

III. *A Collection of the Electrical Experiments communicated to the Royal Society by Wm. Watson, F. R. S. read at several Meetings between October 29. 1747. and Jan. 21. following.*

I.

An Account of the Experiments made by several Gentlemen of the Royal Society, in order to discover whether or no the electrical Power, when the Conductors thereof were not supported by Electrics per se would be sensible at great Distances: With an Inquiry concerning the respective Velocities of Electricity and Sound: To which is added an Appendix, containing some further Inquiries into the Nature and Properties of Electricity.

Read Oct. 29. 1747. **I**N the Paper I did myself the Honour some time since to communicate to the *Royal Society*, I took notice, that, among the many other surprising Properties of Electricity, none was more remarkable, than that the electrical Power, accumulated in any non-electric Matter contained in a glass Phial, described upon its Explosion a Circuit through any Line of Substances non-electrical in a considerable

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ble Degree; if one End thereof was in Contact with the external Surface of this Phial, and the other End upon the Explosion touched either the electrified Gun-barrel, to which the Phial in charging was usually connected, or the iron Hook always fitted therein. This Circuit, where the non-electric Substances, which happen to be between the Outside of the Phial and its Hook, conduct Electricity equally well, is always described in the shortest manner possible; but if they conduct differently, this Circuit is always formed through the best Conductor, how great soever its Length is, rather than through one which conducts not so well, though of much less Extent.

It has been found, that in proportion as Bodies are susceptible of having Electricity excited in them by Friction, in that Proportion they are less fit to conduct it to other Bodies; in consequence whereof, of all the Substances we are acquainted with, Metals conduct best the electrical Powers; for which Reason the Circuit before spoken of is formed through them the most readily. Water likewise is an admirable Conductor; for the electrical Power makes no Difference between Solids and Fluids as such, but only as they are non-electric Matter.

In order to give an Idea of what is understood by this Circuit, we will mention an Example or two, from which all the other may naturally be deduced. If a Person stands upon a dry wooden Floor with a coated Phial ever so highly charged in one of his Hands, and if another Person, without touching the first, stands but six Inches from him, and touches the iron Hook of the Phial, neither of them

are shocked; because the Floor between them, tho' the Distance is so short, will not conduct the Electricity sufficiently quick. But if these two Persons tread upon a Piece of Wire laid between them, they each of them feel the electrical Commotion in that Arm, which touches the Phial and Hook, and in that Foot which treads upon the Wire; the Wire here conducting the Electricity quick enough, which the dry Floor would not. The Circuit is here formed by the coated Phial, its Hook, so much of the Bodies of these two Persons as formed a curve Line between the Wire, the Phial, and Hook, and the Wire between these Persons. If these Persons stand upon, or touch with any Part of their Bodies any Non-electrics, which readily conduct Electricity, the Circuit is completed, and the Effect is the same: And this is occasion'd by the short Space of Time, in which the loaded Phial is discharged, when any Matter of what kind soever readily conducting Electricity happens to be between the coated Phial and its Hook, and is so connected as to communicate with both upon the Discharge of the Phial.

Monsieur *le Monnier* the younger at *Paris*, in an Account transmitted to the *Royal Society*, takes notice of his feeling the Stroke of the electrified Phial along the Water of two of the Basins of the *Thuilleries* (the Surface of one of which is about an Acre) by means of an iron Chain which lay upon the Ground, and was stretched round half their Circumference.

Upon these Considerations it was conjectured, as no Circuit had as yet been found large enough so to dissipate the electrical Power as not to make it

perceptible, that if the non-electrical Conductors were properly disposed, an Observer might be made sensible of the electrical Commotion quite across the River *Thames*, by the Communication of no other Medium than the Water of that River. But as perhaps, in what relates to Electricity less than in any other Part of Natural Philosophy, we should draw Conclusions but from the Facts themselves, it was determined to make the Experiment.

The making this Experiment drew on many others, and as the Gentlemen concerned flatter themselves that they were made with some Degree of Attention and Accuracy, they thought it not improper to lay a Detail of all the Operations relating thereto, before the *Royal Society*.

In order to try whether or no the electrical Commotion would be perceptible across the *Thames*, it was absolutely necessary that a Line of non-electric Matter, equal in Length to the Breadth of the River, should be laid over it so as to touch the Water thereof in no Part of its Length; and the Bridge at *Westminster* was thought the most proper for that Purpose, where the Water from Shore to Shore was somewhat more than 400 Yards.

Accordingly on *Tuesday July 14, 1747*. to see the Success and assist in making the Experiment, there met *Martin Folkes* Esq; President of the *Royal Society*, the Right Honourable the Earl *Stankope*, *Richard Graham* Esq; *Nicholas Mann* Esq; and myself, with proper Persons to execute what was required of them in the various Parts of these Experiments.

A Line of Wire was laid along the Bridge, not only through its whole Length, but likewise turning at the Abutments, reached down the stone Steps on each Side of the River low enough for an Observer to dip into the Water an iron Rod held in his Hand. One of the Company then stood upon the Steps of the *Westminster* Shore holding this Wire in his left Hand, and an iron Rod touching the Water in his right: On the Steps facing the former upon the *Surry* Shore, another of the Company took hold of the Wire with his right Hand, and grasped with his left a large Phial almost filled with Filings of Iron, coated with Sheet-Lead, and highly electrified by a glass Globe properly disposed in a neighbouring House. A third Observer standing near the second dipped an iron Rod held in his left Hand into the Water, and touching the iron Hook of the charged Phial with a Finger of his right Hand, the Electricity snapped, and its Commotion was felt by all the three Observers, but much more by those upon the *Surry* Shore. The third Observer here was no otherwise necessary, than that the River being full, the Iron was not long enough to be fixed in the Mud upon the Shore, and therefore was in want of some Support. The Experiment was repeated several times, and the electrical Commotion felt across the River; but the Gentlemen present being much molested in their Operations by a great Concourse of People, who many times broke the conducting Wire, and otherwise greatly incommoded them, and the Evening growing too dark for the Observers on different Sides of the Water to see each other, they were prevented from

from diversifying the Experiments, as was intended, and only consider'd these Trials as a still further Encouragement for them to prosecute the Inquiry at a more favourable Opportunity.

Early therefore on *Saturday Morning July 18*, there met upon *Westminster-Bridge* the *President* of the *Royal Society*, the Right Honourable the Lord *Charles Cavendish*, *Richard Graham Esq*; *Dr. Bevis*, and myself, with proper Assistants. At the preceding Meeting, the electrical Machine's being placed at some Distance from the Water being found inconvenient, the following Alteration was made in the Disposition of the *Apparatus*.

A Room up two Pair of Stairs in a commodious House nearest the Bridge on the *Surry Shore* was provided, in which was placed the electrical Machine with the Gun-barrel suspended in silk Lines. From this Room, on account of its Height, the Signals on both Sides of the River were easily observable. The coated Phial before-mention'd with its iron Hook was placed upon the Seat of the Window of this Room, and communicated with the Gun-barrel by the means of a Piece of iron Wire. One Extremity of another Wire was likewise fixed into the Bottom of the leaden Coating of the Phial, whose other Extremity reached therefrom over the Bridge to the Steps upon the *Westminster Shore*, the Body of the Wire being placed as much as possible upon the Parapet of the Bridge. One or more Observers took each other by the Hand, the first of which must necessarily take the Wire in his left Hand, and the last, upon the proper Signal given, either dip his right Hand into
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the Water, or (which makes the Posture more agreeable) a Rod of Metal held therein. Another Wire having no Communication with any of the former, was let down from the before-mention'd Room, and down the Steps upon the *Surry* Shore: One Extremity of this Wire was held in the Hand of an Observer standing upon these Steps, who dipped an iron Rod held in his other Hand into the Water: To the other Extremity of this Wire was fastened a short iron Rod, with which, when the electrified Phial was sufficiently charged, and the Signal given, the Gun-barrel was to be touched.

The Gentlemen, by this Disposition of the *Apparatus*, propos'd to examine principally these three Questions: First, whether or no the Observers standing on each Side of the River would perceive the electrical Commotion, each putting an iron Rod into the Water? Secondly, Whether or no the Observers on both Sides of the River would feel the electrical Commotion, when the Observer standing upon the *Westminster* Shore removed the iron Rod held in his Hand out of the Water? Thirdly, Whether or no the electrical Power was perceptible to the Observers on both Sides of the River, if the Observer upon the *Westminster* Shore dipped his Hand into a Pail of Water, which had no Communication with the Water of the *Thames*.

It was determin'd first, upon proper Signals, to discharge the electrified Phial in the manner before-mention'd, the Observers on each Side of the River holding the iron Rods in the Water, and this Experiment was to be repeated three times. This was attempted accordingly; and although the Observer

on the *Surry* Shore was each time smartly struck, the *President* of the *Royal Society*, who observed with the utmost Attention upon the *Westminster* Shore, gave the Signal that he felt nothing. The Company was surpris'd at this Want of Success in the Experiment; but, upon examining the Wire, which was laid over the Bridge, it was found to have been broken by some Accident, after it had pass'd over about a fourth Part of the Bridge. The Wire being refitted, it was agreed to make the same Experiment six times more: This was done accordingly, and the electrical Commotion was felt each time by the Observers on both Sides of the Water, but much smarter by those on the *Surry* Side. It was then thought proper to repeat this Experiment three times more upon the Signal's being given: but, in making the first of these, the Observer in the Room with the Machine, discharged the electrified Phial, before the Observer upon the *Surry* Shore had dip'd his iron Rod into the Water, and therefore no Effect was perceiv'd by the Observer on the opposite Shore. The electrified Phial therefore was again discharged three other times, and the Commotion felt by the Observers on both Sides of the River.

To examine the second Question, no other Alteration was necessary in the whole *Apparatus*, than that the Observer upon the *Westminster* Shore should not dip either his Hand, or the iron Rod held therein in the last Experiments, into the Water of the River. The electrified Phial then was discharged three times without its Effects being in the least perceiv'd by the Observers upon the *Westminster* Shore; those indeed on that of *Surry* felt the Shock as before.

In examining the third Question, the *Apparatus* was in all other Respects the same as in the last ; except that the Observer upon the *Westminster* Shore had a Pail of Water placed upon a wooden Table, which stood upon the Stone Steps, and into which he was to put his right Hand upon the Signal's being given. This was accordingly done, and the electrified Phial being discharged three times, the electrical Commotion was felt as before by the Observer upon the *Surry* Shore ; but not in the least by him on the *Westminster* Side, who held his Hand in the Pail of Water.

In all these Experiments, except in one before-mention'd, where the iron Rod was not in the Water, it was found, that whether the Observers on the *Westminster* Shore, upon the Discharge of the electrified Phial, did or did not feel its Effects, they were always perceiv'd not only in the Arms of those upon the *Surry* Shore, who formed a Line between the Extremity of the Wire there, and the Water of the River ; but by any other Person, who standing upon the Stone Steps, even where they were not wet, touched the Wire with his Hand. They were likewise felt by a Person upon the *Westminster* Shore, standing upon the wet Stone Steps, who did not form Part of the Line between the Extremity of the conducting Wire and the Water, otherwise than by touching the Wire with his Fingers.

As was before-mention'd, the Observers upon the *Westminster* Shore did not feel the Effects of the discharged Phial near so strong as those on that of *Surry* in the first Set of these Experiments. When a Line was there form'd by the joining Hands of two or more Persons, the first of which, on account

of the Situation, held the conducting Wire in his left Hand, and the last touched the Water with an iron Rod held in his right, the Effects were most sensible in the left Arm of him who held the Wire : They were indeed manifestly felt by them all ; but this Feeling was not great enough to be called a Shock, but, as was very properly expressed by one of the Company, it resembled the Pulsation of a large Artery.

