# LECTURE

ON

# ANIMAL ELECTRICITY,

*&c. &c.*

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# ANIMAL ELECTRICITY,

DELIVERED AT THE

## Polytechnic Institution,

BEFORE THE

## MEMBERS

OF THE

# ELECTRICAL SOCIETY,

BY


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GENTLEMEN,—I have the honour of directing attention this evening to a subject which appears to me to be very peculiarly adapted to the notice of your society, namely, *animal electricity*; a subject, too, which has not, until within the last few years, commanded that attention which it really deserves: and this is somewhat surprising, especially when we consider how much interest there is attached to it, from its offering the fairest means of elucidating some of the most intricate problems in the whole science of physiology. Moreover, if the study of electrical phenomena among the elements of the inorganic kingdom be deemed worthy of the attention of our greatest philosophers, and has even, from its importance, called for the constitution of a society like this, to be devoted entirely to its progress, surely such a study must become vastly more important when it is found that it extends its relations to the living world, and that many of the phenomena of life are, in all probability, intimately connected with it. But though we offer such an opinion as this, for it will be our endeavour, during this lecture, to prove the identity of the nervous and electrical forces, and to show that current electricity, consequent on certain chemical changes which are constantly going on in the living organism, is the immediate cause of functional activity, yet I would warn you from falling into the error of supposing that we have therefore discovered the abstract principle of life; and you will understand that it is not my intention, this evening, to have any thing whatever to do with such an inquiry. It is by the pursuit of investigations like these that the progress of physiological science has been much retarded: nor, indeed, is this the only science which has suffered from such abstract reasoners. We should bear in mind that, with all our discoveries and analogical methods of inquiry—with all the facilities of investigation which modern science has placed at our disposal—we shall yet perhaps never discover, or be permitted to know, what life, or electricity, or heat, or magnetism, or indeed the force of any dynamic action is in its essence. To the cost of years of toil and harass, in such pursuits, have too many inquirers found that they had been in search of a principle concerning which the human mind can scarcely have a conception. The phenomena, however, which characterize the existence of these forces are evident to all; and their energies would not have been misspent, or their labours fruitless, had they been directed to a study of them, and of the laws which govern their manifestation.

It will be my object, this evening, to point out those peculiar classes of phenomena which are manifested by certain fish, to show that they are electrical, and that their manifestation is dependent on the integrity of the nervous circles; to show, also, that electricity can be detected in all animals during the active performance of their functions, and that these are dependent on the continuance of chemical action; to prove, moreover, that a current of electricity sent along the nerves of the living organism is capable of simulating precisely all the functional phenomena of the animal body; from all which must result the opinion that the element of nervism is electricity; and if I succeed in establishing these propositions, I shall put you in possession of a more tangible and better understood principle than that which has hitherto gone by the name of the nervous force. It is true that we are still as far off in our ideas of the *nature* of electricity, and that, by such a change, we have merely substituted one unintelligible principle for another: but we have done more than this; we have wiped off one from the many forces whose abstract nature has been so fruitlessly sought after; and there will be no little benefit conferred on science should another Newton be born to generalize upon the numerous and apparently diverse phenomena of nature, and reduce them at last to the action of one principle. Nor is it unreasonable for us to hope for this, or anticipate that that principle may be electricity. Its study, however, must become more general; in relation to physiology at least, more attention must be bestowed upon the physical sciences before we can ever expect to make much advance. Hitherto, with but few exceptions, the consideration of chemical actions has been deemed wholly unconnected with vital phenomena; but, thanks to Liebig, we hope to see these opinions banished, together with all the prejudices which have been incidental to their association. And what must follow upon this? The study of electricity; and from this important tract we shall have branching off a path of inquiry in which, I trust, we shall soon be making a progress as rapid and useful as that which has characterized the advancement of electrical science in its relation to the inorganic kingdom, during the past century.

There are certain fish, but more especially the torpedo, on account of its being better known, which, from time immemorial, have been notorious for their power of evolving something from their bodies capable of producing a numbing sensation on the hand which touched them, and this property has led to the application of various names indicative of its nature: later investigations, however, have shown that the torpedo is not the only fish endowed with this power, but that it has been manifested in the Gymnotus, the Malapterurus or Silurus, the Trichiurus, the Tetraodon, and the Rhinobatus; and from the great analogy of the phenomena which they exhibit with those of ordinary electricity has arisen the specific name of *electricus*, which has been applied to each. At first sight we should be led to imagine that the existence of such a singular property implied a great anatomical as well as zoological relation, and that these animals must possess a structure which not only closely allied them with each other, but essentially distinguished them and set them apart from other fish: such, however, is not the case: on the contrary, we find that they occupy positions widely removed, and that though they possess an organ which gives them the power of exhibiting these phenomena, yet it is but of a secondary or tegumentary nature, and is developed without any infringement on those characters which are common to the genera in which they are placed.

But before I enter into any specific account of the anatomy of these singular fish, it will be more in order if I direct your attention to some of the phenomena which they exhibit, beginning with those of the torpedo, whose effects, until very recently, were the only ones accurately known. The *shock* was that which commanded the earliest attention, though its nature was not philosophically investigated until about the close of the eighteenth century, when Walsh conducted a series of ingenious experiments on this fish, and found that its effects were conducted easily through metals, but they were intercepted by those bodies which were regarded by electricians as non-conductors. In the course of his experiments, also, he discovered the different electrical relations of the back and belly, and, through this, was able to obtain stronger shocks. On one occasion he caused a torpedo to shock eight persons simultaneously. He noticed, moreover, that the discharges were voluntary, and were not performed with any regularity; at one time he counted fifty in a minute and a half, while at others they were few and irregular. He observed, also, that the shocks were stronger in air than in water. Believing these effects to be absolutely electrical, he endeavoured to obtain the spark and evidence of attraction and repulsion, but without success; yet he compared the phenomena to those produced by a quantity of electricity diffused over a large space, and he simulated them by means of a Leyden phial and Lane's electrometer. A few years after, the Hon. Mr. Cavendish very completely imitated all the effects which Walsh had observed, by means of a battery of large surface weakly charged. From these, other inquiries were set on foot; and though they were rather of a contradictory nature, yet on the whole they tended sufficiently to prove their identity with those of ordinary electricity. For instance, in 1827, M. De Blainville and Fleuriau asserted that they had obtained a deflection of the magnet by connecting the two surfaces through Swiggie's multiplier. Two years after this, however, Sir H. Davy was completely unsuccessful in every attempt to identify the phenomena, although he still believed they were electrical; but his brother, Dr. Davy, in following out the investigation, and by using more lively fish, was able to make small needles magnetic, to deflect the galvanometer, and produce chemical decomposition: still, he could not obtain the spark, or get the discharge to pass through air, whether rarified, or moist, or dry. By using Harris's electroscope, however, he had evidence of a heating effect; and from these experiments he ascertained that the dorsal surface of the fish was positive, and the ventral negative. Subsequent to these, Linari and Matteucci have been more fortunate in obtaining the spark; and in still later times experiments have been made by Zantedeschi and others, all of which are confirmatory of the absolute identity of the phenomena which this fish exhibits with those of ordinary electricity; and the laws which regulate the discharges are, that they are voluntary, that the dorsal surface is positive to the ventral, that the discharges takes place through the conductor from the former to the latter, and moreover, as we shall by and by find, that it is dependent on the integrity of the nervous system.

