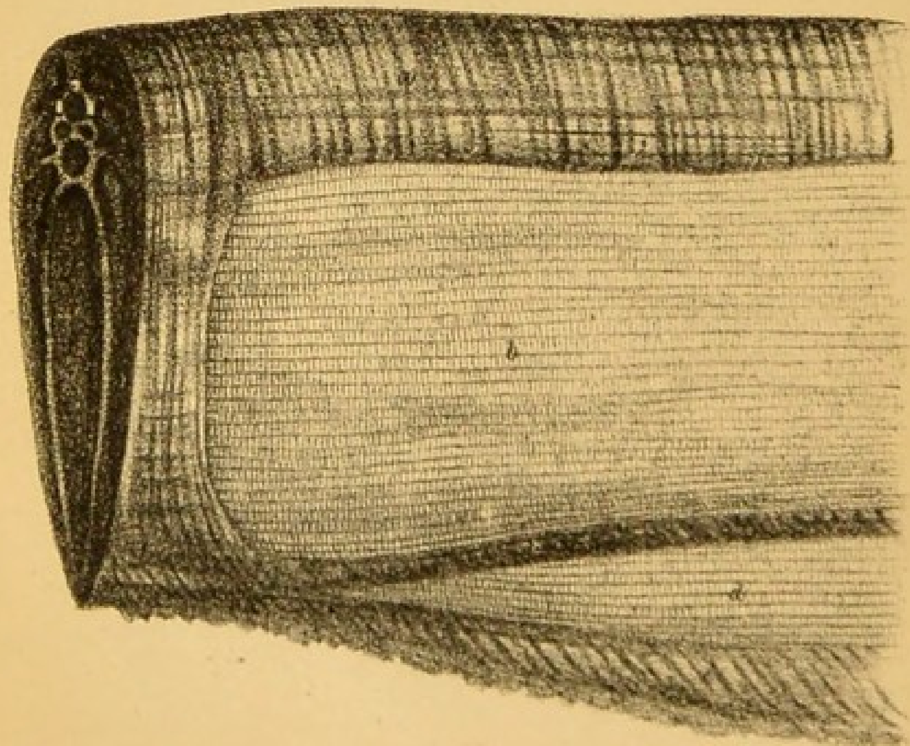


Fig. 34

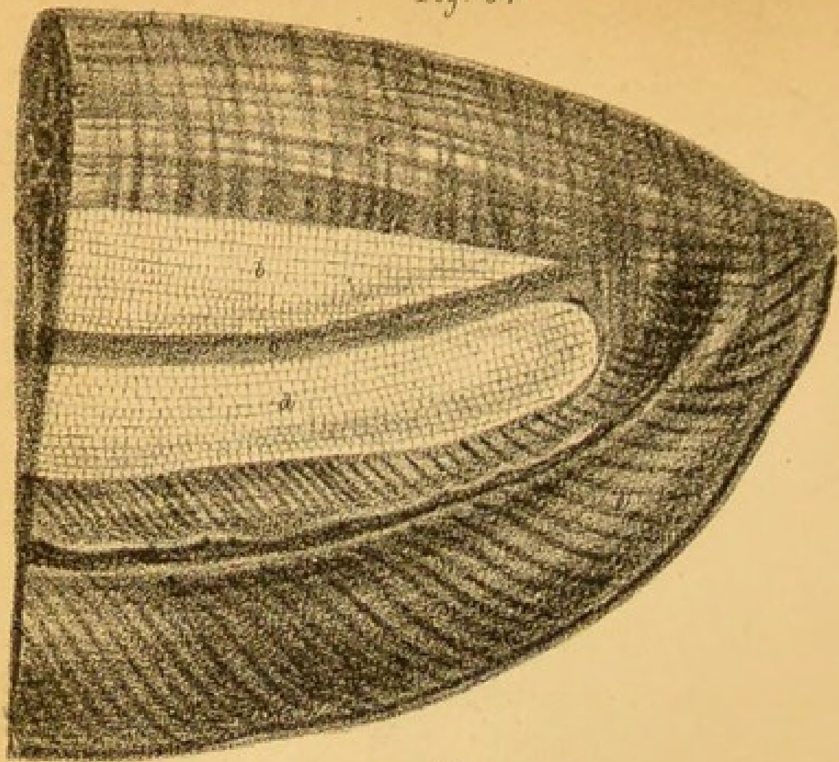


Fig. 36.

