

XII. *An Account of some Attempts to imitate the Effects of the Torpedo by Electricity. By the Hon. Henry Cavendish, F. R. S.*

R. Jan. 18,
1775.

ALTHOUGH the proofs brought by Mr. WALSH, that the phenomena of the torpedo are produced by electricity, are such as leave little room for doubt; yet it must be confessed, that there are some circumstances, which at first sight seem scarcely to be reconciled with this supposition. I propose, therefore, to examine whether these circumstances are really incompatible with such an opinion; and to give an account of some attempts to imitate the effects of this animal by electricity.

It appears from Mr. WALSH's experiments, that the torpedo is not constantly electrical, but hath a power of throwing at pleasure a great quantity of electric fluid from one surface of those parts which he calls the electrical organs to the other; that is, from the upper surface to the lower, or from the lower to the upper, the experiments do not determine which; by which means a shock is produced in the body of a person who makes any part of the circuit which the fluid takes in its motion to restore the equilibrium.

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One of the principal difficulties attending the supposition, that these phenomena are produced by electricity, is, that a shock may be perceived when the fish is held under water; and in other circumstances, where the electric fluid hath a much readier passage than through the person's body. To explain this, it must be considered, that when a jar is electrified, and any number of different circuits are made between its positive and negative side, some electricity will necessarily pass along each; but a greater quantity will pass through those in which it meets with less resistance, than those in which it meets with more. For instance, let a person take some yards of very fine wire, holding one end in each hand, and let him discharge the jar by touching the outside with one end of the wire, and the inside with the other; he will feel a shock, provided the jar is charged high enough; but less than if he had discharged it without holding the wire in his hands; which shews, that part of the electricity passes through his body, and part through the wire. Some electricians indeed seem to have supposed that the electric fluid passes only along the shortest and readiest circuit; but besides that such a supposition would be quite contrary to what is observed in all other fluids, it does not agree with experience. What seems to have led to this mistake is, that in discharging a jar by a wire held in both hands, as in the above mentioned experiment, the person will feel no shock, unless either the wire is very long and slender, or the jar is very large and highly charged. The reason of which is, that metals conduct fur-

surprizingly better than the human body, or any other substance I am acquainted with; and consequently, unless the wire is very long and slender, the quantity of electricity which will pass through the person's body will bear so small a proportion to the whole, as not to give any sensible shock, unless the jar is very large and highly charged.

It appears from some experiments, of which I propose shortly to lay an account before this Society, that iron wire conducts about 400 million times better than rain or distilled water; that is, the electricity meets with no more resistance in passing through a piece of iron wire 400,000,000 inches long, than through a column of water of the same diameter only one inch long. Sea-water, or a solution of one part of salt in 30 of water, conducts 100 times, and a saturated solution of sea salt about 720 times better than rain water.

To apply what hath been here said to the torpedo; suppose the fish by any means to convey in an instant a quantity of electricity through its electric organs, from the lower surface to the upper, so as to make the upper surface contain more than its natural quantity, and the lower less; this fluid will immediately flow back in all directions, part over the moist surface, and part through the substance of its body, supposing it to conduct electricity, as in all probability it does, till the equilibrium is restored: and if any person hath at the time one hand on the lower surface of the electric organs, and the other on the upper, part of the fluid will pass through his body.

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Moreover, if he hath one hand on one surface of an electric organ, and another on any other part of its body, for instance the tail, still some part of the fluid will pass through him, though much less than in the former case; for as part of the fluid, in its way from the upper surface of the organ to the lower, will go through the tail, some of that part will pass through the person's body. Some fluid also will pass through him, even though he does not touch either electric organ, but hath his hands on any two parts of the fishes body whatever, provided one of those parts is nearer to the upper surface of the electric organs than the other. On the same principle, if the torpedo is immersed in water, the fluid will pass through the water in all directions, and that even to great distances from its body, as is represented in fig. 1. where the full lines represent the section of its body, and the dotted lines the direction of the electric fluid; but it must be observed, that the nearer any part of the water is to the fishes body, the greater quantity of fluid will pass through it. Moreover, if any person touches the fish in this situation; either with one hand on the upper surface of an electric organ, and the other on the lower, or in any other of those manners in which I supposed it to be touched when out of the water; some fluid will pass through his body; but evidently less than when the animal is held in the air, as a great proportion of the fluid will pass through the water: and even some fluid will pass through him, though he does not touch the fish at all; but only holds

his hands in the water, provided one hand is nearer to the upper surface of the electric organs than the other.

The second difficulty is, that no one hath ever perceived the shock to be accompanied with any spark or light, or with the least degree of attraction or repulsion. With regard to this, it must be observed, that when a person receives a shock from the torpedo, he must have formed the circuit between its upper and lower surface before it begins to throw the electricity from one side to the other; for otherwise the fluid would be discharged over the surface of the fishes body before the circuit was completed, and consequently the person would receive no shock. The only way, therefore, by which any light or spark could be perceived, must be by making some interruption in the circuit. Now Mr. WALSH found, that the shock would never pass through the least sensible space of air, or even through a small brass chain. This circumstance, therefore, does not seem inconsistent with the supposition that the phenomena of the torpedo are owing to electricity; for a large battery will give a considerable shock, though so weakly charged that the electricity will hardly pass through any sensible space of air; and the larger the battery is, the less will this space be. The principle on which this depends will appear from the following experiments.

I took several jars of different sizes, and connected them to the same prime conductor, and electrified them in a given degree, as shewn by a very exact electrometer; and then found how near the knobs of an instrument

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in the nature of Mr. LANE's electrometer must be approached, before the jars would discharge themselves. I then electrified the same jars again in the same degree as before, and separated all of them from the conductor except one. It was found, that the distance to which the knobs must be approached to discharge this single jar was not sensibly less than the former. It was also found, that the divergence of the electrometer was the same after the removal of the jars as before, provided it was placed at a considerable distance from them: from which last circumstance, I think we may conclude, that the force with which the fluid endeavours to escape from the single jar is the same as from all the jars together.