Respecting the electrical nature of the phenomena of the gymnotus, we have ample evidence from the experiments of Williamson, Humboldt, Walsh, Fahlberg, Guisan, and others; but more particularly from the investigations of Professor Faraday upon the fish formerly belonging to the proprietors of the Adelaide Gallery. During these he obtained the shock, deflected and made magnets, decomposed iodide of potassium, and saw the spark. The liberality of the proprietors also afforded ProfessorSchönbein an opportunity of verifying these results; and the laws which have been observed to regulate the discharge are, that it is voluntary, and takes place from the head through the water to the tail, the anterior parts of the animal being positive to the posterior.

Dr. Faraday compared the shock to that of a large Leyden phial, charged to a low degree, or to that of a good voltaic battery of perhaps one hundred or more pairs of plates; and he endeavoured to form some idea of the quantity of electricity which was sent at each discharge, by comparing the effects with those which resulted from the passage of electricity from a large Leyden phial, between two brass bulbs, which were placed about seven inches apart in a tube of water, taking care to lessen the intensity by having several strands of wetted string intervening somewhere in the circuit: with this arrangement, when a discharge took place, and the hands were placed in the water, a shock was felt exactly like that of the fish; and judging from this, as well as from the amount of chemical decomposition and degree of magnetic deflection, he believed it equal to that of 3500 square inches of glass, coated on both sides, and charged to the highest degree; while Professor Schönbein compares it to that of a hydro-electric pile of 200 pairs. This quantity the Gymnotus is capable of passing again and again, with scarcely an appreciable interval, and doubtless, in its native rivers, the effects are still more tremendous; as indeed we learn from the graphic description which Humboldt has given us of the Indian method of capturing the fish, "which consists in exhausting their energy by making them give repeated shocks. This they do by driving a number of wild horses and mules into the lakes which they frequent." Humboldt saw about thirty of these forced into a pool containing numerous gymnoti. The Indians surrounded the banks closely, and being armed with harpoons and long reeds, effectually prevented the escape of the horses. The fishes were aroused by their trampling, and coming to the surface, directed their electrical discharges against the bellies of the intruders. Several horses were quickly stunned, and disappeared beneath the surface of the water; others, exhibiting signs of dreadful agony, hurried to the bank with bristled mane and haggard eyes, but there they were met by the wild cries and violent menaces of the Indians, which forced them again into the water; and when, at last, the survivors were permitted to leave the pool, they came out enfeebled to the last degree, and their benumbed limbs being unable to support them, they stretched themselves out upon the sand completely exhausted. In the course of five minutes two horses were drowned. By degrees the discharges of the gymnoti becoming less intense, the horses no longer manifested the same signs of agony, and the wearied fishes approached the margin of the pool almost lifeless, and then they were easily captured by means of small harpoons attached to long cords. The fishes left in a pool thus disturbed were found scarcely able to give even weak shocks at the end of two days from the time of the combat. In this way mules are destroyed in attempting to ford rivers inhabited by the gymnotus; and so great a number of mules were lost within the last few years at a ford near Uritucu, that the road by it was entirely abandoned. When small fishes receive the shock, they immediately turn upon their sides stunned; and the gymnotus seems aware of the best means of concentrating its effects, by either attaching itself laterally to a large surface, or else by forming a part of a circle, and making the animal complete it.

It is these immensely powerful effects of the gymnotus that have enabled us to clear up several points relative to the phenomena of electrical fish; for in the torpedo they are so weak that the fishermen on the Italian coasts handle them as playthings; the effect at the greatest is but a slight trembling, which is rarely felt above the elbow. Stories have been told by travellers of persons being knocked down when they accidentally trod on the torpedo as it lay buried in the sand on the sea-shore; but these are doubtless exaggerations, for Dr. Davy never saw the smallest fish affected by them, and there is the greatest doubt thrown over the statement of Reaumur, who asserts that he once saw a duck killed by its repeated discharges.

Respecting the phenomena of other electrical fish I have but little to say. Lieutenant Paterson is the only individual who has reported on the malapterurus of the Nile and Niger, and he says that on taking one by the hand its shock was so great as to oblige him to quit his hold. There remains little doubt, however, that their phenomena are identical with the preceding.

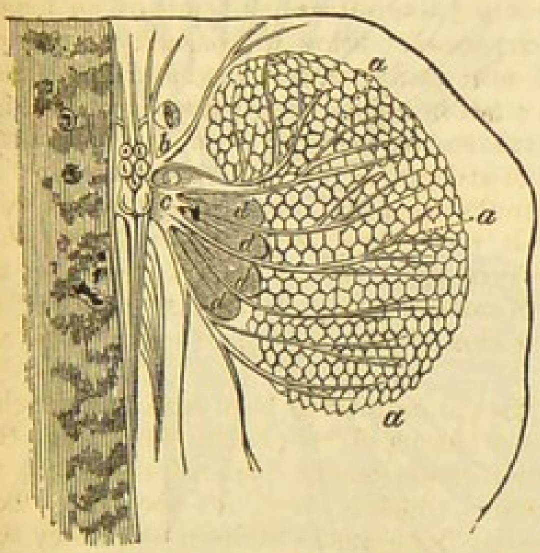
Having, then, briefly reviewed the phenomena of these peculiar fish, our next point of inquiry will be into *their anatomy and general characters.*

The Torpedo, which is the most common of all, belongs to the order Raia of the class of cartilaginous fishes: it is distinguished by its circular disc or body, large pectoral fins, and short tail.