Fig. 35

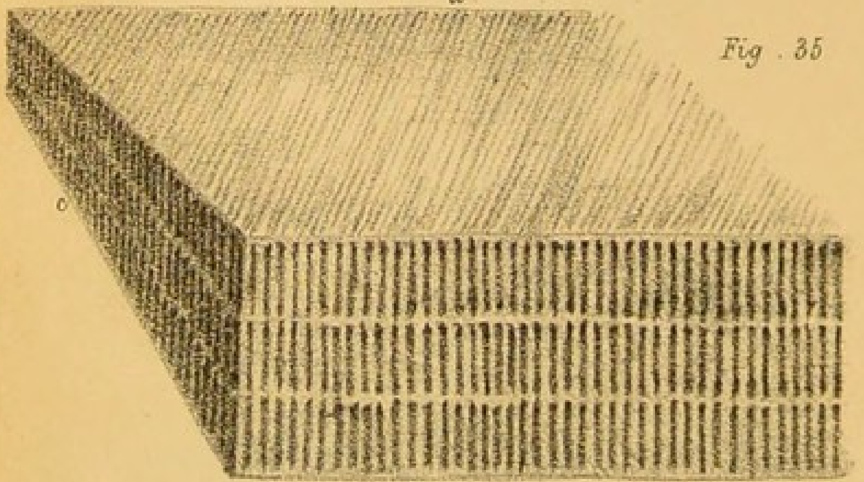
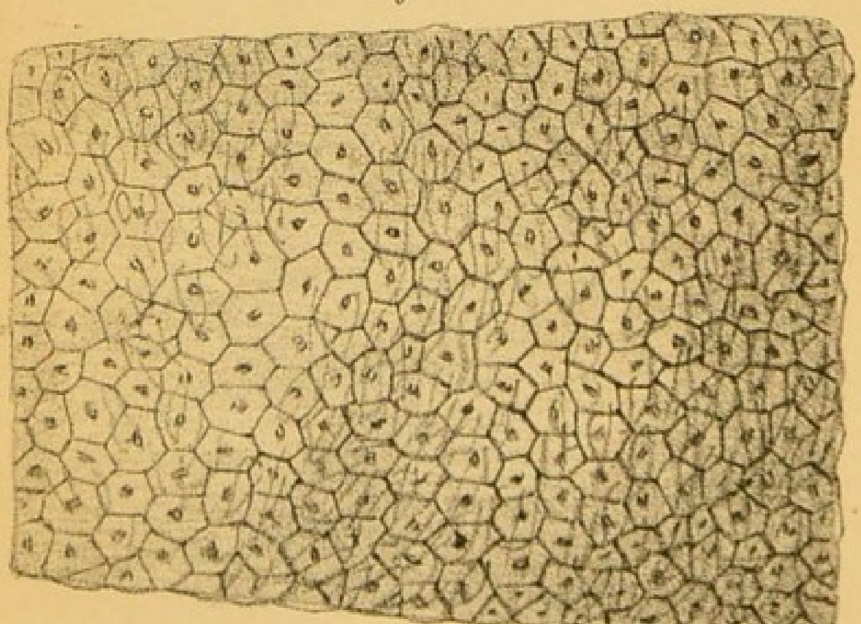


Fig. 37



E. M. Williams, lith. 144, Fleet St.

H. Letheby, ad nat. del.

AN ACCOUNT

OF THE DISSECTION

OF A

GYMNOTUS ELECTRICUS:

TOGETHER WITH

REASONS FOR BELIEVING THAT IT DERIVES ITS ELECTRICITY FROM THE BRAIN AND SPINAL CORD;

AND THAT THE

NERVOUS AND ELECTRICAL FORCES ARE IDENTICAL.

BY HENRY LETHEBY, ESQ. A.L.S.

FROM THE PROCEEDINGS OF THE LONDON ELECTRICAL SOCIETY.

Read, Tuesday, August 16, 1842.

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AN ACCOUNT OF THE DISSECTION OF A GYMNOTUS ELECTRICUS.

THE careful examination of the Gymnotus electricus has been considered, for some time past, a desideratum of no little moment, and the indefatigable exertions of Mr. Hawkins in attempting to procure specimens for this purpose, are well known to the members of the Electrical Society;* to him are we indebted for the present opportunity of examining one of these animals. It was forwarded to him by a friend from Puerto Cabello; it is not however, a native of any of the rivers on that coast, but is procured about 150 miles in the interior of Venezuela; and Mr. Hawkins' correspondent informs him, that exclusive of the difficulty arising from the distance, and present obstruction in the communication, the Gymnotus is by no means abundant even in that locality. At Mr. Gassiot's request, I undertook its dissection, the result of which I have the honour of communicating to the Electrical Society; not that it differs very essentially from that of John Hunter,† made about seventy years ago, and which is the only one on record hitherto made in this country.‡ But as Electrical Science has effected such immense strides since his time, it did appear possible that many points connected with the nervous distribution, and other arrangements of the electrical organs, overlooked, or else not considered of sufficient moment by him, might now afford a clue to an explanation of the wonderful phenomena of these animals, which professor Faraday|| has so recently proved to be identical with those of ordinary electricity. I cannot, however, flatter myself that such a clue has been discovered,

* Proceed. Elec. Soc. Feb. 1839, p. 163.—June 1839, p. 177,—Dec. 1839, p. 188. —Jan. 1840, p. 193.—April 1841, p. 2.

† Philosophical Transactions, 1775.

‡ My friend Mr. J. Quekett has been recently engaged in the dissection of the Gymnotus formerly belonging to the proprietors of the Adelaide Gallery, but I am unacquainted with the results.

§ Phil. Trans. 1839.

nor perhaps will it be, except through the multiplied and most varied investigations of many observers. Certain inferences, however, may be drawn from the investigations already made: these I shall take the liberty of expressing; for if the study of electrical phenomena among the elements of the inorganic world has become of so much interest and importance, surely it must be far more so in its relations to the organized world; indeed, to my thinking, there is the highest purpose in view; for it is possible that the elucidation of this problem may tend to unravel the now mysterious and perfectly incomprehensible principle of functional activity,—I will not say of life; and even if it do not effect so much as that, it will assuredly constitute a new era in physiology, and be there, as Electricity is now, in the Physical sciences, the highest object of consideration.

I propose to consider the subject in this order:—

I.—The anatomy of the animal.

II.—Its electrical properties.

III.—Will the former afford any clue to the comprehension of the latter?

Division I.—*The anatomy of the Gymnotus.*

The Gymnoti are so named from the absence of a dorsal fin. There are several species, all inhabiting the fresh water lakes and rivers of South America, though one species only is electrical, namely, the Gymnotus electricus, which is the subject of our present investigation.