From the Examination of the first and second Questions it appeared, that the Observers upon the *Westminster* Shore were not sensible of the Effects of the Electricity, unless their Bodies described Part of the Circuit before spoken of; and this Circuit here consisted of Part of the Gun-barrel of the electrifying Machine, the Wire going from this Gun-barrel to the iron Hook, the Phial itself, the rail Wire of this coated Phial which reached therefrom across the Bridge and down the Steps on the *Westminster* Shore, the Line of Observers between this Wire and the iron Rod which dipp'd in the Water there, this iron Rod, a supposed Line of Water drawn quite across the *Thames*, the Observers with their iron Rod on the *Surry* Shore, the iron Wire going from the right Hand of the last of these up into the Room where the electrifying Machine was placed, and the short iron Rod to which one Extremity of this Wire was joined, and with which, in making the Explosion, the Gun-barrel was touched. The Length of this Circuit, through which the Electricity was propagated was at least 800 Yards, more than 400 Yards of which was formed by the Stream of the River.

From the Examination of the third Question it appeared, that the electrical Commotion would not be

be felt from the Observer dipping his Hand in Water only, unless that Water was so disposed as to become Part of the Circuit: and this Experiment was made, lest the contrary might be surmised.

The Observers upon the *Westminster* Shore not feeling the electrical Commotion equally strong with those of *Surry*, was judged to proceed from other Causes besides that of Distance. For it must be consider'd, that the conducting Wire was almost throughout its whole Length laid upon *Portland* Stone standing in Water. This Stone, being in a great Degree non-electric, is of itself a Conductor of Electricity: And this Stone standing in Water, no more of the Electricity was transmitted to the Observers on the *Westminster* Shore than that Proportion, wherein Iron is more non-electric, and, consequently, a better Conductor of Electricity than Stone. This was made more manifest, from observing that whether the conducting Wire upon the Bridge was broke or no, and, consequently, whether the Observers upon the *Westminster* Shore felt the electrical Commotion or no, not only the Observers upon the *Surry* Shore, who with their Wire form'd Part of the Line, felt the Shock in their Arms; but those Persons who only stood upon the Stone Steps there, and touched the Wire with their Fingers, felt the electrical Commotion in the Arm of that Hand which touched the Wire, and down their Legs. From whence, and from the Person before spoken of feeling the electrical Commotion standing upon the wet Stone Steps of the *Westminster* Shore, tho' not forming Part of the Line, but only touching the Wire with his Fingers, it was concluded, that, besides the large Circuit before spoken of, there were

formed several other subordinate Circuits between the same Steps of the *Surry* Shore, and the Bridge by means of the Water; whereby that Part of the electrical Power, felt by the Observers upon the *Surry* Side of the River, and not by those on the *Westminster* Side, was discharged.

Dr. *Bevis* having observed, and which was likewise tried here, that however well an electrified Phial was charged, its iron Hook would not fire the Vapours of warm Spirit of Wine held in a Spoon and applied thereto, if the Person who held the Phial, and he who held the Spoon did not take each other by the Hand, or have some other non-electrical Communication between them; it was therefore thought proper to try the Effects of Electricity upon some warm Spirit of Wine through the large Circuit before-mention'd. Accordingly the Observers being placed as before both upon the *Westminster* and *Surry* Shores, no other Alteration was made in the before-mention'd *Apparatus*, than that the Wire which connected the Gun-barrel with the iron Hook of the coated Phial being laid aside, the coated Phial itself was charged at the Gun-barrel, and then brought in the Hands of an Observer near the warm Spirits in the Spoon, which was placed upon the short iron Rod before-mention'd, which was connected with the Wire which went to the Observers upon the *Surry* Shore. Upon presenting properly the iron Hook of the charged Phial to the warm Spirit, it was instantly fired, and the electrical Commotion felt by the Observers on both Sides of the River.

It was then thought proper to try the Effects of the charged Phial upon the warm Spirit, when the
Wire

Wire was divided which was laid over the Bridge : Upon presenting the iron Hook to the Spirit, a sufficient Snap was given to the Spoon to fire the Spirit, but nothing so smart as in the former Experiment where the large Circuit was completed.

It was then tried, what the Effect would be upon the Spirit, if the charged Phial was divested of its long Wire which lay over the Bridge, and was only held in the Hand of an Observer ; whilst the Spoon with warm Spirit was placed in Contact of the iron Rod before mention'd, to which the Wire was connected, which went to the Observers upon the *Surry* Shore ; and the Spirit was fired with much the same Degree of Smartness as in the last Experiment.

In these and all the subsequent Operations, Wires were made use of to conduct the Electricity preferable to Chains, as it before by great Numbers of Experiments had been fully proved, that whatever Difference there was in the Bulk of the Conductor, that is to say, whether it were a small Wire, or a thick iron Bar, the electrical Strokes communicated thereby were equally strong : And it had been further observed, besides the Difficulty of procuring Chains of a requisite Length for the present Purposes, that the Stroke at the Gun-barrel, when the Electricity was conducted by a Chain, was *cæteris paribus* not so strong, as when that Power was conducted by a Wire. This was occasion'd by the Junctures of the Links of the Chain not being sufficiently close, which caused the Electricity in its Passage to snap and flash at the Junctures, where there was the least Separation ; and these lesser Snappings in the whole Length of the Chain less'n'd the great one of the Gun-barrel.

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Encouraged by the Success of these Trials, the Gentlemen were desirous of continuing their Inquiries, and of knowing whether or no the electrical Commotions were perceptible at a still greater Distance. The *New River* near *Stoke-Newington* was thought most convenient for that Purpose; as at the Bottom of that Town, the Twinings of the River are so circumstanced, that from a Place which we will call *A* to another *B*, the Distance by Land is about 800 Feet, but the Course of the River is near 2000. From *A* to another Place, which we will call *C*, in a right Line is 2800 Feet, but the Course of the Water is near 8000 Feet.

Accordingly, on *Friday July 24. 1747* there met at *Stoke-Newington* the *President* of the *Royal Society*, the Right Honourable the Lord *Charles Cavendish*, the Rev. Mr. *Birch*, *James Burrow* Esq; *Peter Daval* Esq; Mr. *George Graham*, *Wm. Jones* Esq; *James Lever* Esq; Mr. *Newcome*, *Charles Stanhope* Esq; Mr. *Trembley* and myself, who were of the *Royal Society*, and Dr. *Bevis*. To this Gentleman the Company were much obliged, not only for his great Readiness in assisting in all the Operations, but likewise for the Use of his electrifying Machine, which from its Size was conveniently portable. This Machine was now placed in a Room up one Pair of Stairs in a House near *A*, and the Signals from thence might easily be perceived by the Observers both at *B* and *C*.

It was proposed, first to try the electrical Commotion by the same Observers as at *Westminster-Bridge*, from *A* to *B*, the Distance as before-mentioned

tion'd being about 800 Feet by Land, and 2000 by Water, in order if possible to determine the Difference of the Strength of the Electricity felt there, and at the Stone-Bridge at *Westminster*; the Difference of the Length of the 2 Circuits being about 400 Feet in Favour of that of the new River.

To make the Experiment, an iron Wire was fastened to the Coating of the glass Phial before-mention'd, and conducted from one of the Windows of the Room over the new River without touching the Water; and from thence to *B*, laying in its whole Length upon the Grass in the Meadows, except where it pass'd over a Hedge. At *B*, when the Explosion was to be made, one or more Observers were to take the Extremity of this Wire in one Hand, and touch the Water of the River as before with an iron Rod held in the other. Another Wire was let down from the other Window of the Room; one Extremity of which was joined to the short iron Rod mention'd in the former Experiments, the other was held in the Hand of an Observer at *A*, whose other Hand held an iron Rod dipp'd into the River.

It was absolutely necessary that these Wires should touch each other in no Part of their Length, otherwise the before-mention'd Circuit would upon the Explosion be completed from their first Contact.

When every thing was thus disposed, and the Signals given, the charged Phial was exploded eight times, and the electrical Commotion every time smartly felt by the Observers both at *A* and *B*. Whether the Line of Observers at *B* consisted of one or more, they were always struck, and that more sharply than at *Westminster Bridge* under the

same Circumstances. One of the Observers, taking the Wire in his Hand without having any Communication either with any of the other Gentlemen or the Water of the River, felt the Shock in his Feet.

It was then thought proper to make right Explosions without any other Alteration in the *Apparatus* than that the Observers at *B*, should stand in the Meadow at some Distance from the Water, without having any Communication therewith other than that furnished by the Ground. This was accordingly done, and the Stroke felt little if at all less than those last-mention'd. But the electrical Strokes being felt smartly at the Distance of at least 20 Feet from the Water occasion'd a very perplexing Difficulty, as it was impossible by this Experiment to determine with any Certainty, whether or no the electrical Circuit was formed throughout the Windings of the River, or much shorter by the Ground of the Meadows. The Experiment plainly shewed that the Meadow-Ground with the Grass thereon conducted the Electricity better than Stone; as it must be remember'd, that the Observers upon the Stone Steps upon the *Westminster* Shore felt not in the least degree the electrical Commotion, when their iron Rod was not in the Water, and themselves stood upon the dry Stone Steps. But this Effect was supposed to be owing to the Meadow Ground here being encompassed on two Sides by the *New River*, and on the other by a wet Ditch, by both which it was generally well moisten'd. To solve therefore this Difficulty a Series of Experiments were executed, of which hereafter.

The Gentlemen then determin'd to examine whether the electrical Commotions were perceptible
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Commutations were perceptible from *A* to *C*; a Distance not less than 2800 Feet by Land, and near 8000 by Water.

To execute this, to the former Wire, which was already conducted to *B*, another was added, which there crossed the River without touching the Water; and reached almost to *C*, where the first of a Line of Gentlemen held as before the Wire in one Hand, and the last dipp'd the Iron into the Water. The Wire from the Machine to *A* was as before. Upon the Signal's being given, the charged Phial was exploded ten times, and its Effects plainly though but faintly perceived each time by some or other of the Observers, but never by them all. The electrical Commotion was always felt by that Observer, who held the Extremity of the Wire, but never by him who held the iron Rod in the Water. It was in one Experiment felt by the Observer who held the Wire, not felt by the next who held the Hand of the former, and yet plainly perceived by the third who joined the second. Those who did not themselves feel the electrical Commotion here, did as at *B* see the involuntary Motions of those who did. The Observers at *A* felt the Shocks in the same Degree, whether the other Observers were station'd at *B* or *C*.

This Experiment further demonstrates the Distance to which the electrical Power may be conveyed: but the same Difficulty occurs here as in the last; to wit, whether the Circuit was completed by the Ground, or by the Water of the River?

These same Operations, which shewed at how great a Distance the electrical Commotion was per-

ceptible, solved likewise three Questions of a subordinate Nature.

First, whether or no, *cæteris paribus*, any Difference occurred in the Success of the Experiment, if the long Wire, instead of being joined to the Coating of the Phial, was fasten'd to the short iron Rod, which upon touching the Gun-barrel occasion'd the Explosion; and if the short Wire, which only went to the Observer at *A*, a Distance from the Machine not more than 30 Feet, was joined to the Coating of the Phial? Upon Trial no Difference * was found.

Secondly, Whether or no, *cæteris paribus*, any Difference in the electrical Commotion would be perceived, when that Power passés through the Arms of two Observers, whose Bodies made Part of the Circuit, standing in the Room near the electrifying Machine; one of which takes the Extremity of the Wire that goes to the Observer at *A* in one Hand, and touches the Gun-barrel with the short iron Rod held in his other Hand? The other Observer takes the Extremity of the Wire which goes to *B* or *C* in one Hand, and touches the Coating of the charged Phial with his other. In several Trials, where each of these Observers frequently changed Stations, no Difference in point of Strength was observed in the electrical Commotion.

Thirdly,

* No Difference is observed when the electrical Circuit is propagated through Substances which readily conduct Electricity; if they conduct it in a less Degree, the electrical Commotion is most perceptible to the Observer, who holds the Wire, which comes from the charged Phial.

