XII. *An Account of some Experiments and Observations on the Torpedo* (Raia Torpedo, *Linn.*) *By* John Davy, *M.D. F.R.S., Assistant Inspector of Army Hospitals.*

Read March 22, 1832.

In a paper published in the Philosophical Transactions for 1829, my brother, the late Sir Humphry Davy, has given an account of some experiments which he made on the torpedo for the purpose of ascertaining the nature of its electricity, whether it is of a peculiar kind or analogous to kinds already known. The results he obtained were altogether negative, and seemed to lead to the former conclusion. But that conclusion was so novel and important, that he did not consider himself justified in adopting it without further investigation. At the time he wrote the paper referred to, namely, in the autumn of 1828, in a very feeble state of health, he was on his way from southern Austria to Italy, where, if his health permitted, he intended renewing the inquiry. He arrived at Rome on the 19th of November, and, with his usual ardour of pursuit, immediately began his observations on the torpedo; but they were directed chiefly to its anatomical structure and natural history, rather than to its electricity; for, though this fish is to be had in abundance in the fish-market of that city, being brought from a distance, it is very difficult to obtain it alive. To make experiments on the living fish, he proposed going either to Civita Vecchia or Tormicina, where it is caught; but before he could accomplish this intention he suddenly experienced another and very severe attack of his complaint. This attack occurred on the 20th of February; and in a letter written from his dictation, five days after, when he considered himself dying, he particularly requested me to carry on the investigation; and such was his zeal for science, that, excepting in a postscript, no mention was made of the alarming state in which he then was. On my joining him from Malta, on the 16th of March, he was still dangerously ill, and had the same feeling of being near his end; but his mind was wonderfully clear and active, and his love of research as great as at any former period of his life. At his request, the following morning torpedos were obtained from the fish-market, and I amused him, day after day, with the results of my dissections, till his complaint acquiring an aggravated form, and threatening speedy dissolution, he was unable to attend to them. I then discontinued the inquiry, and till a few months ago, I have not had an opportunity of renewing it. The results which I have obtained I shall now have the honour of submitting to the Royal Society. The experiments which I shall first detail on the living fish have been made entirely at Malta, and under very advantageous circumstances; for, residing during the summer season close to the sea, I have been able to obtain torpedos fresh from the water, and in a state of great activity.

1. *Experiments on the Electricity of the Torpedo.*

My brother was very desirous of trying the effect of the shock of the torpedo on a needle placed in a spiral wire. The result, he was of opinion, would be conclusive as to the nature of its electricity. Anxious to make this trial, I had an apparatus in readiness, which, with common electricity, I had found to answer extremely well. It consisted of a fine copper spiral wire, about one inch and a half long, and one tenth of an inch in diameter, containing about one hundred and eighty convolutions, and weighing about four grains and a half. This was inserted into a glass tube, just large enough to receive it, and secured by corks. The wire passed through the cork at each end, and was connected with strong wires with glass handles for the purpose of contact. The wire which was intended to be applied to the under surface of the fish was one twenty-fifth of an inch in diameter; that intended for the upper surface was stiffer, being one fourteenth of an inch in diameter, and its greater strength was useful, as it was necessary to employ it occasionally with some force to rouse the fish when averse to give a shock.

The first trial I made with this apparatus was successful. The fish used was a small one, about six inches long; it had been just caught in a hand-net, and immediately put into salt water, and was very active. A needle, perfectly free from magnetism, was introduced into the spiral, and there confined by the corks, and the spiral was carefully connected with the insulated wires for contact. The fish for the experiment was placed in a glass basin, and was barely covered with water. One wire was applied to the under surface of the electrical organ, and the other to its upper surface, and contacts were made at intervals during about five minutes, when the fish seemed much exhausted by its exertions. On taking the needle out, and bringing it near some fine iron filings, it proved magnetic, and powerfully attracted them. This experiment I have repeated several times, with fishes of different sizes, some larger and others smaller, and with the same result, when the fish has been active and the contacts similarly made.

The next trial which I made of the electricity of the torpedo, was on the multiplier. The precaution was taken to insulate the instrument well, by smearing with sealing-wax the feet of the stand supporting the coil. The same wires for contact were used in this as in the former experiment, and the junctions were carefully made. Applying one wire to the under surface, and the other to the upper surface, with every fish which I tried I succeeded in obtaining decisive results; the needle by active fishes was generally thrown into violent motion, and even by the feeblest was distinctly affected. I have met with no instance of a fish which had the power of magnetising a needle in the spiral wire, failing to move the needle in the multiplier; but I have met with more than one example of a fish whose electricity was equal to the latter effect, and not to the former.