The fish sent me to examine was a female, 3 feet 7 inches long, 14 inches round at its thickest part, and 7 at its smallest; in general aspect it very much resembles an eel, from which, however, it is distinguished by many anatomical characters, but especially the absence of the dorsal fin. The body is smooth, without scales; a long ventral fin extends from just behind the head to the very extremity of the tail; around the mouth are many papillæ lodged in crypts, which are merely mucous glands. The mouth is armed with sharp teeth, and projecting into it are numerous fringes, which, from their vascularity, doubtless serve a purpose in respiration. The œsophagus is short, terminating in a capacious stomach, with thick and rugose parieties; the rest of the alimentary canal is short, doubled on itself, and terminates in the cloaca, which is situated in the mesial line, a few inches from the under jaw. The whole cavity of the abdomen is not more than 7 inches long, and contained, besides the alimentary canal, ovaries filled with ova of a bright orange colour, the heart, the liver, and upper part of the air bladder. The rest of the animal is made up of the electrical organs and muscles of progression, together with an air sac, which runs beneath the spine the whole length of its body.

On removing the skin and aponeurosis, we have the appearance represented on the left of fig. 31, Plate VIII,—namely, above are the dorsal muscles, then the greater electrical organ, and beneath this the lateral muscle of the fin: when this is reflected, the lesser electrical organ is brought into view, which we now find to be separated from the greater by a layer of muscles, which I shall call *the inferior plane of lateral muscles.*

A transverse section of the fish better exhibits the arrangement and relation of parts; thus, in Plate IX. fig. 32, above, on each side are the muscles of the back (*c*), made up of five planes; beneath these are the greater electrical organs (*d*), then the inferior planes of lateral muscles (*e*), and, lastly, the lesser electrical organs (*f*), which are covered externally by the external or lateral fin muscles (*g*), the whole being enclosed by an aponeurosis (*b*), and the skin (*a*).

In the mesial line, from above, downwards, we find first an aponeurosis, which extends laterally between the planes of the dorsal muscles; then the vertebral column enclosing the spinal cord; on each side of the body of the vertebra (*k*), appear the cut ends of the peculiar nerve of Hunter, but which I shall call the *posterior or dorsal branch of the 5th;* below the spine is the systemic artery and vein, and beneath these, surrounded by the aponeurosis, is the air-bladder (*o*); on the lower surface of this the aponeurosis unites and passes downwards to form the vertical membranous septum, which separates the larger electrical organs; below all are the interspinous bones and muscles (*h*), and fin (*i*).

Greater Electrical Organs.—These commence a few inches behind the head, upon the thin walls of the abdomen, by a well-defined rounded margin (Plate IX. fig. 33), and continue along the side, tapering gradually to the tail, where they end in a point (Plate X. fig. 34.) Their thickness from within outwards varies in different parts; at their origin it is not more than the eighth of an inch, about the middle it is more than two inches, while at the tail it again diminishes to less than a quarter of an inch.

Viewed externally, they appear made up of longitudinal laminæ or plates, which continue their whole length without division or union with others; and the upper ones run the entire length of the organ. At the commencement, there were thirty-nine of these laminæ, but the number near the tail gradually diminishes by the termination of the lower ones; so that at the very end not more than two or three remained.

The laminæ are easily separated from each other, and by careful management this may be effected quite to the vertical membranous septum, where they decrease in depth, especially the upper ones, as is seen by reference to Plate IX. fig. 32. Between the laminæ run the nerves and vessels to supply the organ, and their anastomoses effect a peculiar reticulated arrangement. Carefully examined, each lamina is found to be subdivided by vertical partitions, and they may be split up at these places so as completely to reach the vertical membranous septum. The course of these vertical septa is not directly outwards, but obliquely as in fig. 35, Plate X., and consequently whether we make a transverse or longitudinal section of the organ, we still see these cut septa, and the subdivision of the laminæ.

When magnified, the ends of the laminæ have the appearance represented in Plate X. fig. 35, and by carefully removing a single vertical plate and examining with a low power, say half an inch, we find it is a perfect cell, much attenuated and compressed laterally, as in Plate X. fig. 36. On splitting it open and examining with a power of quarter-inch focus, its structure is an external basement membrane, upon which are placed two or three layers of plastic epithelium, with their nuclei very distinct, as in Plate X. fig. 37.

We may say then the greater electrical organs are made up of longitudinal laminæ; and these are again composed of cells or vertical plates, compressed laterally, and extending obliquely from within outwards, the whole width of the laminæ; these cells contain a peculiar albumino-gelatinous fluid. Their number upon a given space varies in different parts of the same lamina: thus about the middle of the fish there are about 200 in an inch, while towards the tail they are less numerous; at a rough calculation, there may be about 200,000 of these cells in each larger electrical organ.

Lesser Electrical Organs.—One being on each side, they are separated from the greater by the inferior planes of lateral muscles; internally they rest upon the interspinous bones and muscles, and externally are covered by the lateral fin muscles; these organs commence at a point a little behind the greater, and becoming broader and broader, extend to within half an inch of the tail, where they terminate in a very thin but comparatively broad margin. Like the larger organs, their thickness varies in different parts; at the onset they are very thin, and so also at the termination; but in the middle of the fish their section is triangular, each plane of which is about an inch in length. The number of longitudinal laminæ at this part are about fourteen, the structure of these laminæ is precisely similar to those of the larger organs, being made up of cells; whose number in each smaller organ is about 75,000, so that the entire number of cells in the batteries on both sides is about 550,000.