Thirdly, Whether or no these two Observers last-mention'd received the Shock at the same time? They were seen to be both convulsed in the same Instant.

July 28. 1747, there met again at the same Place, to proceed further in these Inquiries, the *President* of the *Royal Society*, the Right Honourable the Lord *Charles Cavendish*, the Reverend Mr. *Birch*, Sir *Francis Dashwood* Baronet, *Peter Daval* Esq; Mr. *Ellicott*, Mr. *George Graham*, *Richard Graham* Esq; Mr. *Robins*, Mr. *Short*, Dr. *Wilbraham*, and myself, who were of the *Royal Society*, and Dr. *Bevis*.

The electrical Commotion was first tried from *A* to *B* before-mention'd, the iron Wire in its whole Length being supported, without any-where touching the Ground, by dry Sticks placed at proper Intervals of about three Feet in Height. The Observers both at *A* and *B* stood upon Originally-Electrics, and, upon the Signal, dipped their iron Rods into the Water. Upon discharging the Phial, which was several times done, they were both very much shocked, much more so than when the conducting Wires lay upon the Ground, and the Observers stood thereon, as in the former Experiments. The same Experiment was tried with the Observer at *A*, instead of the iron Rod, dipping a narrow Slab of *Portland Stone* into the Water of about three Feet and a half in Length; when the Shock was felt, but not so severe as through the iron Rod. This demonstrated, as was before suggested, why the electrical Commotion was not felt stronger by the Observers upon the Western Shore of the *Westminster-Bridge*;

Bridge; viz. that *Portland* Stone standing in Water will conduct Electricity very considerably.

The Gentlemen then tried what would be the Effect, if the Observer at *B* stood upon a Cake of Wax holding the Wire as before, and touched the Ground of the Meadow with his iron Rod at least 150 Feet from the Water; and if the Observer usually placed near the River at *A*, had his Wire carried 150 Feet over the River as the former, stood upon an Originally-Electric, and touched the Ground with his iron Rod. Upon the Explosion of the charged Phial, which was several times done, both the Observers were smartly struck: This demonstrated, that in these Instances the moist Ground of the Meadows made Part of the Circuit. The Observers were distant from each other about 500 Feet.

The Observers then, station'd as in the last Experiment, stood upon the wax Cakes as before, without touching the Ground with the iron Rods, or any Part of their Bodies, and the charged Phial was exploded four times. These were not at all felt by the Observer next to *B*, and without the greatest Attention would not have been perceived by him next to *A*; and then only in some of the Trials, the Feeling of the Electricity was like that of a small Pulse between the Finger and Thumb of that Hand which held the Wire. The loaded Phial was again discharged four times more, without any other Alteration in the Disposition of the *Apparatus* than that the Observer next to *B* stood upon the Ground; when the electrical Commotion was perceived by that Observer, though not so sharp as when the other Observer at the same time stood upon

upon the Ground. The Observer next to *A* felt the Tingling between his Finger and Thumb as before.

The Gentlemen were desirous of trying the electrical Commotion at a still greater Distance than any of the former through the Water, and where, at the same time by altering the Disposition of the *Apparatus*, it might be tried, whether or no that Power would be perceptible through the dry Ground *only* at a considerable Distance. *Highbury Barn* beyond *Islington* was thought a convenient Place for this Purpose, as it was situated upon a Hill nearly in a Line, and almost equidistant from two Stations upon the *New River*, somewhat more than a Mile asunder by Land, though following the Course of that River their Distance from each other was two Miles. The Hill between these Stations was of a gravelly Soil; which, from the late Continuance of hot Weather without Rain, was dry, full of Cracks, and consequently was as proper to determine whether or no the Electricity would be conducted by dry Ground to any great Distance, as could be desired. This hitherto had not been attempted; the Meadows in the Instances before quoted conducting the Electricity was supposed to be owing to the Moisture of the Ground. The Streets of *London*, when very dry, had been found to conduct it strongly about forty Yards, and the dry Road at *Newington* about the same Distance. Accordingly, on *Wednesday, Aug. 5. 1747.* there met at *Highbury-Barn* the Right Honourable the Lord *Charles Cavendish*, the Reverend Mr. *Birch*, Mr. *George Graham*, *Richard Graham* Esq; *N. Mann* Esq; Mr. *Short*,

Short, Daniel Wray Esq; and myself, who were of the Royal Society, and Dr. Bevis.

The electrifying Machine being placed up one Pair of the Stairs in the House at *Highbury-Earn*, a Wire from the coated Phial was conducted upon dry Sticks as before to that Station by the Side of the *New River*, which was to the Northward of the House. The Length of this Wire was 3 Furlongs and 6 Chains, or 2376 Feet. Another Wire fasten'd to the iron Bar, with which, in making the Exploston, the Gun-barrel was touched, was conducted in like manner to the Station upon the *New River* to the Southward of the House. The Length of this Wire was 4 Furlongs 5 Chains and 2 Poles, or 3003 Feet. The Length of both Wires, exclusive of their Turnings round the Sticks, was 1 Mile 1 Chain and 2 Poles, or 5379 Feet. For the more conveniently describing the Experiments made here, we will call the Station to the Northward *D*, and the other *E*.

At this Distance the Gentlemen propos'd to try, first, Whether or no the electrical Commotion was perceptible, if both the Observers at *D* and *E*, supported by Originally-Electrics, touched the conducting Wire with one Hand, and the Water of the *New River* with an iron Rod held in the other? Secondly, Whether or no that Commotion was perceptible, if the Observer at *E*, being in all respects as before, the Observer at *D*, standing upon Wax, took his Rod out of the Water? Thirdly, Whether or no that Commotion was perceptible to both Observers, if the Observer at *D* was placed upon Wax,
and

and touched the Ground with his iron Rod in a dry gravelly Field at least 300 Yards from the Water?

As from the Situation of the Ground, Trees, &c. neither of the Stations could be seen by each other, or by the Observer at the electrifying Machine, it was agreed to discharge a Gun as a Signal to get ready, and to do the same, as near as might be, half a Minute before each Explosion.

In these Experiments, as well as the former, the coated Phial was each time charged as high as it could be; so that if the Difference of the Shock to the Observers was considerable, it was owing to other Causes more than to the Phial's being differently electrified.

To try the first Proposition, eight Explosions were made with the Observers at *D* and *E*, touching the Water, and standing upon Wax, with their iron Rods in the Water. The first two of these were felt but weakly by the Observer at *D*; but in the other six he was strongly shocked. The Observer at *E* felt nothing of the first six Explosions; when, upon Examination, the Wire was found broken by some Accident; but this Observer was strongly shocked by the two last. The Observer at *D* being shocked in four of these Explosions, while in these four the Observer at *E* felt nothing, was owing to the Circuits being formed by the Ground between the Observer at *D* and the broken Wire. Upon account of the Wire's being broken, the Gentlemen tried three more Explosions, when the Observers at both Stations felt the electrical Shock.

To try the second Proposition, four Explosions were made with the Observer at *D* standing upon
an

an Originally-Electric, and taking his iron Rod out of the Water, the Observer at *E* as before. In each of these the Observer at *D* felt a small Pulsation between his Finger and Thumb of that Hand, which held the Wire. The Observer at *E* felt each of these as strong as before. This being different from the Observations made in the Experiments of the last Trials at our former Stations *A* and *B*, and many others; where *B* in the same Circumstances with *E* here felt the electrical Commotion only in a slight Degree, was owing, as we were afterwards informed, to the impertinent Curiosity of the Servants of the Gentlemen, and other voluntary Observers, who, by touching the Wire which went from the coated Phial to the Observer at *D*, felt the Shock in their Arms and Ankles, and formed subordinate Circuits to *E*. The preventing these People from touching the Wires, was impossible; as great Part of them could be seen neither by the Observers at the Stations, nor by those at the House, and their being more than a Mile long.

The four other Explosions were made without any other Alteration in the *Apparatus*, than that the Observer at *D* stood upon the Ground about four Yards from the Water without any Communication therewith. The Observer at *E* felt the Shocks in his Arms as before; but the Observer at *D* standing upon the Ground was shocked in the Elbow and Wrist of that Arm which held the Wire, and in both his Ankles.

To try the third Proposition, eight Explosions were made with the Observer at *D* standing upon an Originally-Electric with his Rod in the Water of the

the

the River as before; but the Observer at *E* was placed in a dry gravelly Field about 300 Yards nearer the Machine than his last Station, and about 100 Yards distant from the River. He there stood upon the Wax, holding the conducting Wire in one Hand, and touched the Ground with an iron Rod held in the other. The Shock was each time felt by the Observer at *D*, but sensibly weaker than in the former Trials; but the Observer at *E* felt them all equally strong with the former; the four first in his Arms, when he stood upon the Wax, and touched the Ground with his iron Rod; the other four in his Arm and Ankles, when he stood upon the Ground without the iron Rod.

In some of these Experiments, the Observers at *D* felt a Tingling as soon as they laid hold of the conducting Wire. This was conjectured to be owing to the Electricity, which constantly runs off while the coated Phial is filling, and preferably by the Wire, as the best Conductor.

From the Severity of the Shock, the Gentlemen, in some of these Trials, did not choose to have the Electricity pass through their Bodies: But, as it was necessary for them to be sensible of the different Degrees of the electrical Commotions, they bound the conducting Wire round one of their Thumbs, and touched the iron Rod with the Fore-finger of the same Hand; when the electrical Commotion was felt only in so much of the Finger and Thumb of that Hand, as completed the Circuit.

By the Experiments of this Day, the Gentlemen were satisfied, that the dry gravelly Ground conducted the Electricity as strongly as Water; which, though

otherwise at first conjectured, they now found not to be necessary to convey that Power to great Distances; as well as that, from Difference of Distance only, the Force of the electrical Commotion was very little if at all impaired. They were convinced of the Truth of the first of these Facts, not only from both Observers feeling the electrical Commotion in the eight last Experiments, when the Observer at *E* was at such a Distance from the Water, but also from the Observer at *D* feeling the Shock so strong in four of the first six Explosions, when the conducting Wire to *E* being broke at about 100 Yards Distance from the House, that Observer felt nothing.

In this last Instance the Circuit was formed from the Phial by the Observer at *D* and his Wire, a Line of Ground which reached from the Station at *D* to the broken Wire that lay upon the Ground, and so much of this Wire as reached to the short iron Rod, which touched the Gun-barrel in making the Explosions. This induced the Gentlemen to conclude (as from many Experiments it was manifest, that when the intervening Substances conduct Electricity equally well, the Circuit was performed in the shortest manner possible), that when the Observers holding their iron Rods in the River at *D* and *E* were both shocked, the Electricity was not conveyed by the Water of the River, being two Miles in Length, but by Land, where the Distance was only one Mile; in which Space that Power must necessarily pass over the *New River* twice, through several Gravel-Pits, and a large Stubble-Field. So that, admitting the Electricity did not

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follow

follow the Tract of the River, the Circuit from *D* to *E* was at least two Miles; *viz.* somewhat more than one Mile of Wire, which conducted the Electricity from the House to the Stations, and another Mile of Ground, the shortest Distance between those Stations. The same Inference was now drawn with regard to the Experiments at *A*, *B*, and *C*, in the *New River* before recited; *viz.* that as in all of them the Distance between the Observers was much greater by Water than by Land, the Electricity passed by Land from one Observer to the other, and not by Water.

From the Shocks which the Gentlemen received in their Bodies, when the electrical Power was conducted upon dry Sticks, they were of Opinion, that from Difference of Distance simply consider'd, as far as they had yet experienced, the Force thereof was very little if at all impaired. When they stood upon Originally-Electrics, and touched the Water or Ground with an iron Rod, the electrical Commotion was always felt in their Arms and Wrists: When they stood upon the Ground, and touched either the Water or Ground with their iron Rods, they felt the Shock in their Elbows, Wrists, and Ankles: When they stood upon the Ground without the Rod, the Shock was always in the Elbow and Wrist of that Hand, which held the conducting Wire, and in both Ankles. The Observers here being sensible of the electrical Commotion in different Parts of their Bodies, was owing in the first Instance to the Whole of its passing (because the Observer stood upon Wax) through their Arms, and through the iron Rod: In the second, when they stood upon the Ground,

the Electricity passed both through their Legs, and thro' the Iron : In the third, when they stood upon the Ground without either Wax or Rod, the Electricity directed its Way through one Arm, and through both Legs to complete the Circuit.