It is a native of many of the European shores of the Atlantic, and of the several seas which branch from it, being, however, almost entirely limited to between the 30th and 50th deg. of South latitude: it is very common in the Mediterranean, more especially along the Italian coasts, and it is also frequently found on the southern shores of England, as well as in the western parts of France. In these different localities the torpedo has received various names, all, however, having reference to its peculiar numbing property. Thus, in Italy, they are named Haddayla; in France, La Tremble; and in England they are called the Cramp, or Numb fish.

The Italians, moreover, have two species of this fish, both being very commonly met with in their markets, where they are sold, as articles of food, to the lower orders. One kind they term the Tremola; the other, from its spotted appearance, Occhiatella. Of these some naturalists have made many species, but Dr. Davy, who has paid most attention to the subject, is of opinion that they may be reduced to these two of the Italians, all others being merely varieties; and in this he is supported by Cuvier and Rudolphi: for the first of these he proposes the name of Torpedo diversicolor, which includes all the mottled varieties, such as T. marmorata, and galvanii; the second species he names Torpedo oculata, a term which he prefers to occhiatella, or ocellata, and is applied to all such as have the eyelike markings on the back. In general appearance the torpedo resembles the skate, from which, however, it is distinguished by a short tail and round body: it is not covered by scales, but by a thick slimy mucus, secreted by numerous glands situated immediately beneath the skin. On making an incision along the mesial line, and reflecting the skin outwards, we see a thick aponeurosis, composed of two sets of fibres, the most superficial of which run longitudinally, and are very dense, while the deeper layer runs transversely. On elevating these, we observe an organ of a peculiar structure, having the appearance of honeycomb (See Fig. 1.); this is the battery, and between each of the polygonal cells of which it is made we find the before-mentioned aponeurosis dipping down, and so appearing to effect its subdivision, but in reality it is an element of its formation, as we shall by and by describe. This battery is somewhat of a kidney shape, being concave internally where it dips into the several irregularities of the head and branchiæ, convex externally where it is applied to the semilunar cartilage of the great fin, and rounded before and behind. On a careful examination we find it is made up of numerous six- or eight-sided tubes, which extend perpendicularly quite through the fish, and each tube is further divided by a multitude of transverse septa into compartments, which contain an albumino-gelatinous fluid. In the recent state these septa are not so readily seen: indeed, Dr. Davy questioned their existence, but in specimens which have been preserved in alcohol they are very evident. (See Fig. 2.) The organ, then, we find is composed of numerous polygonal tubes or columns, which in their turn are made up of a multitude of compressed cells. Now the number of cells or transverse septa in a tube varies according to its length: on the average Hunter found

Fig. 1.




Dissection from the right dorsal surface of the torpedo, showing the battery (*a a a*), with the distribution of the 5th (*b*) and 8th (*c*) nerves to it. *d d d d*, branchia.

Fig. 2.

Transverse section of the body of the torpedo, showing the columns of the battery extending from the dorsal to the ventral surfaces, and their subdivision into cells.

150 to the inch, and in a very large fish there were in each organ 1182 tubes more than an inch long; from which we may calculate there were not less than 400,000 of these cells in the two batteries: in this way the surface is considerably extended. Lacepede calculated that it amounted in a torpedo of ordinary size to about 58 square feet, and the surface, according to Hunter, increases with the growth of the animal; that is, fresh septa, as well as tubes, are added yearly. I have, however, great reason to doubt the accuracy of this statement, for by a comparison of the distances between

the septa of some small fish which I have had an opportunity of examining and comparing with those of Hunter's, in the museum of the College of Surgeons, I find that in the latter they are much wider apart: and further, this opinion of Hunter seems to be contradicted by the general electrical effects of these fish at different ages, for all experimenters have found that the smaller fish give the greater shocks; and these, I apprehend, are owing to the closer approximation of the insulators, and consequently the charge is capable, as in a thin Leyden jar, of acquiring greater intensity.

The different cells of the battery as well as the tubes are kept together by a loose kind of cellular tissue, in which ramify the blood-vessels and nerves, the latter being very abundant.

*Nervous system.*—In looking at the brain of the torpedo, and comparing it with that of the skate, (Figs. 3 and 4), we are struck with the comparatively small size

FIG. 3.

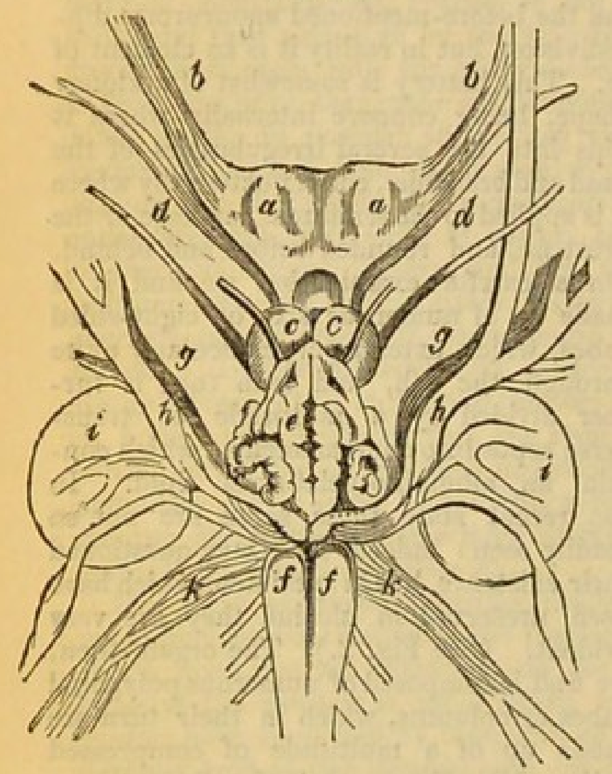


Fig. 3. *Brain of the Skate.*

FIG. 4.