The experiments which I have instituted, with a view to ascertain if the electricity of the torpedo has any igniting power, or power of passing through air and producing light, have been attended with less satisfactory results. Very active fishes were tried on circles of perfect conductors, interrupted only by a space just visible with the aid of a powerful magnifier. The terminal wires, coated with sealing-wax, excepting at their extremities, were introduced through a perforated glass stopple into a small glass globe, which was held in the hand of an assistant. The contacts were made in the dark; but not the faintest spark could be perceived, nor could any ignition be perceived when the extreme points were connected by silver wire not exceeding one thousandth of an inch in diameter.

When a torpedo was put into a metallic vessel, insulated by a glass stand, and contacts were made on its back, with the insulated wire resting on the edge of the vessel, or at a distance from it, luminous appearances were frequently produced, sometimes in the form of sparks, and sometimes in the form of flashes, not unlike summer lightning on an infinitely minute scale. At first, I was disposed to consider the phenomena electrical; but, on reflection, it occurred that they might depend on the presence of animalcules, which became luminous when agitated. And this I believe is the correct explanation of the effects; for, when the salt water was agitated without the torpedo, sparks of light now and then were seen, and the flashes or coruscations might have been owing either to luminous matter thrown off from the surface of the fish when it gave a shock, or to the shock simultaneously stimulating several particles, which, in consequence, shone for an instant.

The only positive result which I have obtained on the passage of the electricity of the torpedo through air, has been by using a chain as a substitute for a wire of communication. It was a small gold chain, composed of sixty-six double links, each circular and about one tenth of an inch in diameter, fastened unstretched to a dry glass rod at each end. Holding the upper portion of this chain in one hand, and the under wire in the other, (the hands being moistened,) I irritated, by means of them, the upper and under surface of an active fish; the shock which it gave was pretty strong, reaching beyond the fingers, and was felt with the same degree of force in both hands. This seems to show that the air is not impermeable to the electricity of the torpedo; and the same conclusion may be drawn from the facility with which I have found it to pass through a circuit of wire in which there have been no less than seven joinings, and these made merely with ordinary care, with the fingers, without the aid of any instrument.

In accordance with Mr. Walsh and my brother, I have in no instance seen the torpedo affect the common electrometer, or exhibit any the slightest indications of a power of attraction and repulsion in air.

The experiments which I have made on it as a chemical agent have been of a satisfactory kind. A small glass globe, of the capacity of about half a cubic inch, was used for holding the fluid to be acted on; and fine wires, communicating with the contact-wires, were introduced into it through a perforated glass stopple, and they were coated with sealing-wax along their whole course in the vessel, excepting at their points. By means of this little apparatus, I first tried the effect of a small active fish on a strong solution of common salt; the terminal wires were of silver. The contacts were made on the upper and under surface of the fish in the usual manner; minute bubbles of air collected round the point communicating with the under wire, but none at the other point. After an interval of some hours, fine gold wires were substituted for the silver wires; now gas was evolved from each extremity, but in largest proportion, and in smallest bubbles, from the point connected with the under wire.

The next experiment was made on a strong solution of nitrate of silver; the terminal wires were of gold. The effect was distinct; the extremity of the under gold wire became black, and only two or three bubbles of air arose from it; the extremity of the upper gold wire remained bright, and it was surrounded with many bubbles of air. A similar experiment was made on a strong solution of superacetate of lead, and with results which were similar; but the effects appeared to be produced with greater difficulty; they were not distinct till the fish had been much irritated, and seemed to put forth all its energy.

Mr. Walsh inferred from his experiments, that the two sides of the torpedo are in opposite electrical states*. The results just described appear to prove that its under surface corresponds to the zinc extremity of a voltaic battery, and its upper surface to the copper extremity.

To ascertain if they preserve the same relation to each other when the fish is made to act on the multiplier, and on the needle in the spiral, the following experiments were made. Successively at different times with the same fish, and also with different torpedos, comparative experiments were tried on the course of the needle in the multiplier when affected by the electricity of the fish, and by that of a couple of very small plates of copper and zinc immersed in a weak acid. In every instance, the wire communicating with the under surface of the torpedo was found to correspond in its effect with the zinc plate, and that with the upper surface with the copper plate; and whether one wire was in communication with the under surface of the fish, and the other with the upper, or the former with the zinc plate, and the latter with the copper plate, the deviation of the needle was in the same direction; its south pole turned to the east, and, of course, its north to the west: and if the lower

* Philosophical Transactions abridged, vol. xiii. p. 475.

contact wire was made the upper, the effect on the deviation of the needle was identical with a change of the plates.