The Gentlemen were desirous of closing the present Inquiry, by examining not only whether or no the electrical Commotions were perceptible at double the Distance of the last Experiments in Ground perfectly dry, and where no Water was near ; but also, if possible, to distinguish the respective Velocities of Electricity and Sound. To execute this, required the whole Sagacity and Address of the Gentlemen concerned ; for they had met with very great Difficulties in the last Day's Operations, where the Wire was conducted but little more than a Mile ; all which could not but be greatly augmented by doubling that Distance ; because it was necessary, that the House, wherein the electrifying Machine was placed, should be visible at least at one of the Stations ; and that the Space between that House and the Stations, through which the Wire was conducted, should be very little intersected by Hedges, Roads, or Foot-paths ; neither should the Wire in this Space be subject to be disturbed by the Horses or Cattle, which were grazing ; nor ought it to touch in its Passage the Trees or any other Vegetables, which at this Season of the Year were every-where luxuriant. To find a Place within a convenient Distance of *London* with these Requisites was not very easy ; but at last, *Shooters Hill* was pitched upon, as the most convenient.

As

As only one Shower of Rain had fallen during the preceding five Weeks, the Ground could not but be very dry; and as no Water was near, if the electrical Commotion was felt by the Observers at the Stations, it might be safely concluded, that Water had no Share in conducting it.

August 14. 1747. there met at *Shooters Hill* for this Purpose, the Rev. Mr. *Birch*, the Rev. Mr. Professor *Bradley*, *Peter Daval* Esq; Mr. *George Graham*, *R. Graham* Esq; Mr. *Nourse*, *George Lewis Scott* Esq; Mr. *Short*, *Charles Stanhope* Esq; and myself, who were of the *Royal Society*, and Dr. *Bevis*.

It was here determin'd (as the Gentlemen were satisfied from many of the former Trials, that if, when the coated Phial was discharged, the Observers at the Stations stood upon Originally-Electrics, and touched neither Water nor Ground with iron Rods, or any Part of their Bodies, the electrical Commotion would be scarcely perceptible) to make twelve Explosions of the coated Phial, with an Observer placed at the seven Mile-Stone, and another at the nine Mile-Stone, both standing upon Wax, and touching the Ground with an iron Rod. This Number of Explosions was thought more necessary, as the Observers at these Stations were not only to examine whether or no the Electricity would be propagated to so great a Distance; but if were, the Observer at the seven Mile-Stone was by a second Watch to take notice of the Time lapsed between feeling the electrical Commotion, and hearing the Report of a Gun fired near the Machine, as close as might be to the Instant of making the
Explosion:

Explosion : And therefore, to examine this Matter with the requisite Exactness, this Number of Explosions should be made.

To execute this, the electrifying Machine was placed up one Pair of Stairs in a House upon the West Side of *Shooters Hill*; and a Wire from the short iron Rod, with which the Gun-barrel was touched in making the Explosions was conducted upon dry Sticks as before into a Field near the seven Mile-Stone. The Length of this Wire, exclusive of its Turnings round the Sticks, was a Mile, a Quarter and eight Poles, or 6732 Feet. In great Part of this Space it was found very difficult to support the Wire, on account of our scarcely being able to fix the Sticks in the strong Gravel there almost without any Cover of Soil; nor could the Wire in some Places be prevented from touching the Brambles and Bushes, nor in one Field the ripe Barley.

Another Wire was likewise conducted upon Sticks from the coated Phial to the nine Mile-Stone. In this Space, the Soil being a strong Clay, the Wire was very well secured, and in its whole Length did not touch the Bushes. The Length of this Wire was 3868 Feet. As much as the Place, where the Observers were station'd in a Corn-Field, was nearer the Machine than the seven Mile-Stone, so much were the other Observers placed beyond the nine Mile-Stone, that their Distance from each other might be two Miles. The forty Feet of Wire in these two Measures exceeding two Miles, was what connected the short iron Rod before-mention'd, and the coated Phial, with their respective conducting Wires.

The Observers being placed at their respective Stations, the Observer at the Machine proceeded in making the Explosions of the coated Phial; he having before placed an Assistant exactly in his View before the Window of the House, who, upon the Word of Command, was to discharge a Musket. As soon as ever the Flash was seen to come from the Mouth of the Gun, the Observer discharged the electrified Phial. When eight Explosions had been made, a Servant was sent from the Gentlemen at the seven Mile-Stone giving an Account of the Wire's being broken, and the Sticks thrown down by a Man riding through them; that the Observers there had felt nothing; and desired, as by this time the Wire was replaced, that we should begin again. This was complied with, and twelve other Explosions made without further Molestation.

Not only the first eight, but eleven of the last twelve very strongly shocked the Observers at the nine Mile-Stone: At the twelfth Explosion the Observer on purpose stood upon the Wax without touching the Ground with his iron Rod, or any Part of his Body; and only felt a slight Tingling in his Finger and Thumb that held the Wire. In another of these Experiments, as the Gentlemen here were satisfied in their own Persons of the Strength of the electrical Commotion, they indulged two Country Fellows, who were By-standers, with feeling one: These two with four of the Gentlemen formed a Chain, the first of them taking hold of the Extremity of the Wire with one of his Hands. They all stood upon the Ground, and made no Use

of the iron Rod. Upon the Explosion they were all so strongly shocked in their Arms and Ankles, that the Countrymen could by no means be prevailed upon to try the Experiment again. Why, in the first eight Explosions, the Observers here were sensible of the electrical Commotion, when the Observers at the other Station felt nothing, was explained in the former Experiments. The Observers at this Station, from their Situation under the Hill, and from what Wind there was being against it, never heard the Report of the Gun.

Though the Observers near the seven Mile-Stone from the breaking of their Wire, were not sensible of the eight first Explosions of the charged Phial, they felt the other twelve. This demonstrated to the Satisfaction of the Gentlemen concerned, that the Circuit here formed by the Electricity was four Miles; *viz.* two Miles of Wire, and two Miles of Ground, the Space between the Extremities of that Wire. A Distance without Trial too great to be credited! How much further the electrical Commotion will be perceptible, future Observations can only determine.

The electrical Commotion by the Observers near the seven Mile-Stone was but slightly felt; nor could it be otherwise expected, the Wire in many Parts of its Length touching, as was before-mention'd, the moist Vegetables; which, in as many Places as they were touched, formed subordinate Circuits. We find, in all other Instances, that the whole Quantity of Electricity, accumulated in the coated Phial, is felt equally through the whole Circuit, when every

every Part thereof is in a great degree non-electric; so here the whole Quantity, or nearly so †, determined that Way, was felt by the Observers at the nine Mile-Stone; whilst those at the other Station felt so much of their Quantity only, as did not go through the Vegetables; that is, that Proportion only in which Iron is a greater Non-electric than the Vegetables.

Tho' the electrical Commotions, felt by the Observers near the seven Mile-Stone, were not strong; they were equally conclusive in shewing the Difference between the respective Velocities of Electricity and Sound.

The Space through which Sound is propagated in a given Time, has been very differently estimated by the Authors, who have wrote concerning this Subject. *Roberval* gives it at the Rate of 560 Feet in a Second; *Gassendus*, at 1473; *Mersenne* at 1474; *Du Hamel*, in the History of the *Academy of Sciences at Paris*, at 1172; the *Academy del Cimento*, at 1185; *Boyle* at 1200; *Roberts* at 1300; *Walker* at 1338; *Sir Isaac Newton* at 968; *Dr. Derham*, in whose Measure *Mr. Flamsteed* and *Dr. Halley* acquiesced, at 1142. But by the Accounts since published by *M. Cassini de Thury* in the *Memoirs of the Royal Academy of Sciences at Paris* for the Year 1738. where Cannon were fired at various as well as great Distances, under great Variety of Weather, Wind, and other Circumstances,
and

† The Author of this Paper, from a great Variety of Experiments, is of Opinion; that in this and the like Dispositions of the Apparatus, the electrical Power, accumulated in the Matter contained in the coated Phial, is directed upon the Explosion thereof towards both Observers at the same Instant.

and where the Measures of the different Places had been settled with the utmost Exactness, Sound was propagated at a *Medium* at the Rate only of 1038 *French* Feet in a Second. The *French* Foot exceeds the *English* by seven Lines and a half, or is as 107 to 114: And consequently 1038 *French* Feet are equal to 1106 *English* Feet. The Difference therefore of the Measures of Dr. *Derham* and M. *Cassini* is $\frac{34 \text{ French}}{36 \text{ English}}$ Feet in a Second.† According to this last Measure, the Velocity of Sound, when the * Wind is still, is settled at the Rate of a Mile, or 5280 *English* Feet in 4" $\frac{77}{100}$.

To return to our Purpose; the Length of the conducting Wire from the Machine to the Observers near the seven Mile-Stone was (as has been before-mention'd) a Mile, a Quarter, and 8 Poles, or 6732 Feet: The Length of that to the nine Mile-Stone, 3868 Feet. The first of these Measures only was made use of in the present Operations concerning the Velocity of Electricity. In twelve Discharges of the coated Phial, which were felt by Mr. *George Graham*, Mr. *Skort*, and *Charles Stanhope* Esq; the Observers near the seven Mile-Stone, and who, by a second Watch of Mr. *Graham's*, measured the
Time

† M. *Cassini de Thury* afterwards measured the Velocity of Sound at *Aiguemortes* in *Languedoc*, and found the Observations there from those made about *Paris* vary only half a Toise in a Second. See *Mem. de l'Acad. Royale des Sciences, pour l'année 1739, p. 126.*

* Dr. *Derham* found, that when Sound was carried against the Wind, not only its Distance but its Velocity was lessen'd; and in M. *Cassini's* Memoir, there is an Experiment, where Sound being carried against the Wind, which then blew very strong, was retarded near a twelfth Part of the usual Time in its Progress.

Time between feeling the electrical Commotion, and hearing the Report of the Gun, with the utmost Attention and Exactness; the Time, I say, between feeling the electrical Commotion, and hearing the Report of the Gun, was, at a *Medium*, 5 Seconds and a Quarter, or $5'' \frac{250}{1000}$. And as the Gun was distant from these Observers 6732 Feet, it follows, from the Experiments, which have been made on the Velocity of Sound, that the real Instant of the Discharge of the Gun preceded that of the Observers hearing its Report, at this time when the Strength of the Wind was not so great as to enter into the Computation, $6'' \frac{687}{1000}$; or preceded the Instant when the electrical Commotion was felt only $0'' \frac{237}{1000}$. But this Instant was, from the Nature of the Experiment, necessarily prior to that of the electrical Explosion, which was not made till the Fire of the Gun was actually seen; and therefore the Time between the making of that Explosion, and its being actually felt by the Observer, which must have been less than $0'' \frac{837}{1000}$, was really so small, as not to fall under any certain Observation, when it is to be distinguished from that, which must of Necessity be lost, between the Firing of the Gun, and the electrical Explosion itself.

In all the Experiments, where the Circuit was formed to any considerable Length, though the coated Phial was very well charged, the Snap at the Gun-barrel, upon the Explosion, was not near so loud as when the Circuit is formed in a Room; so that a By-stander, though versed in these Operations, from seeing the Flash, and hearing the Report, would imagine the Stroke at the Ends of the conducting Wire to be very slight; the contrary whereof,

when the Wire has been properly conducted, has always happen'd.

From a Review of these Experiments, the following Observations may be deduced.