It appears, therefore, that the distance to which the spark will fly is not sensibly affected by the number or size of the jars, but depends only on the force with which they are electrified; that is, on the force with which the fluid endeavours to escape from them: consequently, a large jar, or a great number of jars, will give a greater shock than a small one, or a small number, electrified to such a degree, that the spark shall fly to the same distance; for it is well known, that a large jar, or a great number of jars, will give a greater shock than a small one, or a small number, electrified with the same force.

In trying this experiment, the jars were charged very weakly, inasmuch that the distance to which the spark would fly was not more than the 20th of an inch. The electrometer I used consisted of two straws, 10 inches long, hanging parallel to each other, and turning at one

end on steel pins as centers, with cork balls about $\frac{1}{4}$ of an inch in diameter fixed on the other end. The way by which I estimated the divergence of these balls, was by seeing whether they appeared to coincide with parallel lines placed behind them at about ten inches distance; taking care to hold my eye always at the same distance from the balls, and not less than thirty inches off. To make the straws conduct the better, they were gilded, which causes them to be much more regular in their effect. This electrometer is very accurate; but can be used only when the electricity is very weak. It would be easy, however, to make one on the same principle, which should be fit for measuring pretty strong electricity.

The instrument by which I found to what distance the spark would fly is represented in fig. 2.; it differs from Mr. LANE's electrometer no otherwise than in not being fixed to a jar, but made so as to be held in the hand. The part ABCDEFGKLM is of baked wood, the rest of brass; the part GKL being covered with tin-foil communicating with the brass work at FG; and the part ABM being also covered with a piece of tin-foil, communicating with the brass work at CD.

I next took four jars, all of the same size; electrified one of them to a given degree, as shewn by the electrometer; and tried the strength of the shock which it gave; and found also to what distance the spark would fly. I then took two of the jars, electrified them in the same degree as before, and communicated their electricity to the two remaining. The shock of these four jars united,

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was rather greater than that of the single jar; but the distance to which the spark would fly was only half as great.

Hence it appears, that the spark from four jars, all of the same size, will not dart to quite half so great a distance as that from one of those jars electrified in such a degree as to give a shock of equal violence; and consequently the distance to which the spark will fly is inversely in a rather greater proportion than the square root of the number of jars, supposing them to be electrified in such a degree that the shock shall be of a given strength. It must be observed, that in the last mentioned experiment, the quantity of electric fluid which passed through my body was twice as great in taking the shock of the four jars, as in taking that of the single one; but the force with which it was impelled was evidently less, and I think we may conclude, was only half as great. If so, it appears that a given quantity of electricity, impelled through our body with a given force, produces a rather less shock than twice that quantity, impelled with half that force; and consequently, the strength of the shock depends rather more on the quantity of fluid which passes through our body, than on the force with which it is impelled.

That no one could ever perceive the shock to be accompanied with any attraction or repulsion, does not seem extraordinary; for as the electricity of the torpedo is dissipated by escaping through or over the surface of its body, the instant it is produced, a pair of pith balls

suspended from any thing in contact with the animal will not have time to separate, nor will a fine thread hung near its body have time to move towards it, before the electricity is diffipated. Accordingly I have been informed by Dr. PRIESTLEY, that in discharging a battery he never could find a pair of pith balls suspended from the discharging rod to separate. But, besides, there are scarce any pith balls so fine, as to separate when suspended from a battery so weakly electrified that its shock will not pass through a chain, as is the case with that of the torpedo.

In order to examine more accurately, how far the phenomena of the torpedo would agree with electricity, I endeavoured to imitate them by means of the following apparatus. *ABCFGDE* fig. 3. is a piece of wood, the part *ABCDE* of which is cut into the shape of the torpedo, and is $16\frac{3}{4}$ inches long from *A* to *D*, and $10\frac{3}{4}$ broad from *B* to *E*; the part *CFGD* is 40 inches long, and serves by way of handle. *MNmm* is a glass tube let into a groove cut in the wood. *ww* is a piece of wire passing through the glass tube, and foldered at *w* to a thin piece of pewter *rr* lying flat on the wood, and intended to represent the upper surface of the electric organs. On the other side of the wood there is placed such another glass tube, not represented in the figure, with a wire passing through it, and foldered to another piece of pewter of the same size and shape as *rr* intended to represent the lower surface of those organs. The whole part *ABCDE* is covered with a piece of sheep's skin leather.

In making experiments with this instrument, or artificial torpedo as I shall call it, after having kept it in water of about the same saltness as that of the sea, till thoroughly soaked, I fastened the end of one of the wires, that not represented in the drawing for example, to the negative side of a large battery, and when it was sufficiently charged, touched the positive side with the end of the wire *ww*; by which means the battery was discharged through the torpedo: for as the wires were inclosed in glass tubes, which extended about an inch beyond the end of the wood *FG* no electricity could pass from the positive side of the battery to the negative, except by flowing along the wire *ww* to the pewter *rr*, and thence either through the substance of the wood, or along the wet leather, to the opposite piece of pewter, and thence along the other wire to the negative side. When I would receive a shock myself, I employed an assistant to charge the battery, and when my hands were in the proper position, to discharge it in the above mentioned manner by means of the wire *ww*. In experiments with this torpedo under water, I made use of a wooden trough; and as the strength of the shock may, perhaps, depend in some measure on the size of the trough, and on the manner in which the torpedo lies in it, I have in fig. 4. given a vertical section of it; the torpedo being placed in the same situation as in the figure. *ABCDE* is the trough; the length *BC* is 19 inches; the depth *AB* is 14; and the breadth is 13; consequently, as the torpedo is two inches thick in the thickest part, there is about

$5\frac{1}{2}$ inches distance between its sides and those of the trough.

