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

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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 compleated, 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 muft be approached, before the jars would difcharge themfelves. I then electrified the fame jars again in the fame degree as before, and feparated all of them from the conductor except one. It was found, that the diftance to which the knobs muft be approached to difcharge this fingle jar was not fenfibly lefs than the former. It was alfo found, that the divergence of the electrometer was the fame after the removal of the jars as before, provided it was placed at a confiderable diftance from them: from which laft circumftance, I think we may conclude, that the force with which the fluid endeavours to efcape from the fingle jar is the fame as from all the jars together.

It appears, therefore, that the diftance to which the fpark will fly is not fenfibly affected by the number or fize 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 efcape from them: confequently, a large jar, or a great number of jars, will give a greater fhock than a fmall one, or a fmall number, electrified to fuch a degree, that the fpark fhall fly to the fame diftance; for it is well known, that a large jar, or a great number of jars, will give a greater fhock than a fmall one, or a fmall number, electrified with the fame force.

In trying this experiment, the jars were charged very weakly, infomuch that the diftance to which the fpark would fly was not more than the 20th of an inch. The electrometer I ufed confifted of two ftraws, 10 inches long, hanging parallel to each other, and turning at one end

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 tinfoil communicating with the braſs work at FG; and the part ABM being alſo covered with a piece of tinfoil, 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

 ſuſfuſpended 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 diſſipated. 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 16¾ inches long from A to D, and 10¾ broad from B to E; the part CFGD is 40 inches long, and ſerves by way of handle. MN*nm* is a glaſs tube let into a groove cut in the wood. W*w* is a piece of wire paſſing through the glaſs tube, and ſoldered at W to a thin piece of pewter R*r* 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 ſoldered to another piece of pewter of the ſame ſize and ſhape as R*r* intended to repreſent the lower ſurface of thoſe organs. The whole part ABCDE is covered with a piece of ſheep's ſkin leather.

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In making experiments with this inftrument, or artificial torpedo as I fhall call it, after having kept it in water of about the fame faltnefs as that of the fea, till thoroughly foaked, I faftened the end of one of the wires, that not reprefented in the drawing for example, to the negative fide of a large battery, and when it was fufficiently charged, touched the pofitive fide with the end of the wire W*w*; by which means the battery was difcharged through the torpedo: for as the wires were inclofed in glafs tubes, which extended about an inch beyond the end of the wood FG no electricity could pafs from the pofitive fide of the battery to the negative, except by flowing along the wire W*w* to the pewter R*r*, and thence either through the fubftance of the wood, or along the wet leather, to the oppofite piece of pewter, and thence along the other wire to the negative fide. When I would receive a fhock myfelf, I employed an affiftant to charge the battery, and when my hands were in the proper pofition, to difcharge it in the above mentioned manner by means of the wire W*w*. In experiments with this torpedo under water, I made ufe of a wooden trough; and as the ftrength of the fhock may, perhaps, depend in fome meafure on the fize of the trough, and on the manner in which the torpedo lies in it, I have in fig. 4. given a vertical fection of it; the torpedo being placed in the fame fituation as in the figure. ABCDE is the trough; the length BC is 19 inches; the depth AB is 14; and the breadth is 13; confequently, as the torpedo is two inches thick in the thickeft 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 receive

(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.

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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 $11\frac{1}{4}$ times will be reduced in the proportion of 1 to $\overline{1+x}^{11\frac{1}{4}}$; therefore, $\overline{1+x}^{11\frac{1}{4}}=2$; and $1+x=2^{\frac{1}{11\frac{1}{4}}}$. 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

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

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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

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received under water and out of it, was much lefs than before, and perhaps not greater than in the real torpedo. There is, however, a confiderable 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 fenfation is fharper and more difagreeable. The fame kind of fhock, only weaker, was felt if, inftead of touching the fides, I held my hands under water at two or three inches diftance from it.