I have found the same uniformity of result in the polarity imparted by the torpedo to a needle in the spiral wire; the extremity of it, nearest the under surface in the circle, has always acquired southern polarity, and the other extremity, of course, northern.

By connecting the spiral with the multiplier, and charging the former with as many small needles as it could hold, namely, eight, I ascertained that a single discharge of the electricity of an active fish moved the needle in the multiplier powerfully, and converted all the needles into magnets; and each of them I believe was as strong as if one only had been used.

Using two spirals charged with needles, one connected with one end of the multiplier, and the other with the other end, the effects of the discharge were similar to the preceding, both on the needle of the multiplier and on the needles in the spirals. In two instances, the needles in the spiral connected with the upper surface, were most powerfully magnetised; and in one instance, the effect was greatest on the needles in the lower spiral. In this last instance nine needles were acted on in the under spiral, and six in the upper; the fish which produced the effect, with one exception, was the smallest that I had ever used.

The preceding are the principal experiments which I have made on the electricity of the torpedo, using perfect conductors to convey it. I have, besides, instituted some in which the communication by perfect conductors was interrupted by imperfect ones; a few of these I shall briefly notice.

When I have held the contact-wires in the palm of each hand, wetted with salt water, and have touched with the fore-fingers the upper and under surface of a torpedo, I have felt its shocks distinctly; but in no instance when the multiplier has been connected with the wires, has it been affected; and when the spirals have been connected with them, I have once only seen the needles in them converted into magnets. This effect accompanied a very smart shock from a young active fish, about six inches long, just taken.

When the touching ends of the contact-wires have been covered with leather soaked in salt water, or with cotton thread, all the effects of the fish, as might be expected, were witnessed, as if these imperfect conductors had not intervened; the shock was felt by the hands holding the wires; needles in the spirals were magnetised, and the multiplier was moved.

When a cotton thread, soaked in salt water, or in a strong solution of salt, was interposed beyond the contact-wires, both the power of affecting the multiplier, and of giving polarity to the needle in the spiral, was arrested; and this was uniformly the result in a considerable number of experiments made with three different fishes, of which two were very active, and with perfect conductors, free of this interruption, produced both effects readily. But the power of giving a shock was not equally arrested; for on removing the multiplier and spirals, and holding with the wet fingers the wires attached to the moist cotton thread, the shock was several times distinctly felt on stimulating the fish. The space of cotton thread between the wires was about one tenth of an inch, and to secure its perfect humidity or wetness, it was inclosed in a glass tube, with corks at each end, through which the wires passed.

When the apparatus already described in noticing the chemical effects of the torpedo, was substituted for the wet cotton thread, the tubes being filled with a strong solution of salt, the multiplier was affected, and gas was given off at each of the points of the gold wires, and when steel needles were used, a fine current of gas rose from the point connected with the under contact-wire, and not a particle from the other point. In these experiments, there were interposed, at the same time, the chemical apparatus, one on each side, the spiral, one also on each side, and the multiplier intermediate, and there were necessarily many junctions of wires. I scarcely need add, that in an experiment made expressly to ascertain it, the shock of the fish was felt beyond the saline solution; for it had been previously proved, by the experiments of Mr. Walsh, that salt water, even in a long circuit of imperfect conductors, has the power of transmitting it.

2. *Observations on the Electrical Organs of the Torpedo, and on some parts of its structure connected with them.*

The peculiar columnar appearance of the electrical organs of the torpedo, their great proportional size, the vast proportion of nerve with which they are supplied, the manner in which the columns are sheathed in tendinous fibres, have been dwelt on by all inquirers who have paid any attention to this fish; but I am not acquainted with any attempt to ascertain, by experiment, what is the exact nature of the substance of these organs, or the peculiar structure of which they are composed.

When I have examined, with a single lens which magnifies more than two hundred times, a column of the electrical organs, it has not exhibited any regular structure; it has appeared as a homogeneous mass, with a few fibres passing into it in irregular directions, which were probably nervous fibres.

The specific gravity of the electrical organ, in comparison with that of parts of the fish decidedly muscular, is very low; including the upper and under boundary of skin, I have found it 1·026, to water as 1·000. The specific gravity of a portion of the abdominal muscles of the same full-grown fish, was 1·058, and that of the thick strong muscles of the back close to the spine 1·065.

