

loins. The *os sacrum*, as well as the *os pubis*, imperfectly ossified. All its joints are very rigid and stiff. It has no *anus*, but passes off its water in the natural way. Its *sternum* is very imperfect; and it has no *clavicula*. It seems insensible of pain, not removing its arms or legs, if laid in an uneasy posture.

LXI. *An Account of the Phænomena of Electricity in vacuo, with some Observations thereupon, by Mr. Wm. Watson, F. R. S.*

To the Royal Society.

Gentlemen,

Read Feb. 20, 1752. **I**N a paper I had the honour to lay before you in January 1747, which was the last I communicated to you of my own upon the subject of electricity, and which has been since publish'd in the *Philos. Trans.**, I acquainted you, that I intended upon some future occasion to lay before you a series of experiments in electricity made *in vacuo*; from a comparison of which with those already made in open air it did appear, that our atmosphere, when dry, was the agent, by which, with the assistance of other electrics *per se*, we were enabled to accumulate electricity in and upon non-electrics; that is, to communicate to them a greater quantity of electricity than these bodies naturally have. That, upon the
removal

* Numb. 485, p. 120.

removal of the air, the electricity did pervade the *vacuum* to a considerable distance, and did manifest its effects upon any non-electric substances, which did terminate that *vacuum*; and that by these means, originally-electric bodies, even in their most perfect state, put on the appearance of non-electrics, by becoming themselves the conductors of electricity.

I had not so long delayed the illustration of these opinions by the experiments, which put me in possession of them, but that I was not only diverted therefrom by very various avocations, but desirous of giving them a still greater degree of perfection, in order to place the above deductions beyond all controversy. The executing the apparatus necessary hereto was not easily surmounted: I unsuccessfully tried several artificers, who were not able to arrive at the nicety, which I thought necessary in the construction of my instruments. Animated however by a late very honourable occasion, and assisted by Mr. Smeaton in the completing my apparatus, the event fully answered what I proposed; although from the experiments I had made before the communication of the above accounts, I was fully convinced of their truth. I had other opinions indeed, which did still require a further degree of demonstration.

To make these experiments succeed, two things were more particularly required; first, that the inside of the glasses made use of should be perfectly dry; and therefore it was necessary, that their internal surface should be exposed to the wet leathers, usually employed in pneumatic experiments, as little as might possibly be; otherwise, the vapours, arising therefrom

in exhausting, defeated the intent by conducting the electricity, and thereby preventing its accumulation. Secondly, the more complete the *vacuum* was, *cæteris paribus*, the more considerable were the effects: and here I should not do justice to real merit, were I silent in regard to Mr. Smeaton. This gentleman with a genius truly mechanical, which enables him to give to such philosophical instruments, as he executes, a degree of perfection, scarce to be found elsewhere; this gentleman, I say, has constructed an air-pump, by which we are empower'd to make Boyle's *vacuum*, much more perfect than heretofore. By a well-conducted experiment, which admits of no doubt as to its truth, I have seen by this pump the air rarefied to a thousand times its natural state; whereas commonly we seldom arrive at above one hundred and fifty. As the promotion of the mechanic arts is a considerable object of our excellent institution, if this gentleman could be prevailed upon to communicate to the Royal Society that particular construction of his air-pump, which enables it to execute so much more than those commonly in use, it would not fail to be an acceptable present: but to return:

The experiments treated of in this paper must be considered to have been made in this *vacuum*. The electrical machine, with its prime conductor, need here no particular description; but that of the glass, in which the *vacuum* was made, should be more minutely considered. It consisted of a glass tube nearly three feet in length, and of almost three inches in diameter. A ring of brass, exactly fitting this tube, was cemented to both its extremities, into each
of

of which was screwed a hollow brass cap, nearly of an hemispherical figure. Into the top of one of these caps was adapted a brass box of oiled leathers, through which was admitted a slender brass rod of a length sufficient to reach within eight inches of the other extremity of the tube. Into the top of the other brass cap was fastened a brass rod, like the former, only of eight inches in length. Thus the extremity of one of these brass rods might at pleasure, without letting in the air, be made to touch the other; and for the better observing what difference in effect would arise from an increase of surface, a small brass circular plate was made to screw into each of these extremities. As the sight of this instrument will convey to you at once a more clear idea than the most accurate description, I take the liberty of laying it before you.