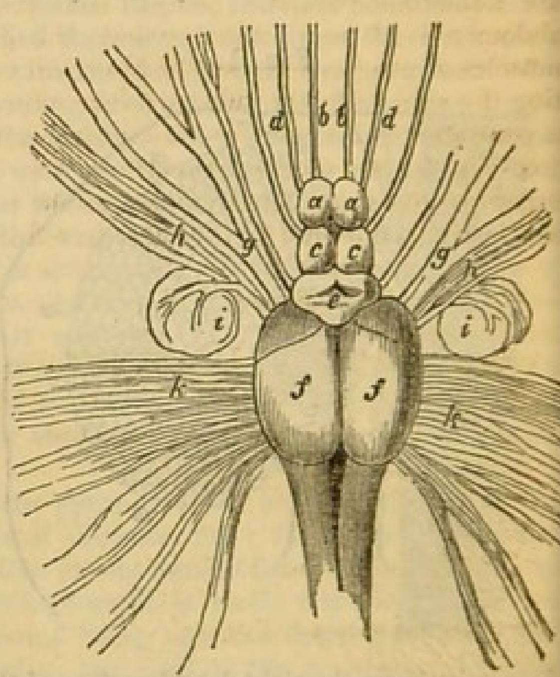


Fig. 4. *Brain of the Torpedo.*

*a a.* Cerebral hemispheres. *b b.* Olfactory commissures going to the olfactory ganglia. *c c.* Optic lobes. *d d.* Optic nerves. *e.* Cerebellum. *f f.* Medulla oblongata. *g. h.* Motor and sensitive branches of the fifth. *i i.* Auditory apparatus. *k.* Eighth pair of nerves.

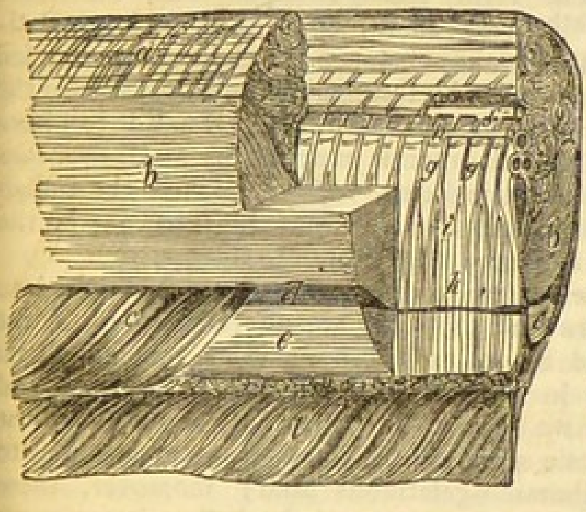
of the centres of the true nerves of sense; there is a want of resemblance also in the figure and size of the cerebellum: but the great point of difference is in that part of the nervous centre whence emanate the nerves supplying the battery: I allude to the medulla oblongata, which gives off the 5th and 8th nerves: this in the torpedo is very large, larger indeed, relatively, than that of any other animal. There is not time for me to give an account of the distribution of the several cerebral nerves, which do not, moreover, differ very essentially from those of other fish, but I shall limit myself to a description of the great nerves of the battery, namely, the 5th and 8th (see Fig. 1.) The 5th pair arises from the medulla oblongata, and passing upwards and outwards, divides into two great branches, the first of which, again dividing into two other branches, proceeds forwards, and winding over the anterior part of the cranium, is distributed to the numerous mucous glands situated upon its under surface. The second great trunk also subdivides into two branches, one of which winds along the anterior margin of the battery, and is distributed to the mucous glands there situated, while the other, or the first electrical nerve, after giving off glandular twigs, as well as motor nerves and branches, to the adjoining branchiæ and auditory apparatus, plunges into the anterior part of the electrical organ, and is distributed to its superior portion.

The 8th pair also arises from the medulla oblongata, and passes outwards through the cartilaginous cranium, where it divides into several branches, which pass between the branchiæ, giving off filaments to them as they pass, and then each plunges into the corresponding portion of the battery, where it spreads out, and is distributed through its substance; another large branch goes to the stomach, where it is lost, while a considerable twig passes backwards towards the tail, to the muscles of which it is distributed: in the Ray all these nerves are seen, but they are much smaller.

The vessels which go to the electrical organs are not so numerous as Hunter supposed: they are derived from the branchial, and are not of sufficient moment to detain us in their description.

We come now to an examination of the gymnotus electricus, and from the dissections of two of these, which were kindly supplied me by Mr. Hawkins, I am able to give ample detail. These animals, of which there are several non-electric species, are so named from the absence of a dorsal fin, and this especially distinguishes them from the eel, to which they bear a great resemblance. The gymnotus electricus is an inhabitant of the fresh-water rivers and lakes of South America, being very common in the Llanos de Caracas, and the waters which flow into the Guyana: here it attains the great length of five or six feet: its body is smooth, uncovered by scales, but lubricated by a thick mucus; the eyes are small, and placed very near the nose; around the mouth are numerous papillæ; beneath and just behind the under jaw is the anus. The abdomen is of very limited extent, the greater part of the fish being made up of the muscles of progression and the electrical organs: these are brought into view by reflecting the skin from the side, together with a dense aponeurosis which covers them, and is continuous with that forming the intermuscular septa. In this stage of the dissection (see Fig. 5) we observe superiorly the dorsal muscles; then the greater electrical organ, composed of longitudinal laminæ; thirdly, an inferior plane of lateral muscles; and lastly, the lateral fin muscles, on reflecting which we see the lesser electrical organ.

Fig. 5.



A transverse as well as longitudinal section of the Gymnotus electricus, showing the position of the batteries as well as the distribution of the spinal nerves. *a*. Dorsal muscles. *b*. Greater electrical organ. *c*. Muscles of the fin, covering in the lesser electrical organ (*e*). *d*. Inferior plane of lateral muscles. *f*. Spinal cord, giving off (*g g*) spinal nerves, which subdivide and run down over the air bladder (*i*) and vertical septum (*k*). *l*. The fin.