The battery was composed of 49 jars, of extremely thin glass, disposed in 7 rows, and so contrived that I could use any number of rows I chose. The outsides of the jars were coated with tinfoil; but as it would have been very difficult to have coated the insides in that manner, they were filled with salt water. In a battery to answer the purpose for which this was intended, it is evidently necessary that the metals serving to make the communications between the different jars should be joined quite close: accordingly care was taken that the contacts should be made as perfect as possible. I find, by trial, that each row of the battery contains about $15\frac{3}{4}$ times as much electricity, when both are connected to the same prime conductor, as a plate of crown glass, the area of whose coating is 100 square inches, and whose thickness is $\frac{55}{1000}$ of an inch; that is, such that one square foot of it shall weigh 10 oz. 12 pwts.; and consequently, the whole battery contains about 110 times as much electricity as this plate^(a).

The way by which this was determined, and which, I think, is one of the easiest methods of comparing the quantity of electricity which different batteries will re-

(a) I find, by experiment, that the quantity of electricity which coated glass of different shapes and sizes will receive with the same degree of electrification, is directly as the area of the coating, and inversely as the thickness of the glass; whence the proportion which the quantity of electricity in this battery bears to that in a glass or jar of any other size, may easily be computed.

ceive with the same degree of electrification, was this: First of all, supposing a jar or battery to be electrified till the balls of the abovementioned electrometer separated to a given distance, I found how much they would separate when the quantity of electricity in that jar or battery was reduced to one-half. To do this, I took two jars, as nearly equal as possible, and electrified one of them till the balls separated to a given degree, and then communicated its electricity to the other; and observed to what distance the balls separated after this communication. It is plain, that if the jars were exactly equal, this would be the distance sought for; as in that case the quantity of electricity in the first jar would be just half as much after the communication as before; but as I could not be sure that they were exactly equal, I repeated the experiment by electrifying the second jar, communicating its electricity to the first, and observing how far the balls separated; the mean between these two distances will evidently be the degree of separation sought, though the jars were not of the same size. Having found this, I electrified one row of the battery till the balls separated to the first distance, and repeatedly communicated its electricity to the plate of coated crown glass, taking care to discharge the plate each time before the communication was made, till it appeared by the electrometer, that the quantity of electricity in that row was reduced to one half. I found it necessary to do this between 11 or 12 times, or $11\frac{1}{4}$ times as I estimate it. Whence the quantity of electric fluid in the row may be thus determined.

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Let the quantity in the plate be to that in the row as x to 1; it is plain, that the electricity in the row will be diminished each time it is communicated to the plate, in the proportion of 1 to $1+x$, and consequently after being communicated $1\frac{1}{4}$ times will be reduced in the proportion

of 1 to $\overline{1+x}^{1\frac{1}{4}}$; therefore, $\overline{1+x}^{1\frac{1}{4}}=2$; and $1+x=\overline{2}^{\frac{1}{1\frac{1}{4}}}$.

Whence the value of x may easily be found by logarithms. But the readiest way of computing it, and which is exact enough for the purpose, is this: multiply the number of times which you communicated the electricity of the row to the plate, by 1,444; and from the product subtract the fraction $\frac{1}{2}$; the remainder is equal to $\frac{1}{x}$, or the number of times by which the electricity in the row exceeds that in the plate.

The way by which I estimated the strength of the charge given to the battery, was taking a certain number of jars, and electrifying them till the balls of the electrometer separated to a given distance, and then communicating their electricity to the battery. This method proved very convenient; for by using always the same jars, I was sure to give always the same charge with great exactness; and by varying the number and size of the jars, I could vary the charge at pleasure, and besides could estimate pretty nearly the proportion of the different charges to each other. It was also the only convenient method which occurred to me; for I could not have done it conveniently by charging the whole battery till an electrometer suspended from it separated

parated to a given distance; because in most of the experiments the electricity was so weak, that a pair of fine pith balls suspended from the battery would separate only to a very small distance; and counting the number of revolutions of the electrical machine is a very fallacious method.

I found, upon trial, that though a shock might be procured from this artificial torpedo, while held under water, yet there was too great a disproportion between its strength, when received this way, and in air; for if I placed one hand on the upper, and the other on the lower surface of the electric organs, and gave such a charge to the battery, that the shock, when received in air, was as strong as, I believe, that of the real torpedo commonly is; it was but just perceptible when received under water. By increasing the charge, indeed, it became considerable; but then this charge would have given a much greater shock out of water than the torpedo commonly does.

The water used in this experiment was of about the same degree of saltness as that of the sea; that being the natural element of the torpedo, and what Mr. WALSH made his experiments with. It was composed of one part of common salt dissolved in 30 of water, which is the proportion of salt usually said to be contained in sea water. It appeared also, on examination, to conduct electricity not sensibly better or worse than some sea water procured from a mineral water warehouse. It is remarkable, that if I used fresh water instead of salt, the shock seemed very little weaker, when

received under water than out; which not only confirms what was before said, that salt water conducts much better than fresh; but, I think, shews, that the human body is also a much better conductor than fresh water: for otherwise the shock must have been much weaker when received under fresh water than in air.

As there appeared to be too great a disproportion between the strength of the shock in water and in air, I made another torpedo, exactly like the former, except that the part ABCDE instead of wood was made of several pieces of thick leather, such as is used for the soles of shoes, fastened one over the other, and cut into the proper shape; the pieces of pewter being fixed on the surface of this, as they were on the wood, and the whole covered with sheep skin like the other. As the leather, when thoroughly soaked with salt water, would suffer the electricity to pass through it very freely, I was in hopes that I should find less difference between the strength of the shock in water and out of it, with this than with the other. For suppose that in receiving the shock of the former torpedo under water, the quantity of electricity which passed through the wood and leather of the torpedo, through my body, and through the water, were to each other as T , B , and w ; the quantity of electricity which would pass through my body, when the shock was received under water, would be to that which would pass through it, when the shock was received out of wa-

ter, as $\frac{B}{B+T+w}$ to $\frac{B}{B+T}$; as in the first case, the quantity

which would pass through my body would be the

$\frac{B}{B+T+W}$ part of the whole; and in the latter the $\frac{B}{B+T}$ part.