The loss of weight which the electrical organ sustains by drying, is greater than I have observed in any other part of the fish. I shall give the results of one trial; the statement will convey an idea of the bulk of the different parts of the torpedo, as well as of the proportion of solid matter which they contain. The subject of the experiment, procured fresh from the fish-market at Rome, was eight inches long, and across the widest part five inches broad. Entire it weighed 2065 grains. It was carefully divided, and the different parts mentioned were found to weigh as follows, in their moist state:

	Grains.
Spleen	5·5
Pancreas	5·0
Testes	3·0
Kidneys	8·0
A pale cream-coloured oval body close to left kidney	0·25
A reddish oval body, like a gland, attached to the large intestine	0·5
Liver, with gall-bladder and ducts	105·0
Heart, and trunk of pulmonary artery	3·0
Gills, including branchial cartilages	53·0
Gullet	11·0
Stomach	65·0

	Grains.
Upper valvular intestine	29·0
Lower intestine	5·0
Electrical organs	302·0
Head, separated at first vertebra	165·0
Thorax, consisting of cartilaginous case and muscles, with pectoral fins attached	670·0
Abdomen, without its contents	440·0
Tail, separated just below the anus	195·0

By exposure to the heat of boiling water for about sixteen hours, the different parts were completely dried; their total weight was reduced to 322 grains, so that they had lost by drying 84·5 per cent.

	Grains.
The electrical organs now weighed	22
Head	25
Thorax	93
Abdomen	53
Tail	36
Liver (abounding in oil)	43
Residue, consisting of other organs and extract of fluids, which exuded during the drying	50

From the above loss of weight of the electrical organs in drying, they appear to consist of 7·28 matter *not evaporable* at 212° Fahr. and of 92·72 water, taking it for granted that the loss sustained is owing merely to the evaporation of the aqueous part. I lay stress on matter not evaporable, because I believe that the solid contents of the moist organs are less, and that the water which they contain holds in solution various substances.

This solution may be obtained by cutting the electrical organs into small pieces, and placing them in a funnel; the fluid part slowly separates. What I have thus collected was slightly turbid, of a very light fawn colour, just perceptibly acrid; it did not change the colour of turmeric or litmus paper; a cloudiness was occasioned by dropping into it a solution of nitrate of silver, which was not completely re-dissolved by aqua ammoniæ; it was copiously precipitated by acetate of lead, and a cloudiness was occasioned in it by nitrate of barytes and by corrosive sublimate. By evaporation, it afforded a residue which deliquesced partially on exposure to a moist atmosphere, and had an acrid and bitter saline taste. The exact proportion of this weak solution of animal and saline matters, I have not ascertained; and, indeed, it would be very difficult to determine it with any degree of accuracy, for only a small portion separates spontaneously, and if pressure be used, the fibres are broken, and the expressed fluid is mixed with a pulpy matter.

When the electrical organs of the torpedo are immersed in boiling water, they suddenly contract in all their dimensions, and the columns, from pentagonal, which they generally are, become circular. In my early experiments at Rome, they were rendered firmer by immersion for a few minutes, and the columns appeared to be tolerably distinctly fibrous and laminated, bringing to recollection the structure of the pile of ZAMBONI. Latterly I have not witnessed this effect; in a few seconds the tendinous fibres have been converted into jelly, and the columns have fallen asunder, having the appearance and consistence of a translucent, very soft mucilage. To what this difference of effect may be owing, I am at a loss to conceive; perhaps the Roman fish were older than the Maltese, or the aqueduct water at Rome may be harder than the rain cistern water of Malta.

On exposure to the air in a damp atmosphere, or by maceration in water, changing the water daily, the electrical organs undergo change more slowly than the parts distinctly muscular; in putrefaction and maceration they have less resemblance to muscular fibre than to tendinous fibre, which latter offers great resistance to both these processes. But I would not lay any stress on this quality of resistance, as it is vague, depending on circumstances which it is extremely difficult to appreciate, as every one must be convinced who has compared the different degrees of rapidity with which different orders of muscles in man and the larger mammalia undergo change from putrefaction and maceration; for instance, the slowness with which the muscular fibres of the stomach and intestines alter, and the rapidity of change of the fibres of the heart and thick muscles.

Quitting the organs of the dead fish, I shall now notice the few observations which I have made on them, before they have been deprived of their vitality.

The effect of the electricity of a small voltaic trough, the shock of which I could just perceive at the extremities of the moistened fingers, was very distinct on the voluntary muscles of a live torpedo just taken from the water; but it did not appear to affect in the least the electrical organs. I could not perceive the slightest contraction of them in whatever manner the wires were applied, not even when a minute portion of integument was removed, or when one of the wires was placed in contact with a fasciculus of the electrical nerves. Even after apparent death many of the parts decidedly muscular continued to contract under this stimulus, especially the muscles of the flank and the cross muscles of the inferior surface of the thorax and the heart; indeed this latter organ, two hours after it had been removed from the body, and had ceased to contract spontaneously, renewed its contractions under the galvanic influence. Other stimulants have been applied to the electrical organs, and with the same negative result. Even when punctured and incised, (a portion of their skin having been removed, which appears to be very sensitive,) no indications whatever were witnessed of their substance being either sensitive or contractile.