In a transverse section of the fish seen on the right of Figure 5, all the parts are better discriminated, and the dorsal muscles are found to be made up of four or five planes, between which exists an aponeurosis; the longitudinal laminæ of the electrical organs also are seen to extend inwards quite to the mesial line: on each side of the vertebral columns are the cut ends of the peculiar nerves of Hunter, but which are the dorsal branches of the fifth, while beneath the spine are the systemic vessels, then the air sac, and lastly a perpendicular aponeurotic septum, which separates the fish into two lateral halves. Observing the electrical organs more closely, we find that each lamina is subdivided by perpendicular septa, which are seen as well in a longitudinal as a transverse section of the battery, and this results from their pursuing an oblique course from within outwards. These septa effect so many divisions or cells in the laminæ, and they are filled with an albumino-gelatinous fluid; so that, to review, we find the electrical organ of the gymnotus composed of laminæ which in their turn are made up of cells; and this arrangement is precisely similar to the battery already described belonging to the torpedo: the surface, however, is much more extensive: thus, in a gymnotus of three feet and a half long, which I examined, there were upwards of fifty of these laminæ in the two organs on each side, while the entire battery contained about 550,000 cells, which were much larger than the compressed hexagonal cells of the torpedo. Lacepede calculated that the discharging surface of the organs of one of these fish, four feet in length, was at least one hundred and twenty-three square feet.

The shape of the greater electrical organ is that of a wedge, commencing by a broad rounded border just behind the head. As it proceeds backwards it gradually tapers from the termination of the inferior laminæ. The lesser organ begins from a point behind and beneath the preceding, and becomes broader and broader towards the tail, where it ends: at the origin as well as termination they are both very thin.

These organs are largely supplied by nerves which are derived from the spinal cord: according to Rudolphi they are 224 in number: each issues through the corresponding interspinal foramina, and passing down over the air-bladder and longitudinal septum, it divides and subdivides into long straight branches, which give off filaments opposite each lamina to the numerous electrical cells. The dorsal branch of the fifth, as far as I could make out, did not give any branches to the battery, but seemed to supply the muscles in its course. These spinal nerves of the gymnotus are very large, in comparison with the same nerves of the eel or conger; and the brain also exhibits several points of interest, particularly in the large size of the cerebellum (see Fig. 6. and 7.) Of the anatomy of the silurus of Linnæus, or malapterus of Lacepede, I have very little to say: its anatomy has been made out by the dissections of Geoffroy, Rudolphi and Muller, and Valanciennes. The fish inhabits the Niger, the Senegal, and the Nile. There are two electrical organs on each side, which are separated by an aponeurotic membrane: the external one, which extends all round the snimal, lies superficially or directly under the skin; the deeper one rests on the muscles: they are composed of a dense aponeurosis, whose fibres in the external one run obliquely, and thus form lozenge-shaped cells, which are very small, and filled with a gelatinous substance. Both these are supplied by nerves. Thus, the superficial battery is supplied by the eighth, which runs under the aponeurosis before mentioned, and sends about 12 or 14 branches through it to pierce the organ, and be distributed to it: the internal organ is supplied by small branches from the intercostals. The structure of the trichiurus, which frequents the Indian seas, and of the tetraodon, which is met with along the shores of Johanna, one of the Comoro islands, has not in either case to my knowledge been described.

Fig. 6.

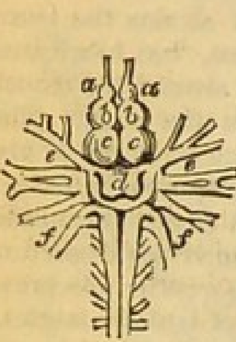
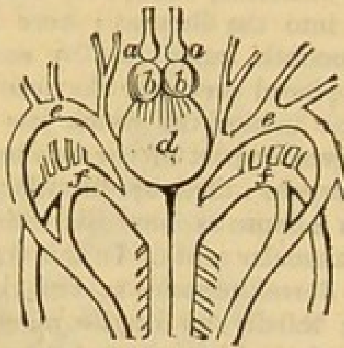


Fig. 7.



Comparative views of the brains of the Conger (Muræna conger, Fig. 6), and Gymnotus electricus (Fig. 7). *a a*. Olfactory lobes. *b b*. Cerebral hemispheres. *c c*. Optic tubercles. *d d*. Cerebellum. *e e*. Fifth pair of nerves. *f f*. Eighth pair of nerves.

In generalizing, then, upon the facts which we have learnt from our inquiries into the anatomy of these singular animals, we find that they are all inhabitants of the water; that their bodies are not covered by scales, but by a thick mucus, which is secreted by glands lying abundantly in the neighbourhood of the head and electrical organs; while in their interior we discover a remarkable organ called the battery, composed alternately of aponeurotic septa, whose fibres are so arranged as to form cells, in which is contained an albumino-gelatinous fluid; moreover, these organs are abundantly supplied with nerves, much more so, indeed, than is necessary to the common purposes of life. Nor is the organ a vital one, but seems rather to be, as Geoffroy supposed, a tegumentary modification, introduced without producing any notable alteration in the rest of the organization; and, judging from the dissections which stand upon the table before you, and of which these are drawings, it would seem that they result from an increased development and peculiar arrangement of a common aponeurosis to be found in all fish. Thus, in the torpedo, of which a transverse section is here seen in comparison with a similar section of the ray, it is produced by an hypertrophy, as it were, of the aponeurosis which exists between the branchiæ and the great semilunar cartilages, and not, as Geoffroy supposed, by an enlargement of a glandular structure. By comparing the sections of the gymnotus and conger, also here preserved, we find in both the same number of dorsal and lateral planes of muscles, with their intervening aponeurotic septa, one of the lower ones of which has become, in the gymnotus, amazingly developed, and so has formed the greater electrical organ, which, by its increase, has pushed up the other planes of muscles, one only remaining beneath it, and which intervenes between it and the lesser organ, which arises in a similar manner from the increase of an inferior septum. In the silurus it is the enveloping aponeurosis which has become developed into a battery. From these considerations we cannot regard the electrical organs as superadded structures, but rather as the increase of a common integument; we know, from the study of comparative anatomy, how chary nature is of any addition to the animal structure, and in any other point of view here would be an addition of a marvellous and unparalleled character: it is probable, too, that the examination of neighbouring species will exhibit to us the same aponeurosis in progress of increase. Dr. Davy has also found that the growth and formation of the battery of the torpedo is of comparatively late occurrence; in very young fish there is little evidence of its existence, but it is formed, as he supposes, from matters absorbed by the branchial filaments, and if Hunter's observations be correct respecting the yearly additions to the organ, they are further evidence of our opinion.