The question then arises; What are these electrical organs? Now, looking at the arrangement of the muscles of the Gymnotus, and comparing it with that of other fish, it appears as if the lateral planes of muscles had undergone displacement, all excepting one plane being pushed up towards the back to make way for the larger electrical organ: that plane which remains I have named *the inferior lateral plane*; it separates the greater from the lesser organ. In this point of view the organs would appear as no other than the increased developement or modification of the aponeurotic intermuscular septa, a part common to all fish, and they are therefore not superadditions of a peculiar structure. It is probable that this developement is not sudden, but that examination would show us some great analogue, or step of developement in the allied genera; and to clear up these points it would be far from uninteresting were we to investigate the structure of other Gymnoti. These views are somewhat in accordance with those of Geoffroy,* who considers the electrical organs of all electrical fish as tegumentary modifications, which may vary in each species without producing any notable modification in the rest of the organization. In his dissections of Rays he found a sort of gland, between the masseter and branchiæ, composed of tubes analogous to those of the Torpedo, excepting however that they open externally to form so many excretory organs, while in the Torpedo they are completely shut. He was wrong, however, in supposing that, because the skin was not reflected over them, they were therefore not electrical; for Mat-

* Annales du Museum National, tom. i. p. 393.

teucci (*) and Todd (†) found that the Torpedo was electrical after the skin was removed, and even after slices were taken from the organs. The real secret probably is in the subdivision of these tubes by transverse membranous plates.

Nervous System.—The brain, as represented in figs. 29 and 30, Plate VIII. is made up of three pairs of ganglia, which do not by any means fill the cavity of the cranium. The brain, however, was not in a good state of preservation; it was soft and confused; but as well as I could make out, the hemispheres were by far the largest portions of the cerebral mass. The olfactory ganglia and optic lobes being comparatively small, the cerebellum had entirely lost its form and connections, so that I could make nothing out of it. The medulla oblongata separated considerably, so as to leave a large fourth ventricle. The spinal cord was of nearly the same diameter throughout, presenting no enlargements, and composed of anterior and posterior columns.

The most remarkable cerebral nerves, and the only ones worth noticing, were the fifth and eighth pairs.

The *fifth* arose from the anterior part of the medulla oblongata, and passing forwards and outwards, emerged from the cranium through the ala of the sphenoid bone; here it formed a ganglion, from which numerous branches were given off, namely, 1st, An *Ophthalmic trunk*, which ran forwards above the orbit, sending a few branches to it, but was distributed principally to the parts above the nose. 2nd, A *Superior Maxillary* branch which coursed forwards along the lower part of the orbit, and ramified upon the sides of the face. 3rd, An *Inferior Maxillary* branch of large size, which wound round the jaw, passing downwards and forwards to the under part of the lower jaw, to which it distributed branches; others were also given off in its course to the back part of the throat and mouth. 4th, An *Opercular* branch which ramified upon the gill cover. 5th, The most important branch, and which seemed a continuation of the nerve itself, passed backwards and outwards, and then inwards, forming a curve, till it attached itself to the side of the spine, along which it coursed to the tail, being imbedded in a soft pulpy substance; in its course it received a branch from the 8th and other smaller branches from the spinal nerves. This nerve may be named *the posterior or dorsal branch of the 5th*, it

* Comptes rendus des Séances de l'Académie des Sciences, tom. iii. p. 451.

† Philosophical Transactions, 1817, p. 32.

distributes branches to the dorsal muscles, which first ramify between the muscles, while a few small twigs pursuing the course of the intermuscular septa, reach the skin to which they are distributed. I could not make out any branch from this nerve to the electrical organs.

The 8th or Pneumogastric, as in other animals, is distributed to the respiratory and gastric apparatuses; it arises from the medulla oblongata behind the 5th, and passing out of the cranium expands a little, and here gives off four branchial nerves and one large branch which passes up to join the posterior branch of the 5th. The principal trunk courses downwards and backwards sending a few twigs to the back of the throat, and is at last distributed upon the stomach; where it also gives off branches to the air sac.

Spinal Nerves. Each of these has an origin by two roots. The first or *sensitive,* composed of five or six filaments, arises from the lateral fissure of the cord; these pass outwards towards the intervertebral foramina, where they unite to form a ganglion. The *posterior or motor root* arises from the inferior fissure of the cord, and passes out underneath the ganglion; emerging from the foraminæ, the spinal nerves course downwards and a little backwards, winding over the bodies of the vertebræ, and under the dorsal branch of the fifth; and continuing down upon the enclosing membrane of the air sac, they there divide into two or three branches, which pass down upon the vertical septum, again dividing and subdividing into long parallel filaments, which are ultimately lost in the muscles of the fin. (Plate VIII. fig. 31, g g.) In this course the spinal nerves give off numerous branches; thus just as they are about to pass under the dorsal branch of the fifth, they send small nerves which wind over and partly embrace that nerve, and accompany its branches to their distribution; when on the membrane of the air bladder, a few twigs pierce the membrane and join the sympathetic. As the parallel filaments pass down upon the vertical septum, small branches are given off exactly opposite each lamina of the electrical organs; these ramify between the laminæ, and ultimately terminate there in loops.

Sympathetic Nerve. This nerve is situated immediately beneath the transverse processes of the vertebræ, externally to the systemic vessels; it gives off numerous filaments, which accompany the branches of the vessels, and are doubtless distributed with these; but it is of too small a size to be of any import to the electrical apparatus.

Division II.—*The Electrical Properties of the Gymnotus.*

I need occupy but little time in the consideration of this part of the subject; the analogy of the phenomena of the Gymnotus electricus with those of electricity, gave origin to its specific name; this analogy was further borne out by the experiments of Williamson,* Humboldt,† and others; while more recently the identity of these phenomena with those of ordinary electricity has been completely established by the investigations of Prof. Faraday‡ on the Gymnotus formerly belonging to the proprietors of the Adelaide Gallery; during these, he obtained the shock, deflected the galvanometer, made magnets, and effected chemical decomposition. The spark, and evidence of heating effect, were obtained by Mr. Gassiot.§ Faraday found that the laws which regulate the discharge are that the anterior parts of the animal are positive to the posterior; the current is from the head through the water to the tail; and the discharges are *voluntary*. He endeavoured to form some estimate of the quantity and force of the electricity sent by the fish, by a comparison with that of a charged Leyden jar; and he thinks from the sensation, the degree of deflection, and amount of chemical decomposition, that a medium discharge of the fish was at least equal to the electricity of a Leyden battery of fifteen jars, containing 3,500 square inches, coated on both sides and charged to the highest degree.