Reflecting on the facts and observations which I have just detailed, it appears to me very difficult to resist the conclusion, that the electrical organs of the torpedo are not muscular, but columns formed of tendinous and nervous fibres distended by a thin gelatinous fluid. Their situation too, surrounded by and exposed to the pressure of powerful muscles, shows that if condensation is required for the exercise of the electrical function, they may experience it without possessing any muscular fibres in their own substance. The arrangement of the muscles of the back and of the fins, and of the very powerful cross muscles situated between the under surfaces of the electrical organs, is admirably adapted to compress them. Without entering into any minute anatomical examination of these muscles and their uses, it is only necessary to compare them in the torpedo and in any other species of Ray, to be convinced that they are adequate to and designed for the effect mentioned.

Mr. Hunter, in his account of the torpedo *, describes the columns of the electrical organs as composed of cells containing a fluid, divided by their horizontal partitions, which he was able to count. This structure seems very probable, and in the specimens I dissected at Rome, I saw what I fancied an

* Phil. Trans. 1773.

approach to it; but I have never witnessed it in a satisfactory manner in the fresh fish. Mr. HUNTER inspected large fishes which had been preserved in spirits. The partitions of the columns in them might have been more visible, (supposing them to exist,) from the action of the spirit on the membrane, and from the greater size of the specimen; or they might have been formed after death, in the spirits, by a slow deposition of the animal matter contained in the columns.

Next to the nature of the substance of the electrical organs, the electrical nerves have occupied my attention. Their three great trunks have been accurately described by Mr. HUNTER; but this distinguished anatomist has very briefly noticed their distribution, which is curious, and deserving, I believe, of minuter investigation. I shall attempt little more than an outline of what I have observed in some dissections conducted with considerable care.

In examining the brain, proceeding from the anterior to the posterior portion, after passing the first, second, third, and fourth pair of nerves, or the olfactory, optic, motor and pathetic nerves of the eye, the fifth pair is seen issuing from the medulla oblongata, or posterior tubercle of the brain *. After quitting the cranium, (confining the description to one side,) it proceeds upwards, divides into two large branches, which go to clusters of mucous glands situated in the front of the head and at the anterior margin of the electrical organs, and they appear to be confined to these parts. The next pair, the first electrical, rises close to the preceding, just behind it, and in passing out of the cranium is firmly connected with it; and also where it passes out, a portion of medullary matter proceeds from it into a cavity filled with fluid, in the cartilage adjoining, which there is reason to consider as the cavity of the organ of hearing, and the medullary matter the nerve of hearing. After this, in passing outwards, it divides into three small branches and two large ones. Of the former, one proceeds to the gills, another to the adjoining muscles, and the third to the mouth. Of the great branches, one ascends, and sweeping round the margin of the electrical organ is distributed to the mucous glands which abound there, and where some of its twigs inosculate with twigs of the former nerve. The other great branch, which is inferior, enters the electrical

* The nerves of the fourth pair are so very small and tender, that it is difficult to demonstrate them, excepting in old and large torpedos.

organ and ramifies through its superior portion. The next pair of nerves, the second electrical, rises a little beyond the preceding. On leaving the cranium it divides into two great branches; these, with the exception of nervous twigs supplying the adjoining branchiæ, are distributed entirely in the substance of the electrical organ and ramify in all directions through its middle portion. The third electrical rises close to the last, divided only by a very thin plate of cartilage; the principal portion of it passes into the electrical organ and ramifies through its inferior part, and besides, gives off three small branches, which are sent to the adjoining branchiæ, to the gullet and stomach, and to the tail. The branch which supplies the stomach appears to be the principal nerve of this organ; it descends along the inner and inferior portion of the gullet, and ramifies in the direction of the great arch of the stomach. The caudal branch descends in a straight line under the peritoneal lining of the abdomen, and under the spinal nerves, without giving off a single branch till it reaches the tail, in the muscular substance of which it is lost.

I have not yet been able to discover any connexions of the electrical nerves, besides those pointed out. It is an interesting fact that the gastric nerves are derived from them. Perhaps superfluous electricity, when not required for the defence of the animal, may be directed to this organ to promote digestion. In the instance of a fish which I had in my possession alive many days, and which was frequently excited to give shocks, digestion appeared to have been completely arrested; when it died, a small fish was found in its stomach, much in the same state as when it was swallowed;—no portion of it had been dissolved.