Suppose now, that the latter torpedo conducts N times better than the former; and consequently, that in receiving its shock under water, the quantity of electricity which passes through the torpedo, through my body, and through the water, are to each other as NT , B , and w ; the quantity of electricity which will now pass through my body, when the shock is received under water, and

out of water, will be to each other as $\frac{B}{B+NT+W}$ to $\frac{B}{B+NT}$;

which two quantities differ from each other in a less proportion than $\frac{B}{B+T+W}$ and $\frac{B}{B+T}$: consequently, the readier the body of the torpedo conducts, the greater charge will it require to give the same shock, either in water or out of it; but the less will be the difference between the strength of the two shocks. It should be observed, that this alteration, so far from making it less resembling the real torpedo, in all probability makes it more so; for I see no reason to think, that the real torpedo is a worse conductor of electricity than other animal bodies; and the human body is at least as good, if not a much better conductor than this new torpedo.

The event answered my expectation; for it required about three times as great a charge of the battery, to give the same shock in air, with this new torpedo as with the former; and the difference between its strength when

received under water and out of it, was much less than before, and perhaps not greater than in the real torpedo. There is, however, a considerable difference between the feel of it under water and in air. In air it is felt chiefly in the elbows; whereas, under water, it is felt chiefly in the hands, and the sensation is sharper and more disagreeable. The same kind of shock, only weaker, was felt if, instead of touching the sides, I held my hands under water at two or three inches distance from it.

It is remarkable, that I felt a shock of the same kind, and nearly of the same strength, if I touched the torpedo under water with only one hand, as with both. Some gentlemen who repeated the experiment with me thought it was rather stronger. This shews, that the shock under water is produced chiefly by the electricity running through one's hand from one part to the other; and that but a small part passes through one's body from one hand to the other. The truth of this will appear with more certainty from the following circumstance; namely, that if I held a piece of metal, a large spoon for instance, in each hand, and touched the torpedo with them instead of my hands, it gave me not the least shock when immersed in water; though when held in air, it affected me as strongly if I touched it with the spoons as with my hands. On increasing the charge, indeed, its effect became sensible: and as well as I could judge, the battery required to be charged about twelve times as high to give the same shock when the torpedo was touched with the spoons under water as out of it. It must be observed, that in trying
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this experiment, as my hands were out of water, I could be affected only by that part of the fluid which passed through my body from one hand to the other.

The following experiments were made with the torpedo in air. If I stood on an electric stool, and touched either surface of the electric organs with one hand only, I felt a shock in that hand; but scarcely so strong as when touching it in the same manner under water. If I laid a hand on one surface of the electric organs, and with the other touched the tail, I felt a shock; but much weaker than when touching it in the usual manner; that is, with one hand on the upper surface of those organs, and the other on the lower. If I laid a thumb on either surface of an electric organ, and a finger of the same hand on any part of the body, except on or very near the same surface of the organs, I felt a small shock.

In all the foregoing experiments, the battery was charged to the same degree, except where the contrary is expressed: they all seem to agree very well with Mr. WALSH's experiments.

Mr. WALSH found, that if he inclosed a torpedo in a flat basket, open at the top, and immersed it in water to the depth of three inches, and while the animal was in that situation, touched its upper surface with an iron bolt held in one hand, while the other hand was dipped into the water at some distance, he felt a shock in both of them. I accordingly tried the same experiment with the artificial torpedo; and if the battery was charged about six times as high as usual, received a small shock in each hand

hand^(a). No sensible difference could be perceived in the strength, whether the torpedo was inclosed in the basket or not. The trough in which this experiment was tried was 36 inches long, $14\frac{1}{2}$ broad, and 16 deep; and the distance of that hand which was immersed in the water from the electric organs of the torpedo, was about 14 inches. As it was found necessary to charge the battery so much higher than usual, in order to receive a shock, it follows, that unless the fish with which Mr. WALSH tried this experiment were remarkably vigorous, there is still too great a disproportion between the strength of the shock of the artificial torpedo when received under water and out of it. If this is the case, the fault might evidently be remedied by making it of some substance which conducts electricity better than leather.

When the torpedo happens to be left on shore by the retreat of the tide, it loosens the sands by flapping its fins, till its whole body, except the spiracles, is buried; and it is said to happen sometimes, that a person accidentally treading on it in that situation, with naked feet, is thrown down by it. I therefore filled a box, 32 inches long and 22 broad, with sand, thoroughly soaked with salt water, to the depth of four inches, and placed the torpedo in it, intirely covered with the sand, except the upper part of its convex surface, and laid one hand on its electrical organs, and the other on the wet sand about 16 inches from

(a) As well as I could judge, the battery required to be charged about 16 or 20 times as high, to give a shock of the same strength when received this way as when received in the usual manner with the torpedo out of water.

it. I felt a shock, but rather weak; and as well as I could judge, as strong as if the battery had been charged half as high, and the shock received in the usual way.

I next took two thick pieces of that sort of leather which is used for the soles of shoes, about the size of the palm of my hand; and having previously prepared them by steeping in salt water for a week, and then pressing out as much of the water as would drain off easily, repeated the experiment with these leathers placed under my hands. The shock was weaker than before, and about as strong as if received in the usual way with the battery charged one-third part as high. As it would have been troublesome to have trod on the torpedo and sand, I chose this way of trying the experiment. The pieces of leather were intended to represent shoes, and in all probability the shoes of persons who walk much on the wet sand will conduct electricity as well as these leathers. I think it likely, therefore, that a person treading in this manner on a torpedo, even with shoes on, but more so without, may be thrown down, without any extraordinary exertion of the animal's force, considering how much the effect of the shock would be aided by the surprise.