The phenomena of other electrical fish, I make no doubt, are also due to a similar force. I am not aware, however, that any experiments to prove this have been made upon the Silurus, Rhinobatus, Trichiurus, or Tetrodon electricus: but that the force in the Torpedo is electrical, is as sufficiently proved as that of the Gymnotus has been; indeed from its being better known and easier of access, it was the first in which the identity was established. As early as 1712, Kœmpfer‖ compared its shock to lightning: sixty years afterwards Walsh¶ recognized the different electrical conditions of the back and belly, and was, in consequence, able to

* Phil. Transactions, 1775, p. 94.

† Recueil d'Observations de Zoologie, &c., tom. i. p. 49.

‡ Phil. Transactions, 1839, p. 1.

§ Trans. Elec. Soc. 1839, pages 175, 179.

‖ Amæn. Exot. 1712, p. 514.

¶ Phil. Transactions, 1773.

get stronger shocks. At a later date he succeeded in the presence of Pringle, Ingenhouss, and others, in getting the spark:* and Fahlenberg afterwards repeated the experiment with like success. More recently, Dr. Davy † further identified it by magnetizing needles, deflecting the galvanometer, and producing chemical decomposition; and later still, Linari and Matteucci ‡ obtained sparks and decomposed water. The power of the Torpedo, however, is by no means equal to that of the Gymnotus; indeed the fishermen handle the Torpedo as a plaything, while the shock of the Gymnotus, acording to Humboldt,§ is powerful enough to stun large animals, as horses and mules.

The laws regulating the discharge of the Torpedo are, that it is voluntary, and depends on the integrity of the nerves. The dorsal surface is positive to the ventral, and the discharge takes place from the former through the conductor to the latter.

Division III. *Do our anatomical investigations of this animal give us any idea of the manner in which its peculiar property originates?*

To aid us in this inquiry, it may not be amiss to turn our attention to the dissections of other electrical fish, and see if there be any analogy or common principle existing in the structure of the electrical organs of these different fish: and we shall find indeed that such is the case. In all instances, the organ is made up of a multitude of aponeurotic fibres which cross each other in such wise as to form cells in which is contained an albumino-gelatinous fluid; moreover, these organs are largely supplied with nerves. Thus in the Torpedo there are three large branches of the vagus, and one from the fifth; in the Gymnotus, according to Rudolphi, there are 224 spinal nerves, supplying the organ. In the Silurus the organs are largely supplied by the eighth and by the intercostals. In all, indeed, the nervous supply is greatly superior to the wants of the part, or rather to the purposes of life. Here then are the two, and the only two propositions that dissection can furnish us with, namely, *an organ composed alternately of septa and fluid,* and secondly, *a large supply of nervous energy to this organ.*

* Journal de Phys. 1776, Oct. 331.

† Phil. Trans. 1832, p. 259. Ibid. 1834. p. 531.

‡ Comptes Rendus des Séances de l'Académie des Sciences, tom. iii. p. 46.

§ Voyage de Humboldt et Bonpland, tom. ii. p. 175.

It has been sufficiently proved and admitted that these organs are in some way connected with the electrical phenomena, and the question now is, *do the organs themselves originate the power?* or, *is it supplied by the nerves, and there concentrated or made tense?* A few words will dismiss the first problem, which is founded on the mechanical arrangement of the organ, and which the advocates of this notion compare to a galvanic pile.* Humboldt, Pfaff, Buntzen, Prevost and Dumas, Kaemtz and others,† have sufficiently shown, by numerous experiments, that the contact of dissimilar animal substances is capable of generating electricity; and further, there can be no doubt that two fluids dissimilar in composition or even density, and separated by a membrane, will also give rise to electricity. It is even possible to suppose that such an arrangement may really exist in the organs of electrical fish:—but, admitting so much, what does it explain?—merely the generation of a power which we shall see can be accounted for much better;—it gives no idea how it is to be accumulated—why it should be at the voluntary service of the animal—why its action does not go on at all times, and the discharge be therefore regular and periodical. On the other hand, there are many good and sufficient reasons for believing that the brain and spinal cord are the seat of power, and that the battery is no other than an apparatus for accumulating that power, as electricity is accumulated in a Leyden jar; for—

1st.—*The power exists only during life, and while the brain is active;*—if, however, it were dependent on the mechanical arrangement of the organ, it should give shocks at all times, and as well directly after death as just before,—for it is then not a vital, but a physical phenomenon.

2nd.—*The power is Voluntary.*—The animal wills the discharge; nay, more,—according to Dr. Faraday, it seems conscious when its discharges are not effective, and will not repeat them unless with advantage; under advantageous circumstances, however, they are repeated again and again with scarcely an appreciable interval.

3rd.—*The power is dependent on the integrity of the nerves.*—Todd‡ found in the torpedo that, on the division of the nerves

* Muller's Physiology, by Baly, vol. i. p . 639.

† Ibid. vol. i. p. 64.

‡ Phil. Trans. 1816, p. 124.

of the battery, although the animal lived as long as others, and seemed equally active, yet it had lost the power of shocking; and Matteucci* found the intensity of the shock to be diminished in proportion to the number of the nervous fibres going to the organ, which he divided.