- I. That, in all the preceding Operations, when the Wires have been properly conducted, the electrical Commotions from the charged Phial have been very considerable only, when the Observers at the Extremities of the Wire have touched some Substance readily conducting Electricity with some Part of their Bodies,
- II. That the electrical Commotion is always felt most sensibly in those Parts of the Bodies of the Observers, which are between the conducting Wires, and the nearest and the most non-electric Substance; or in other Words, so much of their Bodies, as comes within the electrical Circuit.
- III. That, upon these Considerations, we infer, that the electrical Power is conducted between these Observers by any non electric Substances, which happen to be situated between them, and contribute to form the electrical Circuit.
- IV. That the electrical Commotion has been perceptible to two or more Observers at considerable Distances from each other, even as far as two Miles.
- V. That when the Observers have been shocked at the End of two Miles of Wire, we infer, that the electrical Circuit is four Miles; *viz.* two Miles of Wire, and the Space of two Miles of the non-electric Matter

Matter between the Observers, whether it be Water, Earth, or both.

- VI. That the electrical Commotion is equally strong, whether it is conducted by Water or dry Ground.
- VII. That if the Wires, between the electrifying Machine and the Observers, are conducted upon dry Sticks, or other Substances non-electric in a slight Degree only, the Effects of the electrical Power are much greater than when the Wires in their Progress touch the Ground, moist Vegetables, or other Substances in a great Degree non-electric.
- VIII. That by comparing the respective Velocities of Electricity and Sound; that of Electricity, in any of the Distances yet experienced, is nearly instantaneous.

I shall conclude this Paper with observing, that it was thought convenient to lay a Detail of all the Operations relating to these Experiments before the *Society*; in consequence of which the Gentlemen may make themselves Judges, how far the Deductions here recited are warrantable from the Experiments.

* The Gentlemen concerned were desirous, if possible, of ascertaining the absolute Velocity of Electricity

* These Experiments to measure the absolute Velocity of Electricity were made whilst this Paper was at the Press, but as they had so near a Relation to the Experiments made the preceding Year, it was thought proper to insert them here.

Electricity at a certain Distance; because, although last Year, in measuring the respective Velocities of Electricity and Sound, the Time of its Progress was found to be very little, yet we were desirous of knowing, small as that Time was, whether it was measurable; and I had thought of a Method for this Purpose.

Accordingly, *August 5. 1748.* there met at *Stooter's Hill* for this Purpose the *President* of the *Royal Society*, the Rev. Mr. *Birch*, the Rev. Mr. Professor *Bradley*, *James Burrow Esq;* Mr. *Ellicot*, Mr. *George Graham*, *Richard Graham Esq;* the Rev. Mr. *Lawrie*, *Charles Stanhope Esq;* and myself, who were of the *Royal Society*, Dr. *Bevis*, and Mr. *Grischow* a Member of the *Royal Academy of Sciences at Berlin.*

It was agreed to make the electrical Circuit of two Miles, in the middle of which an Observer was to take in each Hand one of the Extremities of a Wire, which was a Mile in Length. These Wires were to be so disposed, that this Observer being placed upon the Floor of the Room near the electrifying Machine, the other Observers might be able in the same View to see the Explosion of the charged Phial and the Observer holding the Wires, and might take notice of the Time lapsed between the discharging the Phial and the convulsive Motions of the Arms of the Observer in consequence thereof; inasmuch as this Time would shew the Velocity of Electricity, through a Space equal to the Length of the Wire between the coated Phial and this Observer.

The electrifying Machine was placed in the same House as it was last Year. We then found ourselves greatly embarrassed by the Wire's being conducted by the Side of the Road, which we were compell'd to, on account of the Space necessary for the measuring of Sound: But so great a Distance from the Machine was not now wanted, though the Circuit through the Wire was intended to be at least two Miles. We had discover'd by our former Experiments, that the only Caution now necessary was, that the Wires conducted upon dry Sticks should not touch the Ground, each other, or any Non-Electric in a considerable Degree in any Part of their Length: if they did not touch each other, the Returns of the Wire, be they ever so frequent, imported little, as the Wire had been found to conduct Electricity so much better than the Sticks. It was therefore thought proper to place these Sticks in a Field fifty Yards distant from the Machine. The Length of this Field being eleven Chains or 726 Feet, eight Returns of the Wire from the Top to the Bottom of the Field made somewhat more than a Mile. and sixteen Returns more than two Miles, the Quantity of Wire intended for the Electricity to pass through to make the Experiment.

We had found last Year, * that, upon discharging the electrified Phial, if two Observers made their Bodies Part of the Circuit, one of which grasped the leaden Coating of the Phial in one Hand, and held in his other one Extremity of the conducting Wire; and if the other Observer held the other Extremity
of

* See Page 66.

of the conducting Wire in one Hand, and took in his other the short iron Rod with which the Explosion was made; upon this Explosion, I say, they were both shocked in the same Instant, which was that of the Explosion of the Phial. If therefore an Observer, making his Body Part of the Circuit, was shocked in the Instant of the Explosion of the charged Phial in the middle of the Wire, no Doubt would remain of the Velocity of Electricity being instantaneous through the Length of that whole Wire. But if, on the contrary, the Time between making the Explosion, and seeing the Convulsions in the Arms of the Observer holding the conducting Wires, was great enough to be measured, we then should be able to ascertain its Velocity to the Distance equal to half the Quantity of Wire employed only, let the Manner of the Electricity's discharging itself be what it would.

It has been a Question with some, who have consider'd this Subject, whether the Electricity, in completing the Circuit from the Matter contained in the Glass, passed, either by the Wire in the Mouth to the Coating of the Glass, the contrary Way by the Coating to the Wire in the Mouth, or otherwise directed itself both Ways at once? That the Electricity must pass off one of these three Ways was certain, as the Explosion would not be complete, unless in the Instant thereof some Matter very non-electric communicated between the Wire in the Mouth, and the Coating of the Glass. Unless therefore the Observer was placed in the Centre of the conducting Wires, it might be objected, that the Experiment was not made with the Exactness necessary; because any Person, who was of Opinion, that the Electricity directed

directed itself from the Mouth of the Glass to the Coating, might object, if the Wire from the short iron Rod to the Observer was only half the Length of that between the Observer and the Coating of the Glass, that the Electricity, in the Time found, passed only through the short Wire; and *vice versa*. But if, as it was here thought proper, the Observer was placed in the Centre of the conducting Wire, let the Direction of the Electricity be what it would, no Difference could happen in the Result of the Experiments, if made with the necessary Caution; because, if the Effects in the Middle and both Ends of the Wires were instantaneous, the Conclusion therefrom would be very obvious.

To make the Experiment, the same Phial filled with Filings of Iron, and coated with Sheet-Lead, which was used last Year, was placed in the Window of the Room near the Machine, and was connected to the prime Conductor by a Piece of Wire. To the Coating of this Phial a Wire was fastened, which, being conducted upon dry Sticks to the before-mentioned Field, was carried in like manner to the Bottom, and being conducted thus from the Bottom of the Field to the Top, and from the Top to the Bottom seven other times, returned again into the Room, and was held in one Hand of an Observer near the Machine. From the other Hand of this Observer, another Wire of the same Length with the former was conducted in the same manner, and returned into the Room, and was fasten'd to the iron Rod with which the Explosion was made. The whole Length of these Wires, allowing ten

Yards for their Turns round the Sticks, amounted to two Miles a Quarter and six Chains, or 12276 Feet.

As the Night preceding these Experiments had been very rainy, Care was taken, by silk Lines properly disposed, that the Wires in their Passage from the Window of the House might not touch the Wood thereof; lest, from the Moisture of this Wood, the electrical Circuit might be shortened.

When all Parts of the *Apparatus* were properly disposed, several Explosions of the charged Phial were made; and it was invariably seen, that the Observer holding in each Hand one of the Extremities of these Wires was convulsed in both his Arms in the Instant of making the Explosions.

Instead of one, four Men were then placed holding each other by the Hand near the Machine, the first of which held in his right Hand one Extremity of the Wire, and the last Man the other in his left. They were all seen convulsed in the Instant of the the Explosion. Every one who felt it, complained of the Severity of the Shock.

It was then desired by one of the Gentlemen concerned, that an Explosion should be made with the Observer holding only one of the Wires. This was done accordingly; but the Observer felt nothing, the Phial discharging itself in a different manner to what it did before, on account of the Circuit's not being completed.

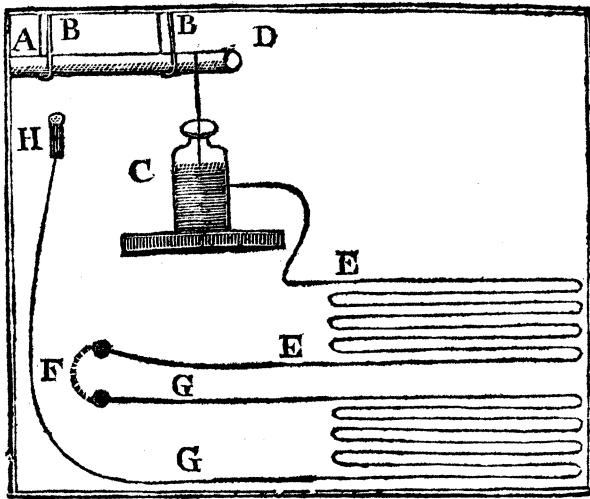
It was then tried, whether an Observer would be shocked upon the Discharge of the Phial, if the two Wires at their Extremities slightly touched each other, whilst an Observer at the same time held one of these about a Foot from their Ends in each of his Hands? Upon Trial he felt nothing, though the
Phial

Phial exploded very quick, because the iron Wire conducted the Electricity better than the Body of the Observer.

It was then tried, whether or no, as the Ground was wet, if the Explosion was made with the Observer holding the Extremity of each Wire standing upon the Ground near the Window of the House, any Difference would arise in the Success of the Experiment? No Difference was found, the Observer being shocked in the Instant of the Explosion as before in both his Arms, and across his Breast.

Upon these Considerations we were fully satisfied, that through the whole Length of this Wire, being as I mentioned before, twelve thousand two hundred and seventy-six Feet, the Velocity of Electricity was instantaneous.

As it was found last Year, we observed again, that although the electrical Commotions were very severe to those who held the Wires, the Report of the Explosion at the prime Conductor was little, in comparison of that which is heard when the Circuit is short. From whence it was conjectured, that the very loud Report, in the Experiment of *Leyden* is confined to a very short Circuit.



A, The prime Conductor.

B B, The silk Lines.

C, The coated Phial.

D, Its Hook communicating with the prime Conductor.

E E, The Wire reaching from the Coating of the Phial to the left Hand of the Observer, being more than a Mile in Length.

F, The Place of the Observer.

---, A supposed Line, drawn upon the Explosion through his Body and Arms.

G G, Another Wire, of the Length of **EE**, which goes from the right Hand of the Observer to **H**.

H, The short iron Rod to make the Explosion.

2. *Some further Inquiries into the Nature and Properties of Electricity; by William Watson F. R. S.*

Read Jan. 21.
1747-8.

§ I. I PRESENTED to the *Royal Society* October 29. last a Paper containing some Accounts of what had been done by some Gentlemen of the *Society*, in order to examine, not only to what Distance the electrical Power was perceptible, but also to investigate, as near as might be, the respective Velocities of Electricity and Sound: Electricity indeed is the Subject of the present Paper, yet, as it relates to *Phænomena* thereof different from those mention'd in the former, I thought proper to separate them.