Thus, then, the two, and the only propositions with which dissection has furnished us, are the existence of peculiar organs composed alternately of septa and fluid; and, secondly, a large supply of nervous energy to them: from these two data, together with others that are to be derived from experiments on the mutilated animal, are we to form our opinion as to the origin of their electrical force. But first, we may take a brief review of the different notions that have been entertained relative to its nature and cause. In 1678, the Italian school, at the head of which was Redi and his pupil Lorenzini, supposed that the shock of the torpedo was dependent on the thrill produced by the contraction of certain muscles, called by the latter *musculi falcati*, of which he considered the battery to be composed; and this was the general opinion until the days of Hunter, whose dissections showed that Lorenzini had mistaken the columns of electrical organ for muscles. Another notion, equally absurd, was prevalent, that it depended on the effluvia of certain small particles which arose from the fish's body. About a century later, when the discovery of the Leyden phial became better known, the analogy of its effects with those of the torpedo were soon recognised. Walsh and Muschenbroek were the first to direct attention to them, though, as I have said, they failed in establishing their identity, and were even unable to get the more common effects of electricity. The Hon. Mr. Cavendish, however, nothing daunted by these failures, soon proved that the effects of a Leyden phial would be similarly destroyed if subjected to the conditions under which a torpedo manifested its discharge. He discovered that when any number of bodies were connected with the excited surfaces, they made so many circuits, each carrying a part of the electricity during a discharge, and in proportion to its conducting power, that if the discharge take place through water, the water is a conductor all around, but in proportion to its distance. By using a torpedo made of leather, and having one disc of metal upon the dorsal and another on the ventral surface, and connecting these respectively with the ends of a battery of 49 small jars previously charged, he obtained effects precisely similar to those of the torpedo; and found, moreover, that he could not get the spark, or make the discharge pass across the nick in a piece of tinfoil; but still, all these only went to prove an apparent identity of the phenomena, they gave no idea whatever of the origin of the force: and so things remained for a quarter of a century, when Volta announced the discovery of his wonderful pile—asserting that two dissimilar bodies placed in contact gave rise to electricity. Such an announcement was certain to attract fresh attention to animal electricity, and the electrical organ of the torpedo was likened to his pile. Many misgivings, however, existed to as the analogy of their effects—Sir H. Davy asserting that they were more allied to those of ordinary than to voltaic electricity; nor could he see in the battery the arrangement of a galvanic apparatus. His brother, too, Dr. Davy, entertained similar opinions, and likened them to the effects of common electricity of large quantity but small tension. Such, also, is the idea formed of it by many of our ablest electricians at this time, although there are not a few physiologists who still adopt the explanation of Volta; and therefore it will be necessary for us to consider the arguments which exist upon both sides of the question, premising that it is everywhere sufficiently proved and admitted that the organs *are* in some way immediately connected with the manifestation of the electrical phenomena. And, first, *Do the organs themselves originate the power?* The advocates of this opinion found their arguments upon the analogy which the mechanical arrangement of the battery furnishes to a voltaic pile, it being composed of alternate layers of dissimilar substances: in such a point of view there ought not to be a single square inch throughout any animal frame but should be a galvanic battery. But the principle itself, namely, that of *contact*, is, in all probability, erroneous, and every day brings fresh facts to overturn Volta's theory. But again, the careful consideration of the elements, and their arrangement in a voltaic pile, will show, as Schönbien has asserted, that the living organ does not possess even an indeterminate resemblance, much less identity of circumstance under which the electric phenomena are produced in the two. But, for argument's sake, were we to admit that the experiments of Humboldt, of Pfaff, Bruntzen, Provost and Dumas, Kaempz, and others, have proved that the *contact* of dissimilar animal substances is capable of producing electricity, and even admitting that the arrangement of the pile exists in the organ, what do we explain ? Merely a generation of power which we have a means of accounting for much better. It gives us 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 like that of a constant battery, and its discharges, therefore, be regular and constant, and why, if it be due to the physical arrangement, we do not get shocks directly after death, or when the nerves are divided : in this case, the elements of the battery, for a short time at least, must remain the same. To my mind, this is a most unsatisfactory explanation, and we must rather look to the brain and nervous centres for the force which accumulates in the battery in the same manner as electricity does in a Leyden phial. Experiments on mutilated animals also tend to support this view. Thus we find, in the first place, *that the shock is only manifested while the nerves are entire.* Todd found that on making a division of the nerves which go to the battery, (and this he did without injury to the other parts,) the animal, though it lived as long as the uninjured torpedo, and seemed equally lively, yet it ceased to give shocks when irritated ; and *Matteucci found that the intensity of the shock diminished exactly in the ratio of the number of nerves which he divided.* Moreover, Matteucci has further observed, that *irritation of the brain would produce shocks* after the animal had otherwise ceased to exhibit them. And Davy remarked, that when a small portion of brain was left attached to the nerves of the battery, it shocked an assistant who held it. Humboldt, also, cut a gymnotus transversely through the middle of its body, and found that the anterior portion alone was able to give shocks. Dr. Todd has divided all parts around the organ, except the nerves, and with the organs thus insulated he was able to get the shocks just as usual. Now if it had been dependent on circulation and secretion, the battery should have ceased to act. Spallanzani, too, found that the extirpation of the heart did not diminish the shock until the great loss of blood had reduced the vital powers generally, and therefore *it could not have been dependent on circulation or secretion.*

Again, the evident nervous exhaustion which is manifested after repeated discharges, or, as Dr. Faraday expresses it, " *the apparently equivalent productions of electricity in proportion to the quantity of nervous force consumed,*" would favour this view : it was observed, that the animal which he experimented on at the Adelaide Gallery appeared fatigued and exhausted after an evening's illustration ; and this fact is made still more evident by the Indian method of capturing the fish. Todd also noticed the same fact relative to the torpedo : he took, for instance, two of these fish of the same size and vigour, and while one was allowed to remain quiet, the other he irritated to give repeated shocks, and it soon became exhausted and died, though the former lived three days ; and this he found was generally the case. Dr. Davy also noticed that with a great expenditure of the electrical force has resulted a want, as it were, of nervous energy in other parts : some torpedos on which he experimented were found, after several days, with fish in their stomachs not in the least digested. Let us look, again, at the *voluntary nature of the discharge ;* moreover it would seem as if the animal was capable of knowing when the shock was effective, for it will not repeat it except with advantage.