Though I have not found the temperature of the electrical organs higher than that of other parts of the fish, or the temperature of the fish generally different from that of the water in which it has been confined, yet it seems probable that as the branchiæ are liberally supplied with twigs of the electrical nerves, there may be some connexion between its respiratory and electrical function; and I venture to offer the conjecture, that by means of its electricity it may have the power of decomposing water and of supplying itself with air, when lying covered with mud or sand in situations in which it is easy to conceive pure air may be deficient; and, in my experiments, I have often fancied that I have witnessed something of the kind,—after repeated discharges of its electricity, the margin of the pectoral fins has acquired an appearance as if very minute bubbles of air were generated in it and confined.

Besides the electrical nerves there is a plexus of nerves deserving attention, of great magnitude, formed by the junction of the anterior and posterior, or upper and under cervical nerves; of the former about seventeen on each side, of the latter about fourteen *. It makes its appearance as one trunk just below the transverse cartilage which is interposed between the thorax and abdomen. It sends a recurrent branch to the muscles and skin of the under surface of the thorax; but its main trunk ascends along the inner margin of the pectoral fin, and is distributed through it. On this plexus the sentient and motive powers of the parts connected with the electrical organs seem to depend.

The electrical nerves at their origin are enveloped in a very thick fibrous sheath. As the branches subdivide in the substance of the organ, the neurilema becomes thin and semitransparent. On examining a minute branch with a powerful lens, its internal or medullary substance is not seen in a continuous line, but interrupted, as it were dotted, as if the sheath contained a succession of portions with a little space between each.

In the anatomical structure of the torpedo, the mucous system forms a very conspicuous part; it consists of several clusters and chains of glands distributed chiefly around the electrical organs, at different depths beneath the cutis; and of strong transparent vessels, of various lengths and sizes, opening externally in the skin, for the purpose of pouring out the thick mucus secreted by the glands, and destined for lubricating the surface. This system has not been noticed by Mr. HUNTER, and it has been but imperfectly described by LORENZINI †. Though it is not peculiar to the torpedo, it is much more strongly developed in this fish than in any other species of Ray with which I am acquainted, and the situation of the glands and the distribution of their vessels are different. Whether it is concerned in any way with the electrical function of the torpedo is deserving of consideration. That it is thus concerned in some

* Towards the origin of the spinal cord there is a small space, from the under surface of which six nerves arise, three on each side; but none from the upper surface, whence the difference of number noticed in the text.

† Osservazioni intorno alle Torpedini fatte da STEFFANO LORENZINI Fiorentino; 4to, Firenze, 1678.

way, seems to be indicated, not only by the situation of these glands, between and surrounding the electrical organs, but still more so by the manner in which they are supplied with nerves, either from the first electrical, or from the fourth pair, which is connected with that nerve. As the thick semitransparent mucus which these glands secrete, is probably a better conductor of electricity than the skin alone, or than salt water, this mucous system may serve as a medium of communication between the electrical organs *. I shall mention some results which are favourable to this idea. When one contact-wire was placed underneath an active torpedo, just anterior to the mouth, and the other at the extremity of the back, out of the circle of the mucous apparatus, the shock of the fish had no effect either on the multiplier, or on needles in the spiral. But when the upper contact-wire was made to touch the back of one electrical organ, the under wire being placed as in the preceding experiment, then both effects were simultaneously produced; and they were also produced when the two wires were brought very close to each other, one being kept as before, and the other moved immediately over it, in front, each about a quarter of an inch from the margin, and not connected with the electrical organs, except by the common integuments and this mucous apparatus. It is worthy of remark, that this little space in front, intermediate between the two electrical organs, so abounding in glandular structure, and so amply provided with nerves, appears from experiment to possess very little sensibility; this was denoted in these trials, in which the fish, though exquisitely sensible of pressure on the margin of the pectoral fins, seemed indifferent to it when applied in front,—as if the fourth pair, which supplies this part, were destined rather for secretion than for the purpose of sensation.

The connexion between the electrical nerves and the mucous system, even more remarkable than between the former and the stomach, may perhaps warrant the conjecture, that the electrical function may not only be aided by, but also aid the secretion of mucus; and that, as was supposed in regard to the stomach, when the electricity is not employed in repelling an enemy in violent efforts, it may be exercised gently in increasing the activity of these glands.