One of the fishermen that Mr. WALSH employed assured him, that he always knew when he had a torpedo in his net, by the shocks he received while the fish was at several feet distance; in particular, he said, that in drawing in his nets with one of the largest in them, he received a shock when the fish was at twelve feet

feet distance, and two or three more before he got it into his boat. His boat was afloat in the water, and he drew in the nets with both hands. It is likely, that the fisherman might magnify the distance; but, I think, he may so far be believed, as that he felt the shock before the torpedo was drawn out of water. This is the most extraordinary instance I know of the power of the torpedo; but I think seems not incompatible with the supposition of its being owing to electricity; for there can be little doubt, but that some electricity would pass through the net to the man's hands, and from thence through his body and the bottom of the boat, which in all probability was thoroughly soaked with water, and perhaps leaky, to the water under the boat: the quantity of electric fluid, however, taking this circuit, would most likely bear so small a proportion to the whole, that this effect can not be accounted for, without supposing the fish to exert at that time a surprizingly greater force than what it usually does.

Hitherto, I think, the effects of this artificial torpedo agree very well with those of the natural one. I now proceed to consider the circumstance of the shock's not being able to pass through any sensible space of air. In all my experiments on this head, I used the first torpedo, or that made of wood; for as it is not necessary to charge the battery more than one-third part as high to give the same shock with this as with the other, the experiments were more likely to succeed, and the conclusions to be drawn from them would be scarcely less convincing: for

I find

I find, that five or six rows of my battery will give as great a shock with the leathern torpedo, as one row electrified to the same degree will with the wooden one; consequently, if with the wooden torpedo and my whole battery, I can give a shock of a sufficient strength, which yet will not pass through a chain of a given number of links, there can be no doubt, but that, if my battery was five or six times as large, I should be able to do the same thing with the leathern torpedo.

I covered a piece of sealing wax on one side with a slip of tinfoil, and holding it in one hand, touched an electrical organ of the torpedo with the end of it, while my other hand was applied to the opposite surface of the same organ. The shock passed freely, being conducted by the tinfoil; but if I made, with a penknife, as small a separation in the tinfoil as possible, so as to be sure that it was actually separated, the shock would not pass, conformably to what Mr. WALSH observed of the torpedo.

I tried the experiment in the same manner with the LANE's electrometer described in p. 202, and found that the shock would not pass, unless the knobs were brought so near together as to require the assistance of a magnifying glass to be sure that they did not touch.

I took a chain of small brass wire, and holding it in one hand, let the lowest link lie on the upper surface of an electric organ, while my other hand was applied to the opposite surface. The event was, that if the link, held in my hand, was the fifth or sixth from the bottom, and consequently, that the electricity had only four or five links

to pass through besides that in my hand, I received a shock; so that the electricity was able to force its way through four or five intervals of the links, but not more. One gentleman, indeed, found it not to pass through a single interval; but in all probability the link which lay on the torpedo happened to bear more loosely than usual against that in his hand. If instead of this chain I used one composed of thicker wire, the shock would pass through a great number of links; but I did not count how many. It must be observed, that the principal resistance to the passage of the electrical fluid is formed by the intervals of the lower links of the chain; for as the upper are stretched by a greater weight, and therefore pressed closer together, they make less resistance. Consequently the force required to make the shock pass through any number of intervals, is not twice as great as would be necessary to make it pass through half the number. For the same reason it passes easier through a chain consisting of heavy links than of light ones.

Whenever the electricity passed through the chain, a small light was visible, provided the room was quite dark. This, however, affords no argument for supposing that the phenomena of the torpedo are not owing to electricity; for its shock has never been known to pass through a chain or any other interruption in the circuit; and consequently, it is impossible that any light should have been seen.

In all these experiments, the battery was charged to the same degree; namely, such that the shock was nearly
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of the same strength as that of the leathern torpedo, and which I am inclined to think, from my conversation with Mr. WALSH, may be considered as about the medium strength of those of a real one of the same size as this. It was nearly equal to that of the plate of crown glass in p. 206. electrified to such a degree as to discharge itself when the knobs of a LANE's electrometer were at ,0115 inches distance; whence a person, used to electrical experiments, may ascertain its strength. The way I tried it was by holding the LANE's electrometer in one hand, with the end resting on the upper surface of the plate, and touching the lower surface with the other hand, while an assistant charged the plate by its upper side till it discharged itself through the electrometer and my body. There is, however, a very sensible difference between the sensation excited by a small jar or plate of glass like this, and by a large battery electrified so weakly that the shock shall be of the same strength; the former being sharper and more disagreeable. Mr. WALSH took notice of this difference; and said, that the artificial torpedo produced just the same sensation as the real one.

As it appeared, that a shock of this strength would pass through a few intervals of the links of the chain, I tried what a smaller would do. If the battery was charged only to a fourth or fifth part of its usual height, the shock would not pass through a single interval; but then it was very weak, even when received through a piece of brass wire, without any link in it. This chain was quite clean and very little tarnished; the lowest link was larger

than the rest, and weighed about eight grains. If I used a chain of the same kind, the wire of which, though pretty clean, was grown brown by being exposed to the air, the shock would not pass through a single interval, with the battery charged to about one-third or one-half its usual strength.

It appears, that in this respect the artificial torpedo does not completely imitate the effects of the real one, though it approaches near to it; for the shock of the former, when not stronger than that of the latter frequently is, will pass through four or five intervals of the links of a chain; whereas the real torpedo was never known to force his through a single interval. But, I think, this by no means shews, that the phenomena of the torpedo are not produced by electricity; but only that the battery I used is not large enough. For we may safely conclude, from the experiments mentioned in p. 200. and 202. that the greater the battery is, the less space of air, or the fewer links of a chain, will a shock of a given strength pass across. For greater certainty, however, I tried, whether if the whole battery and a single row of it were successively charged to such a degree, that the shock of each should be of the same strength when received through the torpedo in the usual manner, that of the whole battery would be unable to pass through so many links of a chain as that of a single row^(b). In order to which I made the following machine.

(b) The battery, as was before said, was divided into seven rows, each of which could be used separately.