The intent of being able to bring the extremities of these rods near together, and to separate them again to what distance you pleased, was, that it might without difficulty be determined, whether, and to what distance, the electrical fluid would manifest itself *in vacuo*, further than in air of the same density with the external.

The tube then thus fitted, and made dry both within and without, was placed in a cylinder of brass, of about two inches long, and of a diameter just sufficient to admit the brass cap before-mentioned; and round the rim of this brass cylinder, to prevent the ingress of air, was adapted a narrow piece of wet leather. These being placed upon the plate of the air-pump, which stood upon cakes of wax, a piece of wire passed from the prime conductor to the long
brass

brass rod, at the other extremity of the tube, and by these means, upon setting the electrical machine in motion, the long brass rod in the tube was electrified. When the brass plate at the bottom of this rod was placed near, or even at the distance of two inches from the plate of the other rod, the brushes of electrical fire were seen passing from the periphery of the upper plate to that of the lower, and every part of the air-pump snapped upon the touch of any one standing upon the floor, and gave the other usual signs of the accumulation of electricity. But, as these plates were made to recede from each other, this effect grew less and less; so that, when they were removed five or six inches from each other, no snaps could be drawn from the air-pump; as the dissipation of the electric fluid was now as easy from every part of the prime conductor, as from the upper brass plate in the tube: but it is to be noted, that this distance is different, as from the weather or other circumstances the electricity is more or less strong.

Upon exhausting this tube, and electrifying as before the air-pump still standing upon cakes of wax, the electrical fire was not only seen to pass from one plate to the other at the distance of 5 inches, but the same effect ensued at the greatest distance, to which in the tube the brass plates could be drawn. Being therefore desirous to see a farther effect, and to avail myself of the whole length of this tube, I took from the inside of it the short brass rod, to which the lower brass plate was fixed, and fasten'd this plate at the very bottom of the tube into the cap. The consequence was, that the electricity, meeting with scarce any resistance, passed from the

top to the bottom of the tube, and electrified the air-pump as before: and it was a most delightful spectacle, when the room was darkened, to see the electricity in its passage; to be able to observe, not, as in the open air, its brushes or pencils of rays an inch or two in length, but here the coruscations were of the whole length of the tube between the plates; that is to say, thirty-two inches, and of a bright silver hue. These did not immediately diverge as in the open air, but frequently, from a base apparently flat, divided themselves into less and less ramifications, and resembled very much the most lively coruscations of the *aurora borealis*.

At other times, when the tube has been exhausted in the most perfect manner, the electricity has been seen to pass between the brass plates in one continued stream of the same dimensions throughout its whole length; and this, with a subsequent observation, seems to demonstrate, that the cause of that very powerful repulsion of the particles of electrical fire one to the other, which we see in open air, is more owing to the resistance of the air than to any natural tendency of the electricity itself; as we observe, that the brushes thereof from blunt bodies, when the electricity is strong, diverge so much, as to form, when seen in the dark, an almost spherical figure. This figure seems therefore to arise from the electricity's endeavouring to insinuate itself between the particles of air. The figure, that an elastic fluid of less density must form, when let loose, and equably compressed by one more dense and more elastic, must necessarily approach to that of a sphere.

Upon

Upon admitting a very small quantity of air into the tube, these phænomena disappeared; not so much from the small quantity of air admitted, as from the vapours, which insinuated themselves therewith. These lined the sides of the glass, and conducted the electricity imperceptibly from one end of the tube to the other. And to illustrate farther, that the vapours, and not the air, in the small quantity admitted, occasion'd this total disappearing of these phænomena; upon experiment they have been visible, though in a less perfect degree, when a much larger quantity of air was omitted to be exhausted from the tube.

These experiments seem to evince, that however great the *vacuum* could be made, the electrical co-ruscations would pervade it through its whole length.