4th.—*Direct irritation of the brain will effect a shock.*—Thus Matteucci† observed that, when a torpedo had become exhausted and ceased to give shocks when irritated, he produced very strong ones by irritating the posterior lobes of the brain, from which the nerves of the battery arise.

5th.—*The evident nervous exhaustion observed always after repeated discharges,* and, (as Dr. Faraday says,) the apparently equivalent productions of electricity in proportion to the quantity of nervous force consumed would favour this view.

6th.—*The anatomical consideration of the nervous supply to the organs being much greater than is necessary for the purposes of life is another argument.*

7th.—*And moreover, those nerves are nerves of volition and sensation, and not those of organic life,* which they should be if the electricity were dependent on a secreted fluid.

8th.—*It is further proved not to depend on the circulation, and therefore not on secretion,* from the circumstance that the animal still continues to shock after the extirpation of the heart.‡

9th.—*The condition of the battery itself favors this view;* it being, as Lacepede § asserted many years ago, very like a Leyden battery, composed alternately of a conductor and a non-conductor.

I am aware of objections that may be raised to some of these arguments. It may be said that division of the nerves or destruction of the brain may check secretion, and so stop the function of the part, whose power is dependent upon that secretion; but we have no example of voluntary secretions, and in such a case this must be so, or the animal would be always giving shocks; it appears to me to be much more reasonable to suppose that the division of the nerves checks the current coming to the part, than that it checks the generation of the power in the battery. Again, it may be said that other fish of allied genera have nerves equally large, and, therefore, they should shock; but then they have not the organ perfected for its

* Comptes Rendus de Séances de l'Académie des Sciences, tom. iii. p. 431.

† Op. cit. ‡ Muller's Physiology by Baly, vol. i. p. 67.

§ Lacepede Histoire Naturelle des Poissons, vol. ii. p. 166.

concentration, and though the nerves are large, and we begin to see the developement of the organ, yet it seems more for the purpose of filling up what otherwise would be the hiatus between them and their neighbours, than for any purpose useful to the fish; it is indeed the organ in process of developement, and for ought we know, they *may* develope as much electricity,—but wanting the battery, it is not manifested. Without detailing, however, other objections,—I say, when all points are taken into consideration, it seems most probable that *the electricity is sent, at will, from the brain or spinal chord along the nerves to be accumulated in the battery, from which probably, after having acquired a certain intensity, it discharges itself through the water in preference to the animal's body.* Humboldt says, one Gymnotus cannot shock another; and this would seem to show that its body was either an imperfect conductor, or else not susceptible of its influence. According to this view, the animal does not will the *discharge,* but rather the *charge,*—the discharge taking place spontaneously, as in Harris' unit jar, when the tension is sufficient to overcome the di-electric; and the animal aware of this, and having no control over its course, adopts the position best suited to concentrate it on its prey when such is large. There wants, however, a long series of experiments upon living electrical fish, and especially gymnoti, to decide if the above be true or not; and these experiments should be conducted especially upon the nervous system: and then, should it eventually be proved that it derives its power from the brain or chord, we have gained a point in Physiology, which may, perhaps, tend to unravel all the phenomena of life; for it has been long suspected by many of our ablest physiologists, that the functions of life are due to electricity. We find that electricity sent along motor nerves gives rise to muscular action,—along the sensitive ones to sensations analogous to those of their special or ordinary function; along the nerves of organic life it will increase secretion, and the question then arises—is electricity the *ordinary* agent of their action?—Can we look upon it as a *cause,* and the performance of the various functions as an *effect?*—a position which has been more or less advocated ever since the more full discovery of the actions of ordinary electricity. Hunter, Wollaston,* Abernethy,† Wilson,

* Philosoph. Mag. vol. xxxiii. p. 488.

† Enquiry into the Probability and Rationality of Mr. Hunter's Theory of Life. Lond. 1814.

Philip,* Prevost and Dumas,† Meissner,‡ Matteucci,§ and many others have adopted the notion that electricity was the cause of the vital functions. Dr. Watson says,‖ "I incline to the opinion that the influence, which originates in the grey matter, and is transmitted by the white, will be found at last to consist in, or to be closely allied to electricity;" for electricity produces in the animal body phenomena similar to vital. In truth, we have gained even a step more than this fact, that *electricity will give rise to functions analogous to the vital functions; electricity has been detected in animals during the activity of the functions.* Pfaff and Ahrens¶ have detected free electricity in man; Matteucci ** observed a deviation of the galvanometer amounting to 15 or 20 degrees; when the liver and stomach of a rabbit were connected with the platinum ends of the wires of a galvanometer,—an action which was not due to the different chemical properties of the secretions, for it ceased with death. More recently Prof. Zantideschi and Dr. Favio†† assert that in all warm-blooded animals there are two *electro-vital* or *neuro-electric* currents—one external or cutaneous, which directs itself from the extremities to the cerebro-spinal axis; and the other internal, going from the cerebro-spinal axis to the internal organs situated beneath the skin: these currents grow weaker in proportion as life ceases or as pain is felt, while the convulsive or voluntary movements give a strong current or increase the discharge. It is true these currents have not been decisively detected in the nerves, if I except the experiments of Versasseur and Berandi, which went to show that needles inserted in the nerves became magnetic, and the nerves lost this property on the division of the spinal cord; Müller‡‡ denies this; but even if they have *not* been detected, it goes for nothing, for Matteucci§§ found that they did not affect the galvanometer even when the current of a battery was sent through them—indeed, we can scarcely expect with our present means to be able to detect a current of such low tension as must be that of the nervous force: look at the great effect of weak currents upon the muscles themselves; and to establish by experiment the identity of the nervous and

* Experimental Inquiry into the Laws of the Vital Functions; also Journal of Science and Art, vol. viii. p. 72.