GM, fig. 5. is a piece of dry wood; *Ff*, *Ee*, *Dd*, *Cc*, *Bb*, and *Aa*, are pieces of brass wire fastened to it, and turned up at bottom into the form of a hook, on which is hung a small brass chain, as in the figure, so as to form five loops, each loop consisting of five links; the part *G* is covered with tinfoil, which is made to communicate with the wire *Aa*. If I held this piece of wood in one hand, with my thumb on either of the wires *Ff*, *Ee*, &c. and applied the part *G* to one surface of an electric organ, while with a spoon, held in the other hand, I touched the opposite surface, I received a shock, provided the battery was charged high enough, the electricity passing through all that part of the chain between *Aa*, and my thumb; so that I could make the shock pass through more or fewer loops, according to which wire my thumb was placed on; but if the charge was too weak to force a passage through the chain, I felt no shock, as the wood was too dry to convey any sensible quantity of electricity. The event of the experiment was, that if I charged the whole battery to such a degree that the shock would but just pass through two loops of the machine, and then charged a single row to such a degree as appeared, on trial, just sufficient to give a shock of the same strength as the former, it passed through all five loops; whether it would have passed through more I cannot tell. If, on the other hand, I gave such a charge to the whole battery, and also to the single row, as was just sufficient to force a passage through two loops of the chain, the shock with the whole battery was much stronger than that with the single row.

It

It must be observed, that in the foregoing machine, each loop consisted of the same number of links, and the links of each loop were stretched by the same weight; so that it required no more force to impell the electricity through one loop than another, which was my reason for using this machine rather than a plain chain. Considerable irregularities occurred in trying the above experiments, and indeed all those with a chain; for it frequently happened, that the shock would not pass with the battery charged to a certain degree, when perhaps a minute after, it would pass with not more than three-fourths of the charge. The irregularity, however, was not so great but that, I think, I may be certain of the truth of the foregoing facts; especially as the experiments were repeated several times. The uncertainty was at least as great in the experiments with LANE's electrometer, when the knobs were brought so close together, as is necessary in experiments of this kind.

It appears therefore, that if the whole battery, and a single row of it, are both charged in such a degree as to give a shock of the same strength, the shock with the whole battery will pass through fewer loops of the chain than that with the single row; so that, I think, there can be no doubt, but that if the battery had been large enough, I should have been able to give a shock of the usual strength, which yet would not have passed through a single interval of the links of a chain.

On the whole, I think, there seems nothing in the phenomena of the torpedo at all incompatible with electricity;

Fig. 4.

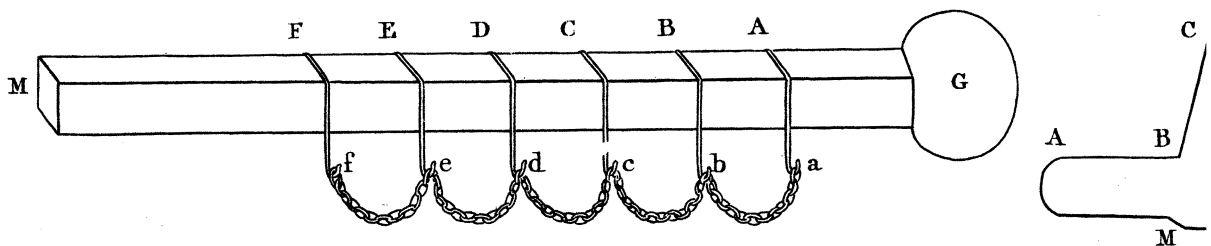
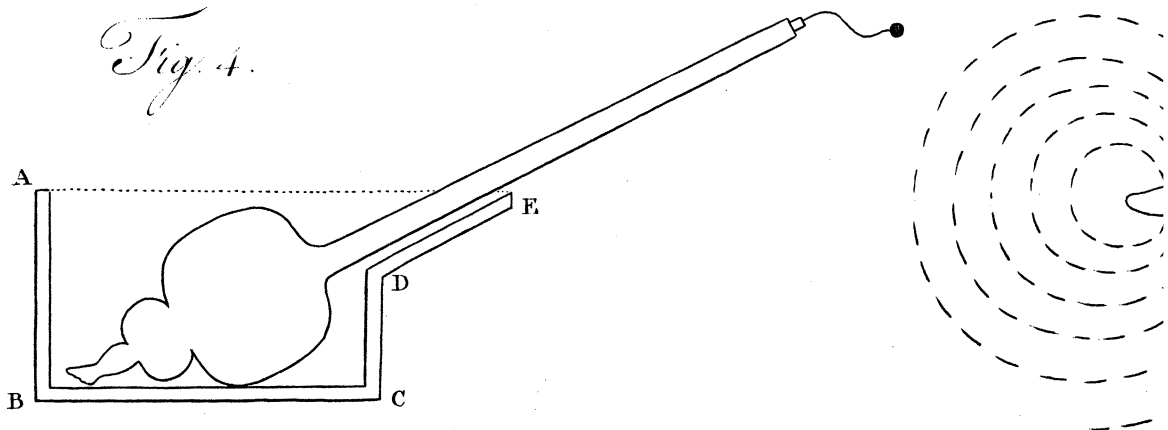


Fig. 5.

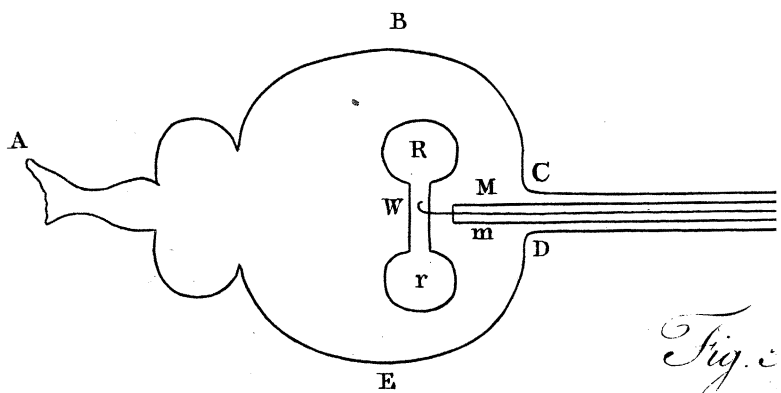


Fig. 6.