From hence it appears, that our atmosphere, when dry, is the agent, by which we are enabled to accumulate electricity upon non-electrics; as in the experiment before us, upon the removal of it, the electricity passed off into the floor through a *vacuum*, of the greatest length we have hitherto been able to make, became visible in this *vacuum*, and manifested itself by its effects upon the air-pump, being the non-electric substance, which terminated that *vacuum*: whereas, when the air is not taken away, the dissipation of the electricity is from every part of the prime conductor. We see here also, contrary to what we have found hitherto, that an originally-electric body, *viz.* a dry glass tube, puts on the appearance of a non-electric, by becoming itself the conductor of electricity, that is, by its keeping out the air, and suffering the electricity to pervade the *vacuum*.

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How much soever the *vacuum*, here made use of, may exceed that, which is usually arrived at, it is far from being a perfect one; and to make one more so, except that of Torricelli, which cannot without difficulty be applied to the present purpose, is not very easy. But it appears from the already mentioned experiments, as well as from a subsequent one, that the *vacuum*, which we are masters of, does not transmit the electricity so perfectly as metals and water; as we are able to draw snaps from the prime conductor, an argument of some degree of accumulation, while the electricity is passing through the *vacuum*. This never happens, when metals, standing upon the ground, touch the prime conductor. As we observe therefore, that the coruscations diverge more or less, in proportion as there is more or less air left in the tube, this effect may arise even from the small quantity of air still remaining undischarged.

I was desirous of knowing, for the farther illustration of my propositions, whether the experiment of Leyden could be made through the *vacuum*. For this purpose I made the before-mention'd exhausted tube part of the circuit, so necessary to this experiment. What this circuit is, I have in my former communications so often and so clearly exemplified, that it would be needless to repeat it here. You know in this experiment it is likewise absolutely necessary, that the whole quantity, or nearly so, of the accumulated electricity should be discharged in the same instant of time. Accordingly, upon making the experiment, at the instant of the explosion, you saw a mass of very bright embodied fire jump from one of the brass plates in the tube to the other: but this did not take place, when one of the plates was

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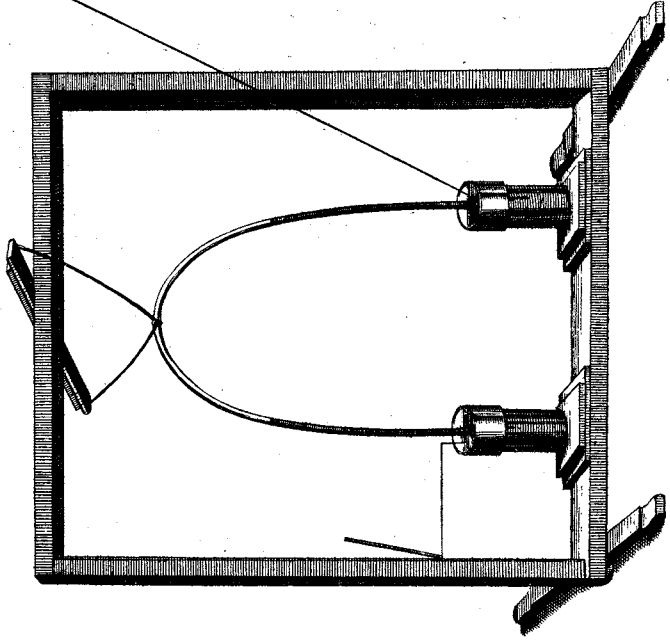
farther

farther distant from the other than ten inches. If the distance was greater, the fire then began to diverge, and lose part of its force; and this force diminished in proportion to its divergency, which was nearly as the distance of the two plates.

The difficulty however of applying the Torricellian *vacuum* to these experiments has been happily got over by the right honourable the Lord Charles Cavendish, our worthy Vice-president. This noble lord, who to a very complete knowledge of the sciences joins that of the arts, and whose zeal for the promotion of true philosophy is exceeded by none, has applied it in the following manner, and his lordship has had the goodness to put his apparatus into my hands. This apparatus consisted of a cylindrical glass tube of about three tenths of an inch in diameter, and of seven feet and half in length, bent somewhat like a parabola in such a manner, that thirty inches of each of its extremities were nearly straight, and parallel to each other, from which an arch sprung, which was likewise of thirty inches*. This tube was carefully fill'd with mercury; and each of its extremities being put into its basin of mercury, so much of the mercury ran out, until, as in common barometrical tubes, it was in equilibrio with the atmosphere. Each of the basins containing the mercury was of wood, and was supported by a cylindrical glass of about four inches in diameter, and six inches in length; and these glasses were fasten'd to the bottom of a square wooden frame, so contrived, as that to its top was suspended by silk lines the tube filled with

* See the representation of this apparatus, Tab. XVI.

p. 370.