Lastly, we cannot but be struck with *the great amount of nervous supply which each organ possesses :* it was this circumstance, indeed, which attracted the attention of Mr. Hunter, who says, " that the magnitude and number of the nerves bestowed on these organs, in proportion to the size, must, on reflection, appear as extraordinary as the phenomena they afford." Nerves are given to parts either for sensation or action : now, if we except the more important senses of seeing, hearing, smelling, and tasting, which do not belong to the electrical organs, there is no part, even of the most perfect animal, which, in proportion to its size, is so liberally supplied with nerves, nor do the nerves seem necessary for any sensation which can be supposed to belong to the electrical organs ; and with respect to action, there is no part of any animal with which I am acquainted, however strong and constant its natural actions may be, which has so great a proportion of nerves. If, then, it be probable that those nerves are not necessary for the purposes of sensation or action, may we not conclude that they are subservient to the formation, collection, and management of the electrical fluid, especially as it appears evident, from Mr. Walsh's experiments, that the will of the animal does absolutely control the electric powers of its body, which must depend on the energies of the nerves. Taking all these points, then, into consideration, it appears far the most probable that the *electric fluid is derived from the brain, to be sent along the nerves, and concentrated in the battery, whence it is discharged through the water in a determinate direction.* It is also probable that the discharge takes place *spontaneously*, as in Harris's unit jar, when the tension has become sufficiently great to overcome the resistance offered to its passage; and the animal appearing aware of this, and having no control over its direction, adopts the position best suited to concentrate it on its prey. The gymnotus, in giving a shock, either attaches itself directly to the body to be shocked, or else, bending itself into a semicircle, it makes the animal complete the circuit between its head and tail. The torpedo also struggles violently before giving a shock, in order to bring its dorsal and ventral surfaces to bear at the same time upon the animal.

And now, to look back upon our inquiries into the phenomena of these singular animals, we cannot but have observed many facts of peculiar interest to the physiologist: and without advancing to the speculations as to the abstract principle of life, against which I cautioned you at the outset of this lecture, we may be permitted to investigate the cause of its secondary operations, and of the manifestation of those actions by which we become cognizant of the existence of such a principle.

Without the nervous agency we should have no conceptions, and in all probability there would be no evidences of animal life; it is through it we become possessed of our relations to the external world, and, though we pause to inquire what it may be, yet we do not hazard ourselves a step further. When I study the complications of a piece of machinery, and the force which keeps these in action, it does not imply an inquiry into the origin of that machine: the first is intelligible, and within our reach; the latter abstractedly cannot be: the principle that called the living world into existence is as rife in its simplest creature as it is in the highest and most complex of God's works. The simple monad, or even its germ, may possess as much, or more, of this element than man—the tenacity of it, at any rate, is greater; but there can be no question that the phenomena which they exhibit are incomparable: and these seem to pursue a ratio exactly equivalent to the amount of chemical action which they exhibit, and to the development of systems, of which the nervous is one necessary to its manifestation.

In our investigations we have seen that the phenomena of electrical fish are due to electricity, and that they derive this from the brain. In all probability it is not a peculiar force evidenced only in these fish, but is the common one of nervism; and the force which traverses all nerves may be electricity. This is a notion which has been long entertained by many of our ablest physiologists; for experiment shews us, that *a current of electricity sent along the different nerves produces effects precisely analogous to those which are consequent upon the transit of the nervous force.* If it be sent along motor nerves, muscular action is the result; along sensitive ones, we affect the sensation peculiar to that nerve. Thus, by means of a simple galvanic current passed through the eye, we produce the effect of light; through the auditory nerve, that of sound; and the nerves of taste and smell may be similarly acted on. Indeed, Dr. Wilson Philip has even asserted that he can produce the secretion of the gastric juice by sending a current along the divided pneumogastric nerves. Some deny this; but it is evident we can augment the secretion of saliva and of the tears by means of electricity. This may be said, however, to be merely a stimulus. I do not quarrel with the explanation—it does it—but I may ask what they mean?

But when we assume that the nervous force is electrical, because a current of electricity sent along the nerves will give rise to effects similating the vital functions, we ought, upon the principle of action and reaction, *to be able, during the natural performance of these functions, to detect a current of electricity.* Various experimenters have inquired into the truth of this, but with somewhat contradictory results. We should remember, however, that most of these have originated in preconceived notions. Thus, Person, Müller, and some others, assert that they have never detected free electricity traversing the nerves. Hermer, however, Pfaff, and Ahriens, have; and this not only in the lower animals, but in man: and the latter observers assert that it is increased after spirituous drinks, but diminished as the body cools; in other words, it keeps pace with the respiratory changes. Matteucci, also, has observed a deviation in the galvanometer, amounting to fifteen or twenty degrees, when the liver and stomach of a rabbit were connected with its platina ends—an action which was not due to the different chemical properties of the secretions, for it ceased with death; and, more recently, Professor 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. 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.

I do not refer to the experiments of Prevost and Dumas, although confirmatory of this position, because there are some objections to them; nor perhaps am I warranted in mentioning those of Vasseur and Berandi, who assert that needles passed through the nerves of a living animal become magnetic, while division of the cord, they say, destroys this property, but the inhalation of oxygen increases it. M. David also reports, that he has seen a galvanometer deflected when its poles were inserted into the bared nerve of an animal, which was made to move, and that there was no deflection when the spinal cord was divided. Müller, however, has repeated both these experiments without success. But, supposing that we had never yet detected a current of electricity traversing the nerves during functional activity, we are not therefore to conclude that there is no passage of an electric current. We should bear in mind the great effects which our weakest and otherwise inappreciable currents are capable of producing on the living muscle; and, to detect a current of as weak tension as must be that of the nerves, we should possess galvanometers as delicate as living muscle. Matteucci has lately, indeed, used this; and, by its means, is able at any time to make the leg of one frog contract by connecting it with a wound made in that of another. We assert too much, also, when we say that the nerves are not better conductors of electricity than any other parts. There are certain facts which seem to prove that they are; nay, more, that the central pulp is the conducting agent; and this explains the action of a ligature or compression on a nerve. I have before met the principal argument against the identity of the nervous and electrical forces, namely, that any stimulus will do as much towards exciting the action of a nerve as electricity. True; but every one of these are originators of electricity.