* Some comparative experiments which I have made seem to indicate that the mucus of the torpedo is a better conductor than sea water; when the hands were smeared with this mucus, or when a portion of the fresh skin of a torpedo, with its natural mucus adhering to it, was wrapped round the ends of the contact-wires by which they were held, the shock received appeared to be stronger than usual.

In support of this notion it may be mentioned, that in the fishes which I have kept, in which digestion was arrested, the secretion also of mucus appeared to be stopped or considerably diminished.

Mr. HUNTER, from the examination of a torpedo whose vascular system was injected, states that the electrical organs of this fish are abundantly supplied with blood-vessels. From what I have witnessed in the living fish and the fresh fish recently dead, I am compelled to conclude that the quantity of blood which circulates through them is very inconsiderable. The blood-vessels which pass into them with the electrical nerves are small; the organs are colourless, and very few branches carrying red blood are perceptible extending through them. The integuments of these organs, and the pectoral fins, and lateral clusters of mucous glands are indeed abundantly supplied with blood-vessels. The contrast of the vascularity of these parts and of the electrical organs, is so strongly marked as to suggest the idea that the latter can possess very little ordinary vital activity, and that in accordance with the common analogies of living parts they must be rather passive than active.

3. *Concluding Remarks.*

The experiments which I have detailed on the electricity of the torpedo confirm those of Mr. WALSH made in 1772, showing its resemblance to common electricity. They moreover show, that, like common electricity and voltaic electricity, it has the power of giving magnetic polarity to iron, and of producing certain chemical changes. In these its general effects it does not seem to be essentially peculiar, but as much allied to voltaic electricity as voltaic electricity is to atmospheric, or atmospheric electricity is to that produced by contact or friction.

When we examine more minutely its phenomena or effects, in relation to these different kinds, or varieties of electricity, certain points of difference occur.

Compared with voltaic electricity, its effect on the multiplier is feeble; its power of decomposing water and metallic solutions is inconsiderable; but its power of giving a shock is great, and so also is its power of magnetising iron.

Compared with common electricity, it has a power of affecting the multiplier, which under ordinary circumstances common electricity does not exhibit; its chemical effects are more distinct; its power of magnetising iron, and giving a shock appear very similar*; its power of passing through air is infinitely less, as is also (if it possess it at all) its power of producing heat and light.

There are other points of difference; I allude chiefly to the results obtained in the experiments already described, in which the metallic communication was interrupted by a strong solution of salt. In this instance the full power of the fish appeared to pass; water was decomposed, a shock was received, needles were magnetised, and the multiplier was affected. When the same experiment was made on the electricity excited by the small voltaic combination of a single plate of copper and zinc, each less than an inch in length, and half an inch in breadth, immersed in an acid, neither water was decomposed nor was the multiplier affected. When it was made on the electricity of the electrical machine by means of a Leyden jar, all the effects were witnessed excepting the motion of the multiplier, and the order of succession of poles in the needles magnetised in the spirals.

How are these differences to be explained? Do they admit of explanation similar to that advanced by Mr. CAVENDISH in his theory of the torpedo; or may we suppose, according to the analogy of the solar ray, that the electrical power, whether excited by the common machine, or by the voltaic battery, or by the torpedo, is not a simple power, but a combination of powers, which may occur variously associated, and produce all the varieties of electricity with which we are acquainted?

As regards the mode of production, or the cause of the electricity of the torpedo, it is unavoidably enveloped in great mystery. Like animal heat, and the light emitted by certain animals, and, I may add, like the secretions of animals generally, it appears to be a result of living action, and connected with a peculiar and unusually complicated organization. All the attempts I have made to obtain electrical excitement in the fish, after it has been deprived of life, have been in vain.

The observations which I have detailed relating to its anatomical structure

* There is this difference when two spirals are used, one connected with the inside of a Leyden jar, and the other with the outside,—a needle in each similarly placed acquires opposite polarities, the north pole in one being where the south pole is in the other; whilst in the instance of the torpedo they accord, so that a line of needles passing from one side of the electrical organ to the other would exhibit a succession of similar poles.

show a complicated adaptation of parts, nerves of unusual magnitude ramifying between apparently insensible columns, saturated with a bad conducting fluid; muscles surrounding these columns and fitted to compress them; and a system of mucous glands and tubes adjoining, well adapted to be the medium of electrical communication between the two organs and their opposite sides.