J. Myndes sc.

with mercury before-mention'd; so that the whole of this apparatus without inconvenience might be moved together. The Torricellian *vacuum* then occupied a space of about thirty inches. In making the experiment, when the room was darkened, a wire from the prime conductor of the common electrical machine communicated with one of the basons of mercury, and any non-electric touching the other bason, while the machine was in motion, the electricity pervaded the *vacuum* in a continued arch of lambent flame, and as far as the eye could follow it, without the least divergency.

That the electricity was not furnished from the glasses employed in these operations, nor from the circumambient air, I have heretofore, in my communications to you upon this subject, endeavoured to evince. I have shewn, that electricity is the effect of a very subtil and elastic fluid, occupying all bodies in contact with the terraqueous globe; and that every-where, in its natural state, it is of the same degree of density; and that glass and other bodies, which we denominate electrics *per se*, have the power, by certain known operations, of taking this fluid from one body, and conveying it to another; in a quantity sufficient to be obvious to all our senses: and that, under certain circumstances, it was possible to render the electricity in some bodies more rare than it naturally is, and, by communicating this to other bodies, to give them an additional quantity, and make their electricity more dense: and that these bodies will thus continue until their natural quantity is restored to each; that is, by those, which have lost part of theirs, acquiring what they have lost;

and by those, to which more has been communicated, parting with their additional quantity. Both one and the other of these is, from the elasticity of the electric matter, attempted to be done from the nearest non-electric; and when the air is moist, this is soon accomplished, by the circumambient vapours, which here may be considered as preventing in a very great degree our attempts to insulate non-electric bodies. But these matters I have copiously treated of in my former communications upon this subject*: this short recapitulation however I thought necessary, for the more easily illustrating what I propose to subjoin; and it is upon these principles that we are able to account for the circulation of electricity described in the *Philosophical Transactions*, Vol. XLIV. p. 740.

If therefore the before-mention'd principles are true, and if the electricity is not furnished by the globe in its rotation, nor by the air, it ought to be visible in the *vacuum* of the before-described glass tube, in its ingress to the frame of the electrifying machine, if this machine, and the man who turns the wheel thereof, are supported by electrics *per se*, and if, during this operation, the electricity, as fast as furnished, is taken off by a bystander, or otherwise, from the prime conductor; as under these circumstances the *vacuum* is the only passage open to its progress, and from its elasticity the electricity should protrude itself through it. And from experiment this is the case; for, upon a piece of wire being connected with the end of the long brass rod,

* See *Phil. Transf.* Vol. XLV. pag. 95 & seq.

rod, or with the brass cap at the upper extremity of that tube, and the other end of the wire fastened to any part of the frame of the electrifying machine, and this last put in motion, the electrical coruscations are seen to pass as before from one of the brass plates contained in the tube to the other ; and to continue, unless the air insinuates itself, as long as the machine is in motion. If, under these circumstances, the hand of a person standing upon the floor is brought near the sides of the glass, the coruscations will direct themselves that way in great variety of forms, extremely curious to behold. But here, as in the former experiment, our *vacuum* did not conduct so perfectly as metals or water ; as a person, standing upon the floor, and applying his finger to the upper brass cap of the tube, receives a smart stroke : and this I conceive to arise, from the electricity of this brass being so much more rarefied, or attenuated, than that of the body of the man, applying his finger.

This experiment should be made in the middle of a large room, and the machine, and man turning it, should be raised from the floor at least a foot : otherwise the effects desired will be diminished by the electricity being in part furnished by the floor to the machine.