§ II. I took notice, in my Sequel to the Experiments relating to Electricity *, of an Observation of the ingenious Professor *Bose* of *Wittemberg*, viz. ' that if the electrifying Machine is placed upon ' Originally-Electrics, the Man who rubs the Globe ' with his Hands, even under these apparently favourable Circumstances, gives no Sign of being electrified when touched by an unexcited Non-electric. ' But if another Person, standing upon the Floor, ' does but touch the Globe in Motion with the End ' of one of his Fingers, or any other Non-electric, ' the Person rubbing is instantly electrified, and that ' very strongly.' This Experiment, almost a Year since, Dr. *Bevis* carried further, by placing whatever

ever Non-electric touched the Globe as a Conductor, whether it were a Man or a Gun-barrel, upon Originally-Electrics. If then, either the Man who rubbed the Globe, or he who only held his Finger near the Equator thereof, were touched by any Person standing upon the Floor, a Snapping from either of them, I say, was perceptible upon that Touch.

§ III. As in my Sequel I had asserted, and by many Experiments therein had endeavoured to evince, that, contrary to the received Opinion, the Electricity was not derived from Glass, the Air, or other Electrics *per se*, I was desired to consider how far this Experiment did not prove the reverse of that Assertion; inasmuch as neither the Man who rubbed the Globe, or he who touched it with his Finger, from their being here both supported by Originally-Electrics, could receive any Supply from the Floor; and yet both of them snapped upon the Touch of a Person not supported by Electrics *per se*. Many Experiments had proved that the Electricity was not derived from the Glass; and therefore it was concluded, by Dr. *Bevis*, and several others to whom this Gentleman shewed the Experiment, that the Electricity here was communicated to the Person rubbing from the Air, by means either of the suspended Gun-barrel, or of the Man who touched the Globe.

§ IV. I was by no means satisfied with this Conclusion, as being directly contrary to numberless Facts. From a careful Consideration therefore of the Experiment itself, from comparing its Effects with those of several others, and, in general, from surveying

ing all the Properties of Electricity we are hitherto acquainted with, I gave the following as my Opinion.

1. That what we call Electricity is the Effect of a very subtil and elastic Fluid, diffused throughout all Bodies in Contact with the terraqueous Globe (those Substances hitherto termed Electrics *per se* probably excepted), and every-where, in its natural State of the same Degree of Density.
2. That this Fluid manifests itself only, when Bodies capable of receiving more thereof than their natural Quantity are properly disposed for that Purpose; and that then, by certain known Operations, its Effects shew themselves by attracting and repelling light Substances, by a snapping Noise, Sparks of Fire, &c. directed towards other Bodies, having only their natural Quantity, or, at least, a Quantity less than those Bodies from which these Snappings, &c. proceed.
3. That no Snapping is observed in bringing any two Bodies near each other, in which the Electricity is of the same Density, but only in those Bodies in which the Density of this Fluid is unequal.
4. That this Snapping is greater or less, in proportion to the different Densities of the Electricity in Bodies brought near each other, and by which Snapping each of them becomes of the same Standard.
5. That Glass, and other Bodies, which we call Electrics *per se*, have the Property of taking this Fluid from one Body, and conveying it to another, and that in a Quantity sufficient to be obvious to all our Senses.
6. That, in the Experiment in Question, the Reason why no Snapping is observed by a Person upon

on the Floor touching him who rubs the Globe with his Hands standing upon Wax, without at the same time some other Non-electric supported by Originally-Electrics, or otherwise being in Contact with the Globe, is owing to whatever Part of this Man's natural Quantity of Electricity, taken from himself by the Globe in Motion, being restored to him again by the Globe in its Revolutions; there not being any other Non-electric near enough to communicate the Electricity to; and that therefore, in this Situation, the Electricity of this Man suffers no Diminution of its Density.

7. That the Fact is otherwise, when every thing else being as before, either a Gun-barrel suspended in silk Lines, or a Man supported by Wax, or such-like, is placed near the Globe in Motion; because then, whatever Part of the Electricity of the Person rubbing is taken from him, is communicated either to the other Man or to the Gun-barrel, these, from their Situation, being the first Non-electrics, to which the Electricity taken from the Person rubbing can be communicated.
8. That, under these Circumstances, as much Electricity as is taken from the Person rubbing, is given to the other; by which means the Electricity of the first Man is more rare than it naturally was, and that of the last more dense.
9. That the Electricity in either of these Persons is in a very different State of Density from what it naturally was, or from that of any Person standing upon the Earth; this last being in a middle State between the two other Persons; that is, he has not his Electricity so rare as the Man rubbing

bing the Globe, nor so dense as that of him supported by Electrics *per se*, and touching the Equator of the Globe.

10. That therefore the same Effect, a Snapping, is observed, upon bringing any Non-electric near either of these Persons, from very different Causes: For it is apprehended, that, by bringing the Non-electric near him, whose Electricity is more rare, this Snapping restores to him what he had lost; and that, by bringing it near him, whose Electricity is more dense, it takes of his Surcharge, by which means their original Quantity is restored to each.

§ V. This Solution of this *Phenomenon*, without allowing any Part of the Electricity of either of these two Persons to be furnished by the circumambient Air, was satisfactory, not only to the Gentleman who proposed it, but to many of the *Royal Society*, excellent Judges of this Matter, to whom I shewed the Experiment: And this the more so, as it is to be observed, that if, under the before-mention'd Circumstances, the Person rubbing the Globe was touched by him who held his Finger to the Globe, the Snapping was much greater than if either of them touched a Person standing upon the Floor; as the Density of the Electricity between these two Persons was so much more different than that of either of them to him on the Floor: Whereas did their Electricity proceed from the Air, from their being both electrified they ought not to snap at all from their touching each other; or, admitting they did touch each other, they both of them, upon a Supposition that they did receive their Electricity alike from the Air, should manifest the Accumulation thereof, and snap

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upon the Touch of a Man standing upon the Floor, the contrary of which invariably happens.

§ VI. At this time I am the more particular concerning the Solution of this singular Appearance, as Mr. *Collinson*, a worthy Member of this *Society*, has received a Paper concerning Electricity from an ingenious Gentleman, Mr. *Franklin*, a Friend of his in *Pennsylvania*. This Paper, dated *June 1. 1747*. I very lately perused, by Favour of our most worthy *President*. Among other curious Remarks there is a like Solution of this Fact; for though this Gentleman's Experiment was made with a Tube instead of a Globe, the Difference is no-ways material. As this Experiment was made, and the Solution thereof given upon the other Side of the *Atlantic Ocean* before this Gentleman could possibly be acquainted with our having observed the same Fact here, and as he seems very conversant in this Part of Natural Philosophy, I take the Liberty of laying before you his own Words.

‘ 1. A Person standing on Wax, and rubbing a
 ‘ Tube, and another Person on Wax drawing the
 ‘ Fire; they will both of them, provided they do
 ‘ not stand so as to touch one another, appear to
 ‘ be electrified to a Person standing on the Floor;
 ‘ that is, he will perceive a Spark on approaching
 ‘ each of them with his Knuckle.

‘ 2. But if the Persons on Wax touch one ano-
 ‘ ther during the exciting of the Tube, neither of
 ‘ them will appear to be electrified.

‘ 3. If they touch one another after the exciting
 ‘ the Tube and drawing the Fire as aforesaid, there
 ‘ will be a stronger Spark between them, than was
 ‘ between either of them and the Person on the
 ‘ Floor.

‘ 4.

‘ 4. After such a strong Spark neither of them
‘ discover any Electricity.

‘ These Appearances we attempt to account for
‘ thus :

‘ We suppose, as aforesaid, that electrical Fire is
‘ a common Element, of which every one of
‘ these three Persons has his equal Share before
‘ any Operation is begun with the Tube. *A*,
‘ who stands upon Wax, and rubs the Tube,
‘ collects the electrical Fire from himself into the
‘ Glass; and his Communication with the com-
‘ mon Stock being cut off by the Wax, his Body
‘ is not again immediately supplied. *B*, who
‘ stands upon Wax likewise, passing his Knuckle
‘ along near the Tube, receives the Fire which
‘ was collected by the Glass from *A*; and his
‘ Communication with the common Stock being
‘ cut off, he retains the additional Quantity re-
‘ ceived. To *C* standing on the Floor, both ap-
‘ pear to be electrified : For he, having only the
‘ middle Quantity of electrical Fire, receives a
‘ Spark upon approaching *B*, who has an over
‘ Quantity, but gives one to *A*, who has an un-
‘ der Quantity. If *A* and *B* approach to touch
‘ each other, the Spark is stronger ; because the
‘ Difference between them is greater. After such
‘ Touch, there is no Spark between either of them
‘ and *C*, because the electrical Fire in all is re-
‘ duced to the original Equality. If they touch
‘ while electrifying, the Equality is never destroyed,
‘ the Fire only circulating. Hence have arisen
‘ some new Terms among us. We say, *B* (and
‘ Bodies alike circumstanced) is electrified posi-

' tively; *A*, negatively; or, rather, *B* is electrified
 ' plus, *A*, minus. And we daily in our Experi-
 ' ments electrify plus or minus, as we think pro-
 ' per. To electrify plus or minus, no more needs
 ' be known than this; that the Parts of the Tube
 ' or Sphere that are rubbed, do in the Instant of
 ' the Friction attract the electrical Fire, and
 ' therefore take it from the Thing rubbing. The
 ' same Parts immediately, as the Friction upon
 ' them ceases, are disposed to give the Fire, they
 ' have received, to any body that has less. Thus
 ' you may circulate it, as Mr. *Watson* has shewn*;
 ' you may also accumulate or subtract it upon or
 ' from any Body, as you connect that Body with the
 ' Rubber, or with the Receiver, the Communi-
 ' cation with the common Stock being cut off.'

The Solution of this Gentleman, in relation to
 this *Phenomenon*, so exactly corresponds with that
 which I offer'd very early last Spring, that I could not
 help communicating it.

§ VII. In Sect. 51. and 62. of my Sequel to the elec-
 trical Experiments, which I presented to the *Royal*
Society last Year, from not having consider'd this Ex-
 periment in a statical View, and from not then ima-
 gining the Velocity of Electricity so great as we since
 have found it, I concluded, that the Snapping observed,
 if a Person standing upon the Floor touched the Man
 standing upon Wax, who turned the Wheel of the elec-
 trifying Machine plac'd likewise upon Wax, to be
 owing to the Inversion of the usual Course of the Elec-
 tricity; as that Snapping was only constant, when
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* See my Sequel, p. 64.

the Gun-barrel suspended in silk Lines was touched by Non-electrics. As from divers Experiments I had found that Electricity was not furnished by dry Air, by many more that it could not come down clean silk Lines; and as, from his Snapping, the Man upon the Wax argued the Presence of Electricity, I conceived that this could happen no other Way, than that the rubbing of the Globe by a Cushion or the Hand of a Man, gave it a Fitness to take off the Electricity, furnished by the suspended Gun-barrel from the Non-electric upon the Floor, and lodge it upon the Machine, and upon the Man who turned the Wheel thereof. But the Experiment of circulating the electrical Fire *, where the Brush of blue Flame from a blunt Wire properly disposed, can always be seen to pass diverging into the Machine, though not so, when brought near the Gun-barrel under the most favourable Circumstances; as well as the Experiment before-mention'd brought to shew that the Electricity came from the Air, have induced me to change my Opinion; and instead of the Course of the Electricity being inverted, the *Phænomena* arose, as far as I am capable of judging, from the Man who turned the Wheel of the electrifying Machine having less than his original Quantity of Electricity, and the Gun-barrel from having more: To these add, that the Person, who touched these while standing upon the Floor, had a Quantity different from each of these, that is, his natural Quantity.

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* See *Sequel* § 65.

§ VIII. I beg Leave to correct also what I mention'd in my *Sequel*, p. 69. in relation to my suggesting, that, in the Explosion of the charged Phial through the Body of a Man, or other Non-electrics, as much Electricity as was taken from his Body, was immediately replaced by the Floor of the Room upon which he stood: I having since found, that the charged Phial would explode with equal Violence, if the Hook of the Wire, which is usually run through the Cork of the Phial, was bent in such a manner as to come near the Coating of the Phial, without any other Non-electric being near, from which such Quantity could be supplied.