It is remarkable, that I felt a fhock of the fame kind, and nearly of the fame ftrength, 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 ftronger. This fhews, that the fhock under water is produced chiefly by the electricity running through one's hand from one part to the other; and that but a fmall part paffes through one's body from one hand to the other. The truth of this will appear with more certainty from the following circumftance; namely, that if I held a piece of metal, a large fpoon for inftance, in each hand, and touched the torpedo with them inftead of my hands, it gave me not the leaft fhock when immerfed in water; though when held in air, it affected me as ftrongly if I touched it with the fpoons as with my hands. On increafing the charge, indeed, its effect became fenfible: and as well as I could judge, the battery required to be charged about twelve times as high to give the fame fhock when the torpedo was touched with the fpoons under water as out of it. It muft be obferved, that in trying this

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 fenfible difference could be perceived in the ftrength, whether the torpedo was inclofed in the bafket or not. The trough in which this experiment was tried was 36 inches long, $14\frac{1}{2}$ broad, and 16 deep; and the diftance of that hand which was immerfed in the water from the electric organs of the torpedo, was about 14 inches. As it was found neceffary to charge the battery fo much higher than ufual, in order to receive a fhock, it follows, that unlefs the fifh with which Mr. WALSH tried this experiment were remarkably vigorous, there is ftill too great a difproportion between the ftrength of the fhock of the artificial torpedo when received under water and out of it. If this is the cafe, the fault might evidently be remedied by making it of fome fubftance which conducts electricity better than leather.

When the torpedo happens to be left on fhore by the retreat of the tide, it loofens the fands by flapping its fins, till its whole body, except the fpiracles, is buried; and it is faid to happen fometimes, that a perfon accidentally treading on it in that fituation, with naked feet, is thrown down by it. I therefore filled a box, 32 inches long and 22 broad, with fand, thoroughly foaked with falt water, to the depth of four inches, and placed the torpedo in it, intirely covered with the fand, except the upper part of its convex furface, and laid one hand on its electrical organs, and the other on the wet fand 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 fhock of the fame ftrength when received this way as when received in the ufual manner with the torpedo out of water.

it.

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 ſurprize.

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

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

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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,

GM, fig. 5. is a piece of dry wood; F*f*, E*e*, D*d*, C*c*, B*b*, and A*a*, 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 A*a*. If I held this piece of wood in one hand, with my thumb on either of the wires F*f*, E*e*, &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 A*a*, 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.

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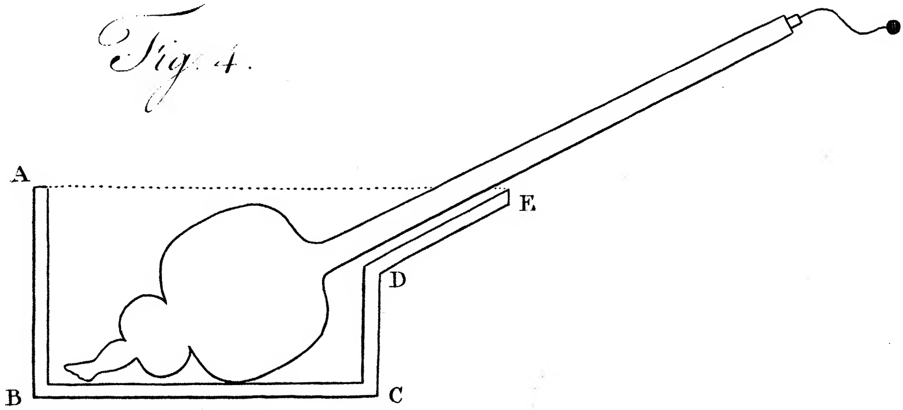
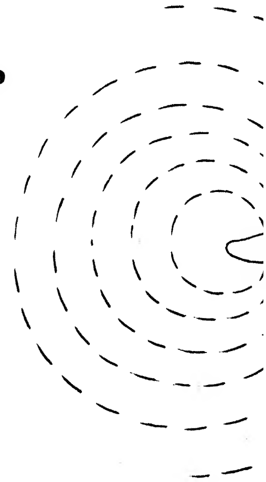
It muſt be obſerved, that in the foregoing machine, each loop conſiſted of the ſame number of links, and the links of each loop were ſtretched by the ſame weight; ſo that it required no more force to impell the electricity through one loop than another, which was my reaſon for uſing this machine rather 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.