† Journal de Physiol. t. iii.

‡ Müller's Physiol. by Baly, vol. i. p. 73.

§ L'Institut, No. 75.

‖ Dr. Watson's Lectures on Medicine.—*Med. Gaz.* vol. i. 1840-1, p. 738.

¶ Müller's Physiology, vol. i. p. 71.

** L'Institut, No. 75.

†† Lond. Ed. and Dub. Phil. Mag. vol. xviii. p. 271.

‡‡ Physiol. by Baly, vol. i. p. 636.

§§ Matteucci, L'Institut, No. 75.

electrical forces, we must have galvanometers as delicate as living muscle; our arguments, therefore, for the present, must necessarily be founded upon the analogy of certain facts which I will endeavour to place before the Society.

"All vital activity," says Professor Liebig,* "arises from the mutual action of the oxygen of the atmosphere and the elements of the food;" every phenomenon of life then is dependent on chemical action, and these phenomena are manifested on account of a something which originates from that chemical action, traverses the nerves and produces in the organism *combinations* and *decompositions.* This is proved by checking chemical action, and we check vitality; sever the nerves, and we check the current; and with it vitality, and also chemical action. From combination in our economy results *nutrition* and *reproduction;* it is the force of *vegetative life,* while decomposition determines *animal life.* There are sufficient grounds for believing that every sensation, every mental effort, every muscular movement is attended by corresponding changes in the structure of the brain and muscle; the force that produces these combinations and decompositions is called the *vital* force, but is it not nearly allied to the *electrical?* Is not electricity due to, and the constant attendant on, chemical action? does it not effect combinations and decompositions? will not the cessation of its current, the division of its conductor, destroy its phenomena and check the original chemical action? These are some of the analogous facts, the primary phenomena of both: in the one kingdom they have received no special name, while in the organized they are called vital phenomena; and, if the manifestations of this force be somewhat different in the two kingdoms, may it not be due to certain combinations or arrangements of elements?—nay more, the peculiarities of this arrangement may effect different changes; and hence different tissues, each with its special arrangement, may effect a special combination and also a special decomposition, and therefore a special series of phenomena; we know that the effect of one force, the electrical, upon all these is to produce a different series of events. It may be, too, that the equable expenditure or passage of the nervous or neuro-electric force, in its proper channel, is the condition necessary to *health,*—and any alteration in the regular supply of this current may be the occasion of *disease.* In *inflammation,* as Dr. Billing has endeavoured to show, there is a diminished supply of nervous energy to the inflamed part; hence

* Organic Chemistry in its application to Physiology and Pathology, p. 9.

the capillaries of that part lose their tone, or power of contraction, and, yielding to the force of circulation, become over distended, while the general symptoms indicate an increased supply to other parts.—The very essence of inflammation,—the stagnation of the blood, and the formation of little clots in the vessels, may be due to the removal of the *neuro-electric* influence. All the phenomena of *fever* may be attributed to this irregular supply of the nervous force; and the critical stages indicate a happy turn to or from some organ well able to bear it. The primary cause of fever has nothing to do with these phenomena, beyond this,—that, as a poison, it enters the circulation, and so affects the nervous centres; the result of this effect is irregular nervous supply. *Morbid secretions*, as well as *morbid growth*, may also be the result of an alteration in the nervous supply, as well as in the matters of nutrition; and every *remedy* may owe its efficacy to its modifying or checking its flow, or determining it to some other organ.

Dr. Billing * uses the very terms "*Galvanoid*" and "*Electroid*," as expressive of the influence which occasions com binations and decompositions and secretions. And although Liebig does not admit the identity of the electrical and vital forces,† yet his explanations almost admit it for him. "As in the closed galvanic circuit, in consequence of certain changes which an inorganic body, or metal undergoes when placed in contact with an acid, a certain something becomes cognizable by our senses, which we call a current of electricity; so in the animal body, in consequence of transformations and changes undergone by matter previously constituting a part oı our organism, certain phenomena of motion and activity are perceived, and these we call life or vitality."‡ Dr. Faraday also seems upon the threshold of admission, when he says § "though I am not yet convinced by the facts that the nervous fluid is only electricity, still I think that the agent in the nervous system may be an inorganic force, and if there be reasons for supposing that magnetism is a higher relation of force than electricity, so it may well be imagined that the nervous power may be of a still more exalted character, and yet within the reach of experiment."

Think about this as we may, mince our methods of expression if we will,—*if it is sufficiently proved that the force of the electrical fish is electricity,—if it is proved that it derives that force*

* First Principles of Medicine, 4th Ed. p. 20 and 36. † Op. cit. p. 261.
‡ Op. cit. p. 11, § Phil Trans. 1839, p. 12.

from the nervous system,—if it is proved that electricity will give rise in the living body to phenomena analogous to those of vitality, —and if it is proved that during the activity of life electricity does traverse the body; we have proved enough to form a conclusion that the functions of the animal economy are maintained by an electrical force.

The only positive argument, worth a consideration, that has ever been advanced against this, is that a ligature, placed on a nervous trunk, will check the passage of the nervous current, while it will not that of the battery. Now, this current may flow along the granular medullary matter or pulp of each fibre; (for the microscopic investigations of Ehrenberg, and others, have shown that each nervous fibre is composed of membranous tubes, filled with granular matter;) and the membrane or neuralema may be sufficient to insulate its current, weak as it is, from the rest of the fibres, making up a fasciculus, or nerve: our division or separation of this medullary pulp by ligature or pressure, would then be sufficient to produce a check in the course of so feeble a current; though not that from a galvanic battery, possessing as it does, an infinitely greater degree of tension.