§ IX. I take notice of these, inasmuch as, notwithstanding the very great Progress that has been made in our Improvements in this Part of Natural Philosophy within these few Years, Posterity will regard us only as in our Noviciate; and therefore it behoves us, as often as we can be justified therein by Experiment, to correct any Conclusions we may have drawn, if others yet more probable present themselves.

§ X. I laid down and consider'd largely in my *Sequel* *, that the Stroke from the Phial, in the Experiment of *Leyden*, was not in Proportion to the Quantity of Matter contained in the Glass, but was increased by the Quantity of Matter in the Glass, and the Number of Points of non-electrical Contact on the Outside of the Glass. This Fact I have pursued further, and increased thereby the electrical Explosion

* See p. 11, 17, 19, &c.

sion to an astonishing Degree. To this End I procured three cylindrical Phials blown very thin, about seventeen Inches in Height and four in Diameter: After these were coated within an Inch of their Necks with Sheet-Lead, I put into each fifty Pounds of leaden Shot. I chose this Form for the Glasses, that the Matter therein contained might be exposed under as large a Surface, as could conveniently be obtained. These Glasses were placed near each other in a convenient Part of my Room, and did communicate with each other by means of a small iron Rod lying upon all their Mouths, and touching Pieces of strong Wire stuck into the Shot contained in them: By this Management one of these could not be electrified without communicating with the rest. The leaden Coatings of these Glasses were also connected together by small Wires, all which center'd in one tail Wire; so that, when the Matter contained in these three Glasses was replete with Electricity, which was done by a Wire from the Gun-barrel fastened to the iron Rod lying upon their Mouths, the whole Quantity of Electricity here accumulated might be discharged at once by touching the Gun-barrel with an iron Rod fastened to the tail Wire. When the Glasses are sufficiently electrified, if the Room is dark, you will see Brushes of blue Flame from several Parts of the conducting Wire; and these indicate the proper Time of making the Explosion. These Glasses, from the Thinness of their Sides, and from the Weight of their leaden Shot, are very liable to burst; and if one of them happens to have the least Crack in any Part of its Surface, which is under the Lead, none of them can be electrified; all the Electricity
passing

passing off by that Crack. The electrical Explosion from two or three of these Glasses is not double or treble to that from one of them; but the Explosion from three is much louder than that from two, that from two much louder than that from one.

§ XI. The Experiment just mentioned induced me to imagine, that the Explosion from these Phials was owing to the great Quantity of non-electric Matter contained in them: And whilst I was considering of some certain Method of assuring myself whether the Fact were so, Dr. *Bevis* informed me, that he had found the electrical Explosion to be as great, as when he had accumulated the Electricity in a half Pint Phial of Water, by the following Method. He covered a thin Plate of Glass, of about a Foot square on both Sides, with Leaf-Silver; this he made to adhere to the Glass with very thin Paste. A Margin of an Inch was left on both Sides; otherwise, upon electrifying this Plate, the Electricity would be prevented from being accumulated upon one of its Surfaces, by being propagated from the Silver on one Side to that of the other. When the glass Plate was thus prepar'd, if it was placed upon a Table in such a Manner, that, when fully electrified by a Wire or such-like from the prime Conductor, a Person touched the under Surface with a Finger of one of his Hands, and brought one of the Fingers of his other near the upper Surface thereof, or near the prime Conductor, he was shocked in both his Arms and across his Breast. The same Effect happen'd, if, when this Plate was electrified in the before-mention'd Manner, a Person holding it in his Hand by the Margin, and without touching the Silver,

Silver presented it, even some time after it had been taken from the prime Conductor, to another Person who touched the under Surface with his Finger, and held it there till he touched the upper Surface with a Finger of his other Hand.

§ XII. This Experiment was sufficiently convincing, that the Greatness of the electrical Explosion, in my former Trials, was not owing solely to the great Quantity of non-electric Matter contained in the Glasses; as the Explosion from the glass Plate silvered was occasioned by about six Grains of Silver, upon which the Electricity was accumulated; more especially as this Explosion was equal, if not superior, to that from half a Pint of Water contained in a thin Glass as usual, under the most favourable Circumstances.

§ XIII. As each of the Surfaces of the glass Plate just mentioned measured sixty-four square Inches, I was desirous of pursuing this Inquiry further; and accordingly procured a cylindrical glass Jar blown very thin, of sixteen Inches in Height, and eighteen Inches in Circumference. This I caused to be covered both within and without with Leaf-Silver, to within an Inch of its Top. This Glass with its Margin made very clean (upon which the Success of the Experiment considerably depends) was fully electrified by the means of a Piece of Chain, let down to the Bottom of the Jar, by a Wire from the prime Conductor; and the Explosion made by its being placed upon a Plate of Metal, to which was fasten'd a Wire connected to an iron Rod, and this Rod was

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brought near some gilded Leather lying upon the prime Conductor. This Explosion was equal to that from the three Glasses before-mention'd, containing a hundred and fifty Pounds of leaden Shot; though here the Weight of the Silver lining the internal Surface of the Glass, upon which the Electricity was accumulated, did not exceed thirty Grains. So much of the internal Surface of this Jar, as was covered with Silver, amounted, as the Surfaces of Cylinders are as their Length multiplied by their Periphery, and allowing thirty six square Inches for the Bottom, to three hundred and six square Inches. If this Explosion was made in a dark Room, the Corruscations within the Jar, at the Instant of the Explosion, were extremely brilliant.

When this Jar is fully electrified, if, instead of making it explode, you only bring the short iron Rod, with which the Explosion is usually made, near a Piece of gilded Leather lying upon the prime Conductor, though not near enough to make the Glass explode at once, you hear the Electricity, accumulated within the Jar, escape with a Noise very like that of a small heated iron Bar quenching in Water.

§ XIV. The great Explosion from the Jar before-mention'd, when so little non-electric Matter was included therein, has caused me to be of Opinion, that the Effect of what we call the Experiment of *Leyden* is greatly increased, if not principally owing, not so much to the Quantity of non-electrical Matter contained in the Glass, as to the Number of Points
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of non-electrical Contact * within the Glass, and the Density † of the Matter constituting those Points, provided this Matter be in its own Nature a ready Conductor of Electricity. For this Reason it is presumed, that so much of the Lead contained in the Shot in the before-mention'd Experiment, only concurred to make the electrical Explosion, as touched the internal Surface
of

* Bodies having the Power of readily conducting Electricity seems to depend very little upon their specific Gravity simply considered: Metals, for Instance, and Water, are in a great Degree Non-electrics, and consequently conduct Electricity the best of any Substances, that have yet fallen under our Notice; whereas the *Calces* of Metals, though very dense Bodies, and very greatly more so than Water, prevent in a great Degree the quick Propagation of the electrical Power. So that a Phial coated within and without with Ceruse, *i. e.* the *Calx* of Lead, and electrified, did not, upon the Application as usual of one Hand to the external Surface thereof, and touching the prime Conductor with the other, occasion any Shock, or make any Explosion more than the simple Stroke from the prime Conductor. The same Observation holds good with regard to red Lead, Litharge, and lunar Caustic or the *Calx* of Silver, none of which snap, when electrified. For the same Reason, Filings of Iron, which are rusty, *i. e.* have their Surfaces converted into a *Calx*, are much less proper to be put in Glasses to make the Experiment of *Leyden*, than those that are not; inasmuch as these last cause a much louder Explosion than the first. The making use of rusty Filings of Iron was the Occasion of my mentioning in my *Sequel*, § XVI. that the Stroke from these was less than that from Water; the contrary of which I afterwards found true, when Filings of Iron not rusty were substituted.

† I heretofore, *p.* II, &c. of my *Sequel*, took notice, how much the Effect of this Experiment depended upon the Quantity of non-electric Contact upon the Outside of the Glass.

of the Glas: As a great Part of this Surface was without Contact, occasioned by such of the Shot as presented themselves thereto, touching, from their spherical Figure, only in one Point, there consequently remained without Contact comparatively great Spaces between each Shot. This Defect was obviated by the universal Contact of the Silver, and thereby was occasion'd the greater Explosion.

§ XV. The following Experiment has some Relation to the preceding. If a Phial of warm Water, without being coated with Sheet-Lead, or other non-electrical Matter, is electrified by connecting it to the prime Conductor; and a Ring of small Wire, in lieu of the usual Coating, is put round this Phial, the Wire being continued of a sufficient Length to touch the prime Conductor; upon discharging the Phial, you have a slight Explosion, and a Flash of Fire seems at that Instant to fill the Glas. But if this Experiment is made in a very dark Room, and with great Attention, this Flash in the Phial will not then seem to proceed from the whole Quantity of Water contained therein; but, as far as the Suddenness of the Explosion will permit the Eye to follow it, will be seen to occupy only the internal Surface of the Phial.

§ XVI. I order'd another glass Jar as large as possible to be blown, so that the Glas thereof might be very thin; and after many Attempts of the Glas-makers I procured one, the Height of which was twenty-two Inches, the Periphery forty-one. This was covered within and without, leaving a Margin
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of an Inch at Top, with Leaf-Brass. As much of the internal Surface as was covered amounted to 1129 square Inches. But the Difficulty I met with in procuring this Glass was sufficiently recompensed by the great Increase of the Explosion therefrom, when fully electrified, and discharged in the same manner as the glass Jar before-mention'd. The Report was vastly louder; all the attendant *Phænomena* greatly exceeded any thing of this kind I was before acquainted with. As the Quantity of Metal within this Jar did not exceed two Drams, this Experiment gives further Weight to my Opinion before-mention'd § XIV. in relation to the manner of increasing the Effects of the Experiment of *Leyden*; and from what the *Phænomena* of that surprising Experiment principally proceed; *viz.* not from the Volume of the prime Conductor, nor from the Quantity of non-electrical Matter contained in the Glass, but from the Number of Points of non-electrical Contact both within and withoutside of the Glass, and from the * Density of the Matter constituting those Points.

§ XVII. It must be observed, that, *cæteris paribus*, the electrical Explosion is greater from hot Water included in Glasses than from cold; and from these glass Jars warmed than when they are cold.

§ XVII.

* Though the Density of the Matter constituting these Points proceeds from their Number in a mathematical Sense, yet in a popular one I take the Liberty to distinguish them.

§ XVIII. The Explosions from the large Glasses just mention'd fully electrified, as well as from small ones under the same Circumstances, will not be considerable, unless the Circuit, frequently mention'd in my Writings upon this Subject, be completed; that is, unless some Matter, non-electric in a considerable Degree, and in Contact with the Coatings of the Phials, is brought into Contact, or nearly so, with such Non-electrics as communicate with the Matter contained in the Phials themselves. When indeed the Circuit can be completed, the Explosion from the large Glasses is prodigious; the whole Quantity of Electricity therein accumulated, or nearly so, being discharged in an Instant. But the Fact is otherwise, if the Circuit is not completed, and the iron Rod in the Mouth of one of these Phials is touched by a Non-electric (the Hand of a Man, for Instance) not in Contact with the tail Wire: For then there will be no Explosion, no Shock; but the Person, approaching his Finger near the iron Rod, will see a Succession of small Sparks, more intensely red than that large one seen, when the Phials explode at once; and the Person making the Experiment, will feel a very pungent Pain, but confined to that Finger which touches the iron Rod. This Succession of Sparks continues, until the Electricity accumulated in the Phials is nearly exhausted. So that the Explosion from any given Quantity of Electricity, accumulated as before-mention'd, is greater or less in proportion to the Time expended in making that Explosion: In like manner as a given Quantity

tity of grained Gunpowder rammed, hard in a Pistol, is almost instantaneously fired, and that with a great Report; when the same Quantity of Gunpowder rubbed fine, and rammed hard, takes a considerable Time in burning as a Squib, and makes no Explosion.