From these propositions we are warranted in assuming that *it is the force of common nervism;* and there are many who entertain a similar opinion. Dr. Watson, in his Lectures on Medicine, which were published last year, 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 be nearly allied to, electricity;" and Dr. Faraday observes, "that from the time it was shewn that electricity could perform the functions of the nervous influence, he has had no doubt of their very close relation, and they probably are effects of one common cause." This was, moreover, Dr. Wilson Philip's opinion, as well as that of Wollaston, Treviranus, Carus, Prevost and Dumas, Matteucci, Meissner, and many others. Nor should I forget to add the name of Sir J. Herschel, who says that the present state of electrical science warrants the conjecture that the brain and spinal marrow form an electrical organ, which is spontaneously discharged along the nerves at brief intervals, when the tension of the electricity reaches a certain point.

But with all this we have yet to inquire into the *origin of the electrical force,* and, secondly, *how it arrives at the brain to be at the voluntary service of the animal.* In the inorganic kingdom the source of electricity is chemical action. It is the same without doubt in the living organism; indeed, the great element of existence seems to be chemical action; and the wonder would be, how this could be maintained without the development of electricity. Many of the principles of our food, as well as the old matters formerly components of our bodies, are undergoing, through respiration, combustion, and being converted into carbonic acid and water. The result of these changes must be a manifestation of heat and electricity. The former keeps up the temperature of our bodies; the latter, in my opinion, serves to maintain the vital functions; for we find, when we check respiration or oxidation, we check every outward evidence of life; while, on the other hand, if we increase it, either by the inhalation of a purer or denser atmosphere, or one containing more oxygen, as protoxide of nitrogen, for instance, we increase these evidences; and so also when we increase chemical action, by throwing into the system compounds which are easily burnt, as, for example, spirituous drinks; so that, to use the words of Professor

Liebig, "*all vital activity arises from the mutual action of the oxygen of the air and the elements of the food;*" therefore, every phenomenon of life is dependent on chemical action; and there is sufficient of this going on in every organism to account for the expenditures which are incidental to the most active existence. There is, moreover, a constant ratio existing between this amount of expenditure and the activity of the respiratory changes; in cold-blooded animals, and in animals during hybernation, there is an apathy and want of energy in all their movements, while in the hot and actively respiring bird there is a proportional increased expenditure and exhibition of nervous energy. To look, then, at the phenomena of life, we see *they are manifested by a something which originates from chemical action, traverses the nerves, and produces in the animal body combinations and decompositions.* From the former result nutrition and reproduction; it is the force of *vegetative life*, while decomposition determines *animal life.* It is an ascertained physiological fact, that when parts cease to perform their duties, whether naturally or otherwise, they begin to waste, and the function of nutrition becomes altered. We believe, therefore, that the passage of the nervous current is necessary to their growth and sustenance; while, on the other hand, there is also sufficient reason for believing that every mental effort, every sensation, every muscular movement, is accompanied by corresponding changes in the brain and muscle; its elements are given up to enter into new combinations with oxygen, from which electricity again results; and thus the circle is completed.

It is, however, a question of a more intricate character as to *how this electrical force is made available*, and reaches the brain—whether it be by the incident nerves, or by the blood in the vessels themselves. Meissner supposed that the blood became charged with electricity in the lungs during the process of respiration, and this, by traversing the ganglionic nerves, reached the brain, and was here accumulated for use. These are points concerning which, at this stage of our inquiry, we can only speculate. Hitherto our attention has not been sufficiently directed to this view of the subject, and we are consequently not in a position to attempt an explanation. There are certain points, however, which are worthy of consideration. We find that the termination of nerves is in loops; that is, they return upon themselves at both extremities, and thus complete their circuit. The one loop is in the brain or cord, the other at the periphery; and we observe, moreover, that both of these loops are imbedded in an intricate plexus of capillary vessels. It is in these capillaries that the great chemical changes of the body are being effected; and we may, from such data alone, speculate rather extensively upon the phenomena of reflex action, but that there is neither time nor warrant for such. We are less able, however, to understand the act of volition—how, at any time when we will, a movement, a connection as it were, should be established, or a current of electricity sent out. But the phenomenon of a single movement is little compared with those of the associated ones, where there is a demand for the operation of a number of muscles, whose work must be done conjointly, and with just so much contraction, and no more, or we should fail in our purpose. When we consider also the multitudes of effects which one series of muscles is capable of producing by their varied degrees and orders of contraction, we are still more amazed. To refer, for instance, as Dr. Carpenter has beautifully shown, to the muscles of the larynx. All our sounds or tones are produced by the vibration of the vocal cords, whose degree of contraction is not more than the eighth of an inch, and yet the stages within this short space are sufficient, in ordinarily cultivated voices, to produce 240 intonations, and in practised vocalists the number is much greater. It is said that Madame Mara was able to sound 100 distinct intervals between each tone; and the compass of her voice was at least three octaves, or twenty-two tones; so that the total number of intervals was 2200, and all comprised in the contracting space of one-eighth of an inch; so that it might be said she was able to determine the contractions of her vocal muscles to the 17-1000th part of an inch; and this could all be done at will, and with the most perfect exactness. And then, again, look at the rapidity with which we can effect these movements. Many persons will pronounce 1500 letters in a minute, each of which must have required a separate contraction of muscular fibre; and when we consider that each such must have been followed by a relaxation of equal strength, it follows that every contraction was effected in the 3000th part of a minute. But the wings of insects are moved with much greater rapidity than this—sufficiently so to produce musical tones. This will give us some idea of the beauty, and regulation, and energy of muscular movement, and how inadequate we are to offer any explanation of the manner in which the transit of this acting force is effected, although we have reason for believing that that force is electricity; for we have seen that *the phenomena of the electrical fish are electrical,* and that *they derive this force from the brain.*

2dly, *That electricity sent along the nerves gives rise in the living organism to effects precisely simulating the vital; and that, during the performance of the vital functions, electricity can be detected traversing the body.*

3dly, *That all vitality results from chemical action, and that chemical action gives rise to electricity.*

Lastly, *That electricity in motion gives rise to combinations and decompositions, and that the nervous force does the same.* But, though we have learnt thus much concerning the phenomena of life, we are yet perhaps but upon the threshold of what we may be permitted to know. Nature seems to have exhibited in these animals glimpses into her more intricate operations; has lifted the veil which before formed an impenetrable screen to the comprehension of her sublimest wonders. There is, as Sir H. Davy expressed it, "a gleam of light here worth pursuing," and which may by its cultivation tend to illumine and make intelligible every problem connected with physiology, and thus raise the study of electricity to the highest position among the physical sciences.

THE END.

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