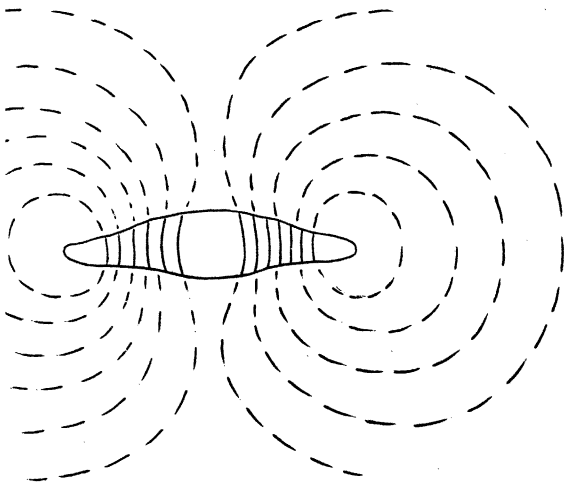


Fig. 1.

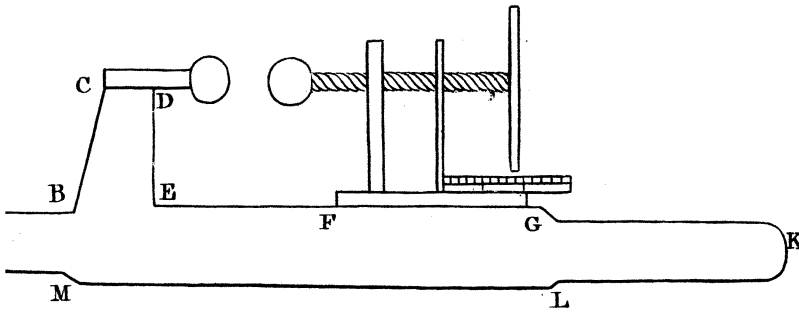


Fig. 2.

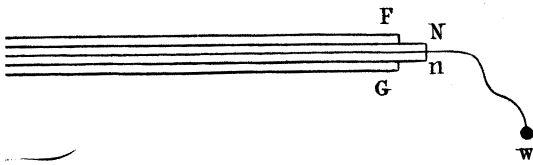


Fig. 3.

tricity; but to make a compleat imitation of them, would require a battery much larger than mine. It may be asked, where can such a battery be placed within the torpedo? I answer, perhaps it is not necessary that there should be any thing analogous to a battery within it. The case is this; it appears, that the quantity of electric fluid, transferred from one side of the torpedo to the other, must be extremely great; for otherwise it could not give a shock, considering that the force with which it is impelled is so small as not to make it pass through any sensible space of air. Now if such a quantity of fluid was to be transferred at once from one side to the other, the force with which it would endeavour to escape would be extremely great, and sufficient to make it dart through the air to a great distance, unless there was something within it analogous to a very large battery. But if we suppose, that the fluid is gradually transferred through the electrical organs, from one side to the other, at the same time that it is returning back over the surface, and through the substance, of the rest of the body; so that the quantity of fluid on either side is during the whole time very little greater or less than what is naturally contained in it; then it is possible, that a very great quantity of fluid may be transferred from one side to the other, and yet the force with which it is impelled be not sufficient to force it through a single interval of the links of a chain. There seems, however, to be room in the fish for a battery of a sufficient size; for Mr. HUNTER has shewn, that each of the prismatical columns of
I which

which the electrical organ is composed, is divided into a great number of partitions by fine membranes, the thickness of each partition being about the 150th part of an inch; but the thickness of the membranes which form them is, as he informs me, much less. The bulk of the two organs together in a fish $10\frac{1}{3}$ inches broad, that is of the same size as the artificial torpedos, seems to be about $24\frac{1}{2}$ cubic inches; and therefore the sum of the areas of all the partitions is about 3700 square inches. Now 3700 square inches of coated glass $\frac{1}{150}$ of an inch thick will receive as much electricity as 30500 square inches, 055 of an inch thick (c); that is, 305 times as much as as the plate of crown glass mentioned in p. 206, or about $2\frac{3}{4}$ times as much as my battery, supposing both to be electrified by the same conductor; and if the glass is five times as thin, which perhaps is not thinner than the membranes which form the partitions, it will contain five times as much electricity, or near fourteen times as my battery.

It was found, both by Dr. WILLIAMSON and by a committee appointed by the Philosophical Society of Pennsylvania, that the shock of the *Gymnotus* would sometimes pass through a chain, though they never perceived any light. I therefore took the same chain which I used in the foregoing experiments, consisting of 25 links, and suspended it by its extremities from the extreme hooks of the machine described in p. 221, and applying the end of the machine to the negative side of the battery,

(c) Vide Note in p. 206.

touched

touched the positive side with a piece of metal held in the other hand, so as to receive the shock through the chain without its passing through the torpedo; the battery being charged to such a degree that the shock was considerably stronger than what I usually felt in the foregoing experiments. I found that if the chain was not stretched by any additional weight, the shock did not pass at all: If it was stretched by hanging a weight of seven pennyweights to the middle link, it passed, and a light was visible between some of the links; but if fourteen pennyweights were hung on, the shock passed without my being able to perceive the least light, though the room was quite dark; the experiment being tried at night, and the candle removed before the battery was discharged. It appears, therefore, that if in the experiments made by these gentlemen the shock never passed, except when the chain was somewhat tense, which in all probability was the case, the circumstance of their not having perceived any light is by no means repugnant to the supposition that the shock is produced by electricity.

Fig. 4.