§ XIX. The Causes why the charged Phial will not explode quick, without the Electricity therein describing a Circuit through Substances non electric in a great Degree, may be very difficult to be assigned. It is sufficient for us in the present Inquiry to be assured of its being a certain, an invariable Law: And in order to prove, that the Electricity, upon the Explosion, passes with its whole Force through the Circuit of Non-electrics, contrary to what has been suggested, I made the following Experiment.

§ XX. I procured two small square iron Bars, of about fourteen Inches long: An Inch at each End of these I caused to be bent at right Angles. These iron Bars were supported in such manner (by Substances whether originally electric, or not, was no ways material) that each of their Ends came within about two Tenths of an Inch of some warm Spirit of Wine, or Essence of Lemons in four Spoons placed upon a Table. I then suspended a common coated Phial filled with Filings of Iron to the Gun barrel, the tail Wire of which reached to a Table at a few Feet Distance, and was placed under a brass Weight which supported the Handle of the first of the Spoons: Over this Spoon, at the Distance just mention'd, I placed one of the square iron
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iron Bars, and at its other End was placed another Spoon: This second Spoon touched the Handle of the third, which was placed under one End of the other square Bar, whose other End came near to the Spirit in the fourth Spoon, the Handle of which lay upon a Weight; and under this was placed a Wire connected to the short iron Rod, with which the Explosion was made, when the coated Phial was charged. When the Phial was well charged, if the Spirit of Wine sent forth Vapours, and the square iron Bars were at a proper Distance from it; upon making the Explosion at the Gun-barrel the Electricity snapped between the Spirit and the iron Bars, and the Spirit was set on Fire at the same Instant in all the Spoons. It sometimes happened, that some of them only were fired. If the iron Bars were too near the Spirit, it was not fired, though the Circuit was completed; because then no electrical Flame snapped between the Rods and Spirit; that Effect happening only, when the Parts of the Non-electrics describing the Circuit are not in immediate Contact; on the other hand, if the Space left between the Bars and Spirit was too great, the Circuit could not be completed, and there would be no Explosion.

§ XXI. This Experiment will seem more surprising in the following manner. When the *Apparatus* is disposed of as before, the tail Wire from the coated Phial, before it reaches to the Table, is fasten'd to an iron Rod standing in a Pail of Water: Another iron Rod is likewise placed in the same Pail of Water, and a Wire from this last reaches under the Weight, which supports the first of the
before-

before-mention'd Spoons. From beneath the Weight which supports the Handle of the fourth Spoon, a Wire reaches to an iron Rod standing in a second Pail of Water, in which is placed also another iron Rod, to which is fastened another Wire connected with the short iron Rod, which is employed to make the Explosion. When, with this Disposition of the *Apparatus*, the charged Phial is caused to explode, the Spirit or Effence of Lemons in some or all of the Spoons is set on Fire; to accomplish which, the Electricity must necessarily pass through one of the Pails of Water, and possibly through both. But here it must be understood, that the Pails of Water stand upon a dry wooden Floor; for if they stand upon one that is wet, or upon the Ground, the Circuit will be, for Reasons frequently mention'd in the Course of these Inquiries, completed between the two Pails, where the non-electric Matter is continuous, and be prevented from passing by the Spoons where it is not so; and this will defeat the Success of the Experiment. The Number of Spoons in the Manner before-mention'd, and their Distance from each other, may be varied as far as is thought necessary. The Circuit may likewise be directed through any Number of Men, provided that each of them holds in one of his Hands a Spoonful of warm Spirit, and brings one of the Fingers of his other Hand at the proper Distance to the Spirit held in the Hand of the Person next him: By these means the Explosion of the charged Phial will set on Fire the Spirit in several of the Spoons at

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the same time, provided the Persons employ'd hold their Hands sufficiently steady.

§ XXII. This Experiment exhibits new and unexpected *Phænomena*: In all the Experiments to kindle inflammable Substances by Electricity hitherto attempted both here and abroad, either the Spirit or the Non-electric, wherewith it was intended to be set on Fire, were placed upon Originally-Electrics. But here, on the contrary, although both one and the other are placed upon Non-electrics, we see the same Effect produced. Nor is the electrical Power lessened, by exciting several different Quantities of Flame; in doing which, it passes so quick as to prevent the Possibility, in several Spoonfuls of Spirit, fired by the same Operation, of determining which of them was on Fire first: And though we know from its Effects, that the Electricity goes through the whole Circuit of Non-electrics with its whole Vigour, its Progress is so quick as not to affect, by attracting or otherwise, light Substances disposed very near the Non-electrics, through which it must necessarily pass.

§ XXIII. I would here recommend to those Gentlemen of the *Royal Society*, who last Summer measured the respective Velocities of Electricity and Sound, a Process of this sort to be executed at a proper Time; whereby they would be able to a very great Nicety to ascertain the absolute Velocity of Electricity. For it may be contrived, that a Man may be placed in the same Room with the electrifying Machine, taking hold of a Wire in each of his Hands:
These

These Wires may be so managed, that by means of the electrical Circuit, the Man holding them may be made sensible of the electrical Commotion, even under the Eye of an Observer at the Machine; though before the Electricity can arrive at the Person holding the Wires, it will be obliged to pass through whatever large Space shall be thought convenient for the Observation. The Time then spent between the Explosion of the charged Phial, and the Person holding the Wires feeling the electrical Commotion, will give the absolute Velocity of Electricity to great Exactness*.

XXIV. As my Inquiries upon the Subject of Electricity have always tended as much as possible to the Analysis thereof, I have often observed, that if, when the electrifying Machine stands upon the Floor, the Globes thereof are rubbed with their Cushions, or with Hands cover'd with Originally-Electrics of a sufficient Thickness, and perfectly dry, no Electricity will be perceptible upon the Touch of a Gun-barrel suspended in silk Lines, and touching the Globe in Motion, or upon the Touch of any other Substances supported by Electrics *per se*; or, in other Words, there will be no Accumulation of Electricity. The only Originally-Electrics fit for this Experiment (as all unctuous Substances, as Wax, Resin, and such-like, though Electrics *per se*, by sticking to the Outside of the Glass render it unfit to excite Electricity

* This has been since put in Execution. See above p. 88.

tricity from other Bodies) are to be obtained from the Animal Kingdom: And of these only such as do not partake, from their Manufacture or otherwise, of any non-electric Substances. Those of this sort, which I have tried, and always with the same Success, when perfectly dry, have been Silk (woven or not), Velvet, Hair-Cloth, Woollen-Cloth, and the dry Skins of Rabbits dressed in their Fur; and the Event has been the same, whether these Substances have been rubbed under a greater or a less Degree of Friction: And scarce any Electricity has been perceptible, when those Parts of these Substances, which immediately are in Contact with the Globes, have been rubbed over with dry Chalk, a non-electric Substance. But the Success is different, when these originally-electric Substances have lain in damp Places, or have been held over the Steam of warm Water; because then the Water imbibed by these Substances serves as a Canal of Communication to the Electricity between the Hands or Cushions and the Globes in the same manner, as the Air, replete with Vapours in damp Weather, prevents the Accumulation of Electricity in any considerable Degree, by conducting it as fast as excited to the nearest Non-electrics. On the contrary, most Substances of the Vegetable Kingdom, whose Form makes them fit for this Treatment, though made as dry as possible, furnish Electricity, though in different Quantities. I have tried Hemp, Linen-Cloth of various Kinds, Paper both of Linen and Hemp, Cotton in the Wool, Fustian, Cotton-Velvet, and

and many others of this Class. I have covered at one time the Cushion, with which I rubbed a Globe, with eight Lamina of Sheet-Lead, and have excited Electricity from that Metal: And however improper a Deal-Board may seem for the Purpose of rubbing a Globe, I have more than once accumulated Electricity from that, though its Substance has the Appearance of being much less fit than every one of the Originally-Electrics I mention'd before.

§ XXV. To the Doctrine here laid down it may be objected, that Leather is an animal Substance, which, though perfectly dry, excites Electricity the strongest of all the Substances hitherto discover'd; that dry Leather ought to be consider'd as an Originally-Electric; and therefore, according to the Rule before-mention'd, should not furnish, from rubbing the Globe therewith, any Electricity at all. To this I answer, that though the dry Skins of Animals are Electrics *per se*, dry Leather is far from being so; and this is owing to the vast Quantities of restraining vegetable Substances imbibed by the Skins throughout their whole Contexture in the Operation of Tanning in some Species of Leather, and of saline Substances, such as Alum, in others; both which Substances are non-electric, and of these Leather very considerably partakes: For by these the Hides and Skins of Animals (and any Muscle of their Bodies is liable to the same Treatment), which otherwise are as putrescent as any Part of their Bodies soever, are made to last through many Ages, and be subservient to
many

many valuable Purposes of Life. The same Conclusion must be drawn concerning Hats, which, tho' made of the Hair of Animals, furnish Electricity, though but in a small Degree: And this is occasion'd by the mucilaginous and gummy Substances made use of by the Hatmakers, to give their Manufacture a suitable Stiffness.

§ XXVI. From what I have advanced § XI. XII. XIII. XIV. XV. XVII. it may possibly be conjectur'd, that the electrical *Effluvia* occupy only the Surfaces of Bodies electrified; as we there found, that a very small Quantity of Matter, distributed under a very large Surface, would occasion a greater Accumulation of Electricity, than a very much more considerable Quantity of Matter under a less. But that the Electricity occupies the whole Masses of Bodies electrified, and passes through their constituent Parts, is clearly demonstrated by the following Experiments.

§ XXVII. When I first engaged in these Inquiries, to assure myself of this Fact, I enveloped an iron Rod about three Feet in Length with a Mixture of Wax and Resin, leaving free from this Mixture only one Inch at each End. This Iron was warmed, when thus fitted, that the whole of its Surface, where it was intended, might be covered. This Rod, when electrified at one of its Ends, snapped as strongly at the other, as though it was without the Wax and Resin. This could not have happened from the Electricity's passing along the Surface of the iron Rod, because there it was prevented
by

by the Originally-Electrics, and consequently must of Necessity pass through it.

§ XXVIII. A Phial of Water, in the Experiment of *Leyden* can be electrified, and may be caused to explode, though the Wire, touching the Water in the Phial in making that Experiment, be run through a wax Stopple, exactly fitted to the Mouth of the Phial.

§ XXIX. I caused a glass Tube, open' at each End, and about two Feet and a half long, to be capped with Brass cemented to the Ends of the Tube. In the Centre of each of these Caps was fastened a slender brass Rod; and these were disposed so in the Tube as to come within half an Inch of each other. When the Tube was properly suspended in silk Lines with one of its Extremities near a glass Globe in Motion, the brass Work at both Ends snapped equally strong. As the Electricity could not pass along the Surface of this Tube warmed and wiped clean, this Effect could not have happened, unless the Electricity pervaded the Substance of the brass Caps. Upon touching the Brass at the End of the Tube most remote from the electrifying Machine, the Snaps from one of the brass Rods within the Tube to the other were seen to correspond with the Snaps without. More Experiments of this kind might be added, but these, I presume, are sufficient to shew, that the Electricity occupies the whole Masses of non-electric Bodies electrified. That the Electricity passes through Originally-Electrics to a certain Thickness I took notice of in a Paper I did myself the Honour to communicate in *February* 1745.

§ XXX.

§ XXX. I shall forbear at present to lay before you a Series of Experiments *in vacuo*; from the Comparison of which, with the Experiments in open Air it appears, that our Atmosphere, when dry, is the Agent, whereby, with the Assistance of other Electrics *per se*, we are enabled to accumulate Electricity in and upon Non-electrics; that is, to communicate to them a greater Quantity of Electricity than they naturally have: From hence also we shall see, that, upon the Removal of the Air, the Electricity pervades the *Vacuum* to a considerable Distance, and manifests its Effects upon any Non-electrics, which terminate that *Vacuum*: And by these Means that originally-electric Bodies, even in their most perfect State, put on the Appearance of Non electrics, by becoming the Conductors of Electricity. But these Matters may possibly be the Subject of a future Communication.