Another argument is, that irritation of a nerve will do as much as electricity. I say that, when we irritate by a chemical or mechanical stimulus, we adopt the very means to ensure the production of an electric current, which is all that is wanted to create pain or produce muscular contraction. This rather proves their identity than otherwise.

In conclusion, I will recapitulate the deductions from the preceding paper.

1. All vitality is the result of chemical action.	1. Electricity is the result of chemical action.
2. The effects of the vital force in motion, are combinations and decompositions.	2. The effects of electricity in motion, are combinations and decompositions.
3. Currents of electricity have been detected in warm-blooded animals during the activity of the functions.	3. Electricity sent along nerves gives rise in the living organism to motion and sensation.
4. The phenomena of the Gymnotus and Torpedo have been proved to be electrical.	4. I have given reasons for believing that this electricity is derived from the brain and spinal cord.

Explanations of the Drawings.

Plate VIII.—Nervous System.

Fig. 29.—*A lateral view of the principal nervous trunks coming from the brain.*

(*a*) Olfactory ganglion giving off; (*b*) the olfactory nerve to be distributed on (*c*) the leaf-like olfactory apparatus.

(*d*) Cerebral hemisphere; (*e*) left optic tubercle; (*f*) optic nerve.

(*g*) the 5th, enlarging into a ganglion, and giving off (*h*) ophthalmic branch; (*i*) the superior maxillary; (*k*) inferior maxillary; (*m*) opercular branch; and (*n n*) the larger posterior or dorsal branch.

(*o*) a large branch given off to the muscles of the pectoral fin.

(*p*) 8th, or pneumogastric, giving off four branchial branches (*q*); and (*r*) a branch to join the dorsal branch of 5th. (*s*) medulla oblongata; (*t*) spinal cord, giving off nerves.

Fig. 30.—*A view of the same from above, the letters refer to the same parts.*

Fig. 31.—*A lateral section of the electrical organs, &c. showing the distribution of the spinal nerves which supply them.* On the left, the skin only is removed, whereby the dorsal muscles (*a*) are brought into view, also the larger electrical organ (*b*), and the lateral fin muscles (*c*); on reflecting the latter, we see (*d*) the inferior or lesser electrical organ: on the right of the figure a section is made quite to the mesial or vertical septum, in order to see the distribution of the spinal nerves: (*f*) the spinal cord, brought into view by opening the vertebral column; it gives off spinal nerves (*g g g*) which wind over the bodies of the vertebræ and under the posterior or dorsal branch of the 5th (*h*), then passing down on the envelope of the air sac (*i*), divide into two or three branches, and these subdividing into long parallel filaments, run down upon the vertical membranous septum as far as the spinous muscles of the fin (*m*). (*n*) the cut edges of the lateral fin muscles; (*o*) the cut dorsal muscles; (*p*) the body of a vertebra, beneath which are the two systemic vessels cut through, and then the cavity of the air sac; (*q*) larger electrical organ; (*r*) inferior plane of lateral muscles; (*t*) lateral fin muscles; (*u*) the fin.

Plate IX.

Different Views of the Electrical Organs.

Fig. 32.—*Transverse section of the fish, about 12 inches from the head.*

(*a*) skin, under which is spread an aponeurosis (*b*), which envelopes the muscles and electrical organs:—(*c c c c*) muscles of the back.

(*d d*) larger electrical organs;—(*e e*) lateral fin muscles.

f f lesser electrical organs—(*g g*) cut edges of the lateral muscle of the fin—(*h*) interspinous muscle—*i* the fin.

In the mesial line from above, downwards, we see first the aponeurosis, which extends laterally, forming the inter-muscular septa; then the cut end of the spinal chord, beneath this the body of the vertebræ (*k*), on each side of which is a section of the dorsal branch of the 5th,—(*m*) the systemic vein—(*n*) the systemic artery—(*o*) air sac.

(*p*) the vertical membranous septum, formed by the prolongation of the membranous envelope of the air sac.

Fig. 33.—*A lateral view of the electrical organs, showing how they begin.* The skin and aponeurosis being removed.

(*a*), dorsal muscles—(*b*) larger electrical organ, commencing by a well-defined rounded border—(*c*) inferior lateral plane of muscles—(*d*) lesser electrical organ, commencing from a point—(*e*) the fin—(*f*) cavity of the abdomen.

Plate X.

Magnified Views, shewing the Structure of the Electrical Organs, &c.*

Fig. 34.—*A lateral view of the Electrical organs, showing how they terminate.*

(*a*) muscles of the back—(*b*) larger electrical organ, terminating in a point,—the inferior laminæ terminate first—(*c*) inferior plane of lateral muscles—(*d*) lesser electrical organ, terminating more obtusely—(*e*) the fin.

Fig. 35.—*A part of three laminæ seen from above, and laterally.*

(*a*) the internal edge in apposition with the vertical membranous septum—(*b*) the outer or skin surface. Viewed

* The figures in the plate are two-thirds the size of the original drawings.—Ed.

from above, the obliquity of the vertical septa of each lamina is observed, whereby it becomes evident that a section made either longitudinally, as (*b*), or transversely, as (*c*), will still exhibit these vertical septa, and the subdivision of the laminæ into cells.

Fig. 36.—A lateral view of one of these cells, as seen under a power of half-an-inch focus—(*a*) the end in contact with the vertical membranous septum—(*b*) the external end.

Fig. 37.—The same under a higher power: its surface looks reticulated from the markings of the tesselated epithelium, each scale or cell of which contains one or more nuclei.

This communication was illustrated by the series of drawings alluded to in the text; and also by preparations of the electrical organs, and of the nervous system. The preserved specimen of Gymnotus electricus belonging to the Society, was also on the table.

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