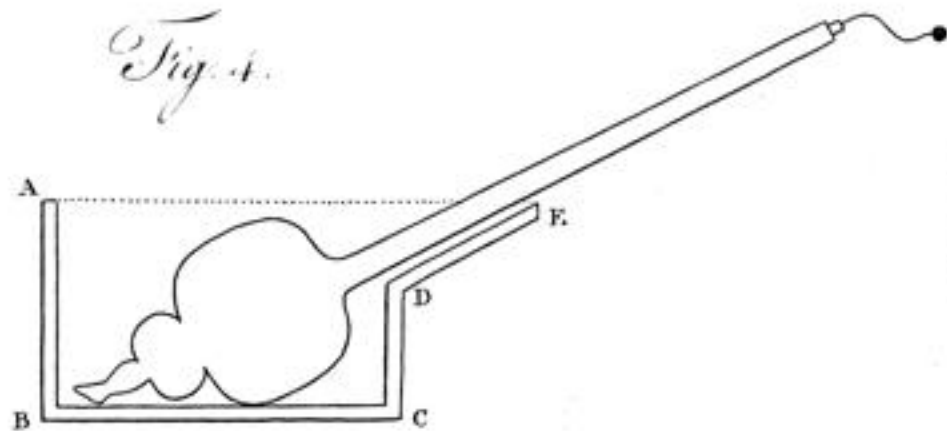


Fig. 1.

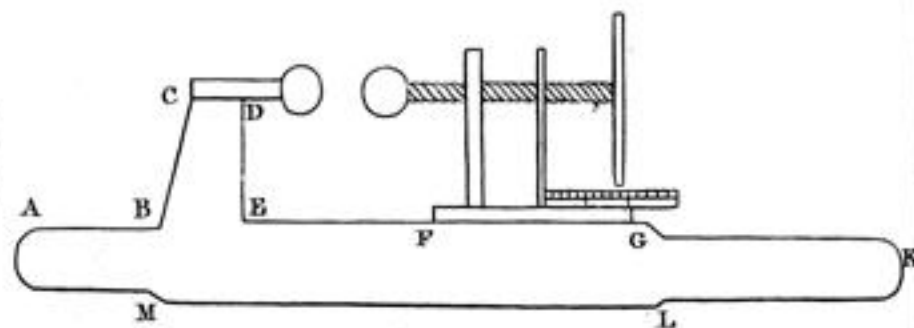
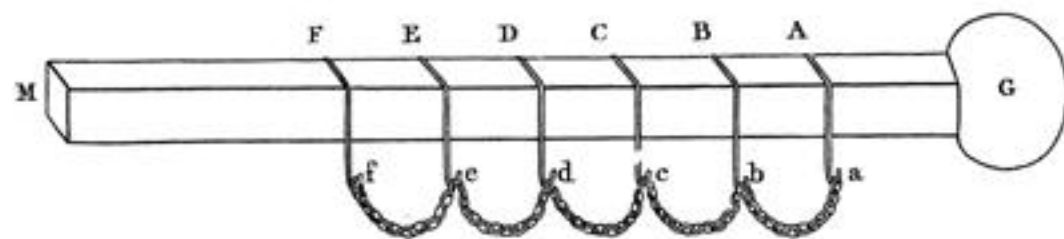
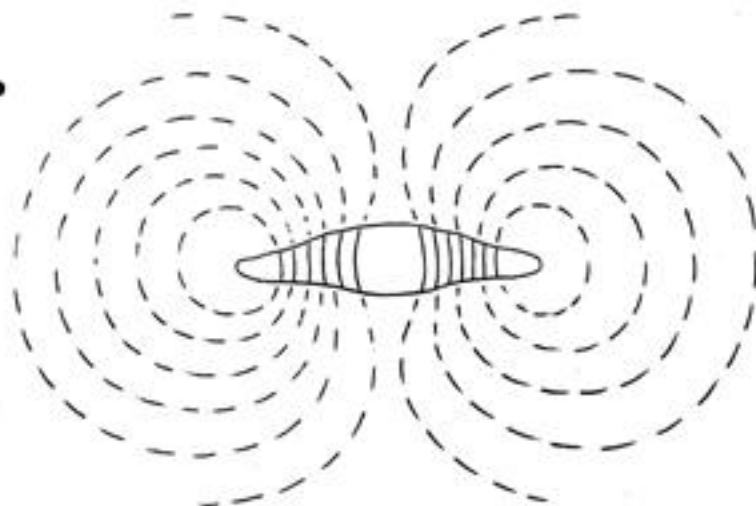


Fig. 5.

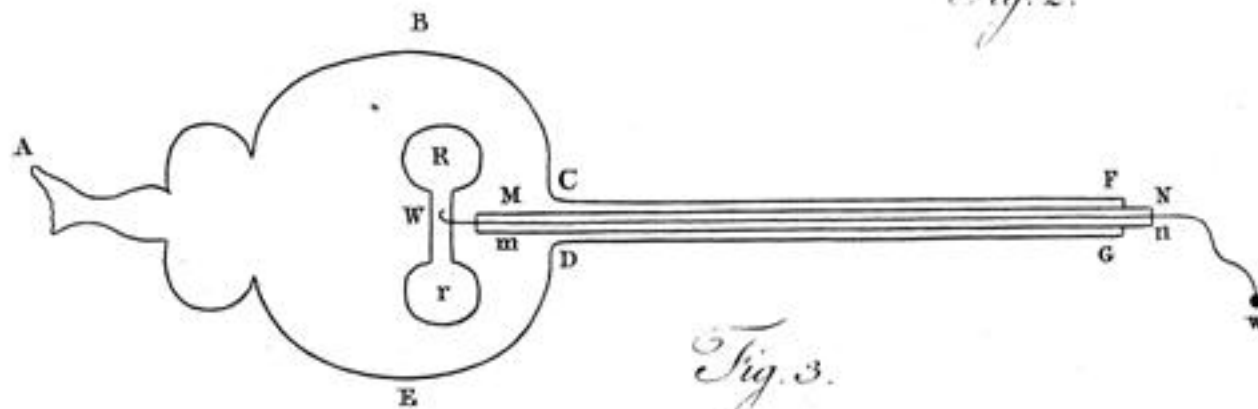


Fig. 2.

Fig. 3.