To what is here laid down it may be objected, that the electrical coruscations in the last experiment proceed, not from the floor of the room, as I have conjectured, but from the electricity being, from the globe in motion, diffused at the same time upon the prime conductor, as well as all over the machine, and which in the tube becomes visible in its passage

to the floor. But it is to be remember'd in this experiment, that no electricity is perceptible either *in vacuo*, or upon any part of the machine, as above-mentioned, unless at the same time the prime conductor is made use of; for, without that, there will be no diminution of the density of the electricity in the machine, as the quantity taken from the cushion by the globe in its rotation is returned upon it again the next revolution, the cushion being the first non-electric, which offers itself: but this I have have consider'd at large, as may be seen in the *Philosophical Transactions* *. This experiment therefore, in which the electricity is seen, without any preternatural force, pushing itself on through the *vacuum* by its own elasticity, in order to maintain the equilibrium in the machine, which had lost part of its natural quantity of electricity by the present operation; this experiment, I say, I do not scruple to consider as an *experimentum crucis* of the truth of the doctrines here laid down; to wit, not only that the electricity is furnish'd by those bodies, hitherto called non-electrics, and not by the electrics *per se* ||; but

* Vol. XLV. p. 96.

|| Since the communication of this paper to the Royal Society in February 1752, *viz.* in the succeeding summer, the truth of this doctrine is put out of all doubt by the discovery made in France, in consequence of Mr. Franklin's hypothesis, of being able, by a proper apparatus, to collect the electricity from the atmosphere during a thunder-storm, and to apply it to the usual experiments, which demonstrates, that the matter of thunder and lightning and that of electricity are one and the same. That the electricity did not proceed from the glass, or other electrics *per se*, as they had been usually called, I first discover'd in the year 1746:

See

but also, that we are able to add to, or take from, that quantity of electricity, naturally adherent to bodies.

By what denomination shall we call this extraordinary power? From its effects in these operations, shall we call it electricity? From its being a principle neither generated nor destroyed; from its being every-where and always present, and in readiness to shew itself in its effects though latent and unobserved, till by some process it is produced into action, and rendered visible; from its penetrating the densest and hardest bodies, and its uniting itself to them; and from its immense velocity; shall we, with Theophrastus, Boerhaave, Niewentyt, s'Gravesande, and other philosophers, call it elementary fire? Or shall we, from its containing the substance of light and fire, and from the extreme smallness of its parts, as passing through most bodies we are acquainted with, denominate it, with Homberg and the chemists, the chemical sulphureous principle, which, according to the doctrines of these gentlemen, is universally diffused? We need not indeed be very solicitous in relation to its denomination: certain it is, that the power we are now treating about is, besides others, possessed of the properties before-mentioned, and cannot

See *Phil. Transf.* Vol. XLIV. p. 713.—749, and explained further Vol. XLV. p. 95, *et seq.* and though the electric matter may be taken from the atmosphere during a storm of thunder, or even when it is only charged with what are usually called thunder-clouds, that is, when the atmosphere is replete with heterogeneous phlogistic matter; yet it must not be considered as coming from pure dry air, which, as I before mentioned, I conceive to contain in its natural state scarce any of the electric matter, and is the agent, by which we are enabled to communicate electricity to other bodies.

cannot but be of very great moment in the system of the universe.

I am, Gentlemen, with all possible respect,

London, Feb. 12, 1752. Your most obedient humble servant,

W. Watfon.

LXII. *A Letter from Dr. Bevis to Dr. De Castro, F. R. S. containing Extracts of Father Augustin Hallerstein's astronomical Observations made at Pekin in 1744 and 1747.*

Read March 5, 1752. **I** AM much obliged to you, Sir, for furthering F. Aug. Hallerstein's letter to me. It informs me, that the instrument I wrote the description and use of, was arrived safe at Pekin. According to that missionary's request, I have carefully looked over the observations he sent to Dr. Sanchez at Paris, to be communicated to the Royal Society through your hands. They are comparisons of all the planets with known fix'd stars taken in the Jesuit's College at Pekin, in 1746 and 1747, with a well-adjusted pendulum-clock, and a micrometer; and appear to me to have been done with judgment and accuracy