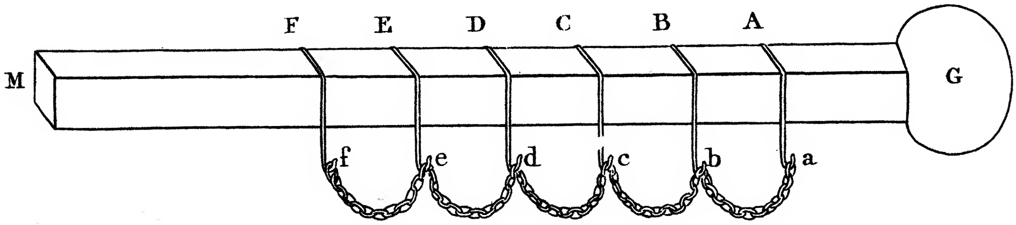
It appears therefore, that if the whole battery, and a ſingle row of it, are both charged in ſuch a degree as to give a ſhock of the ſame ſtrength, the ſhock with the whole battery will paſs through fewer loops of the chain than that with the ſingle row; ſo that, I think, there can be no doubt, but that 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.







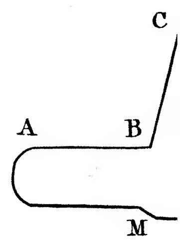


Fig. 5.

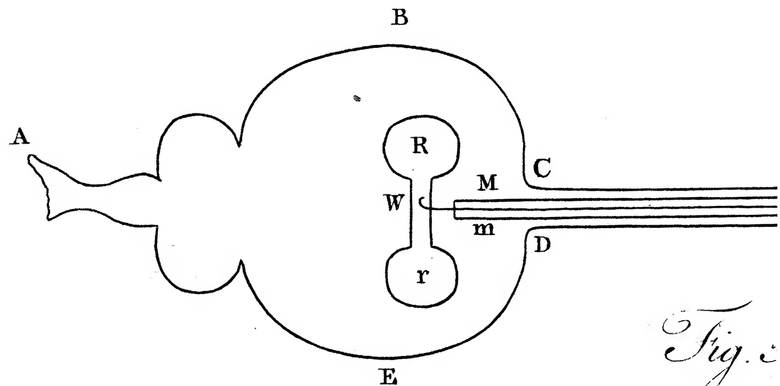
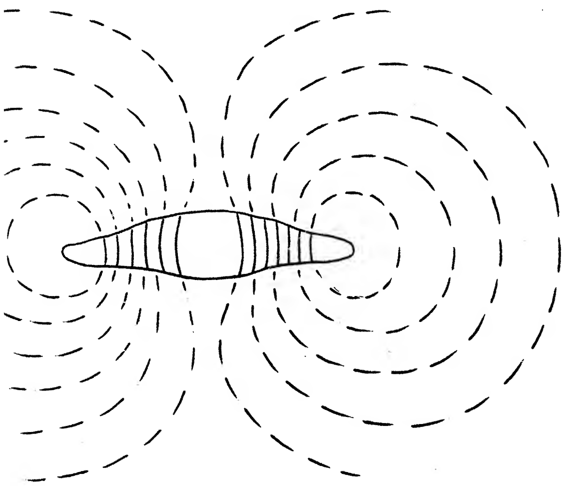


Fig.

Fig. 1.



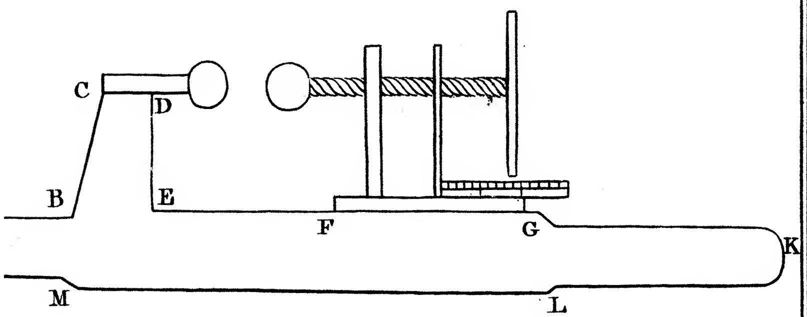


Fig. 2.

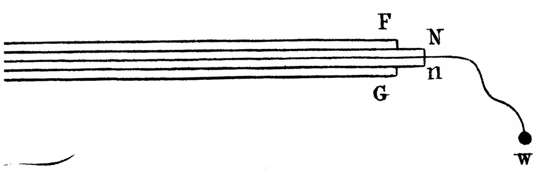


Fig. 3.

Basire. Sc.

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 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 Penſylvania, 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.

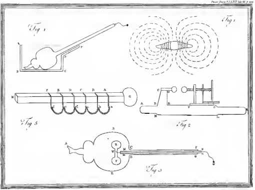


Fig 1
Fig 2
Fig 3
Fig 4
Fig 5