When we consider this structure, it is an easy matter to trace rude analogies between it and the pile of Volta,—or between its columns and a battery of Leyden jars, such a battery as was formed by Mr. Cavendish for imitating the electricity of the torpedo, composed of a large number of jars of very thin glass, feebly charged. But these analogies seem to help very little, if at all, towards the solution of the great difficulty; the question remains unanswered, What is the cause or source of the electricity? Here analogy fails entirely; none of the ordinary modes of excitement appear to be at all concerned; neither friction, nor chemical action, nor change of temperature, nor change of form. Let us consider for a moment a small torpedo in an active state. The smallest which I have employed in my experiments weighed only 410 grains, and contained only 48 grains of solid matter; its electrical organs weighed only 150 grains, and contained only 14 grains of solid matter,—for to this they were reduced by thorough drying. Yet this small mass of matter gave sharp shocks, converted needles into magnets, affected distinctly the multiplier, and acted as a chemical agent, effecting the decomposition of water, &c. A priori, how inconceivable that these effects could be so produced! This fish was about ten days in my possession, during the whole of which time it ate nothing, and its bulk was hardly sensibly altered; and every day it exercised its electrical powers, and to the last they appeared almost as energetic as when it was fresh from the sea. This adds, if possible, to the difficulty of explanation. That this mysterious function is intimately connected with the nerves, and in a manner more striking than all ordinary secretions, is manifest. Beyond this conclusion all is darkness; we have not, as we have in the doctrine of animal heat, advanced another step; we have not been able to connect it with changes in the electrical organs as analogous to known sources of electricity, as the changes which take place in the lungs in respiration are to the known sources of heat or combustion. The attainment of this step is a great desideratum; and beyond it, probably, we shall never be able to proceed.

Without reverting to the conjectures which, in passing, I have offered on the subserviency of the electricity of the torpedo in an auxiliary manner to digestion, respiration and the secretion of mucus, I may remark that its chief use appears to be for purposes of defence, to guard it from its enemies, rather than to enable it, according to vulgar opinion, to destroy its prey and provide itself with food. Small smelts, which I kept in the same vessel with torpedos, appeared to have no dread of them, and I believe they fed on their mucus; and, in an experiment in which, in a confined space, I excited an active torpedo to give shocks, a smelt which was with it was evidently alarmed, and once or twice, when exposed to the shock, leapt nearly out of the vessel; but was not injured by the electricity. In confirmation I may add, that the electric power of the young fish, which most requires it for its protection, is proportionally very much greater than that of the old, and can be exerted without exhaustion and loss of life much more frequently. After a very few shocks most of the old fish which I have had, have become languid, and have died in a few hours, whilst young ones from three to six inches long have remained active during ten or fifteen days, and have never failed to show the effects I have described.

Before concluding, I could wish to explain the difference of the results of the experiments made by my brother, and of those I have detailed; but I must confess my inability to do it in a satisfactory manner. Knowing his great accuracy in experimenting, I am confident that their failure, or negative results must have depended on some circumstance deserving of investigation, and which I hoped by inquiry to discover.

I once imagined that they might have depended on the kind, or variety of fish employed. But the experiments I have made with a view to this have not borne me out in the conjecture. I have tried very many different specimens of the two varieties of the torpedo most common in the Mediterranean, the mottled and the spotted, called at Rome Tremola and Occhiatella, without perceiving any distinguishable difference of electrical effect.

It appeared possible that the sex of the fish might have some influence on its electricity, or that in the instance of the female fish, the state of the ovaries whether pregnant or not, might have an influence. But observation does not confirm the probability of either opinion. I have used, I believe, as many males as females in my experiments, and the results with both have been very similar. Though the great breeding season appears to be in spring, females containing eggs variously advanced are to be met with occasionally both in summer and autumn, and comparing their electricity with that of barren or unimpregnated fish, I cannot say I can be sure of any well marked difference; if there were any difference, the electricity of the former was most powerful.

I have sometimes imagined that the age of the torpedo might modify its electrical effects, and that the older the fish is, the more analogous it is to the Leyden jar, and the younger it is, the more analogous it is to the voltaic battery. Many comparative trials of fishes of different ages appeared to favour this notion. But I soon had an opportunity of ascertaining that it is not universally true; the largest torpedo I have yet obtained disproved it. This fish, a female Tremola, was sixteen inches and a half long, and seven inches and a half broad, in a languid state, having been caught several hours and kept in a small quantity of water; yet a single discharge of its electricity produced a complete revolution of the needle in the multiplier, magnetised feebly four bars of steel weighing seventy-five grains, and magnetised powerfully two small sewing-needles; one of which acquired the power of supporting three times its weight of iron. Nor were the chemical effects produced by this fish less distinct.

Besides the preceding, other probable causes of the difference of results I could wish to explain might be pointed out; but as I have not had an opportunity of submitting them to the proof of experiment, it would be trespassing on the time of the Society to bring them forward.

Malta, September 30th, 1831.